Vadose Zone Primer - Fluid Flow

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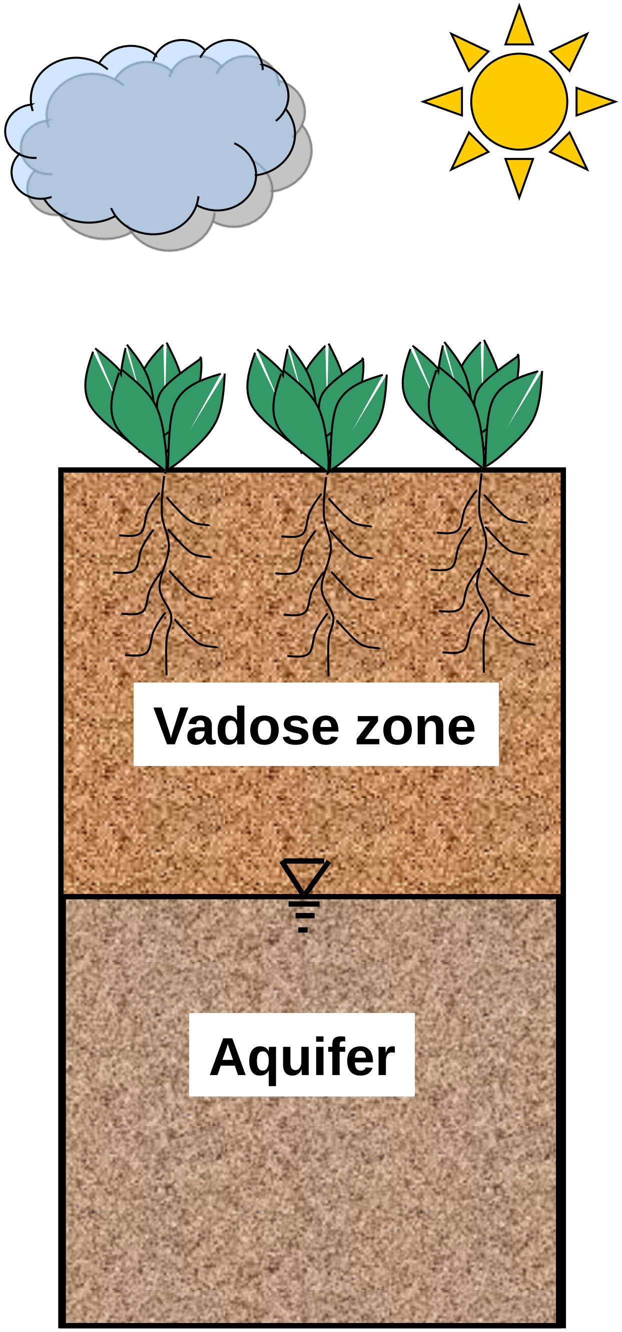
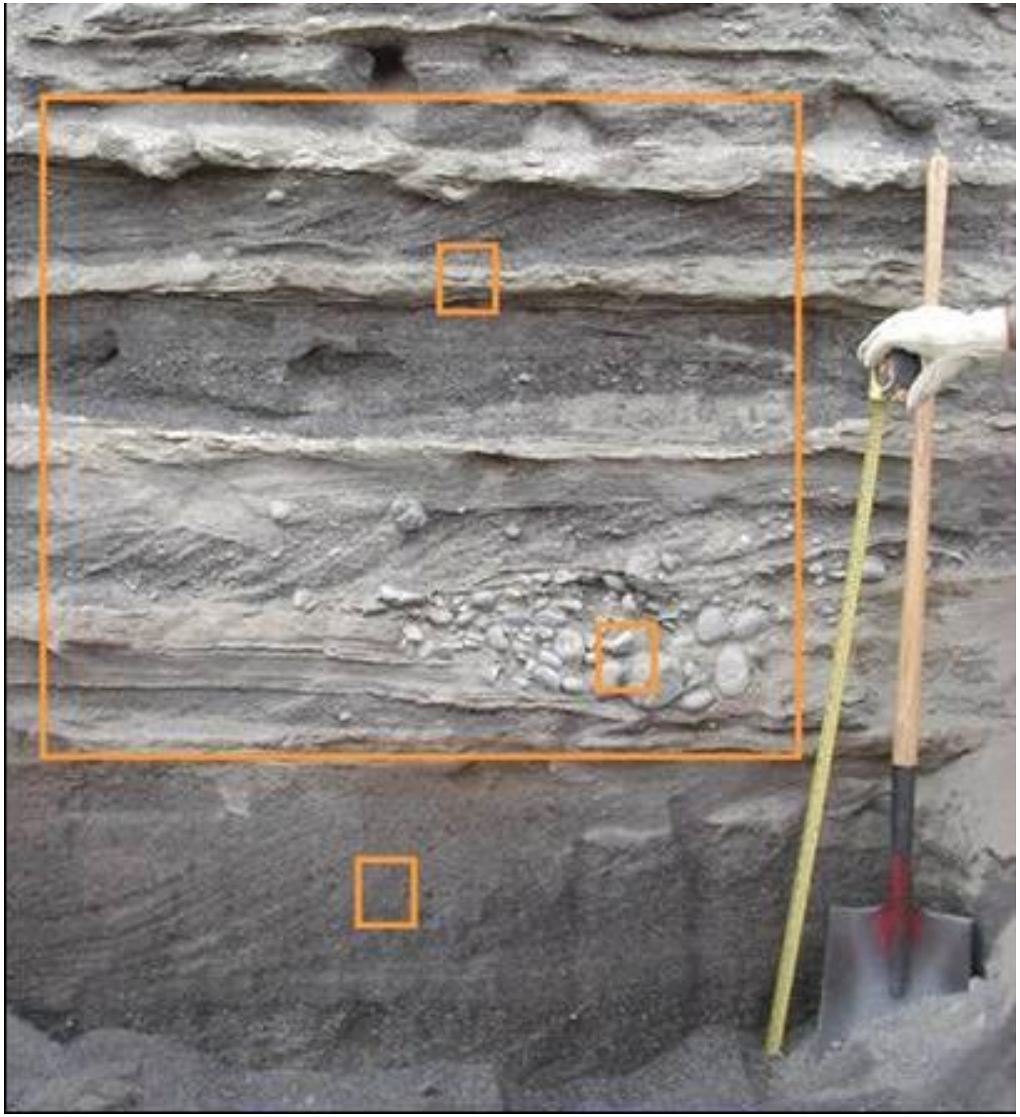
Definitions

- **Vadose zone** ("vadose" derived from Latin for "shallow") – the region between land surface and underlying aquifer (can be up to 100 m or 328 ft thick under Hanford's central plateau)
- **Aquifer** – water-saturated geologic formation underlying the vadose zone that can provide a source of water for irrigation and drinking



What do Hanford vadose zone sediments look like?

- Subsurface sediments at Hanford are very heterogeneous
- Disparities of scale are a fundamental challenge to reliable flow and transport model predictions
  - Scales of heterogeneity
  - Scales of measurement
  - Scales of modeling

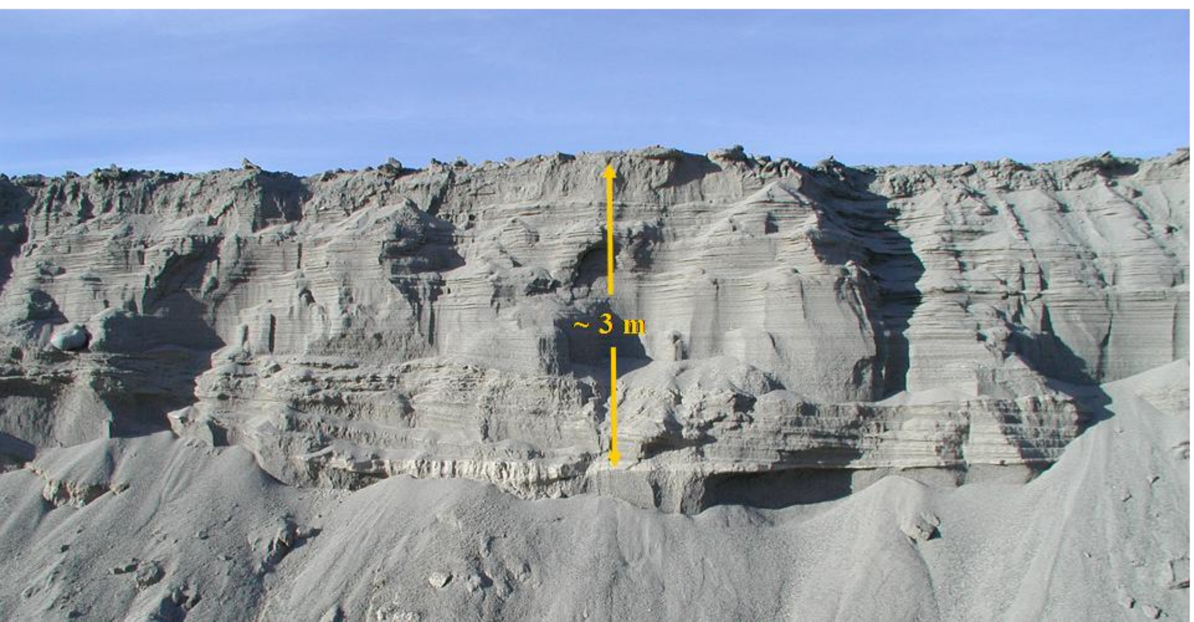


Photograph of Hanford fm sediments in 200 East Area (by John Selker, Oregon State Univ.)

Submarine Reactor Burial Pit

Giant ripples (wavelength ~30 m)

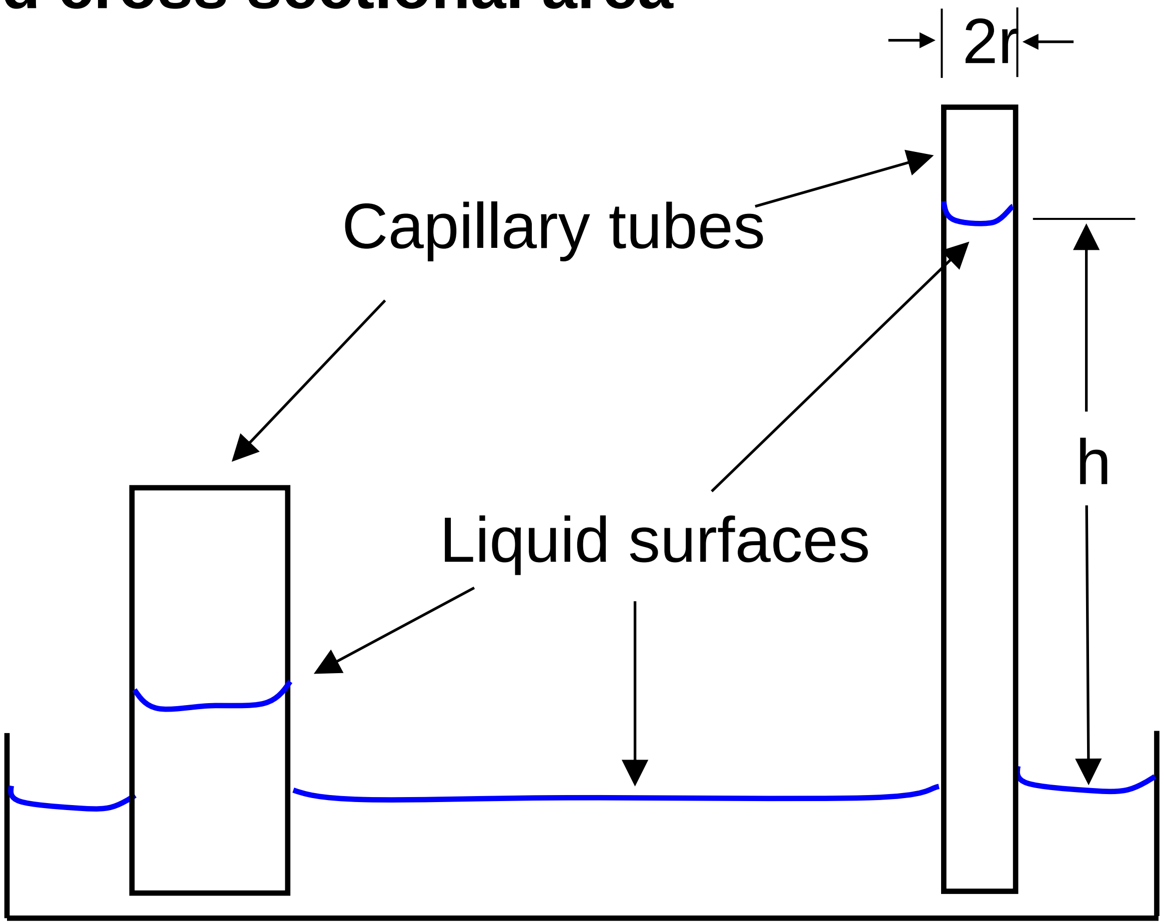
IDF Trench Site



Photograph by Bruce Bjornstad, PNNL

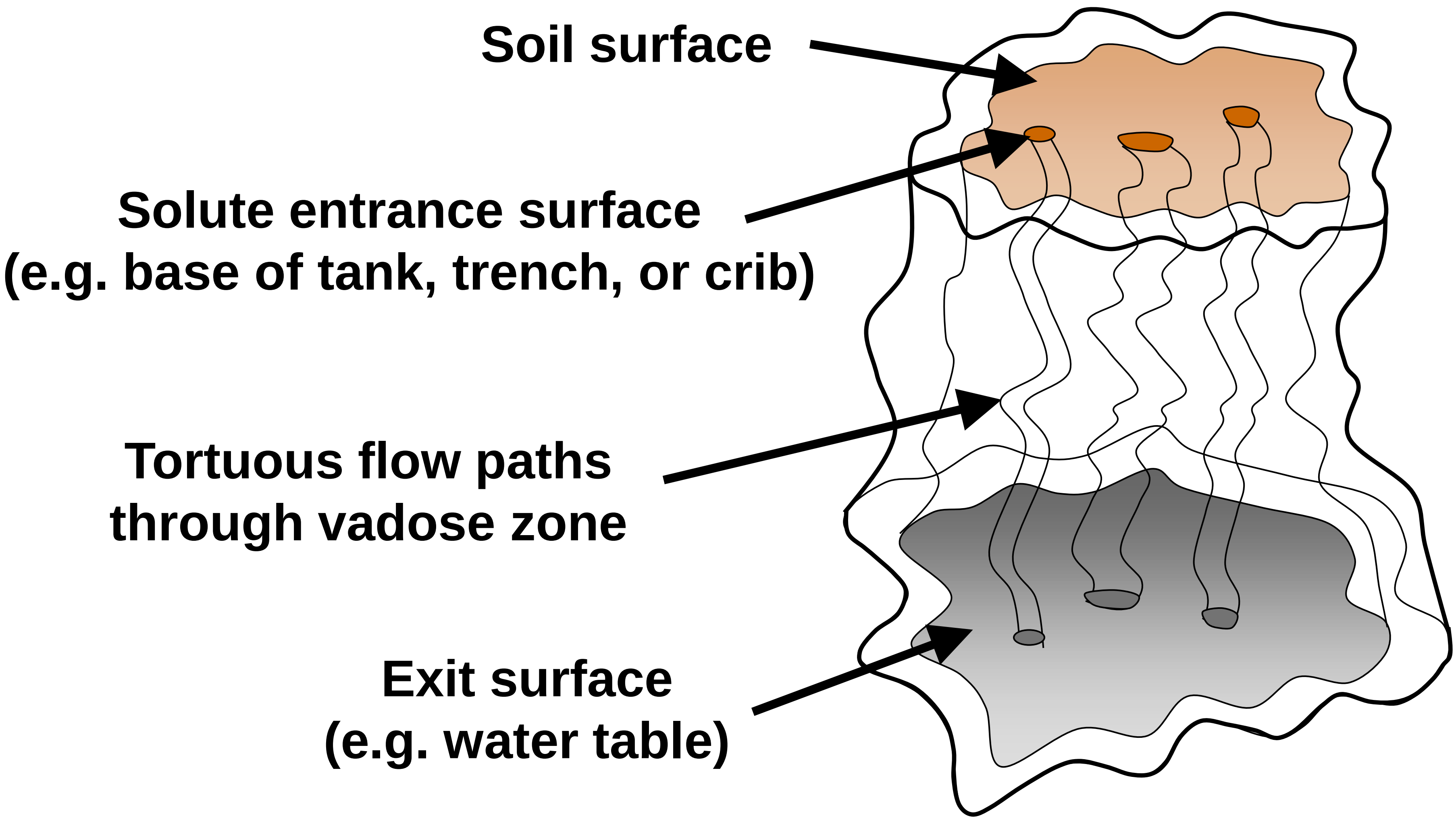
Basics – Capillary rise

- **Height of rise (*h*) of water in a capillary tube is inversely proportional to the tube radius (*r*)**
- **Flow in capillary tube a function of hydraulic gradient, fluid and sediment properties (e.g. grain size and sorting), and cross sectional area**



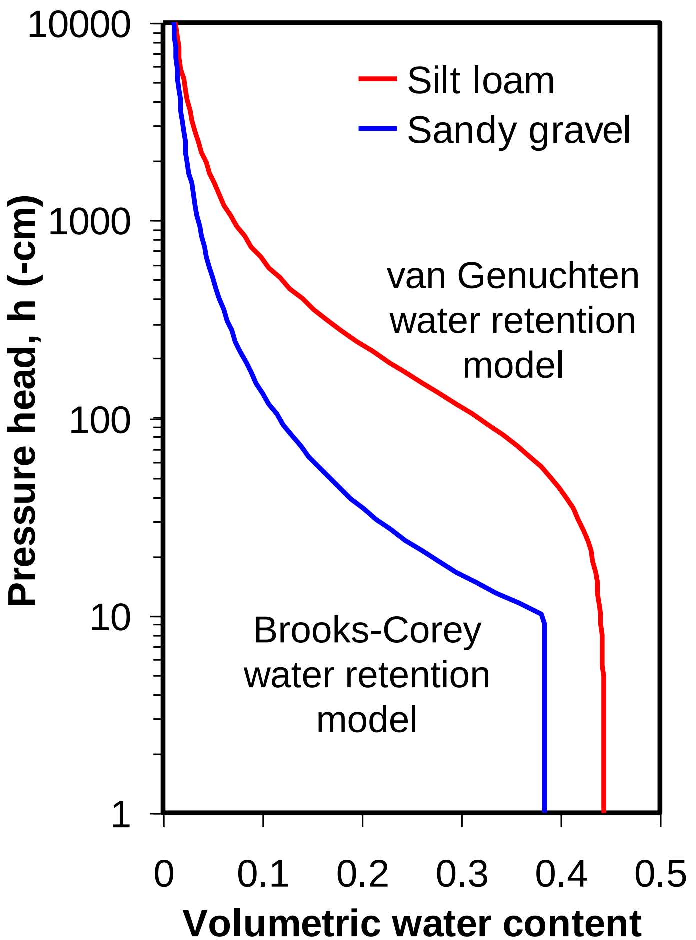
Basics (cont.) – fluid flow

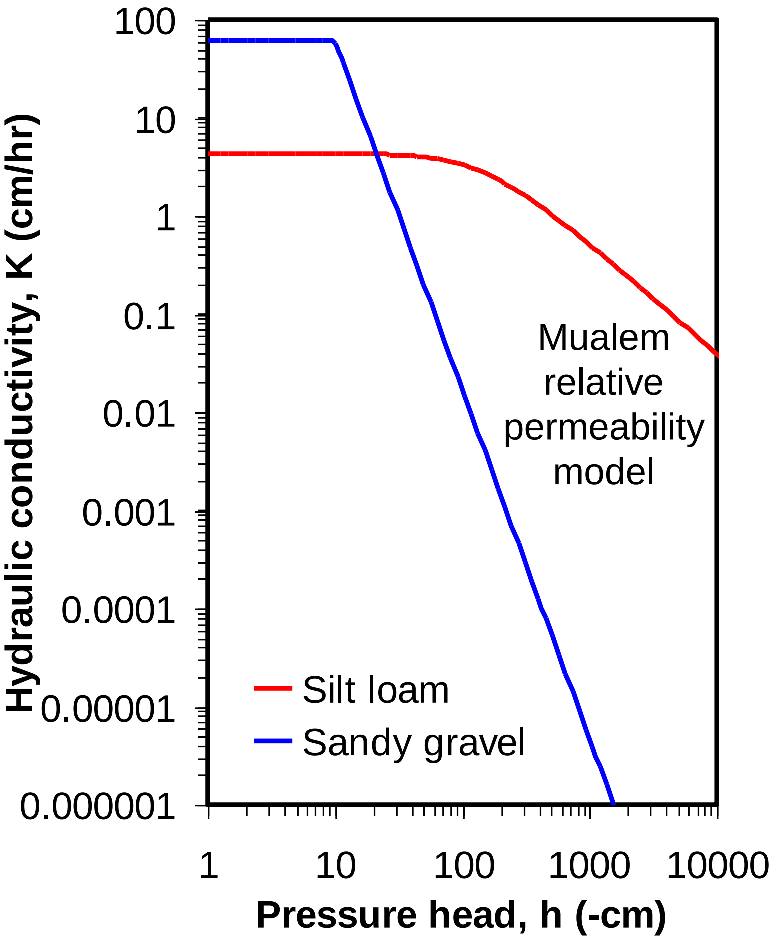
- Bundle of capillary tubes analogy
- Flow varies with size of capillary tube



Basics (cont.) – Fluid flow

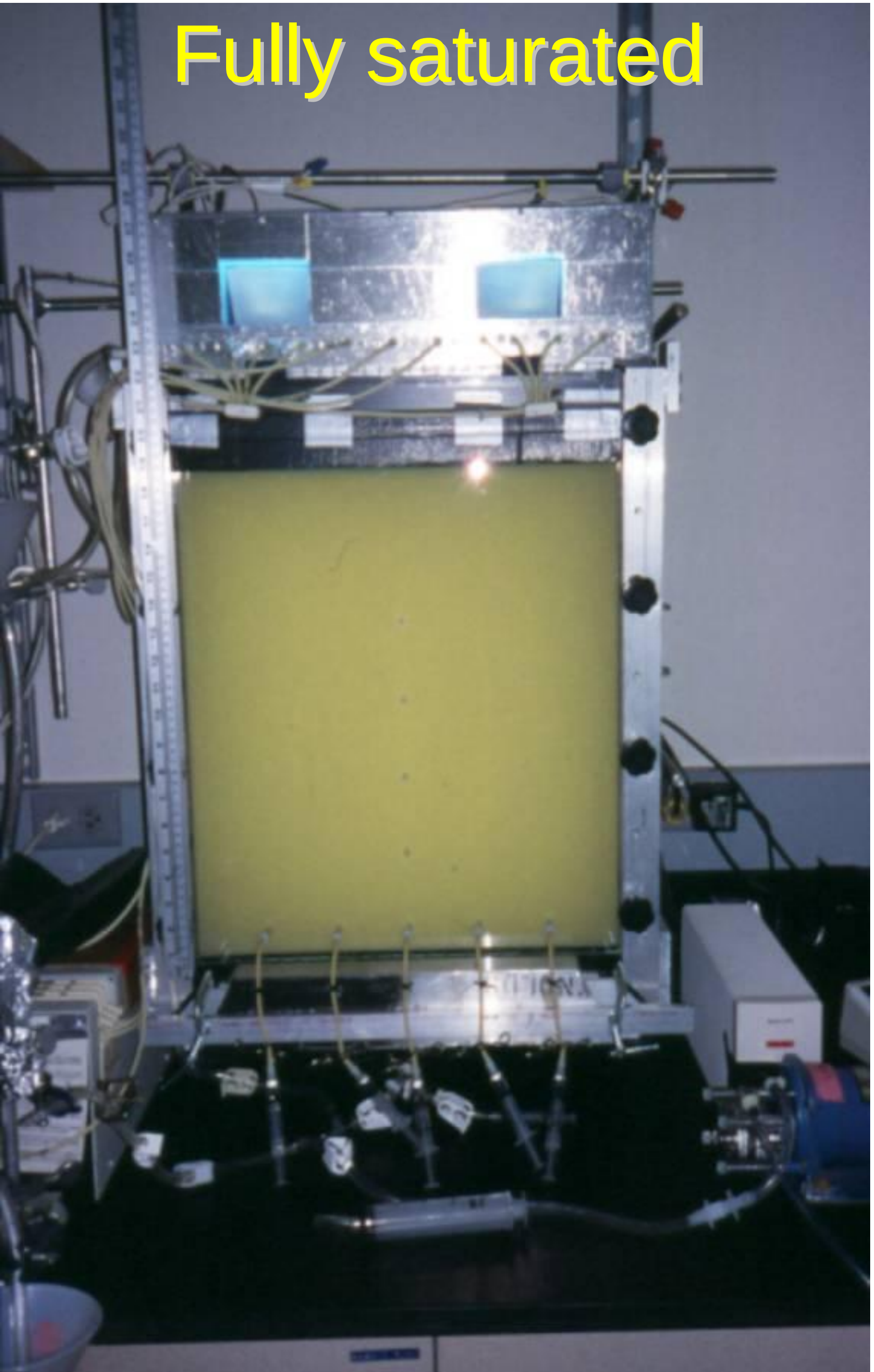
- Finer-textured soils usually have greater water-holding capacity and higher unsaturated K than coarser-textured soils
- Layering of fine/coarse-textured sediments can cause enhanced lateral flow
- Differences in liquid saturation create variable aqueous and gaseous diffusion and redox regimes

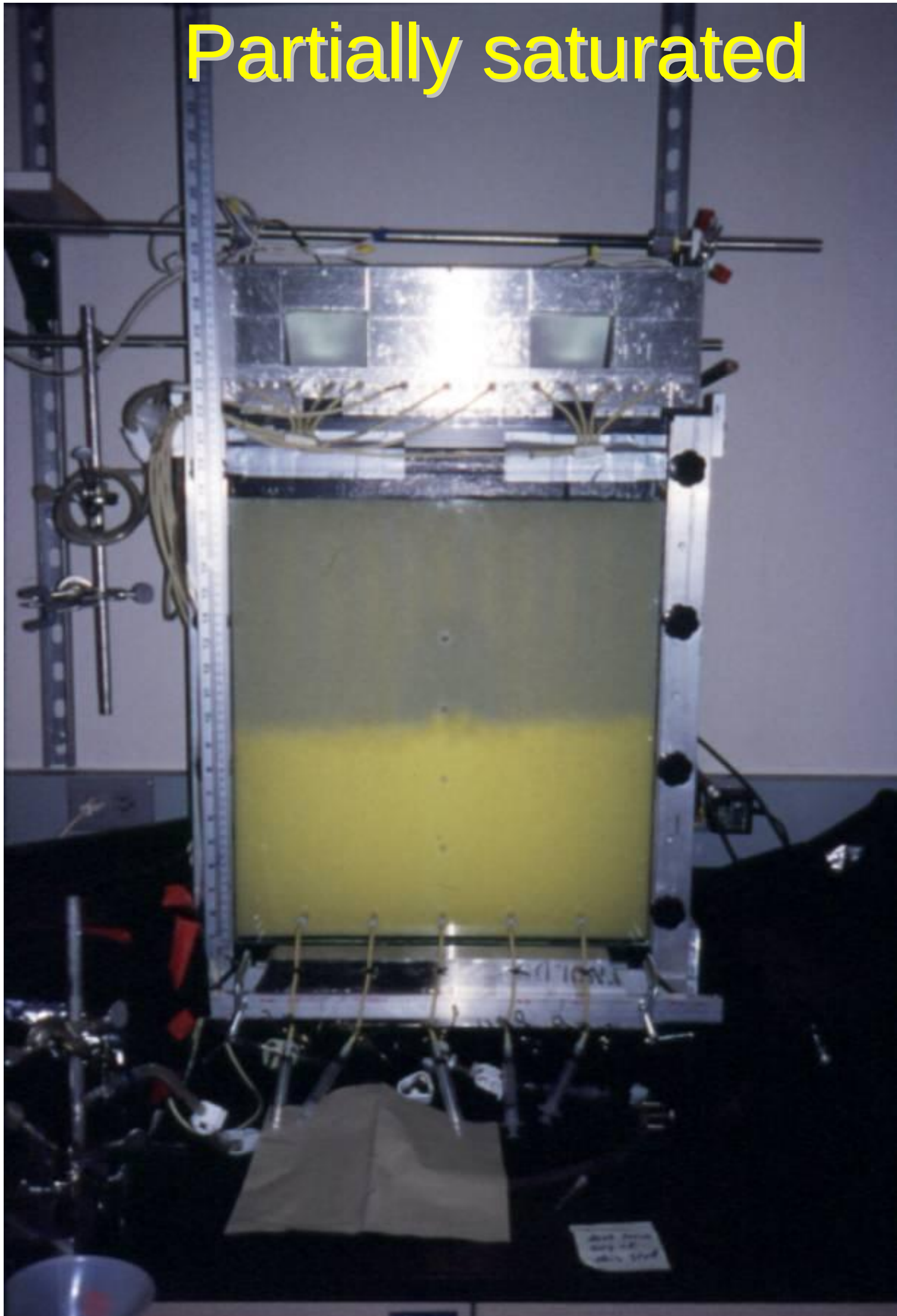




Influence of heterogeneities on vadose zone flow and transport behavior

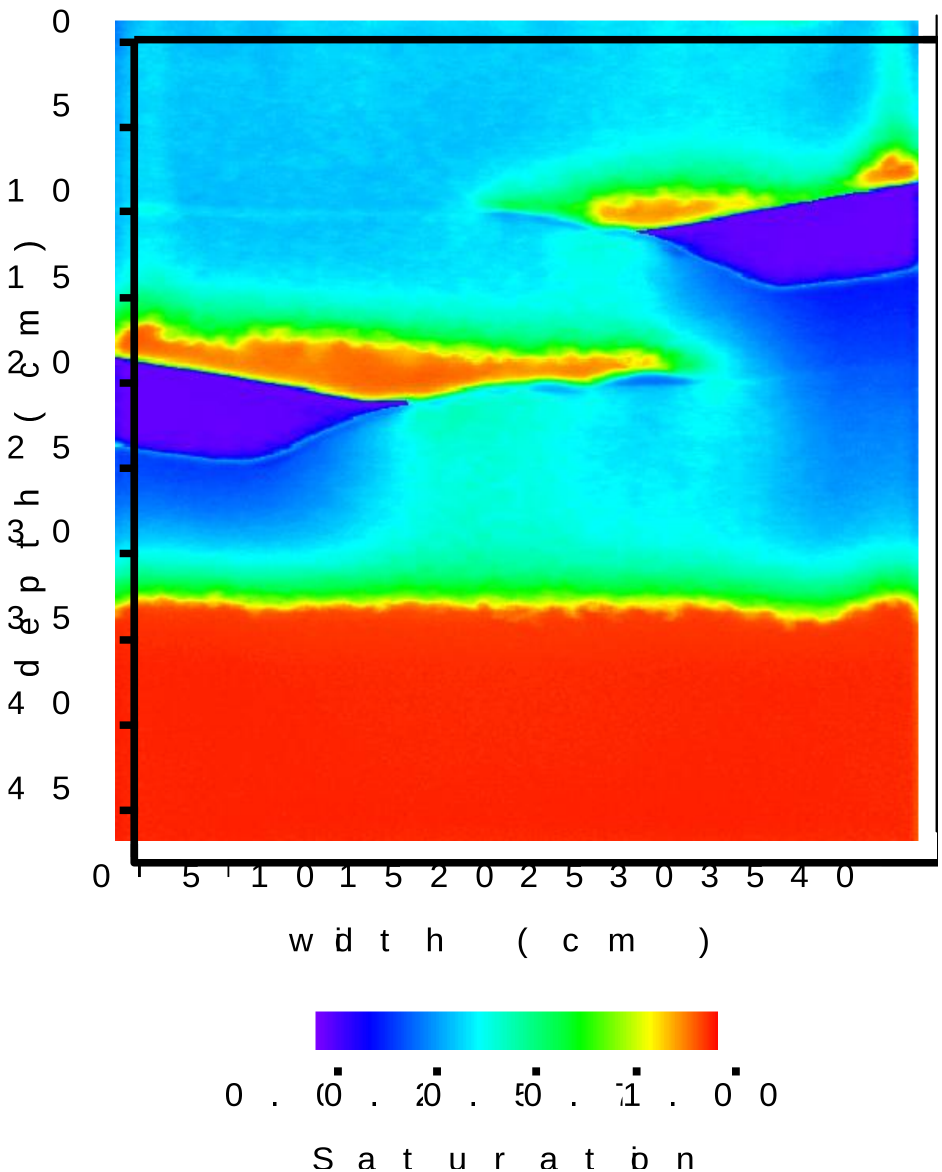
- Intermediate-scale laboratory experiment performed at Oregon State University, Corvallis, OR
- Field experiment performed in Hanford 200E Area
  - Sisson & Lu site – one of a few sites at Hanford where controlled field-scale experiments have been performed in vadose zone sediments


Fully saturated

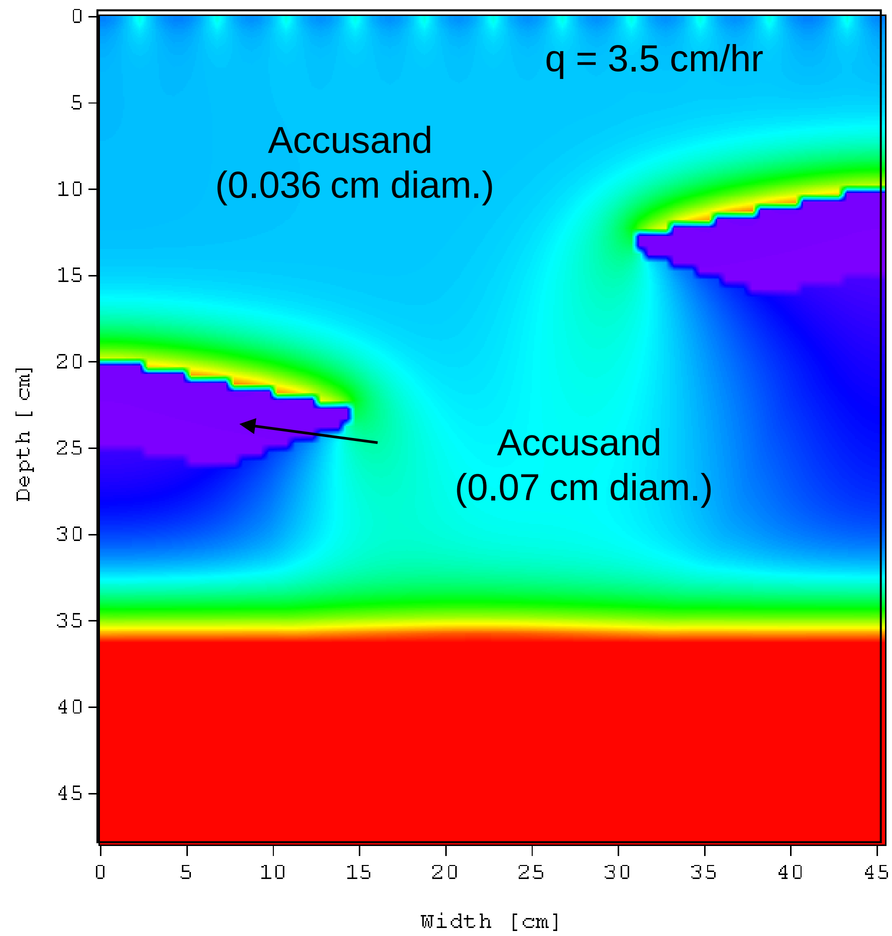

Partially saturated

Saturation distributions after 10 hr of infiltration into sand-packed chamber containing heterogeneities

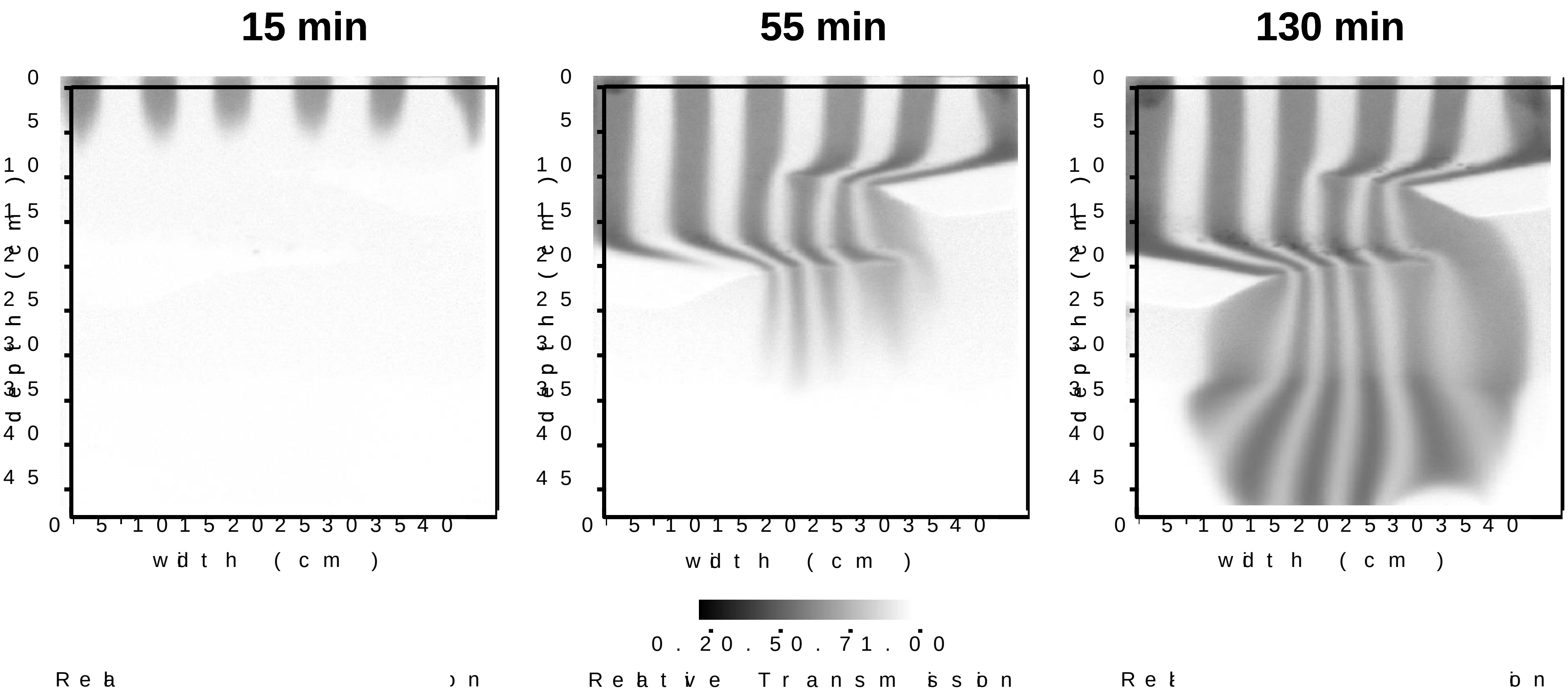
Observed



Simulated



Observed tracer plumes



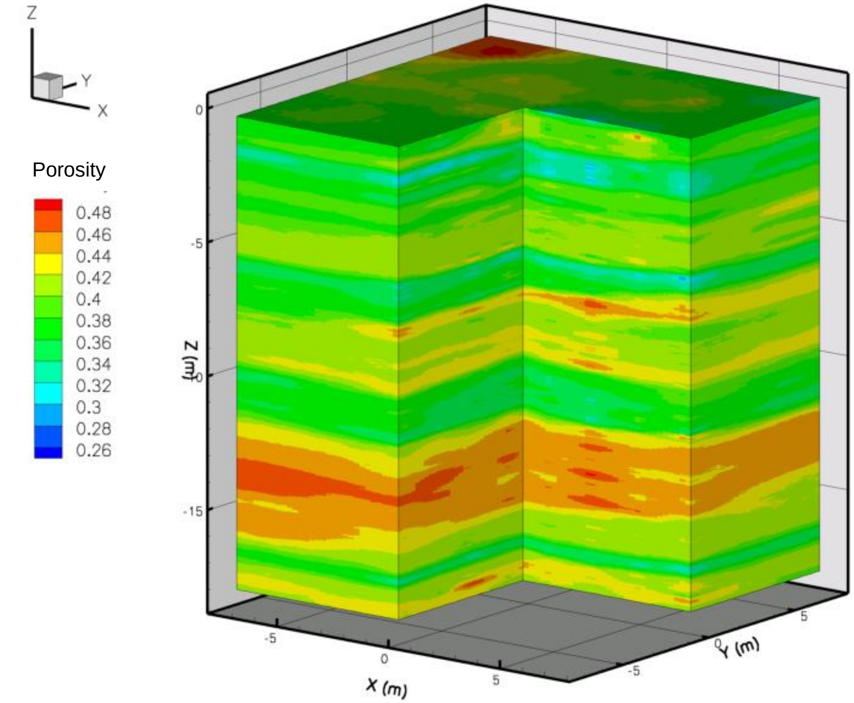
Field experiment in Hanford 200E Area – Sisson & Lu Site

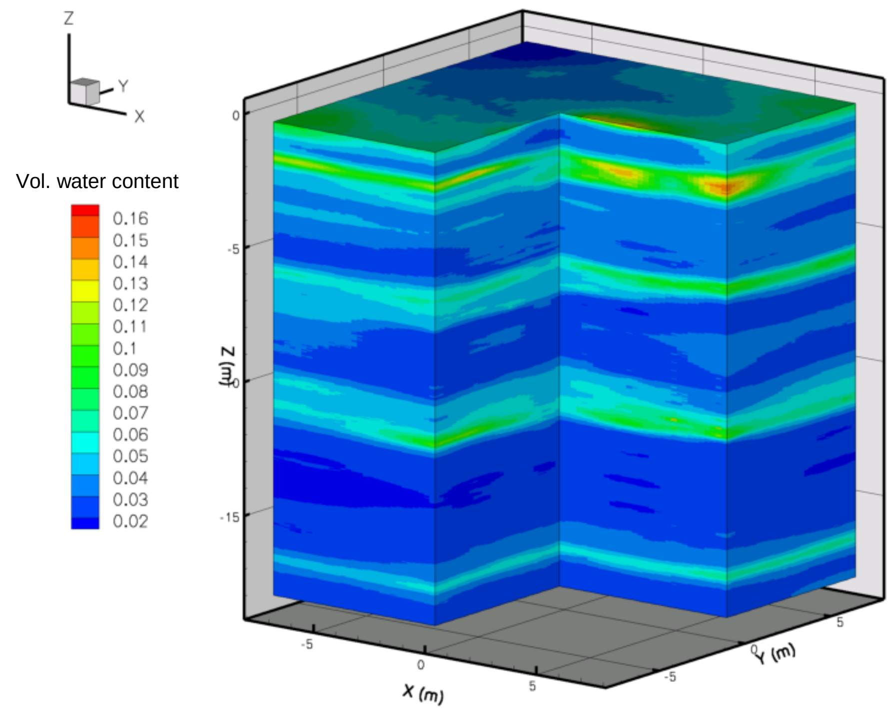
- Injection experiment conducted in inter-bedded sands and silts in 200 East Area of Hanford Site in June-July 2000
- 5 weekly subsurface injections of 4000 L of water, each applied over a period of 4–7 hr, at 4.6 m depth
- Bromide and other tracers added in third injection

Sisson & Lu Site

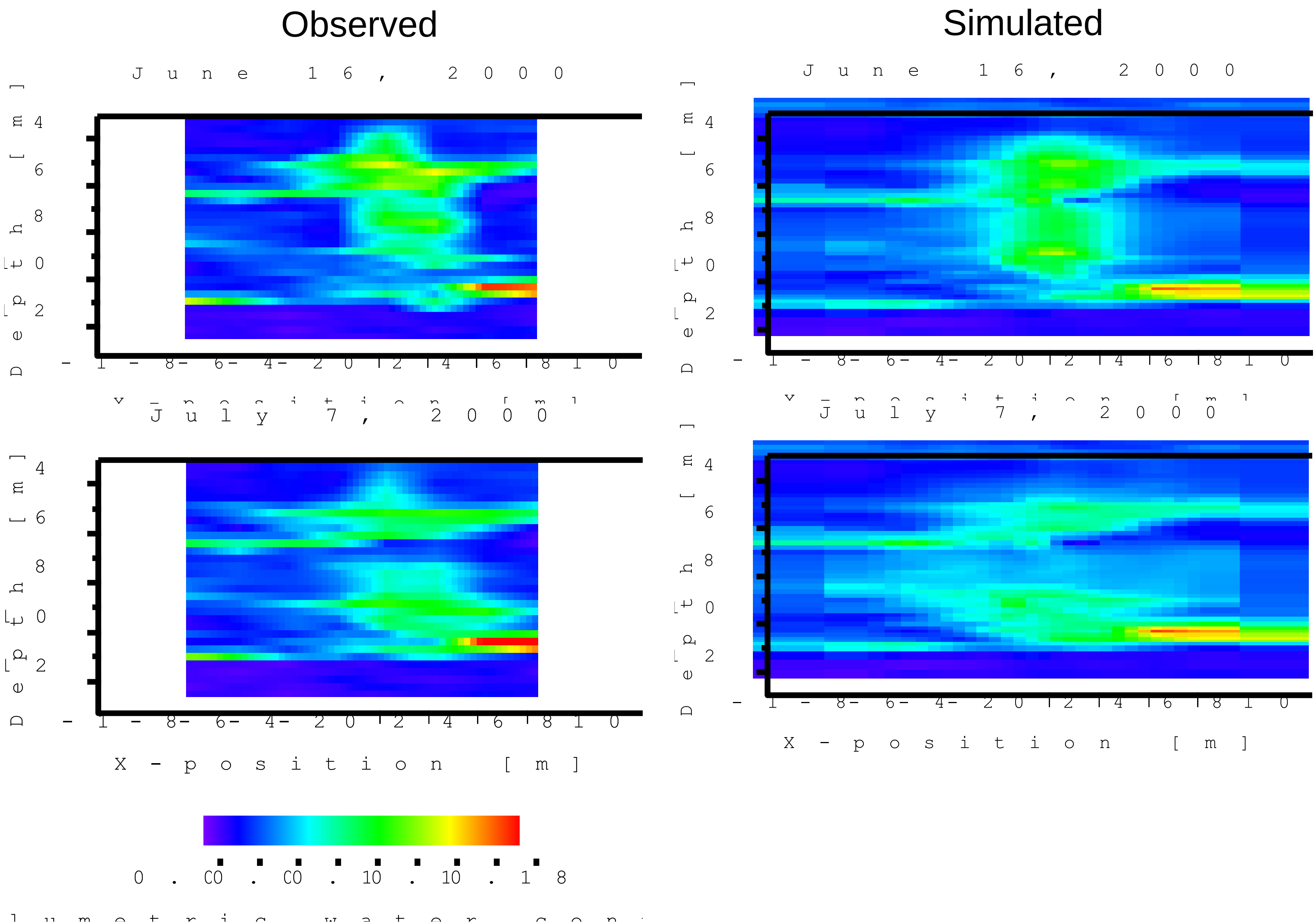
Characterization data

- Neutron probe measurements of initial water content in 32 access wells at 30 cm vertical spacing
- Litho-density sonde measurements of density (used to calculate porosity) in 32 access wells at 2.5 cm vertical spacing
- Approximately 60 cores collected from 3 boreholes using split-spoon sampler with Lexan™ liners
- 53 core samples analyzed for bulk density, particle-size distribution, and permeability-saturation-capillary pressure (*k*-*S*-*P*) relations





Observed and simulated results



Summary

- With sufficient site characterization and calibration data, we can obtain very good correspondence between observed and simulated vadose zone flow and transport behavior
- Modeling results for the deep vadose zone beneath the 200 Areas plateau have many uncertainties
  - Material properties and processes
    - heterogeneous sediments
    - large spatial domain
    - sparse data (characterization and monitoring)
    - unknown reactions of caustic waste solutions with sediments
  - Initial and boundary conditions
    - inventories
    - recharge rates
  - Sources and sinks
    - leaks (tanks and water lines)
- Uncertainty quantification / reduction may require more characterization and monitoring data, focused experiments, and innovative parameterization and (stochastic) modeling approaches