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Cryptosporidium Transport in Unsaturated Flow

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USEPA/USGS Meeting – Cryptosporidium Removal by Bank Filtration
September 10, 2003 – Reston, Virginia

Cornell University
Dept. of Biological and
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EE&T
ENVIRONMENTAL ENGINEERING & TECHNOLOGY, INC.

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Structure of Seminar

- Preferential Flow and Vadose Zone
- Preferential transport of solute/biocolloid *Cryptosporidium parvum* oocysts through vadose zone
- Take-home Messages

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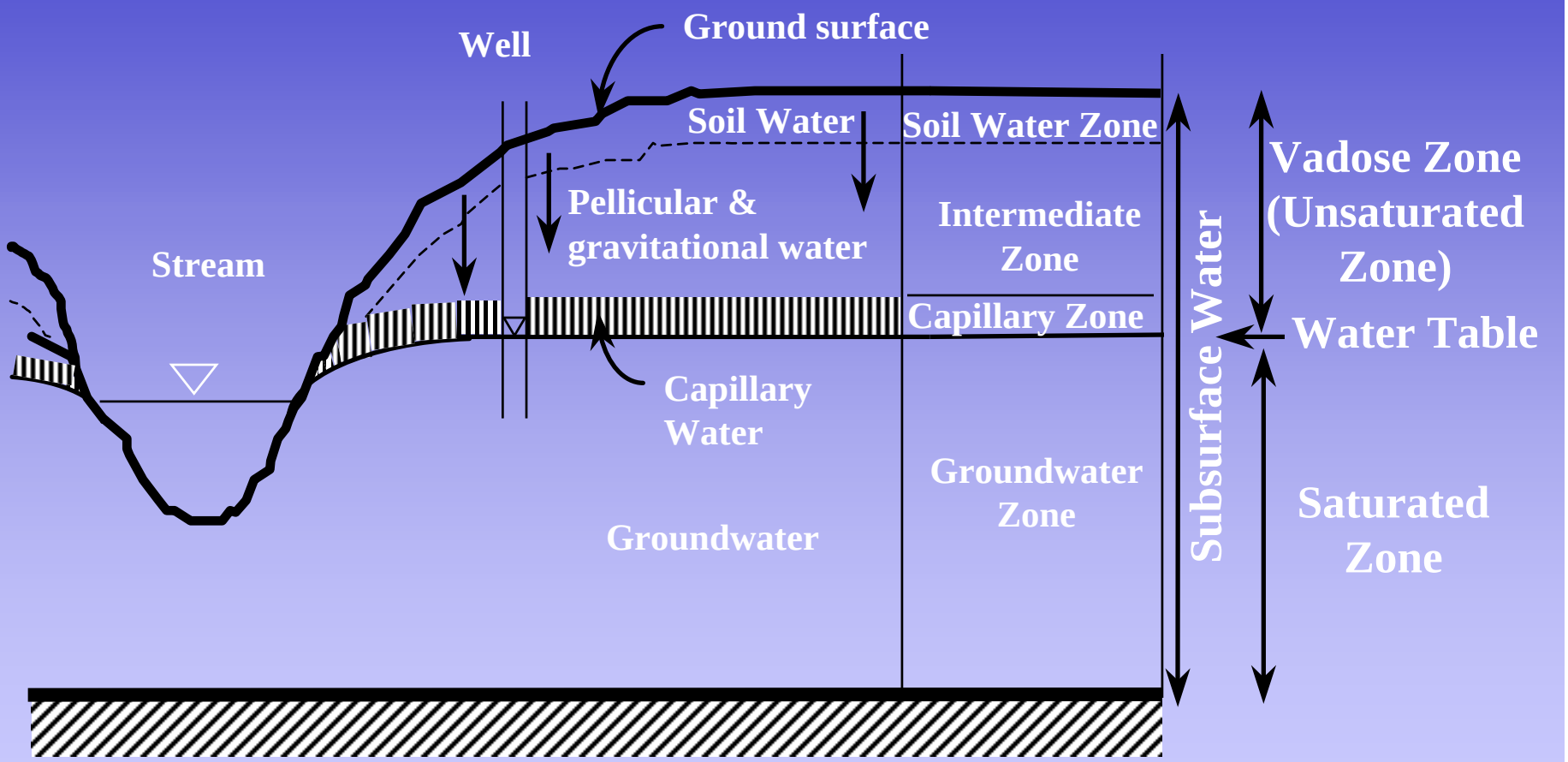
Vadose Zone



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Preferential Flow

- Process
  - By-pass transport phenomena
  - Concentration of flow into channels at soil surface or subsurface
- Types
  - Macropore flow
  - Fingered flow
  - Funneled flow
- Impacts on water resources
  - Non-point sources pollution
  - Water quality

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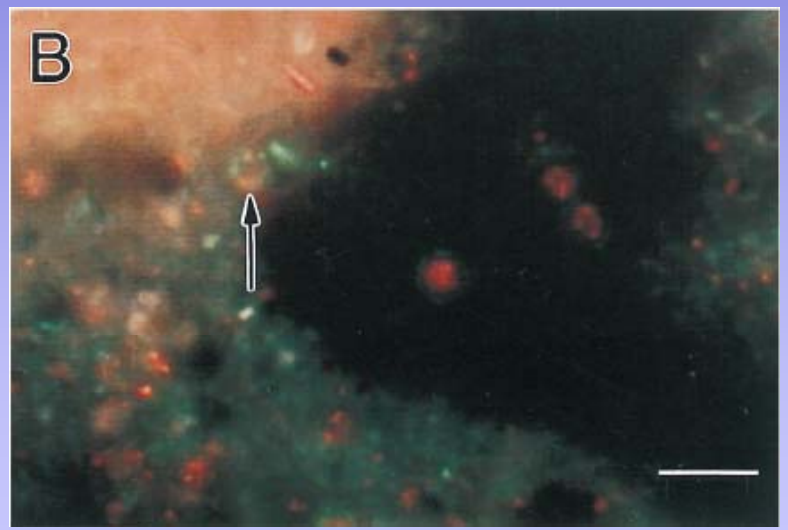
Preferential Transport of *Cryptosporidium*

- Characterize the fate and transport of *Cryptosporidium* in the subsurface environment
- Modeling of solute and biocolloid transport



Issues

- *Cryptosporidium parvum*
  - 4-6 μm diameter
  - Found in feces of infected animals
  - Protozoan pathogen that causes Cryptosporidiosis
- Source of *Cryptosporidium parvum*
  - Application of manure to farm fields
  - Wild animals
- *Cryptosporidium* in drinking water
  - Resistant to chlorination

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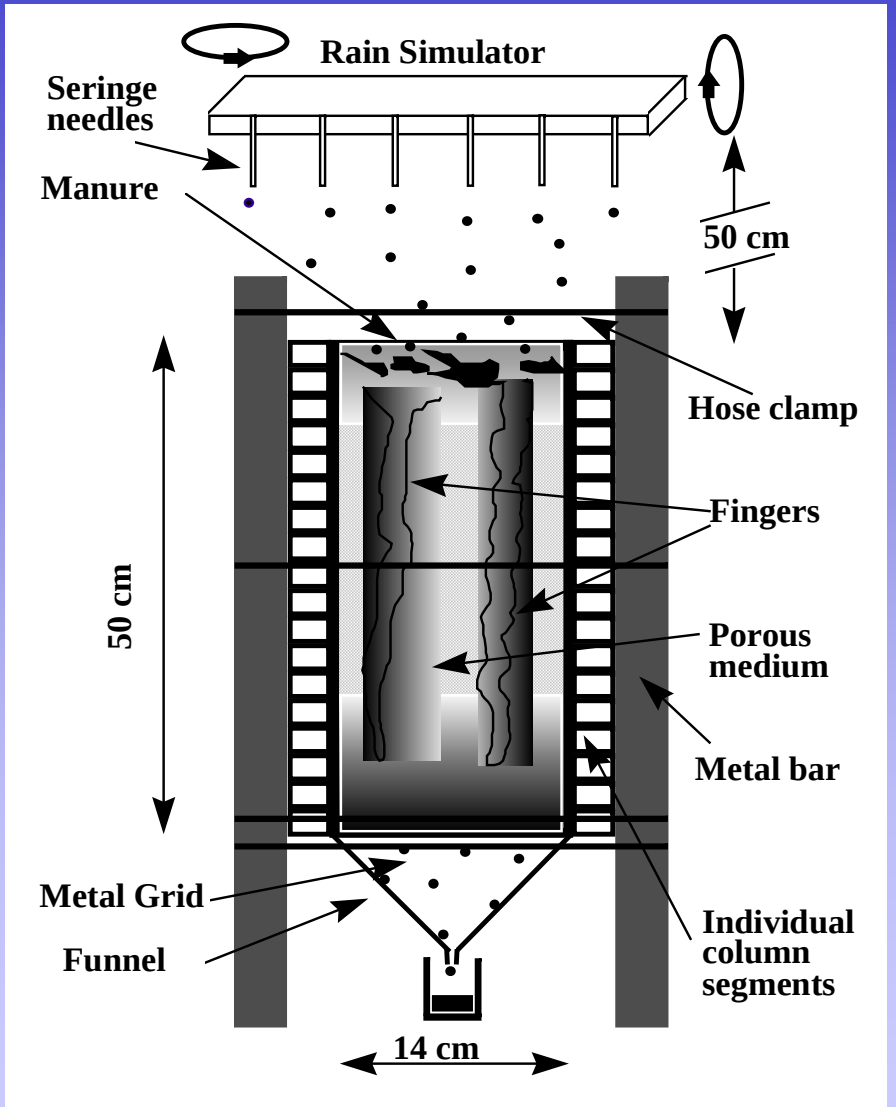
Laboratory Experiments

- Laboratory column experiments
  - *Cryptosporidium parvum* from calves feces
  - Rainfall simulation event
  - Different porous media: silica sand, water repellent sand, sand with water repellent layers
  - Undisturbed soil columns
  - Mixture of *Cryptosporidium parvum* and a tracer (chloride)



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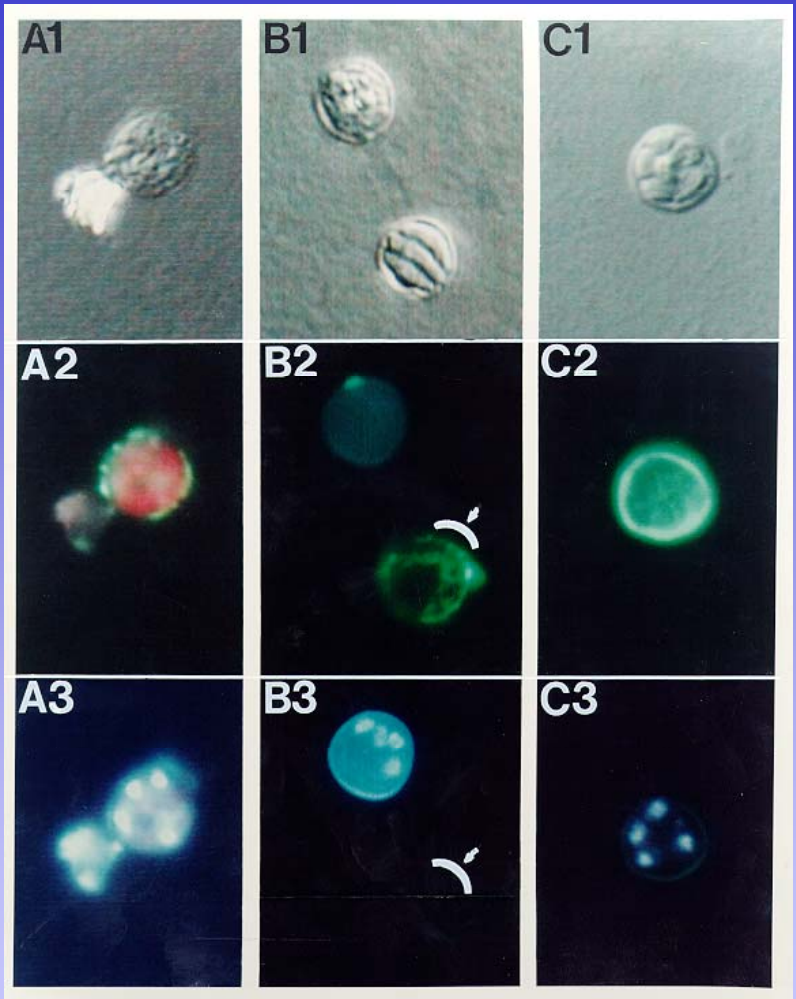
Microbiology Analysis



Dye-uptake types

(Anguish L.J. and W.C. Ghiorse. 1997)

- Oocysts Visualization & Viability
  - Immunofluorescence Staining
  - Dye Permeability Assay
- Soil extraction protocole
  - Tween & gradient concentration by centrifugation
- Fluorescence Microscopy

- Nonviable oocysts:

permeable to DAPI and PI

- Viable oocysts:

impermeable to DAPI and PI, or permeable to DAPI only

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Results

- Visualization of preferential flow path
- Visualization, quantification of oocysts
- Breakthrough curves (BTC)
- *Cryptosporidium* distribution and water saturation in soil profile
- Modeling of solute and colloid transport

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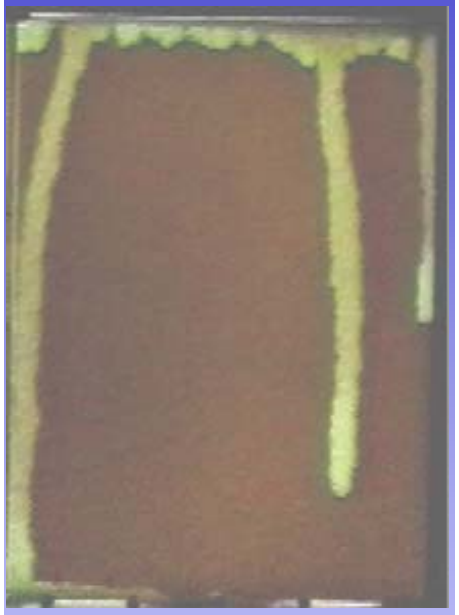
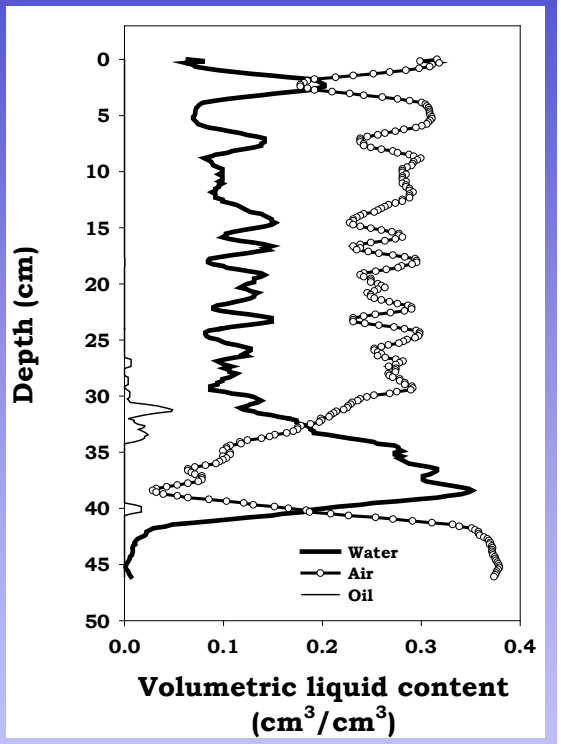
Visualization of Fingered Flow

Water Fingered Flow in Sand





3D - 2D Visualization & Fluid Content Profile

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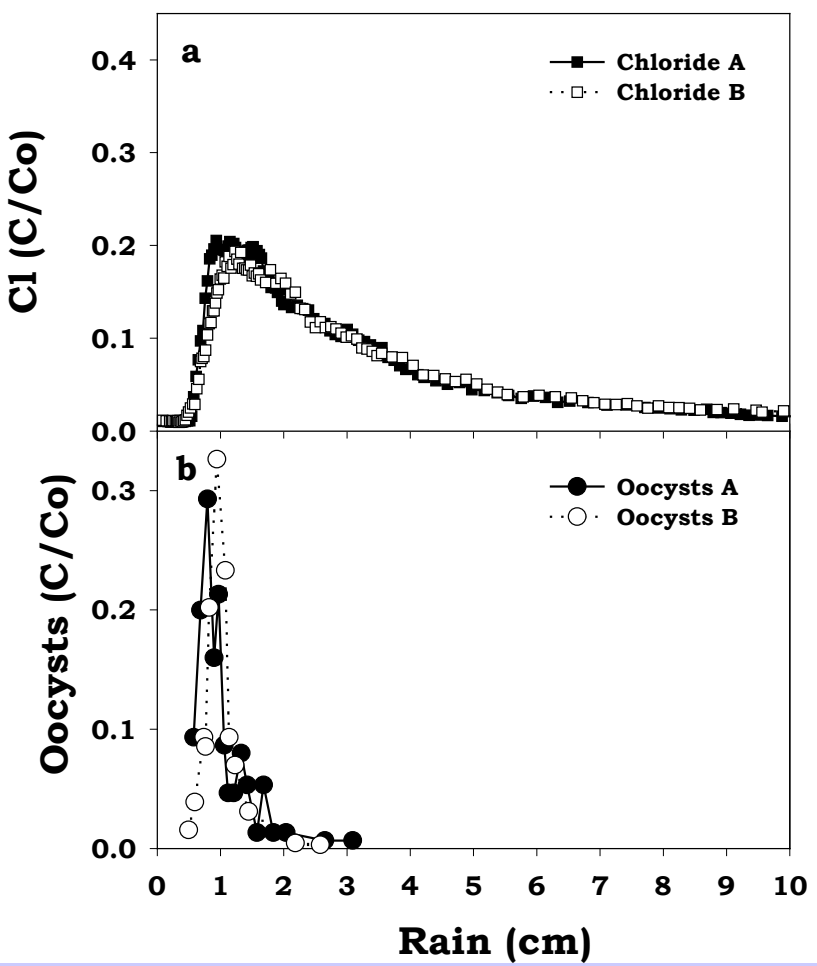
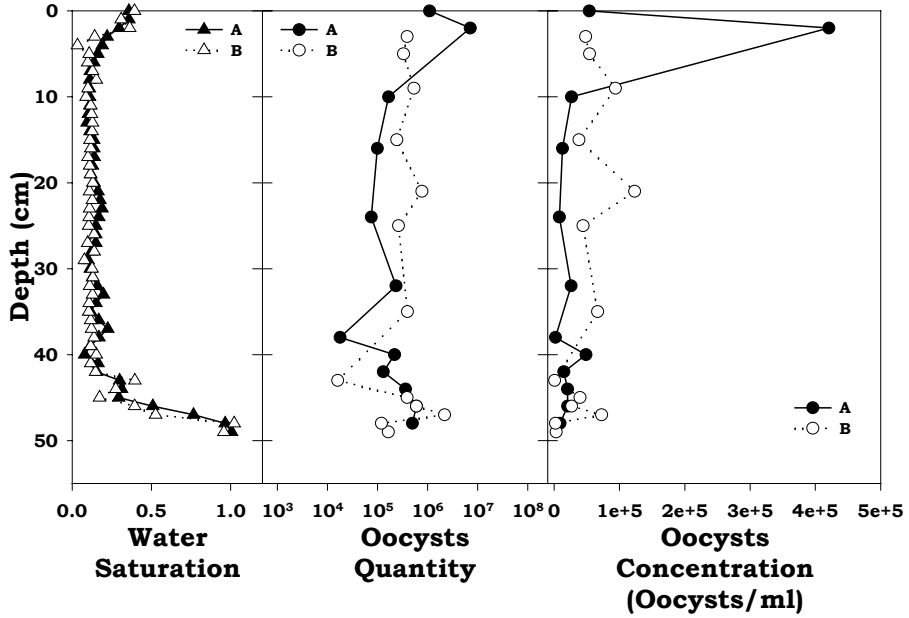
BTC of Cl and Oocysts & Soil Profile Distribution of Water and Oocysts

1 cm/hr rainfall, 12/20 sand





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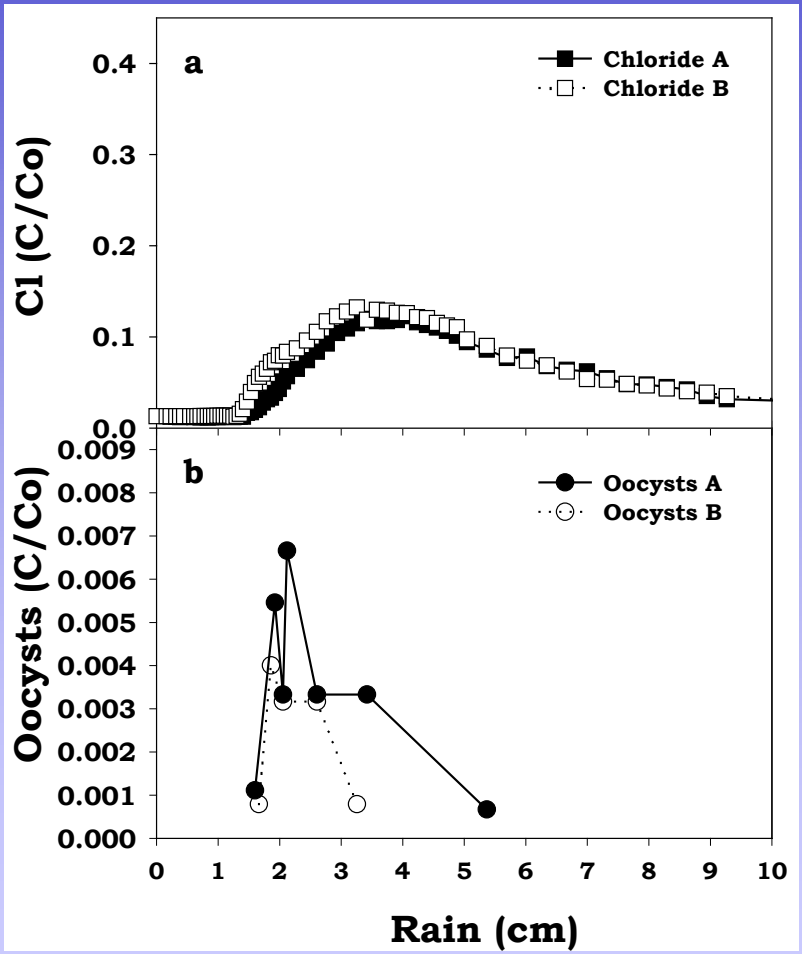
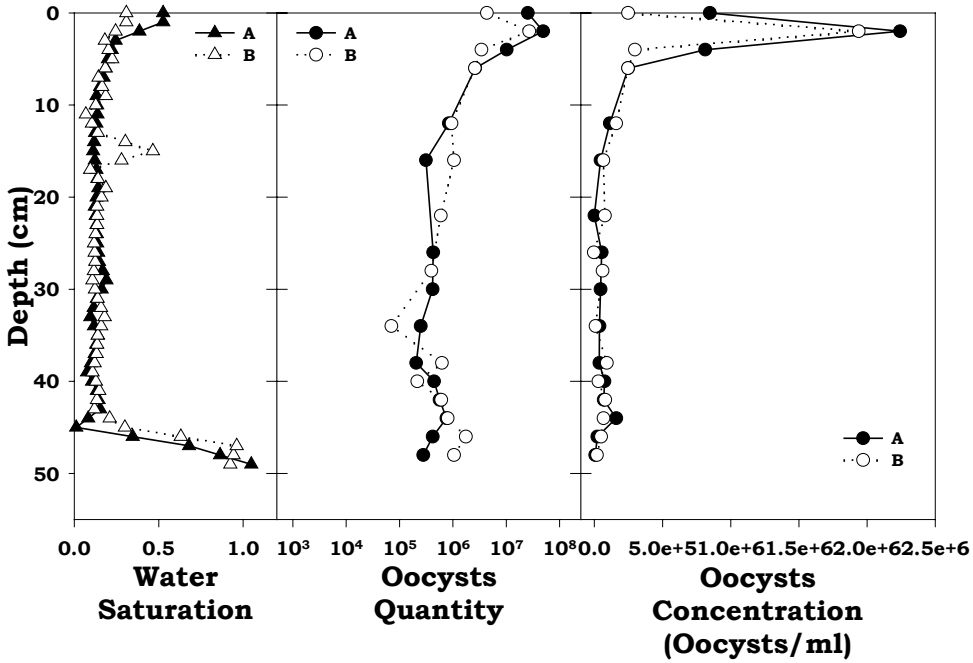
BTC of Cl and Oocysts & Soil Profile Distribution of Water and Oocysts

2 cm/hr rainfall, 12/20 sand





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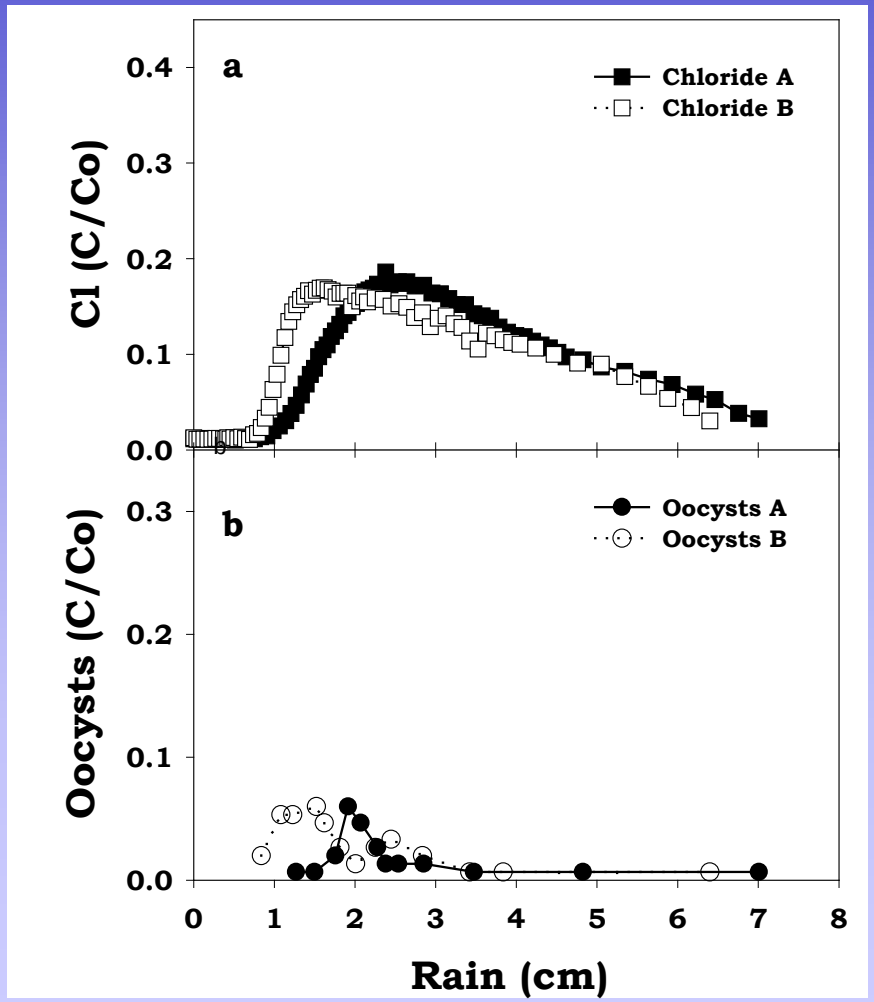
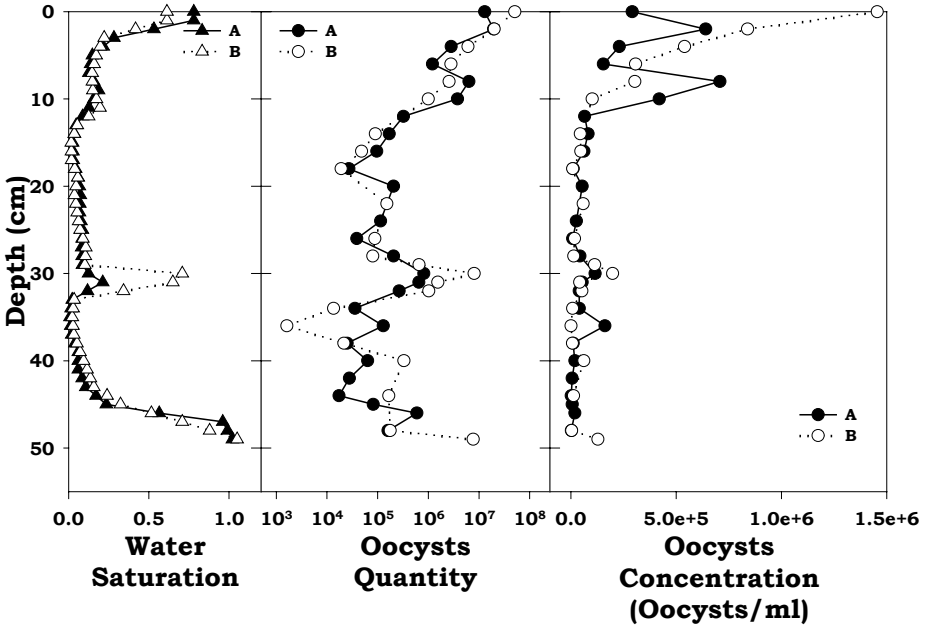
BTC of Cl and Oocysts & Soil Profile Distribution of Water and Oocysts

1 cm/hr rainfall, 12/20 sand

with two water repellent interfaces layers





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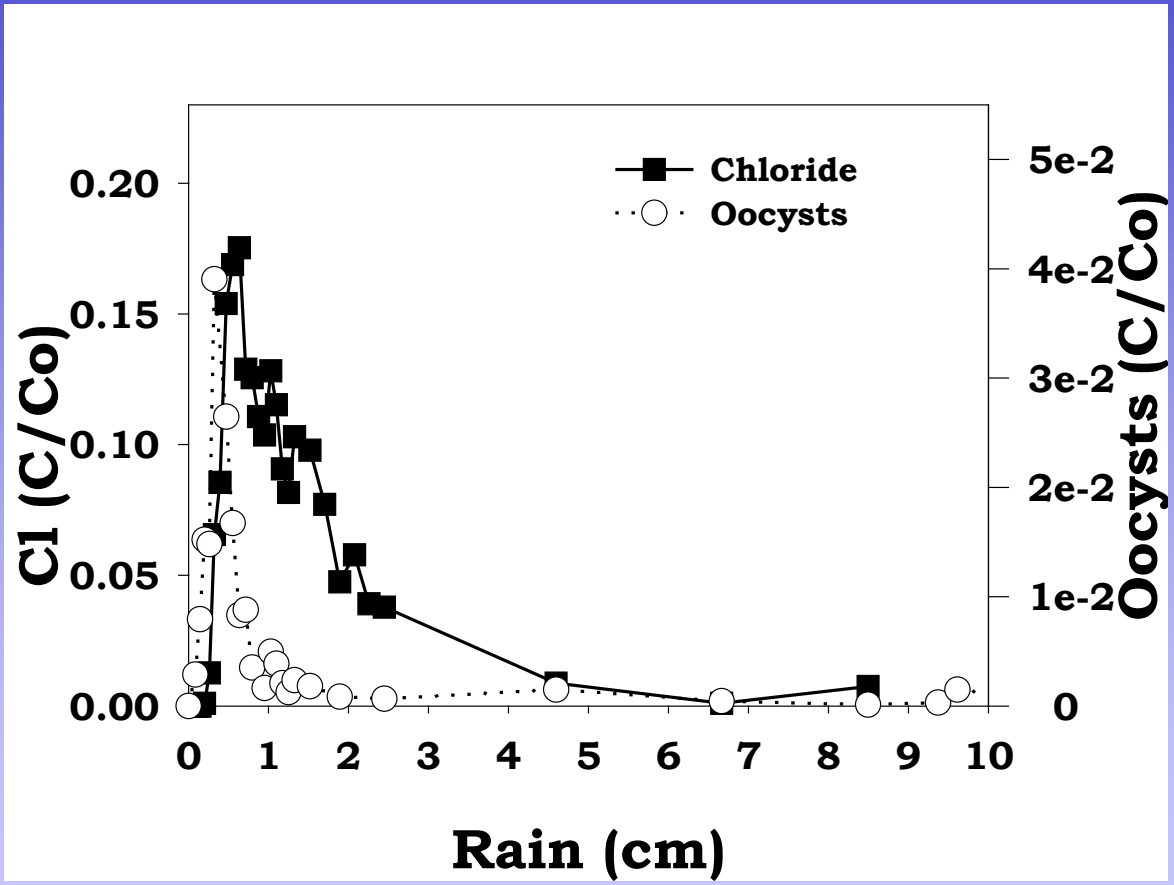
Undisturbed Soil Column



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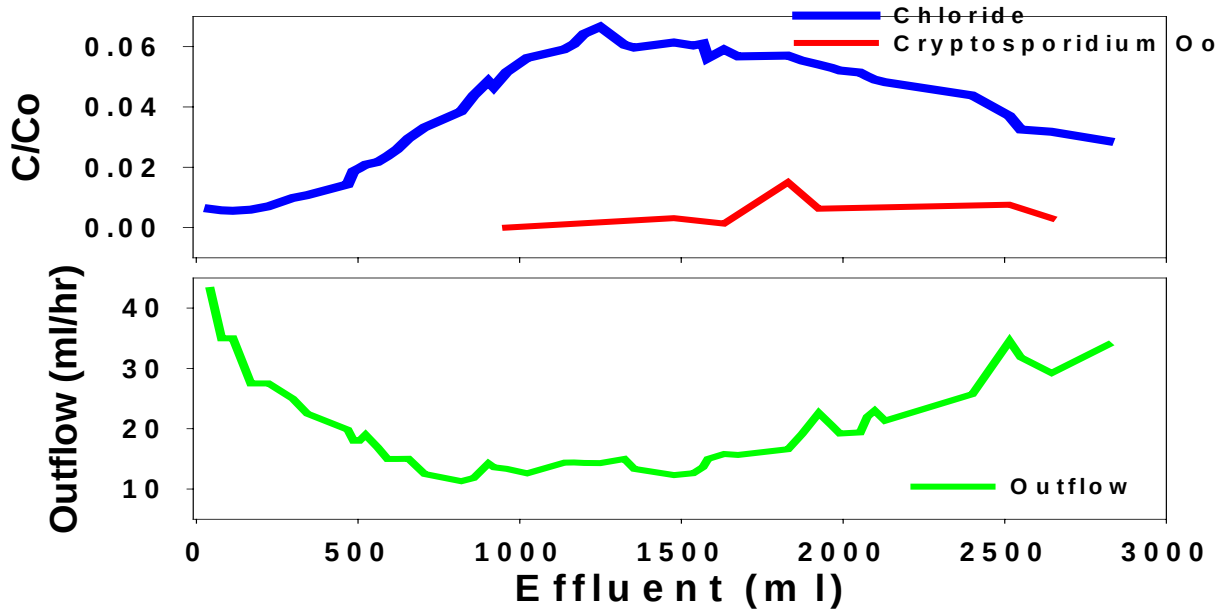
BTC of Cl and Oocysts



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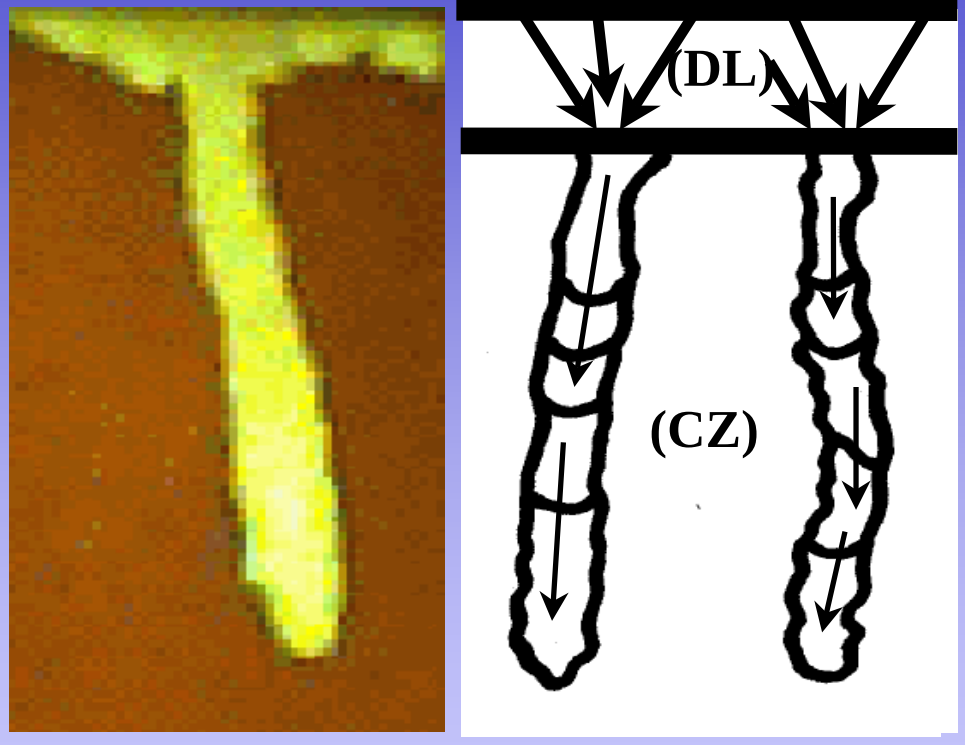
Schematic and Model for Preferential Flow



Distribution Layer (DL)

Exponential loss of solutes/colloids

$$C = C_0 \exp(-\lambda t)$$

Conveyance Zone (CZ)

Convective-dispersive equation

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial t}$$

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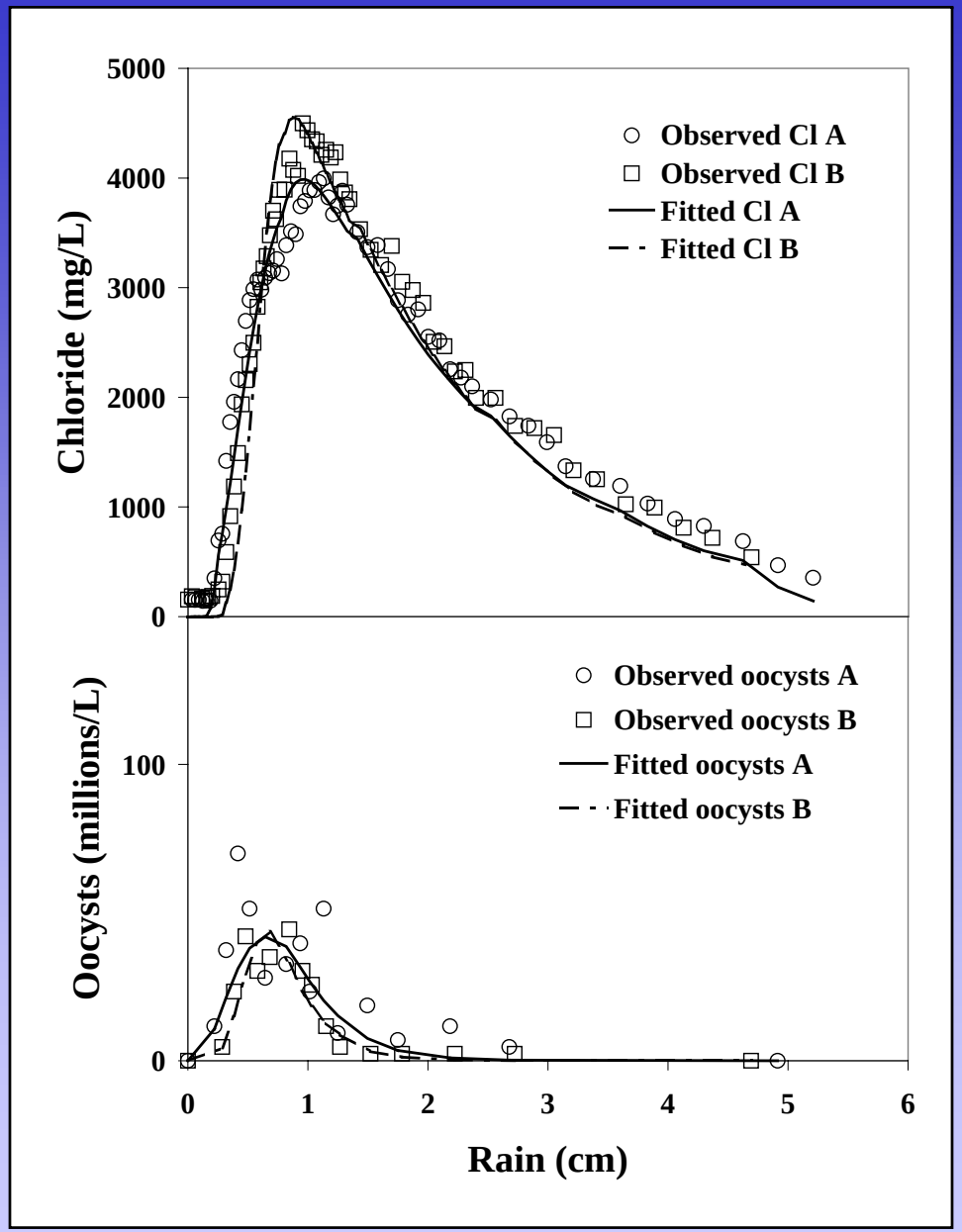
Observed & Predicted BTC

Solutes concentration

$$C = \frac{1}{2} C_0 \exp(-\lambda t)\left[\exp\left\{\frac{vx}{2D}(1-\alpha)\right\} erfc\left(\frac{x - vt\alpha}{2\sqrt{Dt}}\right) + \exp\left\{\frac{vx}{2D}(1+\alpha)\right\} erfc\left(\frac{x + vt\alpha}{2\sqrt{Dt}}\right)\right]$$

Colloids concentration

$$C = \frac{1}{2} C_0 \exp\left[-\left(\frac{q}{W} + \beta\right) t\right]\left[\exp\left[\frac{vx}{2D}(1-\alpha')\right] erfc\left(\frac{x - vt\alpha'}{\sqrt{4Dt}}\right)\right]$$



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Unsaturated Zone and Bank Filtration

- **Unsaturated zone and its occurrence in bank filtration**
  - well production over-pumping
  - during high river stage
  - flooding of dry river bench
- **Unsaturated zone and its role in fate and transport of contaminants**
  - preferential transport phenomena
  - gas-water interfaces
  - physical, chemical and biological processes
  - contaminants attenuation and entrapment

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Take-home Messages

- Demonstrated fast transport of *Cryptosporidium parvum* oocysts by fingered and macropores flow through vadose zone
- Experiments results suggest that human pathogens, like *Cryptosporidium parvum* oocysts, can be rapidly transported to significant depths in situations where preferential flow occurs
- Gas-water interfaces limit the movement of oocysts
- Modeled preferential transport of solutes and colloids
- Unsaturated zone and its importance in bank filtration

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Acknowledgements

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