Models of coupled matrix and preferential macropore flow in VSoil.

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Context

Modified from Christophe Salin

- **Durability of services provided by soils ?**

  → **context : climate change**
  agro-ecological transition

  - Regulations of water fluxes (quantity, quality)
  - Support of agriculture
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  - ↗ availability of nutriments
  - ↗ stability of soil structure
  - contribute to regulation of water fluxes

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Macropores (> 300 µm)

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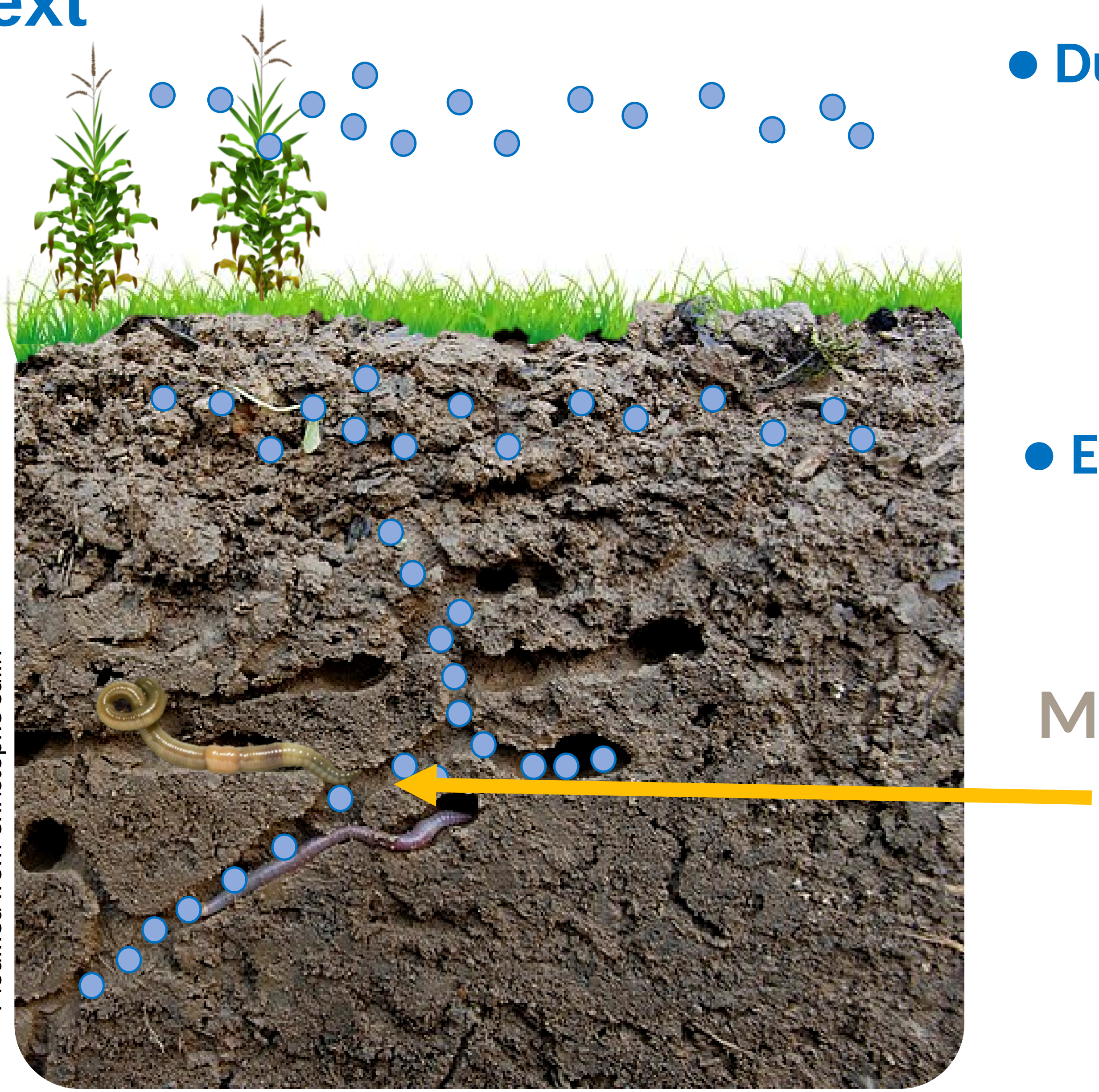

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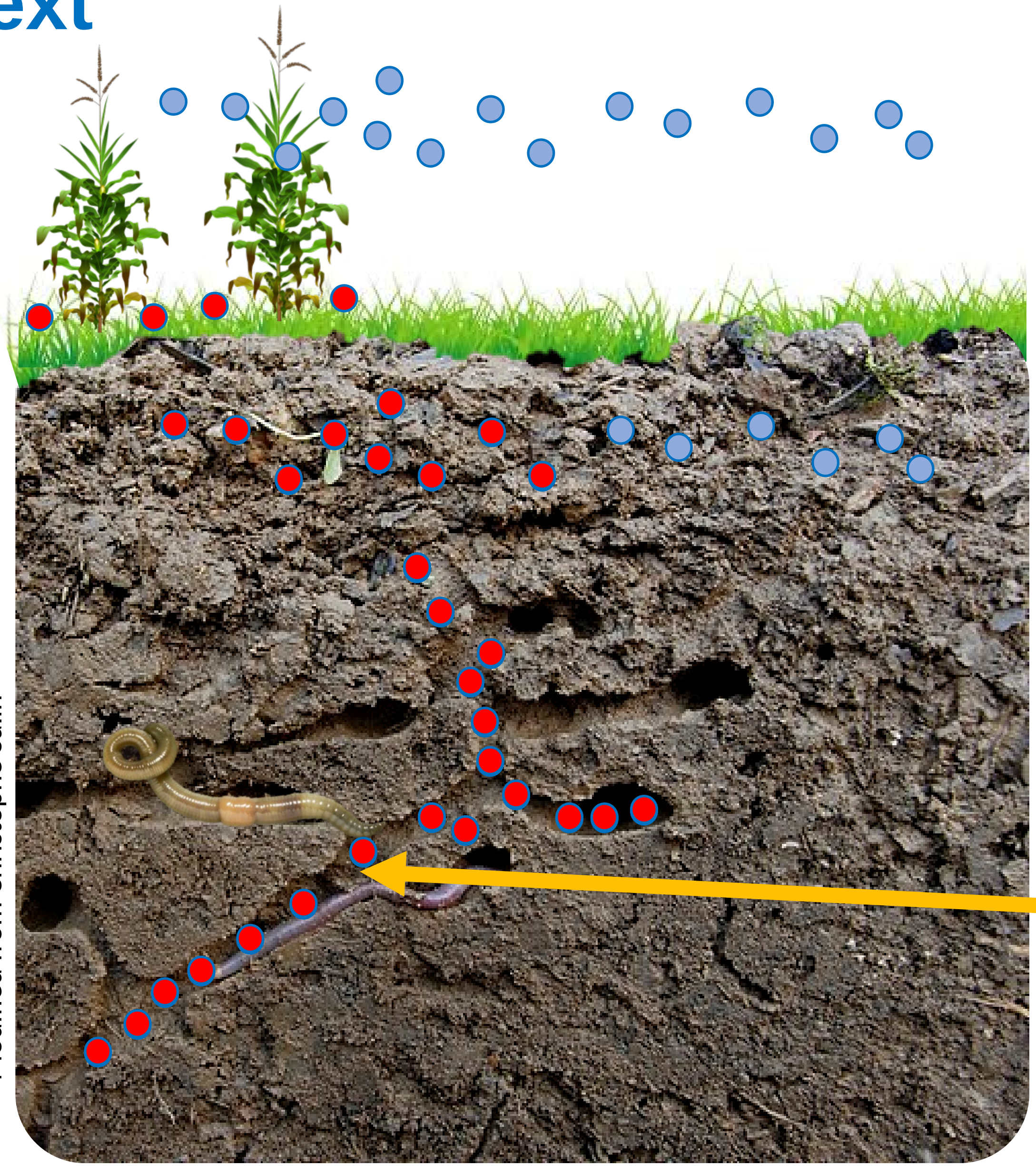

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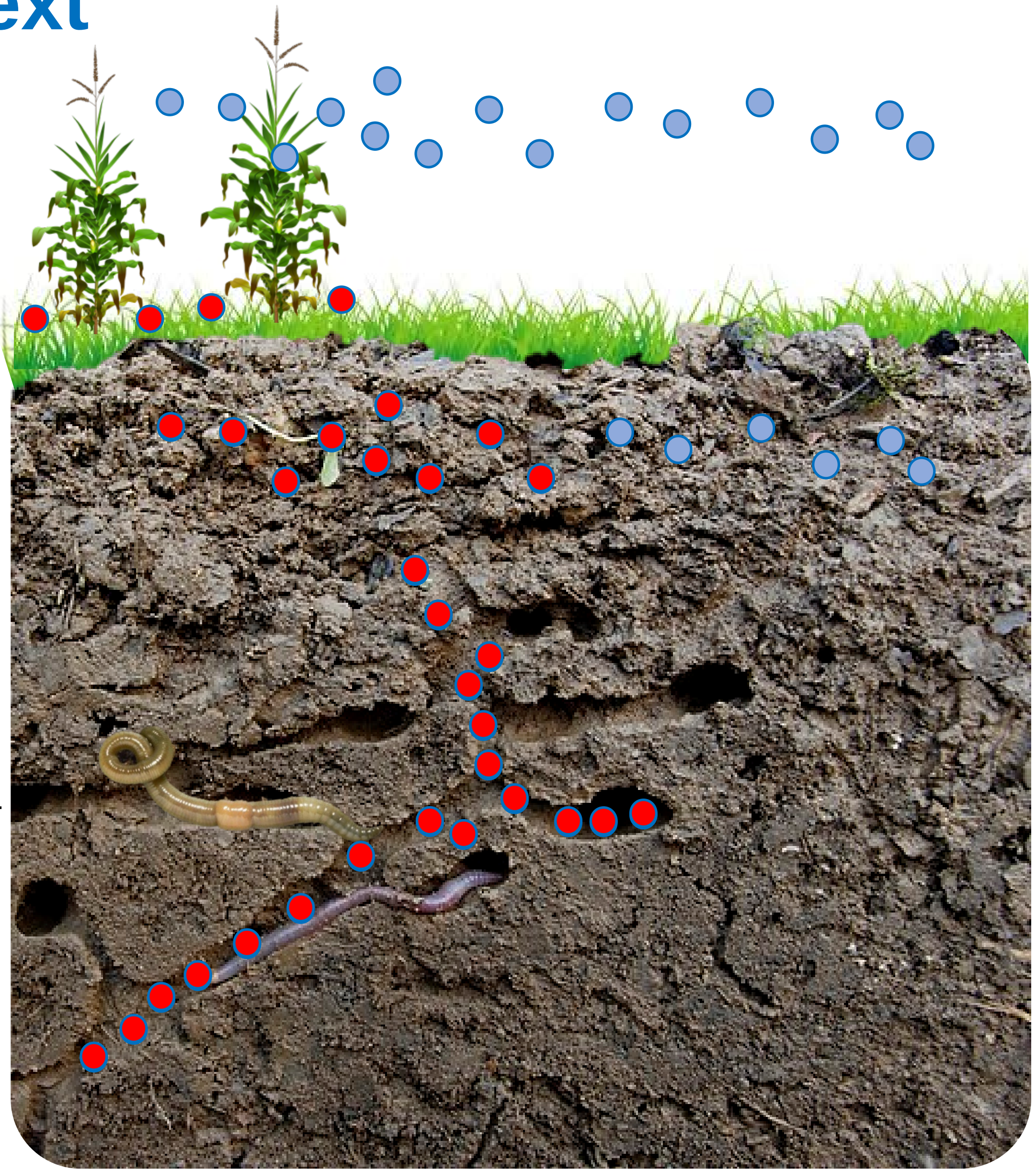

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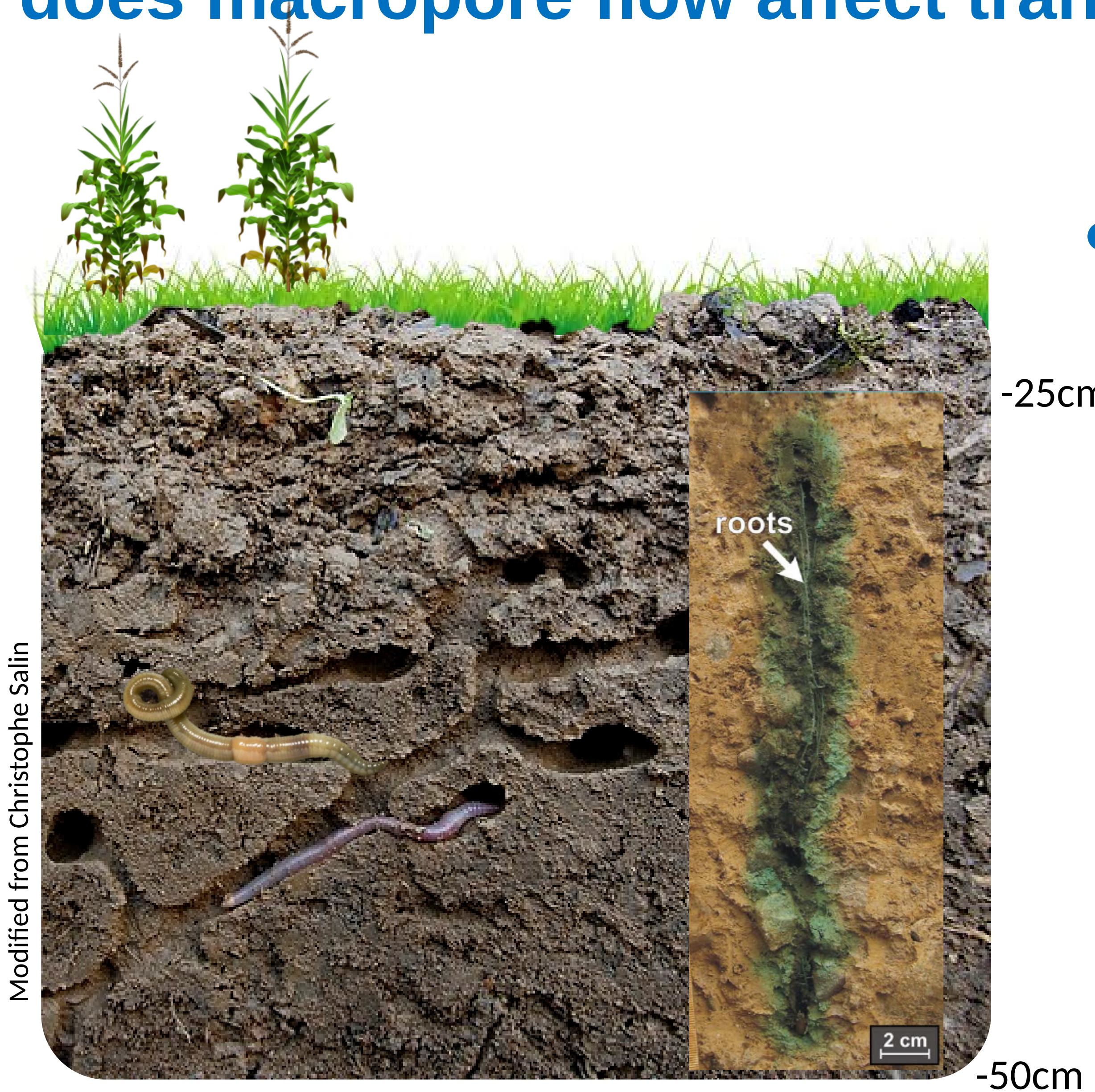
- **Long-term goal: coupled models of:**

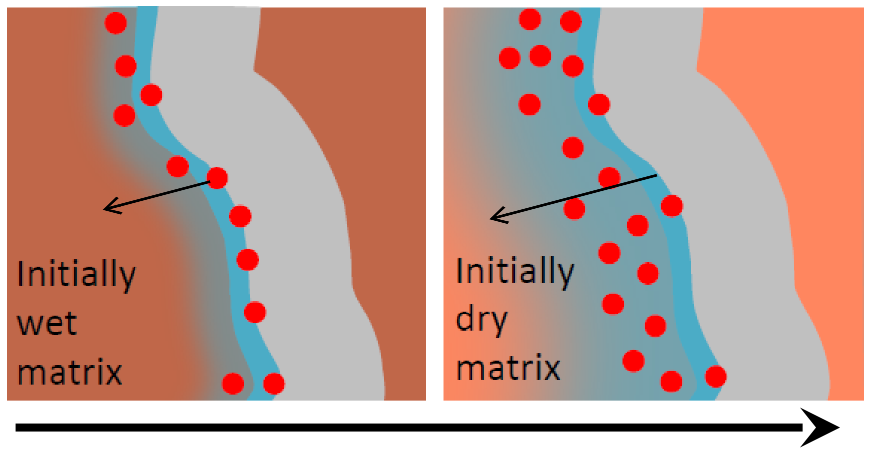
Earthworm Population Dynamics → Burrow characteristics → Water Transfers → Contaminant Fate

How does macropore flow affect transfers?



Cey et al.
J. Cont. Hydrol., **2009**

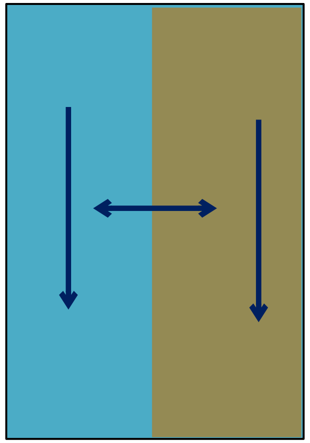
- **Macropore – matrix exchanges**
  - Water
  - Contaminants (solutes and colloids)



Van den Bogaert et al. *Geoderma.*, **2016**

Current coupled models of macropore & matrix flow

"Double permeability models"



macropores matrix

≈

Cey et al.
J. Cont. Hydrol., **2009**

• 1D compartment models

- matrix and macropore characterized by effective parameters
- Interface macropore—matrix not described explicitly

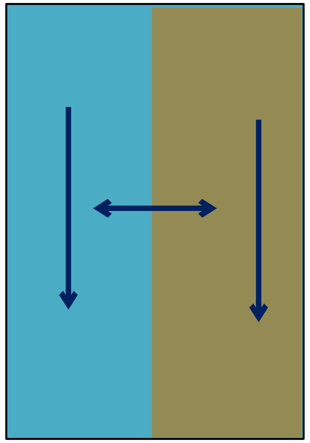
• Water transfer model outputs

- water content $\boldsymbol{\theta} = f(z,t)$
- flow rate $q = f(z,t)$

in each compartment

Current coupled models of macropore & matrix flow

"Double permeability models"



macropores **matrix**

$$q_{ma} = -b\theta_{ma}^{\boldsymbol{a}} - v_\theta \frac{\partial \theta_{ma}}{\partial z}$$

$$q_{mi} = -K_{mi}(\theta_{mi}) \frac{\partial (h - z)}{\partial z}$$

$$\frac{\partial \theta_x}{\partial z} = -\frac{\partial q_x}{\partial z} \pm S$$

• Water transfer models

- matrix : Darcy-Richards: $K(\theta)$, $\theta(h)$
- macropore: Kinematic (Dispersive) Wave: a, b, v_θ

• Water transfer model outputs

- water content $\boldsymbol{\theta} = f(z,t)$
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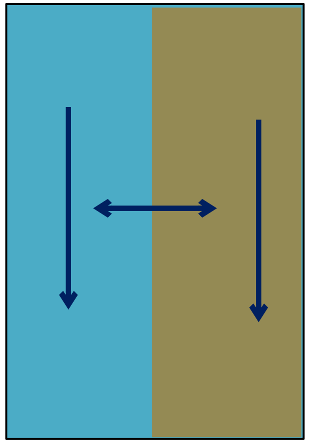
in each compartment

Coupled models of macropore matrix flow

"Double permeability models"



macropores **matrix**

$$S = \frac{K_{mi}(\theta_{mi})}{\boldsymbol{d}} \times \frac{-h}{\boldsymbol{d}} \times \frac{\theta_{ma}}{\boldsymbol{\theta_{ma\_max}}}$$

d = effective diffusion pathway
= half distance between macropores

• Water transfer models

- matrix : Darcy-Richards: $K(\theta)$, $\theta(h)$
- macropore: Kinematic (Dispersive) Wave: a, b, v_θ
- exchange term: 1st order approximate diffusion equation: d, θ_{ma_max}

• Water transfer model outputs

- water content $\boldsymbol{\theta} = f(z,t)$
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in each compartment

Current coupled models of macropore & matrix flow

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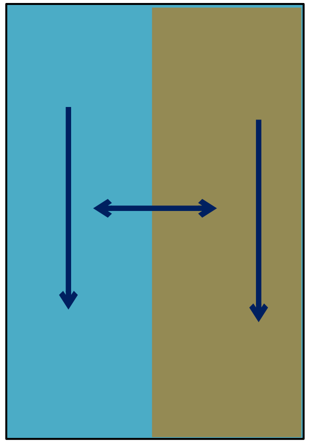

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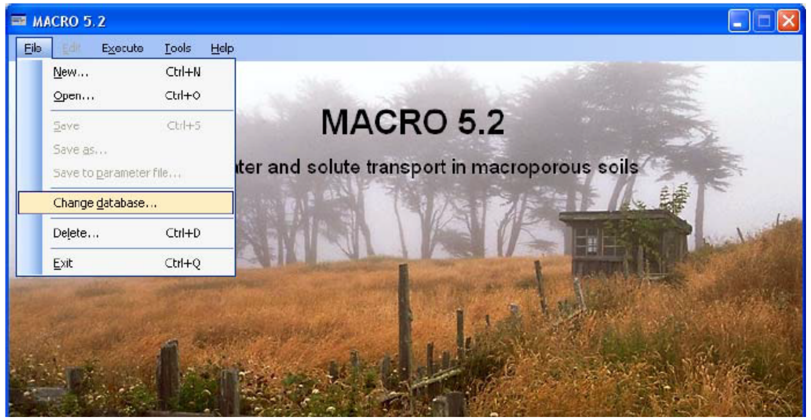
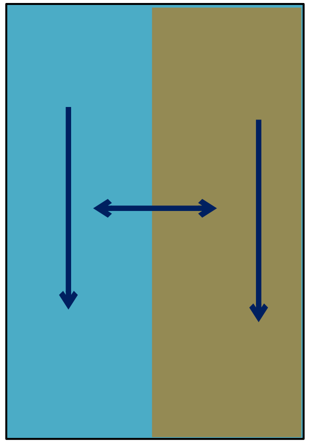


“The **initial "values of *d*** for the different layers based on visual observations of the soil structure **were increased considerably to obtain a better fit**”
(Larsson & Jarvis, J. Hydrol., 1999)

“A **value of 10 cm for d is considered large in relation to the size and scale of aggregation** in the Lanna clay soil. This suggests that some process or feature which restricts mass exchange between different pore classes is not included in the model.”
(Saxena, Jarvis, Bergström, J. Hydrol., 1994)

Current coupled models of macropore & matrix flow

"Double permeability models"



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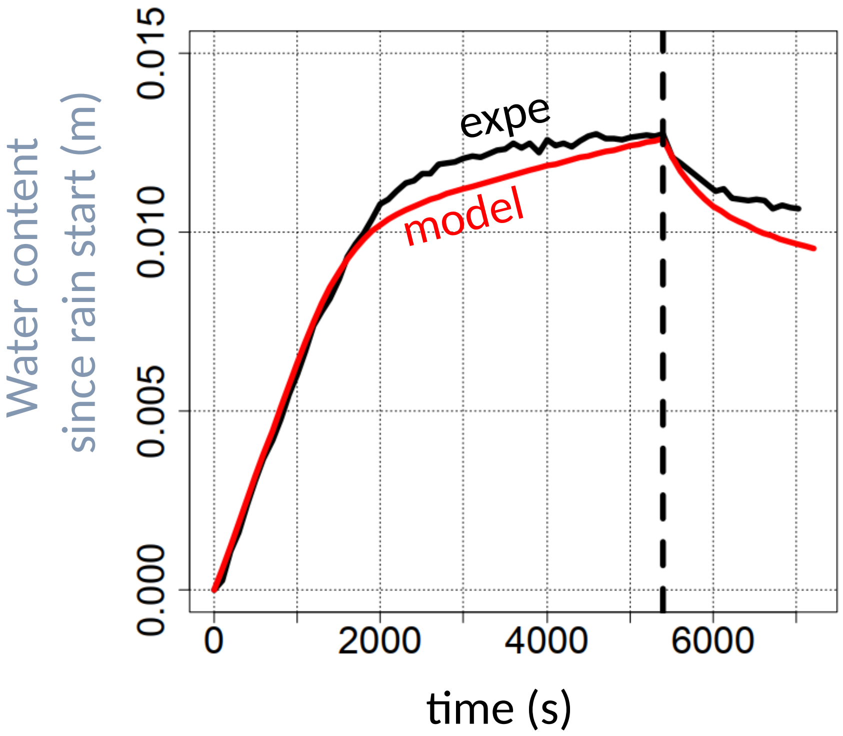
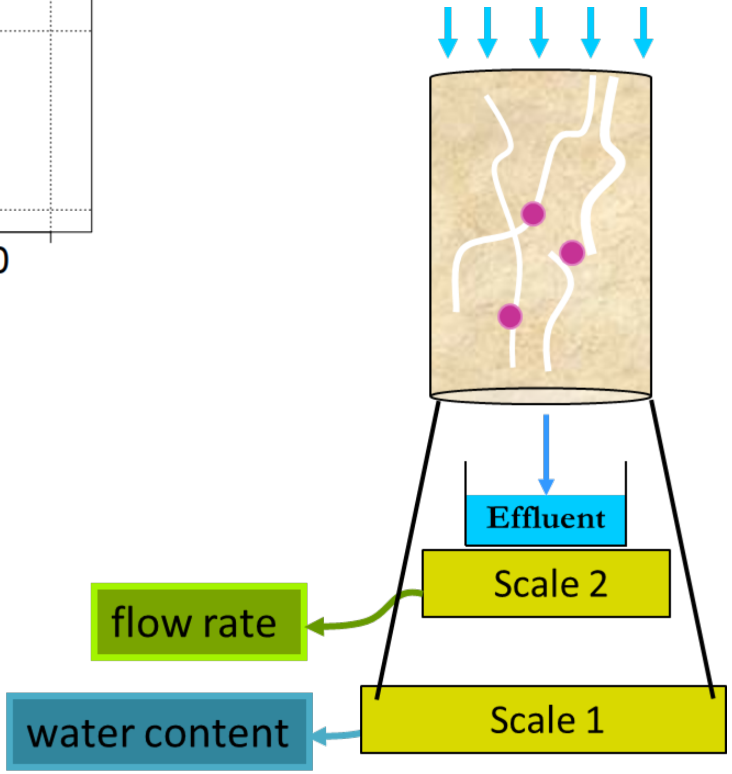
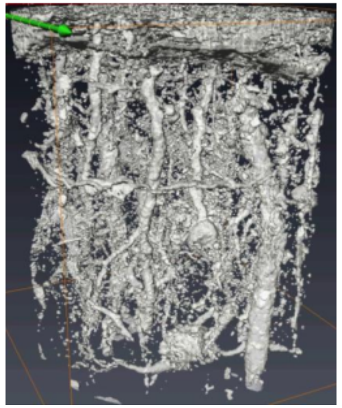


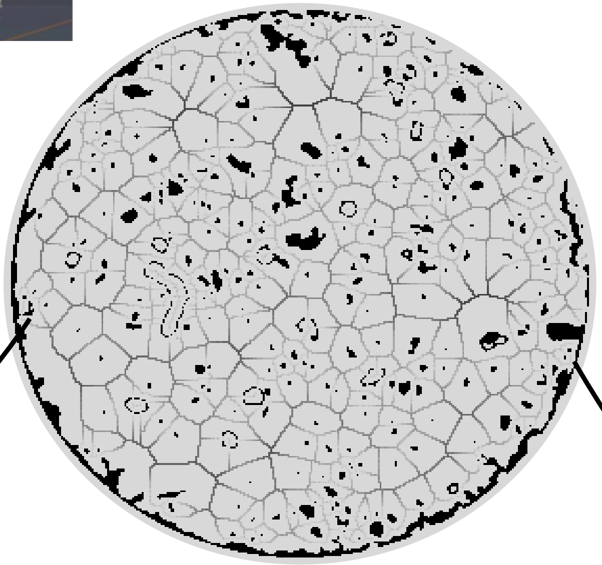
Lissy et al. *Geoderma.*, ***2020***



Coupled models of macropore matrix flow



X-ray CT → Macropores



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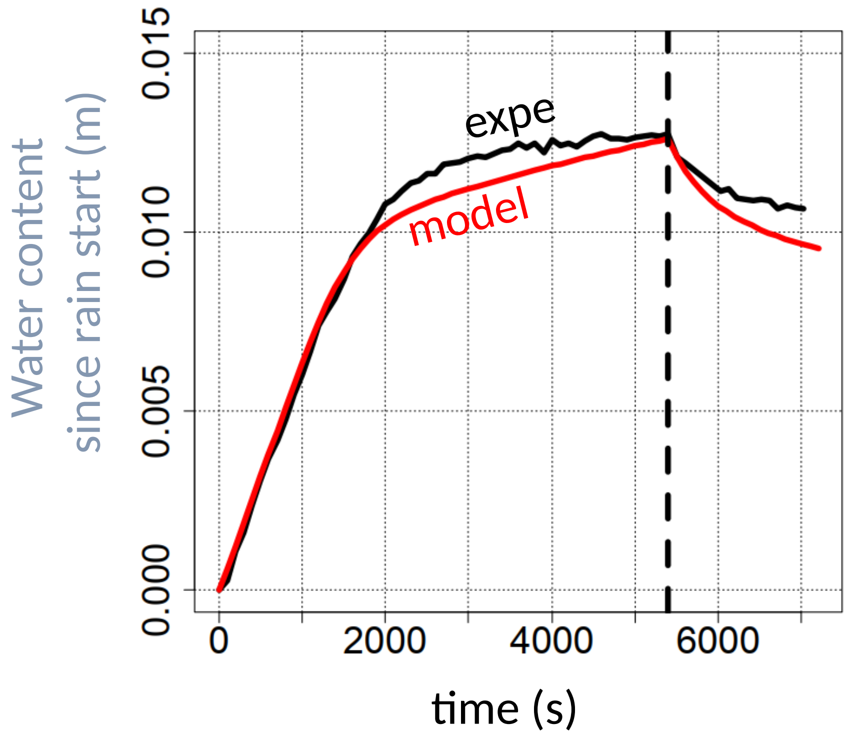
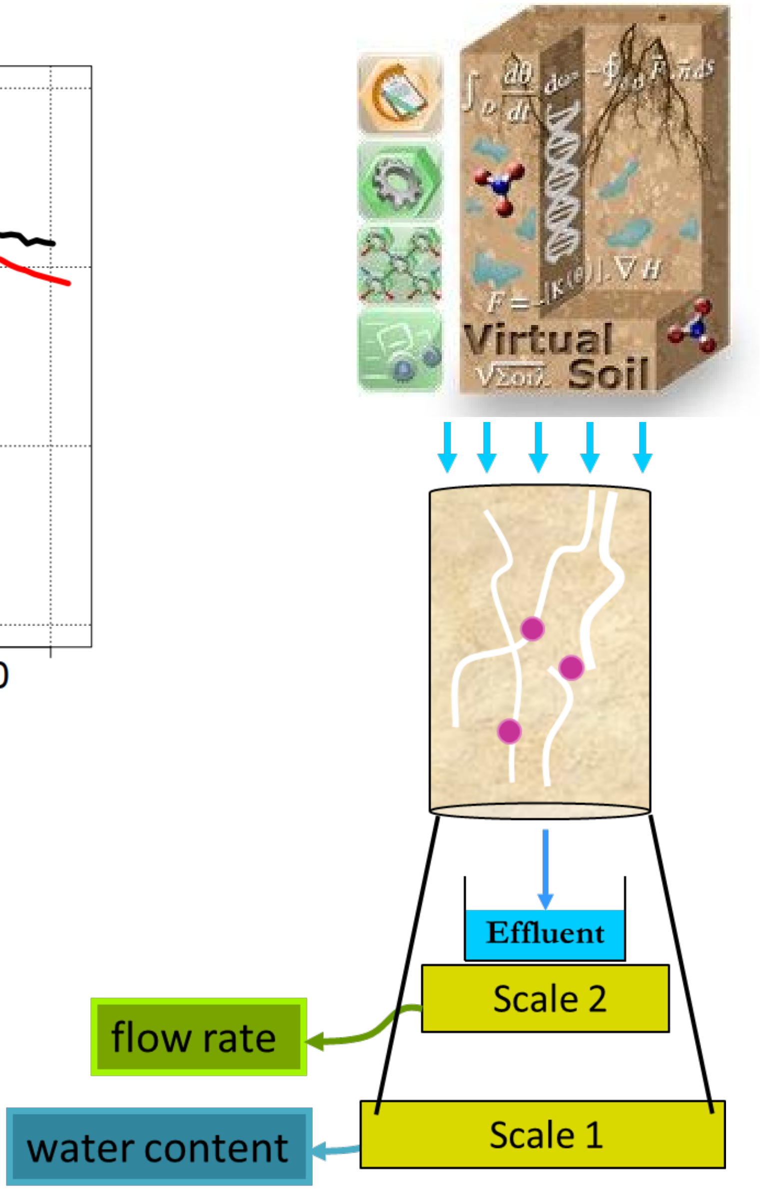


Calibrated to fit exp. data
$\boldsymbol{d = 6.6}$ **cm**

Lissy et al. *Geoderma.*, ***2020***



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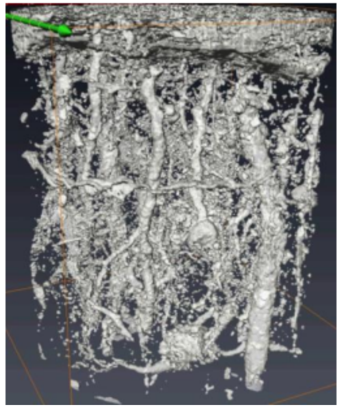

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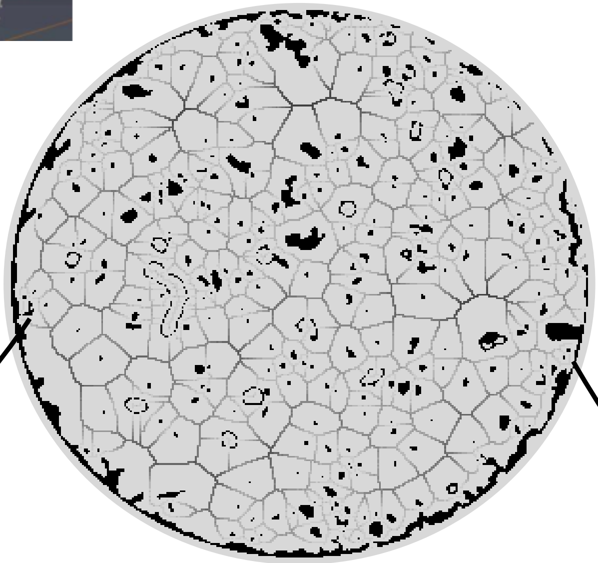

$$S = \frac{K_{mi}(\theta_{mi})}{d} \times \frac{-h}{d} \times \frac{\theta_{ma}}{\theta_{ma\_max}}$$

d = effective diffusion pathway
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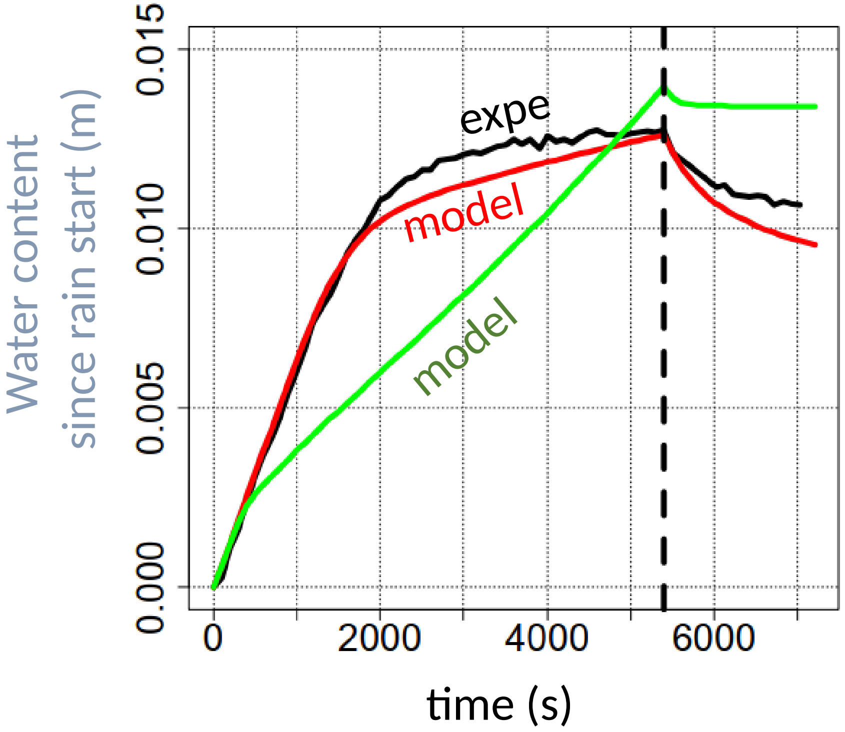
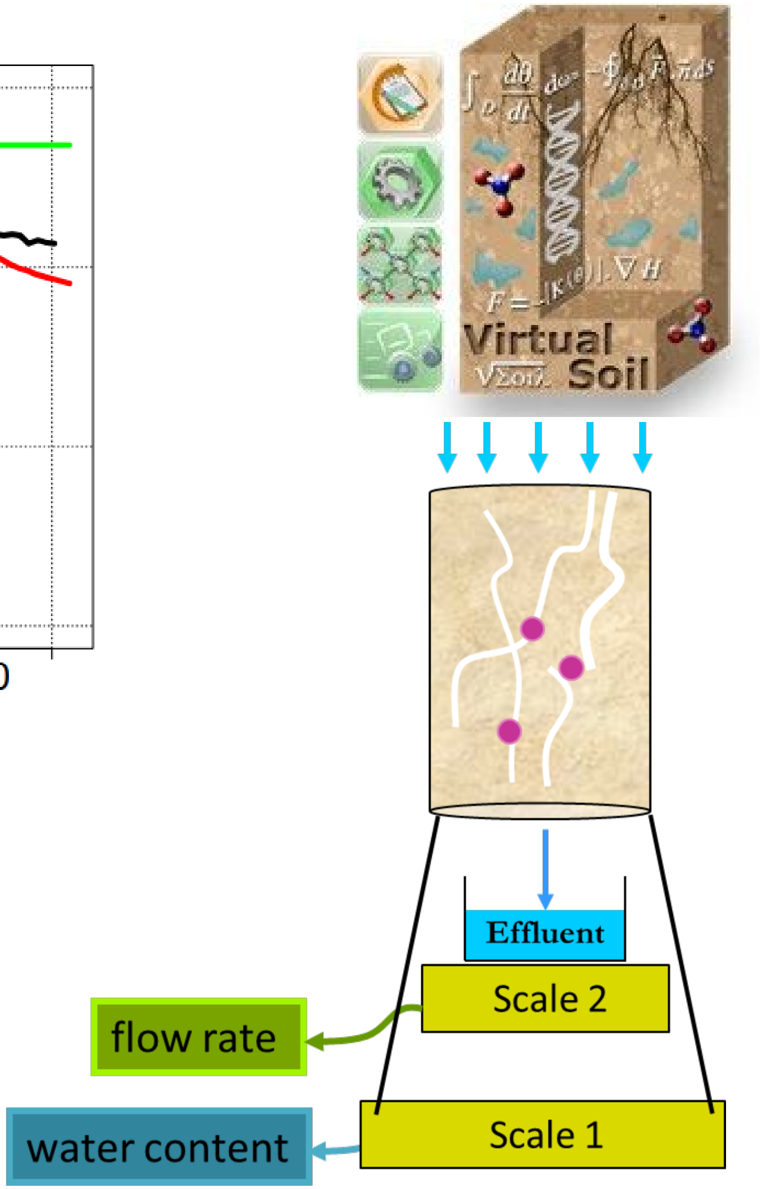


Calibrated to fit exp. data
$d = 6.6$ cm

Determined from X-ray CT images
d = 0.7 cm

Lissy et al. *Geoderma*., ***2020***



Current coupled models of macropore & matrix flow: bottom line

● Measured d values lead to overestimated water transfer from macropore to matrix

● ***d* has a physical meaning, but is calibrated** to fit the data.

● Precludes the possibility to determine *d* values from :

Experimental data

Another model

Earthworm Population Dynamics → Burrow characteristics → Water Transfers → Contaminant Fate

$$S = \frac{K_{mi}(\theta_{mi})}{\boldsymbol{d}} \times \frac{-h}{\boldsymbol{d}} \times \frac{\theta_{ma}}{\boldsymbol{\theta_{ma\_max}}}$$

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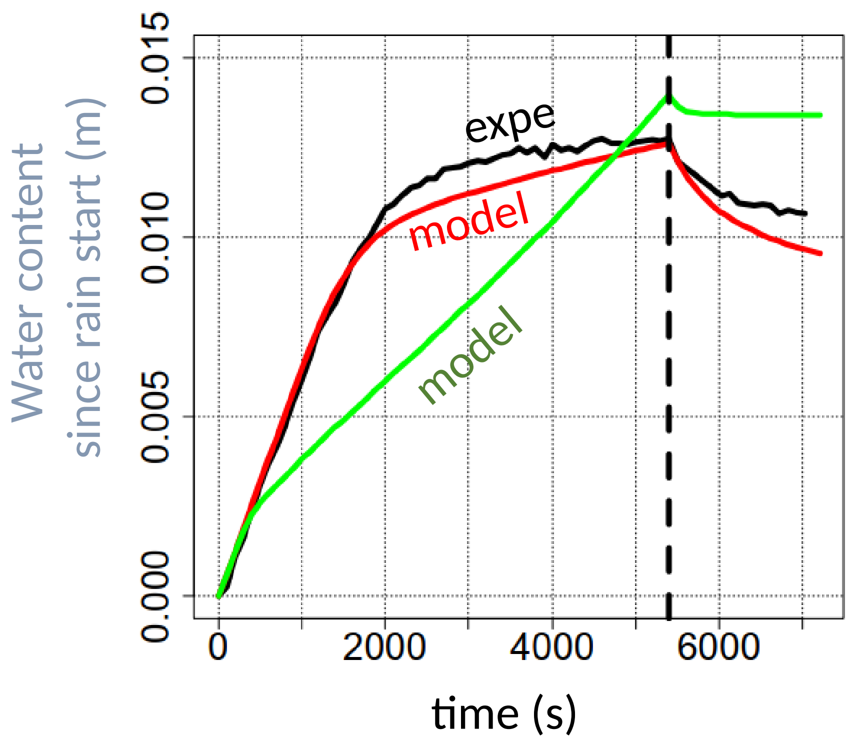

● Issue stems from the form of the **first-order exchange term**: **Does not capture completely the exchange dynamics.**

● Way out: 3D model ?

A new — pseudo 2D — model of macropore & matrix flow

Cey et al.
J. Cont. Hydrol., **2009**

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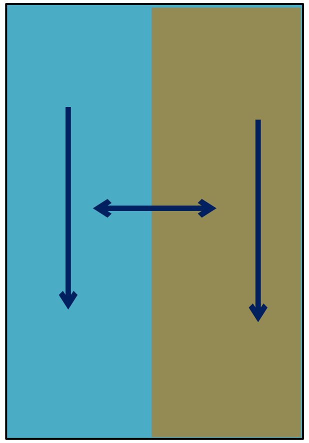
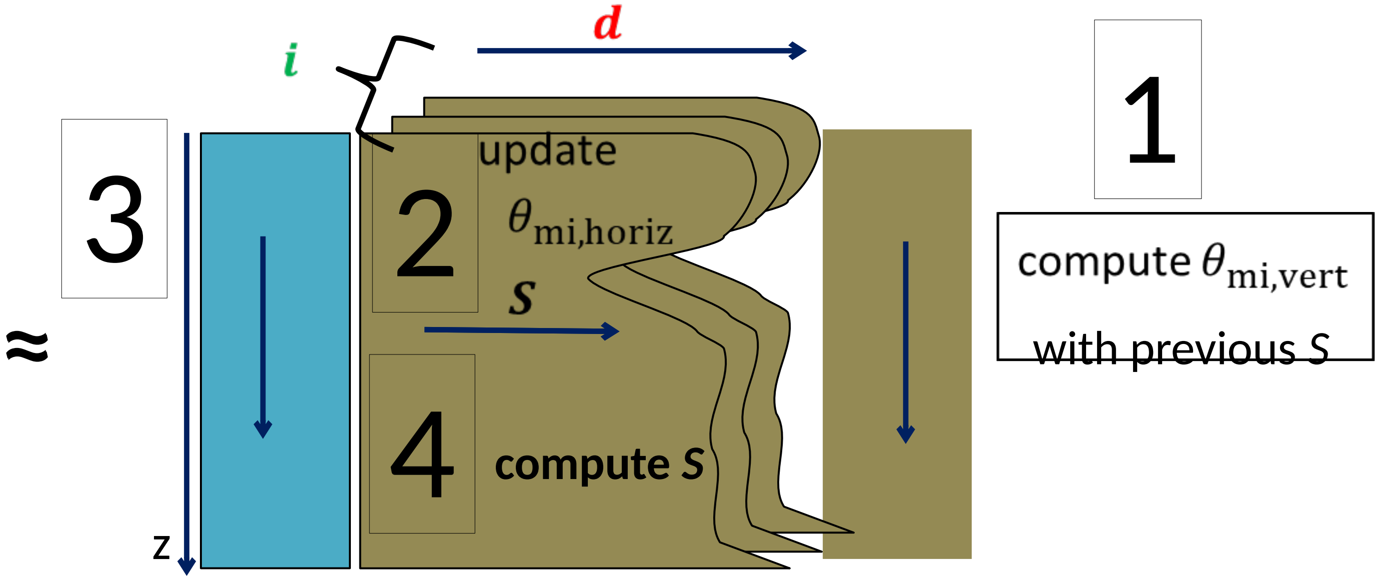


macropores **matrix**

A new — pseudo 2D — model of macropore & matrix flow

Two representations of matrix to keep memory of water distribution in the matrix

Cey et al.
J. Cont. Hydrol., **2009**



macropores
Kinematic
Dispersive Wave

matrix
Horizontal
Richards equation

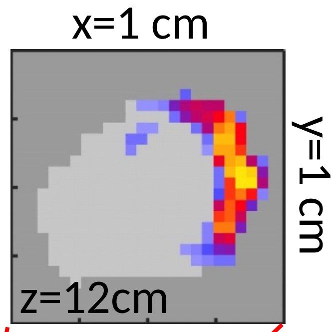
matrix
Vertical
Richards equation

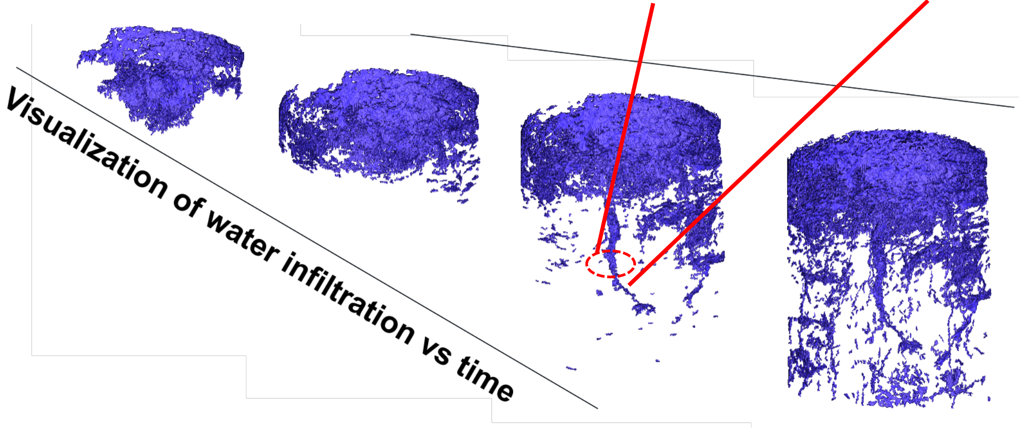
$S(z) = \sum_i$ (difference between water content at t and t+dt)$_i$ x (**Exchange Surface**)$_i$

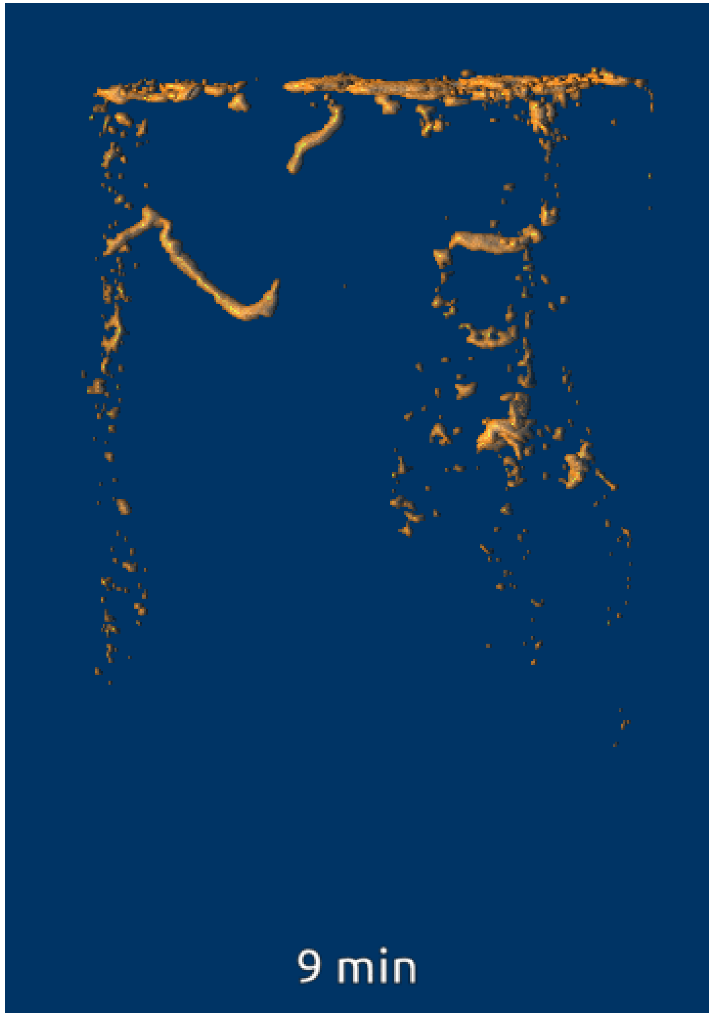
$m^3_{eau}\ s^{-1}\ m^{-2}_{sol}$ $m^2_{sol}\ m^{-3}_{sol}$

A new — pseudo 2D — model of macropore & matrix flow

Besoin de connaitre la surface d’échange en fonction de la teneur en eau des macropores







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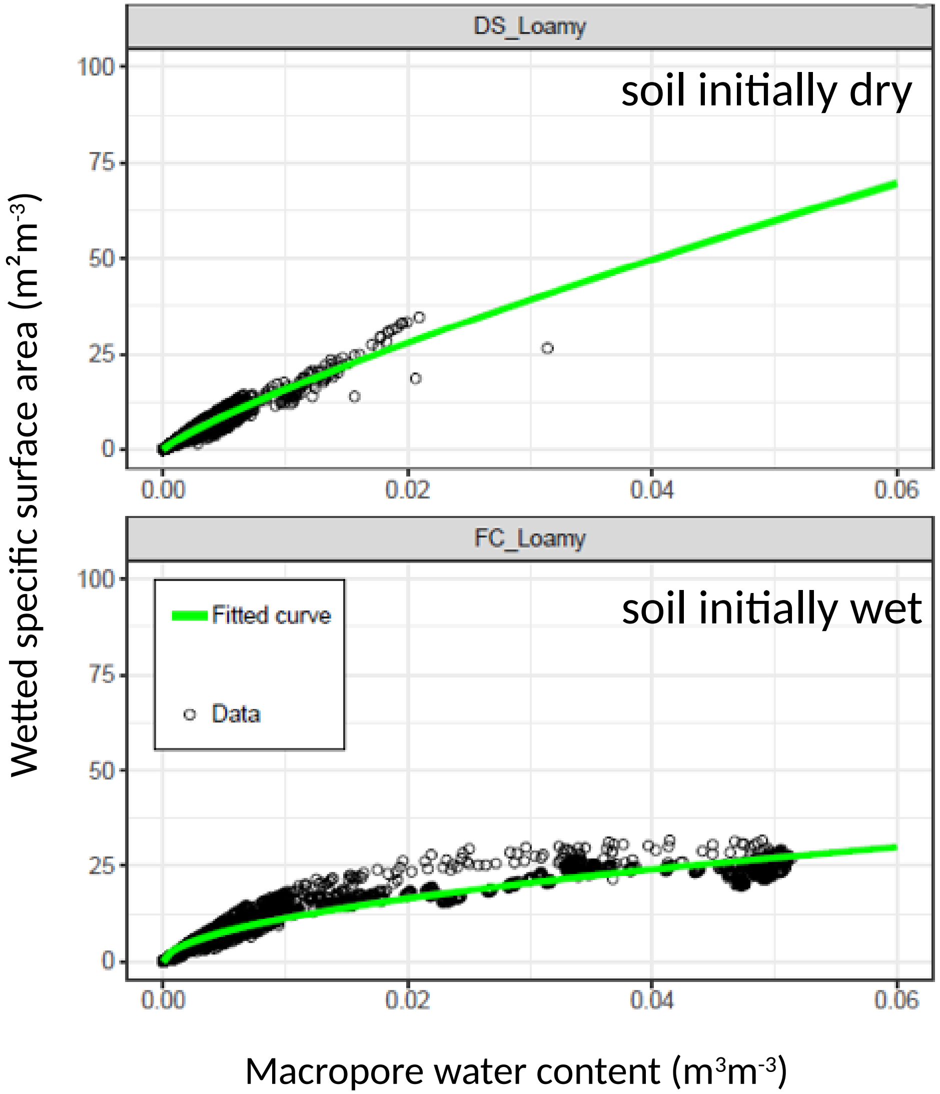


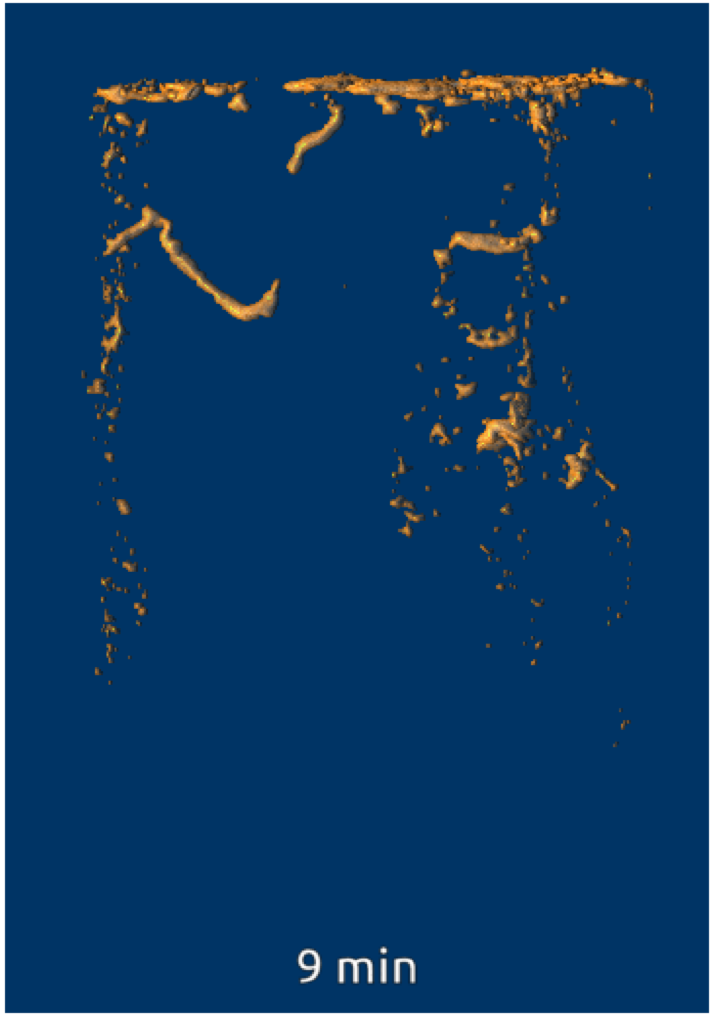
Exchange Surface:

$$A_{exch} = \gamma \theta_{mac}{}^{\beta}$$

Beta linked to kinematic expinent a :

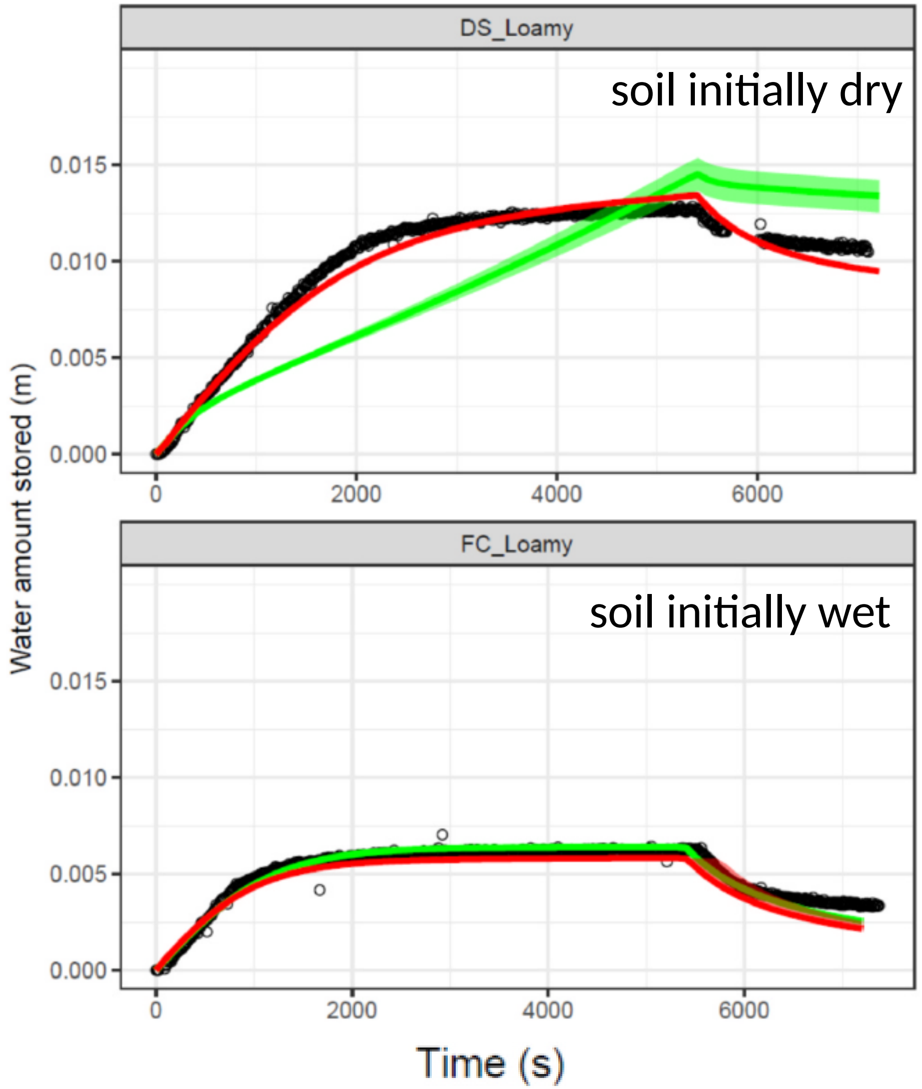
a =3- 2 β

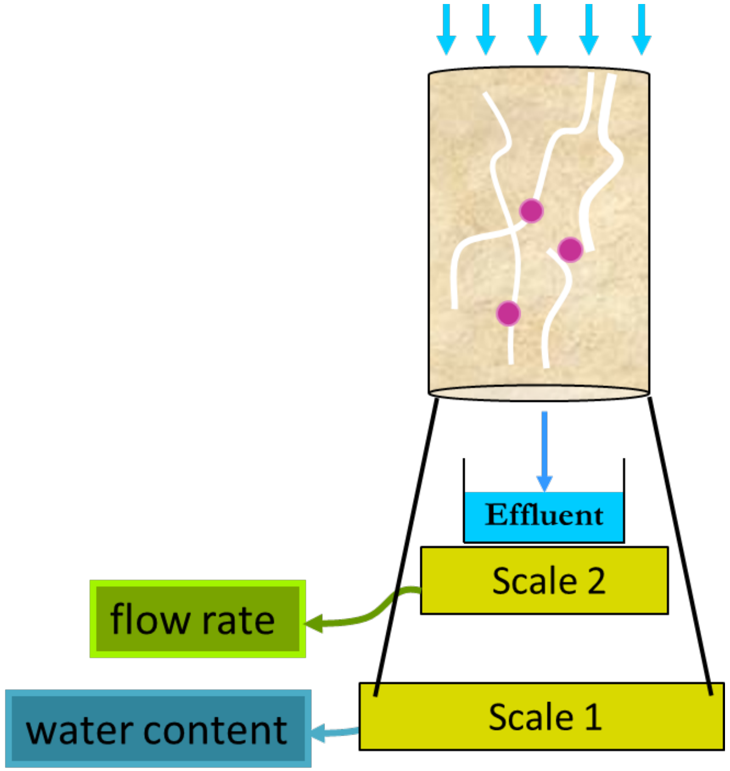
Jarvis et al., 2017



A new — pseudo 2D — model of macropore & matrix flow

seven parameters: $d(z)$, $\theta_{ma,max}(z)$, a, b, ν , β and γ Determined from X-ray CT calibrated





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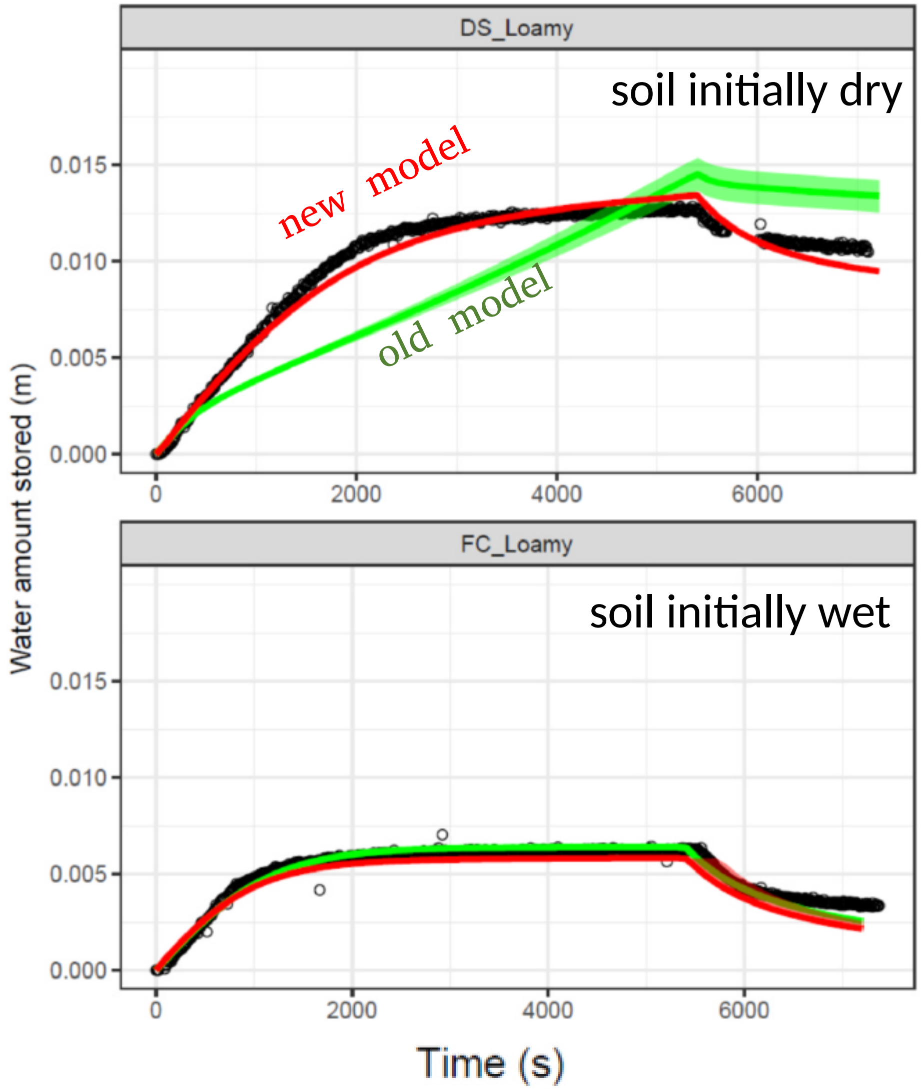
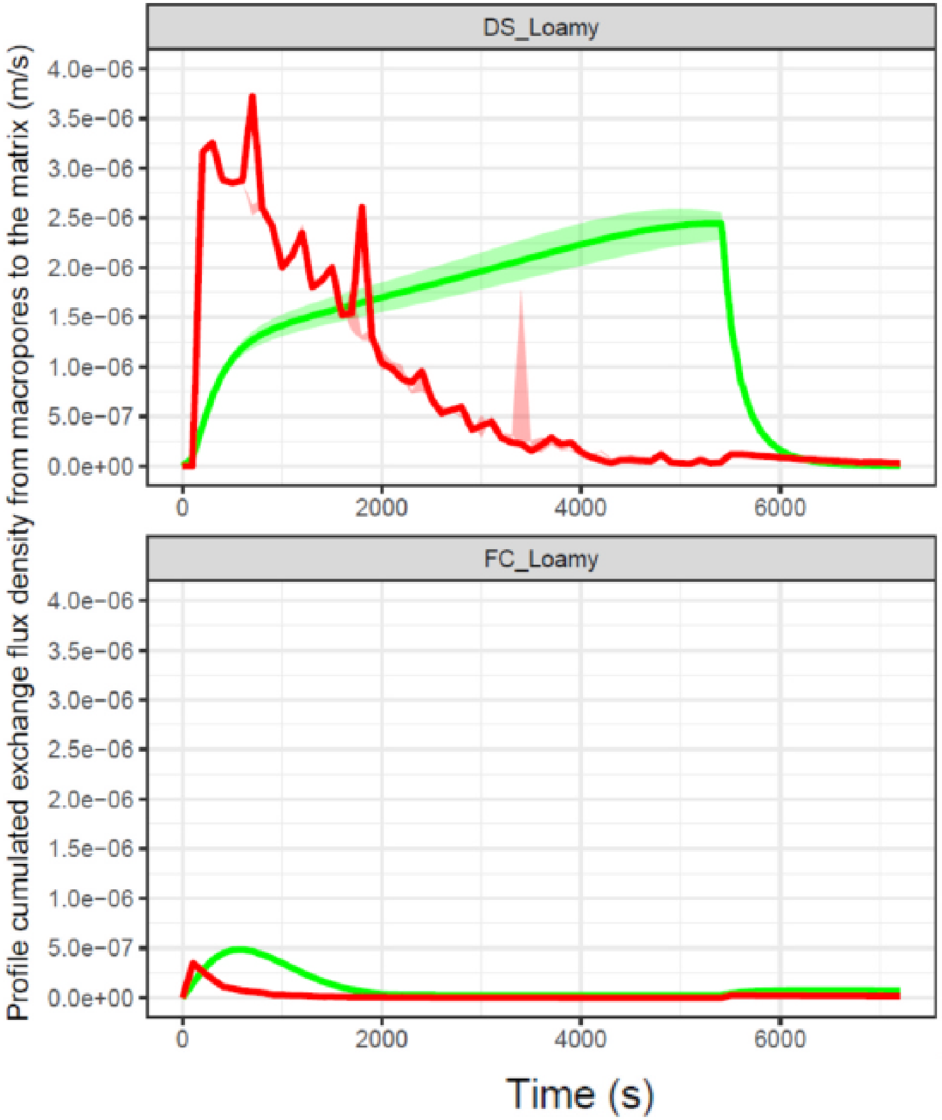
Water storage (m)



Water exchange flux (m s^{-1})

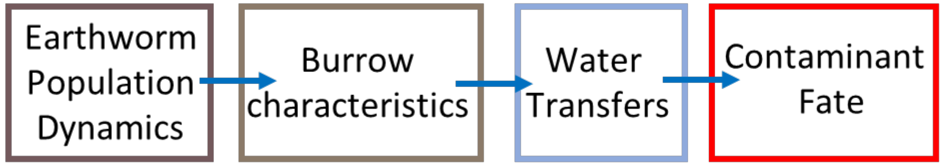


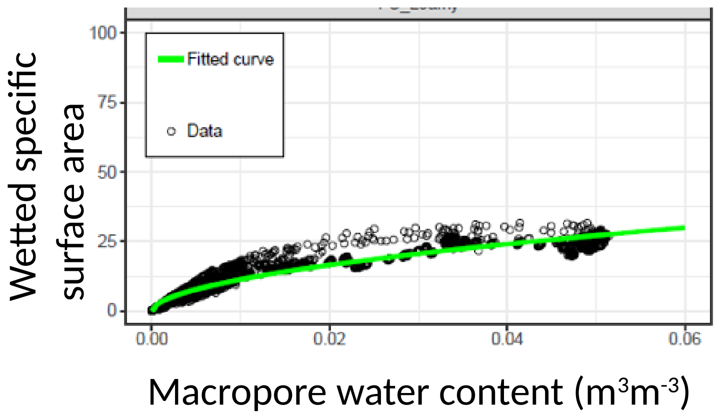
Conclusion

The new model:

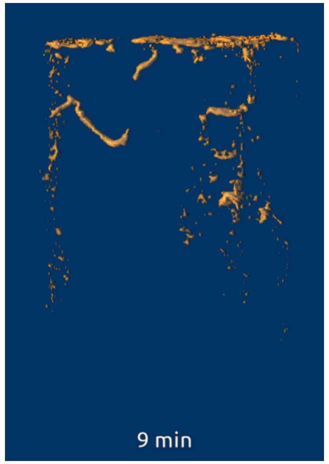
● considers the horizontal **heterogeneity of water content** in the soil matrix without computationally-intensive and difficult to parameterize full 2D or 3D models

● opens up the possibility to use **measured or modeled *d* values**, that can evolve as the soil macroporosity changes under the influence of roots or earthworms.





● highlights **research needs**: relationship between the wetted macropore exchange surface and the water content of the macropores as a function of soil type, boundary conditions (rain intensity) and initial water content.



● Features the value of combining transfer modelling with the rich —but partial— spatiotemporal information obtained by X-ray CT.

$$A_{\text{exch}} = \gamma \theta_{\text{mac}}{}^{\beta}$$

$$A_{exch\_max} = \frac{1}{d}\left(1 - \theta_{\text{ma,max}}\right)$$

$$\gamma = \frac{1}{d}\frac{1}{\theta_{\text{ma,max}}^{\beta}}\left(1 - \theta_{\text{ma,max}}\right)$$