Foreseeing nitrate concentration in groundwater: A review of available modelling approaches

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Context:

- Increasing deterioration of groundwater quality due to nitrate diffuse pollution
- Need for groundwater management to implement policy
- Statistical tools are generally poorly adapted to prediction
- Need to link changes in land use and groundwater quality trends

Objectives:

- Develop and apply modelling application for groundwater quality trend assessment and prediction at the regional scale
Scale: from a few 100 to several 1000 km²
Challenges

Parameterization/ Calibration of groundwater flow and transport at regional scale

- Conceptual model / objective function
  - Model complexity $\leftarrow \rightarrow$ model objectives
  - Data requirements $\leftarrow \rightarrow$ data availability
- Groundwater quantity
  - Groundwater levels: usually available
  - Base flow / GW fluxes: case specific
- Groundwater quality
  - Contaminant transport: usually site-scale, few information at regional scale
<table>
<thead>
<tr>
<th>Available modelling approaches</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| **Black box models**          | • Easily used  
• Few parameters | • Results not spatially distributed  
• Lower predictive capability |
| **Distributed black-box models** | • Easily used  
• Few parameters  
• Results spatially distributed | • Lower predictive capability |
| **Distributed physically based models** | • Results spatially distributed  
• Good predictive capability | • Large amount of parameters required |
The Hybrid Finite Element Mixing Cell approach

Physically-based, spatially-distributed, variably saturated subsurface model

- Control volume finite element code SUFT3D (University of Liège)
- For large-scale applications
  - Flexible discretization / meshing approach
  - Mathematical models of various complexities for flow and transport

<table>
<thead>
<tr>
<th>FLOW</th>
<th>TRANSPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Reservoir (Linear…)</td>
<td>OK</td>
</tr>
<tr>
<td>Distributed Reservoir (Linear…)</td>
<td>impossible</td>
</tr>
<tr>
<td>Flow in porous media</td>
<td>impossible</td>
</tr>
</tbody>
</table>

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**Groundwater quality**: Intensive agriculture (65% of the basin) nitrate concentrations approach or are even above the drinking water threshold of 50mg/L NO$_3$.
The Geer basin case study
Spatial distribution of tritium contents
- N : TU = ~ 1, old water
- S : TU = ~ 10, young water
- E : TU = ~ 5, mixing between old/young

Spatial distribution of nitrate contents
- N : NO₃ = ~ 0 mg/L
- S : NO₃ = ~ 30 – 90 mg/L
- E : NO₃ = ~ 20 – 25 mg/L

The Geer basin case study
• Limits of the model similar to the limits of the hydrological basin
• 5 layers (2 loess, 3 chalk)
• Heterogeneity of the chalk
Groundwater flow

- Finite element solution of groundwater flow equation in equivalent porous media

Solute transport

- Dual-porosity concept
- Distributed mixing cells
Calibration of the groundwater flow model in steady-state on 2 contrasted datasets (high and low groundwater levels)
• Calibration of the solute transport model:
  • Groundwater flow in steady-state
  • Solute transport in transient conditions (period 1950-2008)

• Use of two datasets
  • Tritium data:
    • Input function is well known (Groningen measurement station)
    • Peak in the input function
  • Nitrate data:
    • Input function difficult to estimate
Calibration with $^3$H data measured in 2004

Mean observed velocity across the unsaturated zone = ~1m/y

Groundwater model
Conclusions & Perspectives

• The HFEMC method is a new flexible modelling tool for large-scale groundwater modelling capable of dealing with real cases, interesting to implement the EU WFD

• Combination of specific data (nitrate trend and environmental tracer data) and HFEMC shows promising results for regional scale groundwater quality modelling

• More advanced NO3 scenarios based on crop / soil modelling (SVAT models)

• Combined scenarios: Climate change, NO3 and changes in land use
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