University of Liège – Faculty of Applied Sciences
ArGEnCo – Architecture, Geology, Environment and Constructions
GEO³ - Geotechnologies, Hydrogeology and Geophysical Survey
Aquapôle

The Hybrid Finite Element Mixing Cell Method

A new flexible method for large-scale groundwater modelling

Ph. Orban, S. Brouyère, **S. Wildemeersch**, J. Couturier, A. Dassargues

CMWR 2008 - San Francisco, CA, USA, July 6-10, 2008

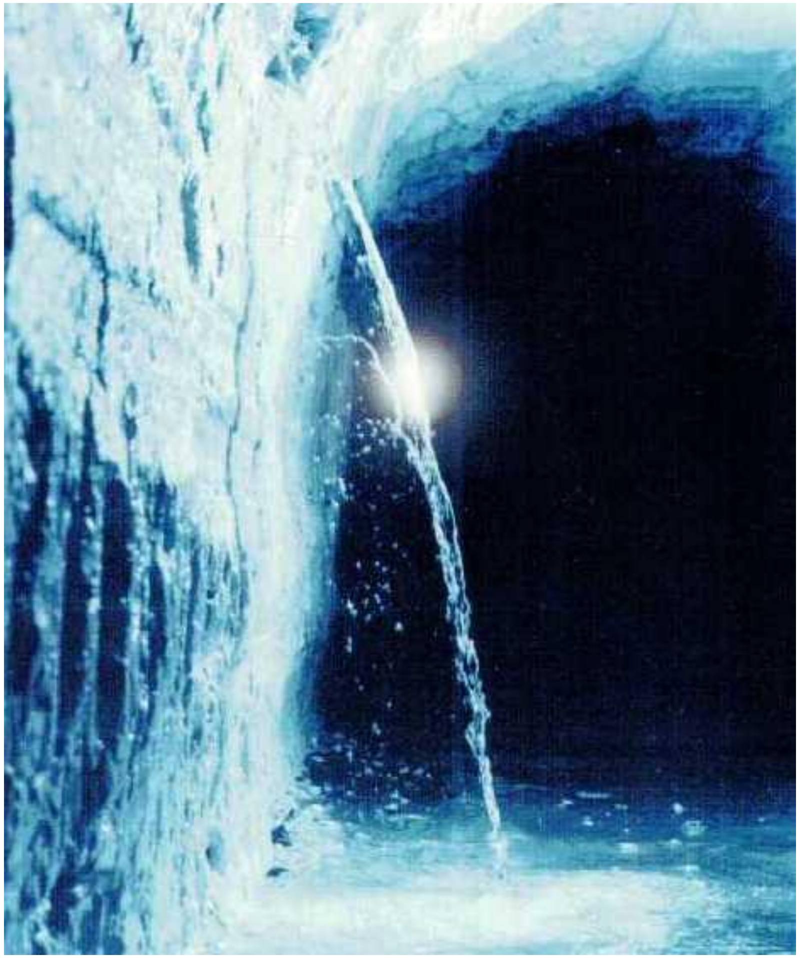
Introduction

Introduction

- Large-scale groundwater models are more and more used as managing and understanding tools for policy makers

- At this scale, groundwater models range from black-box to distributed physically-based models

- Each technique has advantages and disadvantages



Introduction

	Advantages	Disadvantages
Black box models	▫ Easy to use ▫ Few parameters required	▫ Not spatially distributed results ▫ Low predictive capability
Distributed black-box models	▫ Easy to use ▫ Few parameters required ▫ Spatially distributed results	▫ Low predictive capability
Distributed physically-based models	▫ Spatially distributed results ▫ Good predictive capability	▫ Lot of parameters required

Introduction

- The HFEMC method is a new and pragmatic approach which allows:
  - combining, in a single model and in a fully integrated way, different mathematical and numerical approaches
  - keeping the advantages of the spatial representation using finite element mesh
- The HFEMC method was implemented in the SUFT3D (Saturated and Unsaturated Flow and Transport in 3D) finite element code

Concepts and equations of the HFEMC method

Concepts and equations of the HFEMC method

- The flexibility of the HFMEC method allows solving the groundwater flow and transport problem using simultaneously different types of equation (one by subdomain)

		TRANSPORT		
		Simple Linear Reservoir	Distributed Mixing Model	Advection - Dispersion
FLOW	Simple Linear Reservoir			
	Distributed Linear Reservoir			
	Flow in porous media			

Concepts and equations of the HFEMC method

- Choice of flow and transport equations depends on:
  - level of knowledge of hydrogeological conditions in the subdomain
  - hydrogeological interest in the subdomain

Poor level of knowledge/interest → High level of knowledge/interest

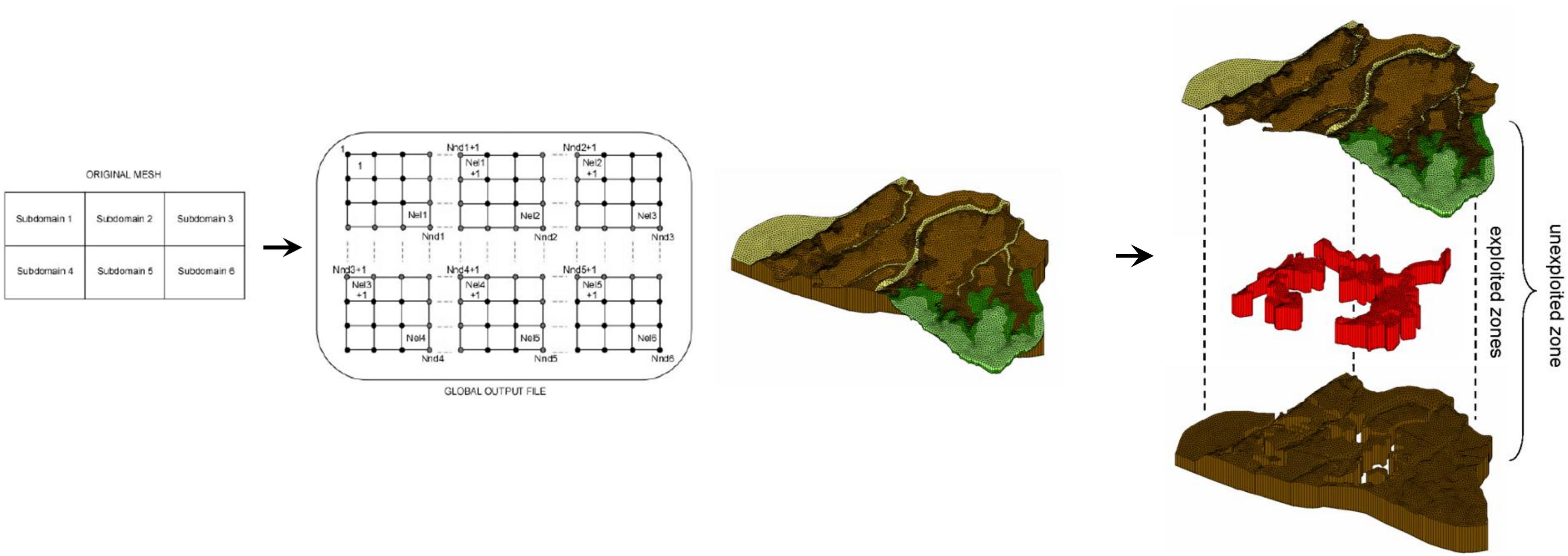
Poor level of knowledge/interest ↓ simple linear reservoir

High level of knowledge/interest ↓ flow in porous media

advection - dispersion

Concepts and equations of the HFEMC method

- Fundamental principle of the HFEMC method consists in dividing the modelled zone into several subdomains



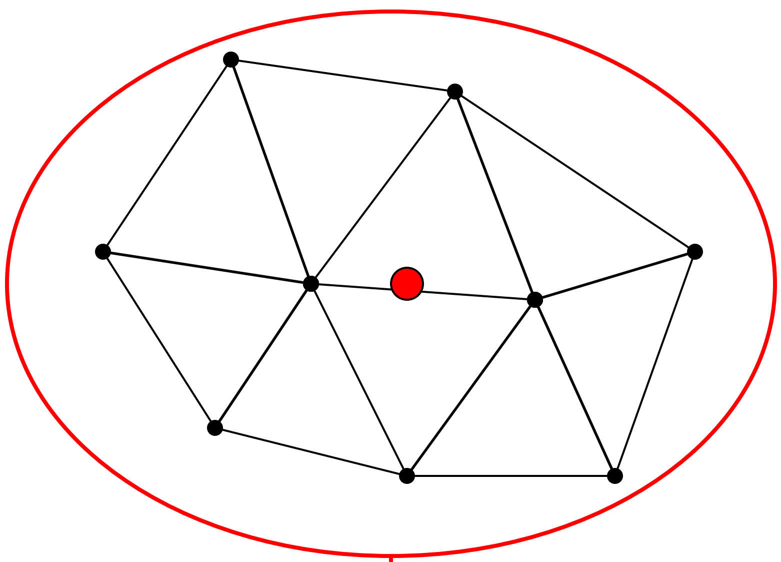
Concepts and equations of the HFEMC method

- Internal boundary conditions defined at the interfaces between subdomains allow:

  - considering groundwater fluxes between subdomains
  - calculating separate groundwater budgets for each subdomain
  - considering implicitly thin and low permeable formations (e.g. clay or shale) in order to avoid irregular elements and limit the number of unknowns

Concepts and equations of the HFEMC method

- Flow equations:
  - Simple linear reservoir: $Q_{LR} = S_{LR} \times A_{LR} \times \frac{\partial \overline{H}_{LR}}{\partial t} = -\alpha_{LR} \times (\overline{H}_{LR} - H_{ref}) + Q$



- Q_{LR} = flow rate entering or leaving the linear reservoir
- α_{LR} = exchange coefficient of the linear reservoir
- H_{LR} = mean water level in the linear reservoir
- H_{ref} = reference level
- Q = source/sink term

N nodes but 1 unknown

(e.g. mean water level in the reservoir)

Concepts and equations of the HFEMC method

- Flow equations:
  - Distributed linear reservoir:
    - Generalisation of the simple linear reservoir to multiple interconnected reservoirs (along the three dimensions)

$$Q_{LR,I} = S_{LR,I} \times A_{LR,I} \times \frac{\partial \overline{H_I}}{\partial t} = \sum_{j \in \eta_I} \alpha_{IJ} \times (\overline{H_J} - \overline{H_I}) + Q_I$$

    - Reservoirs are finite element control volumes
  - Flow in porous media equation (CVFE formulation of the classical groundwater flow equation based on Darcy's law)

Concepts and equations of the HFEMC method

- Transport equations:
  - Simple linear reservoir:

$$\frac{\partial\left(V_{eff,res}\overline{C}\right)}{\partial t} = Q_{in}C_{in} - Q_{out}\overline{C}$$

  - Distributed mixing model:

$$V_{res,I}\frac{\partial\left(\theta_I C_I\right)}{\partial t} - \sum_{J\in\eta_I}\alpha_{IJ}C_{ups}^{(I,J)}\left(H_J - H_I\right) - Q_{CI} = 0$$

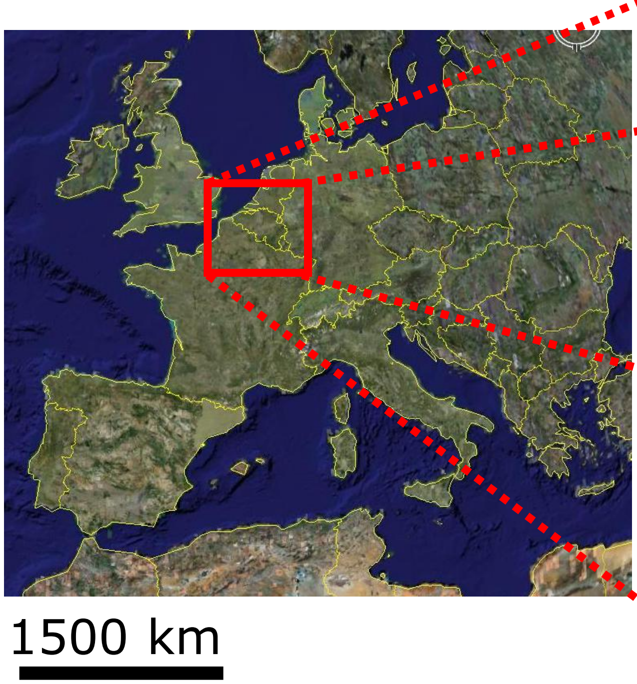
    - Unconditionally stable
    - Dispersion only governed by the size of the mixing cells. However, for diffuse pollution, the spatial dispersion of the source is dominant.

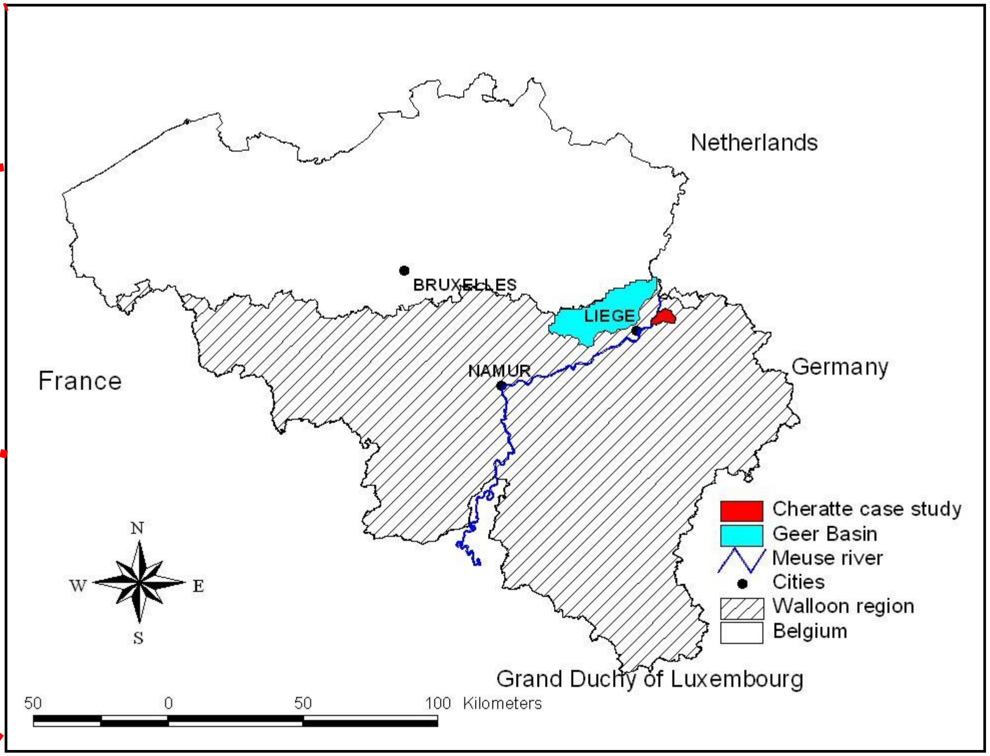
  - Advection-diffusion transport equation

Application of the HFEMC method

Applications of the HFEMC method

- Abandoned coalfield of Cheratte
- Chalk aquifer of the Geer basin

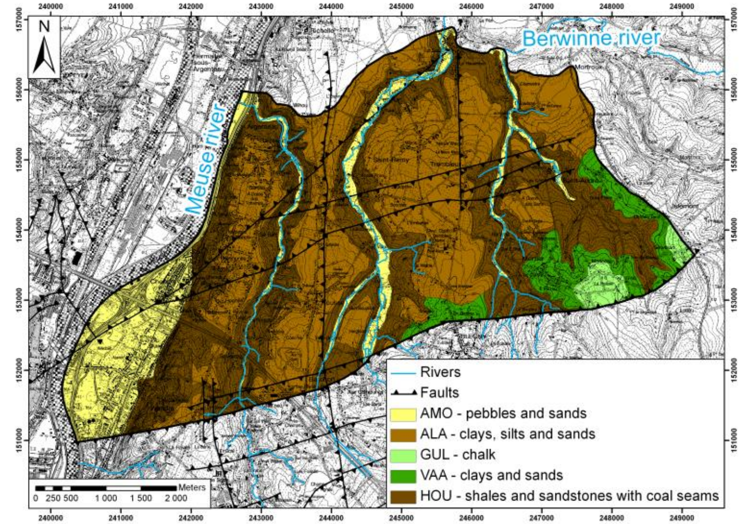


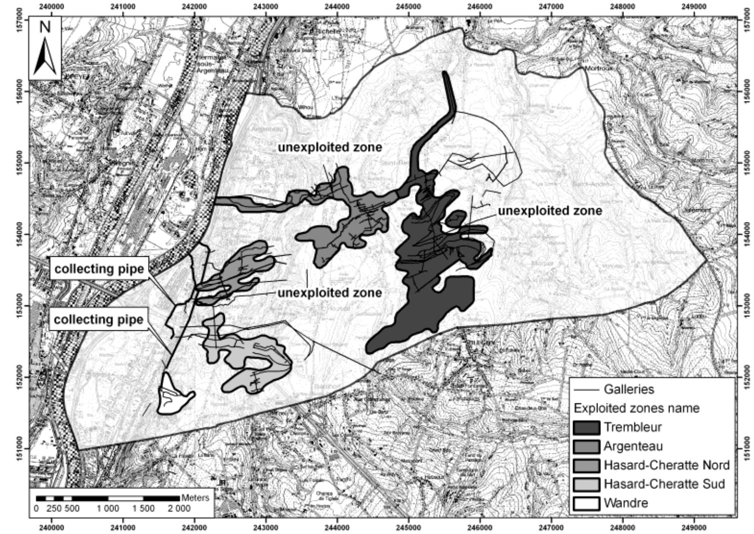


Applications of the HFEMC method

Abandoned coalfield of Cheratte

- Abandoned underground coalfield exploitation
- Five exploited zones
- Stop of dewatering operations from mine closure





Applications of the HFEMC method

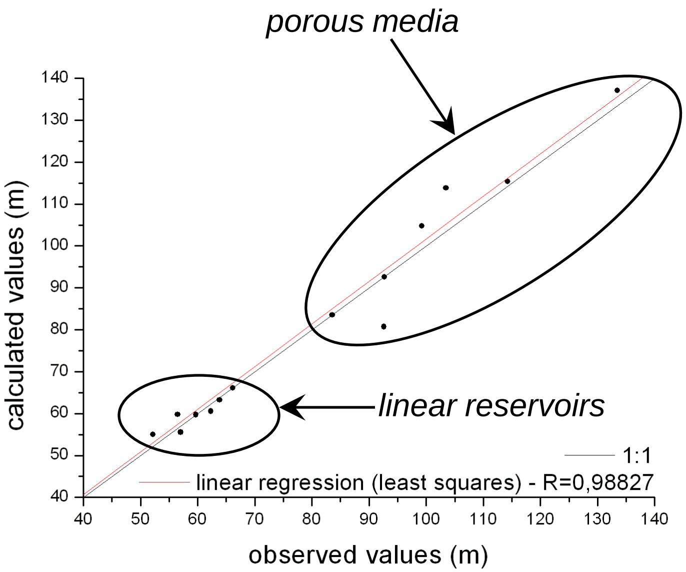
- Objective :
  - modelling of the current piezometry (groundwater rebound almost completed)

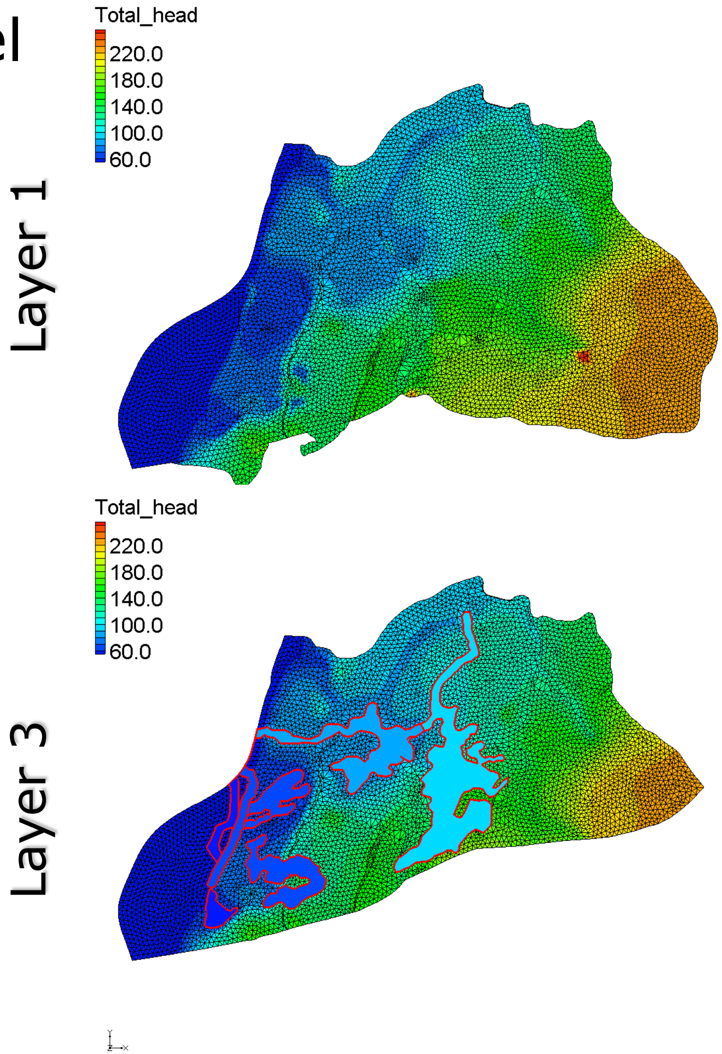
  → Development of a 3D spatially distributed groundwater flow model

  → For groundwater flow:
    - → use of simple linear reservoirs for exploited zones
    - → use of flow in porous media equation for adjacent and overlying unexploited zones

Applications of the HFEMC method

- Calibrated steady-state model

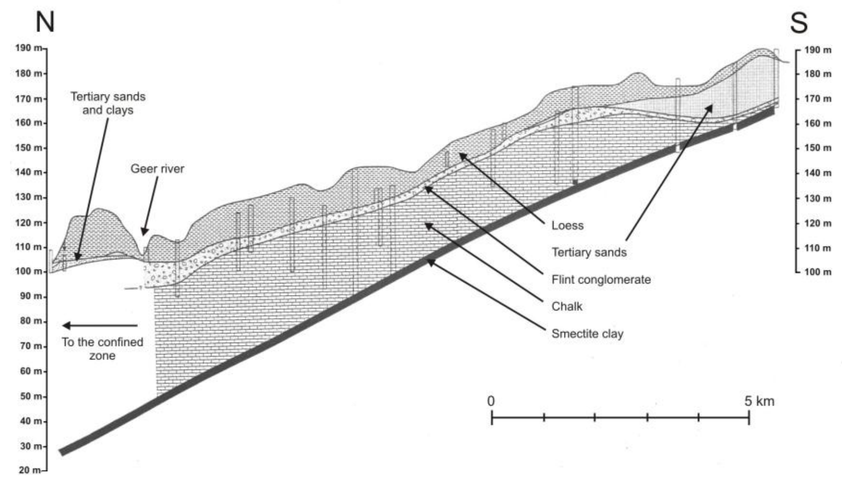


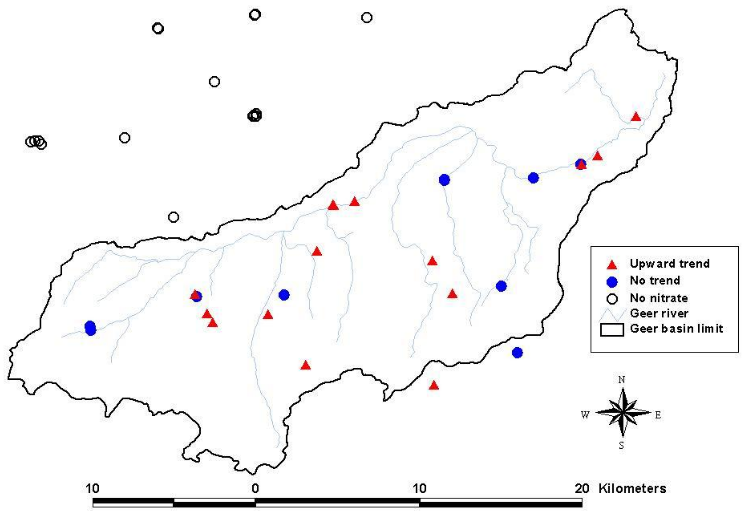


Applications of the HFEMC method

Chalk aquifer of the Geer basin

- Chalk aquifer constitutes important groundwater resources for the city of Liège and its suburbs (around 30 millions m³/y)
- 65 % of the basin occupied by agriculture
- Nitrate concentrations in groundwater increasing for 50 years



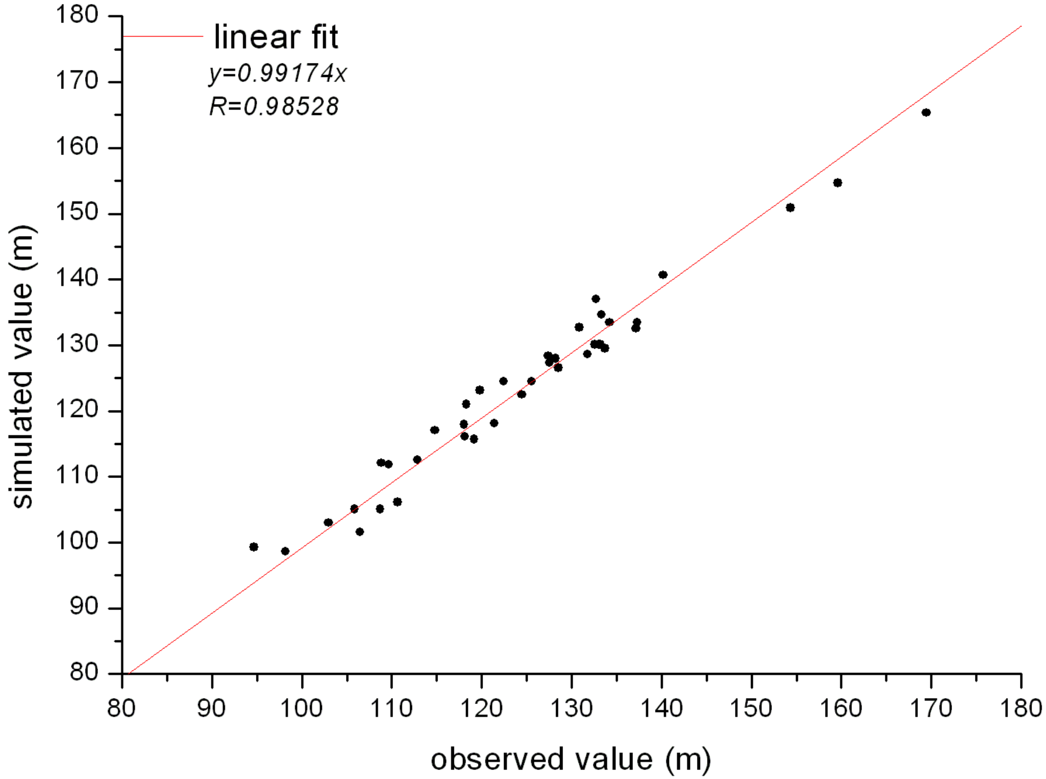


Applications of the HFEMC method

- Objectives :
  - modelling of the spatial distribution of the observed nitrate trends in the aquifer
  - prediction of nitrate trends evolution in groundwater
  - ➔ Development of a 3D spatially distributed groundwater flow and solute transport model
  - ➔ For groundwater flow:
    - ➔ use of flow in porous media equation
  - ➔ For transport:
    - ➔ use of the distributed mixing model (nitrate = diffuse pollution)

Applications of the HFEMC method

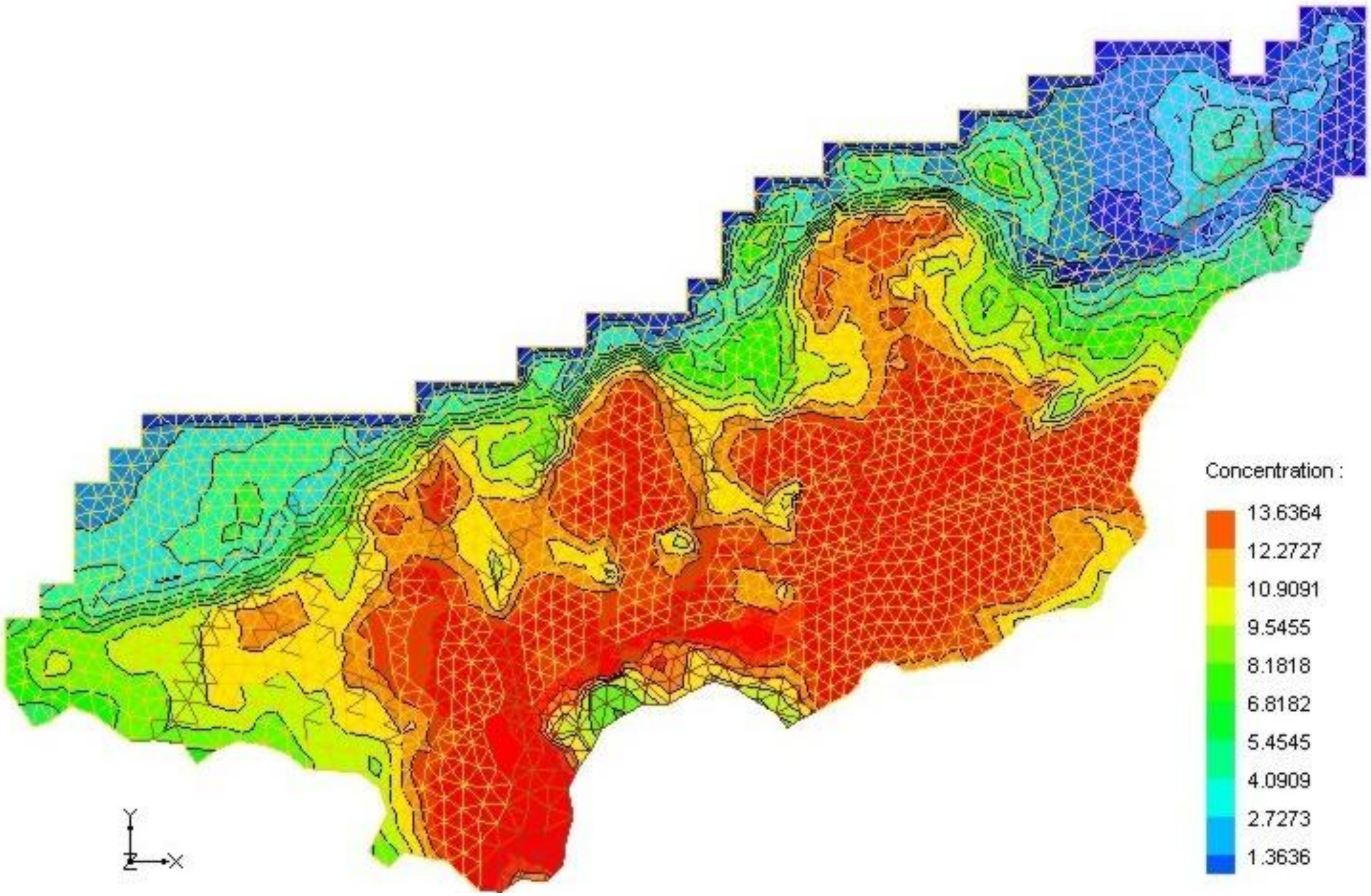
- Calibration of the groundwater flow model on two contrasted steady state situations



Steady-state calibration for the high groundwater level period 1983-1984

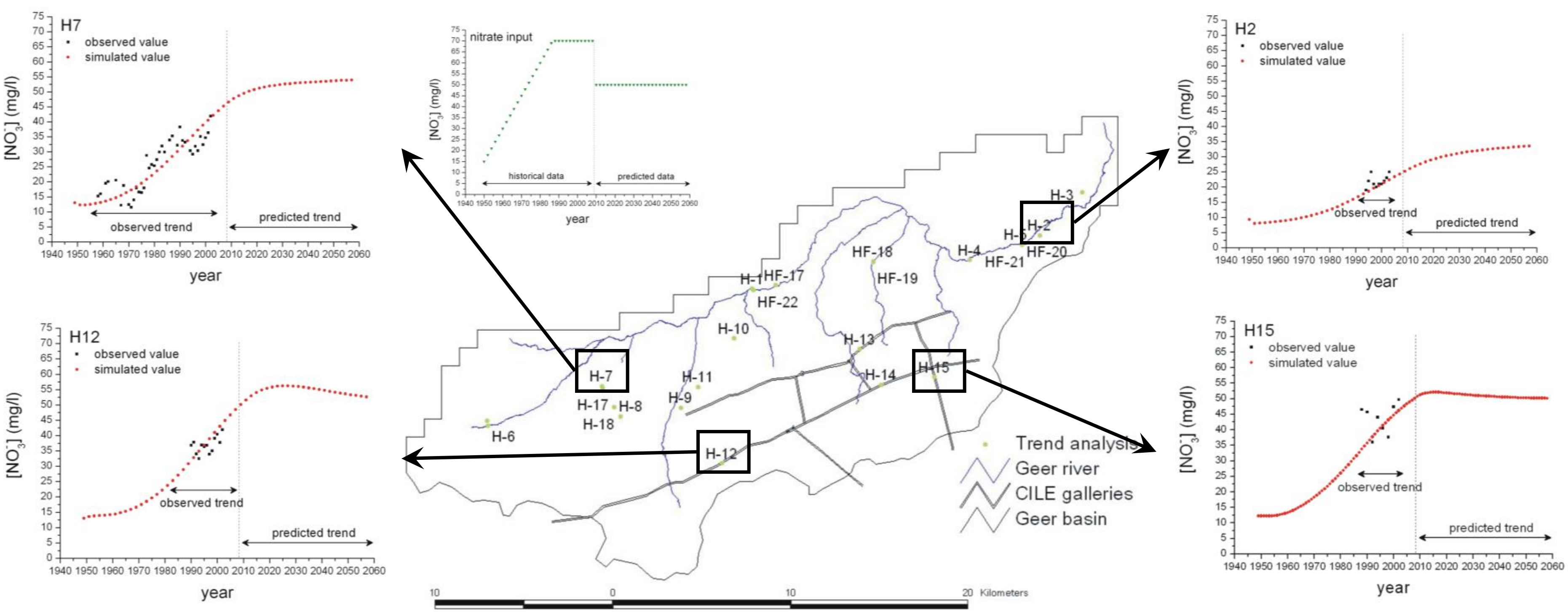
Applications of the HFEMC method

- Calibration of the solute transport model using tritium data



Applications of the HFEMC method

- Calibration of the solute transport model using estimated trends and prediction of trends



Conclusions and perspectives

Conclusions and perspectives

- Conclusions:
  - The HFEMC method is a new flexible modelling tool for large-scale groundwater modelling
  - Applications on the abandoned Cheratte coalfield and the Geer basin show promising results
- Perspectives
  - Other applications on large-scale basins
  - Coupling of the groundwater model with a soil model to represent more accurately the nitrate input

Acknowledgements

Acknowledgements

- Conceptual and numerical developments of the HFEMC method have been performed in the framework of:

  - The ISSeP (Institut Scientifique de Service Public)-AIDE (Association Intercommunale pour le Démergement et l'Epuration) project "Après-Mine" funded by the Walloon Region

  - The Interuniversity Attraction Pole TIMOTHY (IAP Research Project P6/13) funded by the Belgian Federal Science Policy Office (BELSPO)

  - The European Integrated Project AquaTerra (GOCE 505428) funded by the Community's Sixth Framework Programme

Thanks for your attention!