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

The Hybrid Finite-Element Mixing-Cell method: a candidate for modelling groundwater flow and transport in karst systems

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Introduction

- Similarities between groundwater flow modelling issues in mining and karstic contexts:
  - Lack of knowledge about internal hydrogeological conditions
  - Scarcity of data concerning the geometry of the main and secondary exploited/karstified zones
  - Large voids constituting preferential flowpaths
  - Double porosity/permeability media

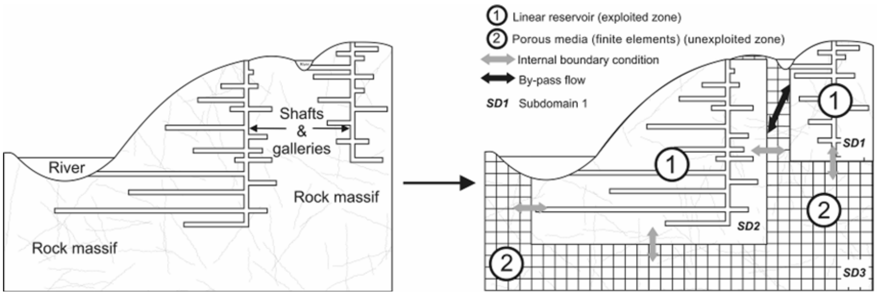
➡ specific techniques required

Introduction

- From simple to complex modelling techniques:
  - Box models
  - Physically-based and spatially-distributed models based on (FD, FEM, FVM, …)
  - Intermediate models: lets try !
    Hybrid Finite Element Mixing Cell (HFEMC)

Fundamental principle of the HFEMC method

- Fundamental principle:
  - Subdivision into sub-domains: exploited zones and unexploited zones
  - Definition of <u>internal</u> boundary conditions
  - Definition of by-pass flow connections



Fundamental principle of the HFEMC method

- Groundwater flow equations available:
  - Exploited zones ➔ Linear reservoir

$$Q_{LR} = S_{LR} A_{LR} \frac{\partial \overline{H}_{LR}}{\partial t} = -\alpha_{LR} (\overline{H}_{LR} - H_{ref}) + Q$$

  - Unexploited zones ➔ Flow in porous media

$$F \frac{\partial h}{\partial t} = \underline{\nabla}\left(\underline{\underline{K}}\,\underline{\nabla}(h+z)\right) + q$$

  - By-pass flow connections ➔ 1st order transfer equation

$$Q = \alpha_{BF}\left(h_i - h_j\right)$$

Fundamental principle of the HFEMC method

- Types of <u>internal</u> boundary conditions available:
  - 1st type « dynamic » boundary condition

$$h_{SD,i}(x,y,z,t) = h_{SD,j}(x,y,z,t)$$

  - 2nd type « impervious » boundary condition

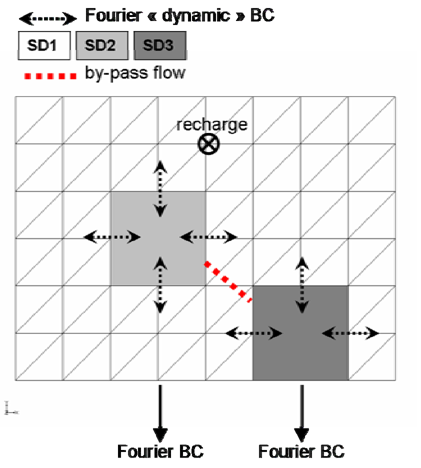
$$\frac{\partial h(x,y,z,t)}{\partial n} = 0$$

  - 3rd type « dynamic » boundary condition

$$Q_{SD,i-SD,j} = \alpha_{FBC}\, A\left(h_{SD,j}(x,y,z,t) - h_{SD,i}(x,y,z,t)\right)$$

Test cases for the HFEMC method

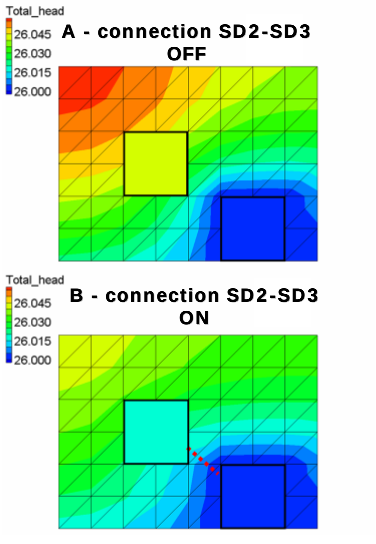
- Third test case
  - Subdomains:
    - One unexploited zone (SD1-FE)
    - Two exploited zones (SD2 and SD3-LR)
  - Internal boundary conditions:
    - Fourier "dynamic" BC
  - External boundary conditions:
    - Fourier BC for SD3
    - Fourier BC for the south boundary of SD1, Neumann BC (impervious) for the others
    - Constant recharge on the upper faces of SD1, SD2 and SD3
  - By-pass flow connection:
    - SD2↔SD3



Test cases for the HFEMC method

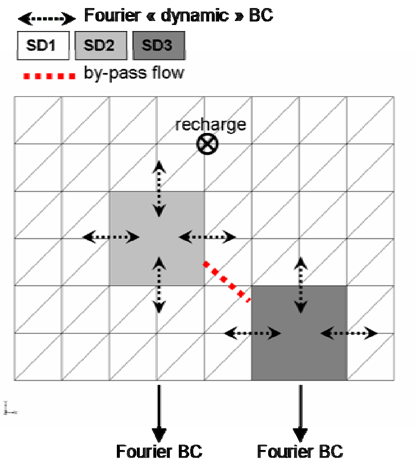
- A - simulation without any connection between SD2 and SD3
- B - simulation with a by-pass flow connection between SD2 and SD3
- When the connection between SD2 and SD3 is activated, the mean water level of SD2 decreases

Connection works properly

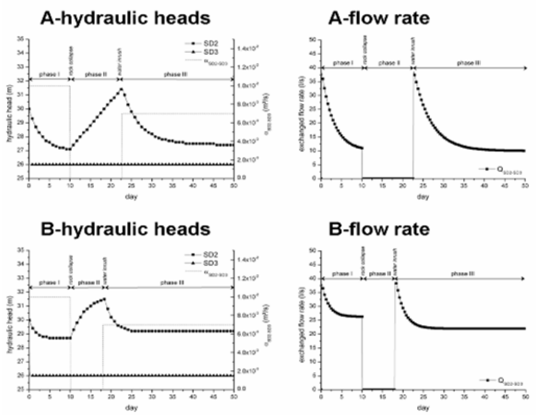


Test cases for the HFEMC method

- Fourth test case
  - Water inrush simulation using a model similar to the previous one
  - Three phases:
    - Phase I: by-pass flow connection works normally $(\alpha_{BF}>0)$
    - Phase II: obstruction of the connection because of a rock collapse $(\alpha_{BF}=0)$
    - Phase III: obstruction breaks under the exerted ground water pressure and by-pass flow connection works normally again$(\alpha_{BF}>0)$
  - A - simulation with a box model technique (deactivation of SD1)
  - B - simulation with the HFEMC method



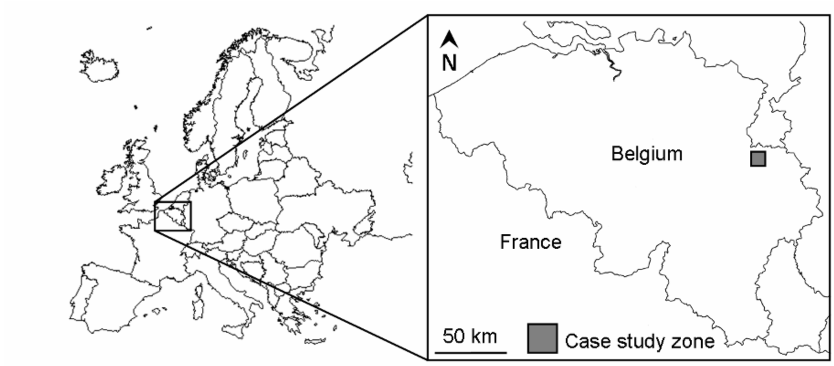
Test cases for the HFEMC method



Taking explicitly into account interactions between exploited and unexploited zones, the HFEMC method allows simulating more realistic hydraulic heads and flow rate evolution

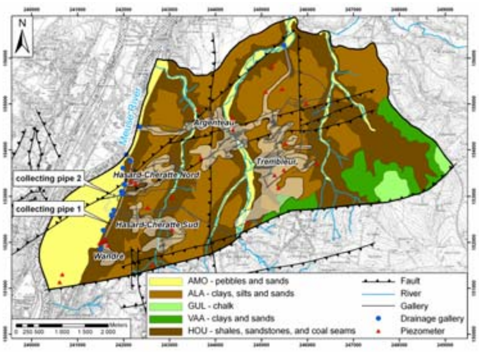
Case study

- Abandoned coal mine of Cheratte



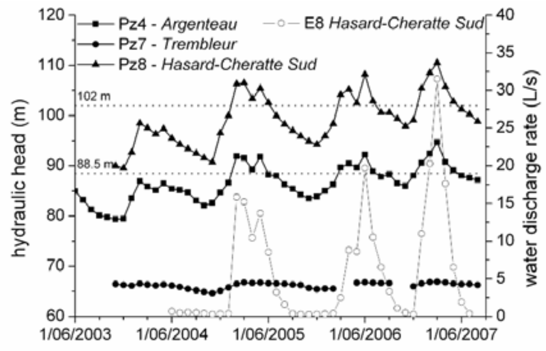
Case study

- Five exploited zones:
  - *Trembleur*
  - *Argenteau*
  - *Hasard-Cheratte Nord*
  - *Hasard-Cheratte Sud*
  - *Wandre*
- Each zone made up of a network of galleries
- Closure in the end of the 1970's



Case study

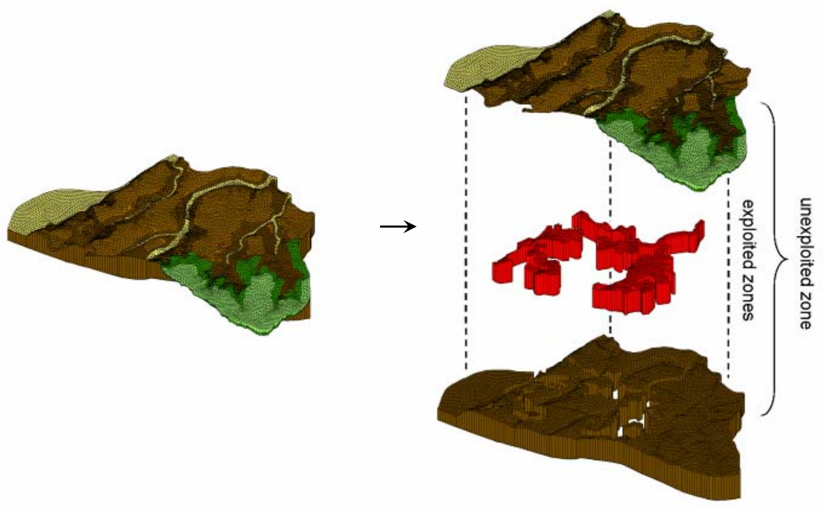
- Exploited zones interact with:
  - Surface water network
  - Exploited zones
  - Unexploited zones



Conceptual and numerical models

- 8 subdomains:
  - 5 exploited zones ➔ linear reservoirs
  - 2 collecting pipes ➔ linear reservoirs
  - 1 unexploited zone ➔ flow in porous media
- 5 drainage galleries ➔ 3rd type external boundary conditions
- 7 by-pass flow connections (some with thresholds)➔ 1st order transfer equations
- 3rd type <u>internal</u> boundary conditions

Conceptual and numerical models

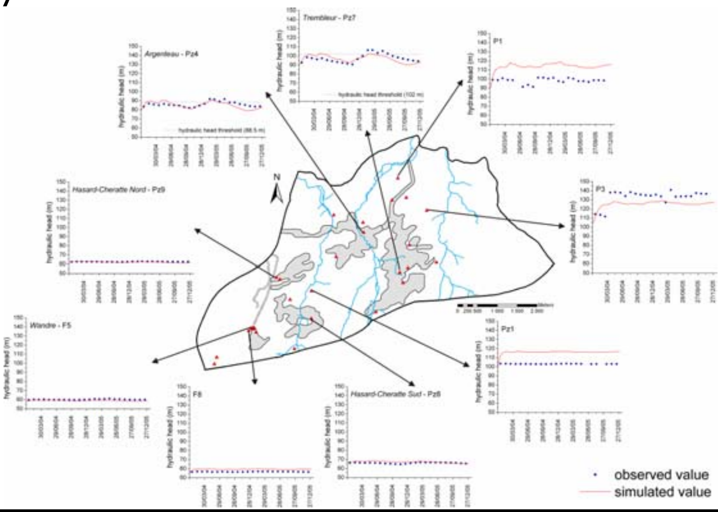


Calibration in transient conditions

- Period:
  - January 2004 - December 2005 with monthly solicitations (recharge from a water budget)
- Observations:
  - Hydraulic heads
  - Water discharge rates
- Parameters:
  - K, S_y, $\alpha_{external\ BC}$, $\alpha_{internal\ BC}$, $\alpha_{by\text{-}pass}$

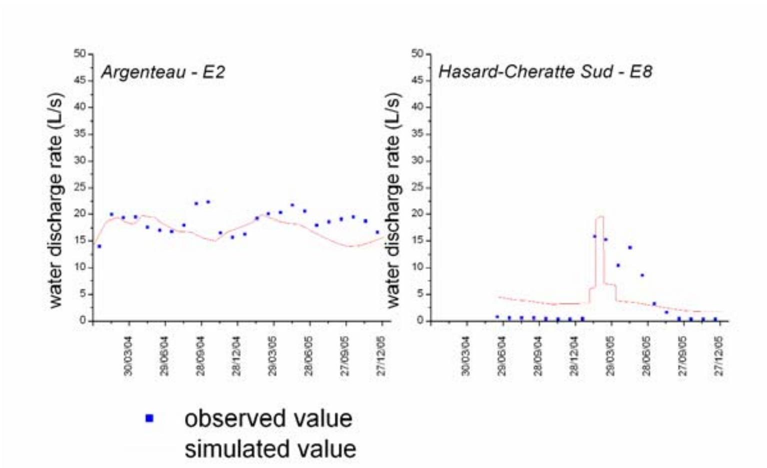
Calibration in transient conditions

- Hydraulic heads



Calibration in transient conditions

- Water discharge rates



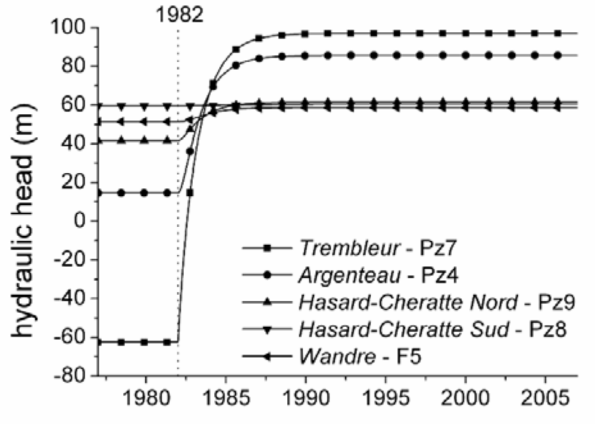
Scenario 1: Groundwater rebound

- Goal:
  - Assess the state of the groundwater rebound by simulating its evolution since 1982

- Simulation:
  - 30 years:
    - 1977-1982: pumping in *Trembleur* maintaining the water level to -64 m
    - 1982-2007: no pumping
  - Constant recharge of 189 mm/year

Groundwater rebound

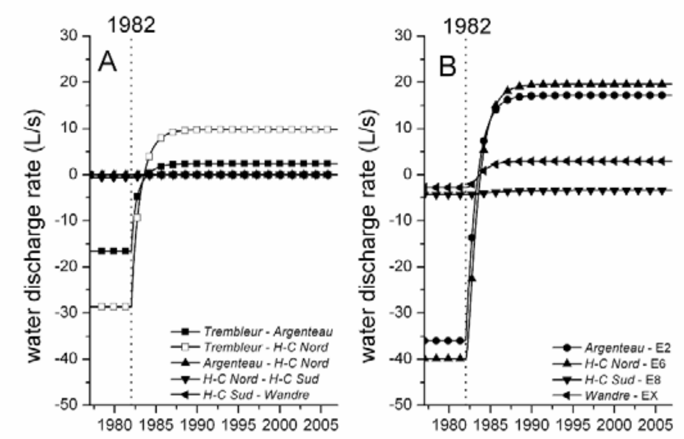
- Hydraulic heads



1982: end of dewatering operations

Groundwater rebound

- Water discharge rates



1982: end of dewatering operations

Groundwater rebound

- Conclusions:
  - Exchanged flow rates reversed after 2 years
  - Essential of the groundwater rebound (97 %) probably occurred within 5 years

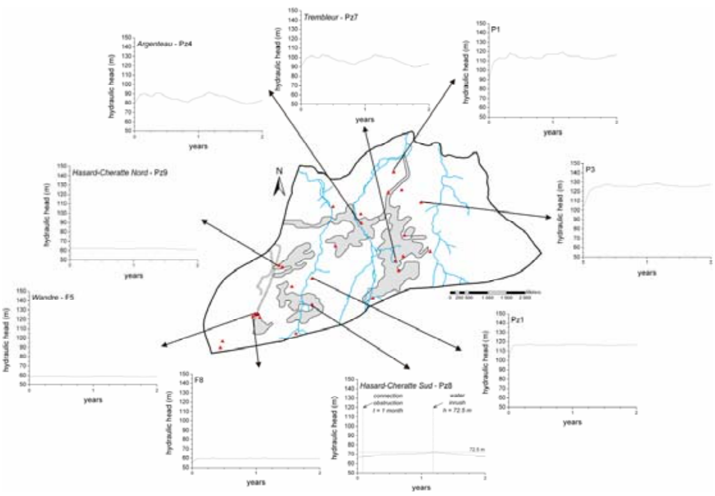
Scenario 2: Water inrush

- Goal:
  - Predict system response in case of a drainage gallery obstruction

- Simulation:
  - 2 years
  - *Hasard-Cheratte Sud* drainage gallery obstruction after 1 month
  - Obstruction strength of 72.5 m
  - Recharge, computed from a water budget for the period 2004-2005,varies monthly

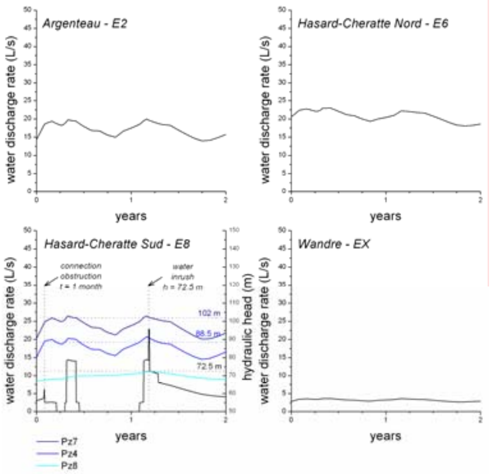
Water inrush

- Hydraulic heads



Water inrush

- Water discharge rates



Water inrush

- Conclusions:
  - *Hasard-Cheratte Sud* drainage gallery obstruction could cause:
    - An immediate though relatively slow water level increase in the exploited zone concerned
    - A water inrush as soon as the obstruction breaks (water inrush intensity depends on the obstruction strength)

Conclusions and perspectives

- Conclusions:
  - HFEMC method:
    - Compromise between simple and complex modelling techniques
    - Useful in mining context including mines with complex system of connections between exploited zones
- Perspectives:
    - Improving and updating using automatic calibration (UCODE_2005 or PEST) + Uncertainty analysis
    - **Application to a karstic aquifer system !**

      Who is candidate to try ? Let us know: Alain.Dassargues@ulg.ac.be
    - Solute transport simulations !

Thank you for your attention!

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