Dual-Permeability Modeling and Evaluation of Drift-Shadow Experiments

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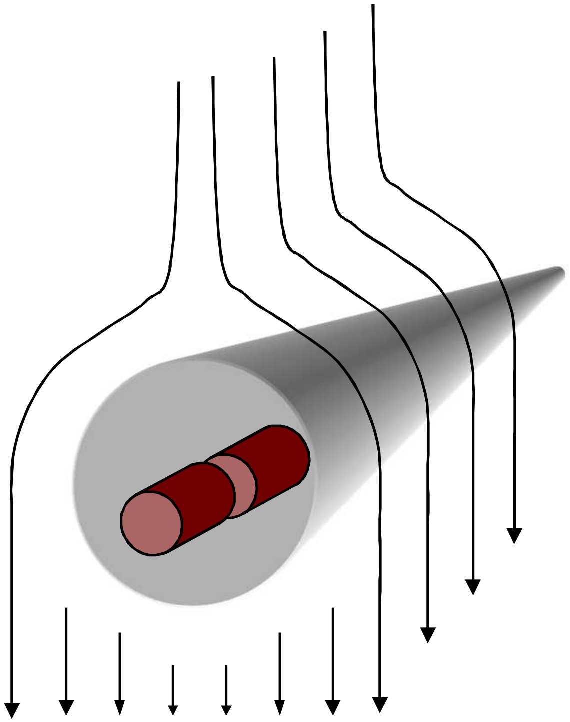
Overview

- Background and Objectives
- Experimental Summary
- Modeling Approach & Results
- Conclusions

Background and Objectives

- **Capillary diversion around tunnel may cause "drift shadow" effect**
- **Previous models evaluated drift-shadow effect**
  - **Philip et al. (1989)**
    - **Analytical Solution**
  - **Houseworth et al. (2003)**
    - **Dual-permeability model**
  - **No comparisons to data**
- **Simulate drift-shadow tests (Altman et al., 2008) with dual-permeability models**



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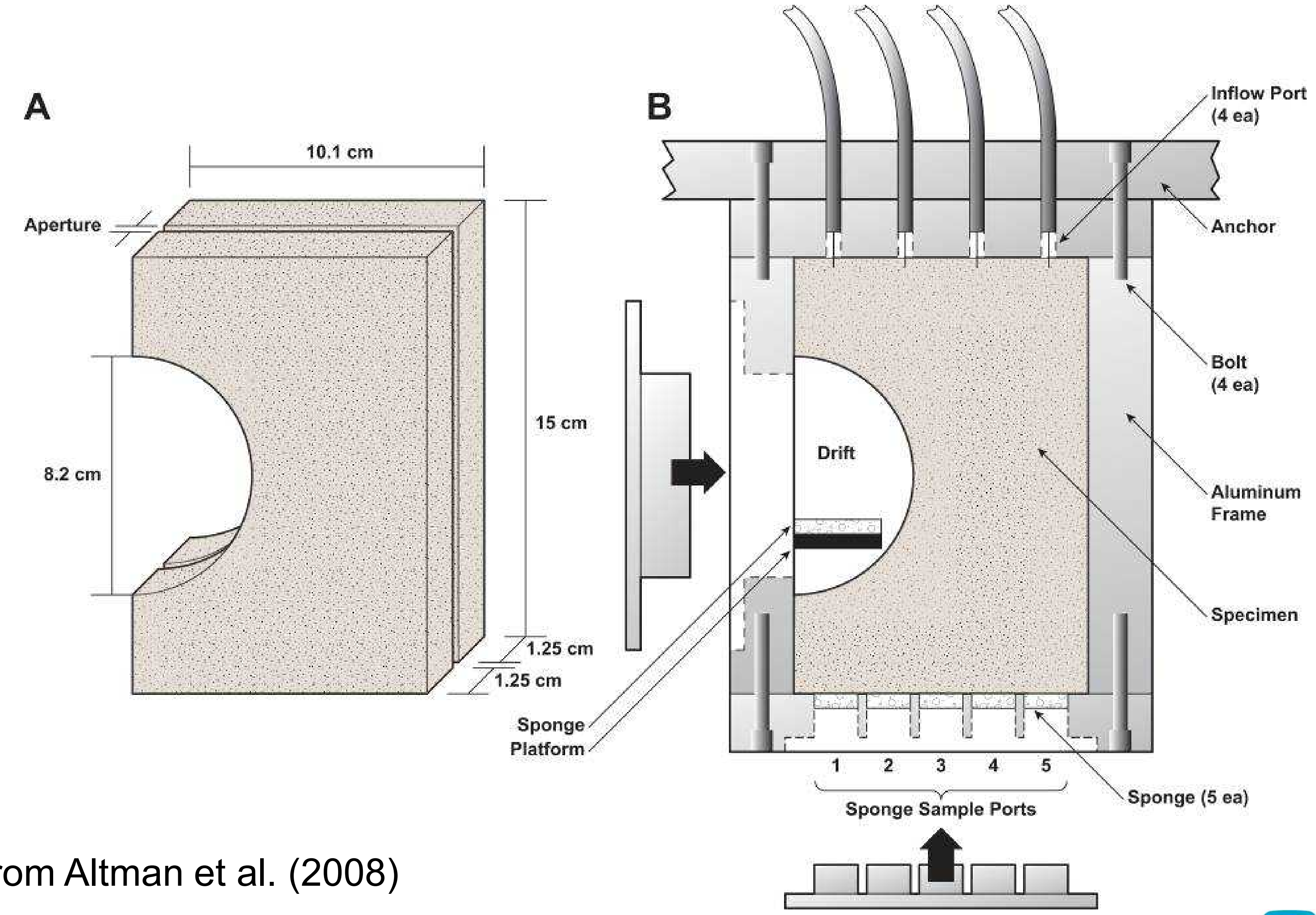
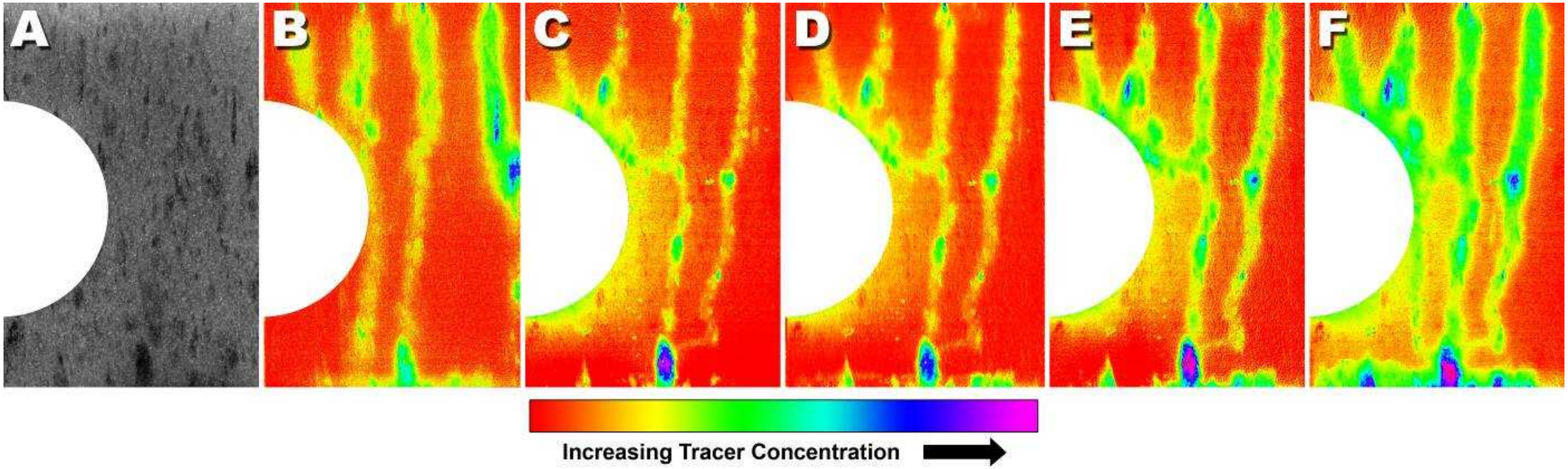
Experimental Design



from Altman et al. (2008)

X-Ray Imaging Results



X-ray absorption images of the 500-micron aperture test cell taken (A) before and (B) 5 h after the start of experiment at 0.01 ml/min and (C) 1, (D) 2, (E) 3, and (F) 5 h after start of experiment with 0.23 ml/min flow rate. Image of cell without tracer (A) shows porous pumice fragments as darker areas. From Altman et al. (2008).

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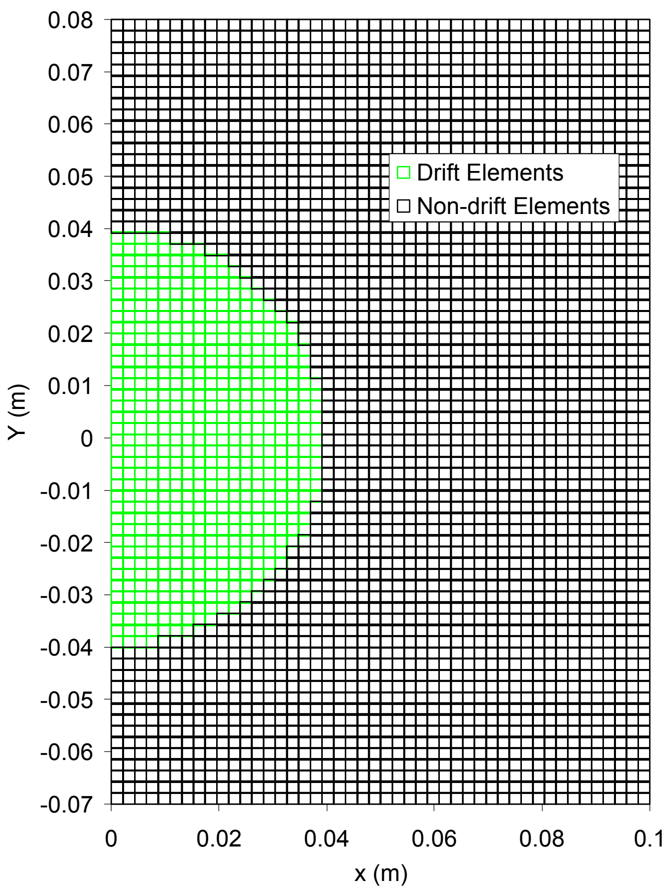
Computational Domain

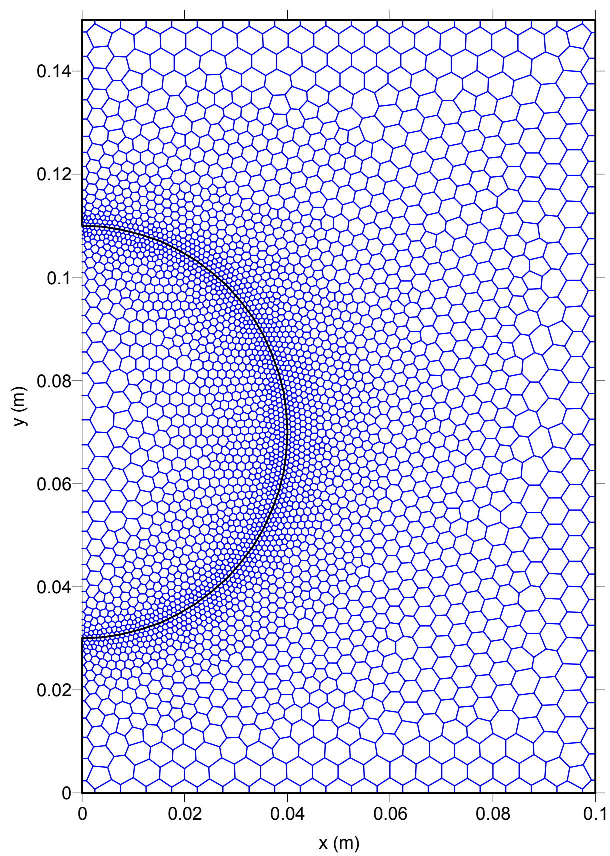
Dual-Permeability Model

Fracture and Matrix Continua Simulated

Structured Orthogonal Mesh



Unstructured Voronoi Mesh



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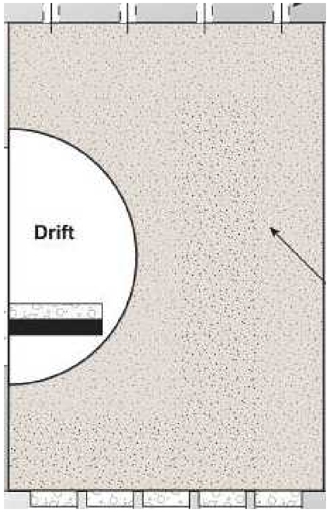
Model Parameters

- **Matrix properties taken from Flint (2003) and Altman et al. (2006)**
  - **Porosity, permeability, van Genuchten α and n**

- **Fracture properties calculated as a function of fracture aperture**

Model Boundary Conditions

- Lateral and top boundaries were no-flow
- Elements located within the drift specified as seepage boundaries (zero capillary pressure)
- Bottom boundary specified as gravity drainage flow (no capillary-pressure gradient)
- Simulated water injection rates and fracture apertures were varied



Aperture (microns)	Low Injection Rate per Port (mL/min)	High Injection Rate per Port (mL/min)
100	0.01	0.12
250	0.01	0.24
500	0.01	0.23

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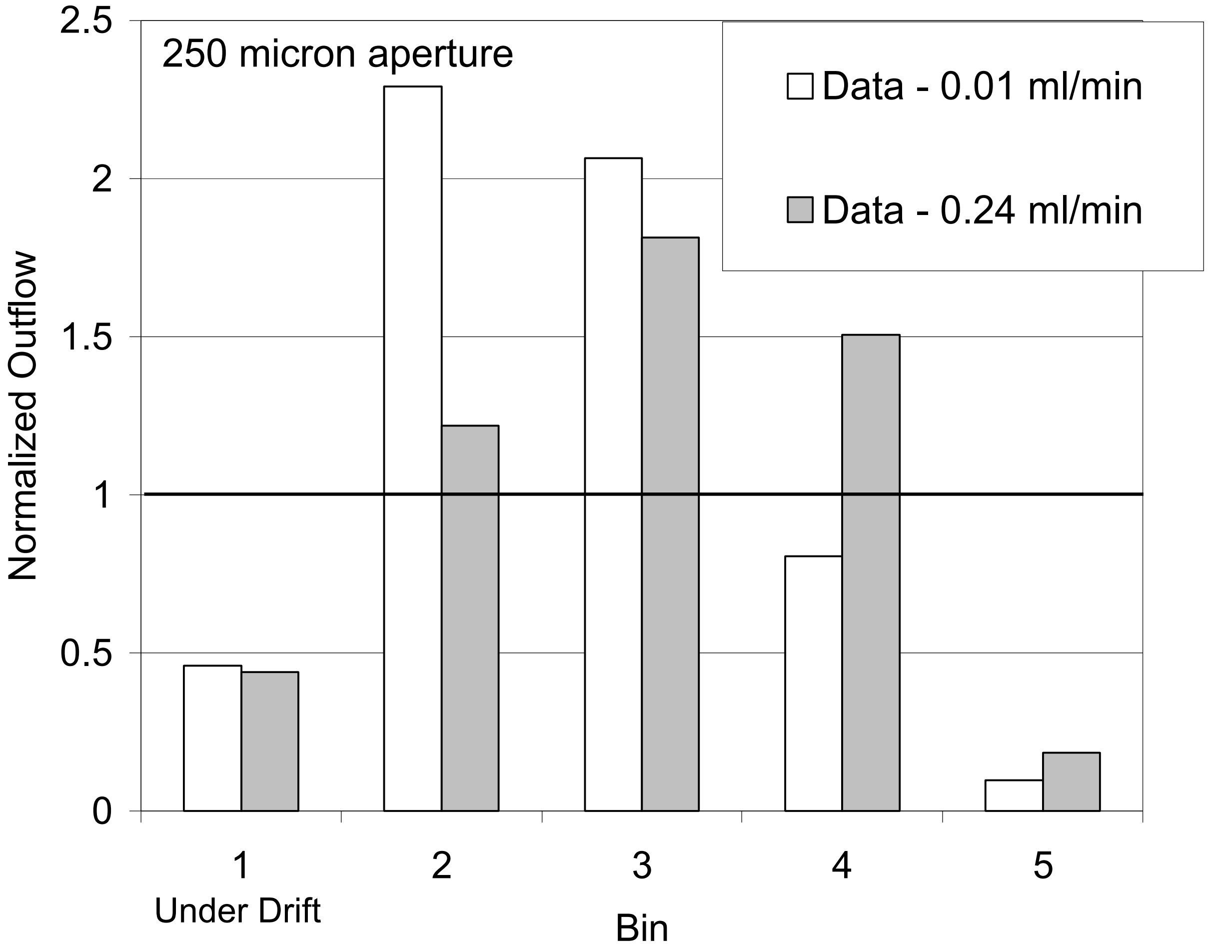
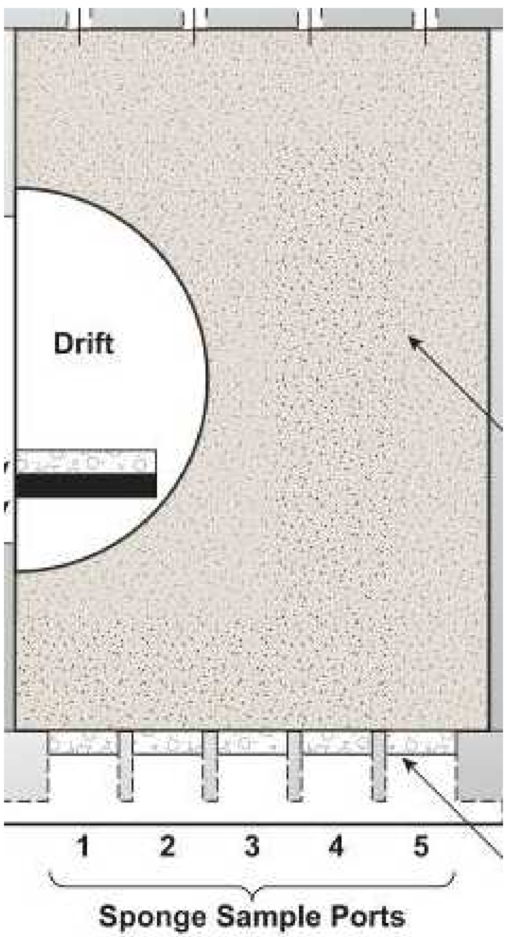
Model Results & Comparisons

Distribution of Normalized Outflow

Less than ~1% of flow observed to enter drift during test





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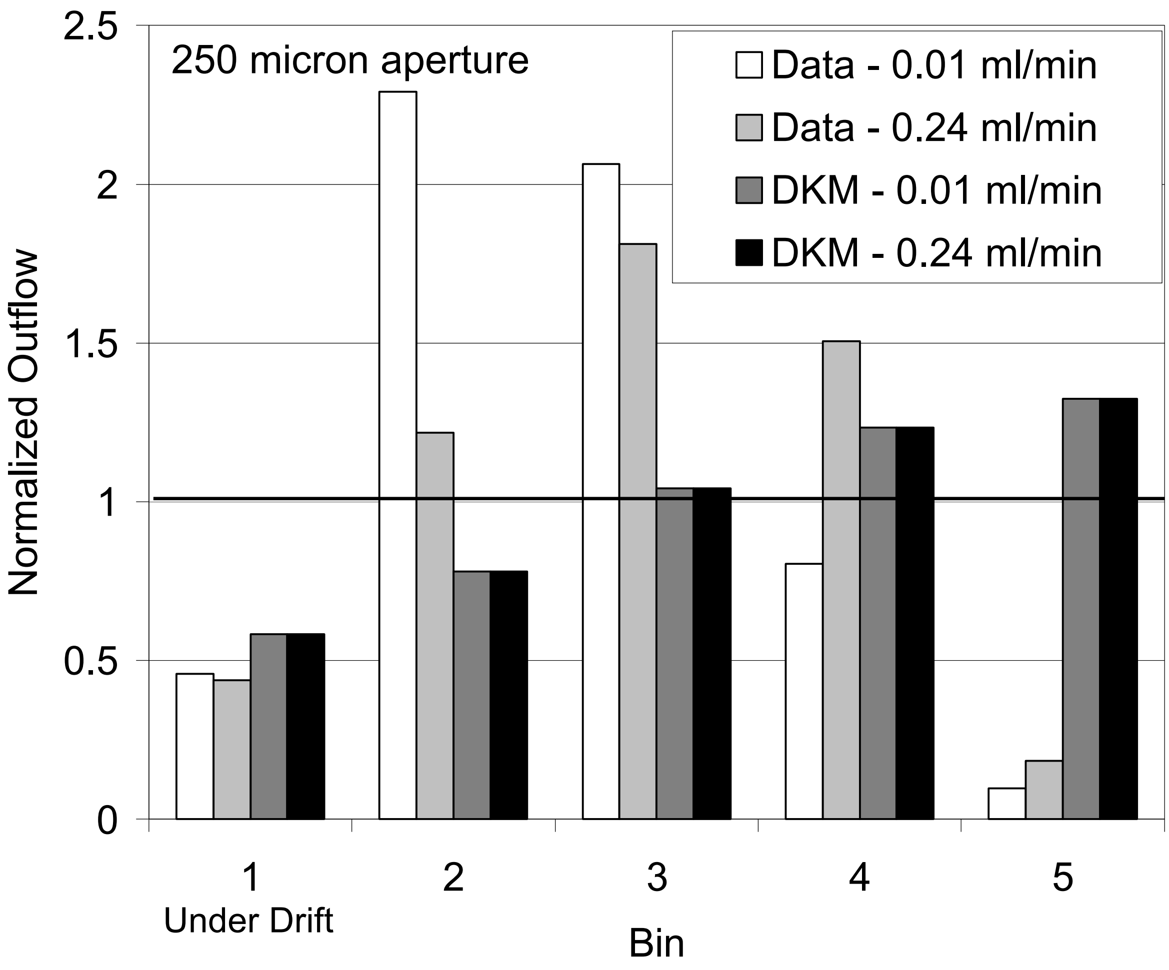
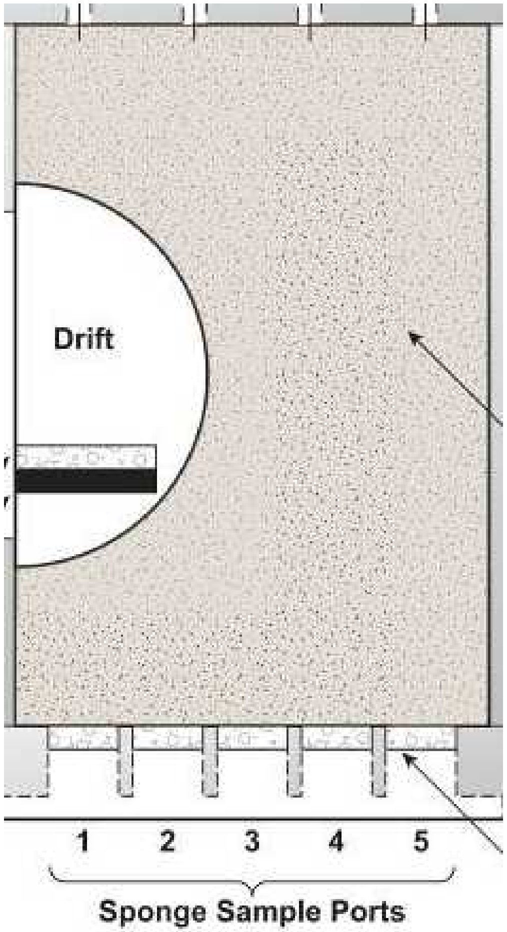
Model Results & Comparisons

Distribution of Normalized Outflow

Less than ~1% of flow observed to enter drift during test





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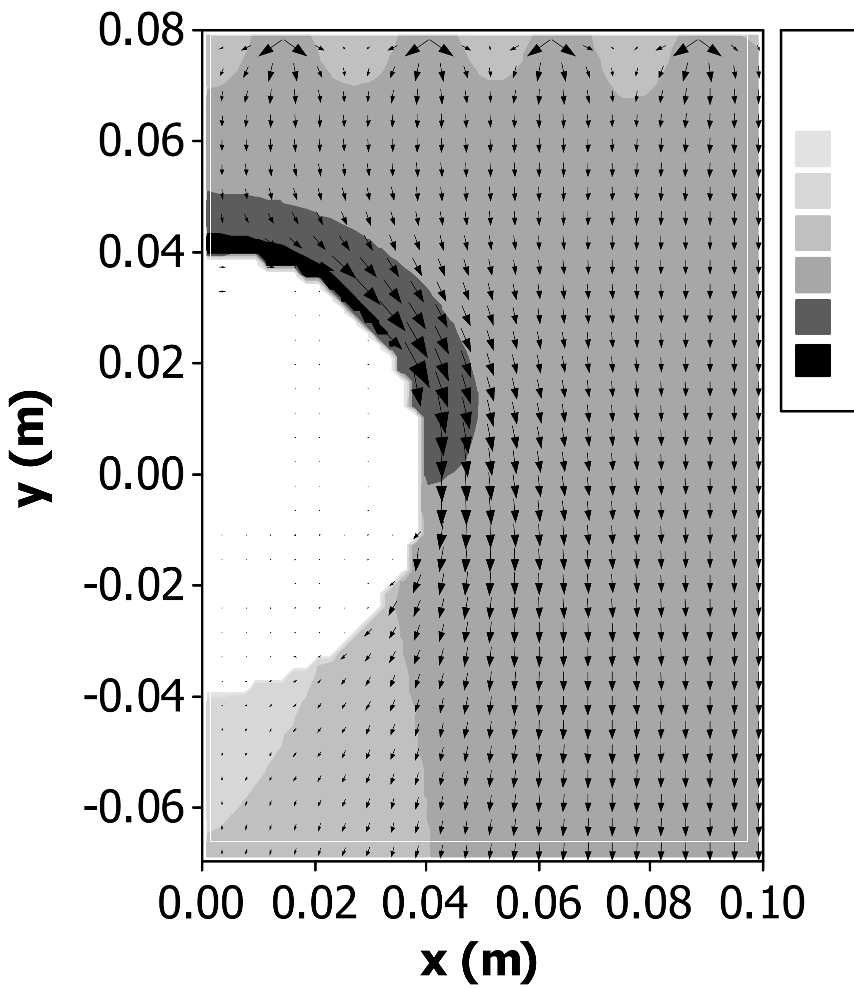
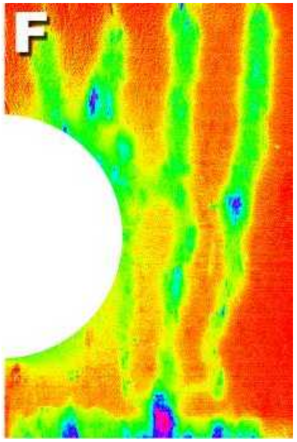
Simulated Fracture Saturation

500 micron aperture, 0.23 ml/min

- **van Genuchten capillary pressure curves with unbounded maximum pressure (1e10 Pa)**
- **Distribution of flow within the fracture is too uniform (no fingers)**





X-ray Image

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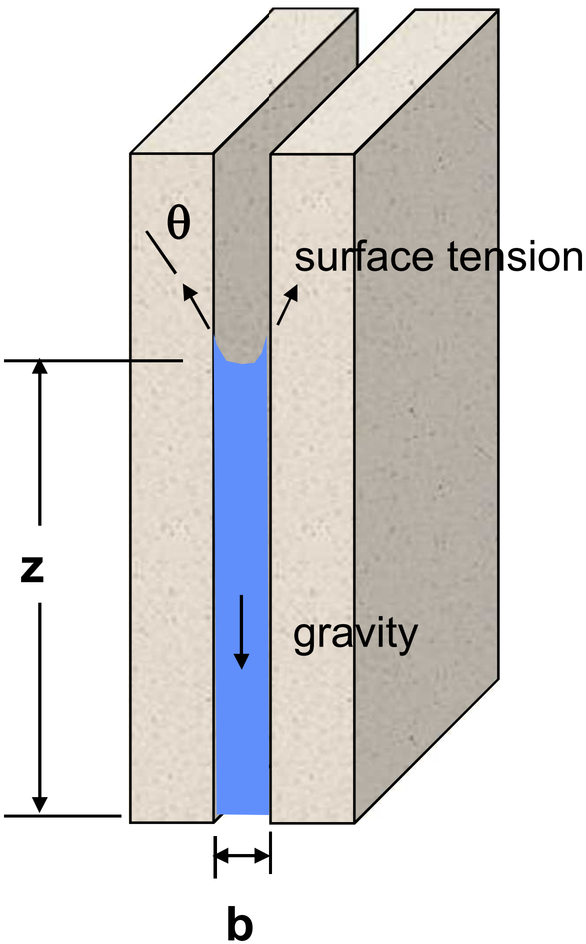
Capillarity in a Smooth Fracture Plane



↑ **Surface tension = ↓ liquid weight**

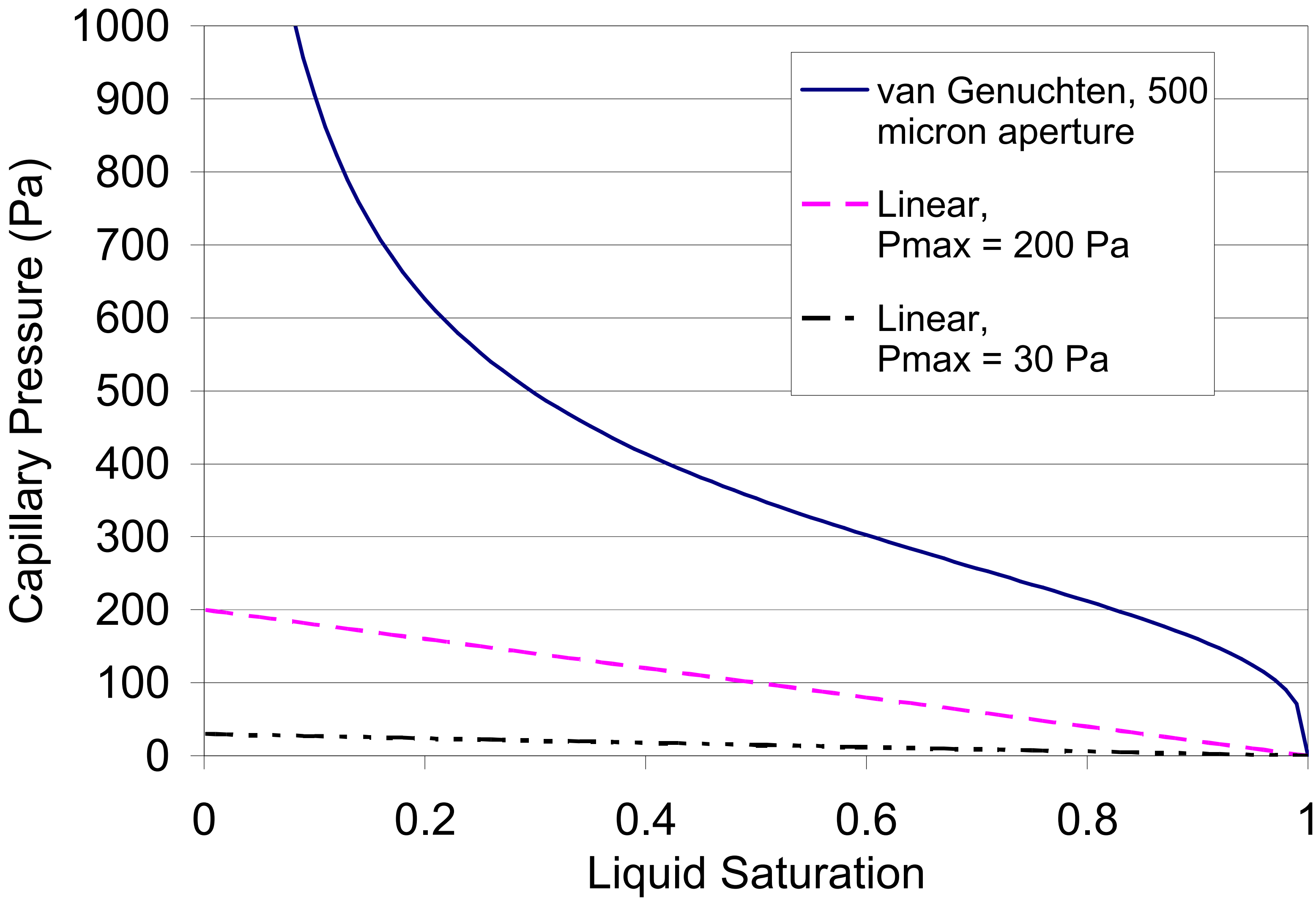
$$z = \frac{2\sigma \cos\theta}{\rho g b}$$

or

$$P_{cap} = \rho g z = \frac{2\sigma \cos\theta}{b}$$

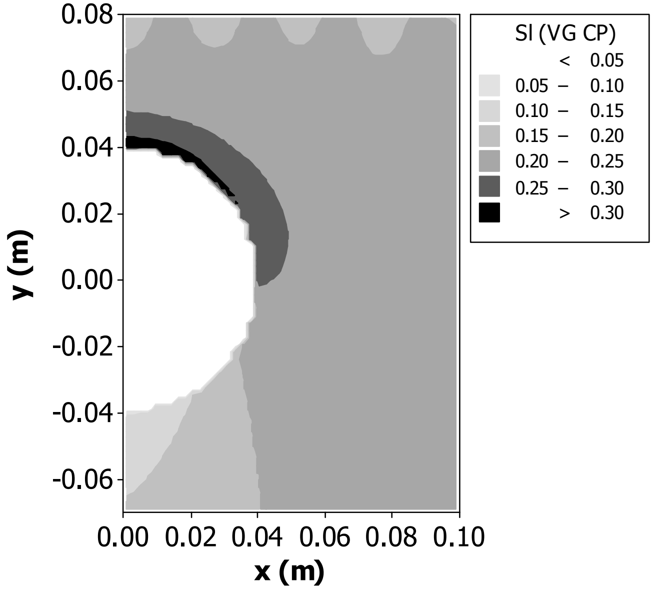
b **(microns)**	***Pcap*** **(Pa)**
100	**1440**
250	**578**
500	**288**

Capillary Pressure Curves

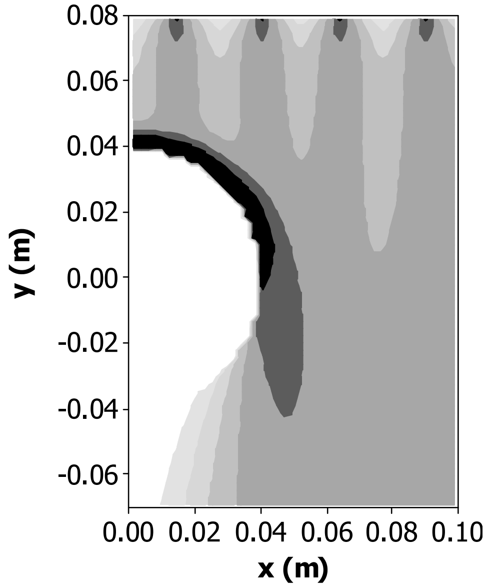


Impact of Fracture Capillary Pressure

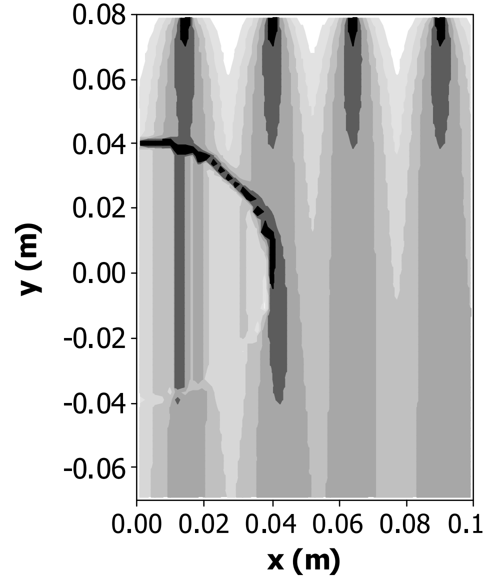
van Genuchten
(Pmax = 1e10 Pa)



Linear
(Pmax = 200 Pa)



Linear
(Pmax = 30 Pa)

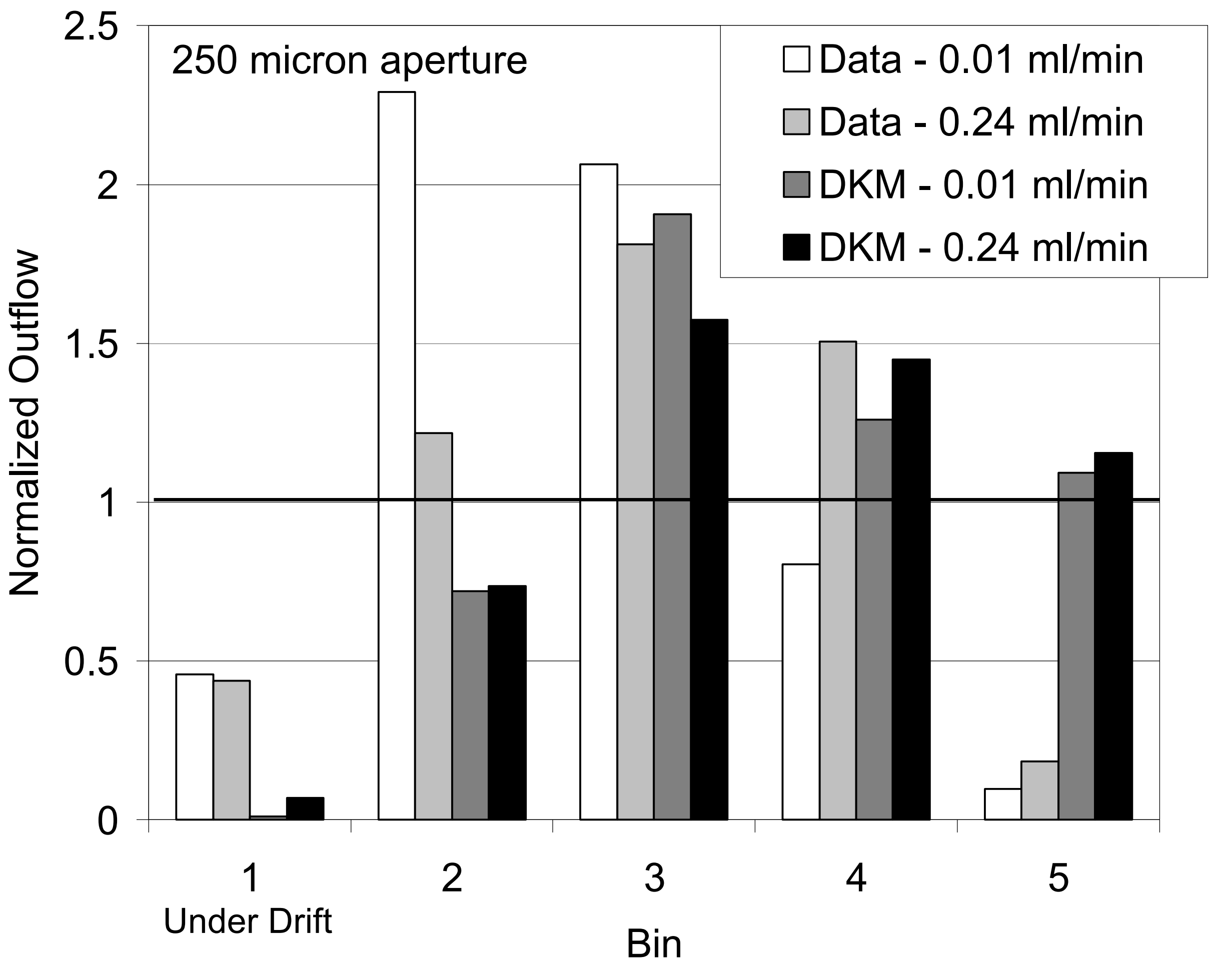


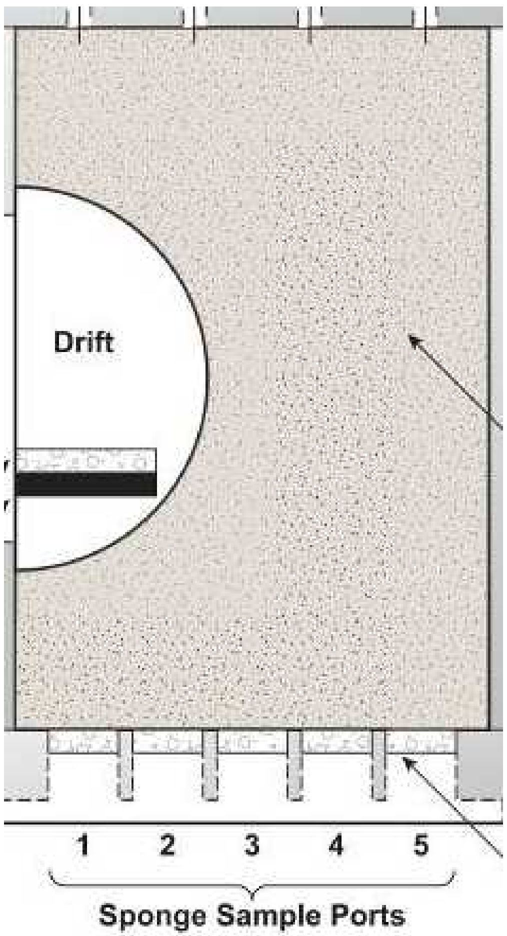
500 micron aperture and 0.23 ml/min flow rate

Model Results & Comparisons

Distribution of Normalized Outflow with Reduced Capillary Pressure (Linear, Pmax = 200 Pa)

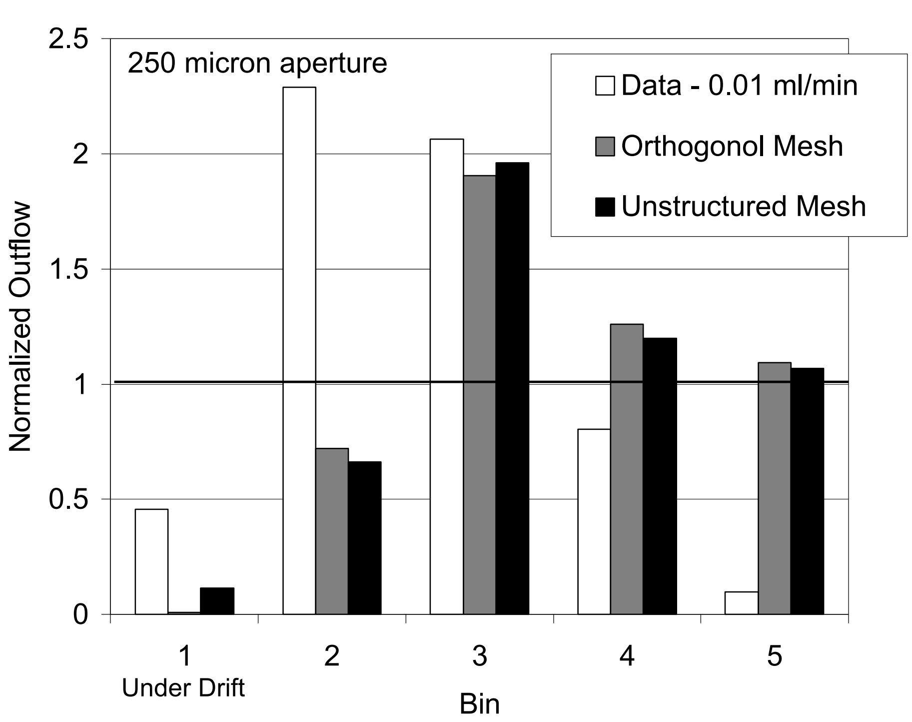
Less than ~1% of flow observed to enter drift during test



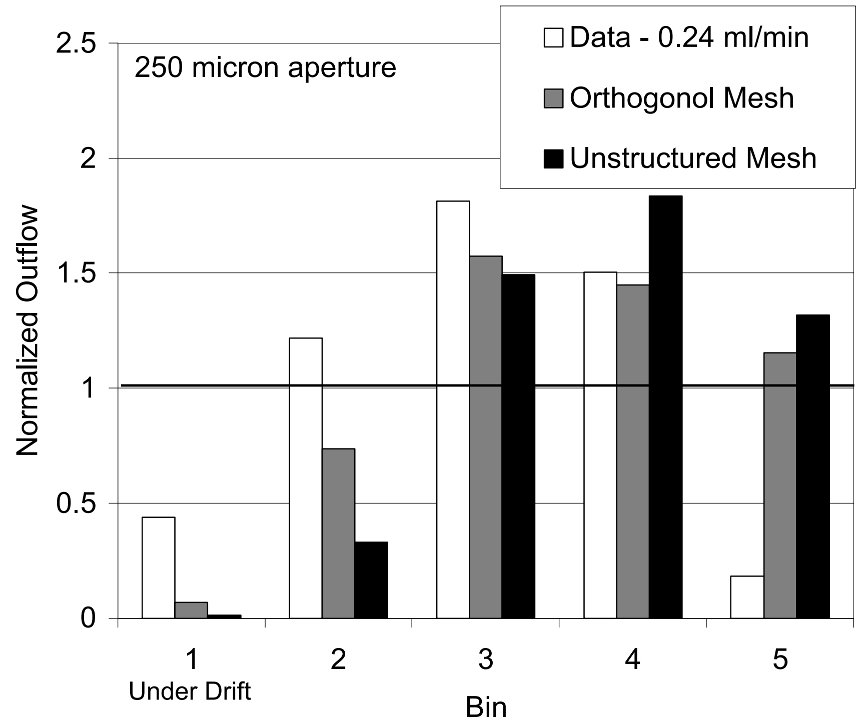


Impact of Mesh

0.01 ml/min



0.24 ml/min



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Conclusions

- Capillary diversion and drift shadow can be modeled by existing dual-permeability models
- Distribution of flux beneath the drift depends on magnitude of fracture capillary pressure
  - van Genuchten curves with unbounded capillary pressures yielded more uniform fluxes
  - Linear curves with reduced maximum capillary pressures yielded better matches to data
- Orthogonal and unstructured meshes yielded similar results

Backup Slides

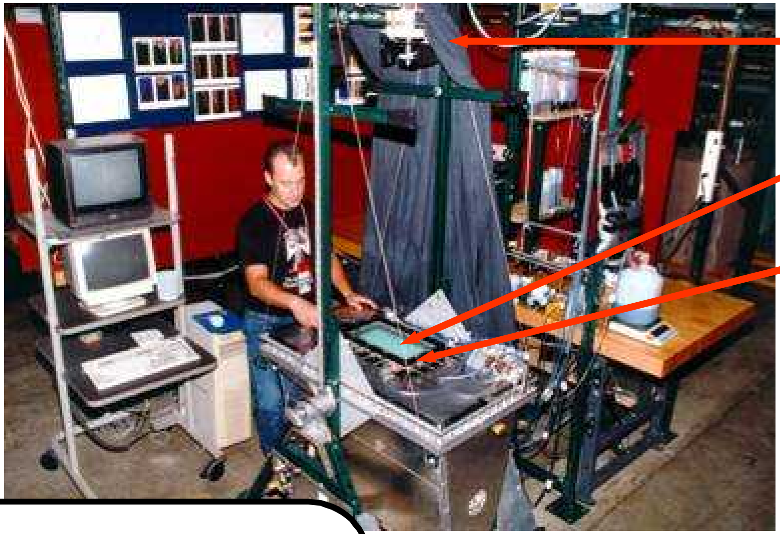
Image Analysis

Digitize X-Ray Film

↓

Grey-Level Adjust Film

↓



From digitized film know light intensity (I) at each pixel

From image of Dry Sample	From image of Saturated Sample	From images of samples taken during the experiment
$I_{d\ i,j}$	$I_{s\ i,j}$	$I(t)_{i,j}$

↓

Calculate Porosity C/Co(t)

Pixel Size = 0.3 mm x 0.3 mm

Tidwell, V. C., and R. J. Glass Jr., WRR, 1994.

Tidwell, et al., *Journal of Contaminant Hydrology*, 2000.

Altman, et al., *Journal of Contaminant Hydrology*, 2004.

X-Ray Imaging Formulation

$$\phi_{i,j} = \frac{\ln(I_s) - \ln(I_d)}{E[\ln(I_s) - \ln(I_d)]}\phi_{bulk}$$

$$\frac{C}{C_o}(t) = \frac{\ln(I(t)) - \ln(I_d)}{\ln(I_s) - \ln(I_d)}$$

$$\frac{M}{M_o}(t) = \frac{\sum_{i=1}^{N}\left(\frac{C}{C_o}(t)\right)_i \phi_i}{\sum_{i=1}^{N}\phi_i}$$

Tidwell, V. C., and R. J. Glass Jr., WRR, 1994.

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