MODELLING SOLUTE TRANSPORT WITH PREFERENTIAL FLOW PATHS

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

Distribution layer

Conveyance zone
Finger Flow in Water repellent sand

Distribution layer

Conveyance zone
Funneled Finger Flow
Preferential flow models must have two layers:

- Distribution layer
- Conveyance zone
Preferential flow model

\[ C = C_0 \exp(-\lambda t) \]

\[ \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - \nu \frac{\partial C}{\partial t} \]
Preferential flow model

No flow outside preferential flow path in conveyance zone

\[ C = \frac{1}{2} C_0 \left[ \text{erfc} \left( \frac{x - Vt}{\sqrt{4Dt}} \right) - \exp \left( \frac{Vx}{2D} (1 - \alpha) - \lambda t \right) \text{erfc} \left( \frac{x - V\alpha t}{\sqrt{4Dt}} \right) \right] \]

\[ \alpha = \sqrt{1 - \frac{4D\lambda}{V^2}}, \quad \lambda = \int \frac{qdt}{W} \]

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

- two-region
- predicted
- observed
Predicting chloride breakthrough through undisturbed sandy loam columns

chloride concentration, meq/l

cumulative drainage, cm

mobile reg. = 2%

observed

mobile reg. = 5%
Experiments

Two sets of soil column experiments 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

$q = 0.002$ cm/min
$v = 0.3$ cm/min
$D = 3$ cm$^2$/min
$W = 2$
fingered flow

$q = 0.017$

$q = 0.017 \text{ cm/min}$
$v = 0.7 \text{ cm/min}$
$D = 0.4 \text{ cm}^2/\text{min}$
$W = 2.7$
fingered flow

$q = 0.033 \text{ cm/min}$

$v = 0.5 \text{ cm/min}$

$D = 1.2 \text{ cm}^2/\text{min}$

$W = 3.4$
Solute transport in structured soil
Preferential flow model for structured soil

\[
C = \frac{1}{2} a C_0 \left[ \text{erfc} \left( \frac{x - v_p t}{2\sqrt{D} t} \right) - \exp \left\{ \frac{v_p x}{2D} (1 - \alpha_p) - \lambda t \right\} \text{erfc} \left( \frac{x - v_p t \alpha_p}{2\sqrt{D} t} \right) \right] +
\]

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

Where \(a\) is the fraction of the flow through the macro pores
### Low rate

![Graph showing cumulative drainage (cm) for low rate]

<table>
<thead>
<tr>
<th>Rate</th>
<th>a</th>
<th>q</th>
<th>v_p</th>
<th>v_m</th>
<th>D</th>
<th>w</th>
<th>(\alpha_p)</th>
<th>(\alpha_m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0.15</td>
<td>0.003</td>
<td>2</td>
<td>0.01</td>
<td>0.01</td>
<td>25</td>
<td>0.99</td>
<td>0.721</td>
</tr>
<tr>
<td>High</td>
<td>0.38</td>
<td>0.025</td>
<td>2</td>
<td>0.1</td>
<td>0.1</td>
<td>4</td>
<td>0.99</td>
<td>0.866</td>
</tr>
</tbody>
</table>
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:
