

# Groundwater Models Gone Green

## Using 2D Models to Improve Green Stormwater Infrastructure Design

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**Smith**®

# Outline

- Philadelphia Water Green City, Clean Waters
- 3D Groundwater and 2D Infiltration Modeling
- Tree Trench 2D Model
  - Model Setup
  - Monitoring Data
  - Baseline Model Results
  - Sensitivity to Hydraulic Conductivity and Water Table Depth
- Model Applications

# Green City, Clean Waters

## Philadelphia Water

- 25 year CSO Long Term Control Plan
- \$2.4 billion investment by 25 year mark
- Reduce CSO volume by 7.9 billion gallons per year
- Largest green stormwater infrastructure (GSI) program in US (\$1.7 billion)
- Convert 1/3 of all impervious cover to “Greened Acres”
  - First 1 inch rainfall from 1 impervious acre controlled by GSI
  - 9,500 Greened Acres throughout program

Stormwater Tree Trench

Green Roof

Rain

Rain Barrel

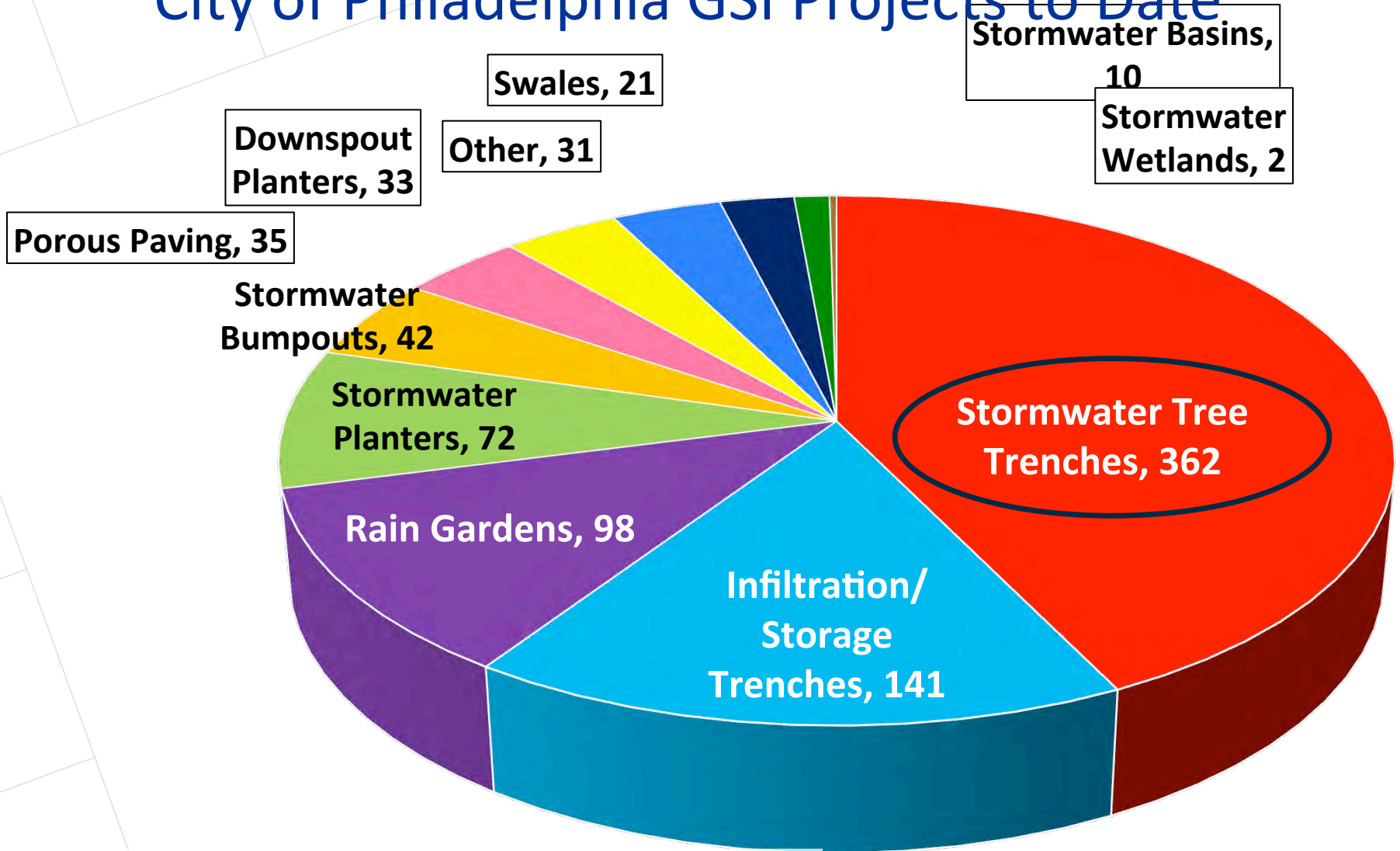
Stormwater Planter

Stormwater Bump-out

Pervious Paving

<http://phillywatersheds.org>

# City of Philadelphia GSI Projects to Date



<http://phillywatersheds.org/biggreenmap>, May 2015

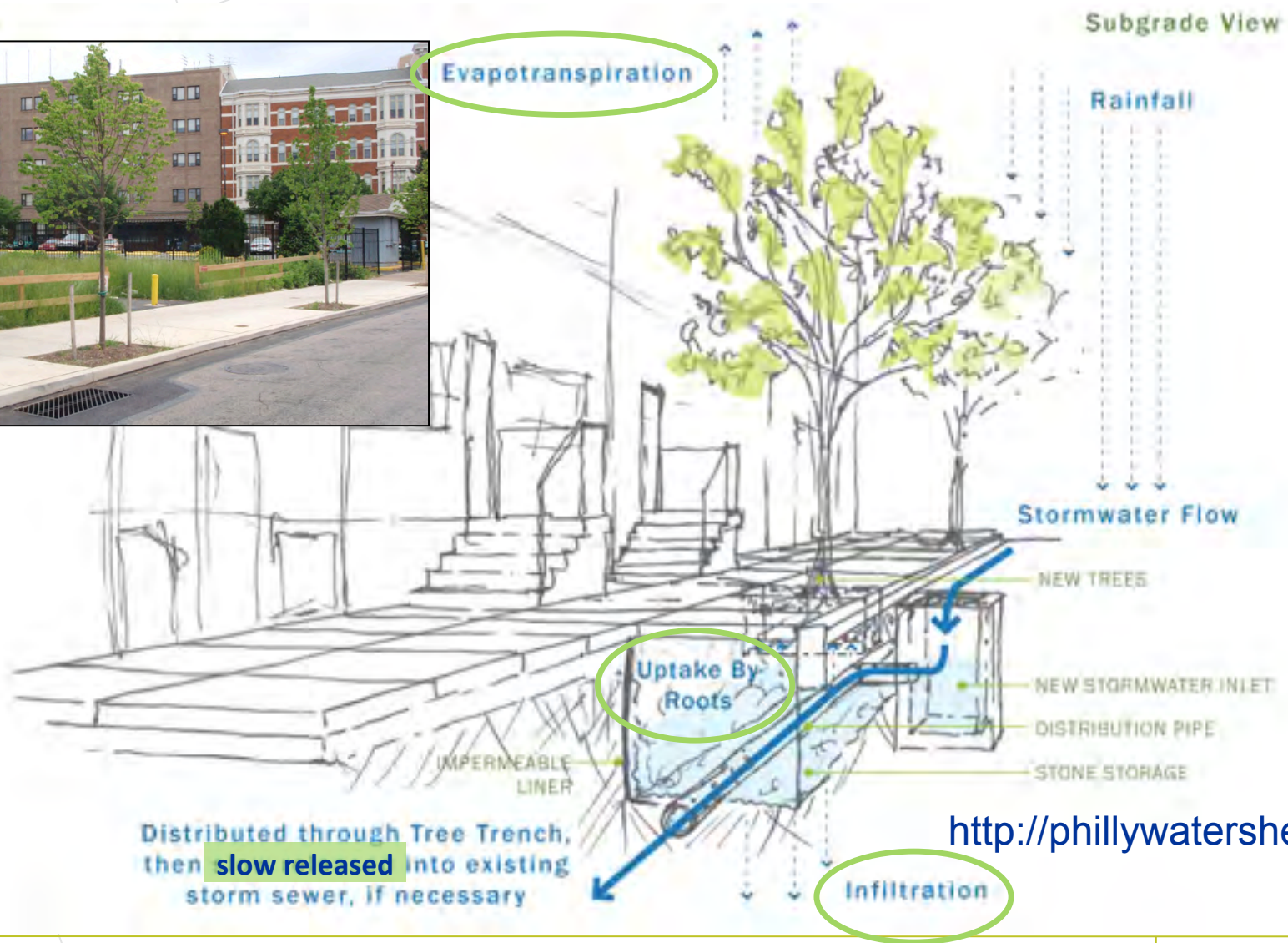
# Stormwater Tree Trench Schematic

Street View



Evapotranspiration

Subgrade View



Stormwater Flow

NEW TREES

NEW STORMWATER INLET

DISTRIBUTION PIPE

STONE STORAGE

Uptake By Roots

IMPERMEABLE LINER

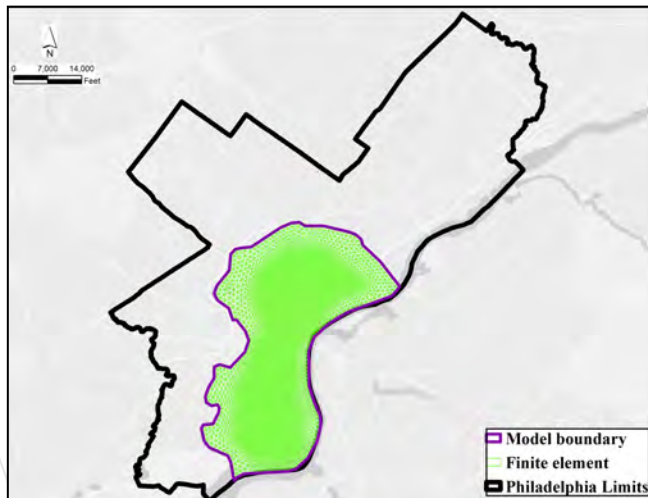
Distributed through Tree Trench, then slow released into existing storm sewer, if necessary

<http://phillywatersheds.org>

Infiltration

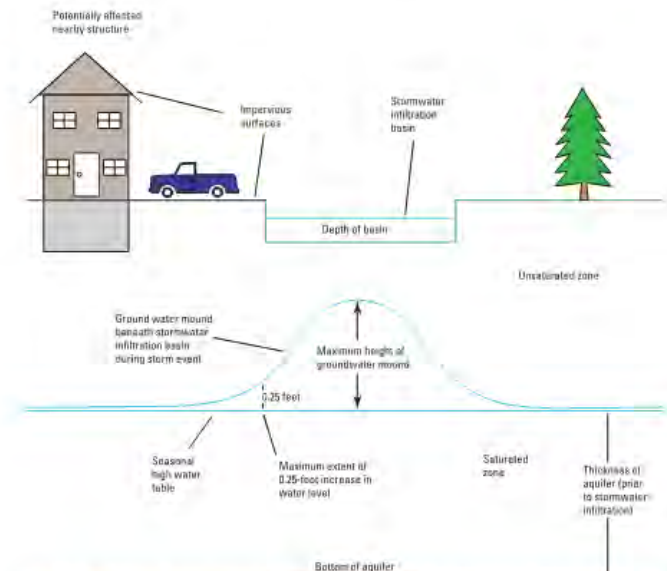
# Groundwater Flow Modeling

- 3D regional and site scale models in DYNFLOW ([www.dynsystem.com](http://www.dynsystem.com))
- 1D mounding calculations using Hantush equation
- **Both models bypass unsaturated zone**



Prepared in cooperation with the  
New Jersey Department of Environmental Protection

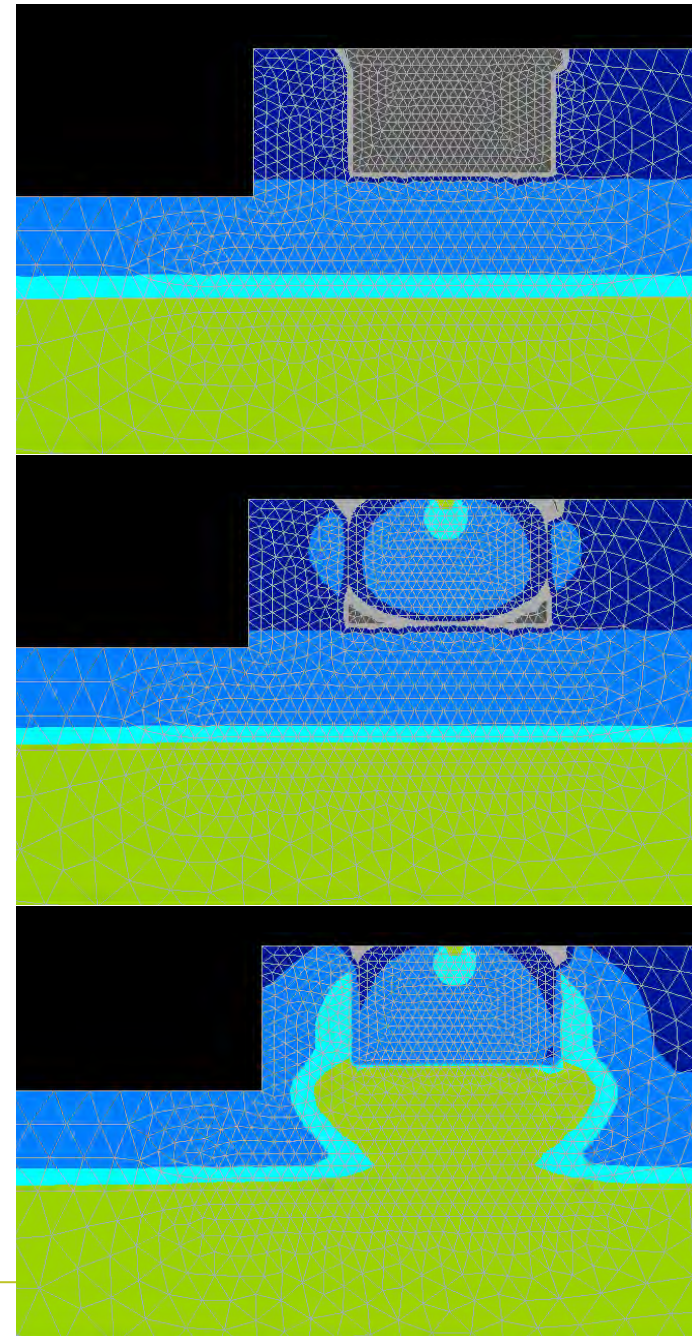
## Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins



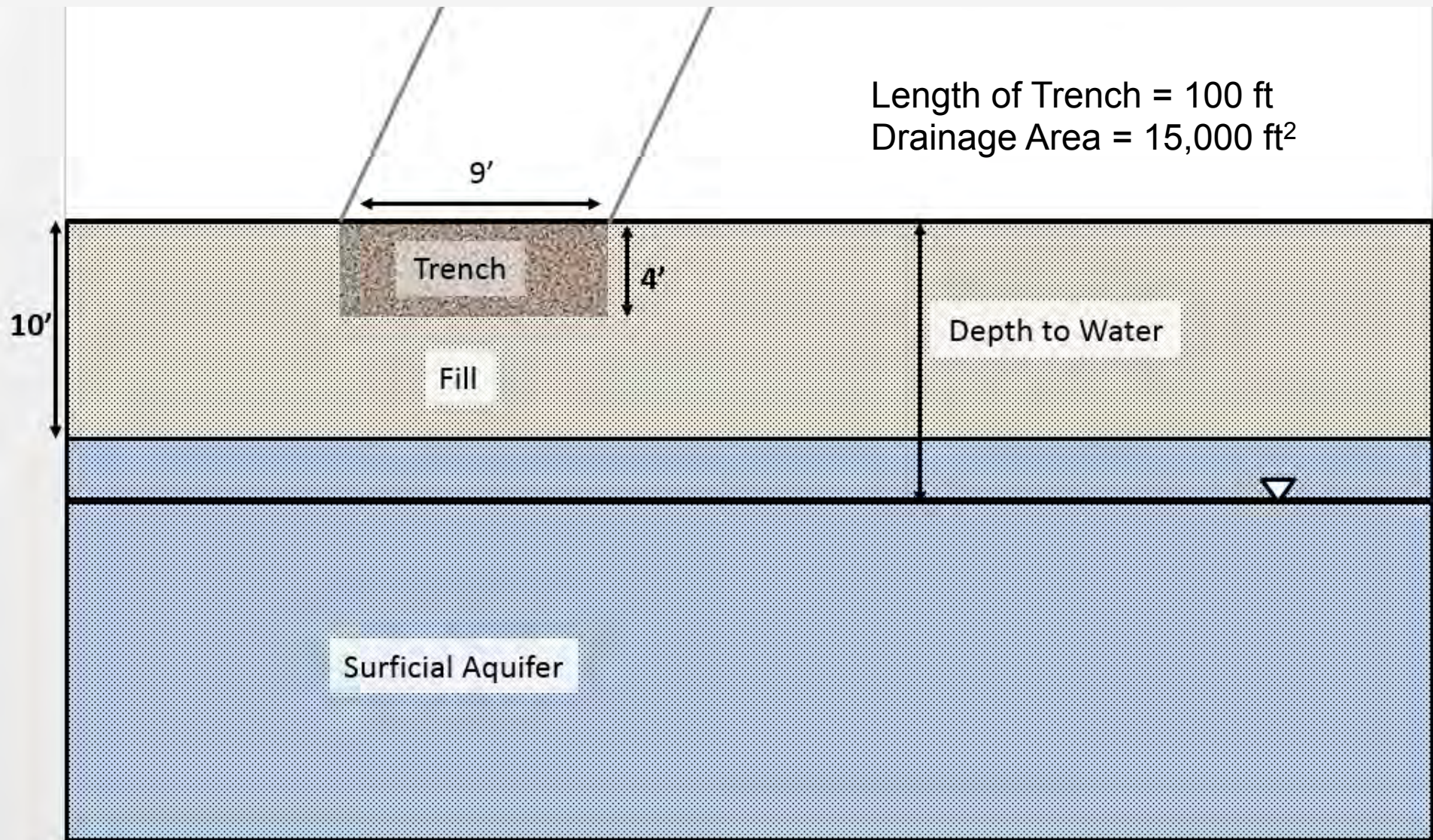
Scientific Investigations Report 2010-5102

# Unsaturated Zone Modeling: SWMS 2D

- USDA code
- Solves Richards equation for **saturated** and **unsaturated** groundwater flow
- Finite element formulation
- Requires 5 parameters
  - Saturated hydraulic conductivity ( $K_s$ )
  - Residual saturation ( $\theta_r$ )
  - Maximum saturation ( $\theta_s$ ) = porosity ( $\phi$ )
  - Coefficient in soil water retention equation ( $\alpha$ )
  - Exponent in soil water retention equation ( $\eta$ )

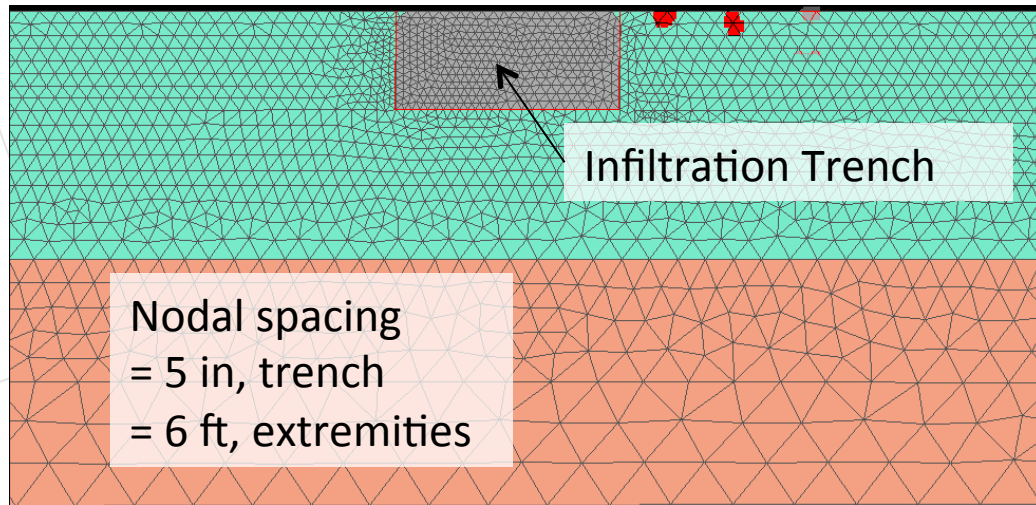
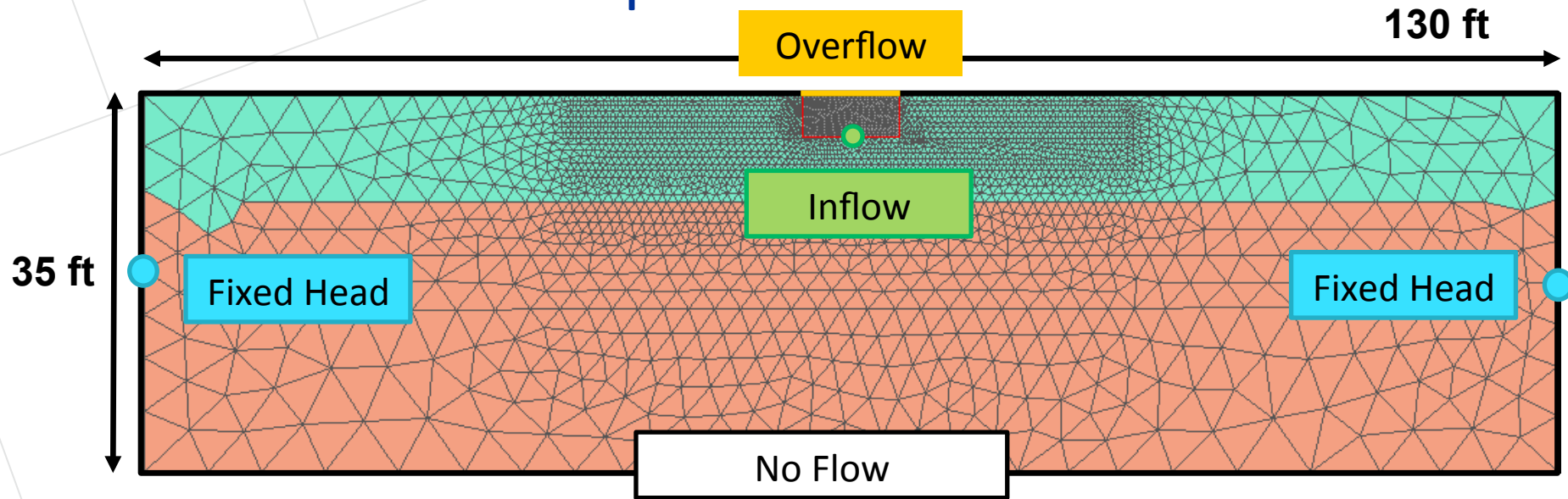


# Tree Trench 2D Model Schematic








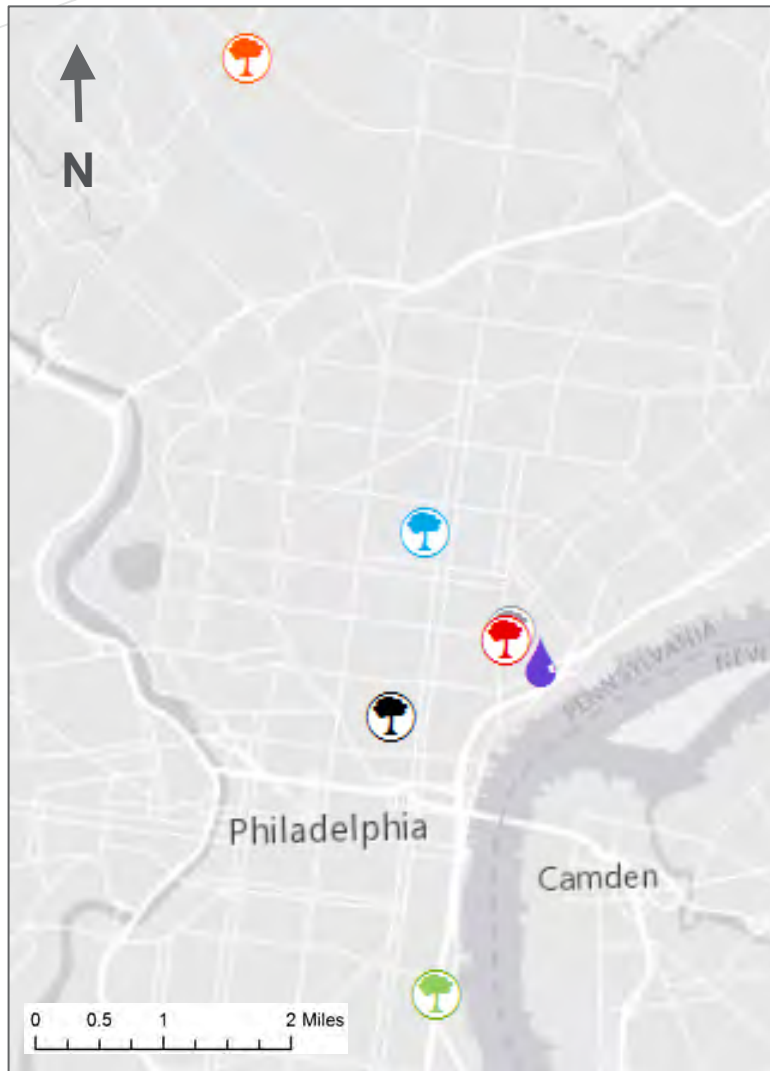
# Material Properties and Boundaries



Hydraulic Conductivity (ft/day)

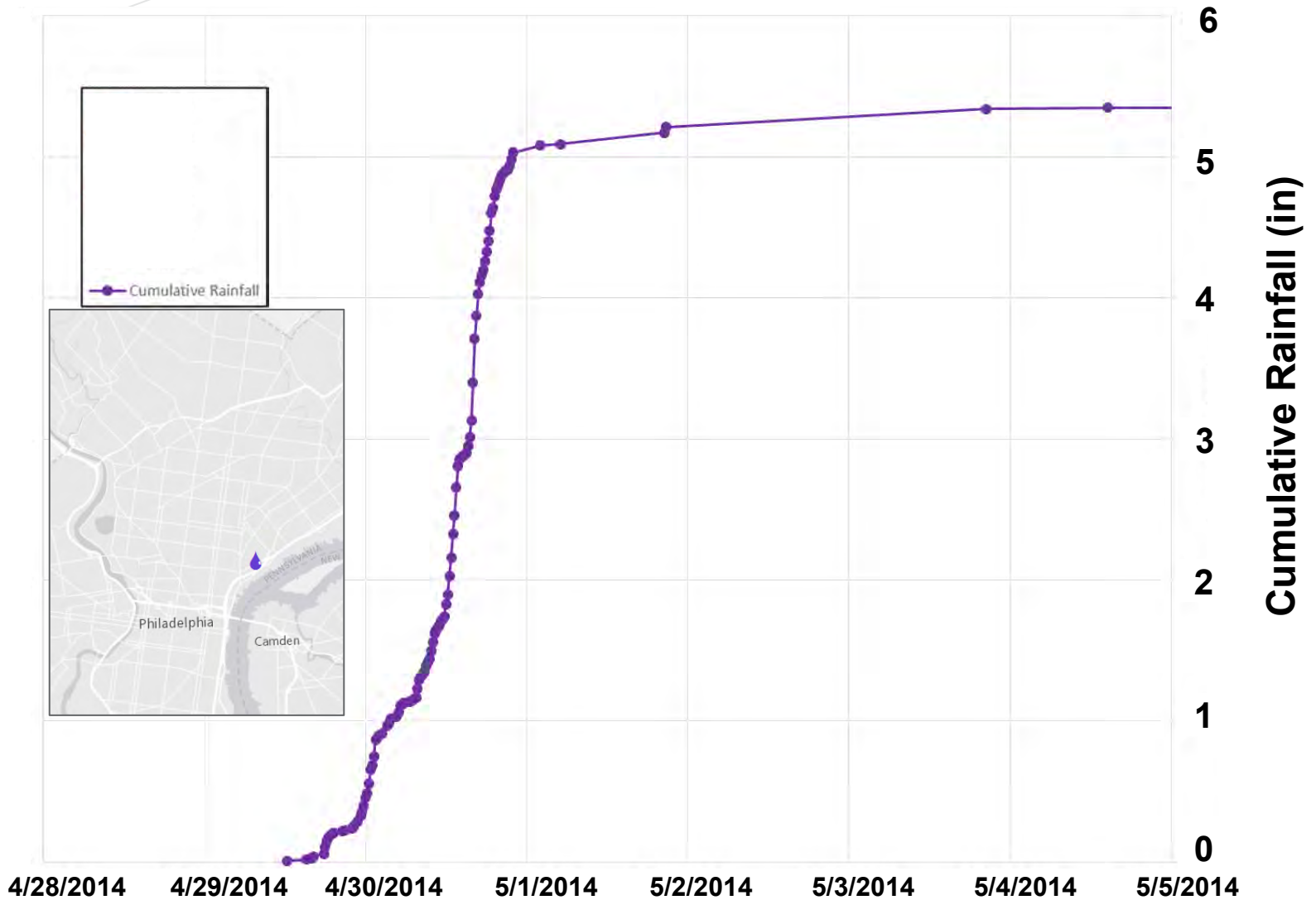
	$K_x = 1,000$	$K_z = 1,000$
	$K_x = 10$	$K_z = 1$
	$K_x = 0.5$	$K_z = 0.25$

# Monitoring Data – 5” Storm April 2014

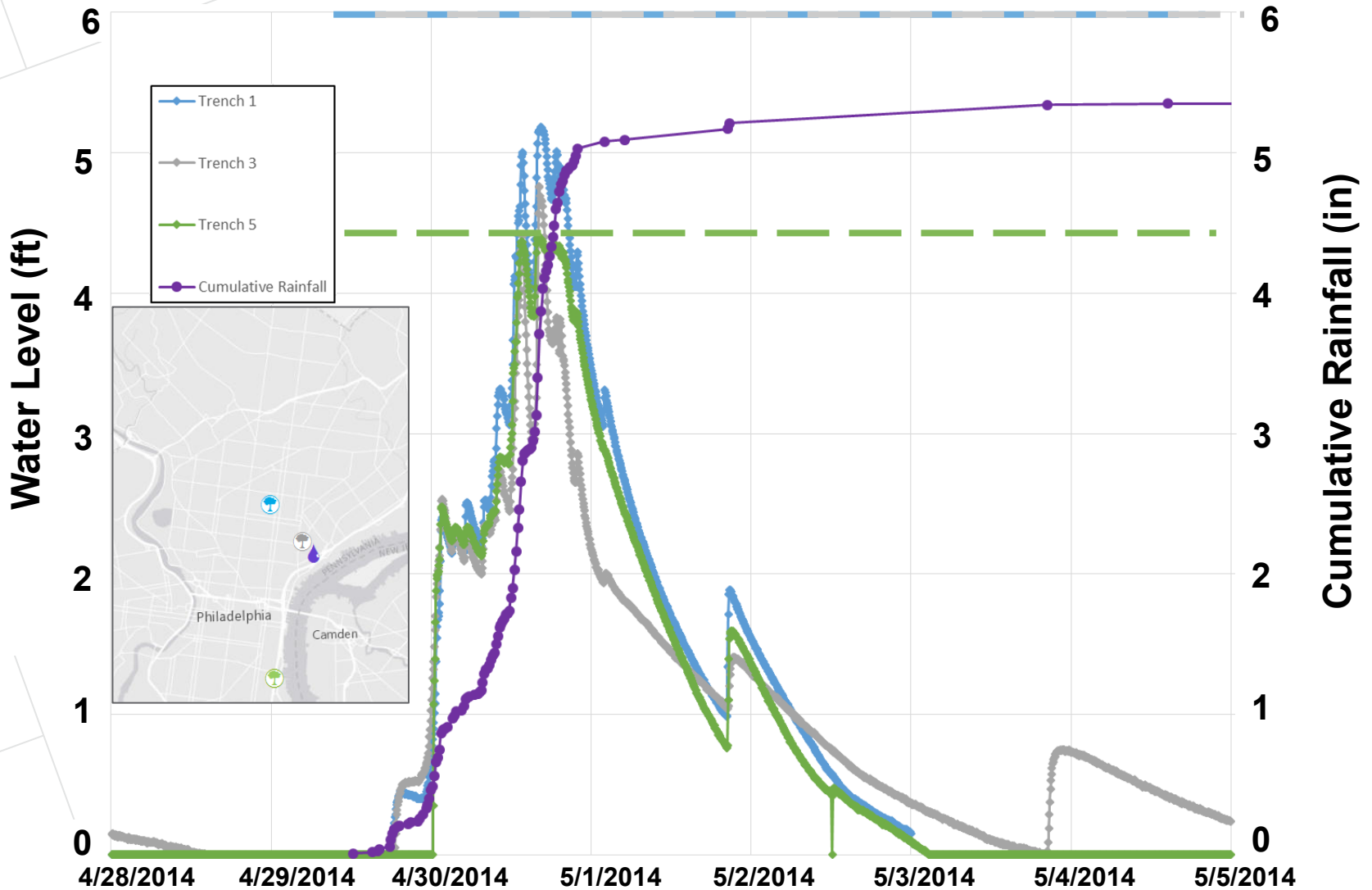


-  Rain Gage
-  Trench 1
-  Trench 2
-  Trench 3
-  Trench 4
-  Trench 5
-  Trench 6

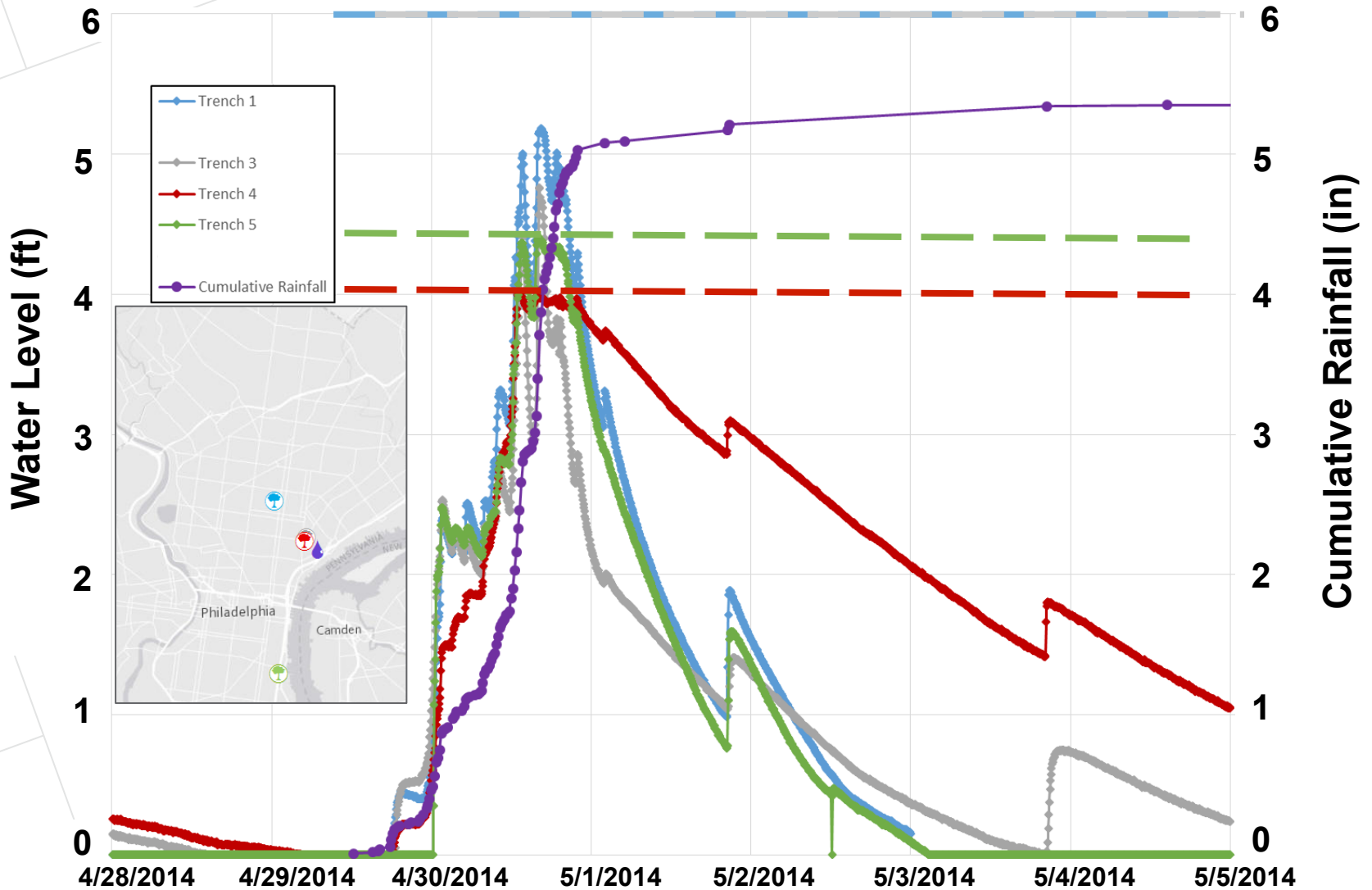
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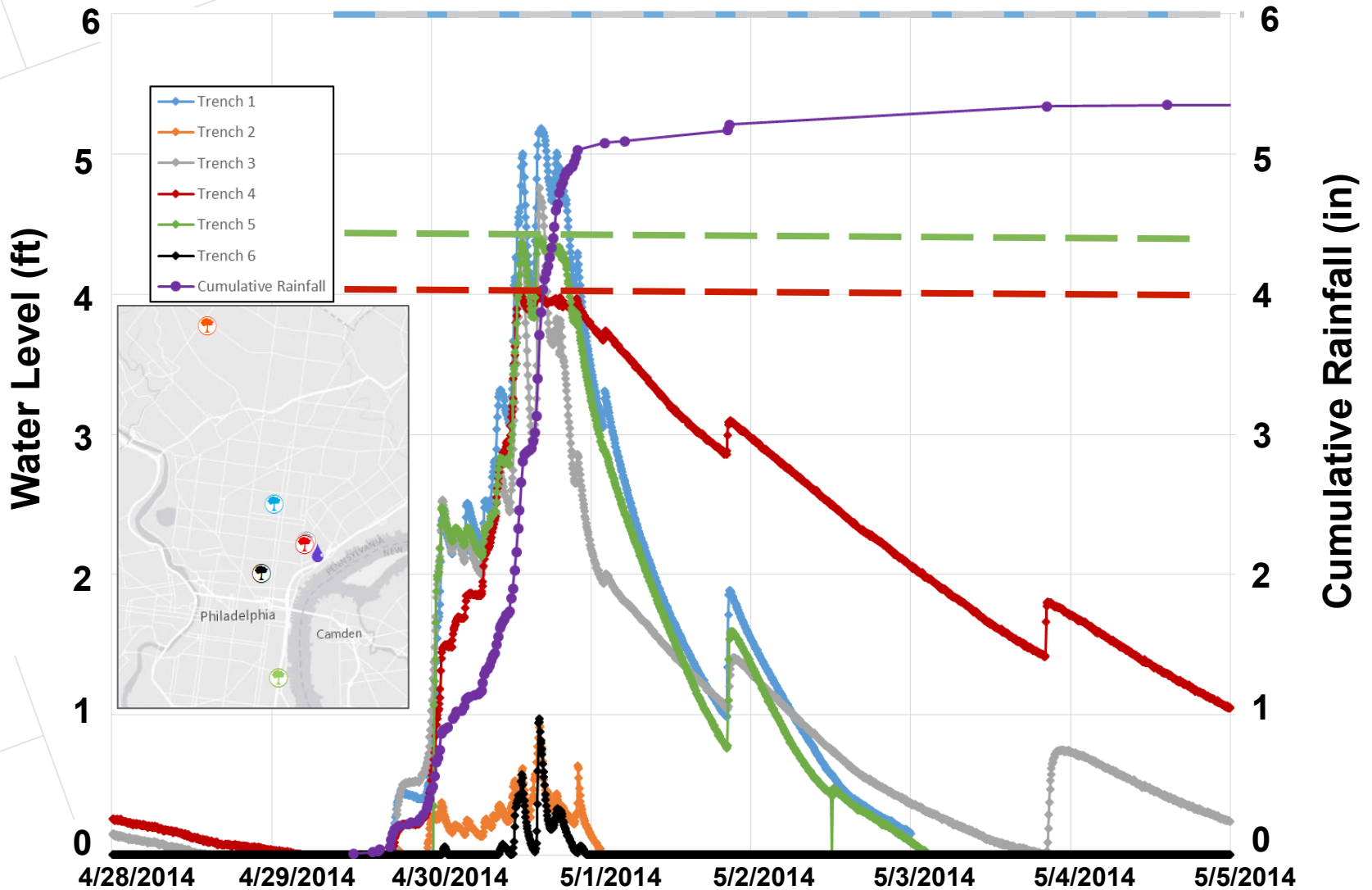
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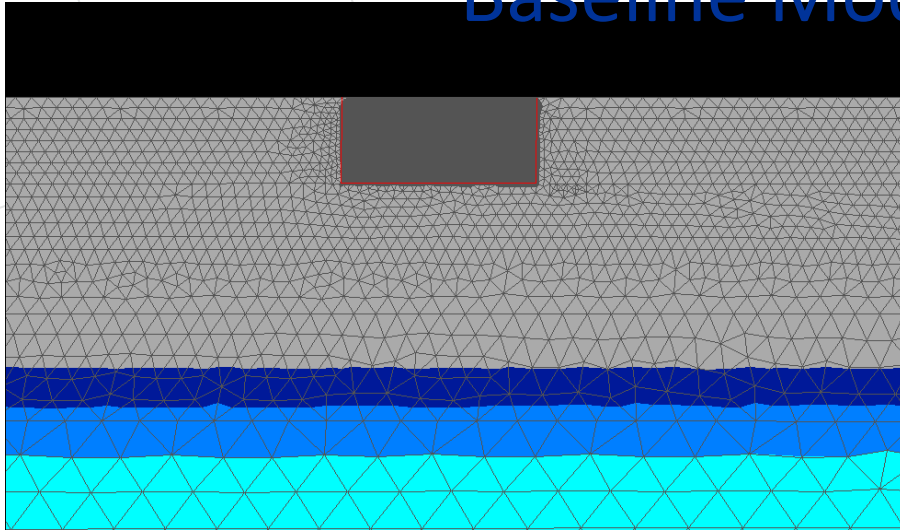
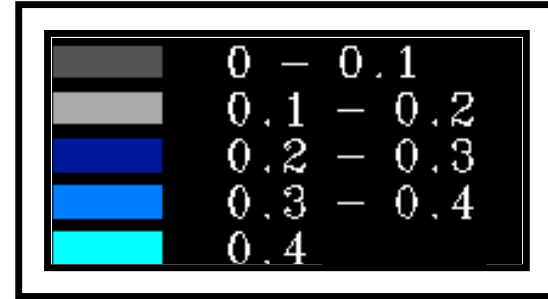
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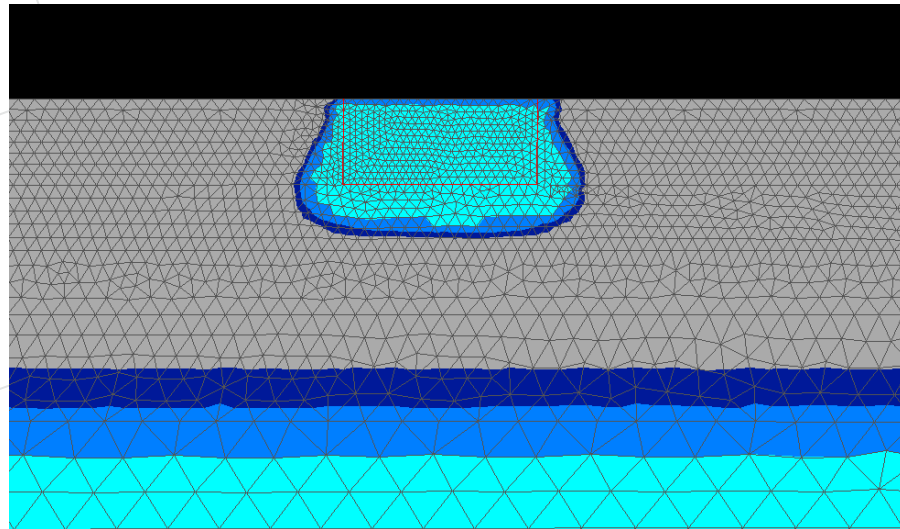
Starting Water Content Contours

# Baseline Model – 5" Storm

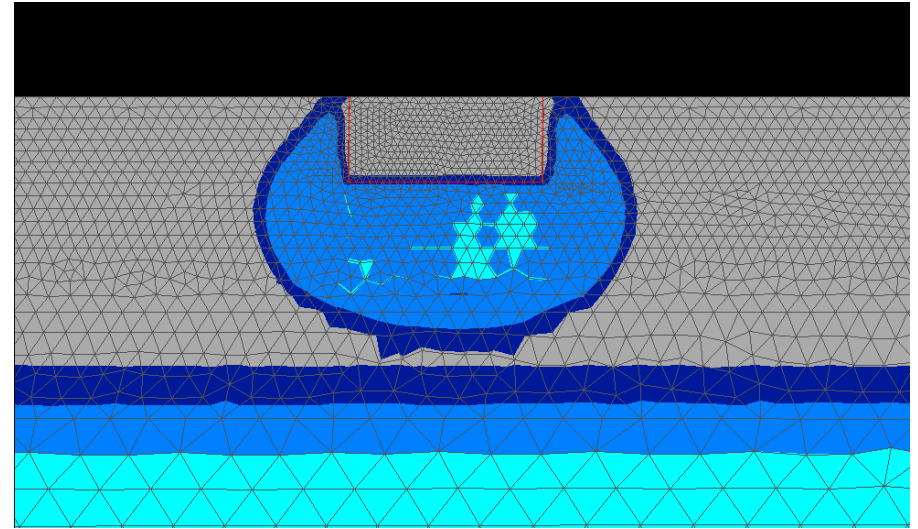
Legend – Water Content (unitless)



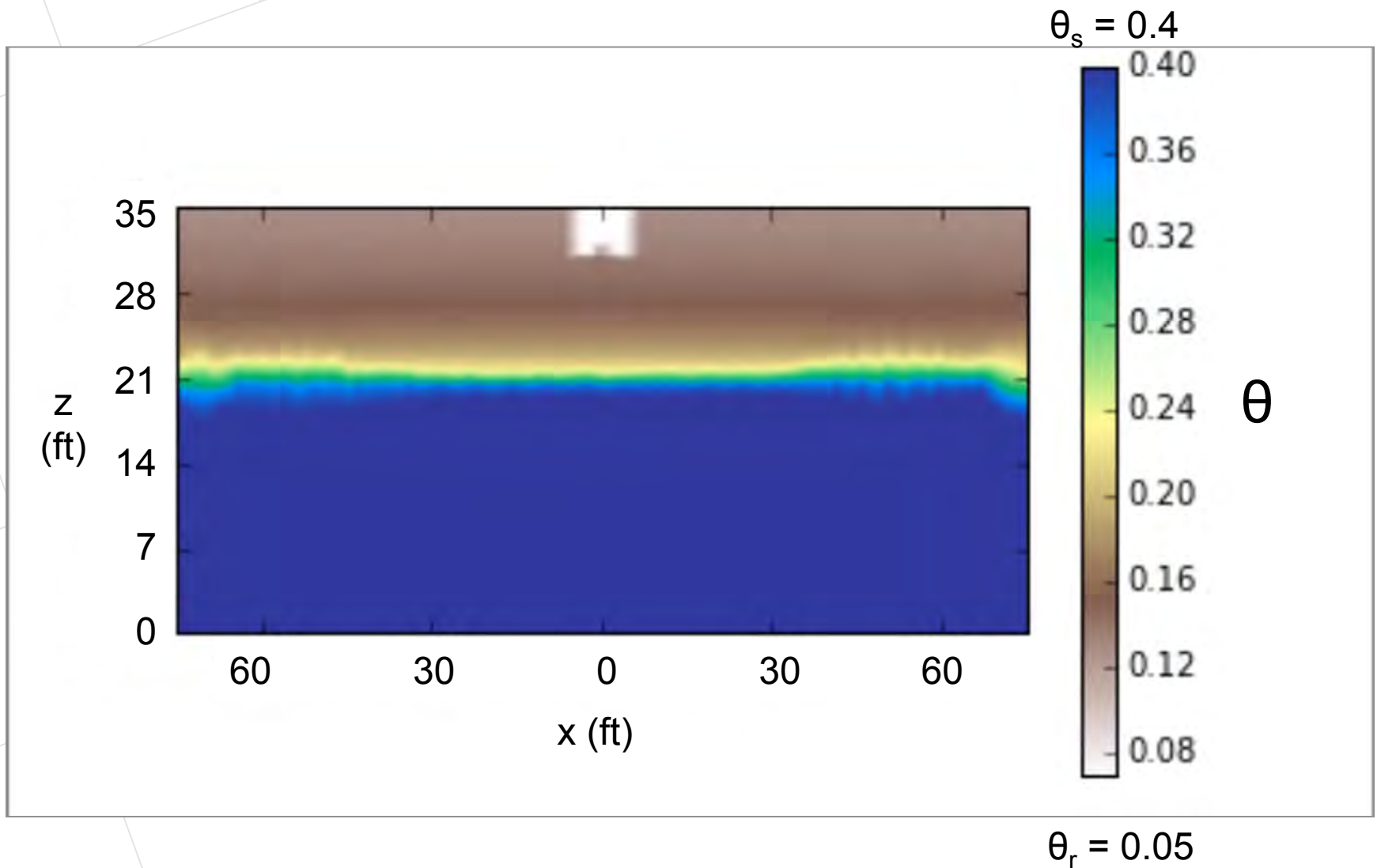
Water Content Contours after 1 day



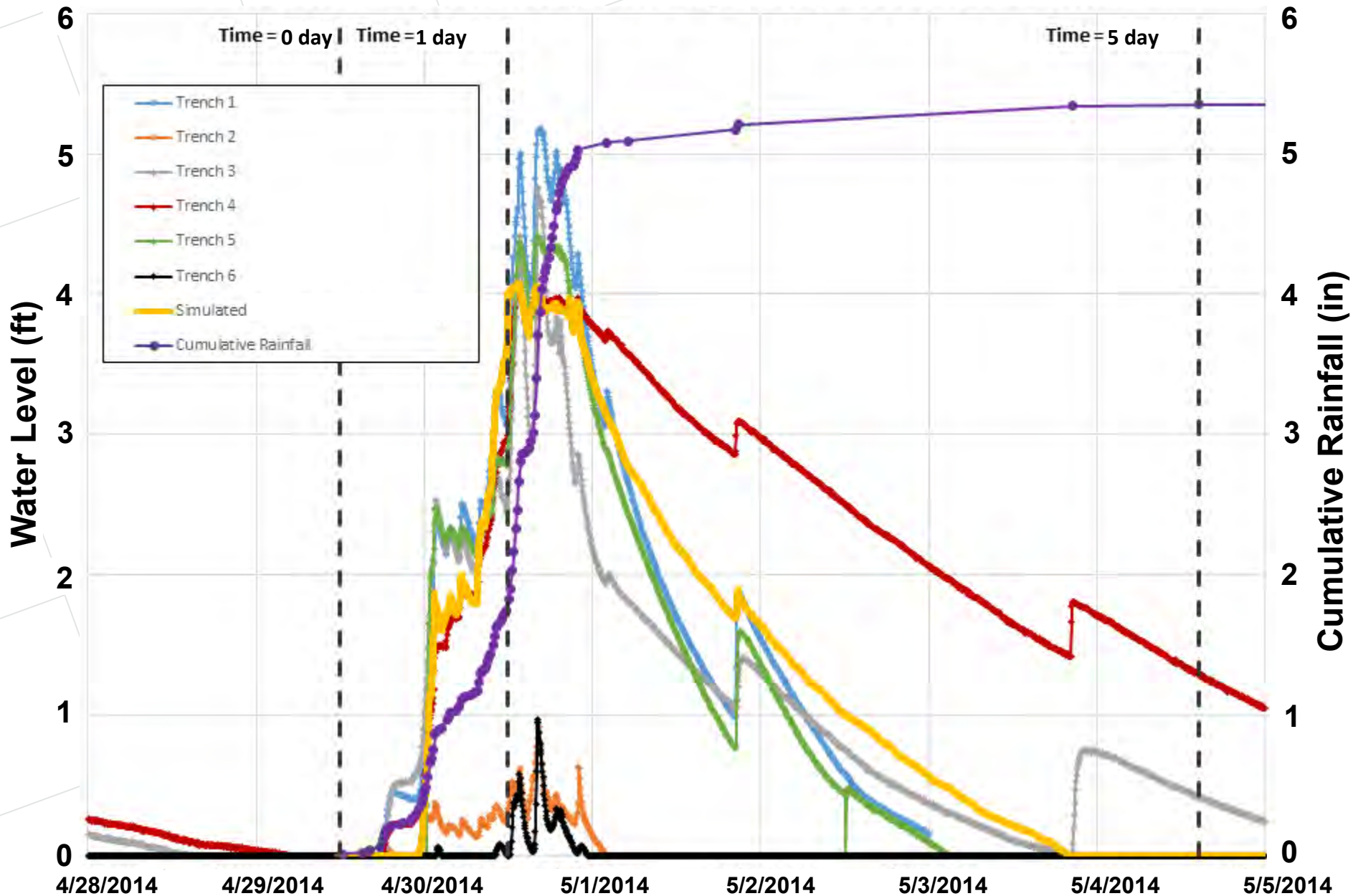
Water Content Contours after 5 days



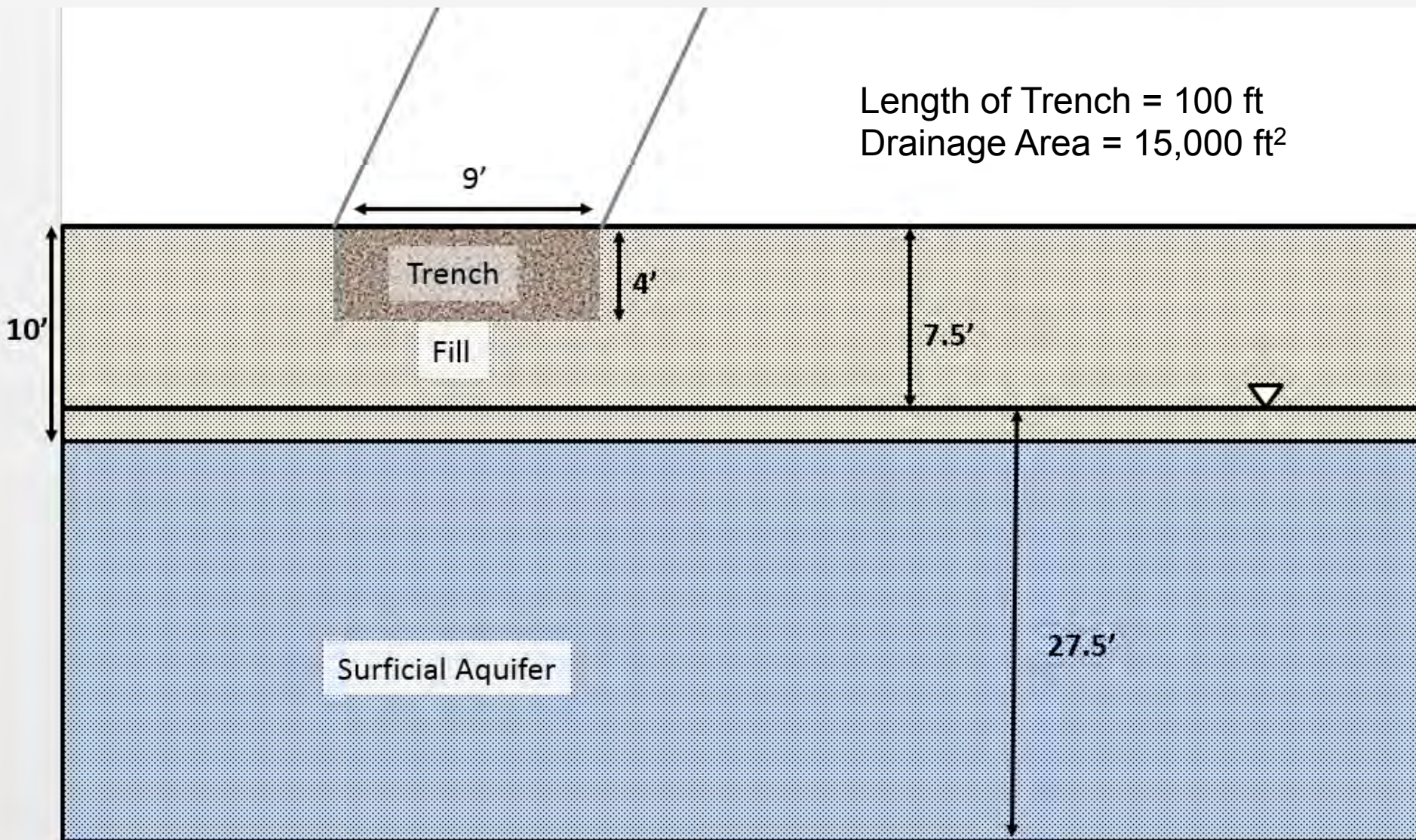
# Animation: Baseline Model



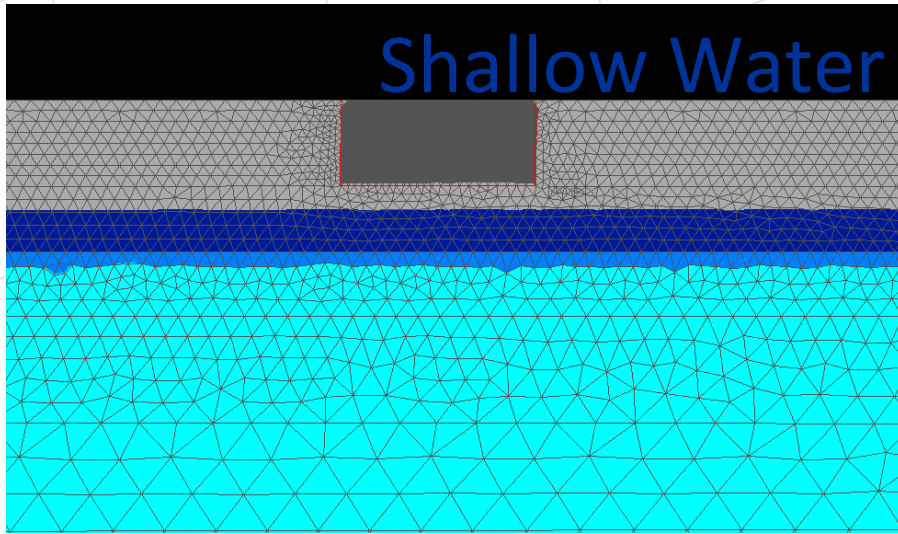




# Model Schematic – Shallow Water Table

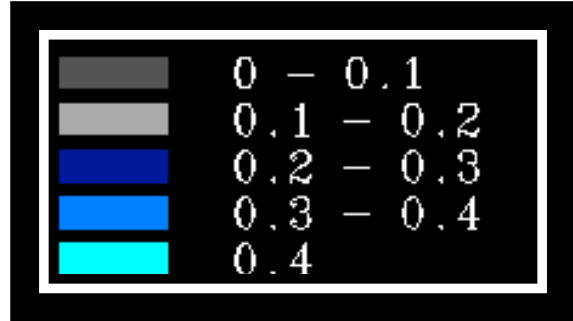


# Starting Water Content Contours

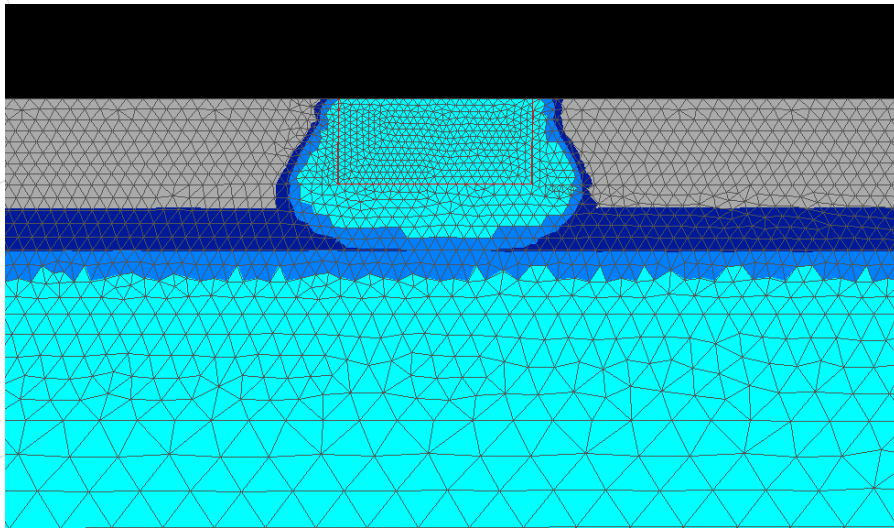


# Shallow Water Table – 5” Storm

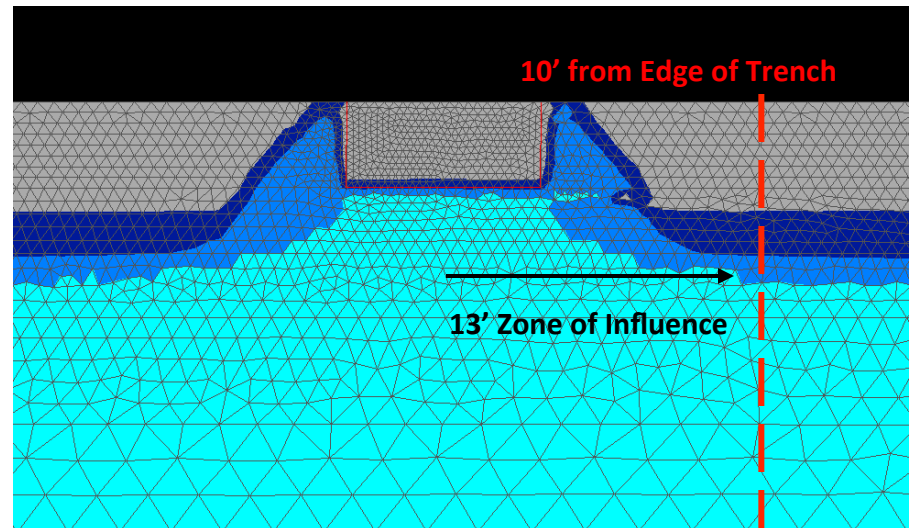
Legend Water Content (unitless)



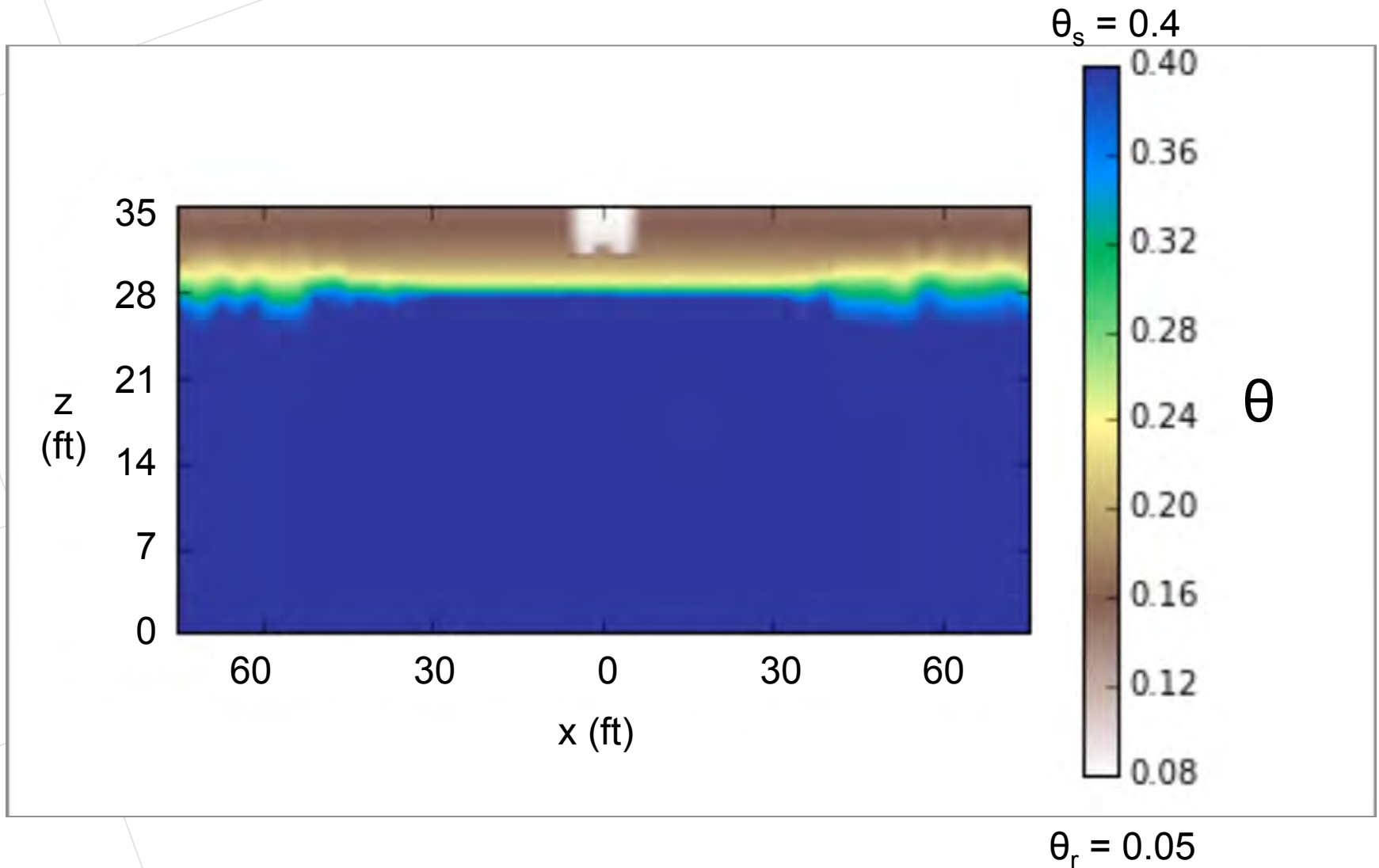
## Water Content Contours after 1 day



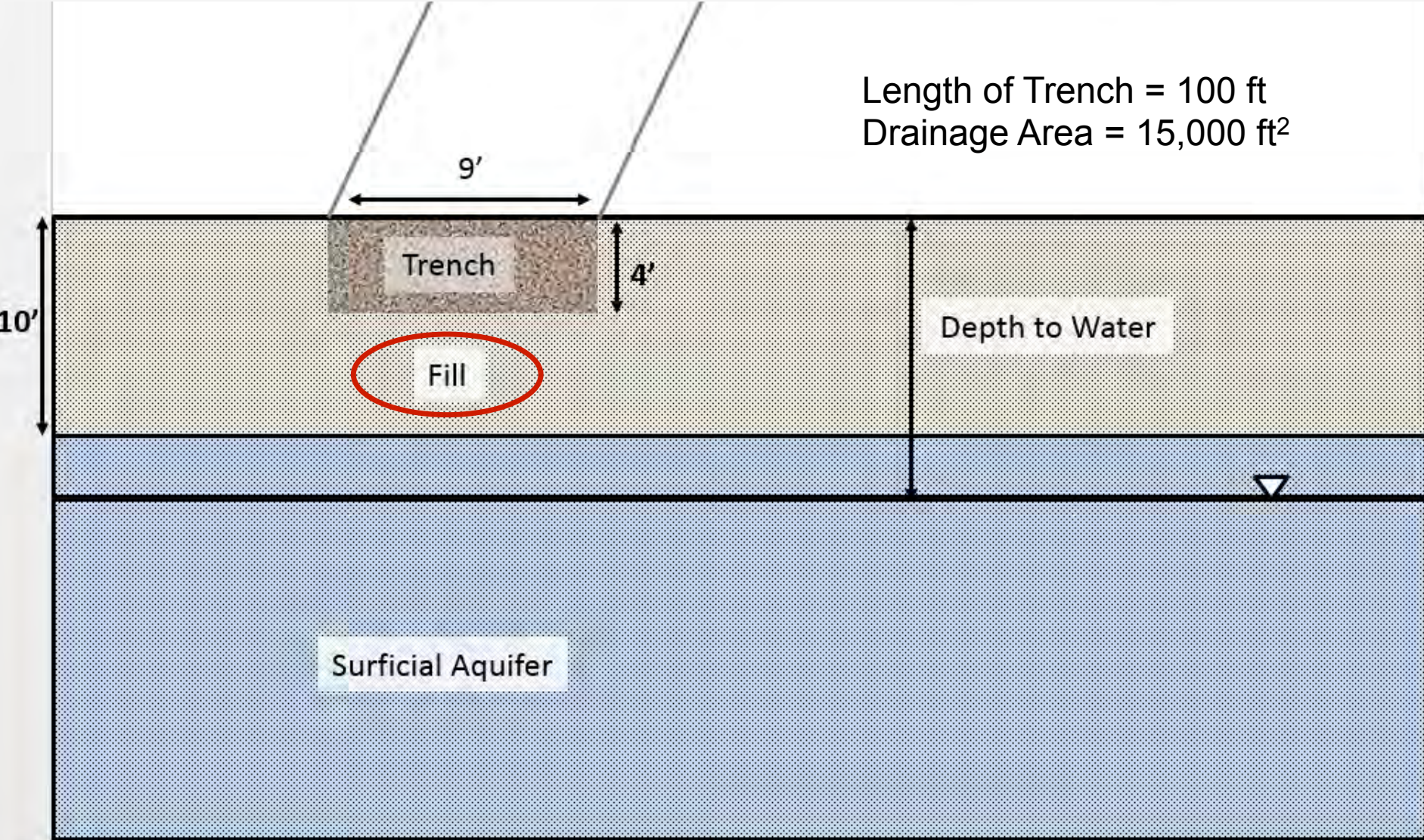
## Water Content Contours after 5 days



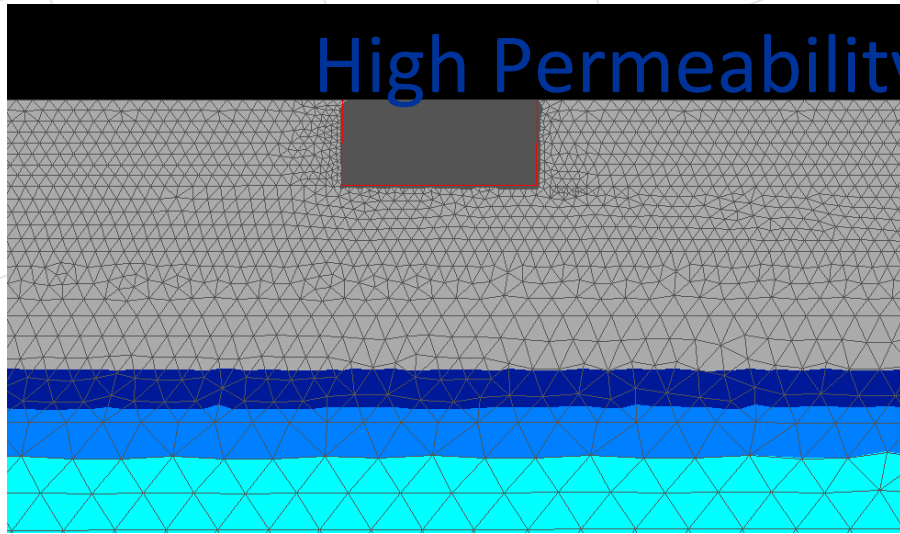
# Animation: Shallow Water Table



# Model Schematic - High Permeability of Fill

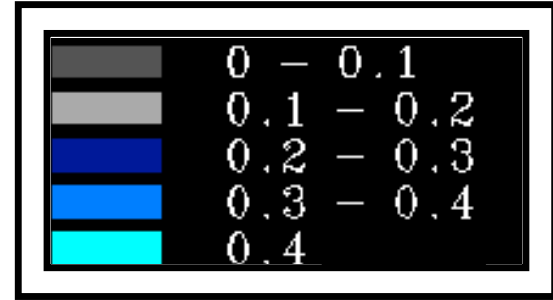


# Starting Water Content Contours

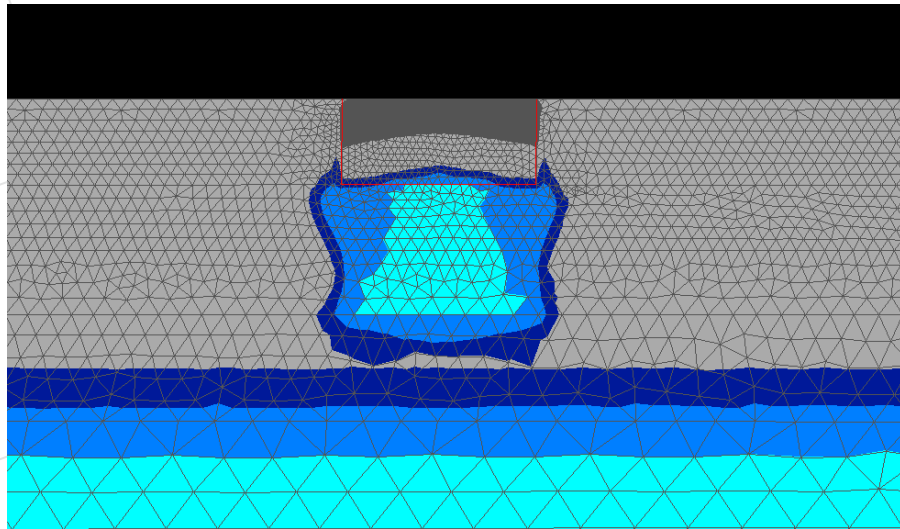


## High Permeability of Fill - 5" Storm

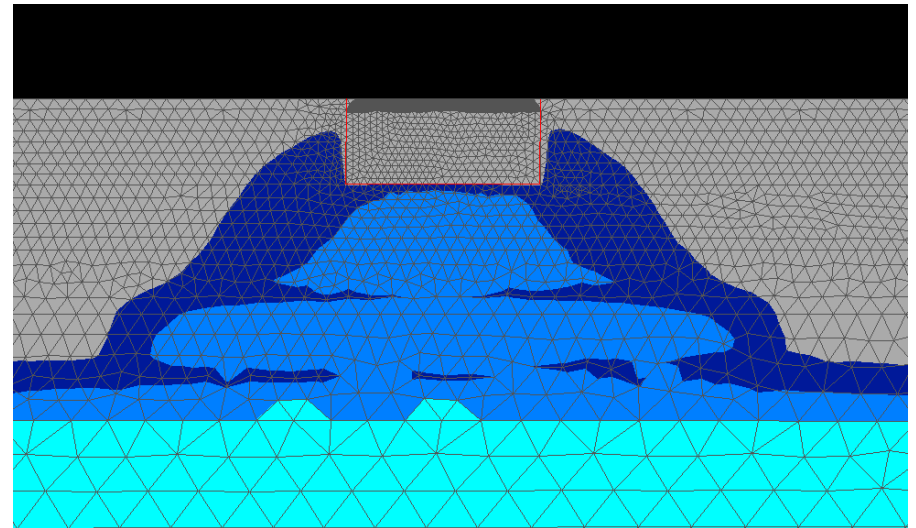
Legend - Water Content  
(unitless)



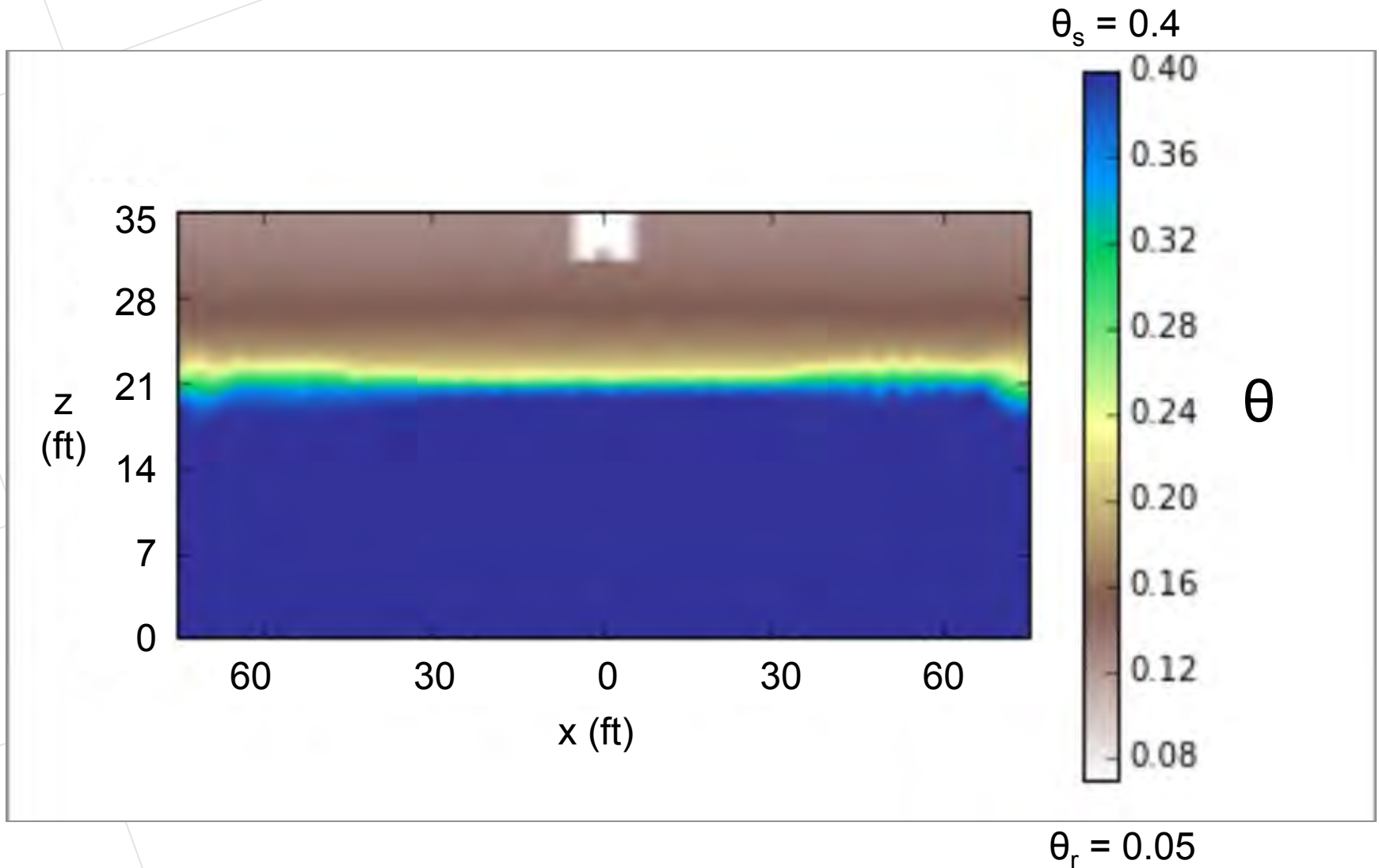
# Water Content Contours after 1 day

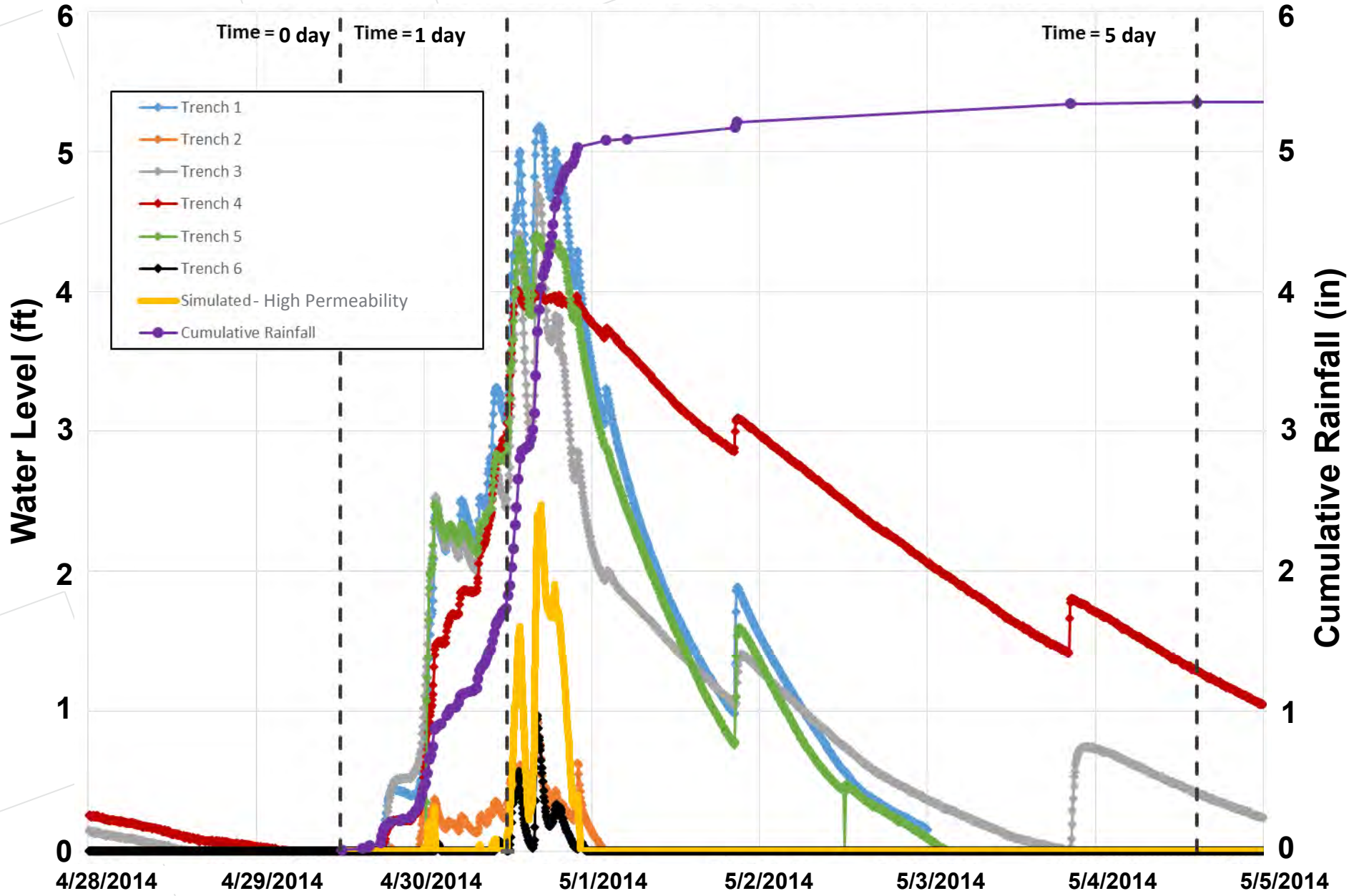


# Water Content Contours after 5 days



# Animation: High Permeability of Fill Material





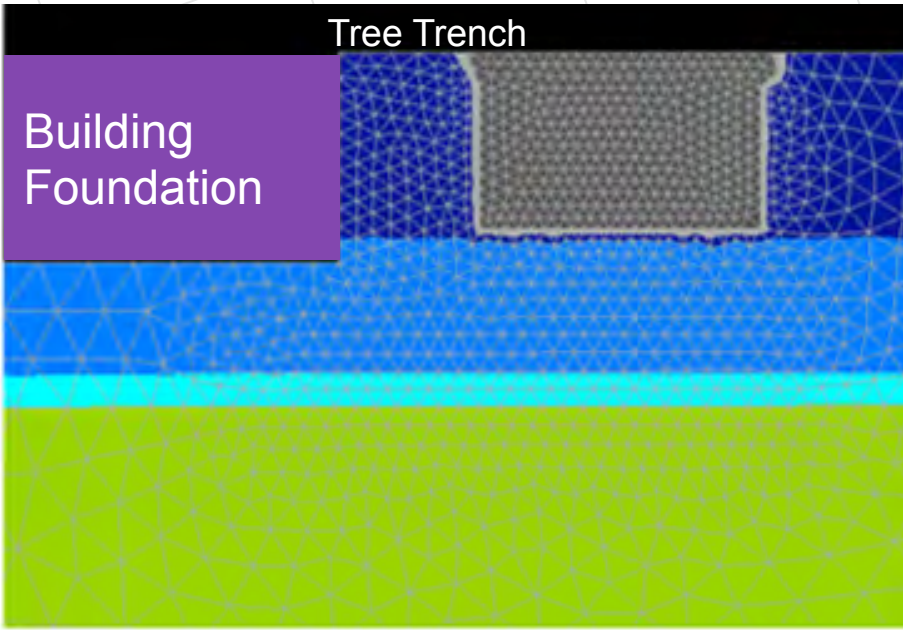


# Applications of 2D Model

- Additional model simulations run to
  - Understand when horizontal flow of infiltrated water would be expected
  - Provide guidance on the value of GSI liners
  - Perform comparative analyses between different types of GSI
    - Tree trenches
    - Drainage wells
    - Combined tree trench with drainage well
    - Large stormwater storage basins
  - Provide guidance on siting GSI
    - Potential for inducing infiltration in basements, pipes, and subway tunnels
    - Data to be collected on soils, water table elevation, infiltration rates

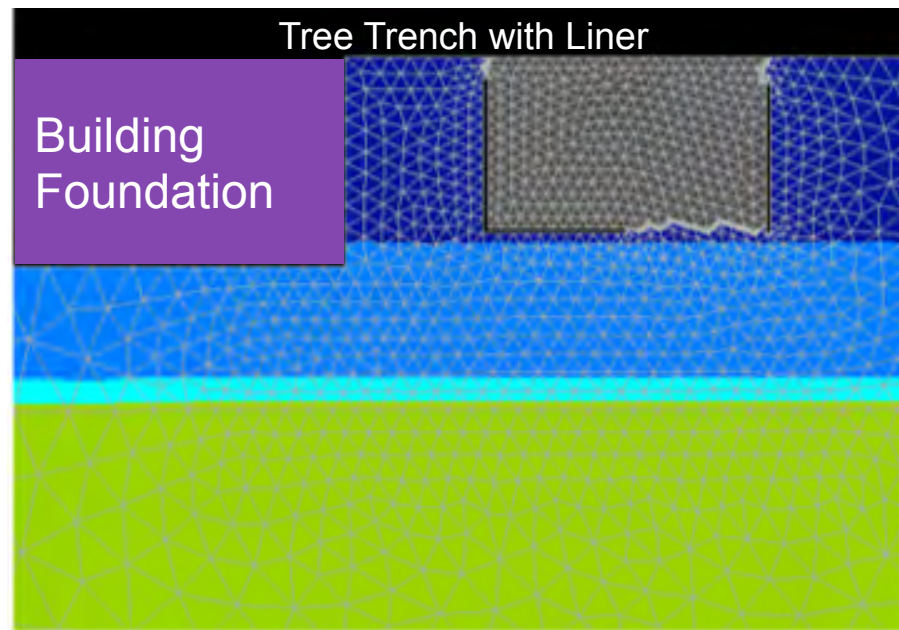
Tree Trench

Building  
Foundation



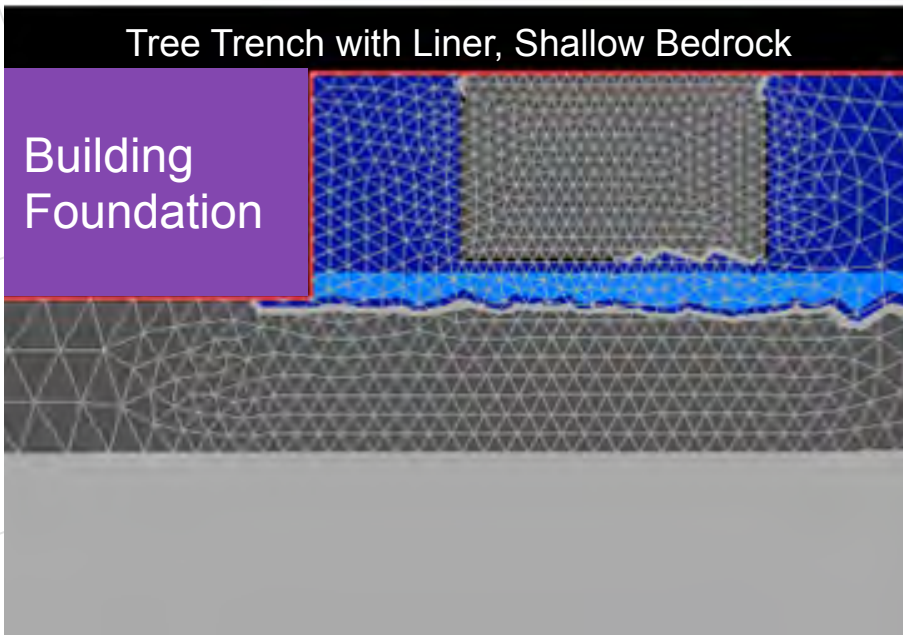
Tree Trench with Liner

Building  
Foundation



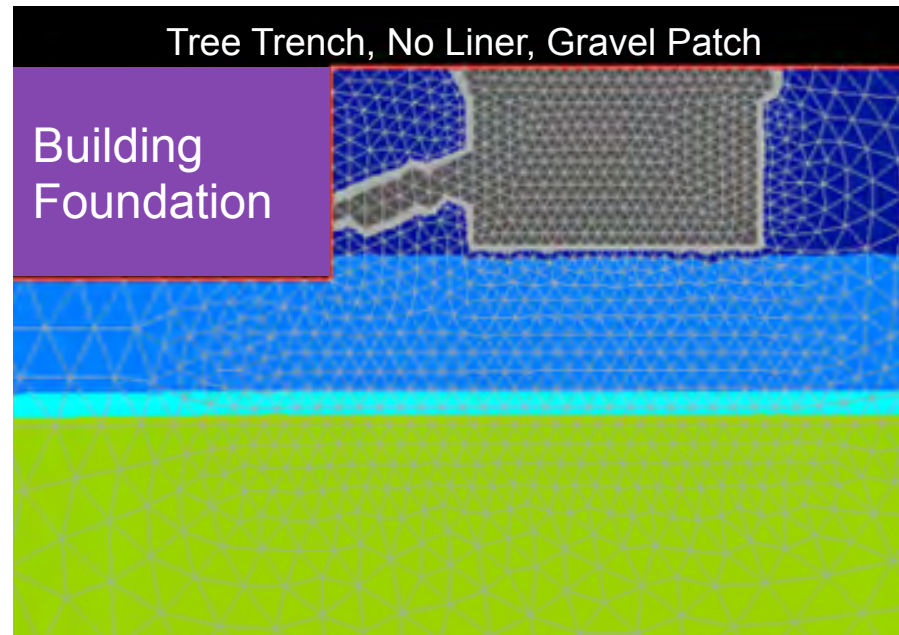
Tree Trench with Liner, Shallow Bedrock

Building  
Foundation



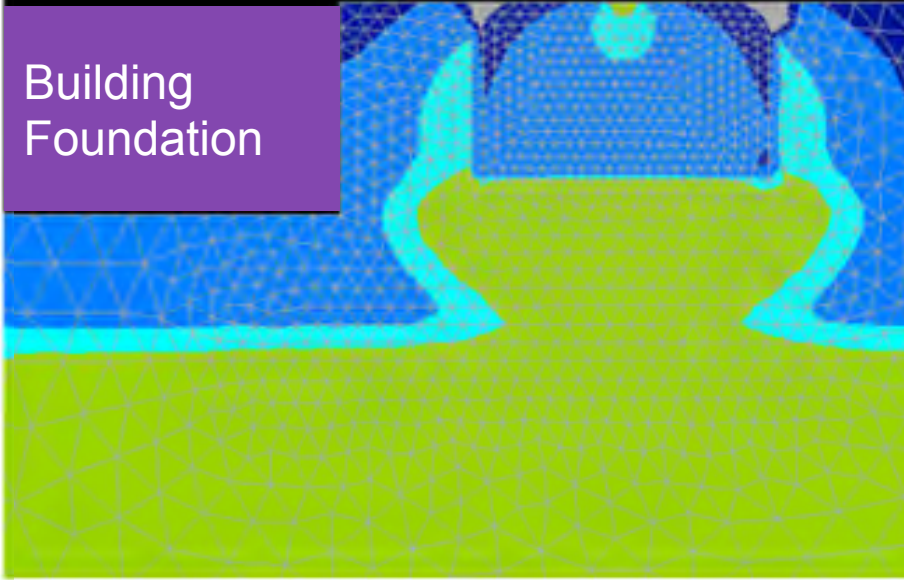
Tree Trench, No Liner, Gravel Patch

Building  
Foundation



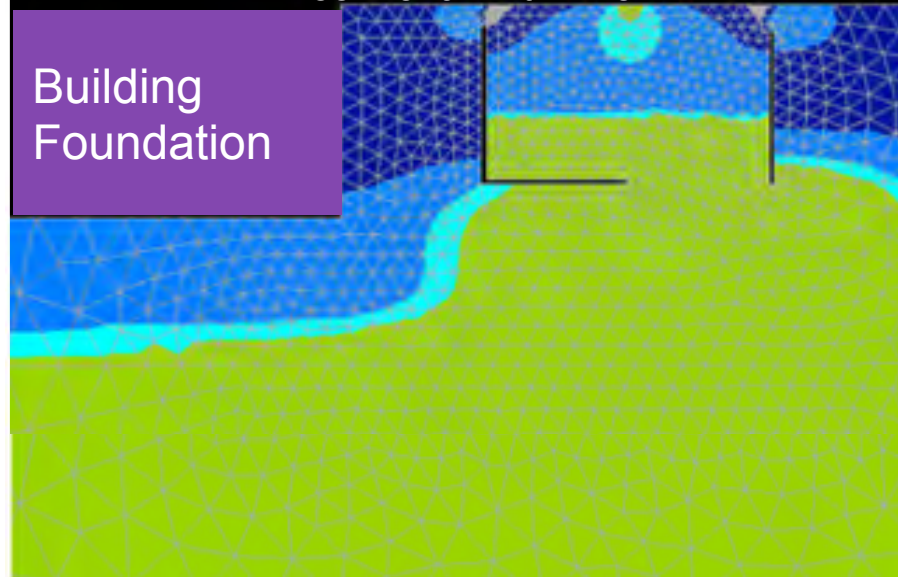
Tree Trench

Building  
Foundation



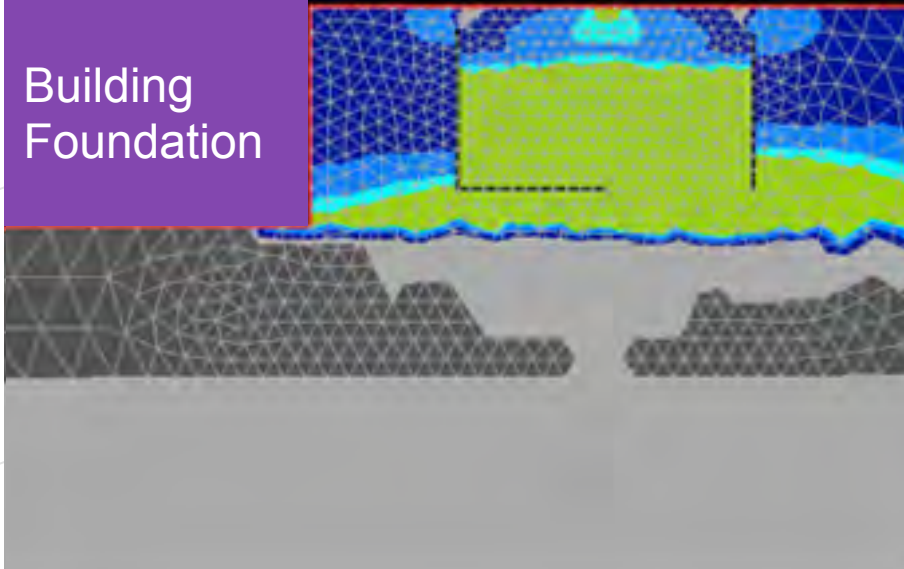
Tree Trench with Liner

Building  
Foundation



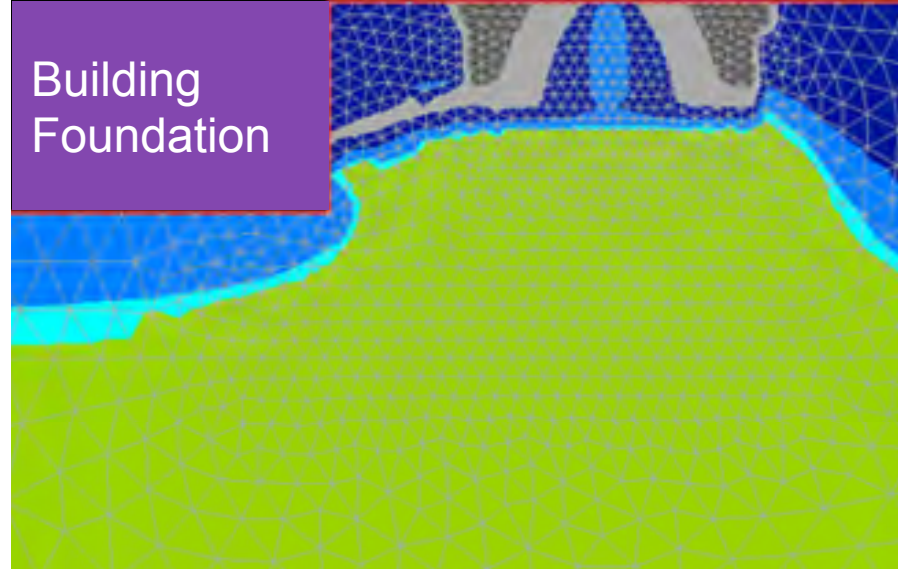
Tree Trench with Liner, Shallow Bedrock

Building  
Foundation



Tree Trench, No Liner, Gravel Patch

Building  
Foundation



# Questions

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