Quantification of environmental risks in contaminated sites – transport of solutes and solids in structured soils

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Content of the presentation

- Properties of climate and soils in Nordic countries
- Computational modelling basics
- FLUSH model
- Example application of the solute transport model
- Example application of the hydrological model (snow melt)
Hydrology in Nordic conditions

Kirkkojoki stream in Siuntio during snow melt in southern Finland.

The same stream in summer looks quite different (Nurminen, J.).
Structured soils in Nordic conditions

Dry and moist clay. Earthworm burrow and a root channel (Paasonen-Kivekäs, M.). Till soil with various particle sizes.
Preferential flow and transport

D1: Dry soil; before infiltration
D2: Transport through matrix pores
W1: Wet soil; before infiltration
W2: Matrix transport mainly through large pores (light rain)
W3: Preferential flow transport through macropores (heavy rain)
Computational modelling

\[ \frac{\partial h}{\partial t} + \frac{\partial h}{\partial x} + \frac{\partial s}{\partial y} = S \]

\[ S_w = S_u, \quad \frac{\partial h}{\partial x} \quad \text{and} \quad S_n = S_v, \quad \frac{\partial h}{\partial y} \]

\[ v = \frac{g}{\sqrt{\gamma}} \]

\[ \frac{\partial \theta}{\partial t} + \frac{\partial (\theta s)}{\partial x} = \frac{1}{\gamma} \left[ K_{s} (\theta_s \left( \frac{\partial h}{\partial x} \right)^2 + 1) - S_n + \frac{\Gamma}{1-w} \right] \]

\[ \frac{\partial \theta}{\partial t} + \frac{\partial (\theta s)}{\partial x} = \frac{1}{\gamma} \left[ K_{s} (\theta_s \left( \frac{\partial h}{\partial x} \right)^2 + 1) - S_n + \frac{\Gamma}{1-w} \right] \]

\[ \Gamma_e = a_e (b_e \cdot h_e) \quad a_e = \frac{\beta}{\alpha} K_{s} \]

\[ K_{s} = 0.2 (K_{s1}(b_{s1}) + K_{s2}(b_{s2})) \]

\[ \frac{\partial (\theta_s \cdot \epsilon)}{\partial t} + \frac{\partial (\theta_s \cdot \epsilon)}{\partial x} = \frac{1}{\gamma} \left[ \theta_s D_e \frac{\partial \theta_s}{\partial x} - \phi_s - \frac{\Gamma}{w} \right] \]

\[ \frac{\partial (\theta_s \cdot c_e)}{\partial t} + \frac{\partial (\theta_s \cdot c_e)}{\partial x} = \frac{1}{\gamma} \left[ \theta_s D_e \frac{\partial \theta_s}{\partial x} - \phi_s + \frac{\Gamma}{1-w} \right] \]

\[ \Gamma_e = a_e (1 - w_e) \left[ K_{s1}(b_{s1}) + K_{s2}(b_{s2}) \right] \]

\[ a_e = \frac{\beta}{\alpha} D_e \quad D_e = 0.5 (D_s + D_w) \]

Mathematical formulation of the problem.  
Numerical solution of the mathematical formulation.  
Simulated solutions to the original problem.
FLUSH model

Overland domain
Suspended sediment
Water
Infiltration
Subsurface domain
Matrix system
Macropore system
Cutout

Water flow
Sediment transport

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Winter time processes in FLUSH

Conceptual figure of the winter time processes. The right side of the figure depicts conditions when the temperature is below freezing point. The left side describes the melt period.
FLUSH benchmark applications

Field scale simulations (e.g., Turunen et al., 2013).

Laboratory scale simulations (e.g., Kesäniemi, 2009).

Analytical models (e.g., Warsta et al., 2013).
Solute transport simulation example

Photograph of the simulated area (4.7 ha).

Simulated area is marked with a red outline.
Solute transport simulation example (2/6): Input data

Websites of National Land Survey of Finland, Finnish Meteorological Institute and PalTuli spatial data service. The site features were drawn in Quantum GIS.
Solute transport simulation example (3/6): Applied model types

Single pore system model.

Dual-porosity model.

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Solute transport simulation example (4/6):
Model setup

Single pore system model (1 h).

Dual-porosity model (1 h).
Solute transport simulation example (5/6):

Animated simulation results

Single pore system model (1-100 h).

Dual-porosity model (1-100 h).
Solute transport simulation example (6/6): Discussion of the results

Single pore system model (100 h).

Dual-porosity model (100 h).
Snow and runoff simulation example

The field site in Kirkkonummi in southern Finland. Snow water equivalent was measured at points T1 and T2.

Aerial view of the site. Field area is outlined in red.
Snow and runoff simulation example (2/3):

Snow accumulation and snow melt

Measured (red dots) and simulated (blue line) snow water equivalents (SWE) [m] in Kirkkonummi in southern Finland.
Snow and runoff simulation example (3/3):

Surface runoff and drainflow

Measured and simulated surface runoff (red) and drainflow (blue) [mm] in Kirkkonummi in southern Finland.
Conclusions

• Computational modelling is a powerful tool in solute transport studies

• Inclusion of the relevant processes key to successful simulations
  ➢ Long terms simulations require description of winter time processes
  ➢ Structured soils require description of preferential flow and transport in macropores

• FLUSH model was introduced which includes these processes
  ➢ The model is well suited for simulation of complex multispecies transport, e.g. from munitions fragments
Thank you! Questions or suggestions?

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Measuring instruments are also interesting to cows (Nurminen, J.).