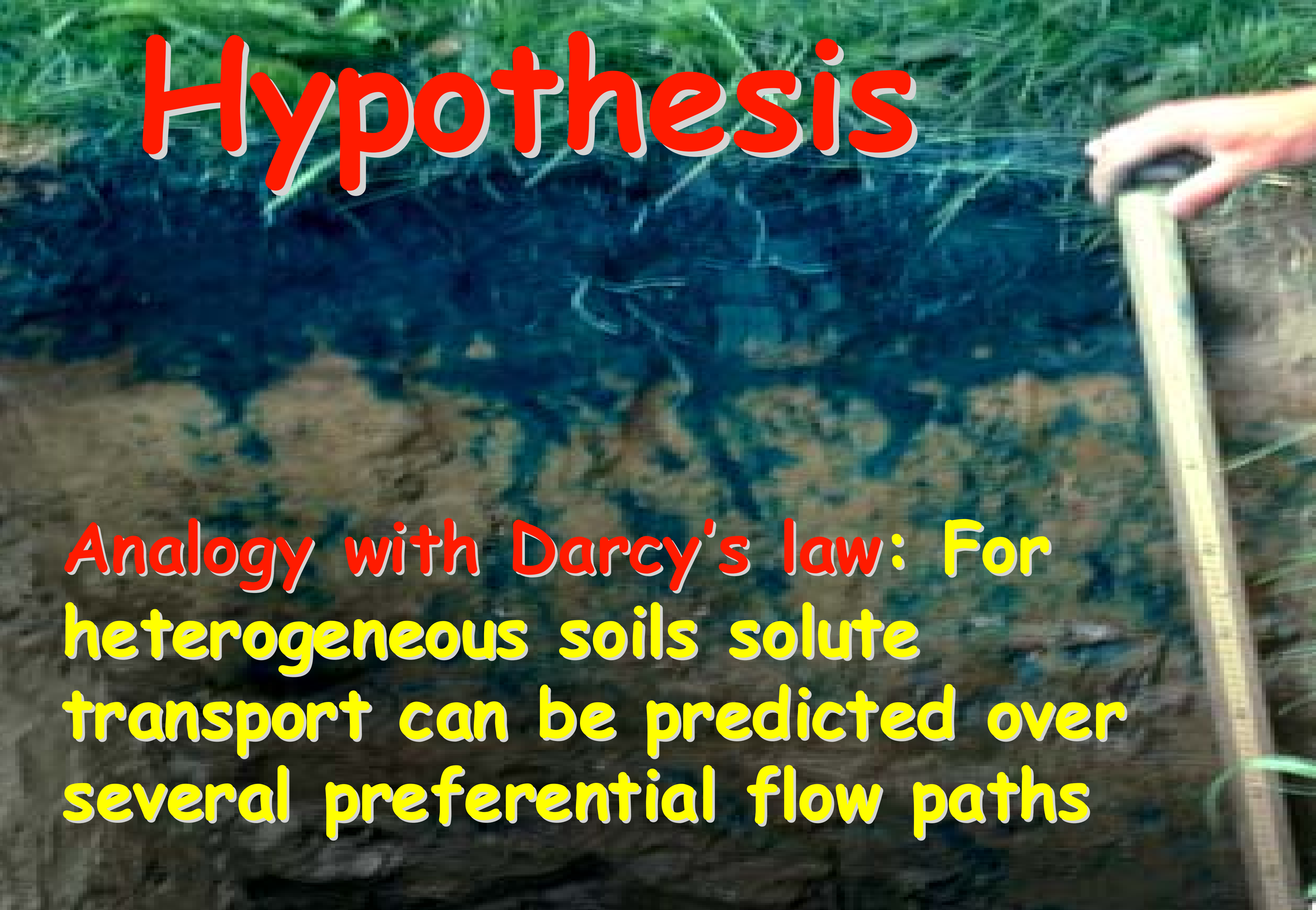
MODELLING SOLUTE TRANSPORT WITH PREFERENTIAL FLOW PATHS

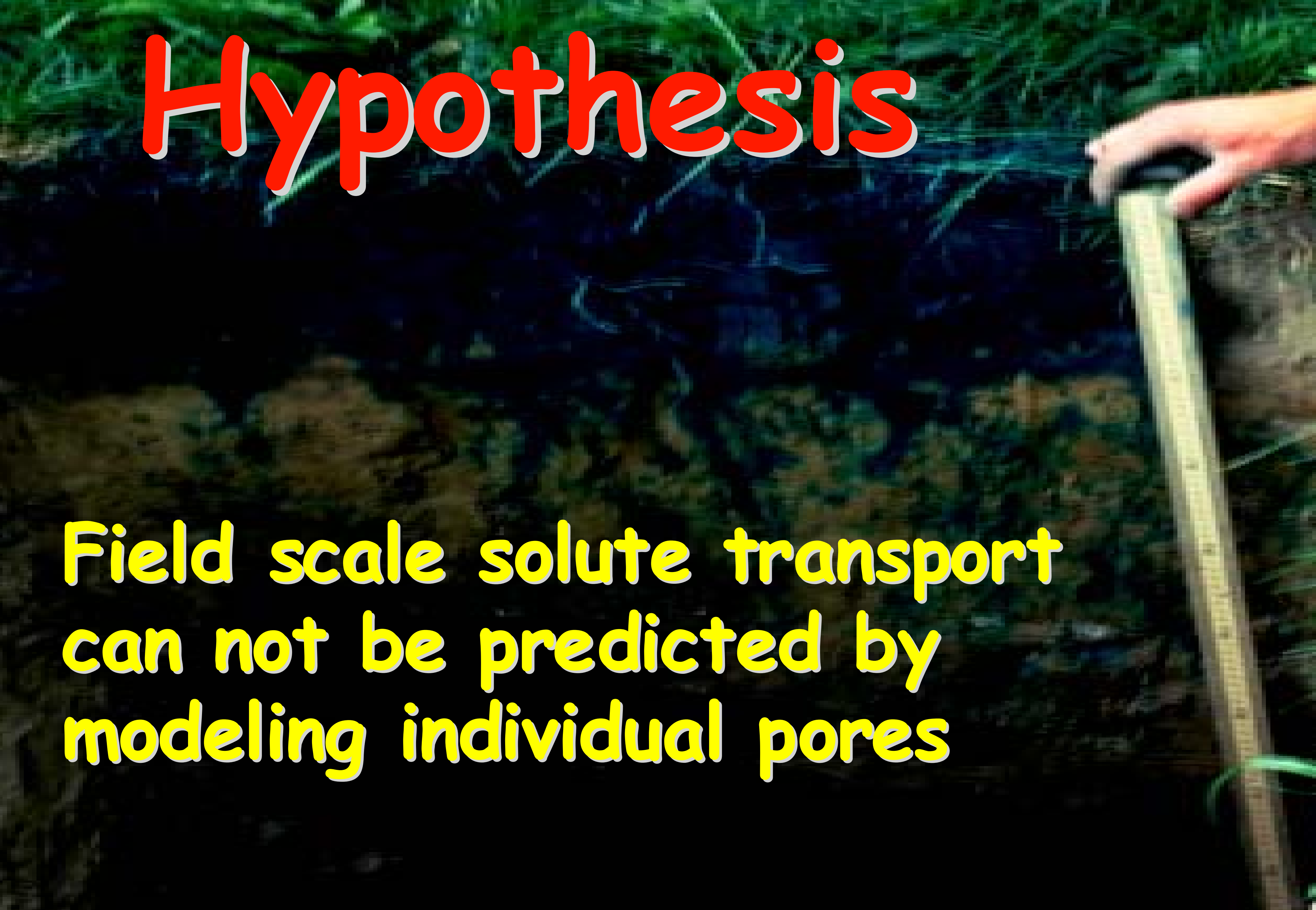
T.S. Steenhuis, Y-J.Kim, J.-Y. Parlange, M.S. Akhtar, B.K. Richards, K.-J.S. Kung, J. Boll, C. Darnault, T.J. Gish, L.W. Dekker, C.J.Ritsema, S.O. Aburime, and many others


For homogeneous soils Darcy's law is valid only for several pores
Fact

Hypothesis

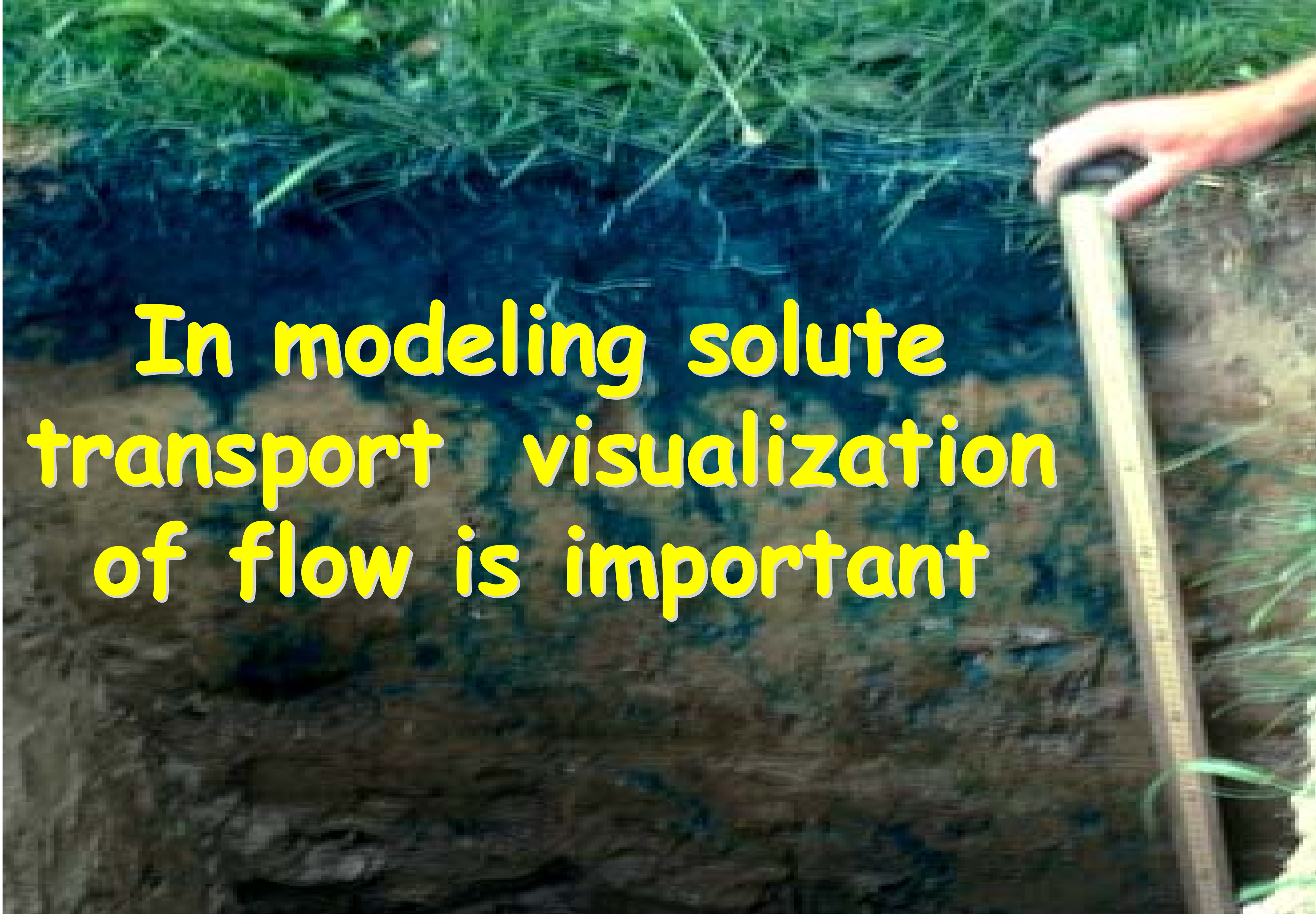


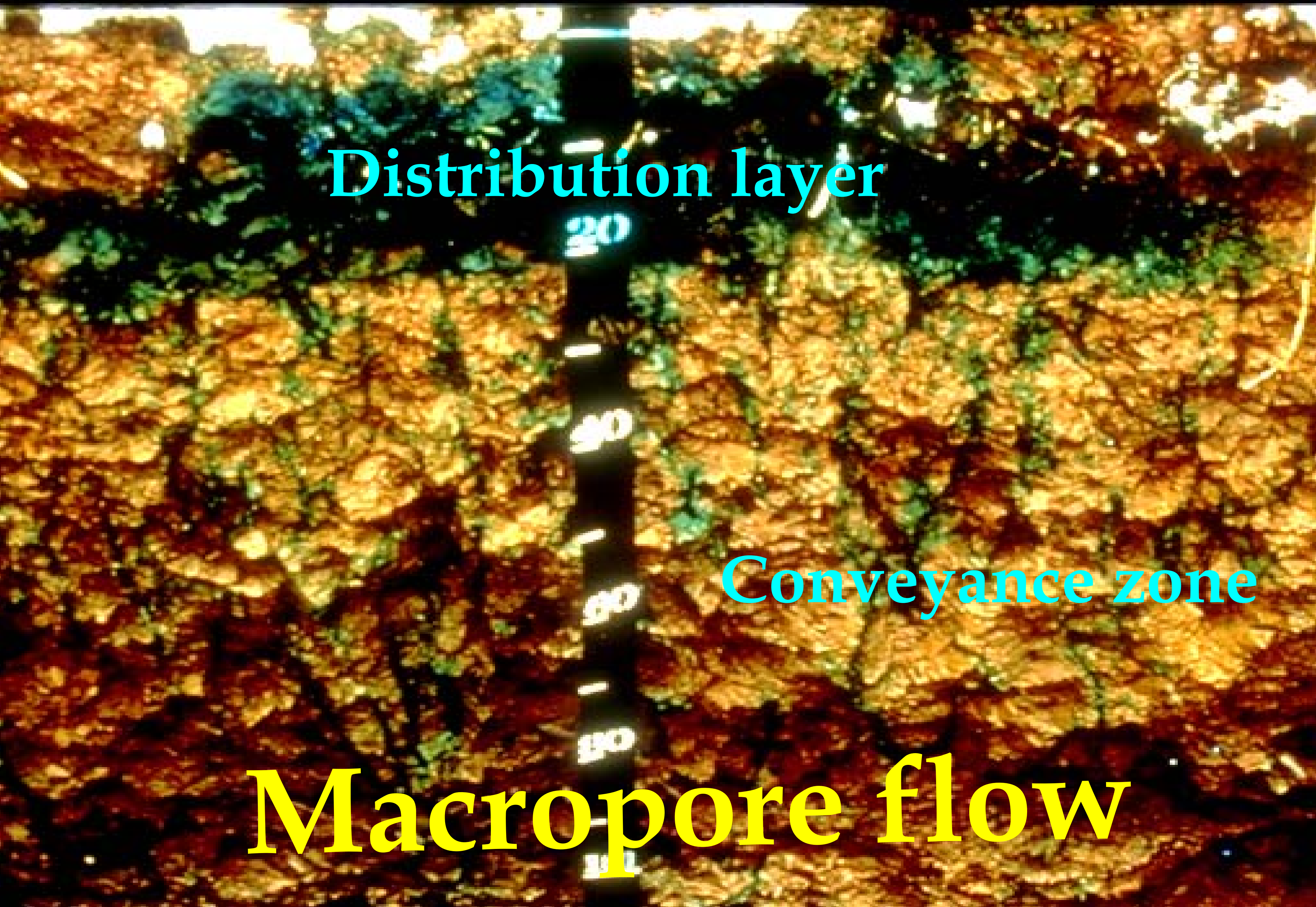
Analogy with Darcy's law: For heterogeneous soils solute transport can be predicted over several preferential flow paths


Hypothesis
Field scale solute transport
can not be predicted by
modeling individual pores

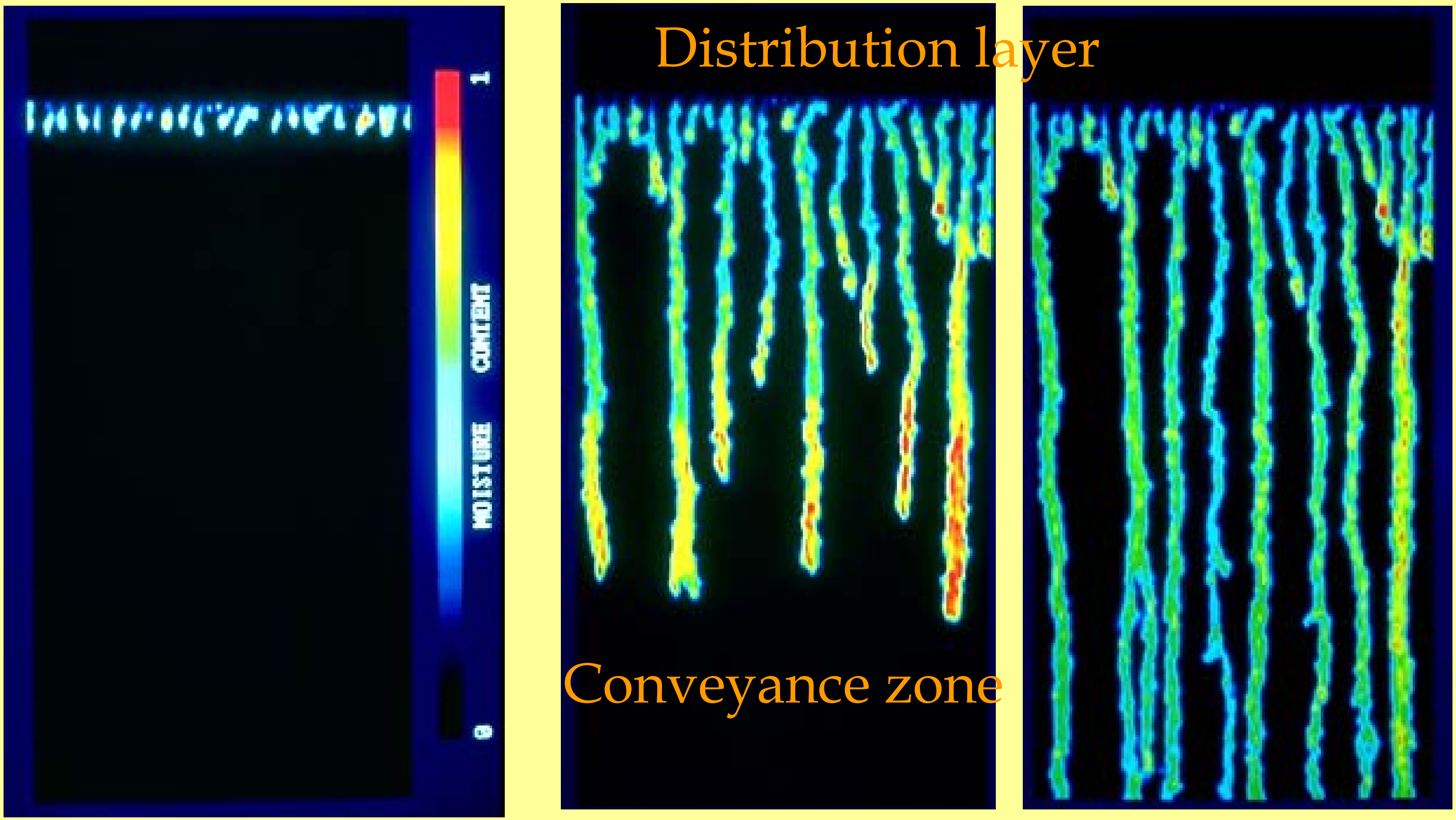
Modeling Philosophy

- Begin with most simple configuration
- Steady state water flux
- Add solute as a pulse
- Wet subsoil
- No uptake of water and solute by soil matrix in subsoil

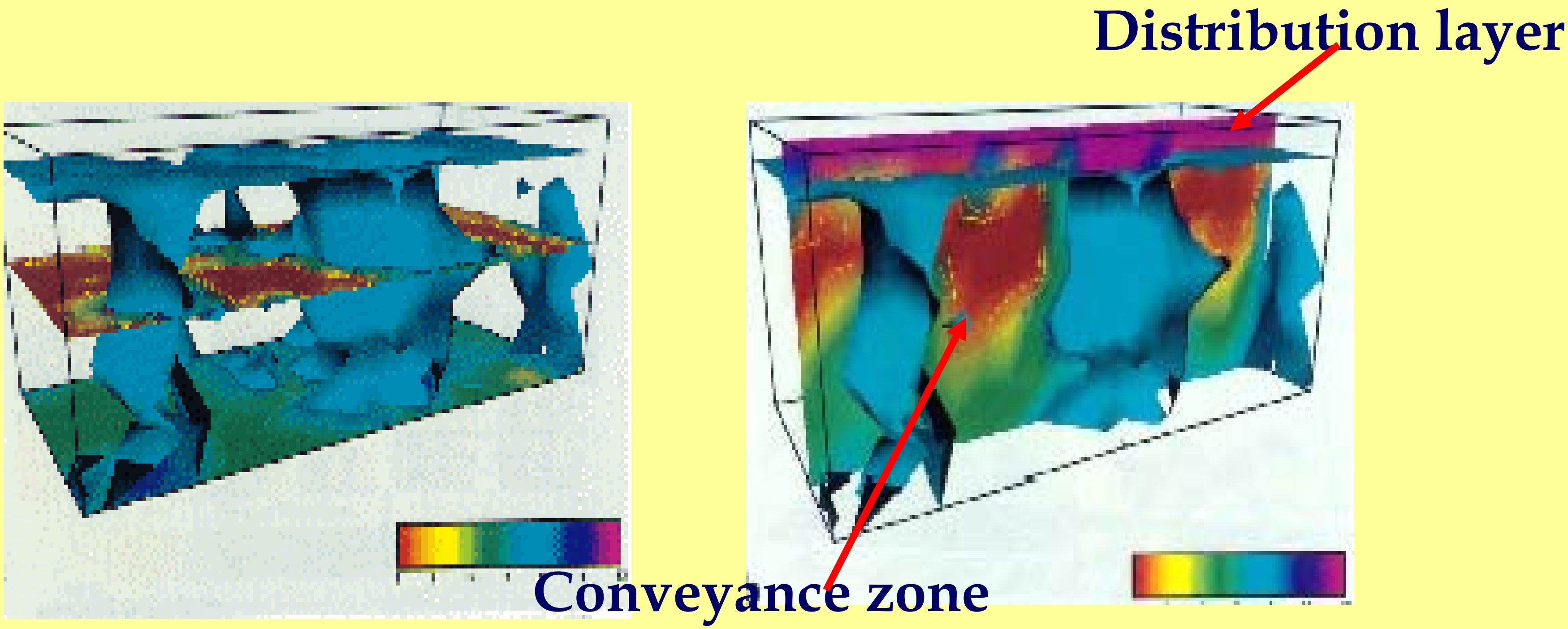

In modeling solute
transport visualization
of flow is important


Distribution layer
Conveyance zone
Macropore flow

Finger Flow in Homogenous Sand



Finger Flow in Water repellent sand

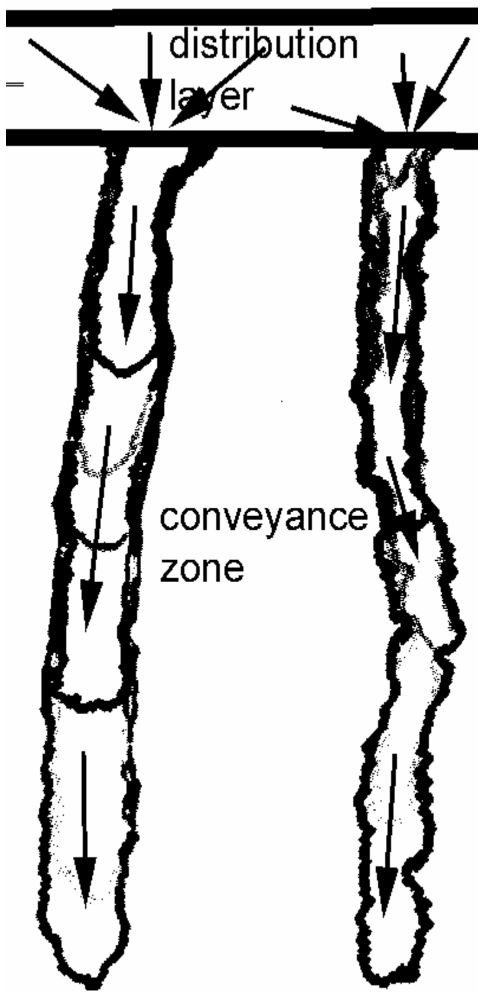


Funneled Finger Flow

Preferential flow models must have two layers:

- Distribution layer
- Conveyance zone

Preferential flow model



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

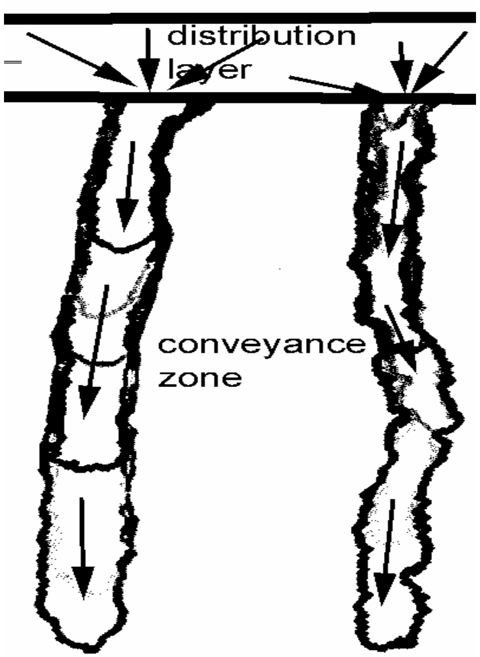
$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - V\frac{\partial C}{\partial t}$$

Preferential flow model

No flow outside preferential flow path in conveyance zone

$$C = \frac{1}{2} C_o \left[erfc\left(\frac{x - Vt}{\sqrt{4Dt}} \right) - \exp\left[\frac{Vx}{2D}(1-\alpha) - \lambda t \right] erfc\left(\frac{x - V\alpha t}{\sqrt{4Dt}} \right) \right]$$

$$\alpha = \sqrt{1 - \frac{4D\lambda}{V^2}}, \qquad \lambda = \int \frac{qdt}{W}$$



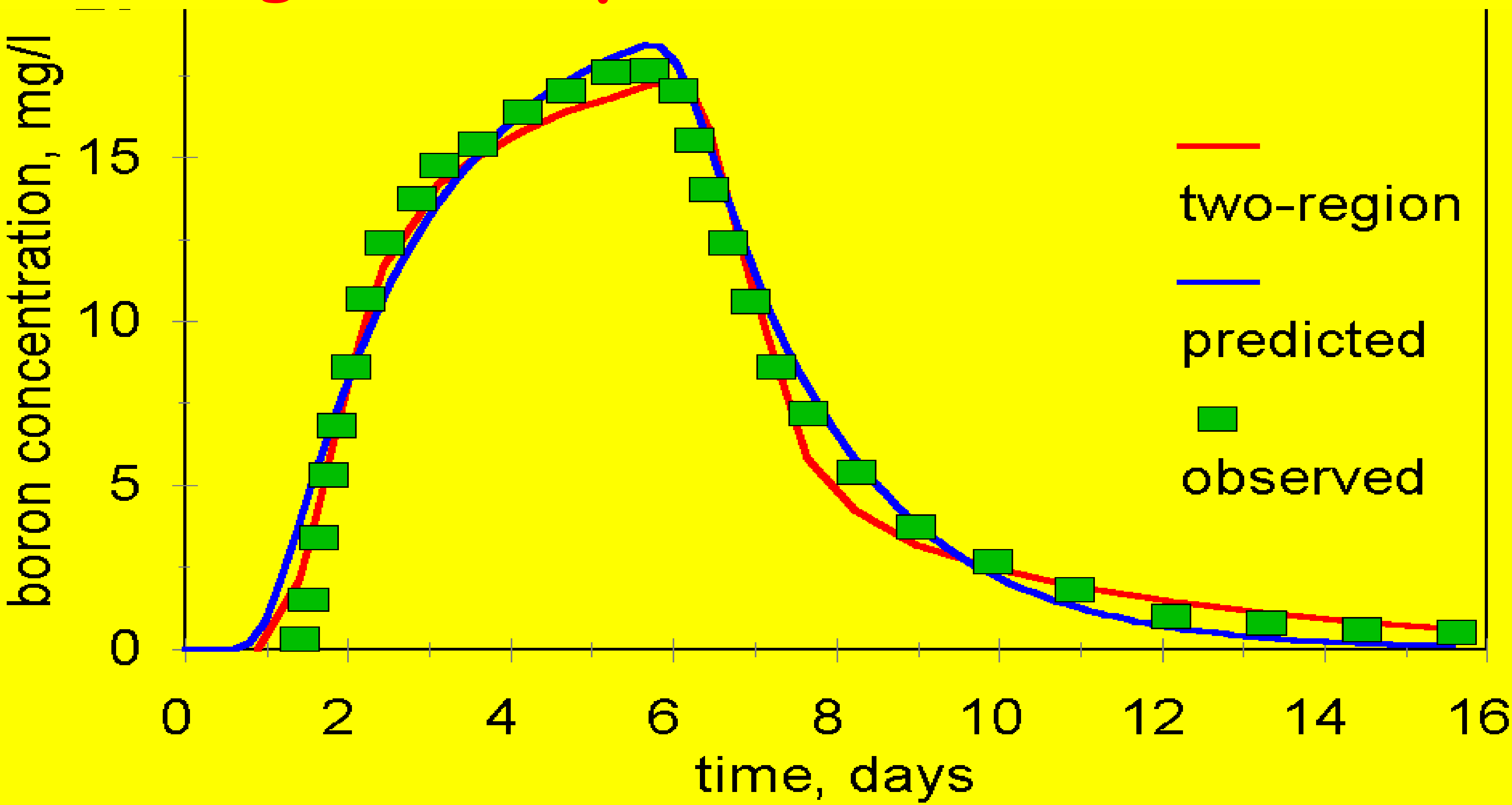
Input parameters for soil

W =water content distribution layer

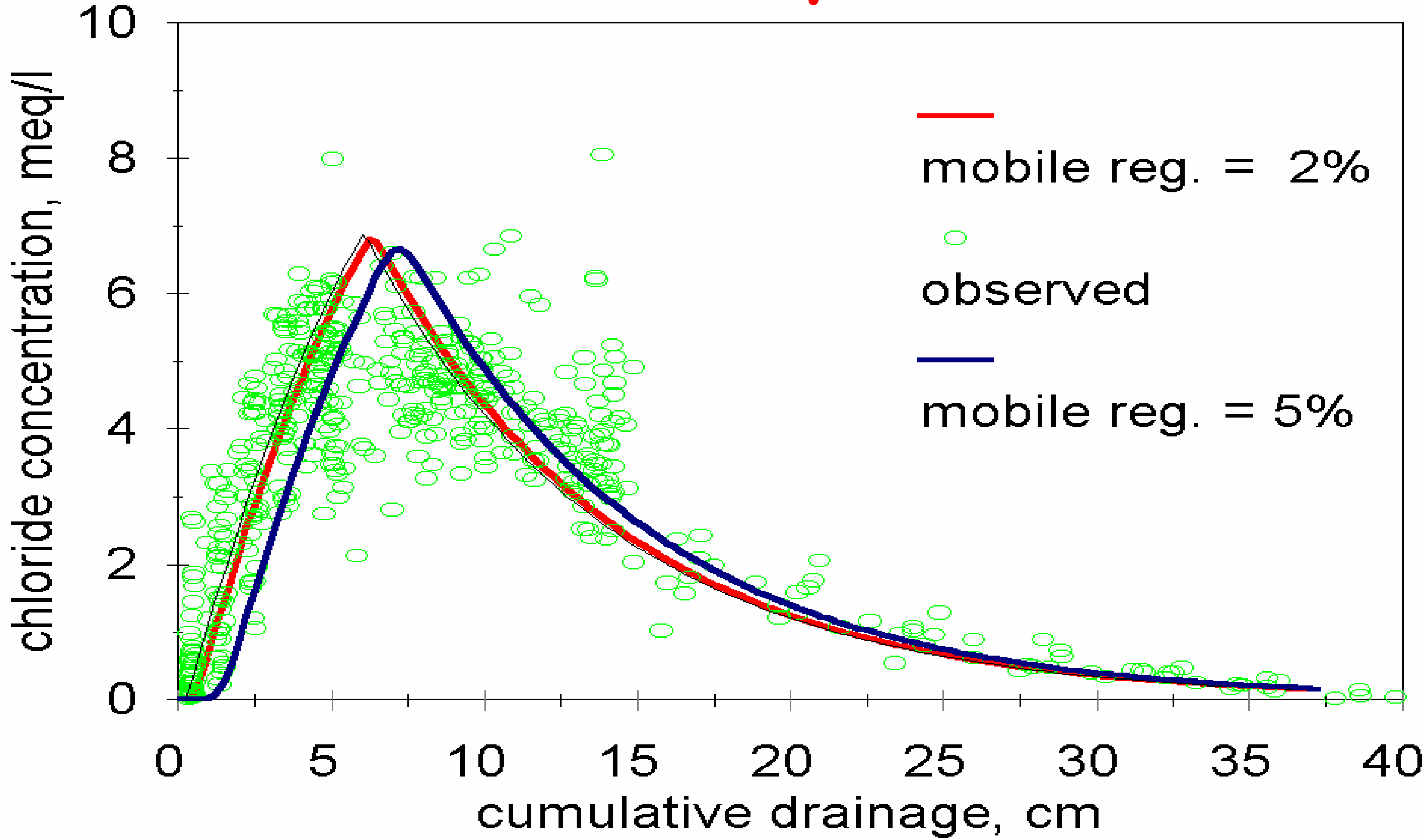
V= velocity in preferential flow paths, or
fraction of preferential flow path in soil

D= dispersion coefficient

Comparison of the two region and preferential flow model



Predicting chloride breakthrough through undisturbed 39 sandy loam columns



Experiments

Two sets of soil column experiments with were performed. Rain was applied with rainfall simulator.

1) instantaneous Cl application on homogeneous sand columns (fingered flow experiments)

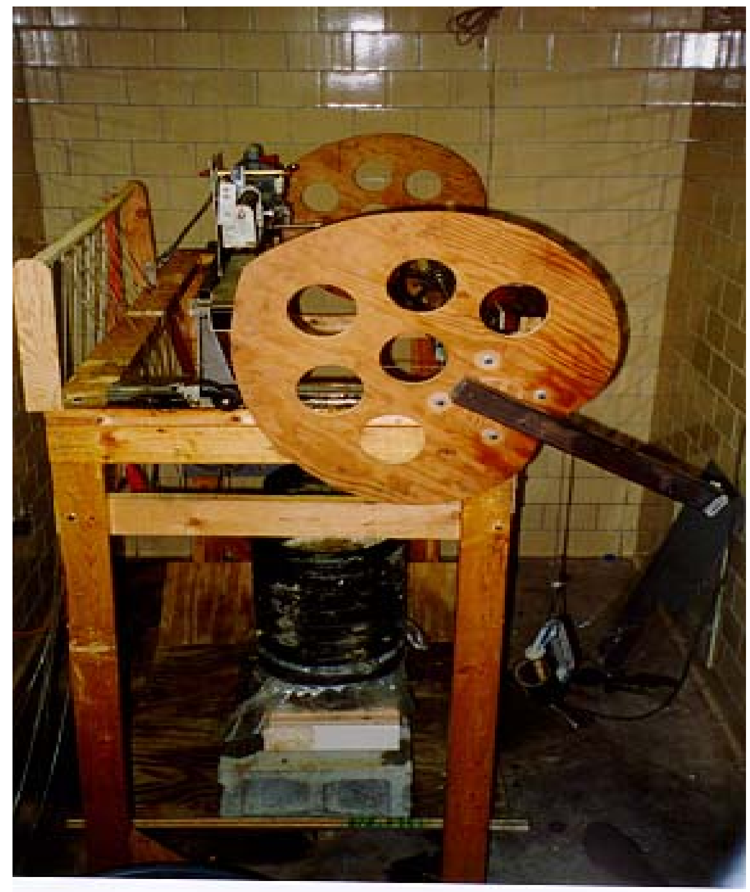
2) Pulsed application on undisturbed soil columns (macropore flow experiments)

EXPERIMENTAL SETUP

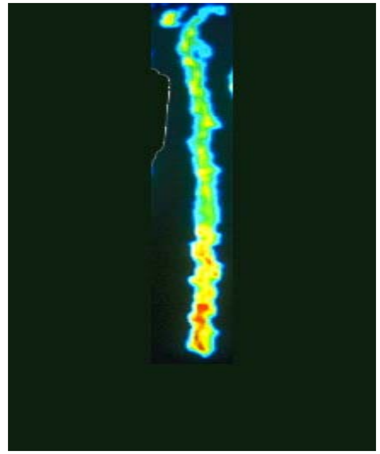
for studying conveyance zone transport

40 cm long undisturbed clay loam or coarse sand

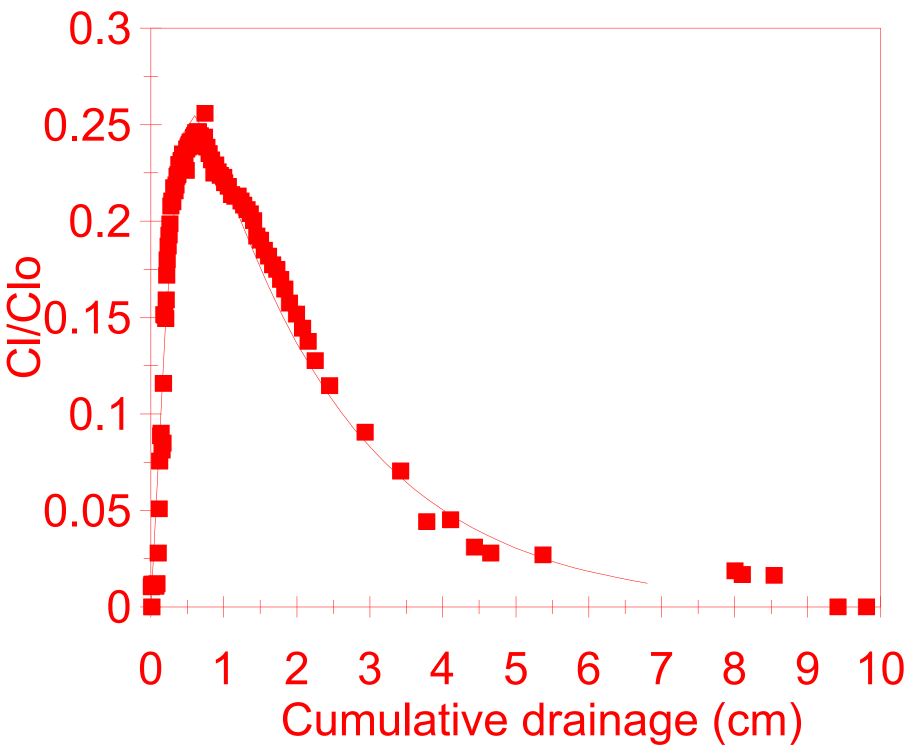
Rainfall rate varied from 0.002 to 2 cm/hr



fingered flow



q=0.002



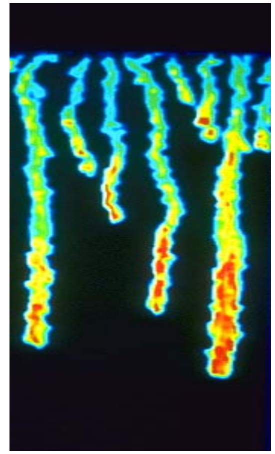
q= 0.002 cm/min

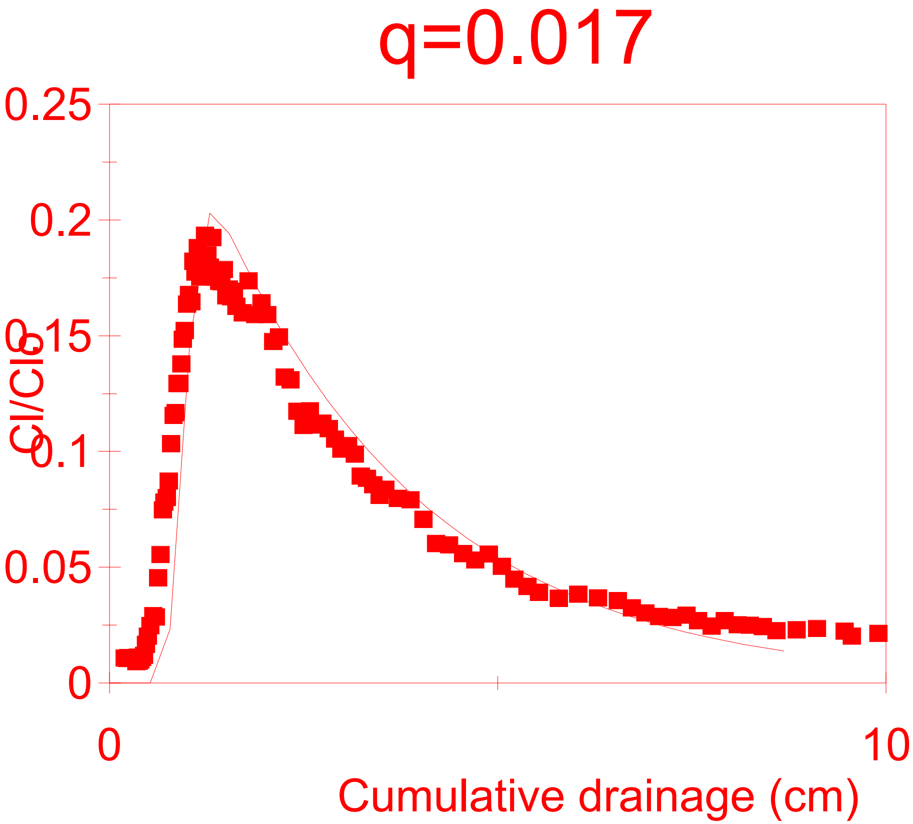
v= 0.3 cm/min

D= 3cm^2/min

W= 2

fingered flow





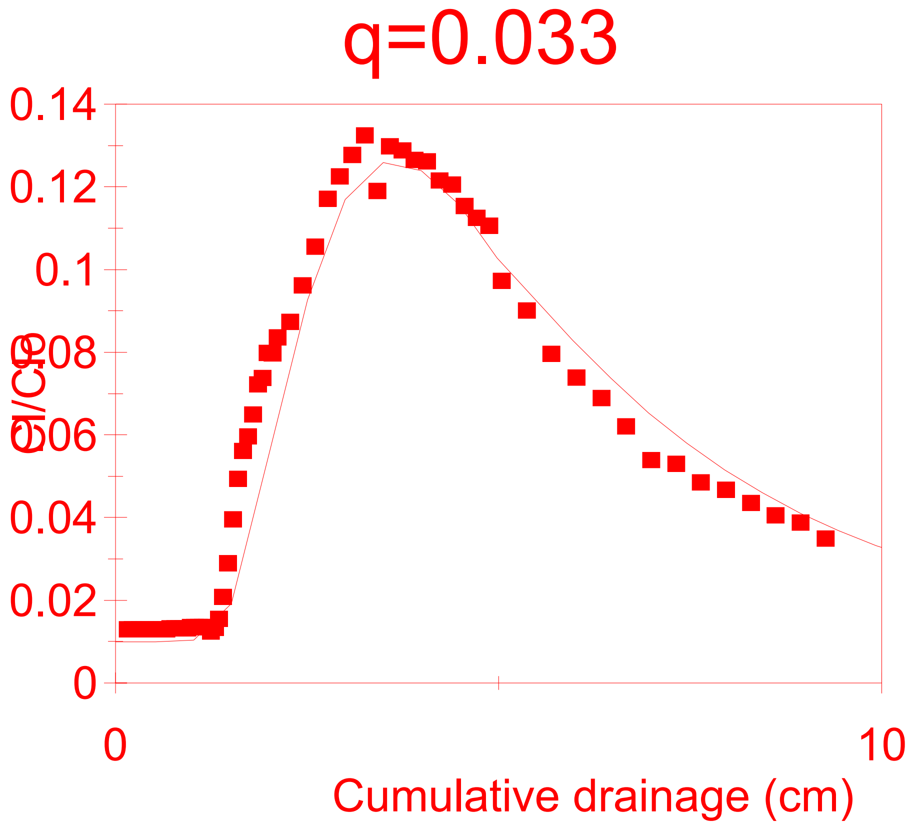
q= 0.017 cm/min

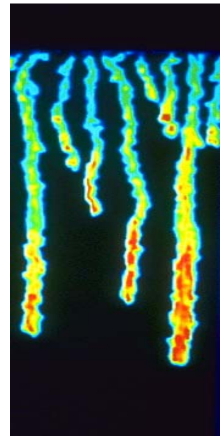
v= 0.7 cm/min

D= 0.4 cm^2/min

W= 2.7

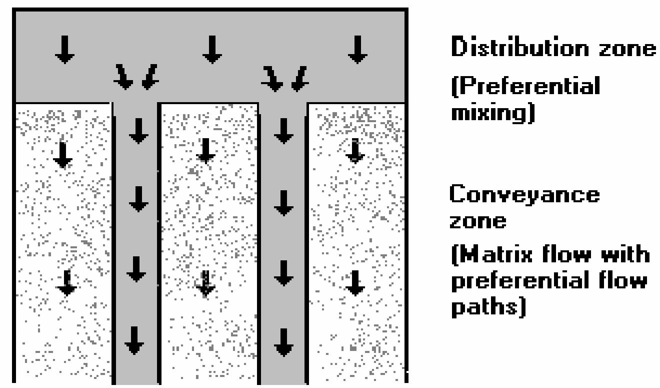
fingered flow





- q= 0.033 cm/min
  v= 0.5 cm/min
  D= 1.2 cm^2/min
  W= 3.4

Solute transport in structured soil

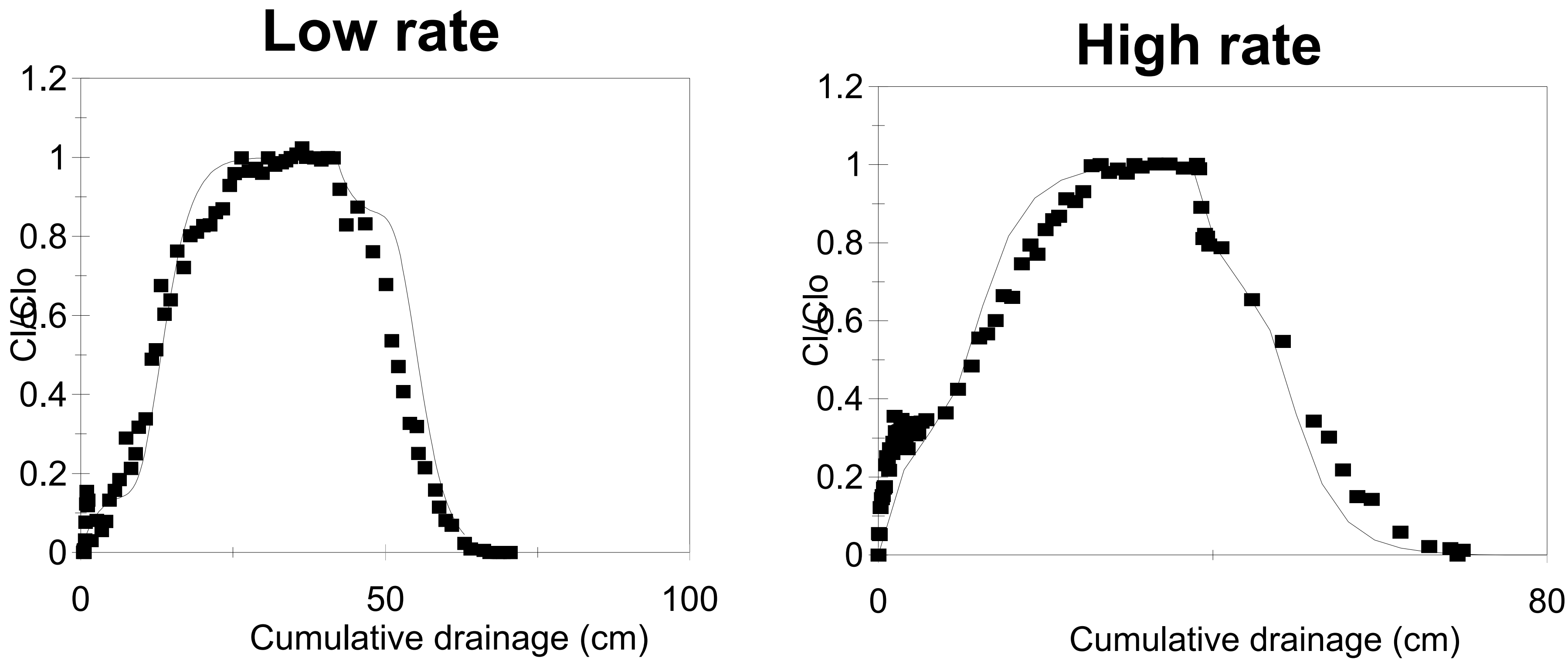


Preferential flow model for structured soil

$$C=\frac{1}{2}aC_0\left[erfc\left(\frac{x-v_p t}{2\sqrt{Dt}}\right)-\exp\left\{\frac{v_p x}{2D}(1-\alpha_p)-\lambda t\right\}erfc\left(\frac{x-v_p t\alpha_p}{2\sqrt{Dt}}\right)\right]+$$

$$\frac{(1-a)}{2}C_0\left[erfc\left(\frac{x-v_m t}{2\sqrt{Dt}}\right)-\exp\left\{\frac{v_m x}{2D}(1-\alpha_m)-\lambda t\right\}erfc\left(\frac{x-v_m t\alpha_m}{2\sqrt{Dt}}\right)\right]$$

Where a is the fraction of the flow through the macro pores



Rate	a	q	v_p	v_m	D	w	α_p	α_m
Low	0.15	0.003	2	0.01	0.01	2.5	0.99	0.721
High	0.38	0.025	2	0.1	0.1	4	0.99	0.866

Conclusions

- The generalized model was able to describe the breakthrough of solutes with three parameters (v, D, and W)
- Apparent water contents, W, increased proportional to the flow rate
- For fingered flow the velocity was almost independent of flow rate

References:

Steenhuis, T.S., Y.-J. Kim, J.-Y. Parlange, M.S. Akhtar, B.K. Richards, K.-J.S. Kung, T.J. Gish, L.W.Dekker, C.J. Ritsema, and S.O.Aburime. An equation for describing solute transport in field soils with preferential flow paths. In: Proceeding of the 2nd ASAE International Symposium on Preferential Flow: Water Movement and Chemical Transport in the Environment. Honolulu, HI. January 3-5, 2001.

Kim, Y.J., C.J.G. Darnault, N. Bailey, J.-Y. Parlange, and T.S. Steenhuis. 2003. An equation for describing solute transport in field soils with preferential flow paths. Submitted to Soil Sci. Soc. Am. Journal.