AUBURN
STORMWATER

AU-STORMWATER RESEARCH FACILITY UPDATE AND INFILTRATION SWALE RESEARCH

Wesley N. Donald, PhD

September 25-26, 2024
Landmark Park
Dothan, Alabama

The Law: Clean Water Act - 1972

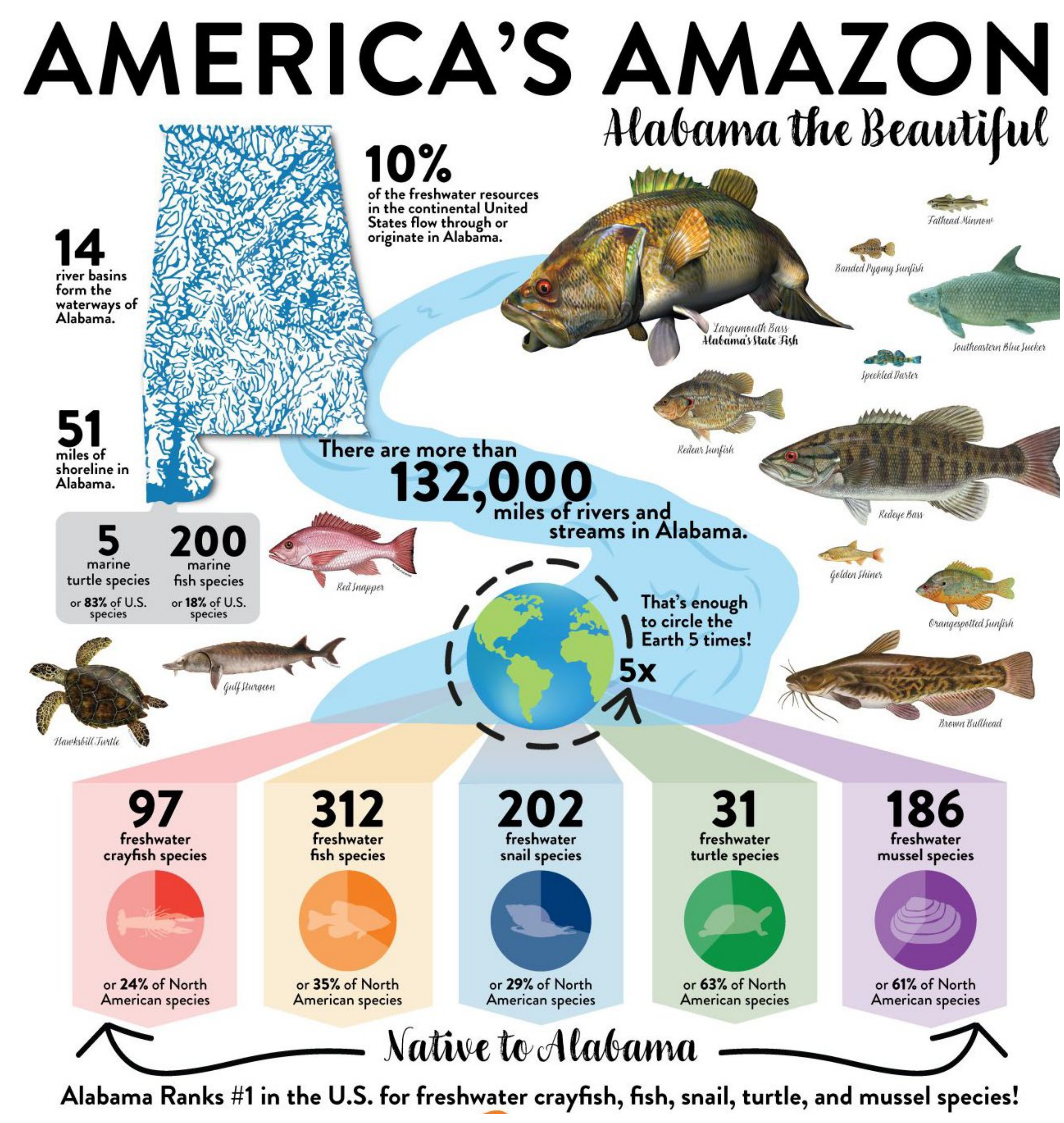
Purpose: Restore and maintain chemical, physical, and biological integrity of our Nation's waters.

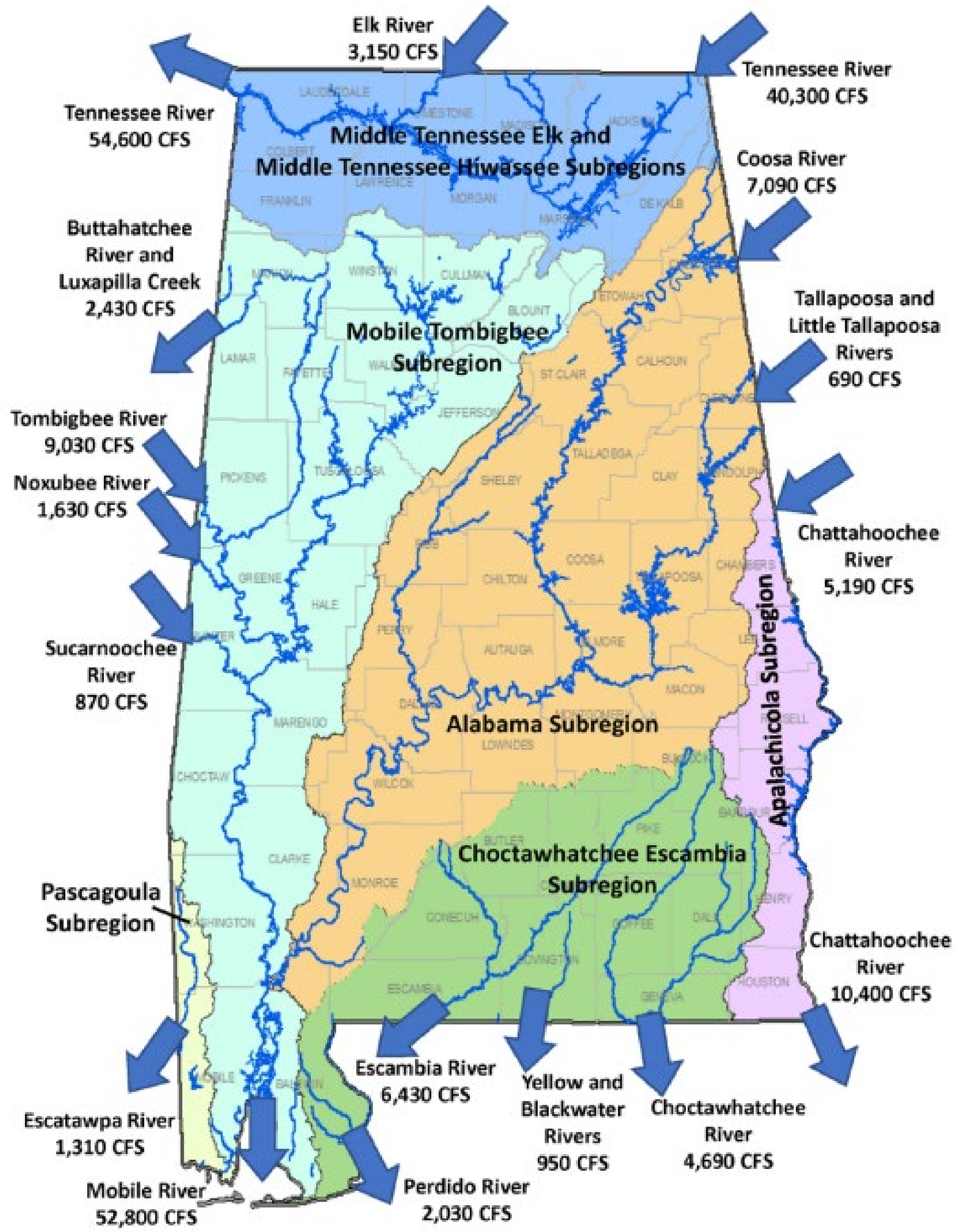
Prohibition of toxic pollutants

"Fishable" and "swimmable" goal by 1983

Elimination of pollutant discharge by 1985

Modified in 1987 to create NPDES & MS4


AMERICA'S AMAZON
Alabama the Beautiful
10%
of the freshwater resources in the continental United States flow through or originate in Alabama.
14
river basins form the waterways of Alabama.
51
miles of shoreline in Alabama.
5
marine turtle species
or 83% of U.S. species
200
marine fish species
or 18% of U.S. species
There are more than
132,000
miles of rivers and streams in Alabama.
That's enough to circle the Earth 5 times!
5x
Fathead Minnow
Banded Pygmy Sunfish
Largemouth Bass
Alabama's State Fish
Southeastern Blue Sucker
Speckled Darter
Redear Sunfish
Redeye Bass
Red Snapper
Golden Shiner
Orangespotted Sunfish
Gulf Sturgeon
Hawksbill Turtle
Brown Bullhead
97
freshwater crayfish species
or 24% of North American species
312
freshwater fish species
or 35% of North American species
202
freshwater snail species
or 29% of North American species
31
freshwater turtle species
or 63% of North American species
186
freshwater mussel species
or 61% of North American species
Native to Alabama
Alabama Ranks #1 in the U.S. for freshwater crayfish, fish, snail, turtle, and mussel species!


Elk River
3,150 CFS
Tennessee River
40,300 CFS
Tennessee River
54,600 CFS
Middle Tennessee Elk and
Middle Tennessee Hiwassee Subregions
Coosa River
7,090 CFS
Buttahatchee
River and
Luxapilla Creek
2,430 CFS
Mobile Tombigbee
Subregion
Tallapoosa and
Little Tallapoosa
Rivers
690 CFS
Tombigbee River
9,030 CFS
Noxubee River
1,630 CFS
Chattahoochee
River
5,190 CFS
Sucarnoochee
River
870 CFS
Alabama Subregion
Apalachicola Subregion
Choctawhatchee Escambia
Subregion
Pascagoula
Subregion
Chattahoochee
River
10,400 CFS
Escambia River
6,430 CFS
Yellow and
Blackwater
Rivers
950 CFS
Choctawhatchee
River
4,690 CFS
Escatawpa River
1,310 CFS
Mobile River
52,800 CFS
Perdido River
2,030 CFS

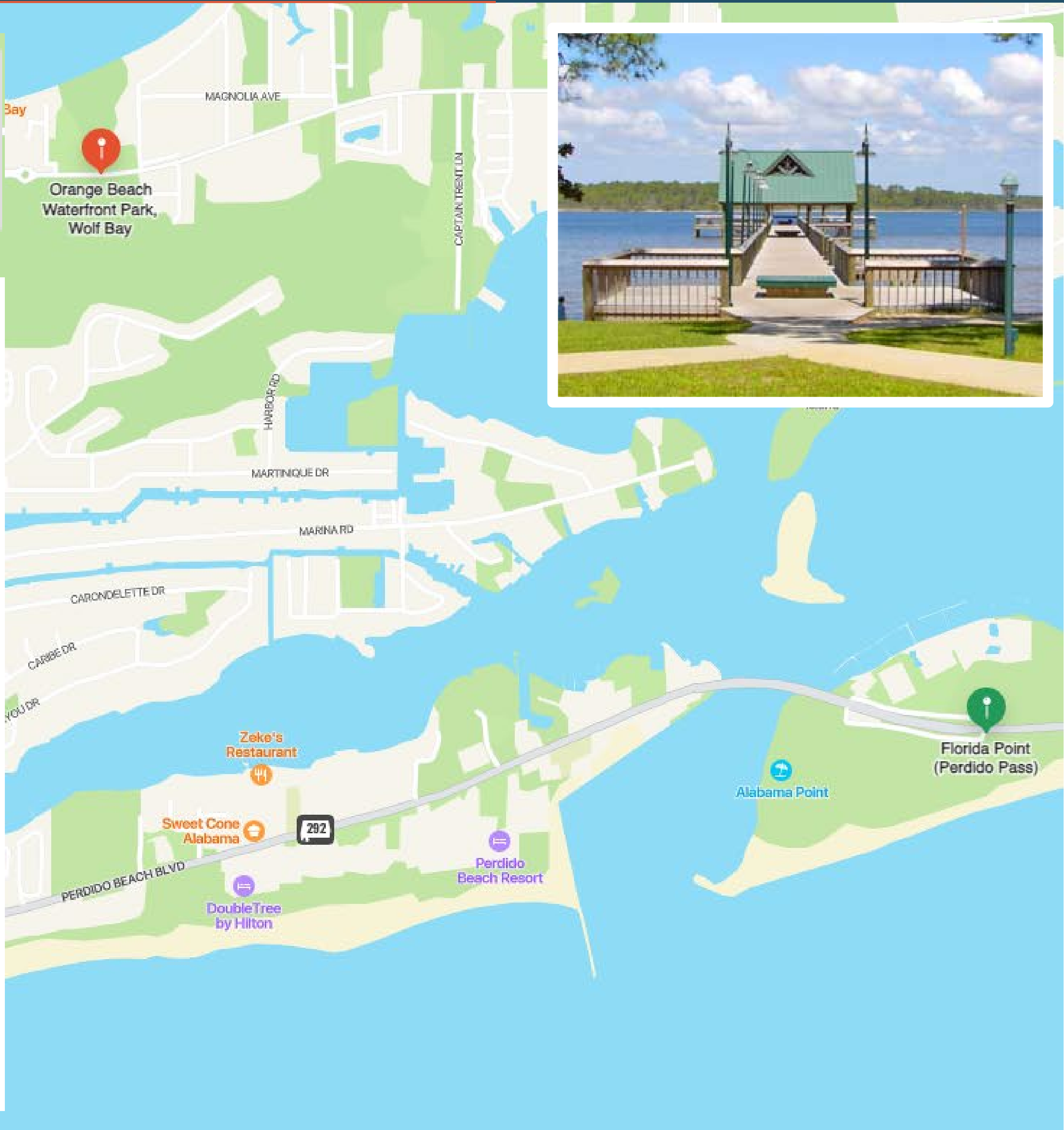
SWIM GUIDE

BEACH BASICS BEACH FINDER ABOUT

Orange Beach Waterfront Park, Wolf Bay

Met water quality standards less than 60% of the time

More info

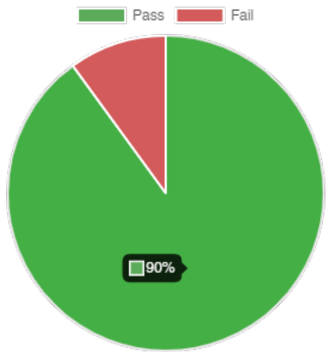


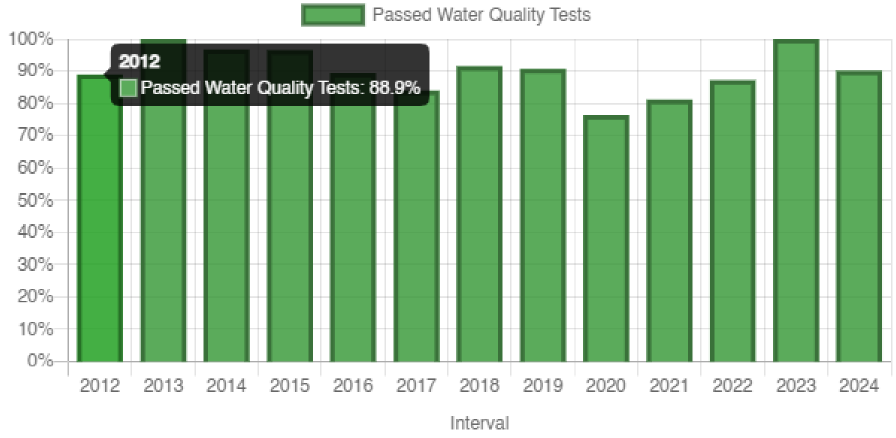
Current Water Quality

Failed to meet water quality standards

This status is based on the latest sample, take on July 5th, 2024 Mobile Baykeeper updates the status of this beach as soon as test results become available. These results were posted to Swim Guide on July 5th at 1:19 PM.

Monitoring Frequency: Orange Beach Waterfront Park, Wolf Bay is sampled Weekly from March 10th to October 1st





2022 REPORT CARD FOR ALABAMA'S INFRASTRUCTURE

Stormwater

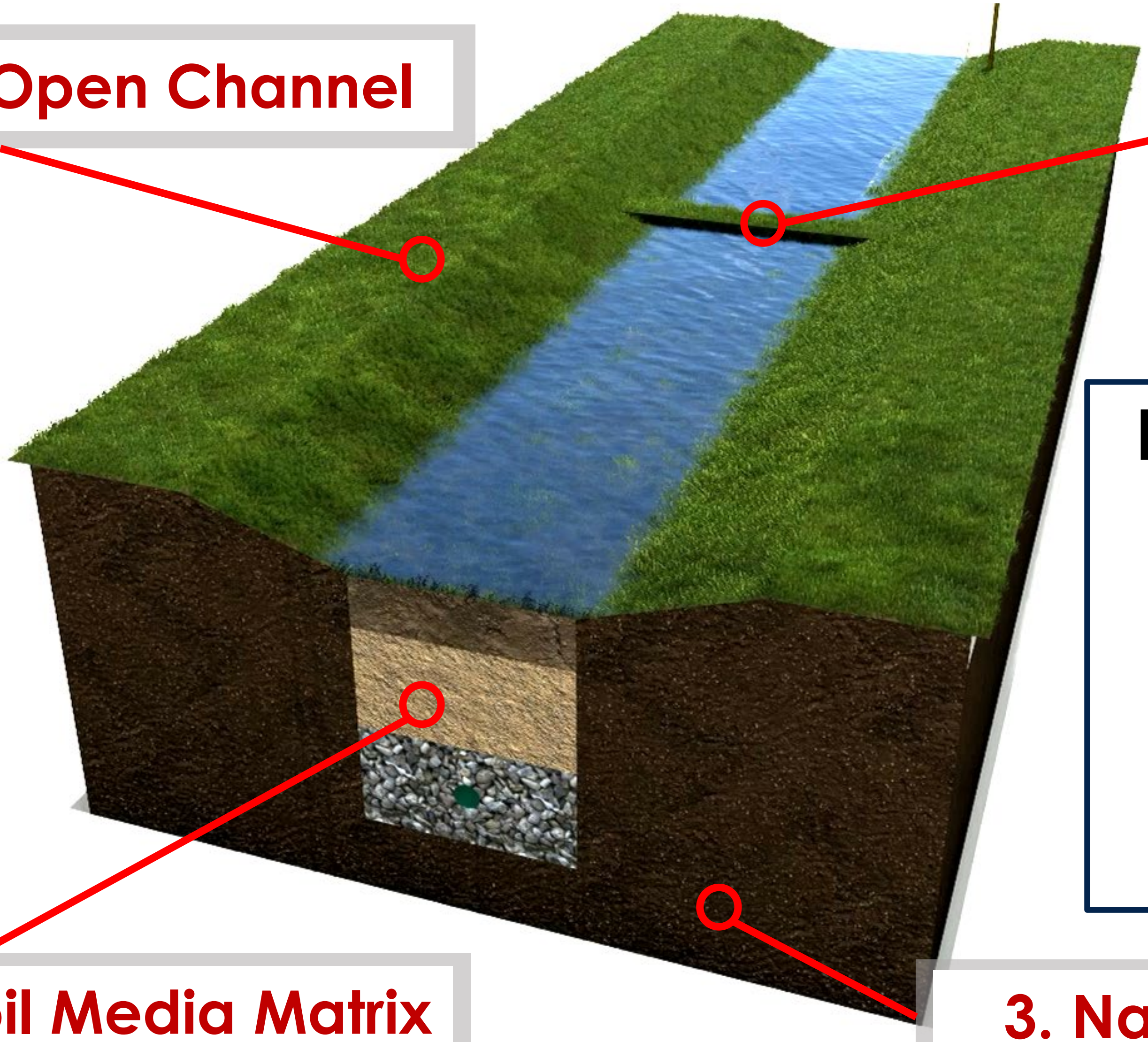
D+

EVALUATING INFILTRATION SWALE PERFORMANCE

ALDOT
Alabama Department of Transportation

BACKGROUND

POST CONSTRUCTION INFILTRATION SWALES

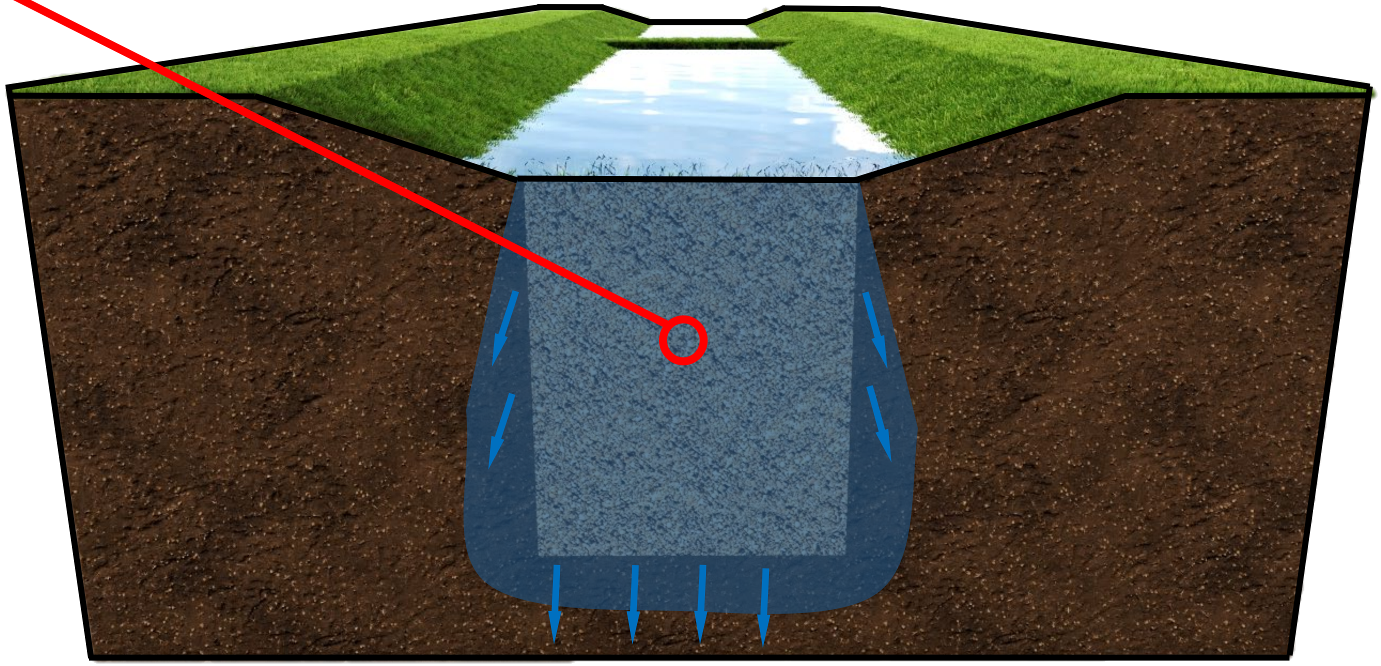


Engineered system that promotes groundwater infiltration and reduces surface runoff

INFILTRATION SWALES

Engineered Soil Media Matrix

- Reduces runoff
- Mimics pre-hydrology
- Promotes infiltration



SMALL-SCALE TESTING

SMALL-SCALE TESTING

STANDARD PERMEAMETER

COLUMN APPARATUS

- Material properties
  - Gradation
  - Porosity
  - Bulk unit weights
  - Compaction
- Permeability testing
- Infiltration testing
  - Falling head test
  - Constant head test

TESTING MATERIALS

#57 Stone

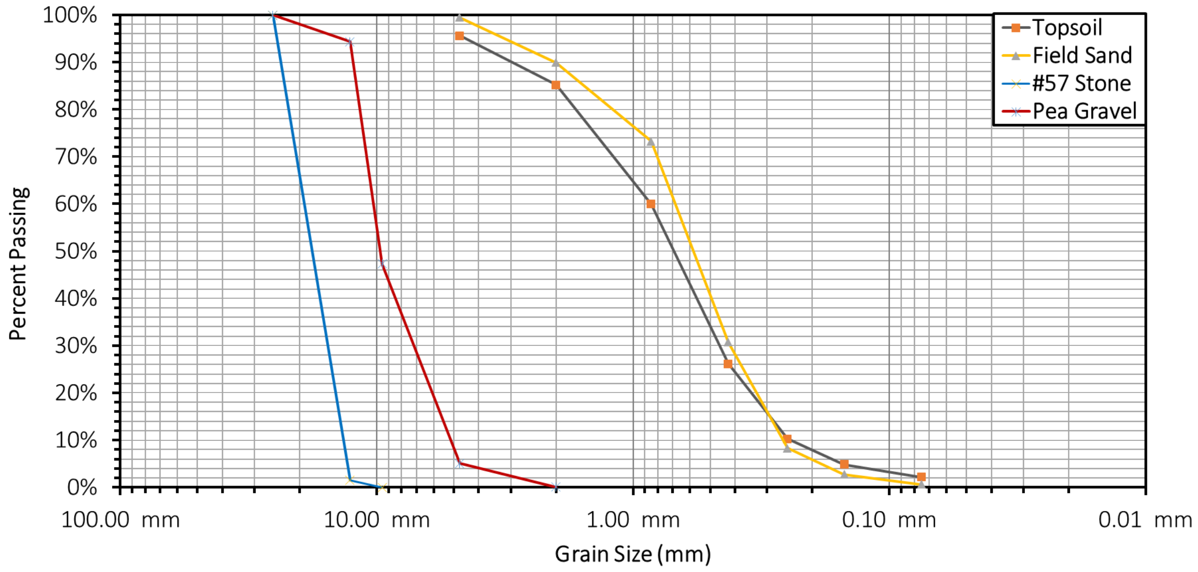
Pea gravel

Fill Sand

Washed Sand

Topsoil

GRADATION, POROSITY, & BULK DENSITY



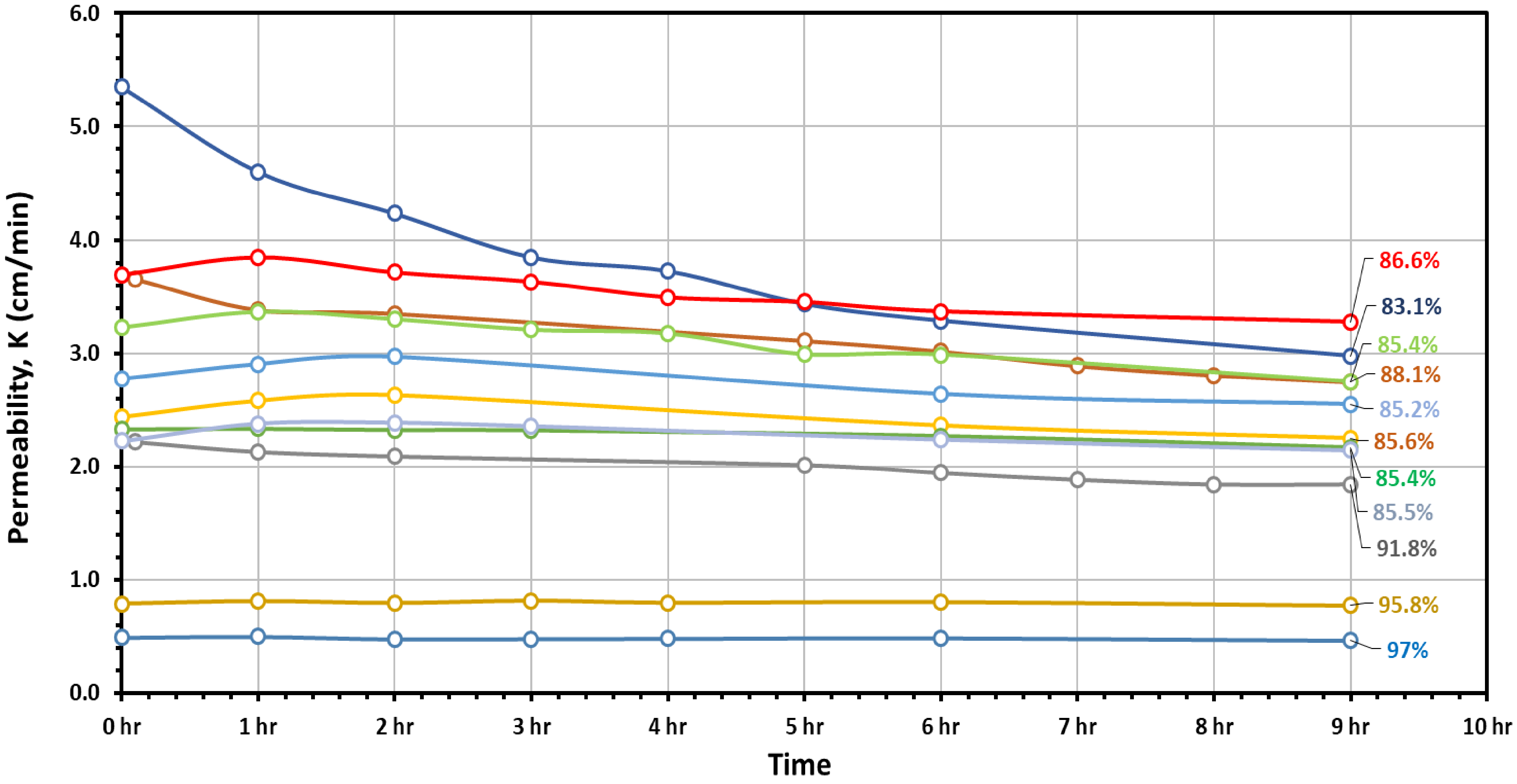
POROSITY: LOOSE SAMPLES

Sample	Graduated cylinder Weight (g)	G. Cylinder + Dry sample Weight (g)	Dry Sample weight (g)	Sample volume (cm3)	Water Volume Added (cm3)	Porosity (%)
Field sand	217.4	731.1	513.7	330	127	38.5%
Top Soil	216.8	659.4	442.6	315	128.9	40.9%
#57 Stone	157.7	601.5	443.8	450	235.8	52.4%
Ever green Top soil	86.8	109.5	22.7	130	95.6	73.5%

BULK DENSITY: LOOSE SAMPLES

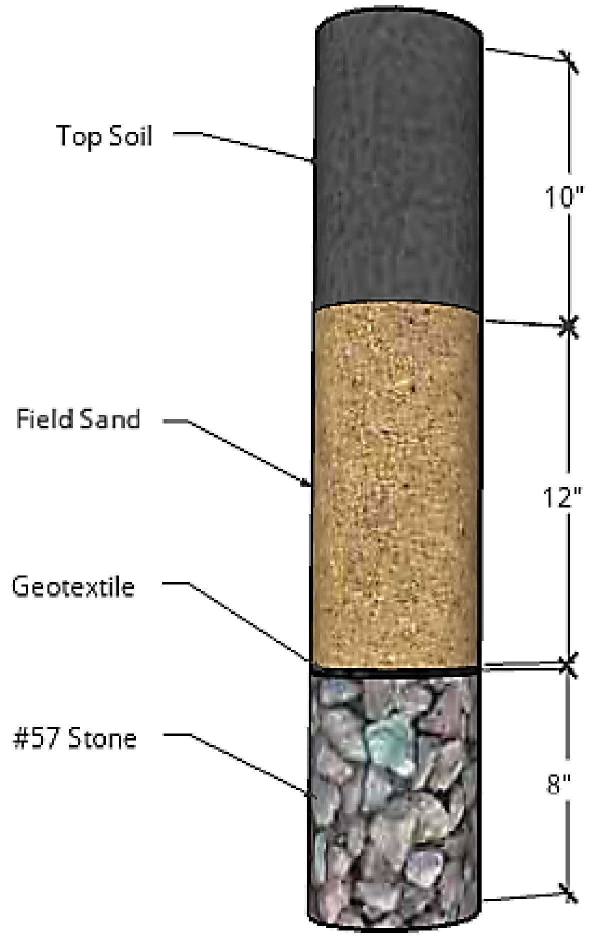
Sample	Graduated cylinder Weight (g)	G. Cylinder + Dry sample Weight (g)	Dry Sample weight (g)	Sample volume (cm3)	Bulk density (g/cm3)
Field sand	217.4	716.7	499.3	350	1.43
Top Soil	216.8	644.8	428	330	1.30
#57 Stone	157.6	651	493.4	405	1.22
Ever green Top soil	86.8	110	23.2	135	0.17

PERMEABILITY OF FIELD SAND VS TIME AT DIFFERENT DENSITIES

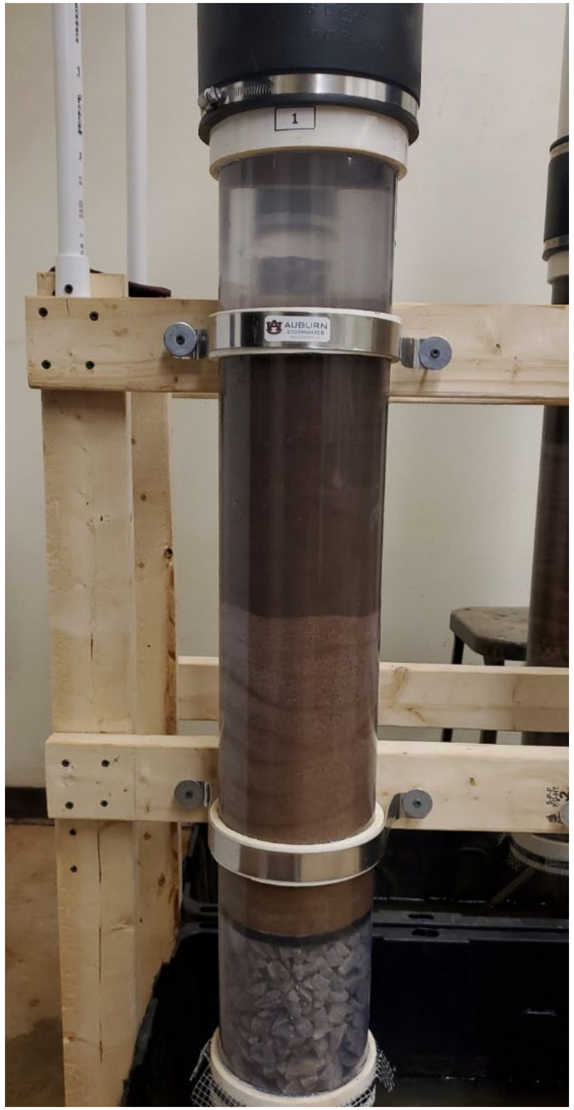


ALDOT INFILTRATION SWALE SAMPLES

ALDOT DESIGN



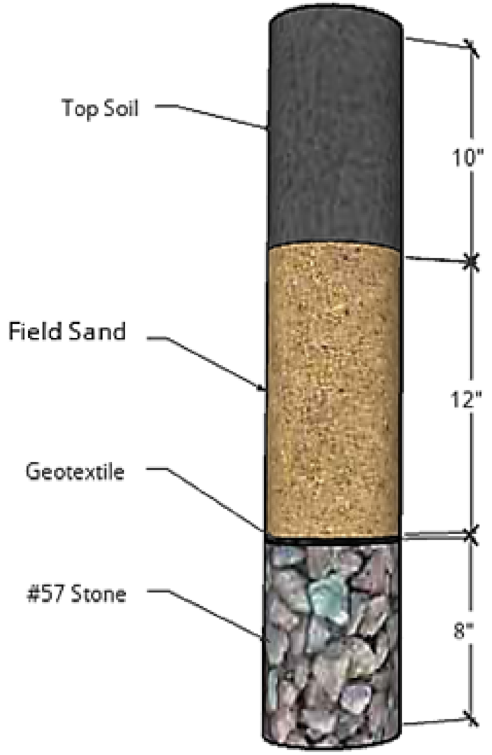
Column 1



Column 2

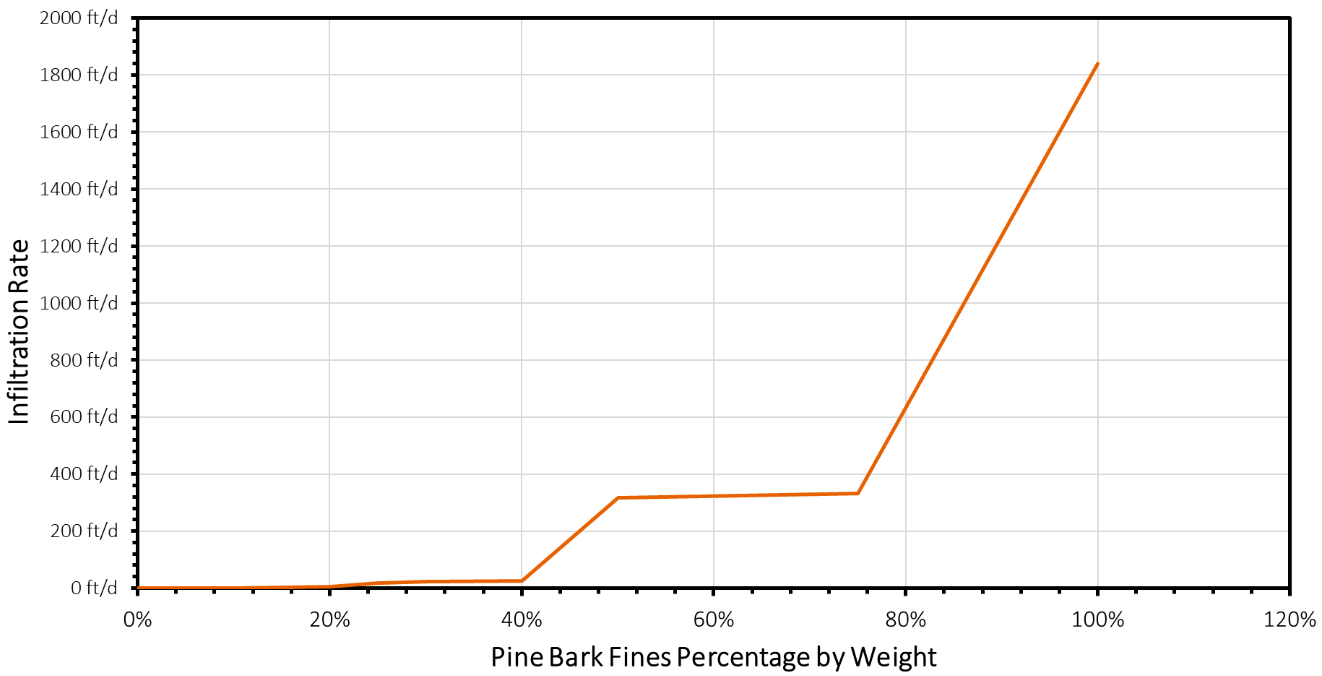
Column 3

SAMPLES TESTED – FALLING HEAD TEST

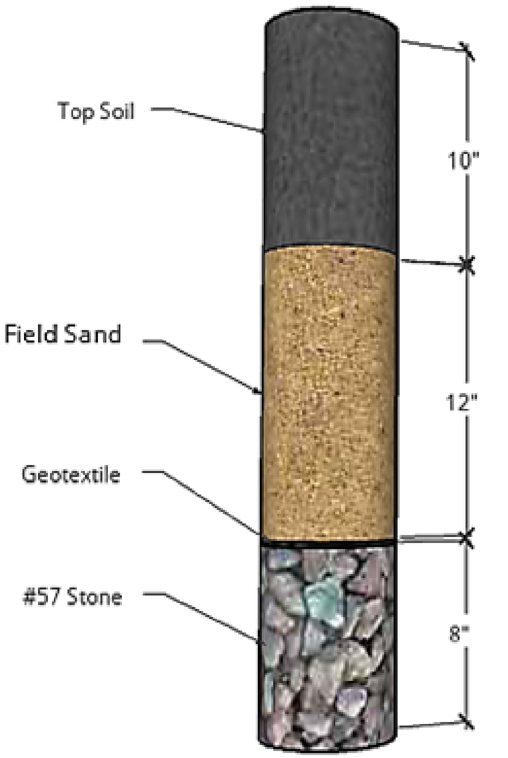
	SAMPLE OUTLINE	AVERAGE INFILTRATION RATE
A		**0.31 ft/day**

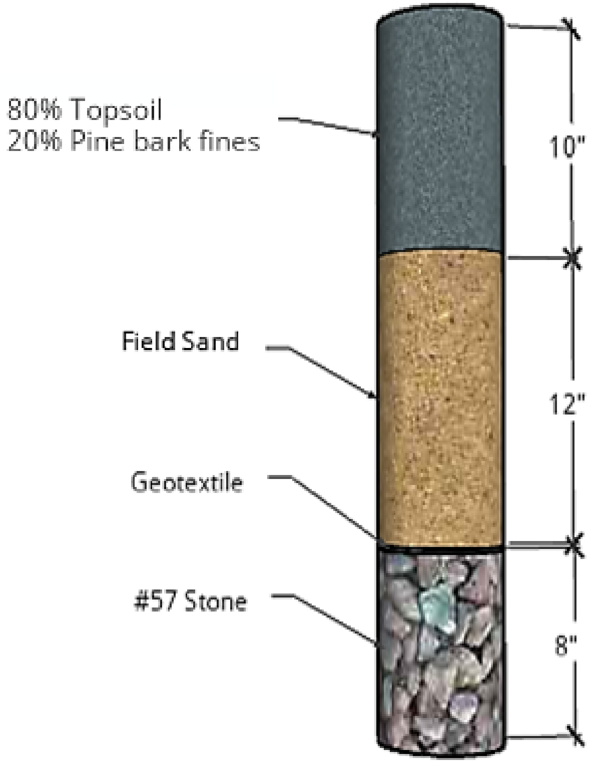
TOPSOIL AMENDED WITH PINE BARK FINES – INFILTRATION RATES

Pine Bark Fines	Top Soil	Infiltration rate
0%	100%	0.63 ft/day
5.0%	95%	0.76 ft/day
7.4%	93%	0.89 ft/day
10%	90%	1.14 ft/day
15%	85%	2.37 ft/day
20%	80%	5.60 ft/day
25%	75%	17.54 ft/day
30%	70%	26.23 ft/day
40%	60%	25.61 ft/day
50%	50%	317.66 ft/day
75%	25%	331.08 ft/day
100%	0%	1840.00 ft/day



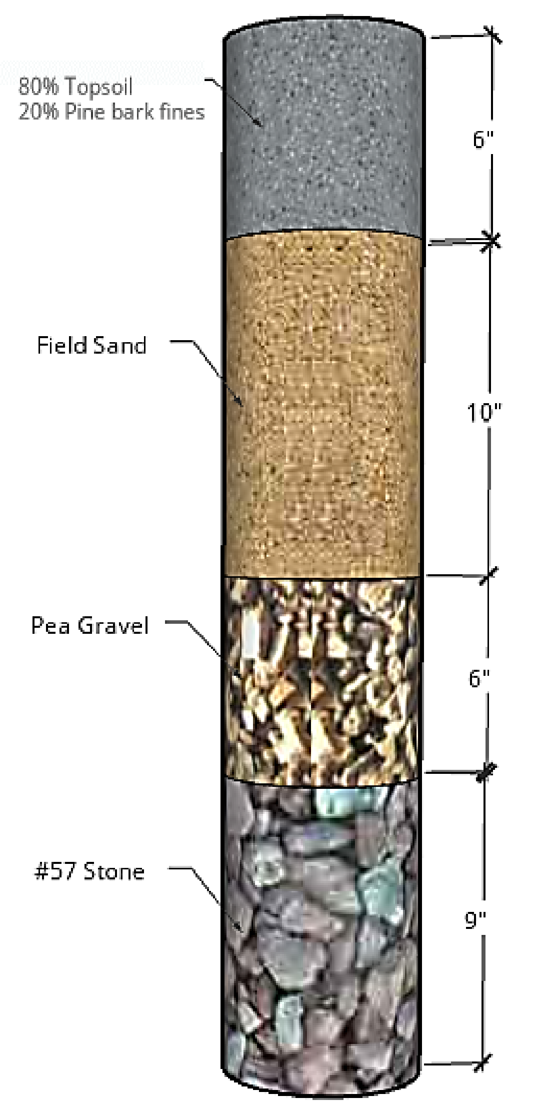
SAMPLES TESTED – FALLING HEAD TEST

	SAMPLE OUTLINE	AVERAGE INFILTRATION RATE
A		0.31 ft/day

	SAMPLE OUTLINE	AVERAGE INFILTRATION RATE
B		1.10 ft/day

F3 SAMPLE POTENTIAL NEW DESIGN

F3 DESIGN

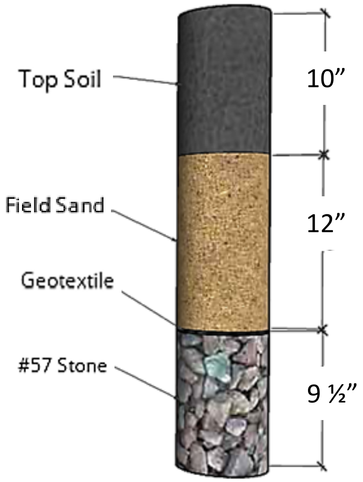
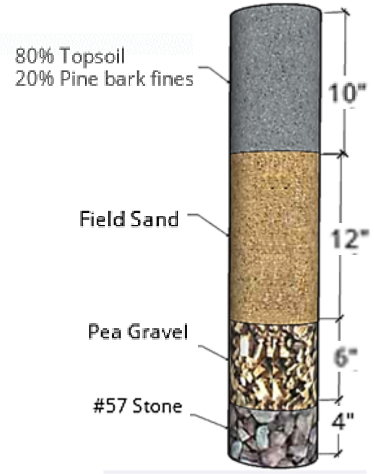
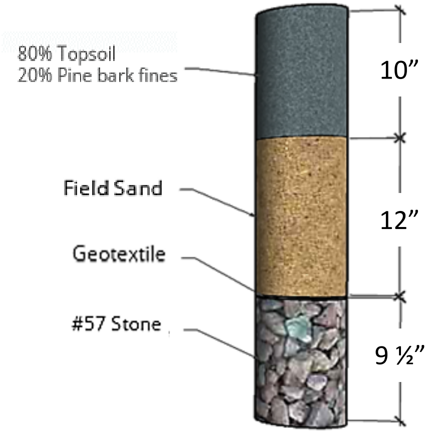
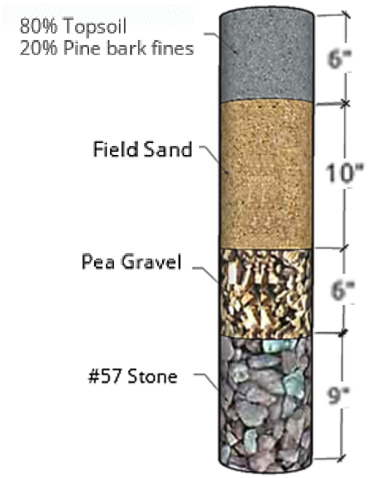


Column 1

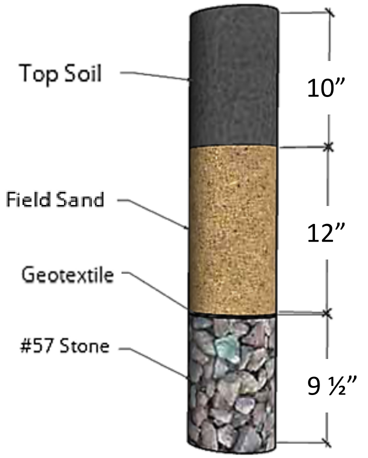
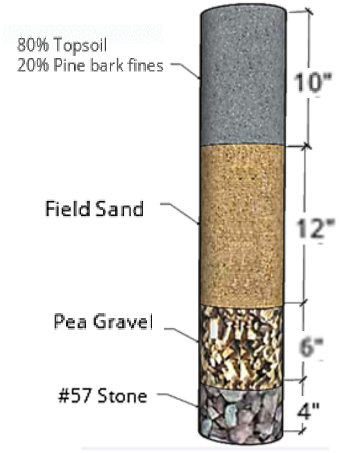
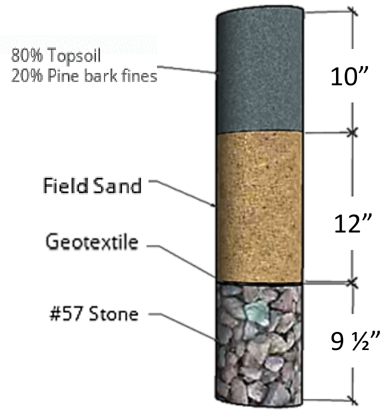
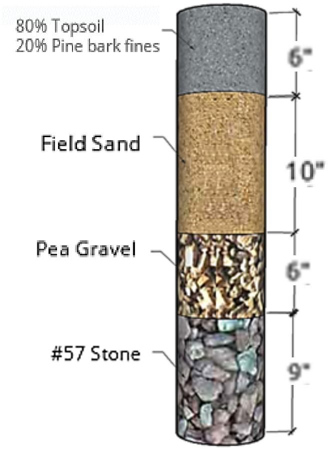
Column 2

Column 3

BEST SAMPLES - CONSTANT HEAD TEST

SAMPLE OUTLINE		AVERAGE INFILTRATION RATE	SAMPLE OUTLINE		AVERAGE INFILTRATION RATE
ALDOT Consolidated		**1.73 ft/day**	F Consolidated		**5.31 ft/day**
A1		**5.38 ft/day**	F3		**5.75 ft/day**

BEST SAMPLES – FALLING HEAD TEST

<table>
<tr><th colspan="2">SAMPLE OUTLINE</th><th>AVERAGE INFILTRATION RATE</th><th colspan="2">SAMPLE OUTLINE</th><th>AVERAGE INFILTRATION RATE</th></tr>
<tr><td>ALDOT
Consolidated</td><td>
</td><td>0.49 ft/day</td><td>F
Consolidated</td><td>
</td><td>1.26 ft/day</td></tr>
<tr><td>A1</td><td>
</td><td>1.10 ft/day</td><td>F3</td><td>
</td><td>2.24 ft/day</td></tr>
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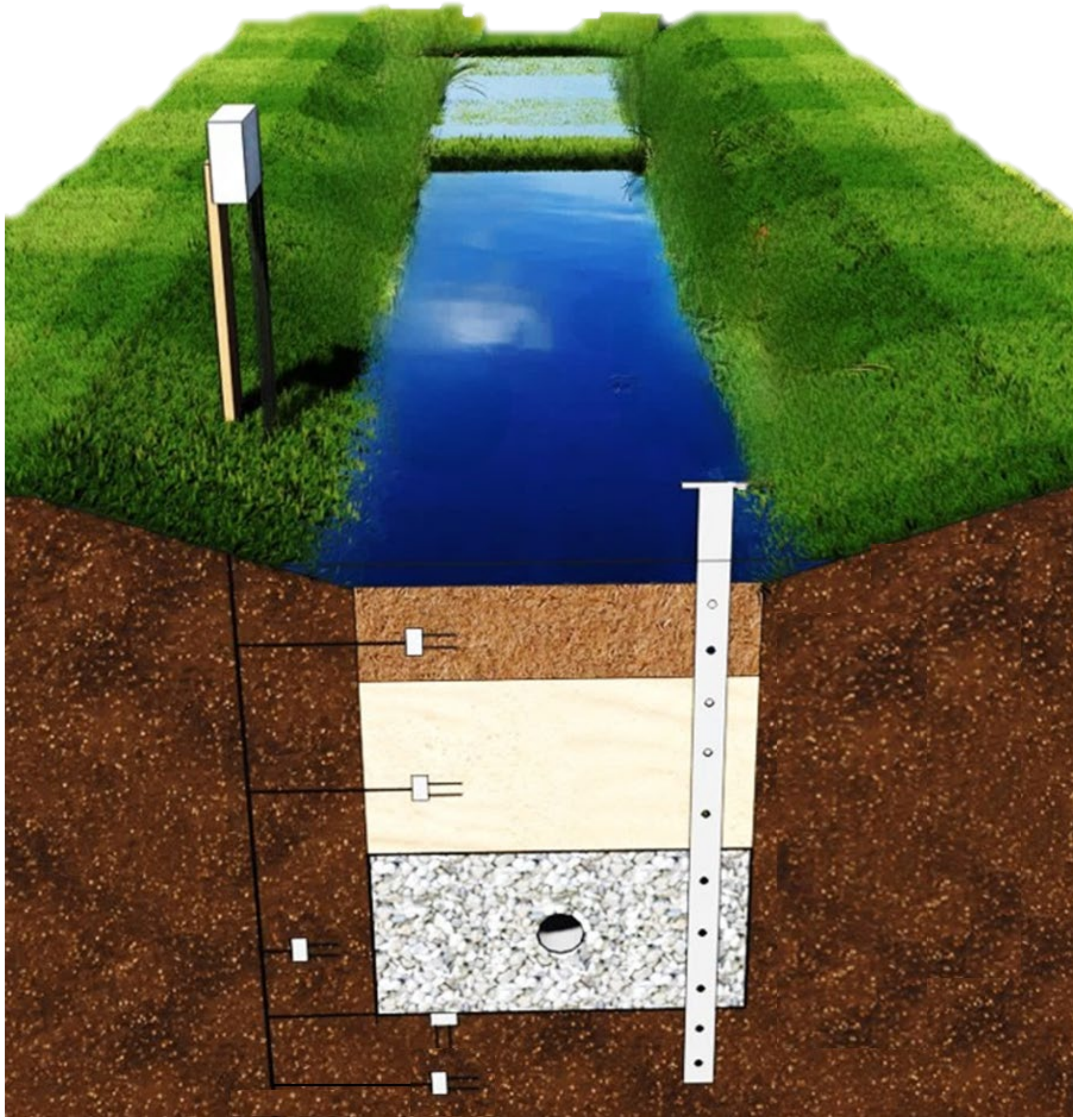
COLUMN TESTING FINDINGS ❯ FIELD APPLICATION

- Topsoil is limiting layer
- 80/20 pine bark fines amendment improves infiltration
  - Increased permeability by 9x
  - Column test infiltration improved by 2.6 to 3.1x
- Consider reducing 12 in. topsoil layer to 6 in.
- Geotextile reduces infiltration rate
  - Pea gravel increased infiltration rate by 2.2 to 3.1x



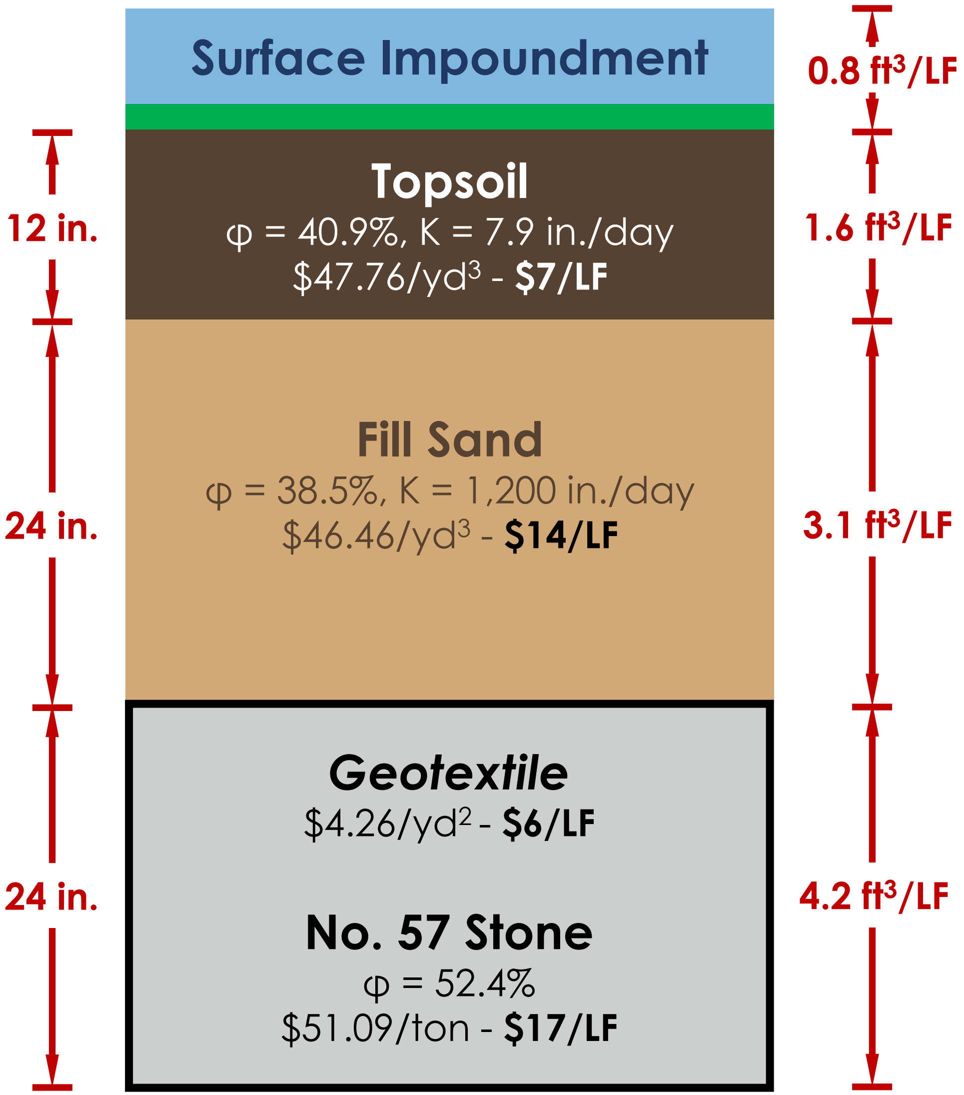
COST COMPARISON

ALDOT Standard

Infiltration Rate = 1.22 ft/day

Storage = 9.7 ft^3/LF

Material Cost Estimate: $44/LF

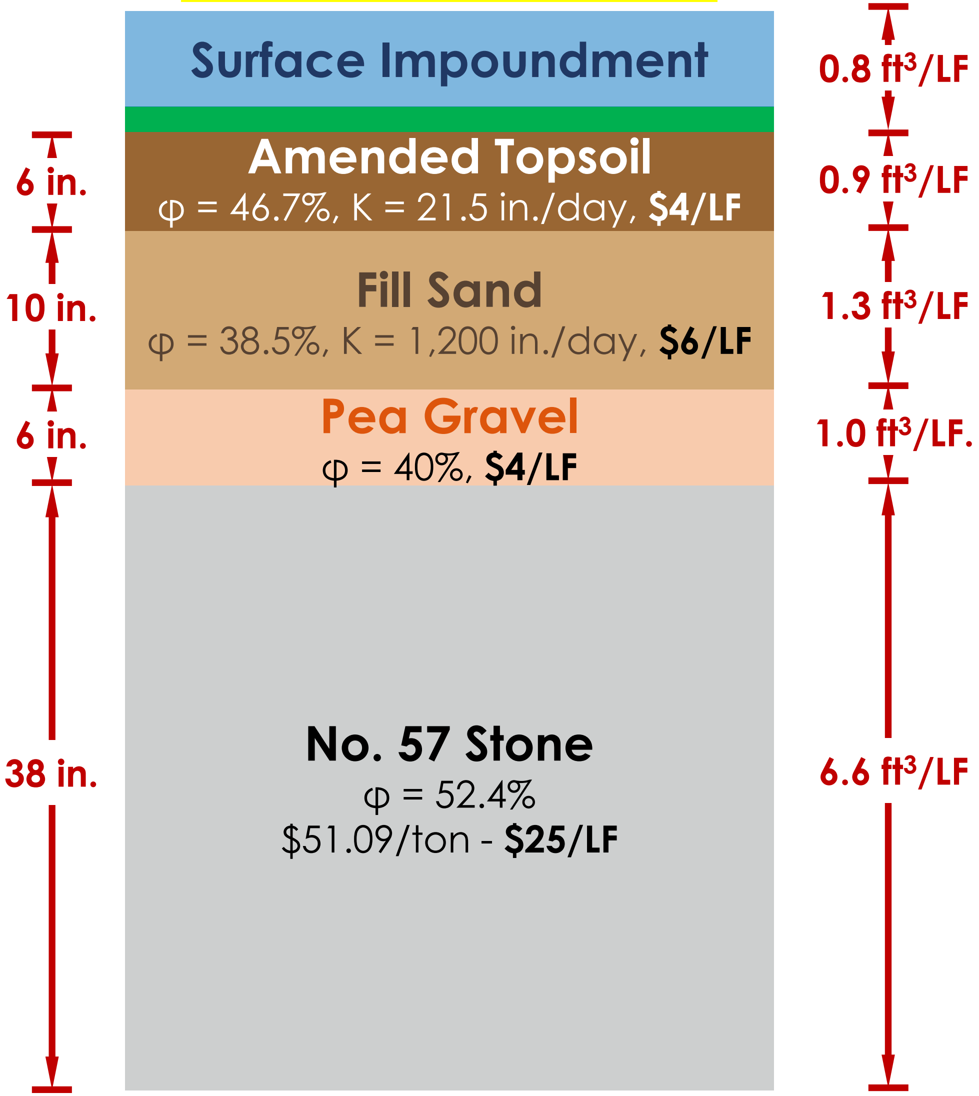


Enhanced Swale

Infiltration Rate = 3.15 ft/day

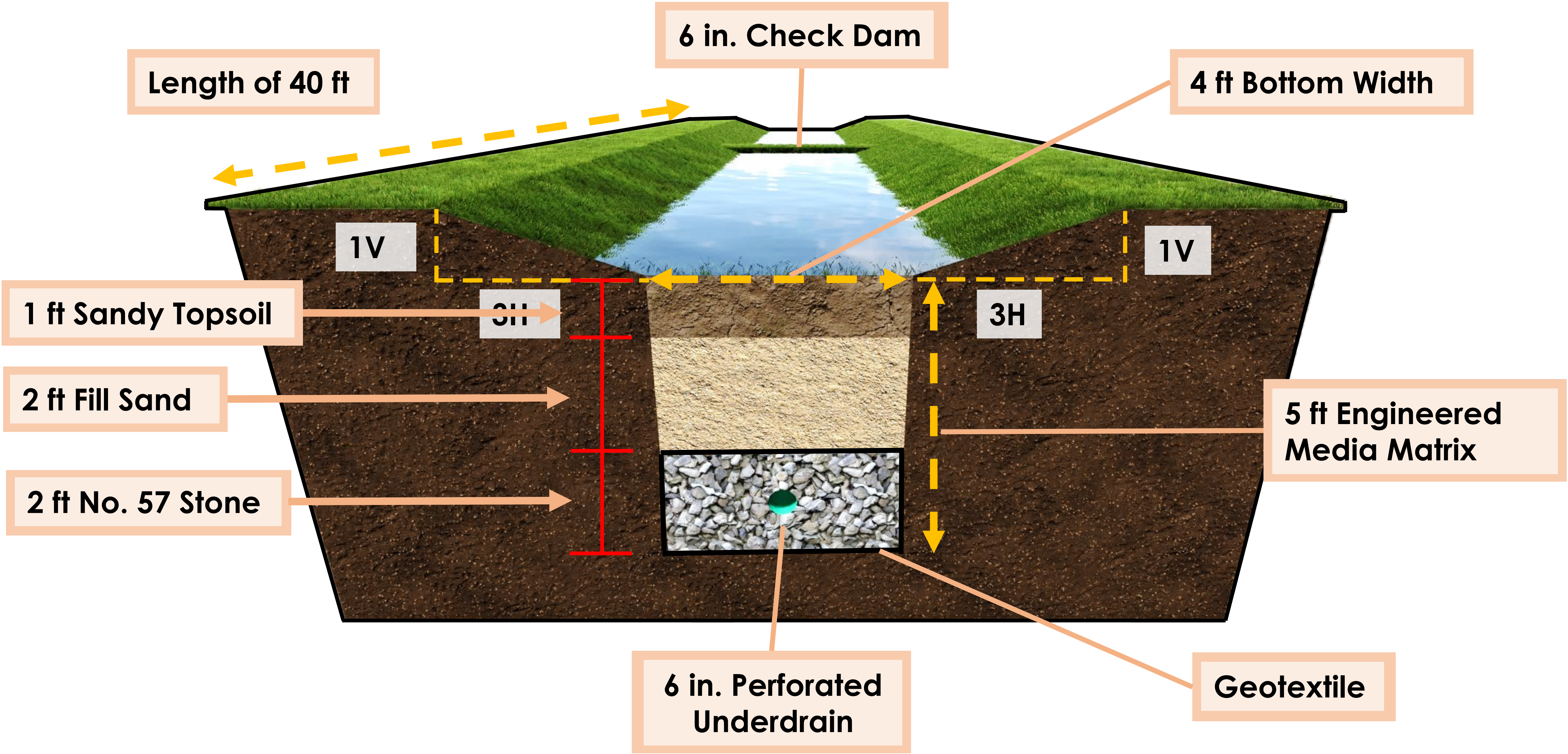
Storage = 10.6 ft^3/LF

Material Cost Estimate: $39/LF



FIELD SCALE TESTING PHASE

ALDOT INFILTRATION SWALE DESIGN



ALDOT SWALE SITE SELECTION

Double Ring Infiltrometer

Hydrologic Soil Group	Infiltration Rate (in/hr)	Infiltration Rate (cm/hr)	Soil Textures
A	1.63	4.14	Silty Gravels Gravelly Sands Sand
	0.8	2.03	Sand Loamy Sand Sandy Loam
B	0.45	1.14	Silt Sands
	0.3	0.76	Loam Silt Loam
C	0.2	0.51	Sandy Clay Loam Silts
D	0.06	0.15	Clay Loam Silty Clay Loam Sandy Clay Silt Clay Clay

Table: MnDOT

DOUBLE RING INFILTROMETER RESULTS

Double Ring V

Time (min)	Initial (cn
0-30	90.0
30-60	90.0
60-90	90.0
90-120	91.0
120-150	90.0
150-180	90.9
180-110	91.9
Average Infiltratio	

Safety Fa

Hydrologic Soil Group	Infiltration Rate (in/hr)	Infiltration Rate (cm/hr)	Soil Textures
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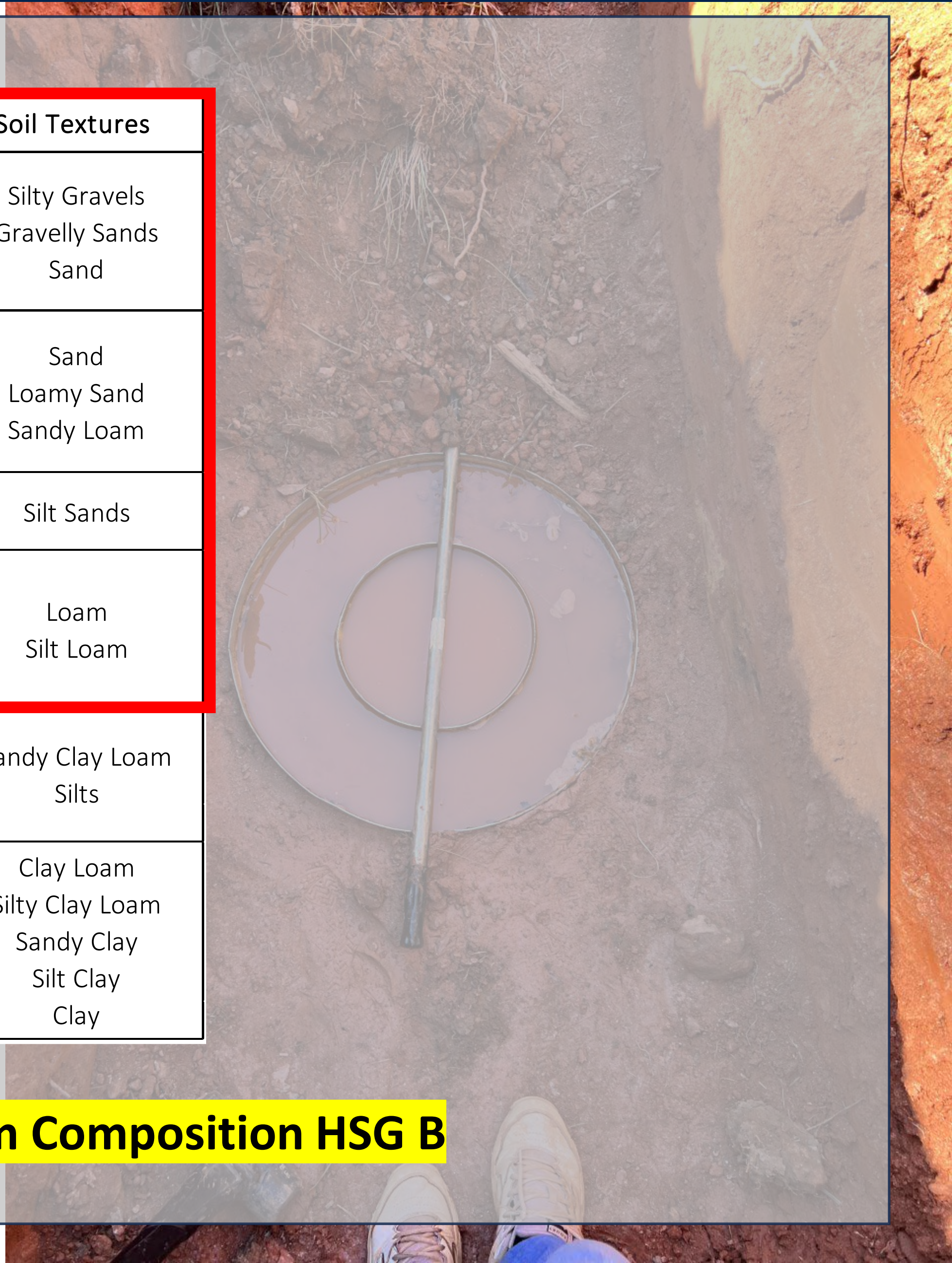


Infiltration Soil Classification: Native Soil – Sandy Loam Composition HSG B

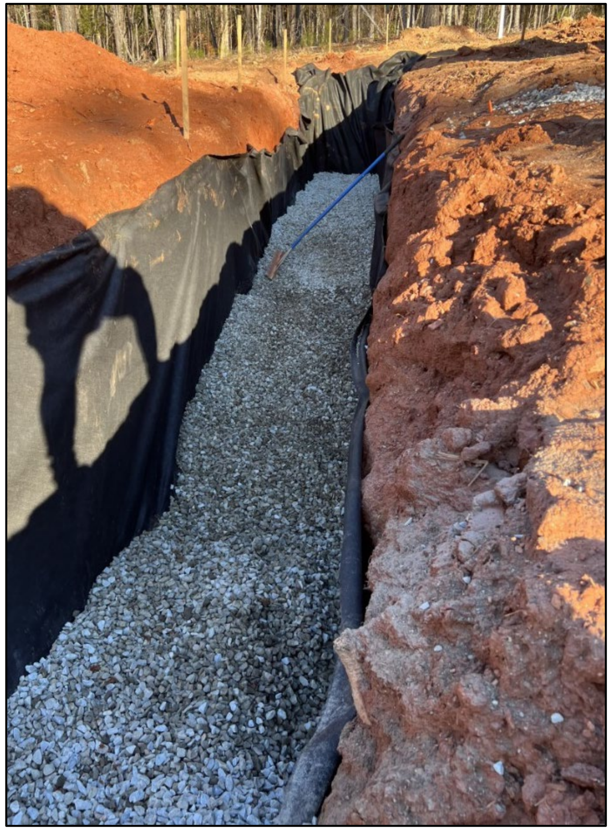
SWALE CONSTRUCTION

EXCAVATION

CHANNEL CONSTRUCTION

CONSTRUCTION OF ALDOT INFILTRATION SWALE

5 ft Excavation



Geotextile

2 ft #57 and Underdrain

Closed #57 Stone

CONSTRUCTION OF ALDOT INFILTRATION SWALE

2 ft Sand

1 ft Topsoil

1% Grade & Channel Shaping

STABILIZED SWALE

LARGE WEIR BOX CONSTRUCTION AND INSTALLATION

SWALE VOLUMES WERE VERFIED

TEROS 10 MOISTURE CONTENT SENSORS

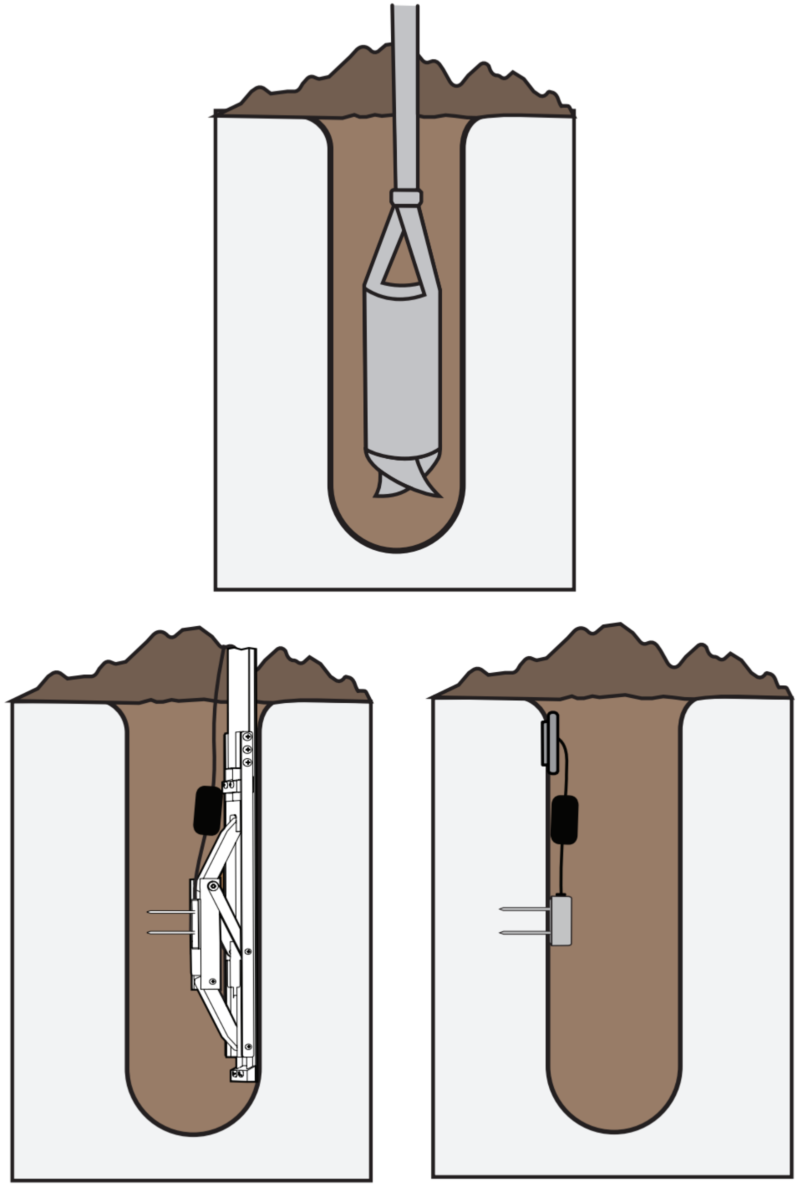
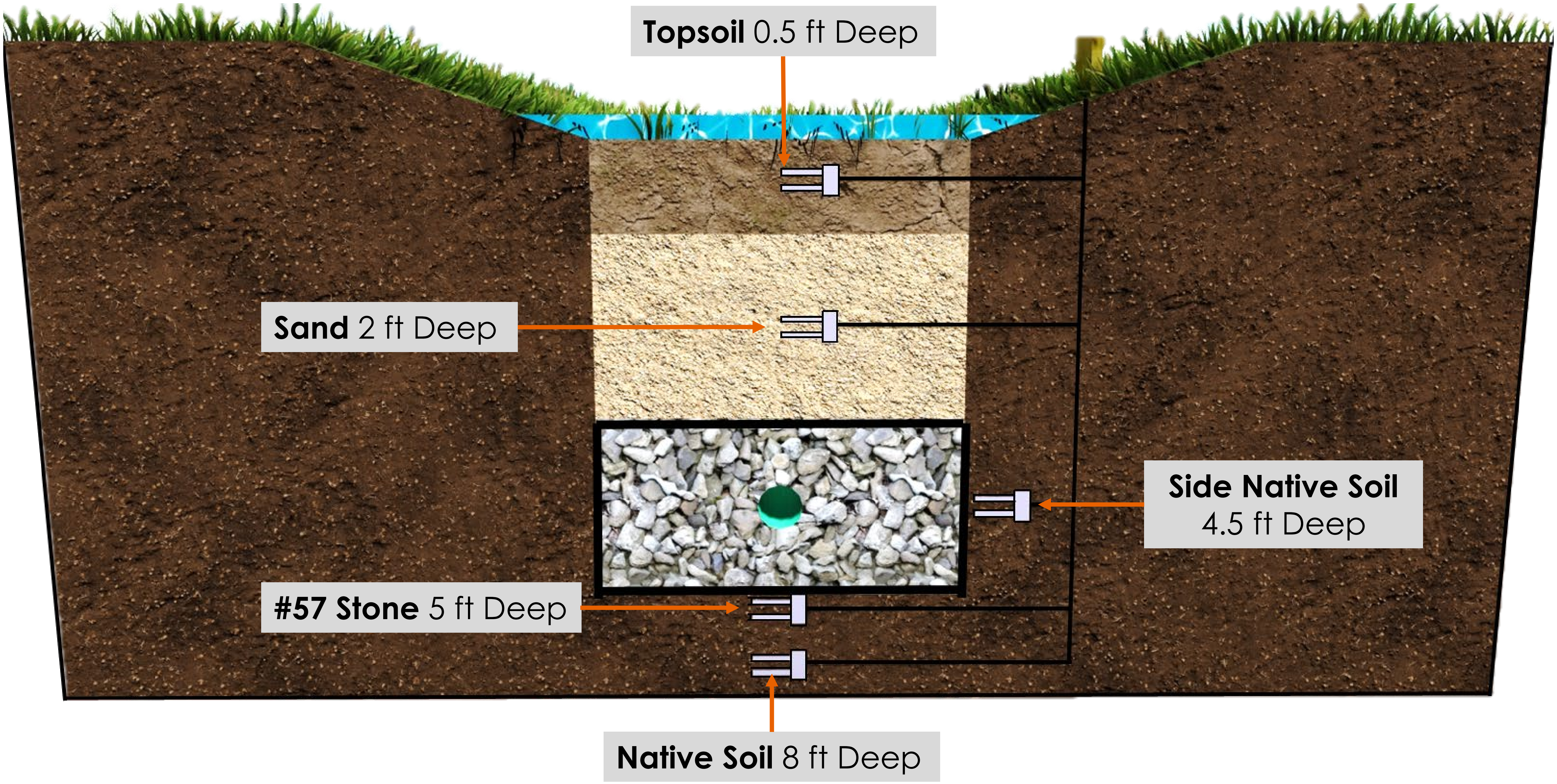
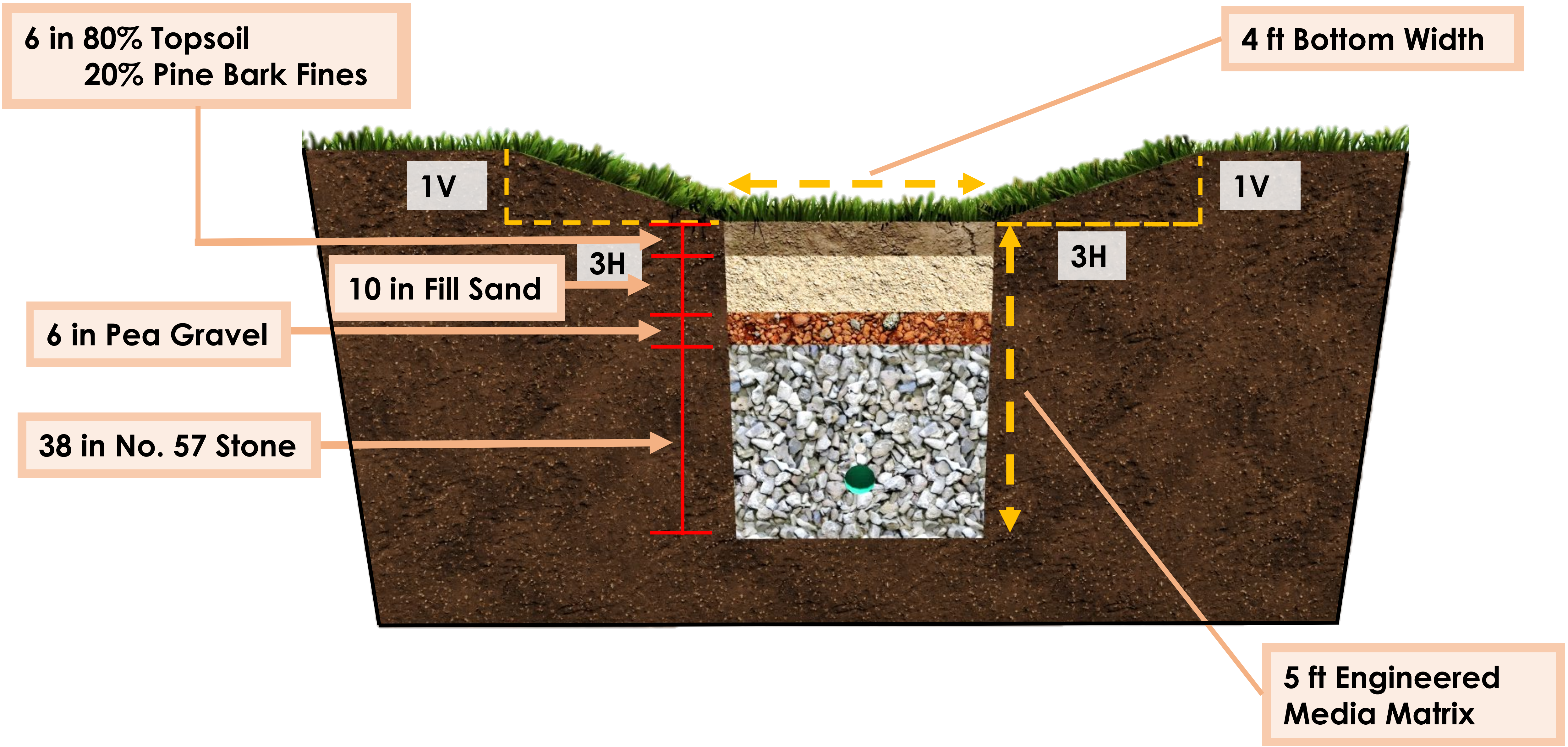


Figure: METER Group

ALDOT MOISTURE CONTENT SENSORS



MODIFIED SWALE INFILTRATION SWALE DESIGN



MODIFIED SWALE SITE LAYOUT

MODIFIED SWALE EXCAVATION

UNDERDRAIN AND NO.57 STONE

UNDERDRAIN AND NO.57 STONE

PEA GRAVEL LAYER

FILL SAND LAYER

SURFACE WEIR BOX

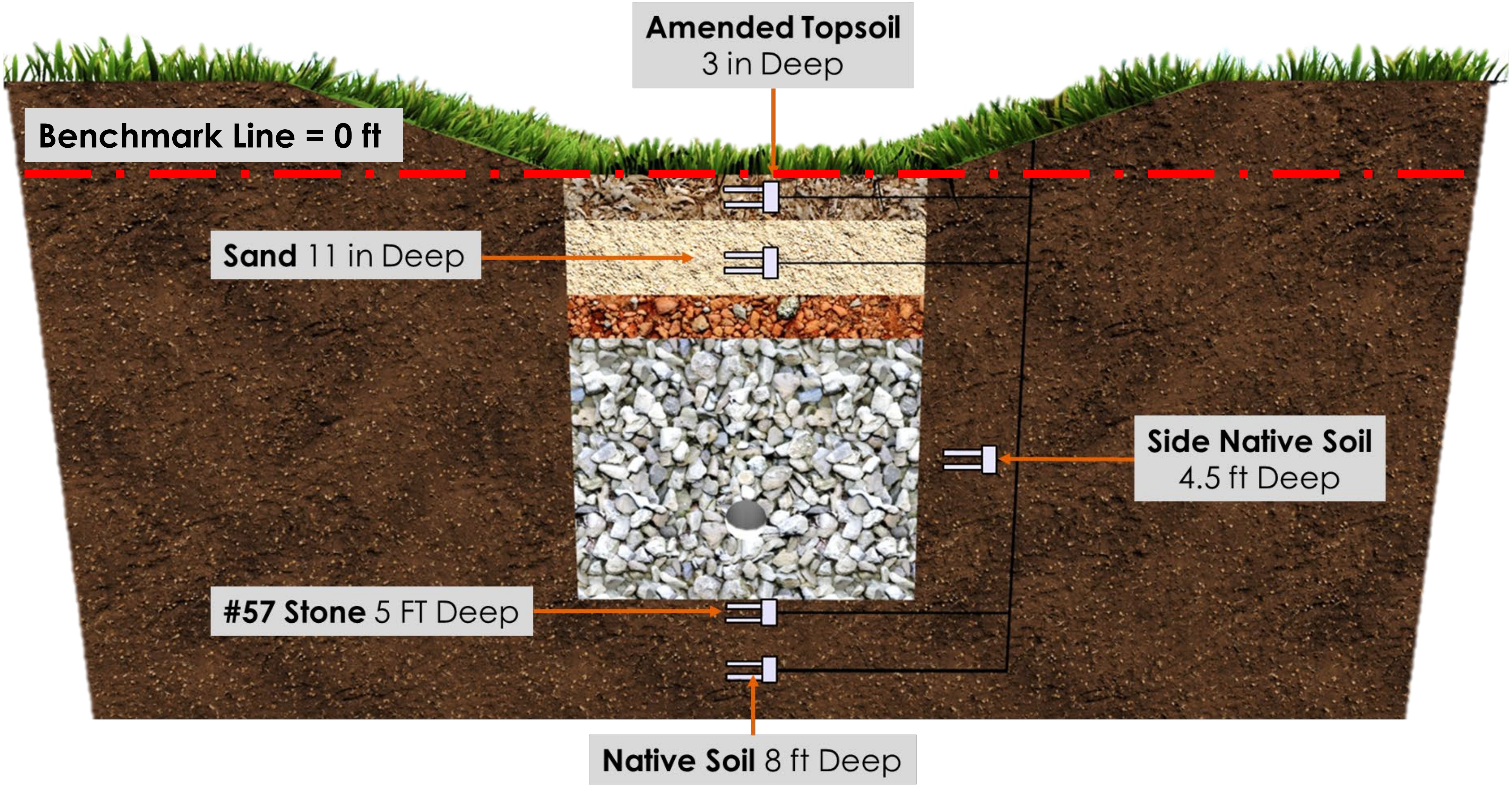
TOPSOIL LAYER

FINAL GRADING AND SWALE SHAPING

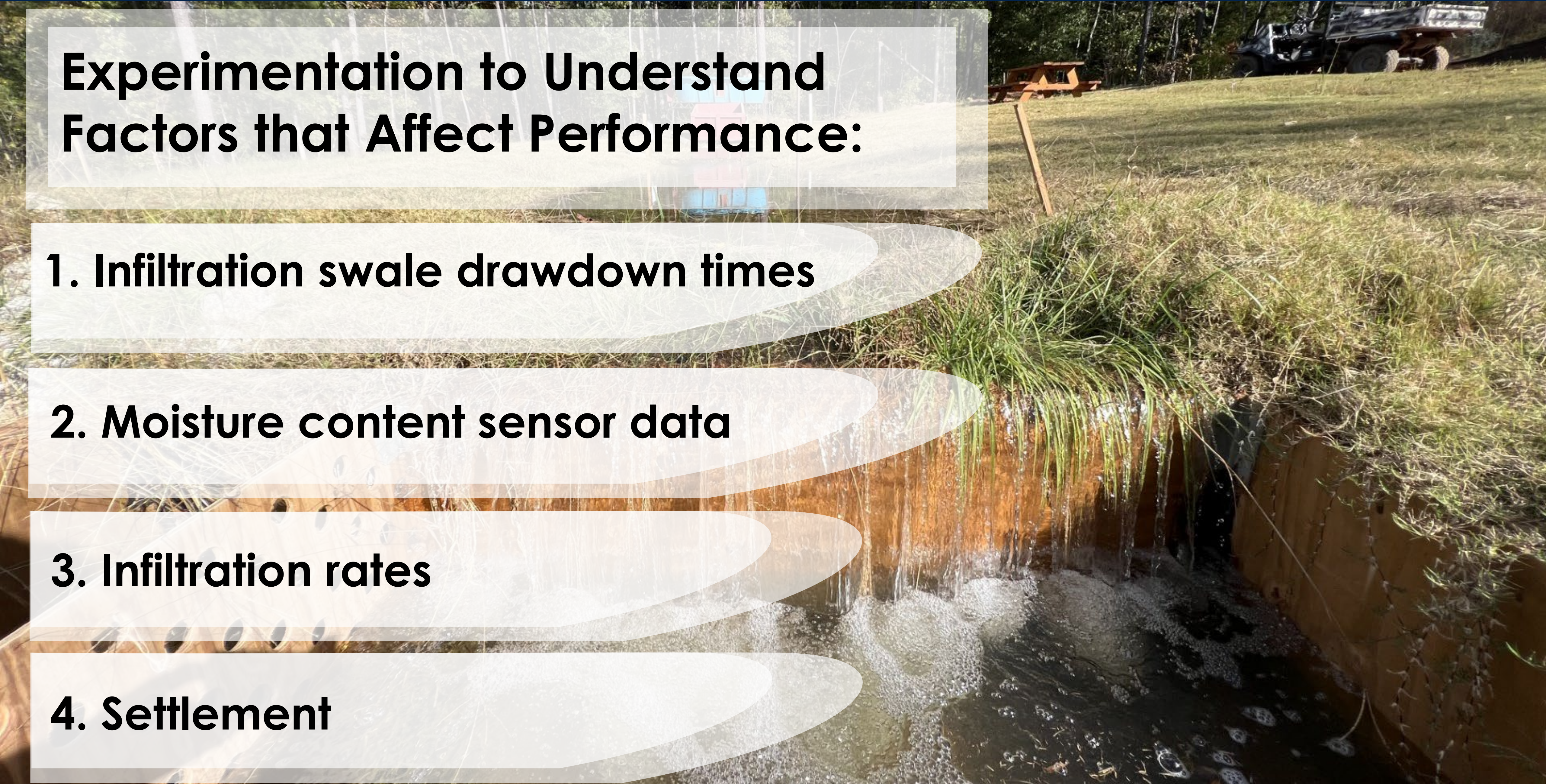
BERMUDA TIFWAY SODDING

READY FOR TESTING

SWALE MOISTURE CONTENT SENSORS



RESEARCH TESTING

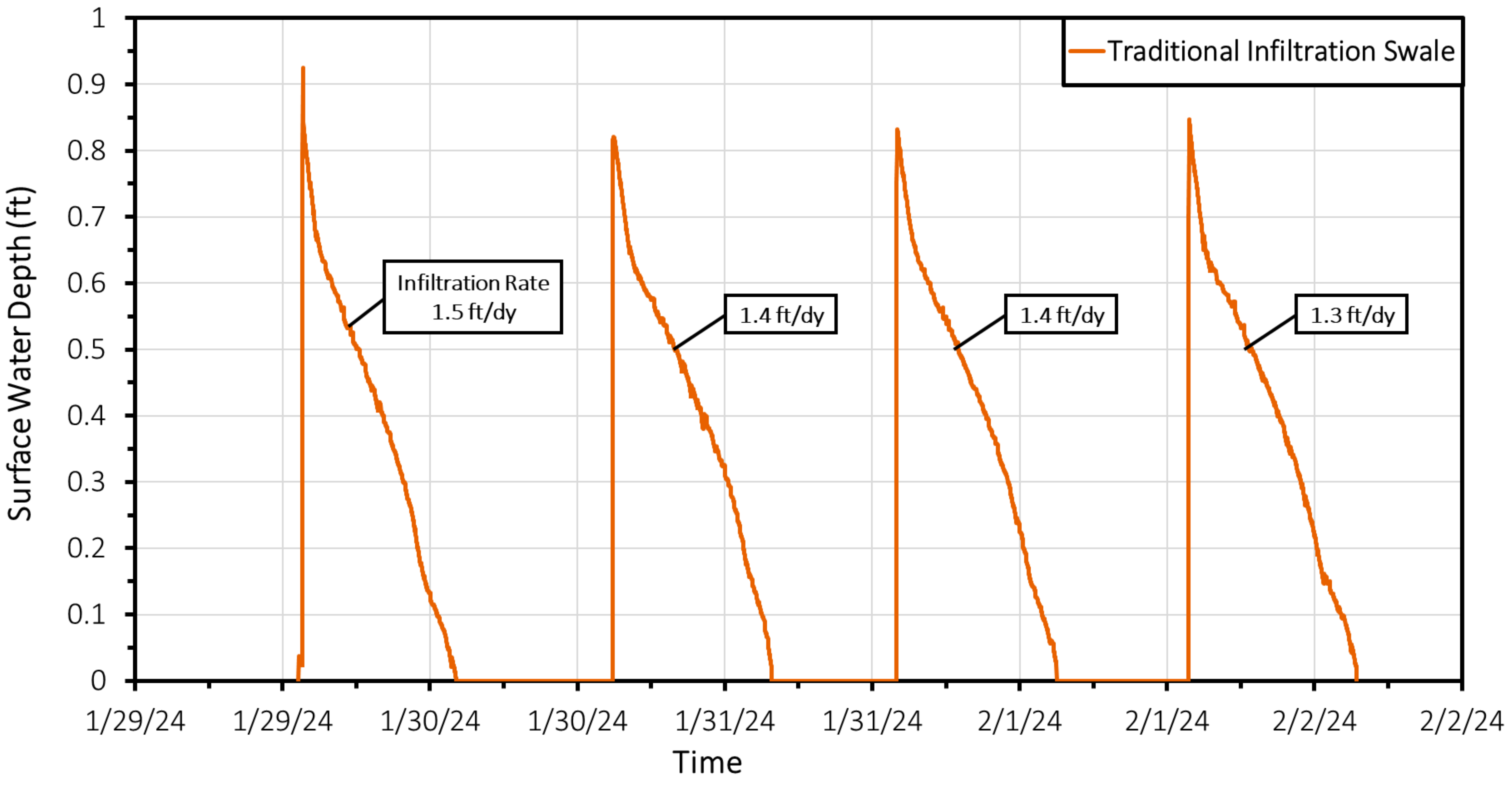


Experimentation to Understand Factors that Affect Performance:

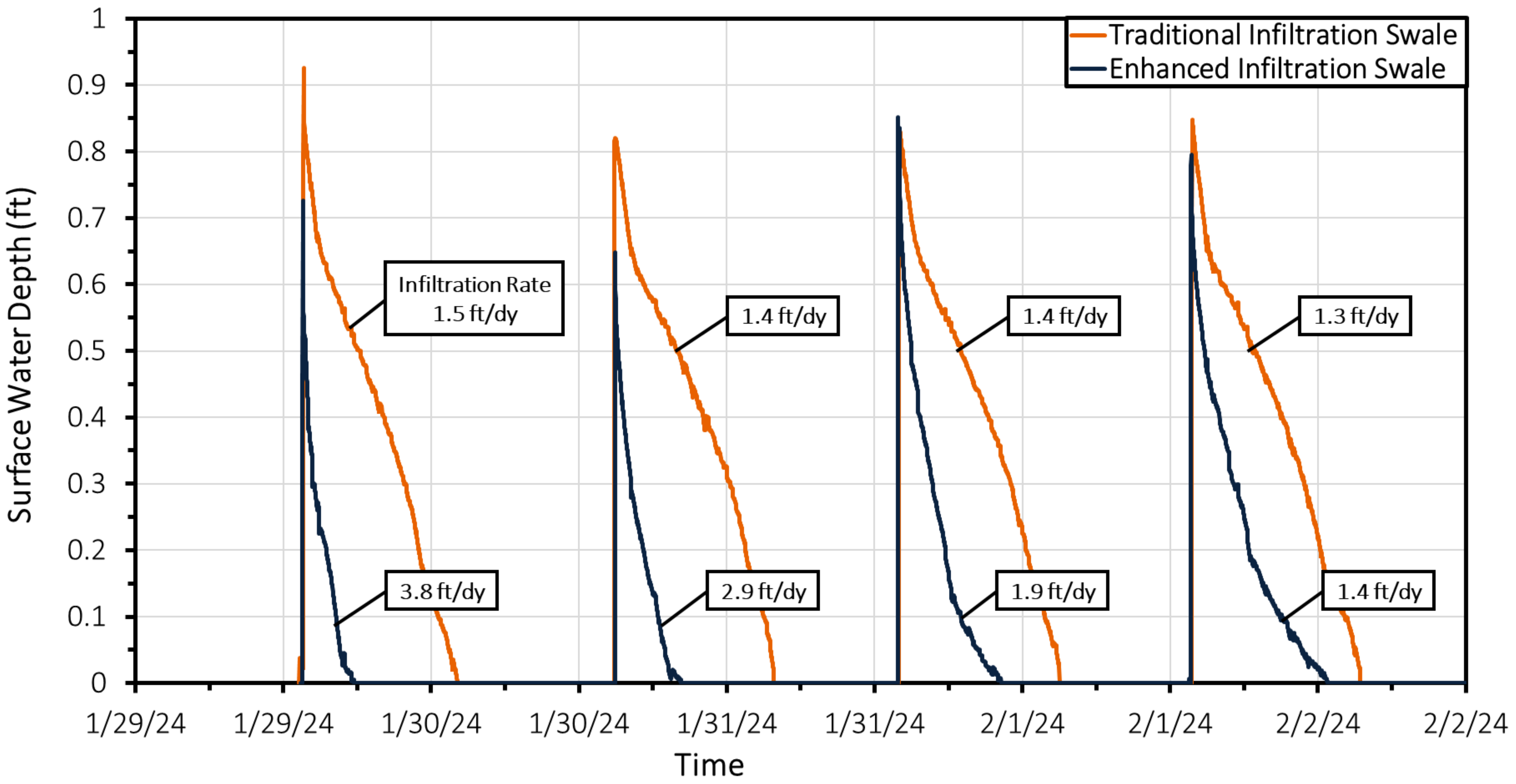
1. Infiltration swale drawdown times
2. Moisture content sensor data
3. Infiltration rates
4. Settlement

1. INFILTRATION SWALE DRAWDOWN

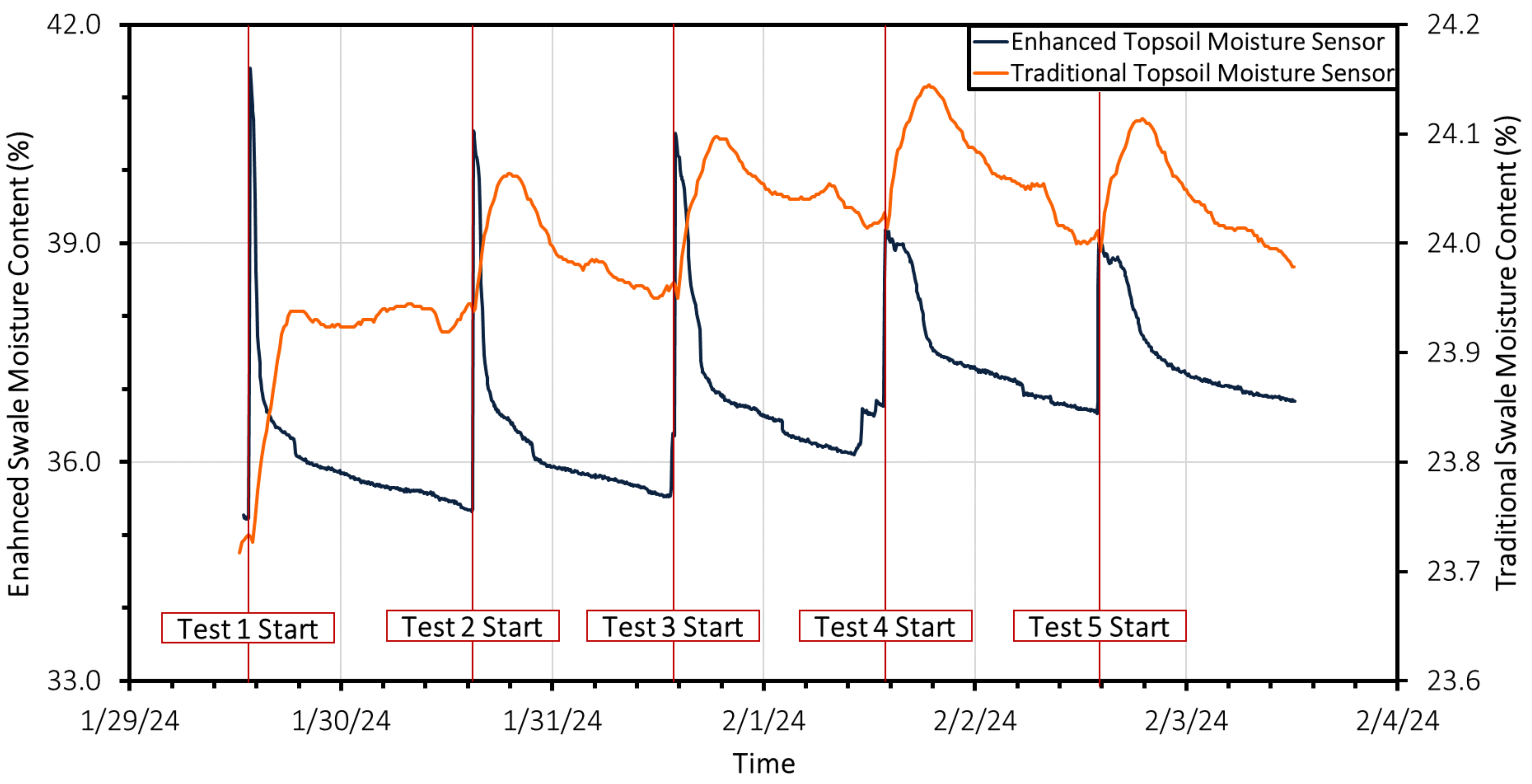
ALDOT SWALE DRAWDOWN



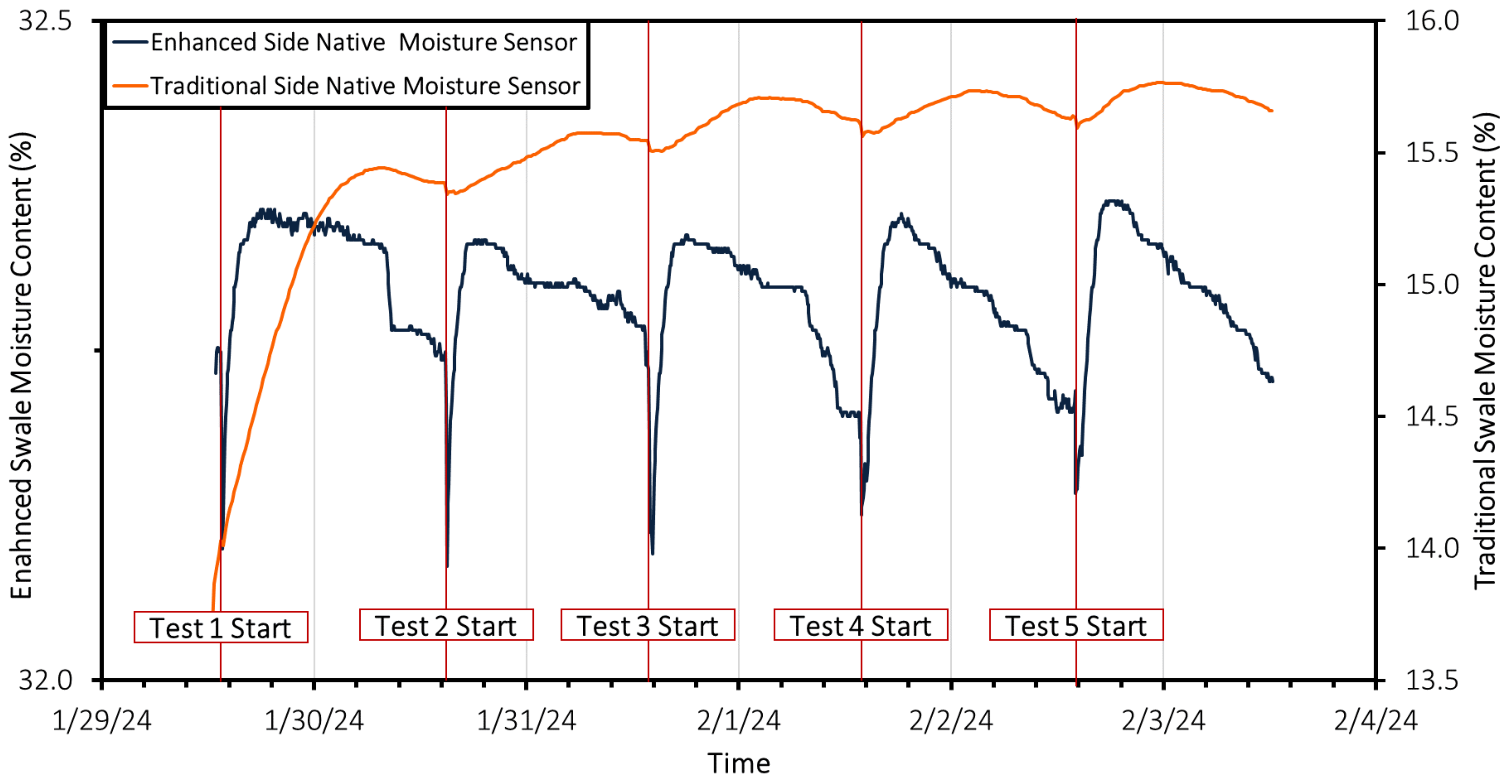
DRAWDOWN COMPARISON



TOPSOIL MOISTURE CONTENT

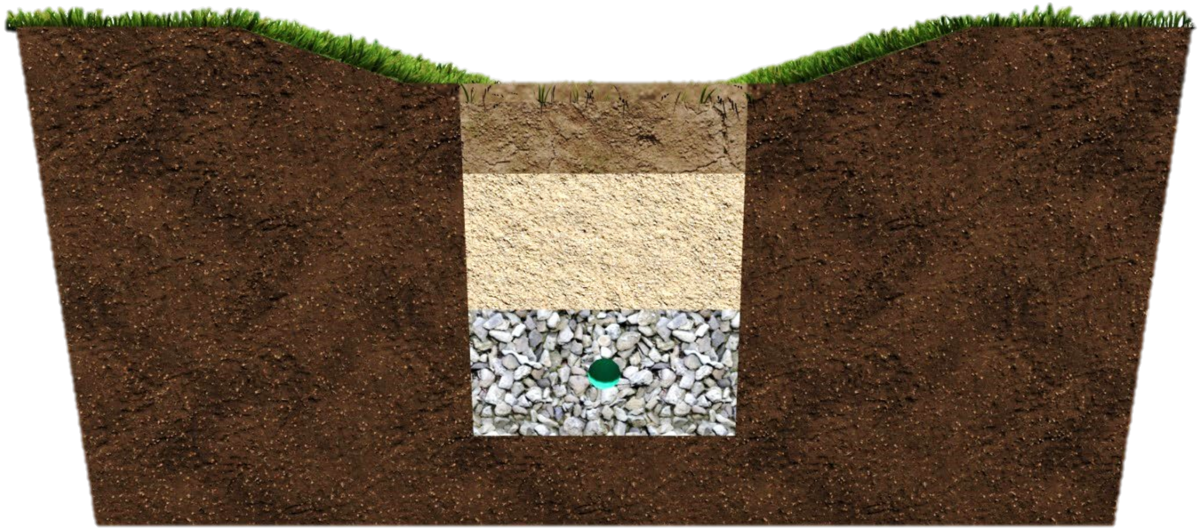


SIDE NATIVE MOISTURE CONTENT



FIELD SCALE MAJOR FINDING

ALDOT Infiltration Swale



Infiltration Rate: 1.22 ft/d

Drawdown Time: 16.1 hr

Enhanced Infiltration Swale

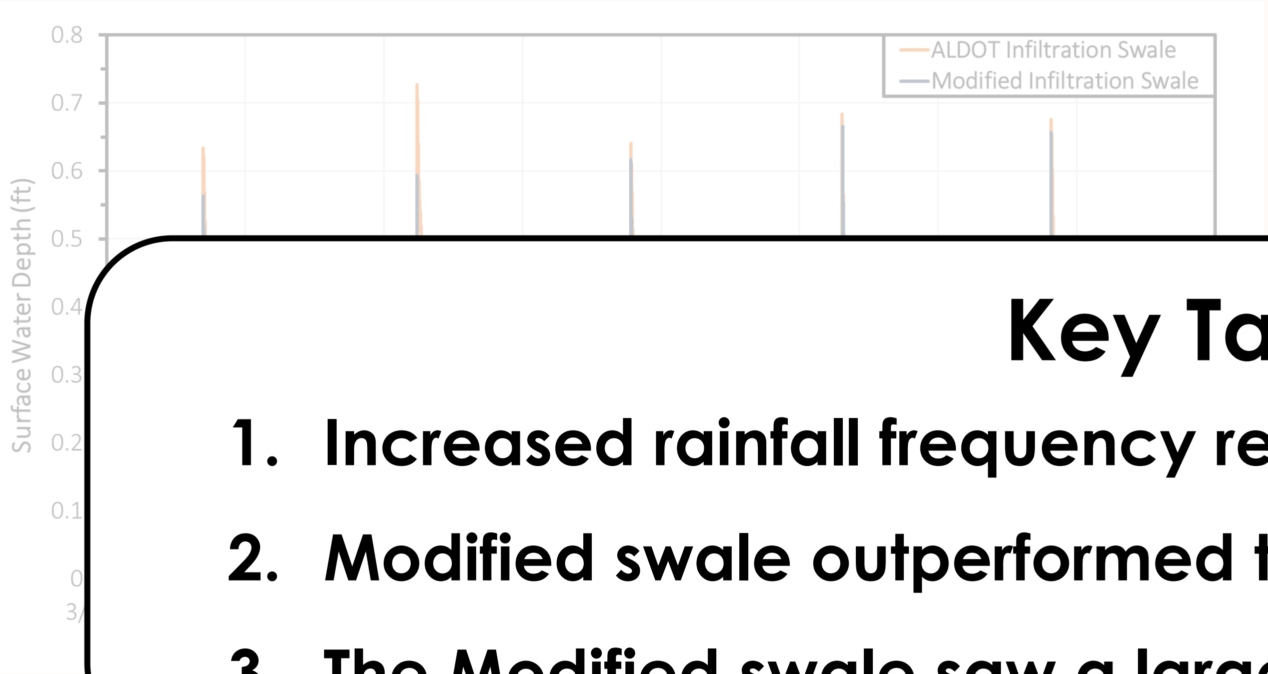
Infiltration Rate: 3.15 ft/d

Drawdown Time: 6.6 hr

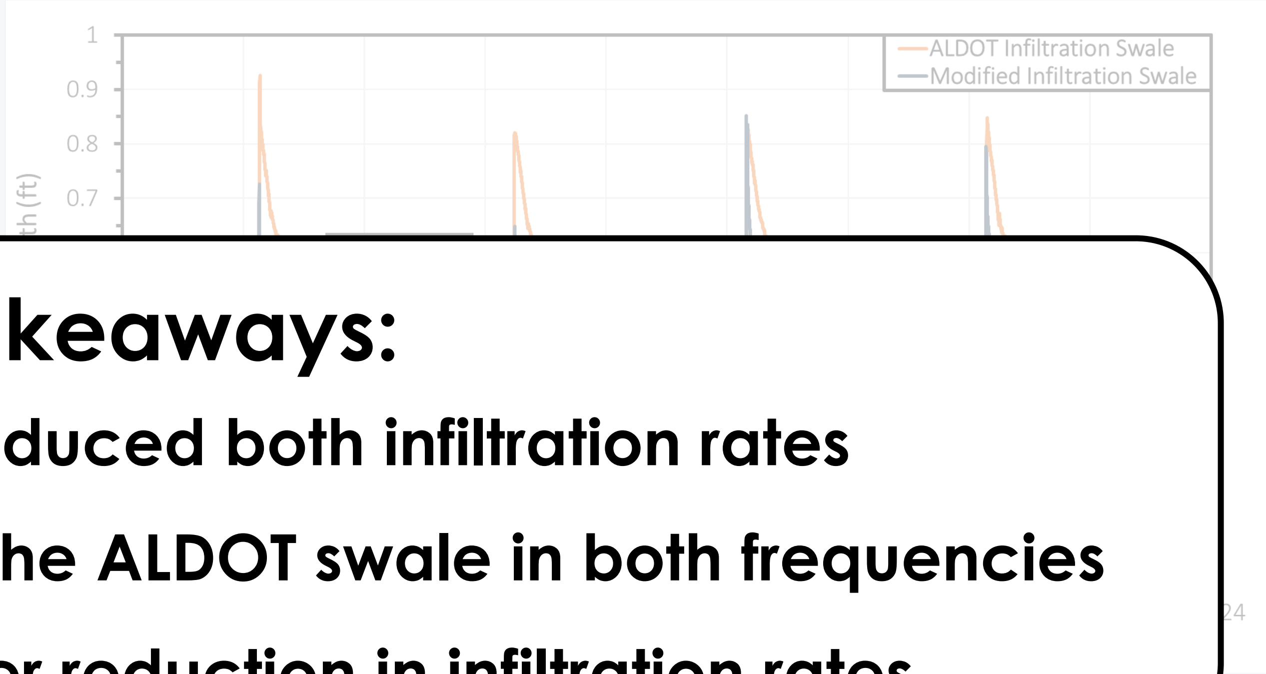
Enhanced Swale draws down 2.5x faster than ALDOT Swale

INFILTRATION EVALUATION – ONE DAY VS. THREE DAY

3 DAY DRY PERIOD



1 DAY DRY PERIOD



Key Takeaways:

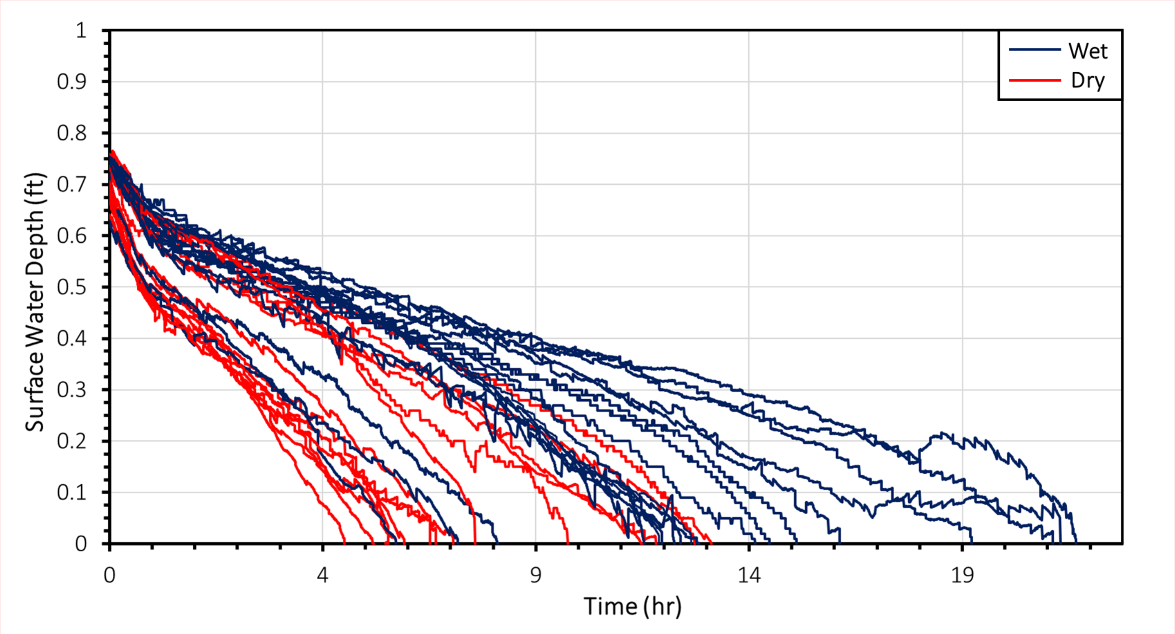
1. **Increased rainfall frequency reduced both infiltration rates**
2. **Modified swale outperformed the ALDOT swale in both frequencies**
3. **The Modified swale saw a larger reduction in infiltration rates**

- Modified avg. infiltration rate: **5.88 ft/day**
- Modified swale **2.6x** faster

- Modified avg. infiltration rate: **2.5 ft/day**
- Modified swale **1.8x** faster

WET VS. DRIER SOILS

ALDOT SWALE



Wet Soil Conditions:

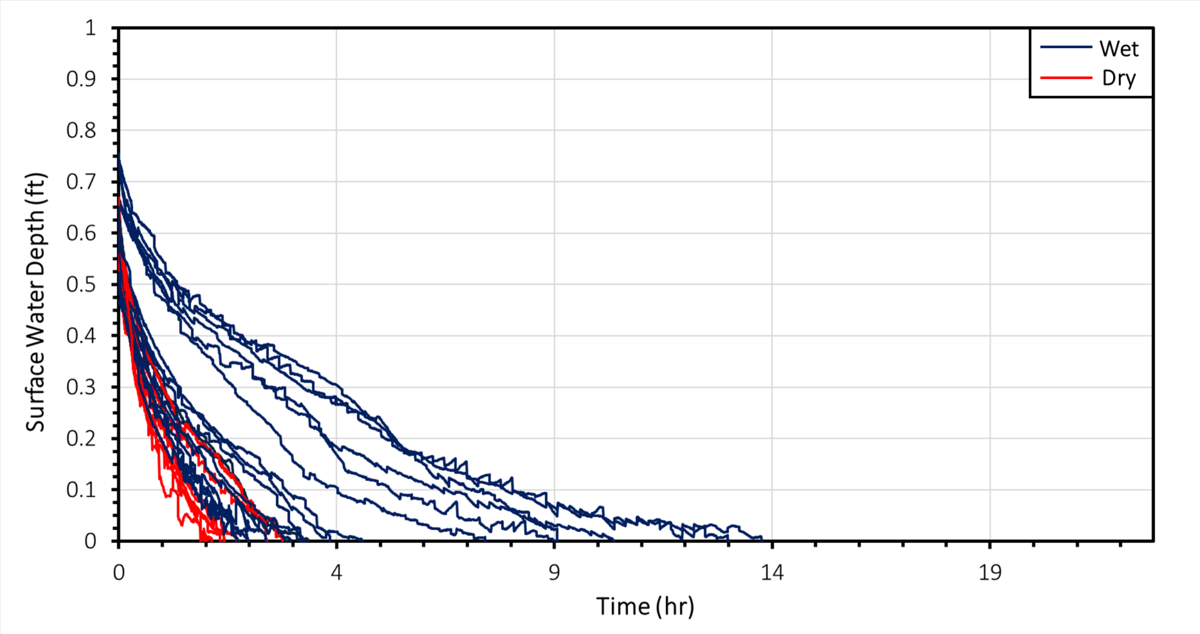
- Average infiltration rate: **1.4 ft/day**
- Average drawdown time: **13.7 hours**

Drier Soil Conditions:

- Average infiltration rate: **2.1 ft/day**
- Average drawdown time: **8.7 hours**

Δ5 hrs

MODIFIED SWALE



Wet Soil Conditions:

- Average infiltration rate: **2.5 ft/day**
- Average drawdown time: **8.1 hours**

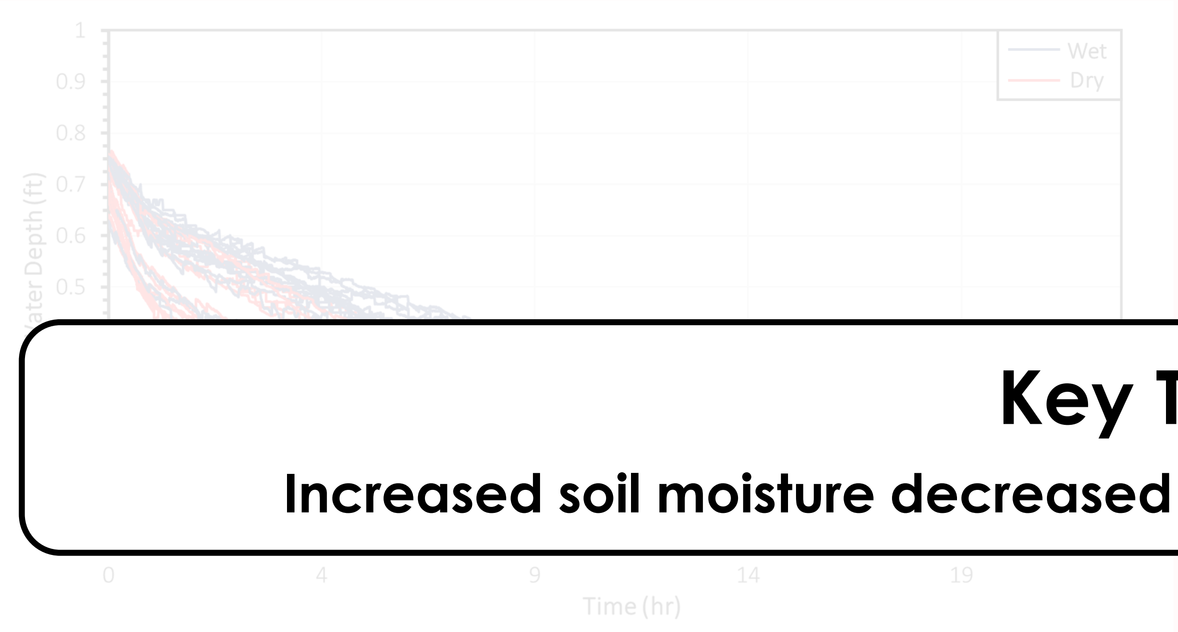
Drier Soil Conditions:

- Average infiltration rate: **5.8 ft/day**
- Average drawdown time: **2.7 hours**

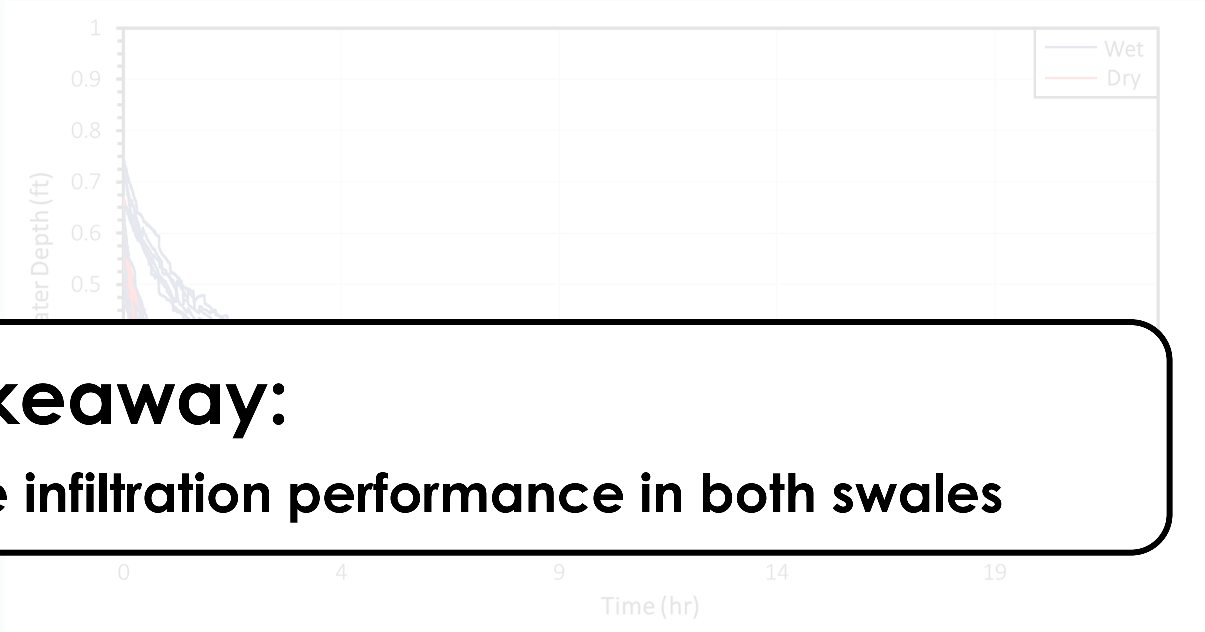
Δ5.4 hrs

WET VS. DRIER SOILS

ALDOT SWALE



MODIFIED SWALE



Key Takeaway:

Increased soil moisture decreased the infiltration performance in both swales

Wet Soil Conditions:

- Average infiltration rate: **1.4 ft/day**
- Average drawdown time: **13.7 hours**

Drier Soil Conditions:

- Average infiltration rate: **2.1 ft/day**
- Average drawdown time: **8.7 hours**

Δ5 hrs

Wet Soil Conditions:

- Average infiltration rate: **2.5 ft/day**
- Average drawdown time: **8.1 hours**

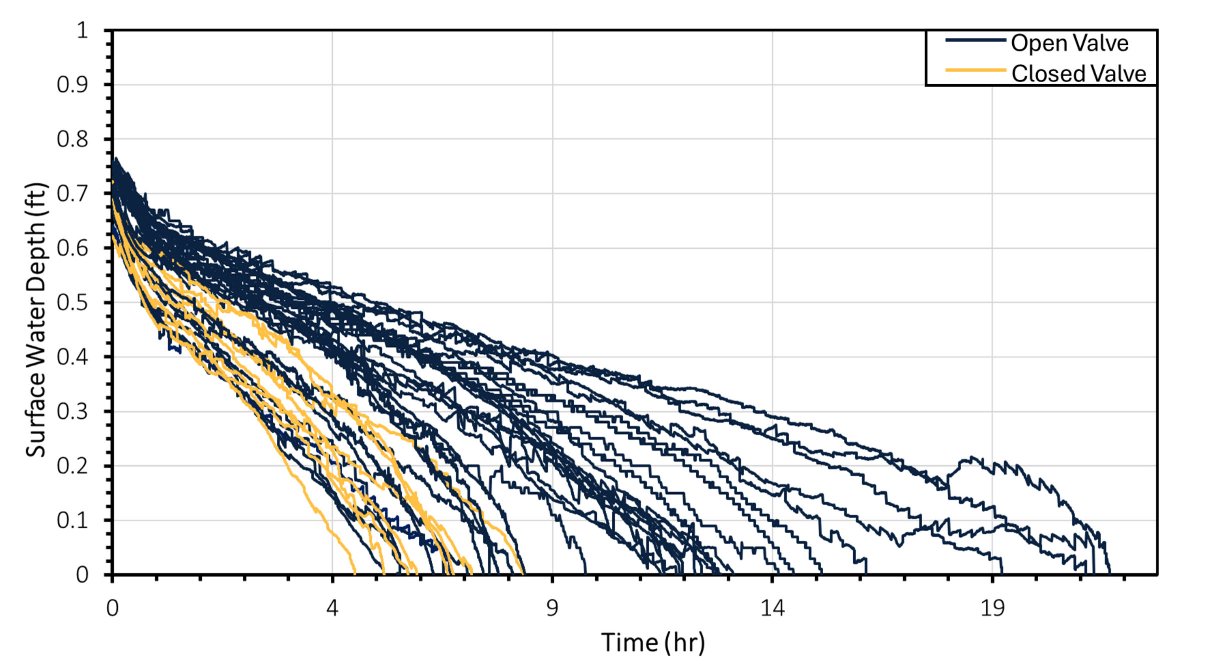
Drier Soil Conditions:

- Average infiltration rate: **5.8 ft/day**
- Average drawdown time: **2.7 hours**

Δ5.4 hrs

OPEN VALVE VS. CLOSED VALVE

ALDOT SWALE



Open Valve:

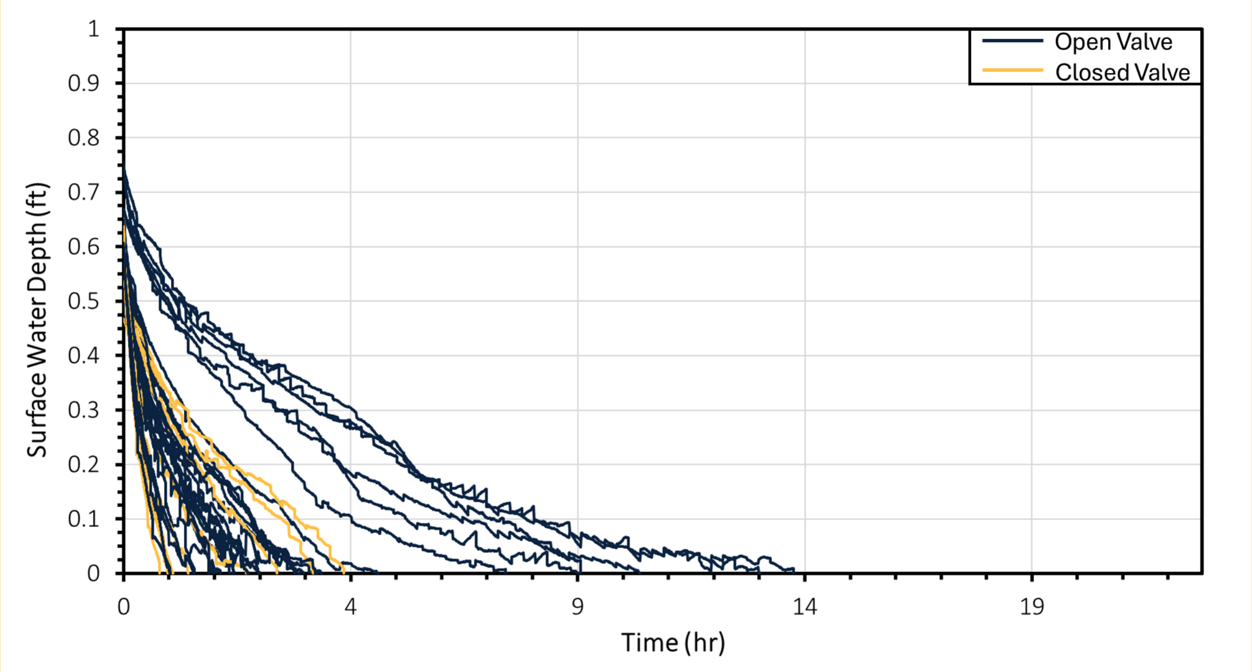
- Average infiltration rate: **1.6 ft/day**
- Average drawdown time: **12 hours**

Closed Valve:

- Average infiltration rate: **2.5 ft/day**
- Average drawdown time: **7 hours**

Δ5 hrs

MODIFIED SWALE



Open Valve:

- Average infiltration rate: **5.2 ft/day**
- Average drawdown time: **5 hours**

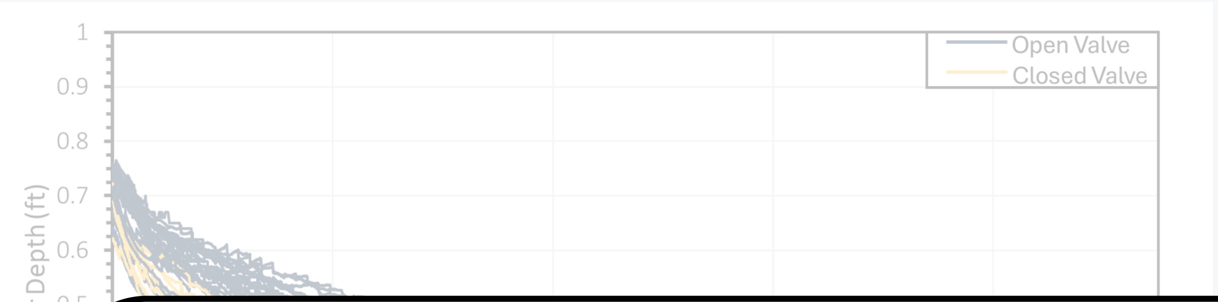
Closed Valve:

- Average infiltration rate: **9.5 ft/day**
- Average drawdown time: **2.3 hours**

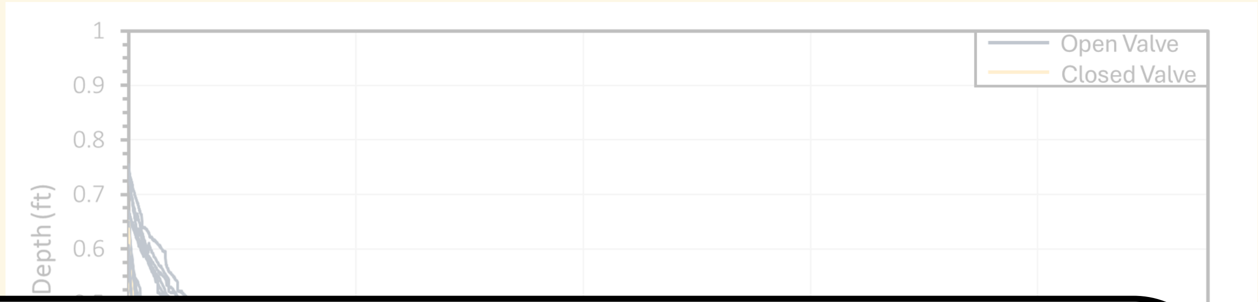
Δ2.7 hrs

OPEN VALVE VS. CLOSED VALVE

ALDOT SWALE



MODIFIED SWALE



Key Takeaways:

1. Closed valve tests outperformed open valve contrary to prediction
2. Closed valve tests were performed in warmer months
3. Leads to investigate if seasonal variation is the cause for results

- Average drawdown time: **12 hours**

Closed Valve:

- Average infiltration rate: **2.5 ft/day**
- Average drawdown time: **7 hours**

Δ5 hrs

- Average drawdown time: **5 hours**

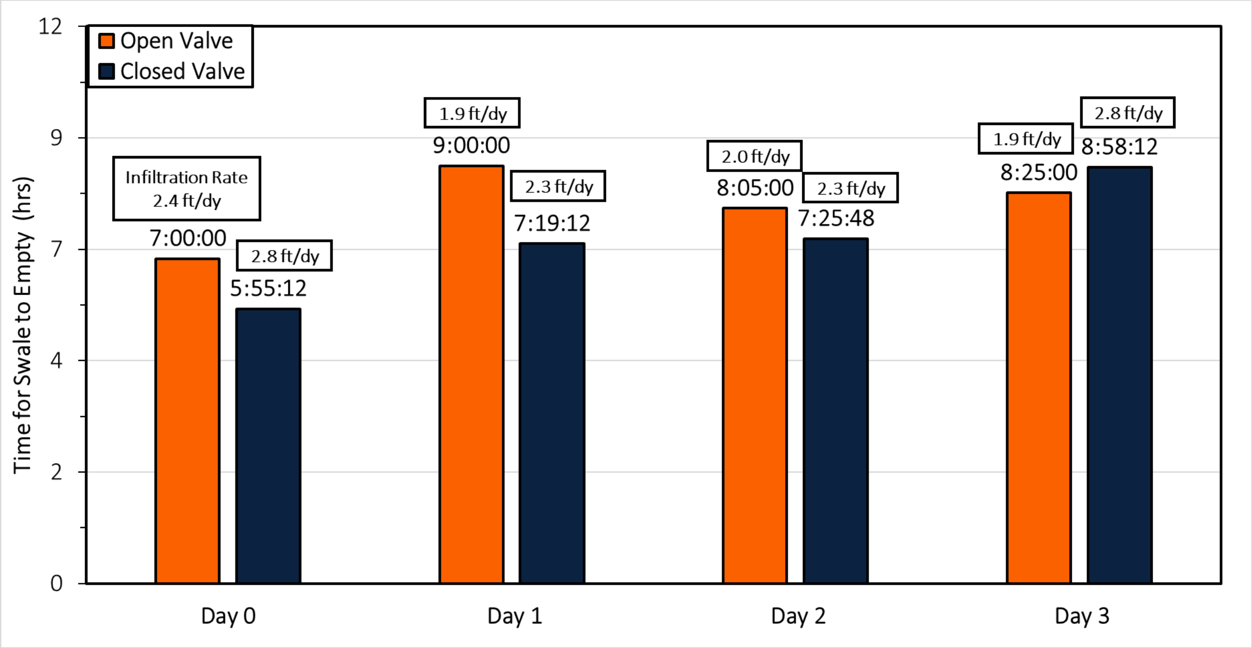
Closed Valve:

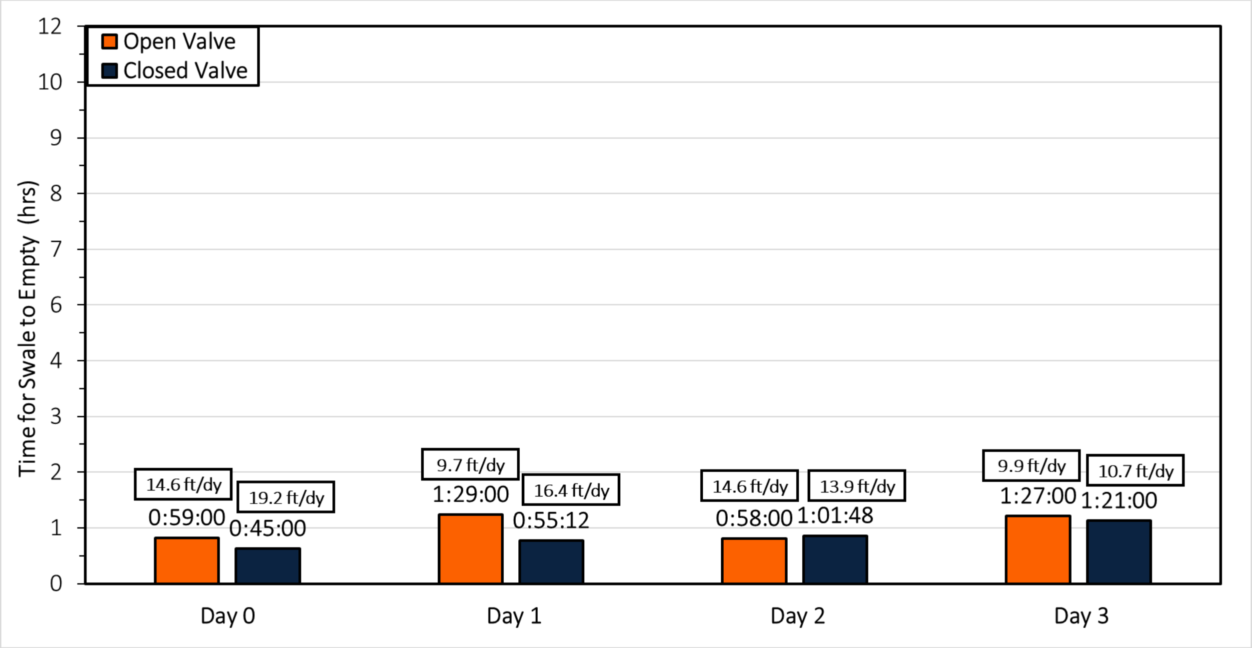
- Average infiltration rate: **9.5 ft/day**
- Average drawdown time: **2.3 hours**

Δ2.7 hrs

OPEN VALVE VS. CLOSED VALVE

ALDOT SWALE ← JUNE → MODIFIED SWALE





Closed average infiltration rate: **2.3 ft/day**

Open average infiltration rate: **2.1 ft/day**

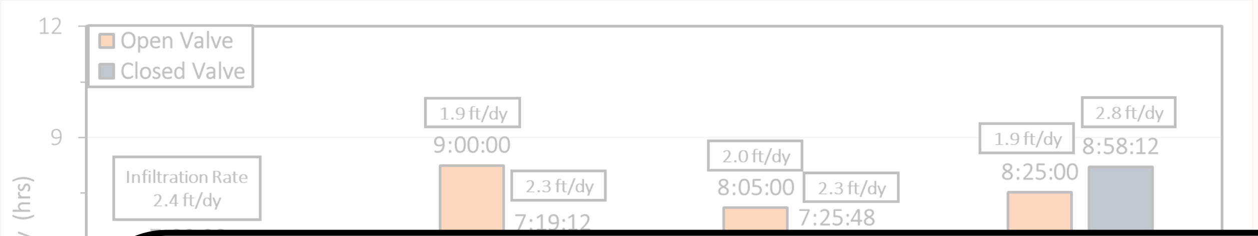
Closed average infiltration rate: **15 ft/day**

Open average infiltration rate: **12.3 ft/day**

Difference between open and closed valve infiltration rate averages is not statistically different

OPEN VALVE VS. CLOSED VALVE

ALDOT SWALE



MODIFIED SWALE

Key Takeaways:

1. Open and closed valve performed in the same month
2. Both swales showed similar infiltration performances
3. Seasonal variation appears to affect infiltration performance

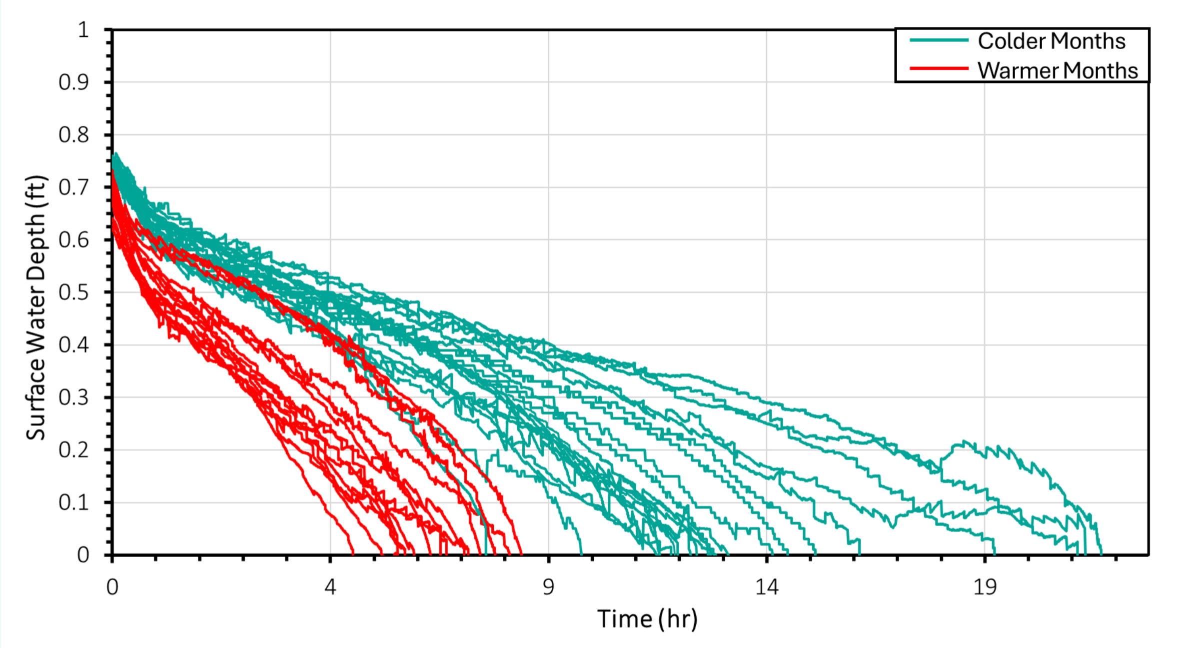
- Open average infiltration rate: **2.1 ft/day**

- Open average infiltration rate: **12.3 ft/day**

The difference between the open and closed valve infiltration rate averages is not big enough to be statistically significant.

SEASONAL VARIATION

ALDOT SWALE



Colder Months:

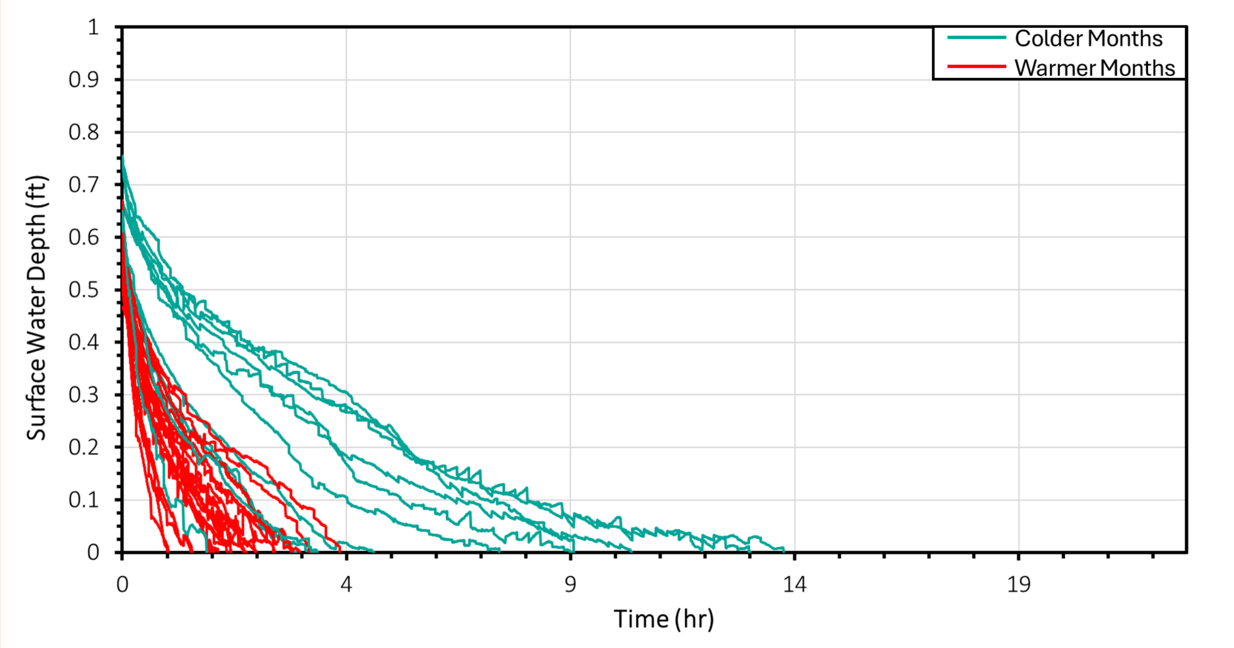
- Average infiltration rate: **1.3 ft/day**
- Average drawdown time: **14.4 hours**

Warmer Months:

- Average infiltration rate: **2.2 ft/day**
- Average drawdown time: **7.5 hours**

Δ6.9 hrs

MODIFIED SWALE



Colder Months:

- Average infiltration rate: **2.7 ft/day**
- Average drawdown time: **8.5 hours**

Warmer Months:

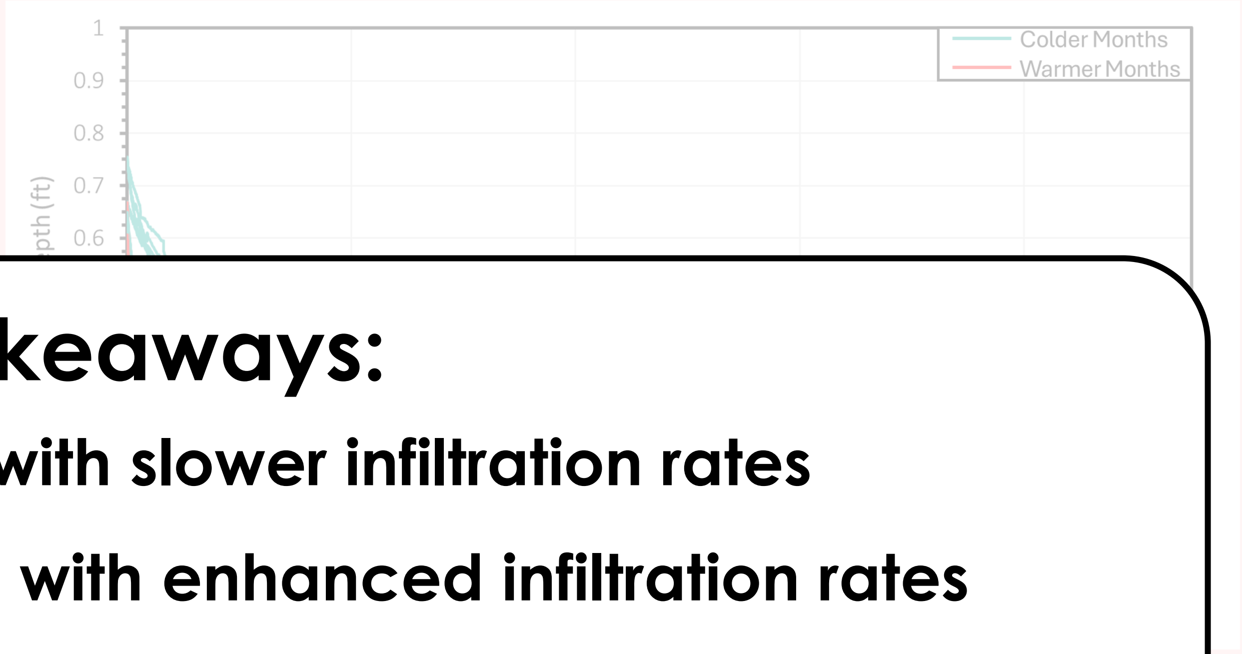
- Average infiltration rate: **7.2 ft/day**
- Average drawdown time: **2.3 hours**

Δ6.2 hrs

SEASONAL VARIATION

ALDOT SWALE

MODIFIED SWALE



Key Takeaways:

1. **Colder months are associated with slower infiltration rates**
2. **Warmer months are associated with enhanced infiltration rates**
3. **Seasonal variation affects infiltration performance for both swales**

Co

- Average infiltration rate: **1.3 ft/day**
- Average drawdown time: **14.4 hours**

Warmer Months:

- Average infiltration rate: **2.2 ft/day**
- Average drawdown time: **7.5 hours**

Δ6.9 hrs

- Average infiltration rate: **2.7 ft/day**
- Average drawdown time: **8.5 hours**

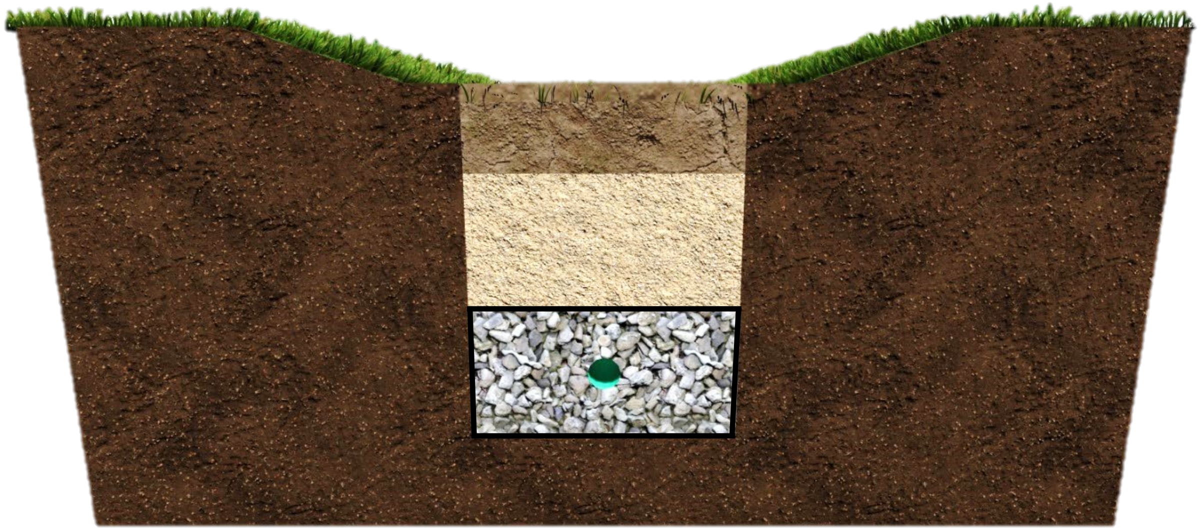
Warmer Months:

- Average infiltration rate: **7.2 ft/day**
- Average drawdown time: **2.3 hours**

Δ6.2 hrs

OVERALL PERFORMANCE

ALDOT Infiltration Swale



Avg. Infiltration Rate: 1.6 ft/day

Avg. Drawdown: 12.25 hr

Modified Infiltration Swale

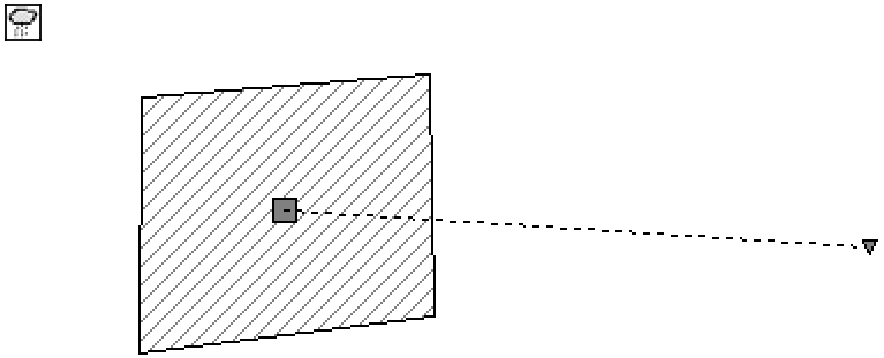
Avg. Infiltration Rate: 5.2 ft/day

Avg. Drawdown: 5.06 hr

Modified Swale infiltration rate avg. is 3x greater than ALDOT Swale

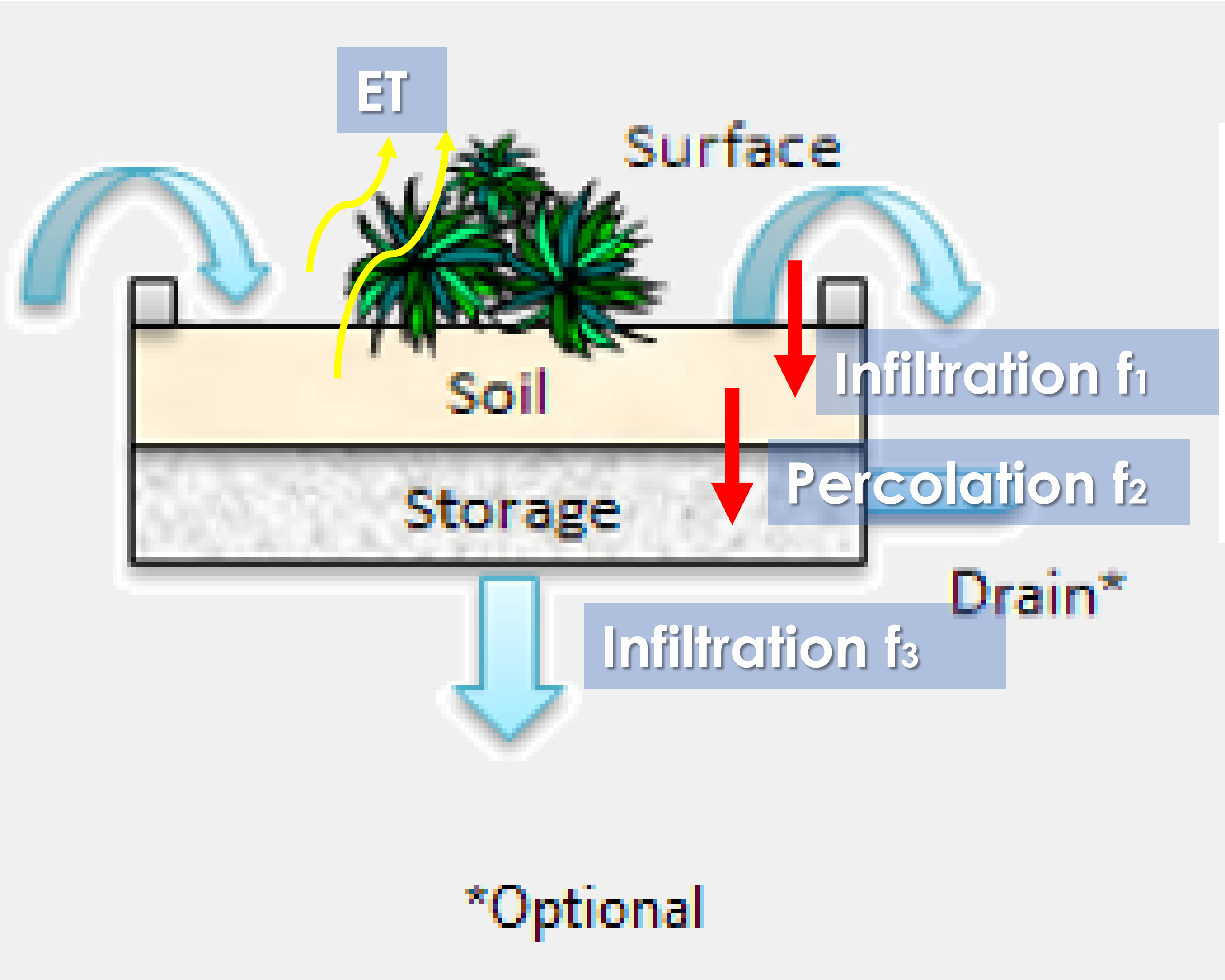
Modeling Infiltration Swale Performance w/ SWMM

- EPA Storm Water Management Model (SWMM)
- SWMM model development: a basin with the infiltration swale that fills the water (runoff) up to the maximum height of a ditch check (berm).



- Several model parameters (factors) are used to control the infiltration rate in each layer.
- Compare the observed and modeled drainage times for the SWMM model calibration.

SWMM Model basic parameters of Bio-retention (infiltration swale)



$$\phi_1 \frac{\partial d_1}{\partial t} = i + q_0 - e_1 - f_1 - q_1 \quad \text{Surface Layer} \quad (6\text{-}1)$$

$$D_2 \frac{\partial \theta_2}{\partial t} = f_1 - e_2 - f_2 \quad \text{Soil Layer} \quad (6\text{-}2)$$

$$\phi_3 \frac{\partial d_3}{\partial t} = f_2 - e_3 - f_3 - q_3 \quad \text{Storage Layer} \quad (6\text{-}3)$$

where:

d_1 = depth of water stored on the surface (ft),

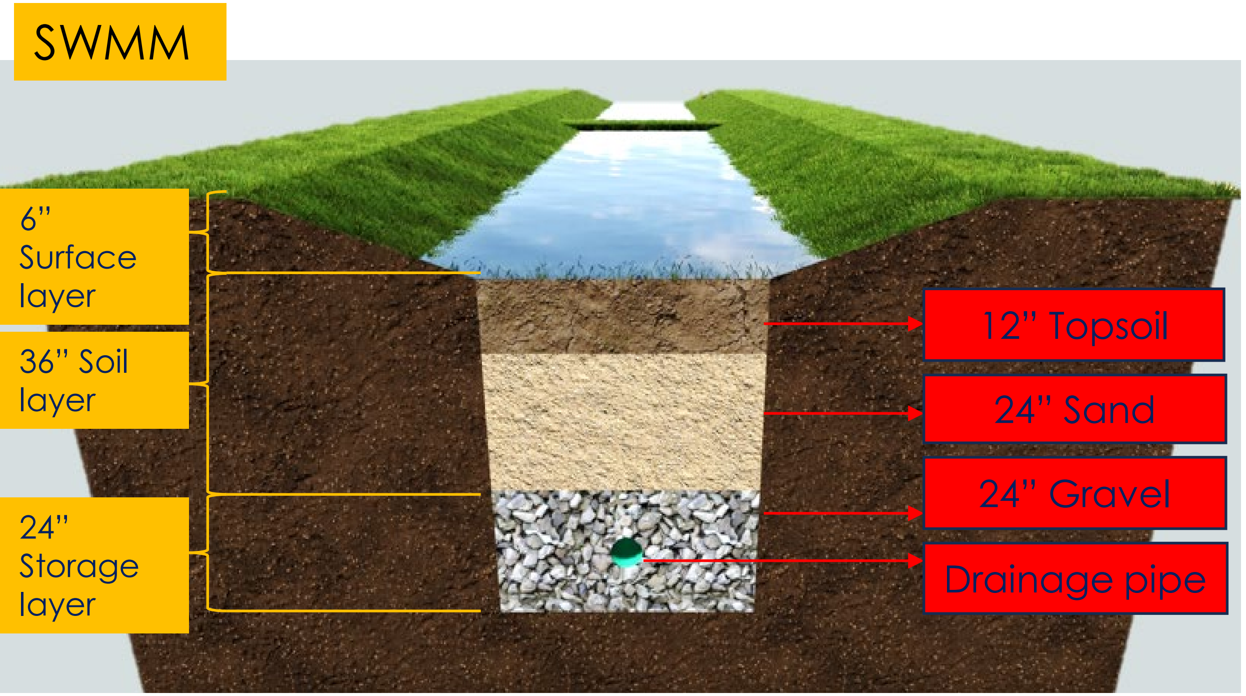
θ_2 = soil layer moisture content (volume of water / total volume of soil),

d_3 = depth of water in the storage layer (ft),

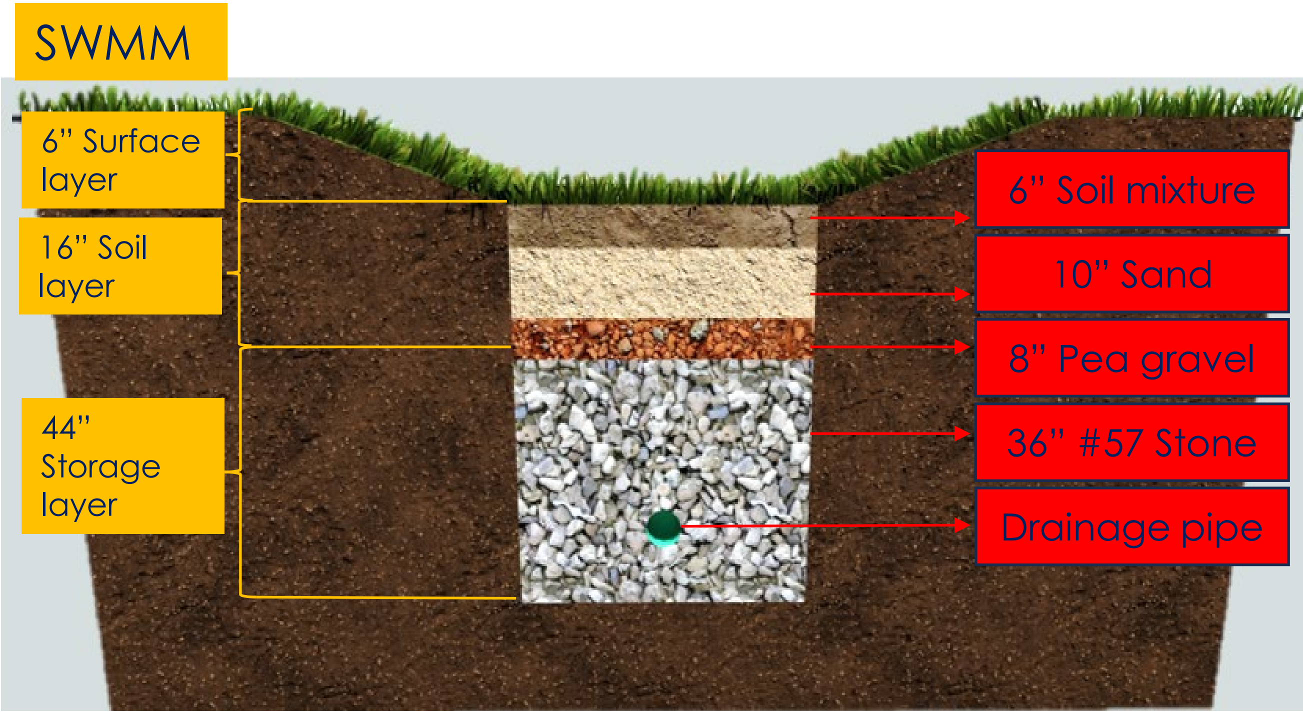
$$f_1 = K_{2S}\left(1 + \frac{(\phi_2 - \theta_{20})(d_1 + \psi_2)}{F}\right)$$

$$f_2 = \begin{cases} K_{2S} exp(-HCO(\phi_2 - \theta_2)), & \theta_2 > \theta_{FC} \\ 0, & \theta_2 \le \theta_{FC} \end{cases}$$

Constructing & Evaluating Infiltration Swales



ALDOT Swale



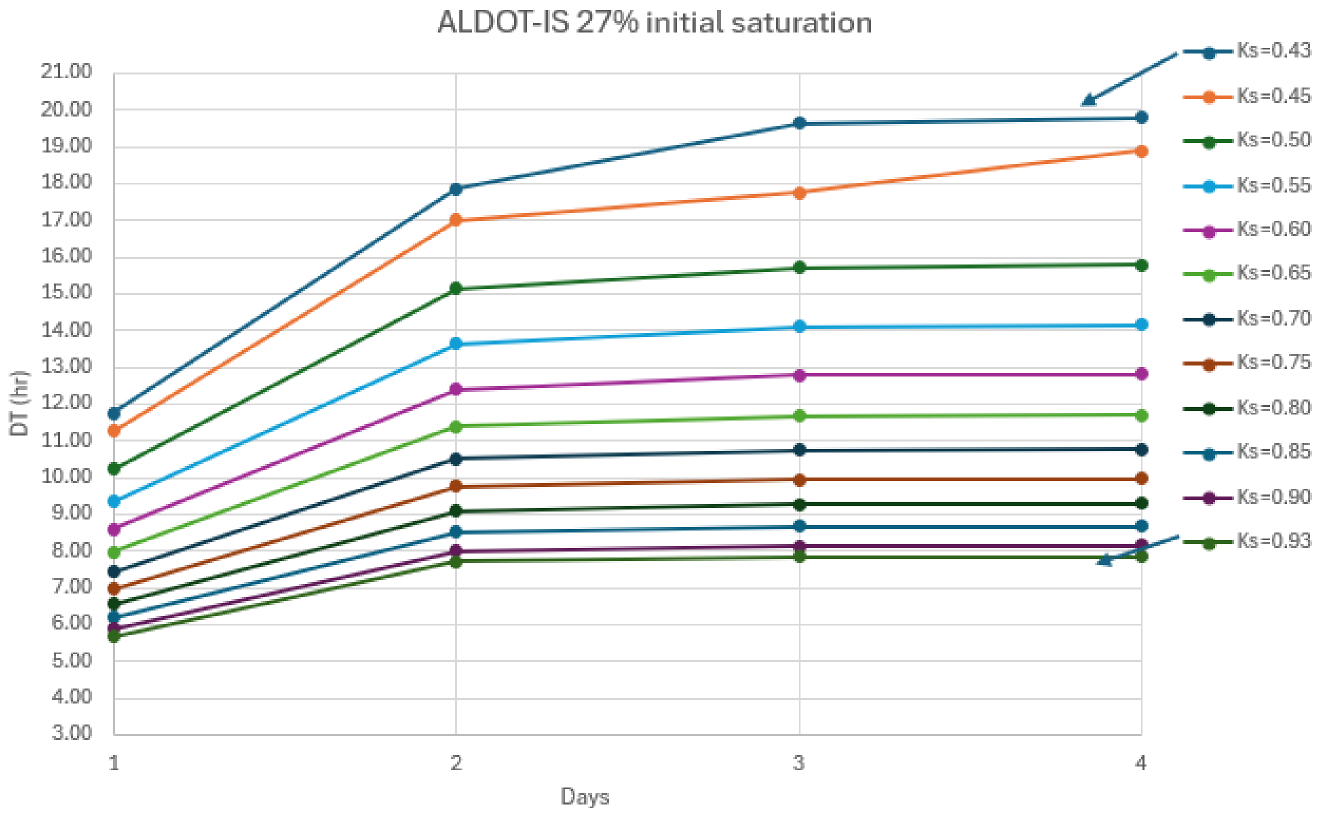
AU Swale

Drainage Time (TD) versus Soil Conductivity For One-day Dry Period

ALDOT-IS

% Initial saturated = 27 %

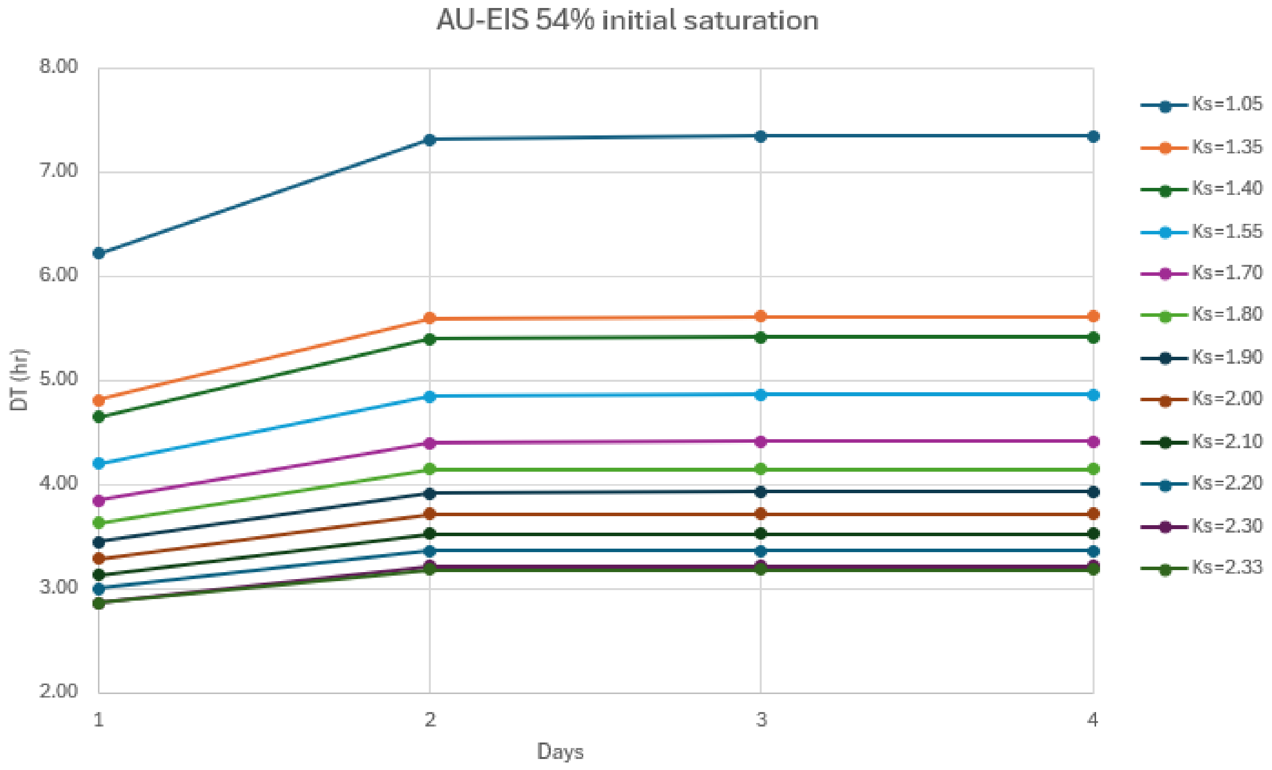
Seepage rate = 0.43 in/hr



Time	Observed (TD)	Ks of Soil	Simulated (TD)
Jan-Feb	12.70 ± 0.30	0.55	12.81 ± 2.02
April	6.56 ± 0.90	1.05	6.39 ± 0.77
June (open)	8.45 ± 0.75	0.80	8.55 ± 1.15
June (close)	7.76 ± 1.16	0.90	7.54 ± 0.97

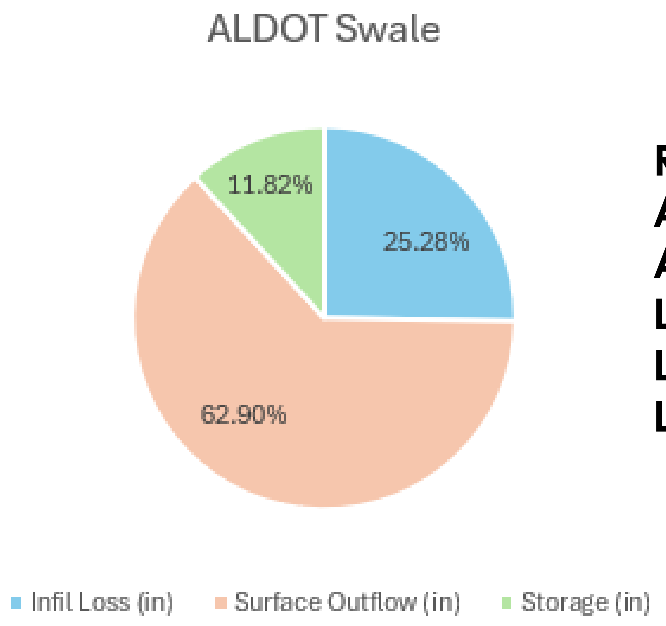
Drainage Time (TD) versus Soil Conductivity For One-day Dry Period

AU-EIS
% Initial saturated = 54 %
Seepage rate = 0.43 in/hr

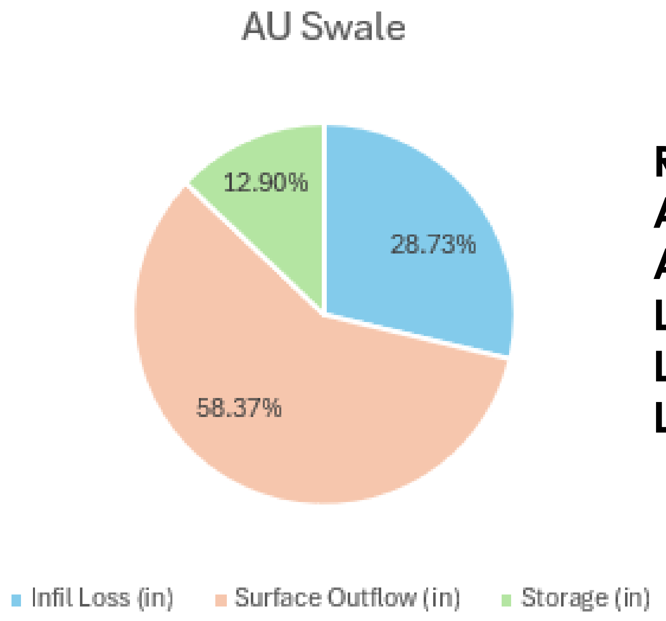


Time	Observed (TD)	Ks of Soil	Simulated (TD)
Jan-Feb	8.55 ± 3.65	0.85	8.75 ± 0.69
April	3.63 ± 0.78	2.00	3.61 ± 0.19
June (open)	1.23 ± 0.27	5.4	1.32 ± 0.03
June (close)	1.03 ± 0.22	6.2	1.15 ± 0.02

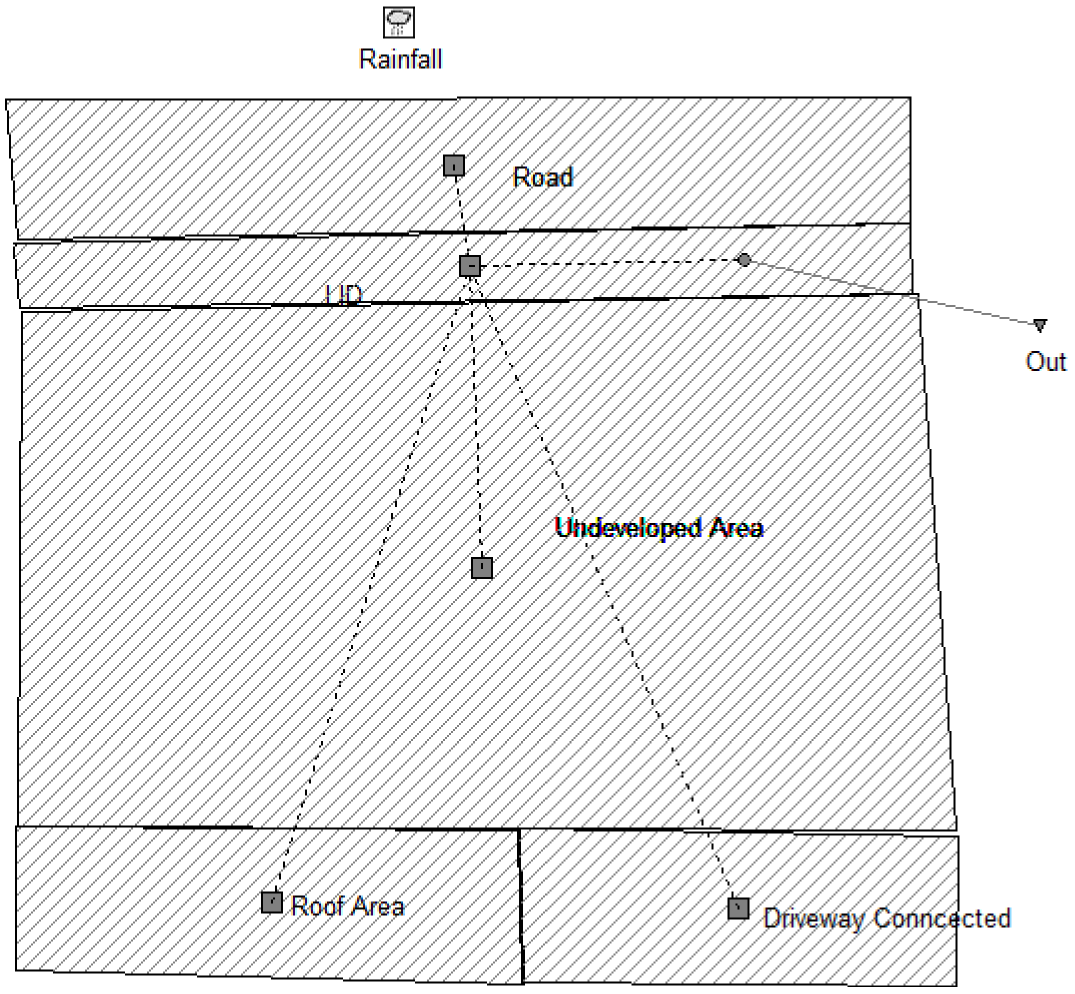
Swale's Runoff-control Performance at Design Rainfall



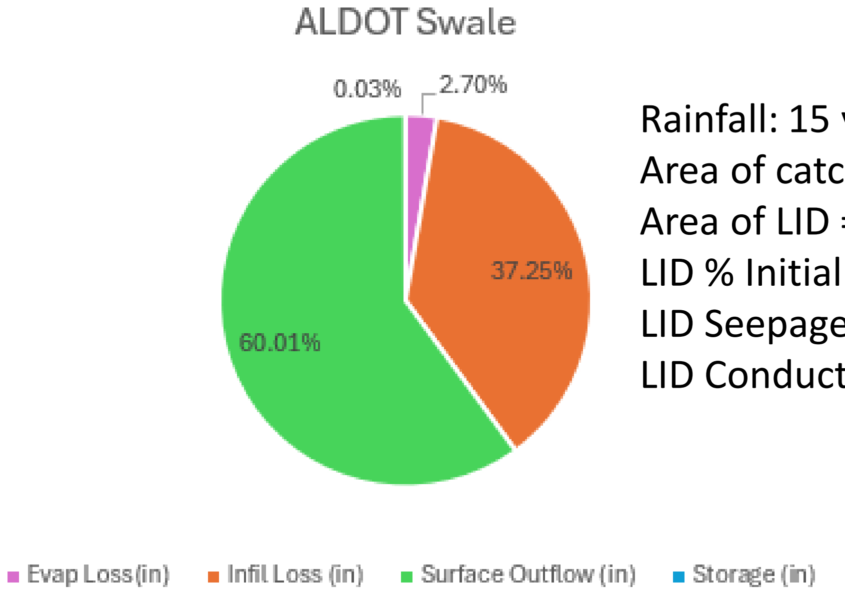
Rainfall: 2.6 in Type III
Area of catchment = 5.85 ac
Area of LID = 4020 ft ^{2}
LID % Initial saturated = 27 %
LID Seepage rate = 0.43 in/hr
LID Conductivity = 0.93 in/hr



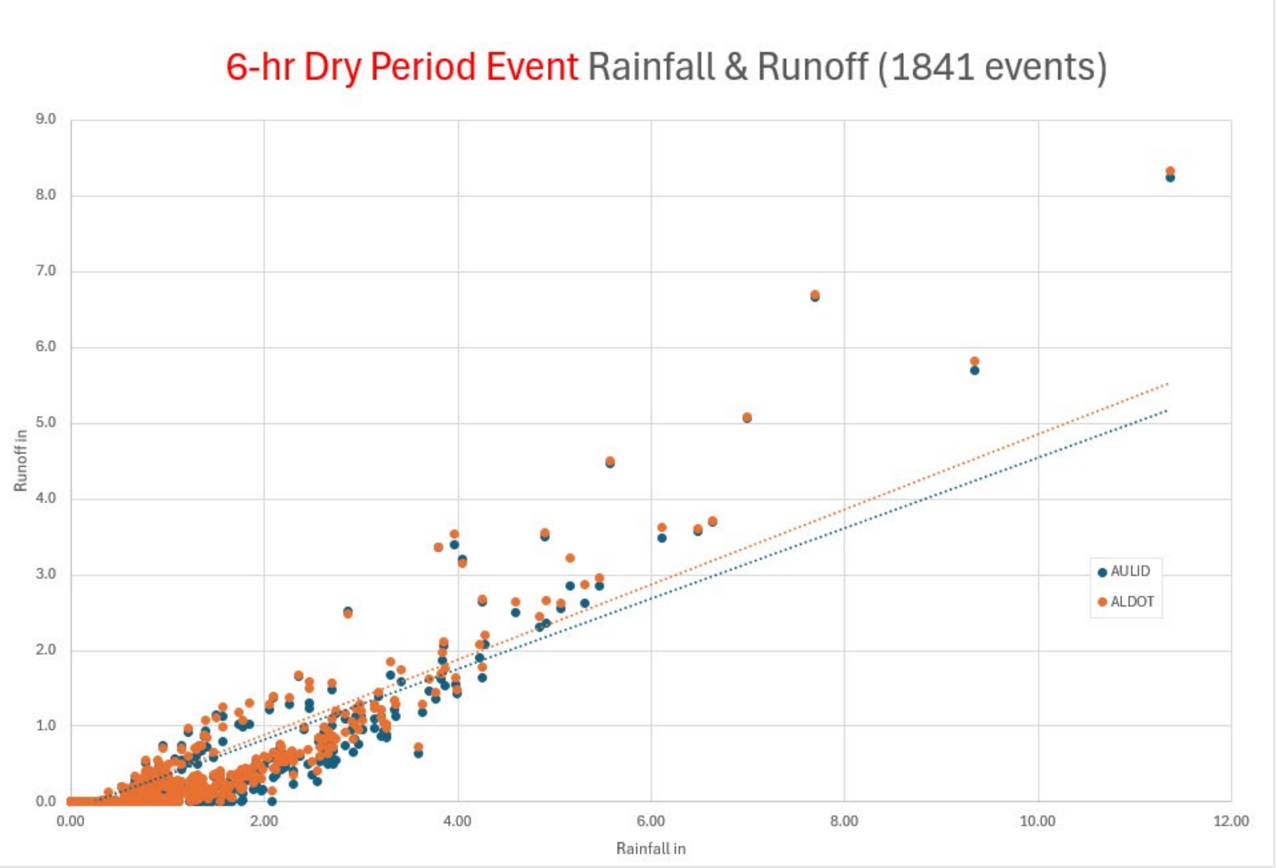
Rainfall: 2.6 in Type III
Area of catchment = 5.85 ac
Area of LID = 4020 ft ^{2}
LID % Initial saturated = 54 %
LID Seepage rate = 0.43 in/hr
LID Conductivity = 2.33 in/hr

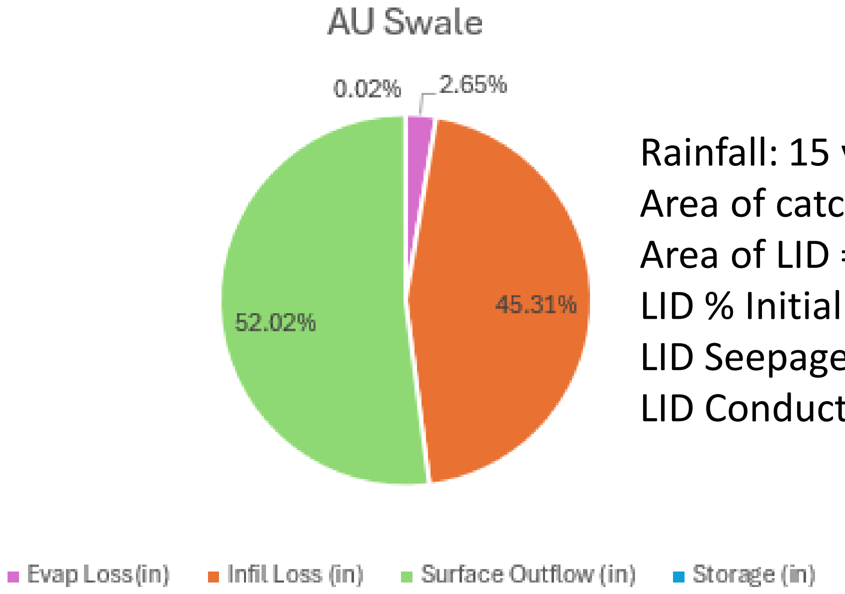


Long-term (Continuous) SWMM Modeling



Rainfall: 15 yr long-term rainfall
Area of catchment = 5.85 ac
Area of LID = 4020 ft ^{2}
LID % Initial saturated = 0 %
LID Seepage rate = 0.43 in/hr
LID Conductivity = 0.93 in/hr





Rainfall: 15 yr long-term rainfall
Area of catchment = 5.85 ac
Area of LID = 4020 ft ^{2}
LID % Initial saturated = 0 %
LID Seepage rate = 0.43 in/hr
LID Conductivity = 2.33 in/hr

SWMM Modeling Conclusions

- In the field-scale test, the average drainage time for ALDOT-IS ranged from 7.8 to 12.7 hours and from 1.03 to 8.6 hours for AU-EIS for a one-day dry period.
- The infiltration swale was modeled using SWMM, and the average drainage time for AU-EIS and ALDOT-IS does not change hours when the native soil's saturated hydraulic conductivity increases from 0.3 in/hr to 1.2 in/hr (Hydrological Soil Group B).
- Under 24-hour design rainfall (95^{th} percentile rainfall), AU-EIS has 4.54% less runoff, 3.45% more infiltration, and 1.09% more water in storage.
- Under long-term simulation (15 years), AU-EIS has 8.00% less runoff, 8.07% more infiltration.

AUBURN STORMWATER

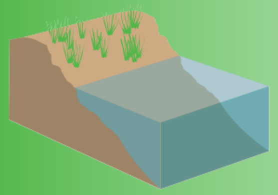
USGS science for a changing world

DOES THIN LAYER PLACEMENT LEAD TO REPLANTING LIVING SHORELINES?

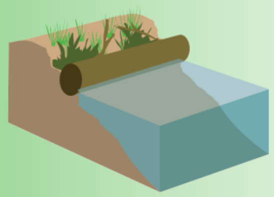
Mitigation Methods

GREEN – SOFTER TECHNIQUES | **GREY – HARDER TECHNIQUES**

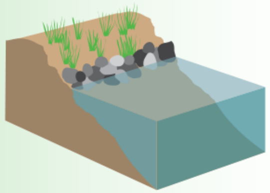
Living Shorelines



VEGETATION ONLY
Provides a buffer to upland areas and breaks small waves. Suitable for low wave energy environments.

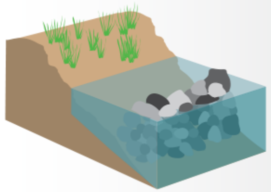


EDGING
Added structure holds the toe of existing or vegetated slope in place. Suitable for most areas except high wave energy environments.

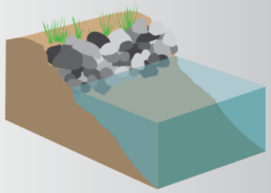


SILLS
Parallel to vegetated shoreline, reduces wave energy, and prevents erosion. Suitable for most areas except high wave energy environments.

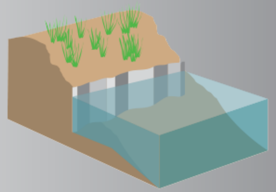
Coastal Structures



BREAKWATER
(vegetation optional)
Offshore structures intended to break waves, reducing the force of wave action, and encourage sediment accretion. Suitable for most areas.



REVETMENT
Lays over the slope of the shoreline and protects it from erosion and waves. Suitable for sites with existing hardened shoreline structures.



BULKHEAD
Vertical wall parallel to the shoreline. Intended to hold soil in place. Suitable for high energy settings and sites with existing hard shoreline structures.

LOW — **GRADIENT OF WAVE ENERGY** — **HIGH**

Photo credit: CLIMAtlantic

Living Shorelines Types

Living Shorelines – Marshes

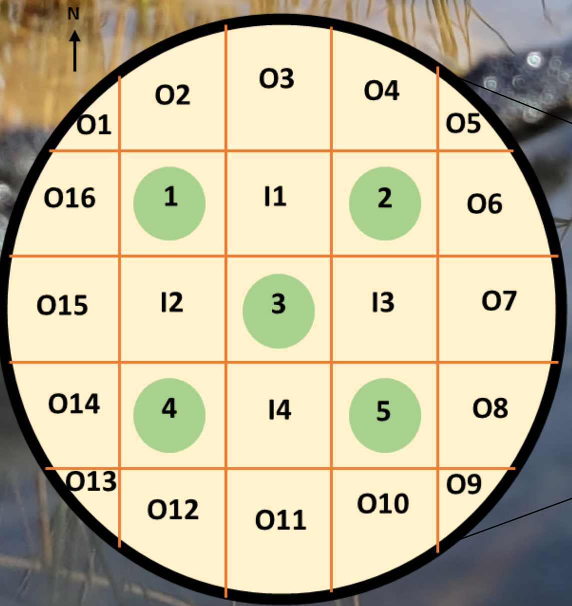
Marsh Benefits:
Habitat
Biodiversity
Pollution control
Flood protection
Carbon storage
Wave damping
Buffering
Stormwater storage
Sediment capture & retention

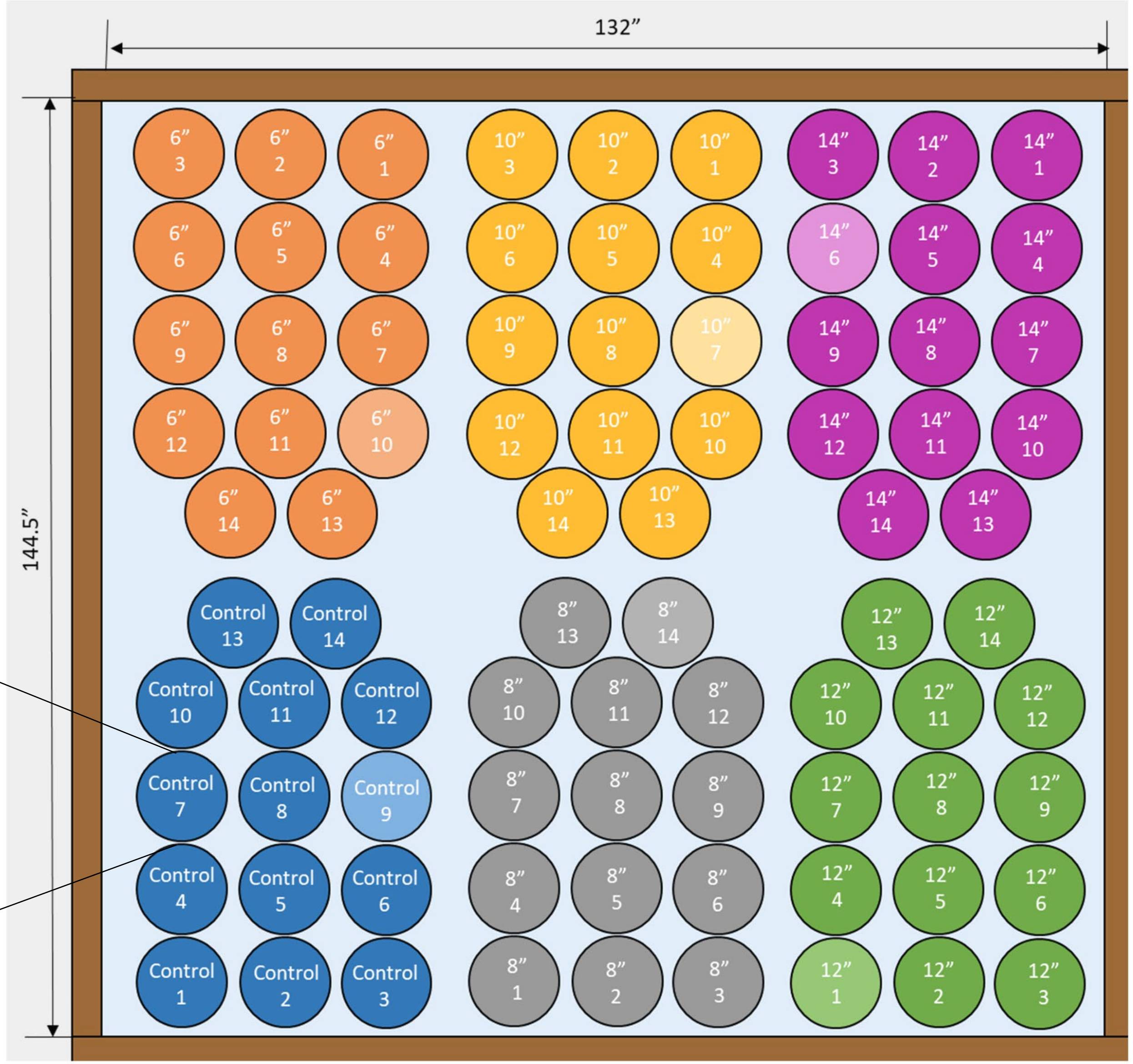
% Wave Energy to Marsh Length
- 50% dissipated in the first 8 ft
  - 100% dissipated in 100 ft

Sea Level Rise has consumed 25–50% of salt marshes globally

Experimental Design

- 6 tests with 14 replicates = 84 total buckets
- 3 buckets from each of the 6 tests = 18 buckets pulled every 2 months for destructive sampling

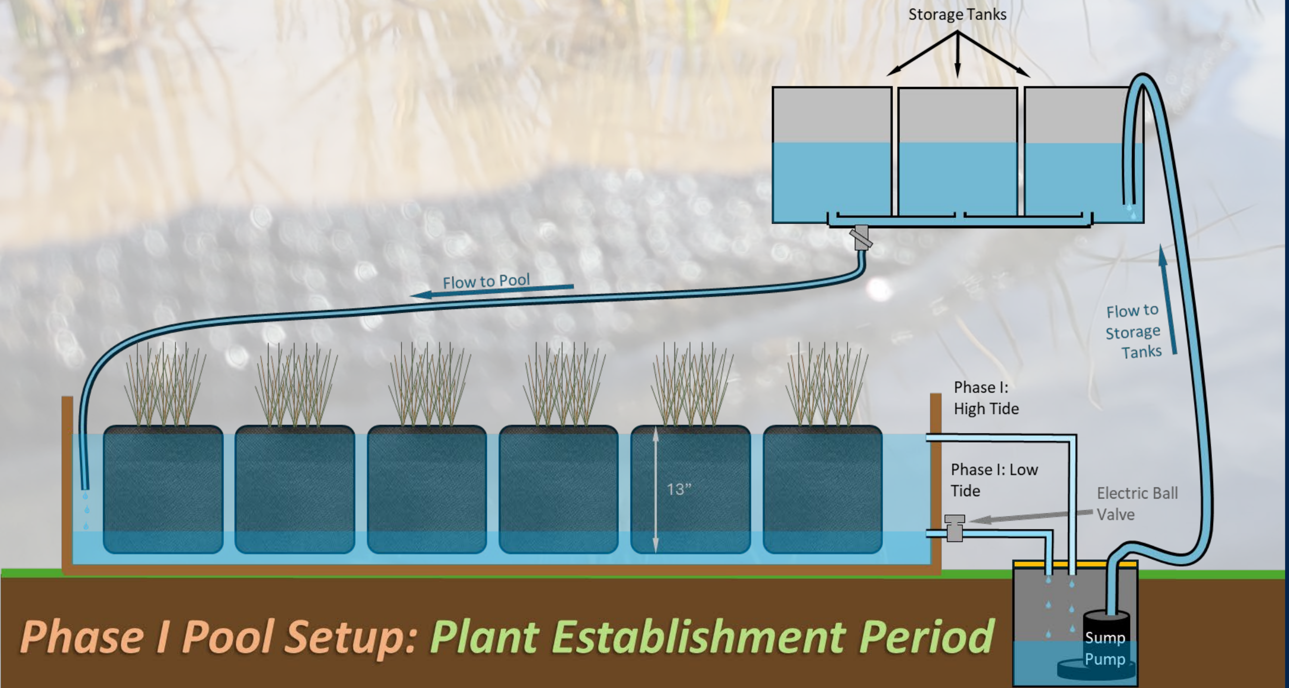




Experimental Design

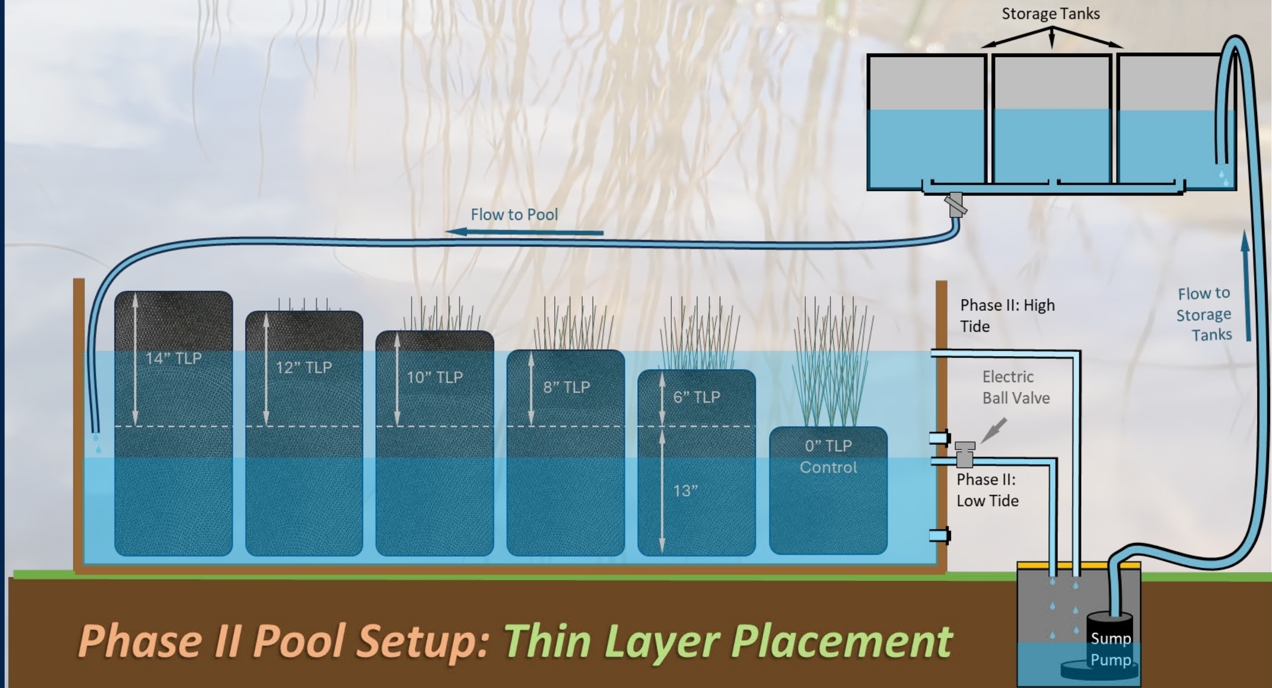
Phase I

- Phase I gave plants 4 months to establish before proceeding to Phase II
- Tides were set to 3 in. Low Tide and 13 in. High Tide



Phase II

- Simulated sea level rise and increased tidal heights to 11 in. Low Tide and 21 in. High Tide
- Phase II will last 5 months before concluding the experiment



Experimental Design

Phase I

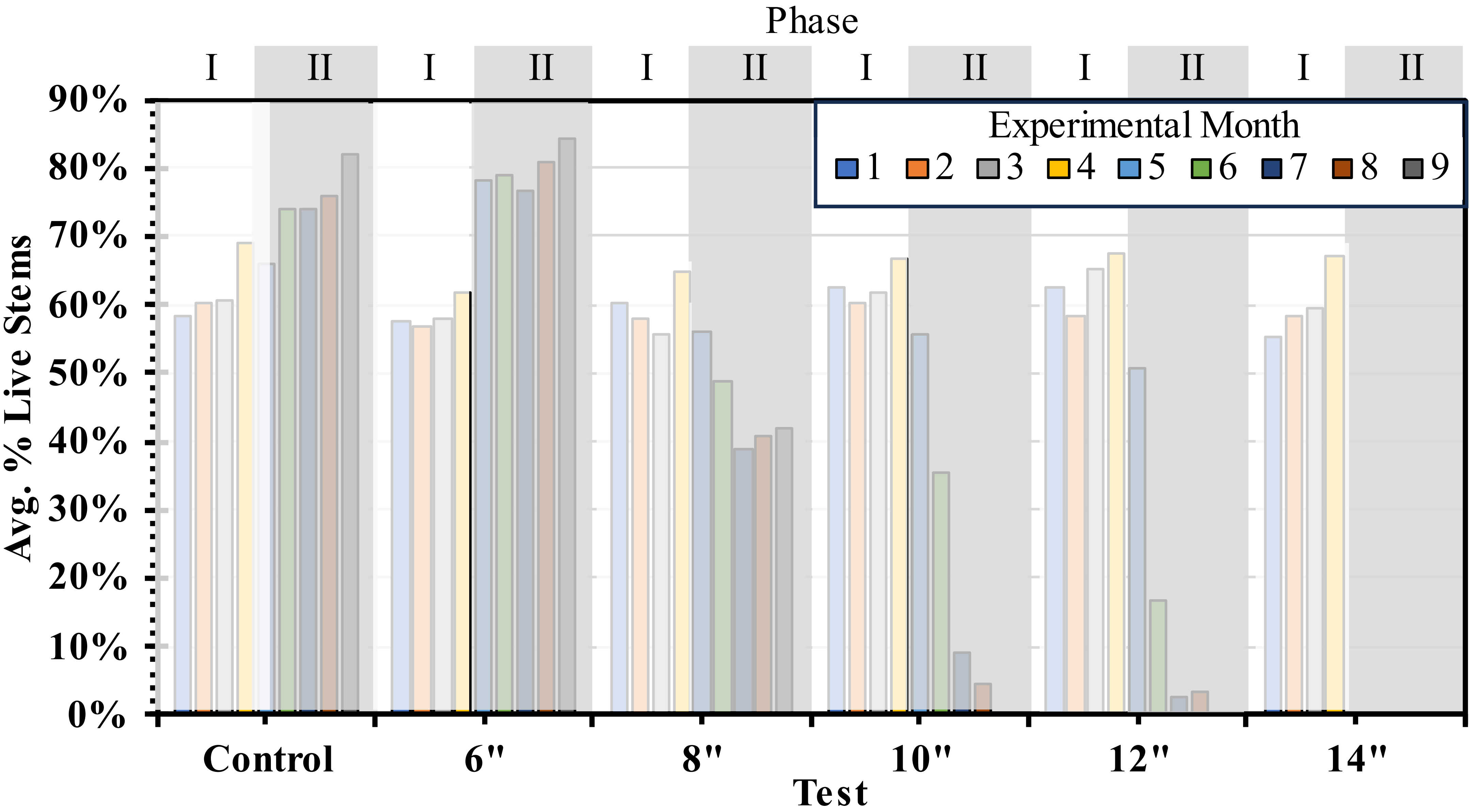
Phase II

DATA COLLECTION – MONTHLY LIVE DATA COLLECTION

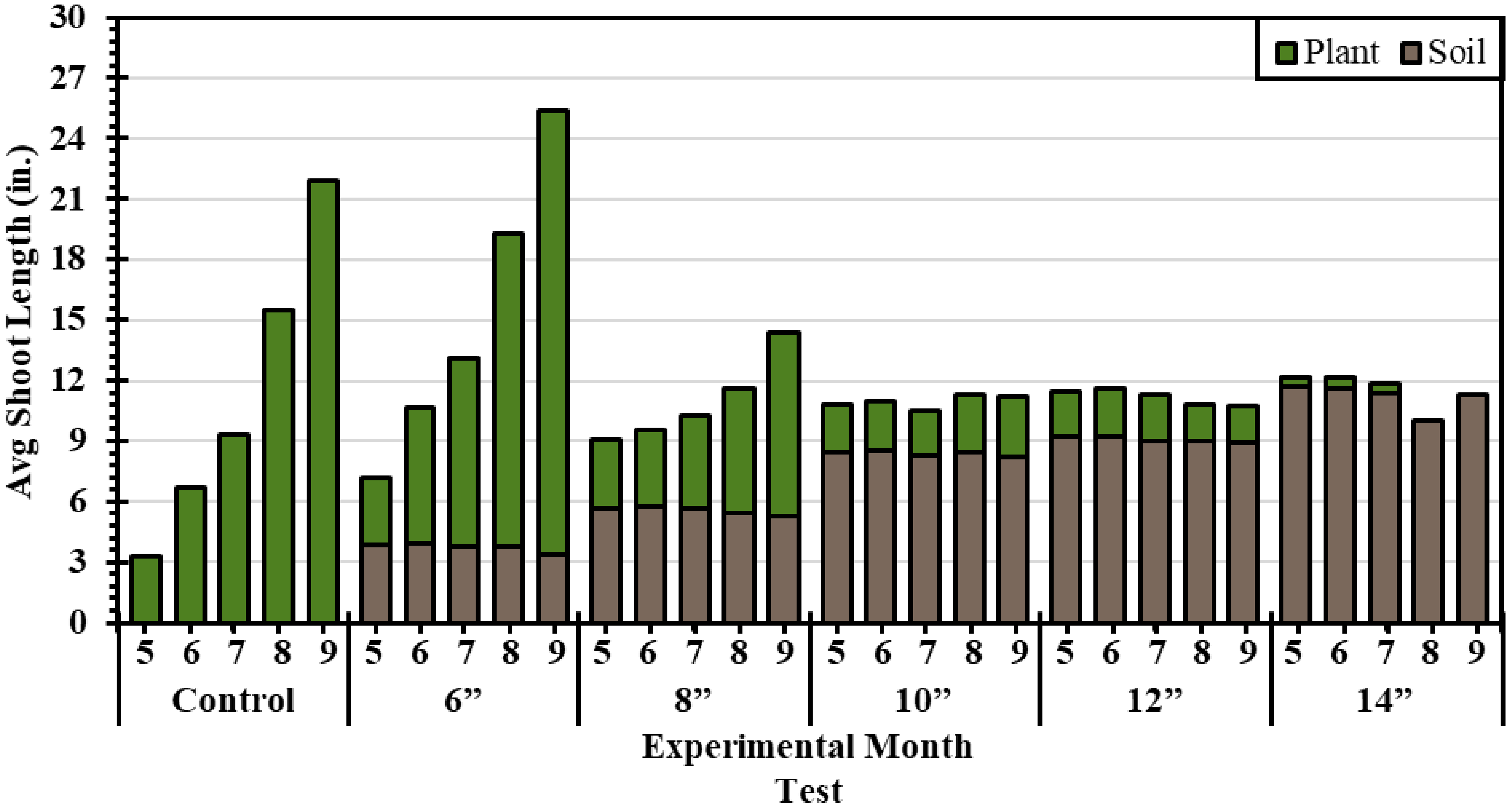
Data collected: Total shoot count (live:dead/grid), shoot length (average of 30 random/bucket), shoot basal diameter (average of 30 random/bucket), and soil compaction (height of soil in bucket from floor)

Data Collection – Bi-Monthly Destructive Sampling

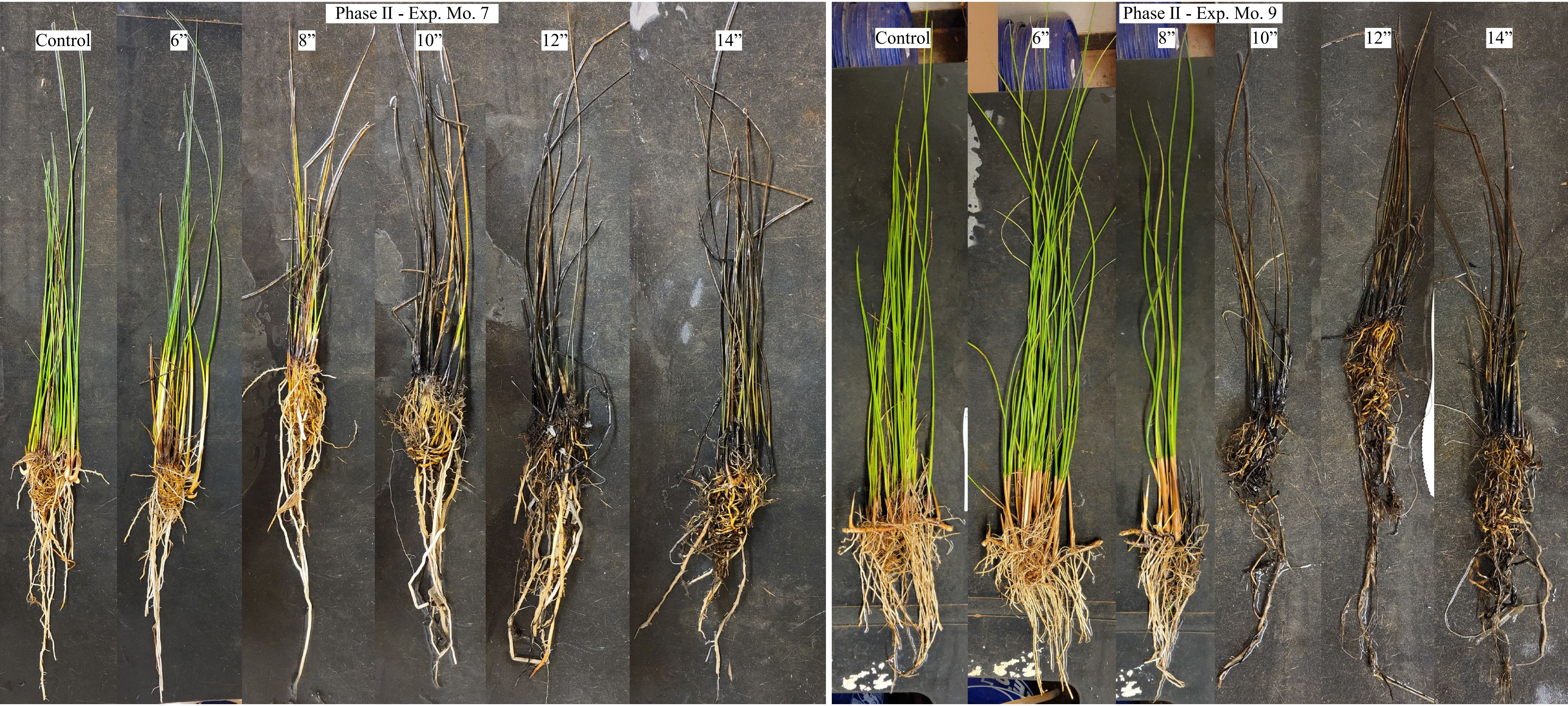
SHOOT SURVIVAL



Phase II Shoot Length



Phase II Plant Recovery



Results & Impact

- **6 in. TLP application depth (47% buried) demonstrated consistent growth and adaptation**
- **Threshold exists between 8-10 in. TLP application depth (62-78% buried)**
- **≥10 in. TLP application depth (≥78% buried) results in significant stress with no recovery**

- **<u>Under moderate TLP, replanting would not be necessary</u>**
- **<u>Future Study: Can the plants survive w/out thin layer placement</u>**

Questions?

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