Selected applications of HYDRUS models to evaluate uniform and nonequilibrium flow in structured soils

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Objectives
- Non-equilibrium water flow and solute transport in soils
- Models of water flow and solute transport in soils
- Examples of observed and simulated water flow and pesticide transport

Objectives
- Example of observed and simulated water flow and metal transport + root uptake
- Interaction between domains - parameter identification
- Other applications of HYDRUS programs

Equilibrium and non-equilibrium water flow
- Equilibrium water flow – one continuum (single domain approach)
- Non-equilibrium water flow – multiple continuum (multiple domain approach)
  - Immobilization of water and solute in isolated pore domains (soil aggregates)
  - Preferential flow of solute transport through fractures, gravitational pores, large capillary pores
Non-equilibrium flow detection and visualization

- Dye experiments
- Computer tomography
- Nuclear magnetic resonance
- Micromorphological images
- Water flow and tracers experiments
  - Breakthrough curves
  - Tracer concentrations in soil water

Visualization of non-equilibrium flow

- Solute of dye Brilliant Blue FCF (5g/litr)
- 100 x 100 cm plot
- **Haplic Luvisol** - 100 liters, initial ponding depth of 10 cm
- **Haplic Cambisol** - 50 liters, initial ponding depth of 5 cm
- Horizontal and vertical sections to the depth of 100 cm


Dye tracer patterns

**Haplic Luvisol** (loess)  **Haplic Cambisol** (orthogneiss)


Dye tracer patterns

**Haplic Luvisol**

- **Ap1** - regularly distributed + some isolated domains
- **Ap2** (plow pan) - compact matrix structure with the gravitational biopores
- **Bt1** and **Bt2** - the gravitational biopores and prismatic structure affected by clay coatings

**Dye tracer patterns**

**Haplic Luvisol**
- Bt1 and Bt2 - the gravitational biopores and prismatic structure affected by clay coatings

**Haplic Cambisol**
- Ap, Bw, C
  - compact structure
  - dye tracer distribution affected by the gravitational fractures and biopores

**3D image reconstruction**

**Haplic Luvisol**
- Image processing using JMicroVision
- Threshold filtering
- 3D image rendering using ArcGIS 3D Analyst
  - Raster processing
  - Raster to vector conversion
  - 2D to 3D conversion
  - 3D GIS to VRML conversion
- 3D Visualisation using VRML viewer

**Micromorphological images**

**Haplic Luvisol**
- Undisturbed soil samples using the frame $12 \times 8$ cm
- Thin soil sections
- Bt2 - depth of 100 cm
- Large biopore, clay coating

Micromorphological images

**Haplic Luvisol**

- **Ap1**: 13 - 21 cm
- **Bt1**: 43 - 51 cm


**Haplic Cambisol**

- **Ap**: 10 - 18 cm
- **Bw**: 50 - 58 cm
- **C**: 85 - 93 cm


**Soil structure impacted by soil management**

**Haplic Luvisol**

- **Arable land**: A1 0-25 cm
- **Permanent grass**: A1 0-10 cm

Physical equilibrium and non-equilibrium models

- **Single-porosity model**
  - One flow domain
  - Richards equation (RE) and advective-dispersion equation (ADE)

- **Dual-porosity model**
  - Mobile domain - Set of equations: RE and ADE
  - Immobile domain - Mass balance equations
  - Mass transfer equations

- **Dual-permeability model**
  - Matrix domain - Set of equations: RE and ADE
  - Macropore domains - Set of equations: RE and ADE
  - Mass transfer equations

Chlorotoluron transport in soils field experiment

- 4 m² – 2 liters of solution
- Soil sampling 5th, 13th and 35th day
- Chlorotoluron concentration in methanol extract using HPLC


Chlorotoluron transport in soils field experiment – Greyic Phaeozem

- **Observed data**
- **Single-porosity model**
- **Dual-permeability model**

- Fraction of large pore domain – micromorphological images
- Larger capillary pore pathways and sufficient infiltration fluxes that occasionally filled up these pores

**Chlorotoluron transport in soils laboratory experiment**

- Applied chlorotoluron solution: 10 cm³, c = 198 g cm⁻³
- Ponded infiltration
- Cumulative infiltration and outflow
- Pressure heads
- Outflow solute concentrations using HPLC


**Chlorotoluron transport in soils laboratory experiment – Haplic Luvisol - Bt2**

- SP – single-porosity
- DP – dual-permeability + two-site sorption model


**Modelling of Cd, Cu, Pb and Zn transport in metal contaminated soil and their uptake by willow**

- Applied Irrigation
- Monitored outflow + metal concentrations
- Monitored average soil water content
- Final metal content in soil and plant
- HYDRUS-2D (3D) parameter identification - quasi-three dimensional system

Modelling of Cd, Cu, Pb and Zn transport in metal contaminated soil and their uptake by willow

- Single porosity model
- Single porosity model – no anisotropy
- Single porosity model – anisotropy – vertical Ks 10 time higher than horizontal Ks
- Dual porosity
  - Mobile domain
  - Immobile domain


Interaction between domains - parameter identification

Water flow – parameter determination

- Control - Single porosity
- Vegetation - Dual porosity


Water flow – parameter determination

- Single-porosity
- Dual-permeability – fast interaction between macropore and matrix domain


Permeability of aggregate coatings

- Retention curve measured on each aggregate
- Cumulative capillary rise – multiple aggregates without and with coatings


Applied Pressure Head -5 cm

Observed aggregates without coatings
Simulated - optimized Ks, aggr
Observed aggregates with coatings
Simulated - optimized Ks, coat

RETC – optimization of parameters of SWRC
HYDRUS-1D optimized Ks values

Other applications of HYDRUS programs

Water flow and Al transport in forest soils

- Beech forest
- Uneven water distribution
- Parameter identification
- HYDRUS-1D a HYDRUS-2D

Nikodem et al. (2010): Vadose Zone Journal, 9, 238-251

Water flow and Al transport in forest soils

- Pressure head distribution – even (left); stemflow, throughfall (right)
- Al concentrations – even (left); stemflow, throughfall (right)

Fly-ash transport

- Fly-ash applied at the top
- Parameter identification
- HYDRUS-1D


3 sands of various particle size distribution
- 0.10-0.63 mm; 0.315-0.80 mm; 0.63-1.25 mm


Thank you for your attention