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

Application of the HFEMC method to an abandoned coalfield in Belgium

From conceptualisation to scenario simulations

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Introduction

Introduction

- Groundwater flow modelling issues in mining context:
  - Lack of knowledge about hydrogeological conditions
  - Scarcity of data concerning the exploited zones
  - Large voids constituting preferential flowpaths

➡ specific techniques required

Introduction

- From simple to complex techniques:
  - Box model
  - Hybrid Finite Element Mixing Cell (HFEMC)
  - Physically-based and spatially-distributed

Introduction

SIMPLE TECHNIQUES

Strengths

- Easy to use
- No need of a lot of data

Weaknesses

- Only mean water levels
- Exploited and unexploited zones interactions not taken explicitly into account

COMPLEX TECHNIQUES

Strengths

- Accuracy
- Exploited and unexploited zones interactions explicitly taken into account

Weaknesses

- Lot of data needed

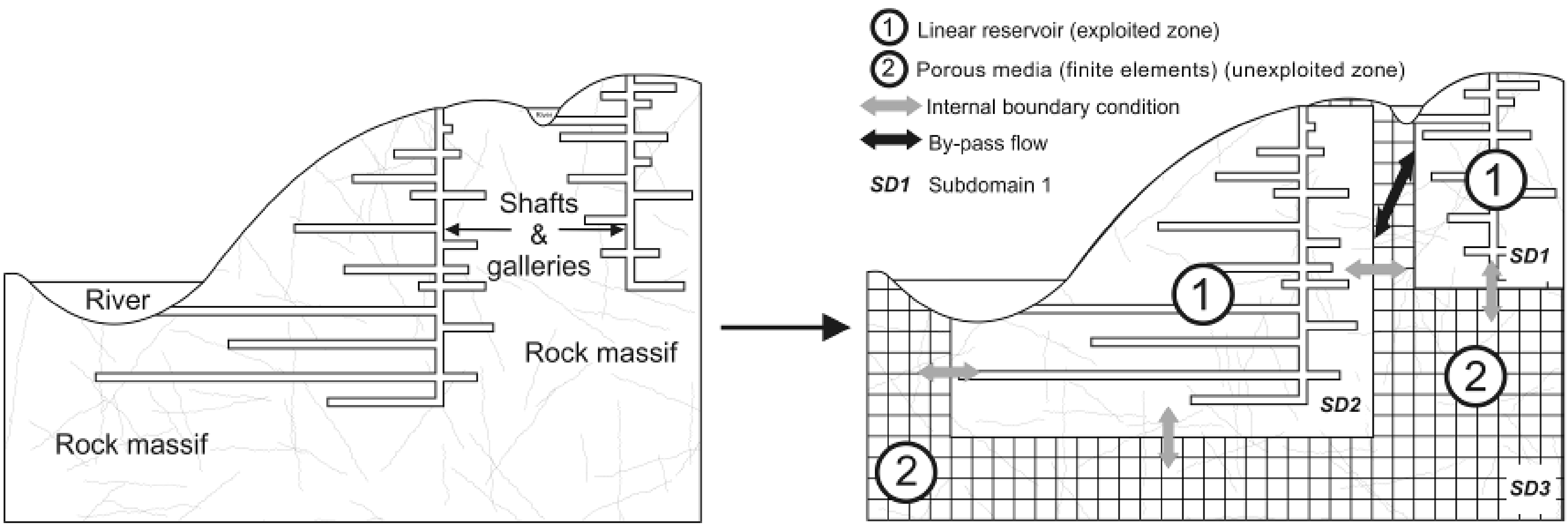
Introduction

- HFEMC technique:
  - Compromise between simple and complex techniques
  - Coupling between:
    - Classical finite elements for unexploited zones
    - Mixing cells for exploited zones
  - Implemented in the SUFT3D code

Fundamental principle of the HFEMC method

Fundamental principle of the HFEMC method

- Fundamental principle:
  - Subdivision into exploited zones and unexploited zones
  - Definition of internal 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

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

  - 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

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

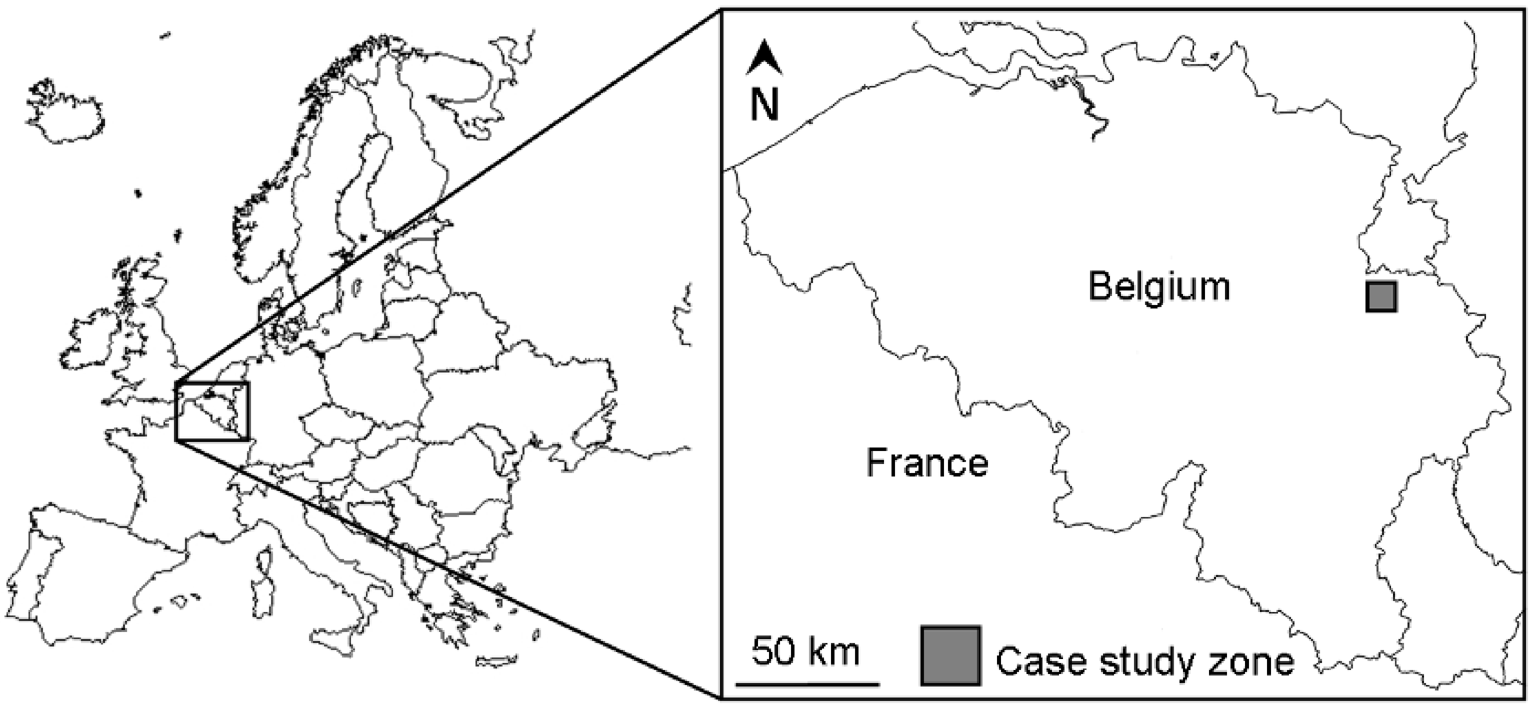
  - 3rd type « dynamic » boundary condition

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

Case study

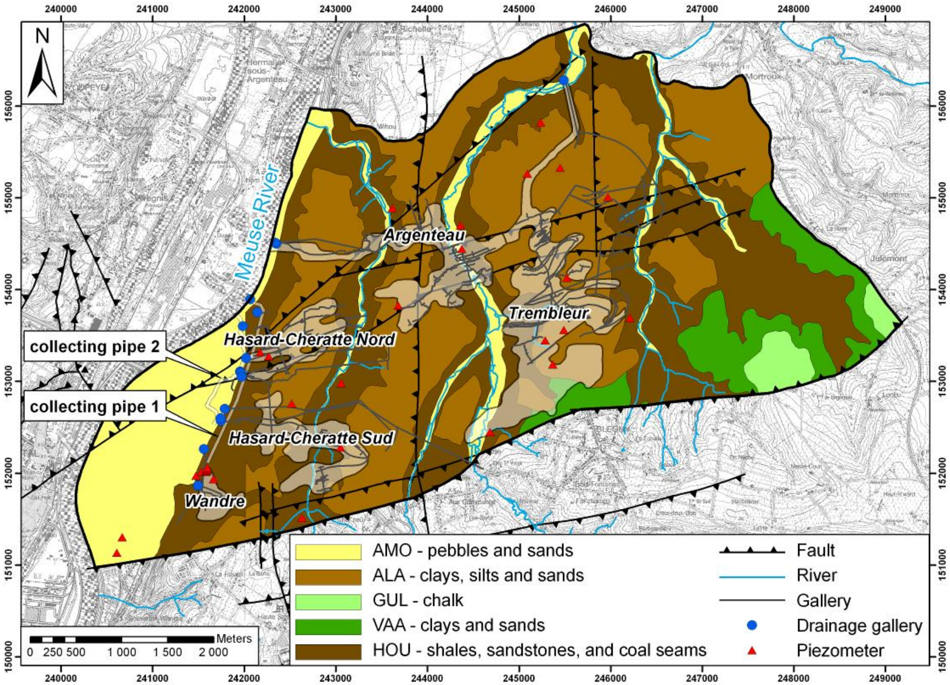
Case study

- Abandoned coal mine of Cheratte



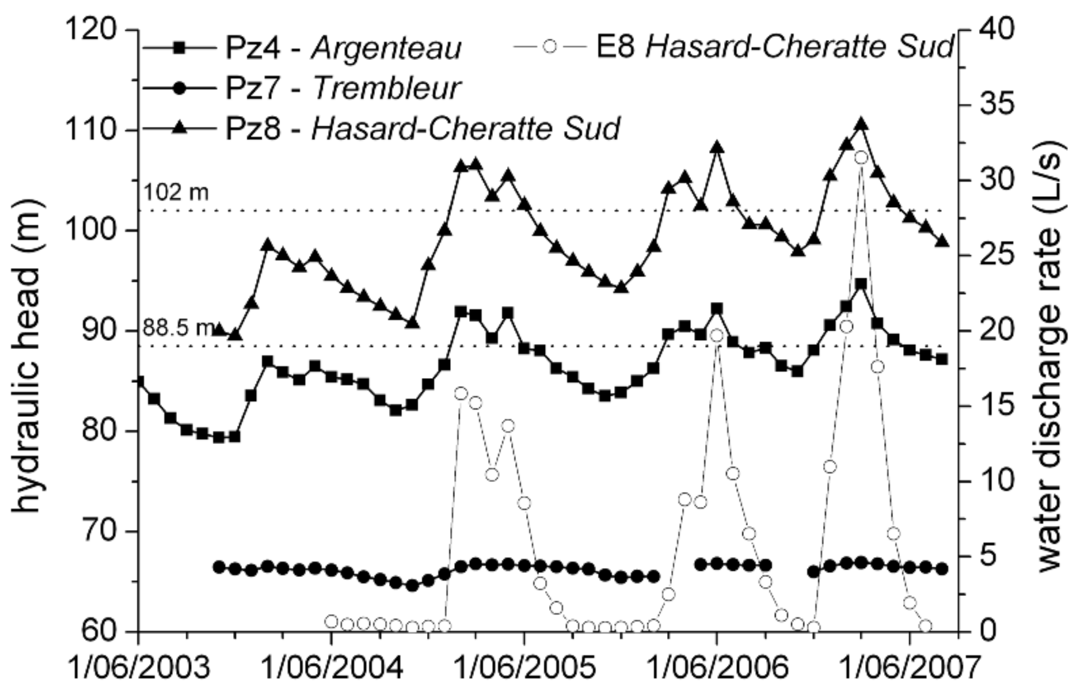
Case study

- 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

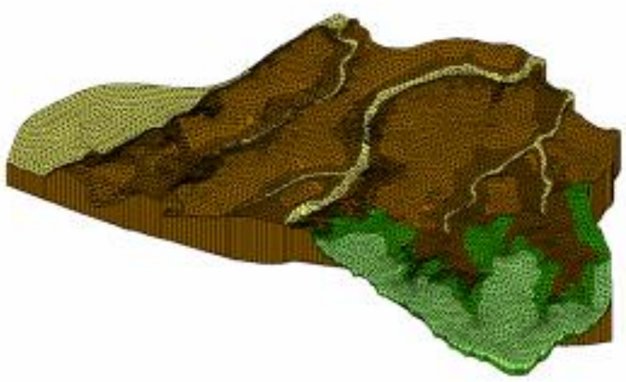


Conceptual and numerical models

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



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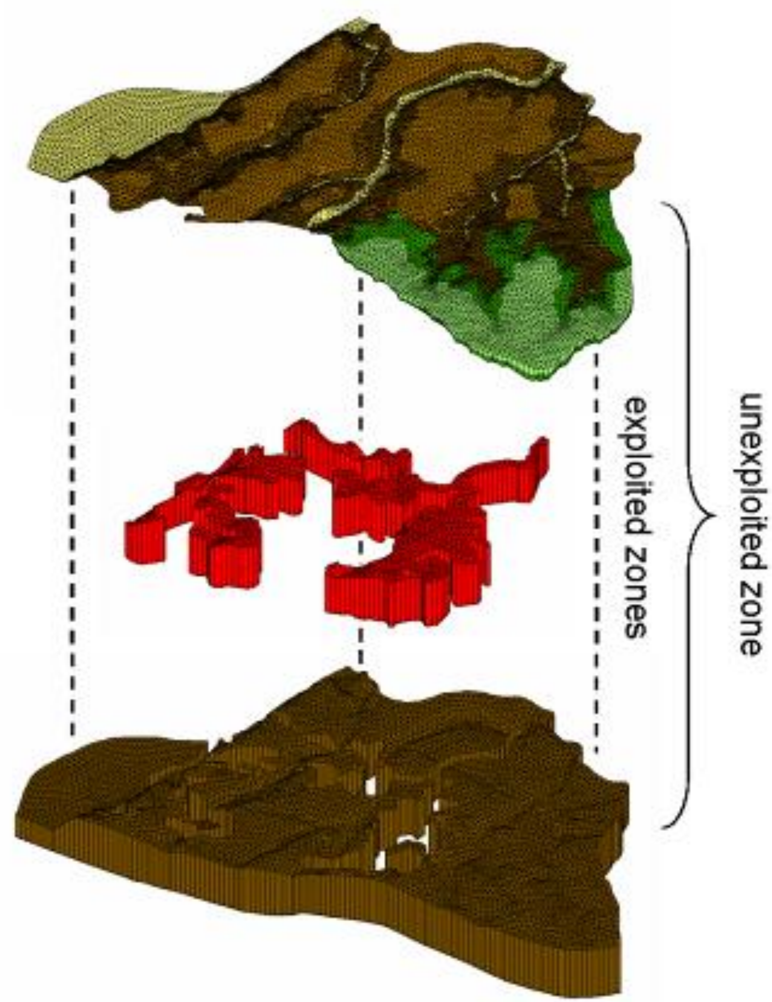


Calibration in transient conditions

Calibration in transient conditions

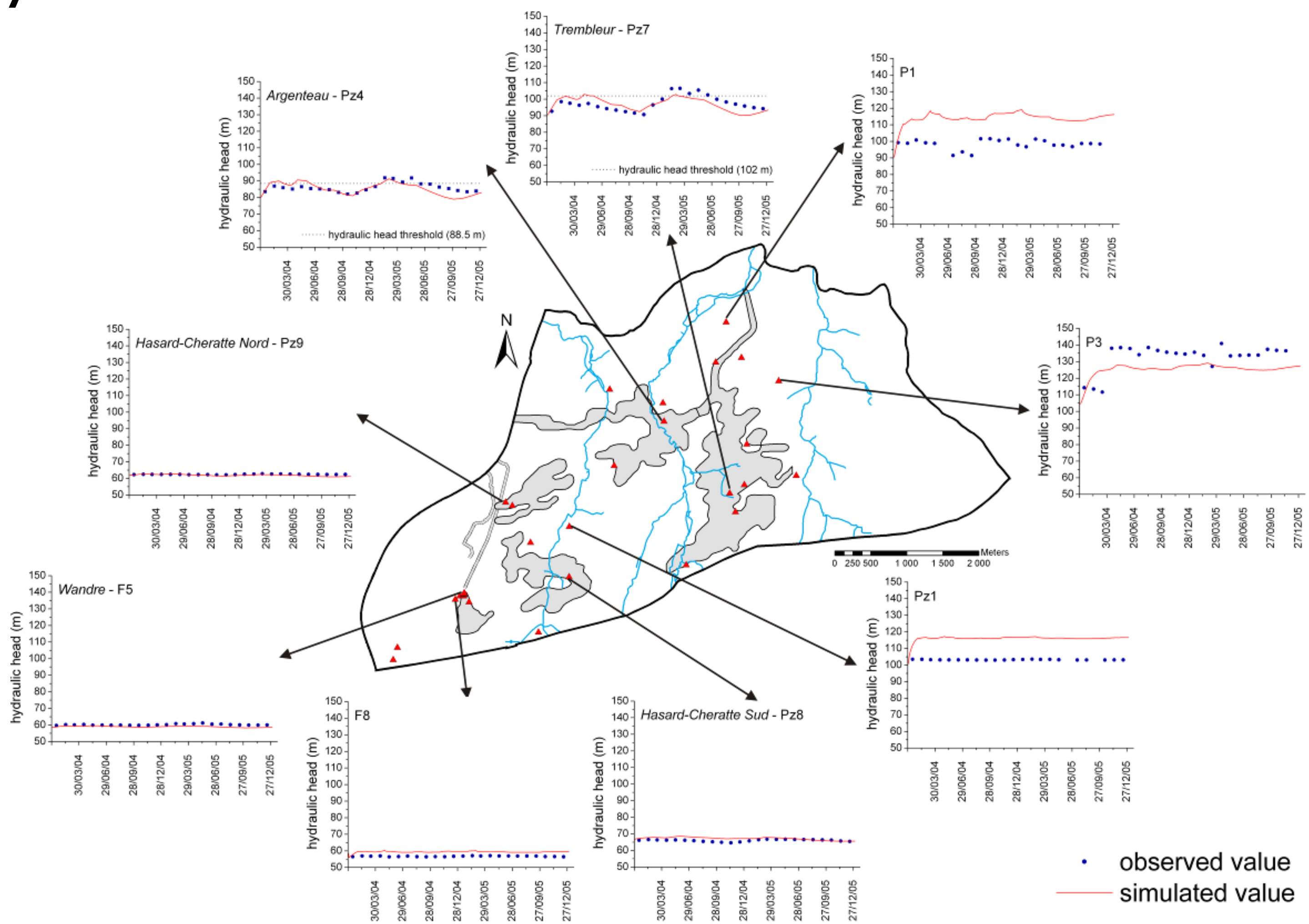
- Period:
  - January 2004 - December 2005 with monthly solicitations (recharge from a water budget)

- Observations:
  - Hydraulic heads
  - Water discharge rates

- Parameters:
  - K, S_y, $\alpha_{\text{external BC}}$, $\alpha_{\text{internal BC}}$, $\alpha_{\text{by-pass}}$

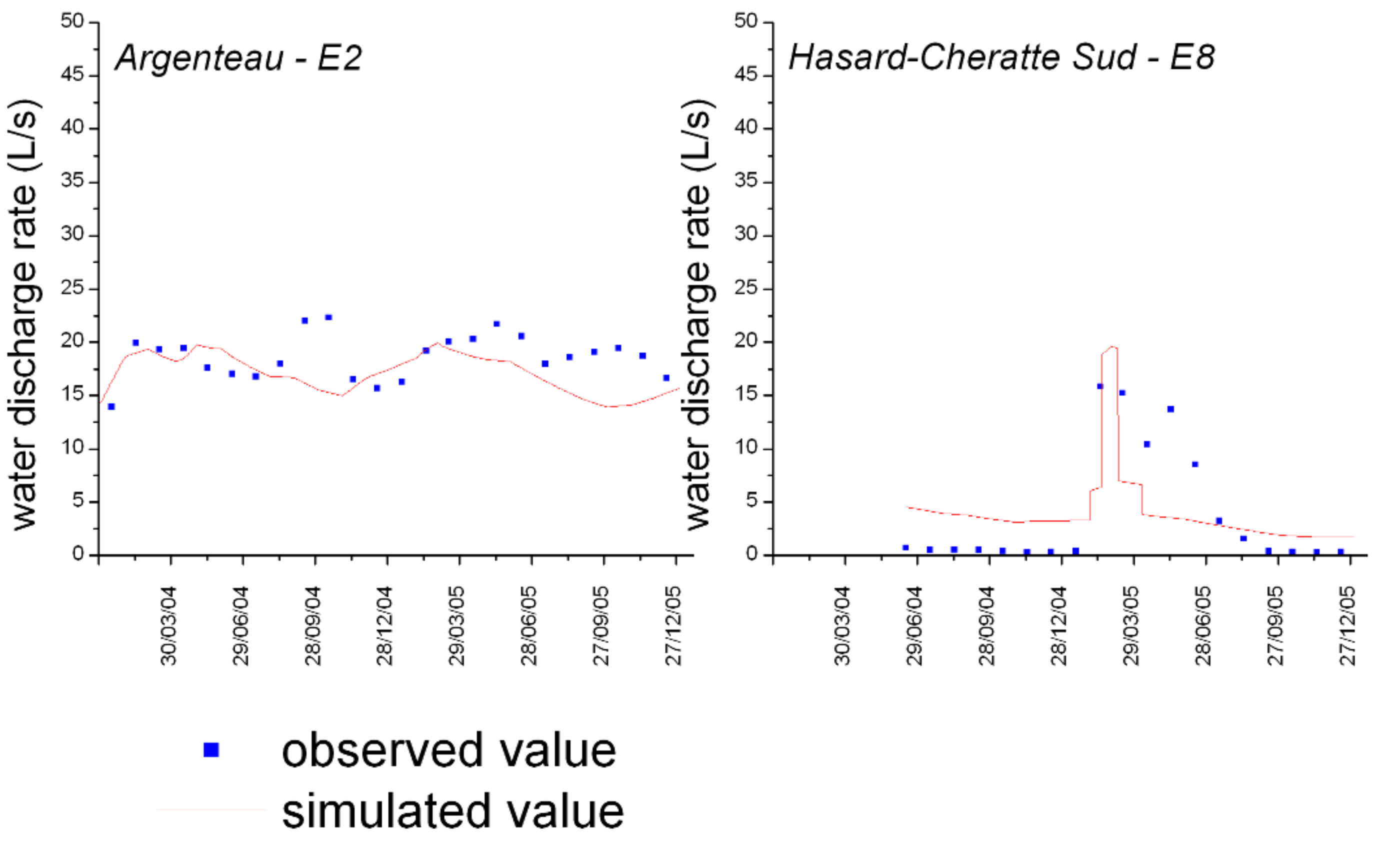
Calibration in transient conditions

- Hydraulic heads



Calibration in transient conditions

- Water discharge rates



Scenarios

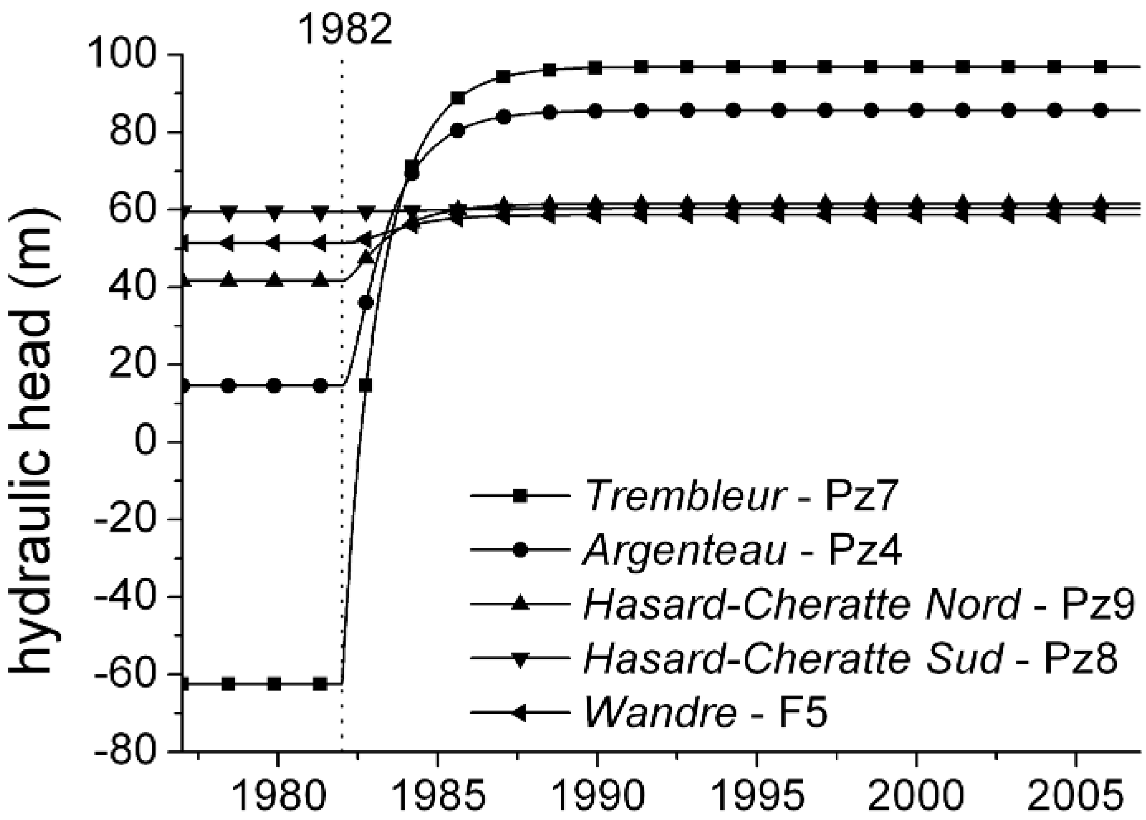
Groundwater rebound

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

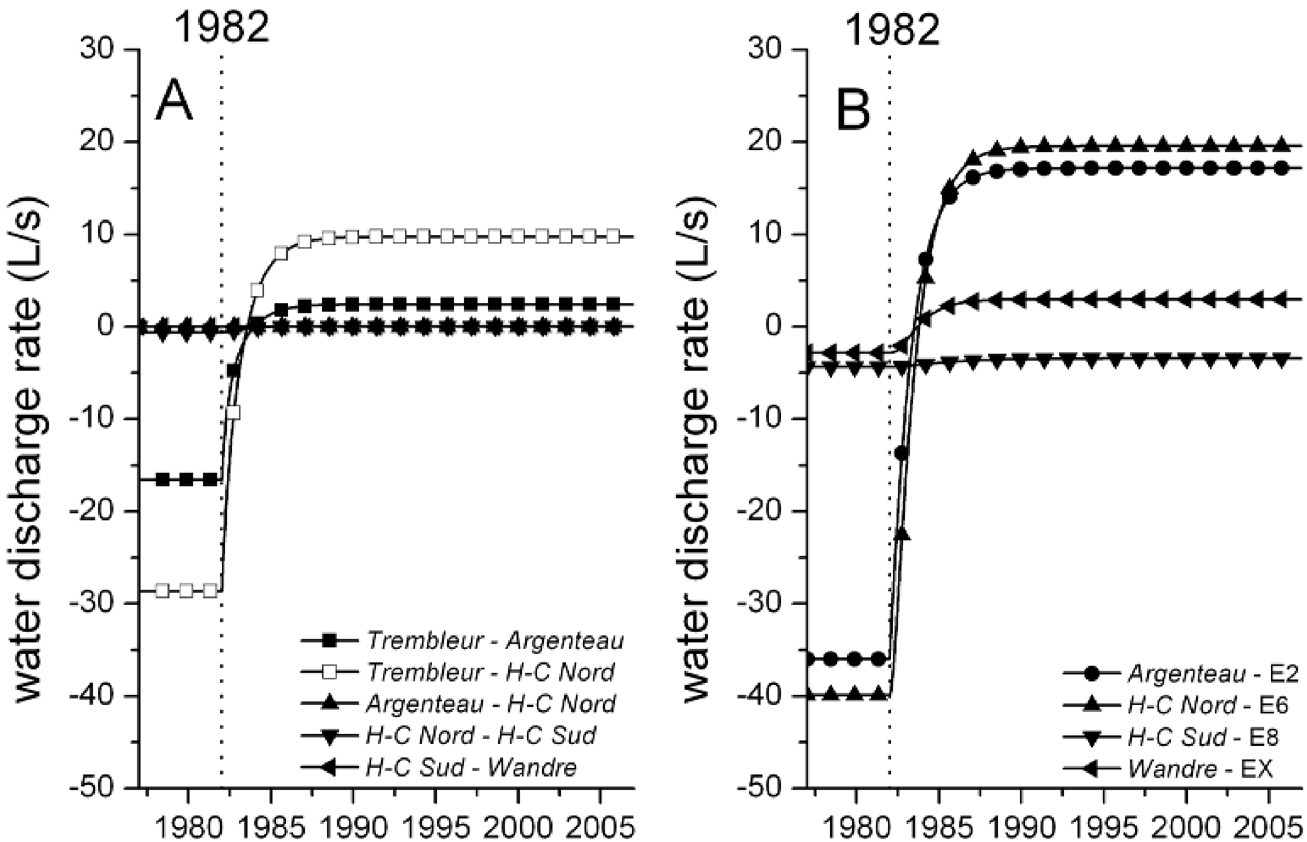
- Hydraulic heads



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

Scenarios

Water inrush

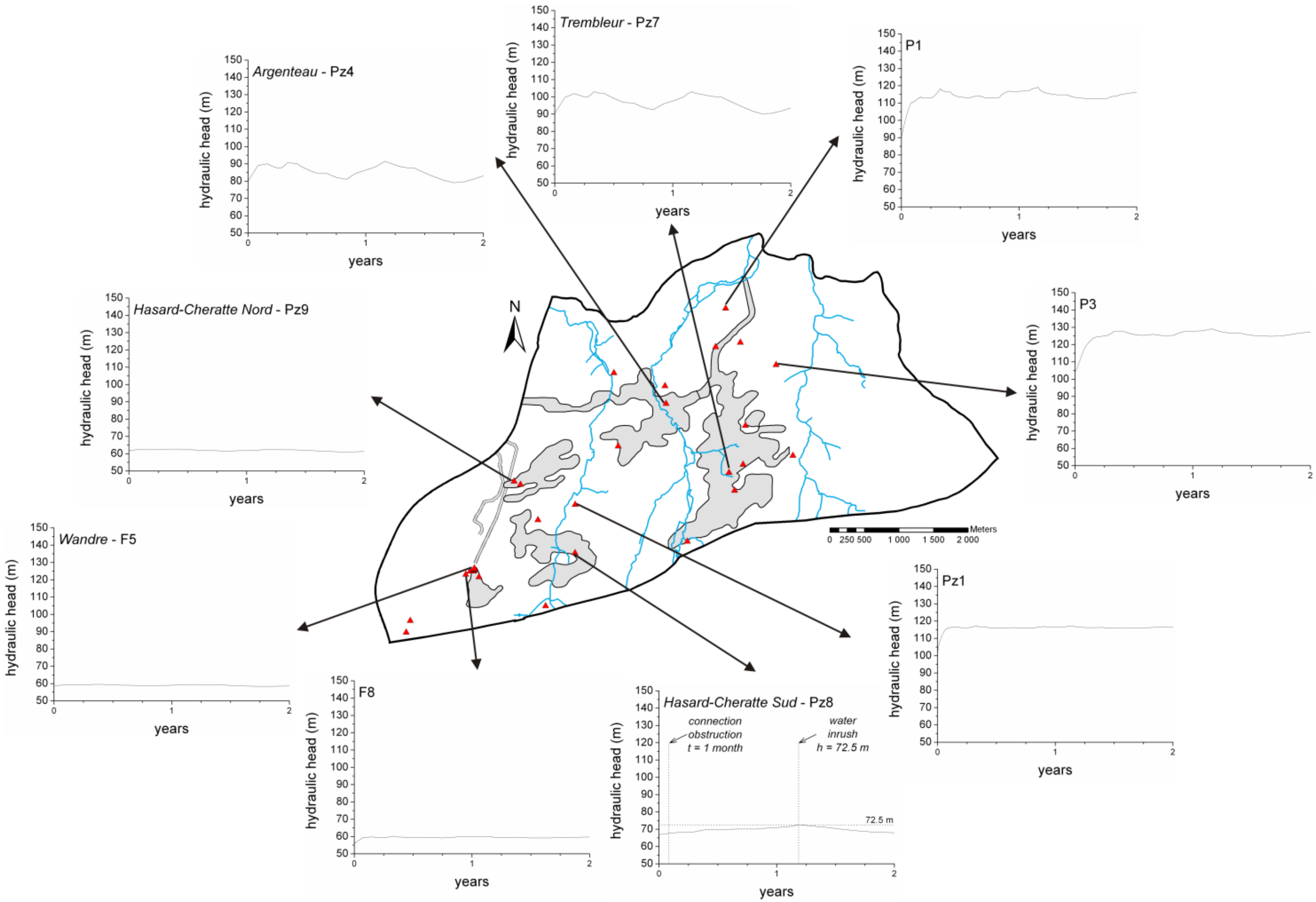
Water inrush

- 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

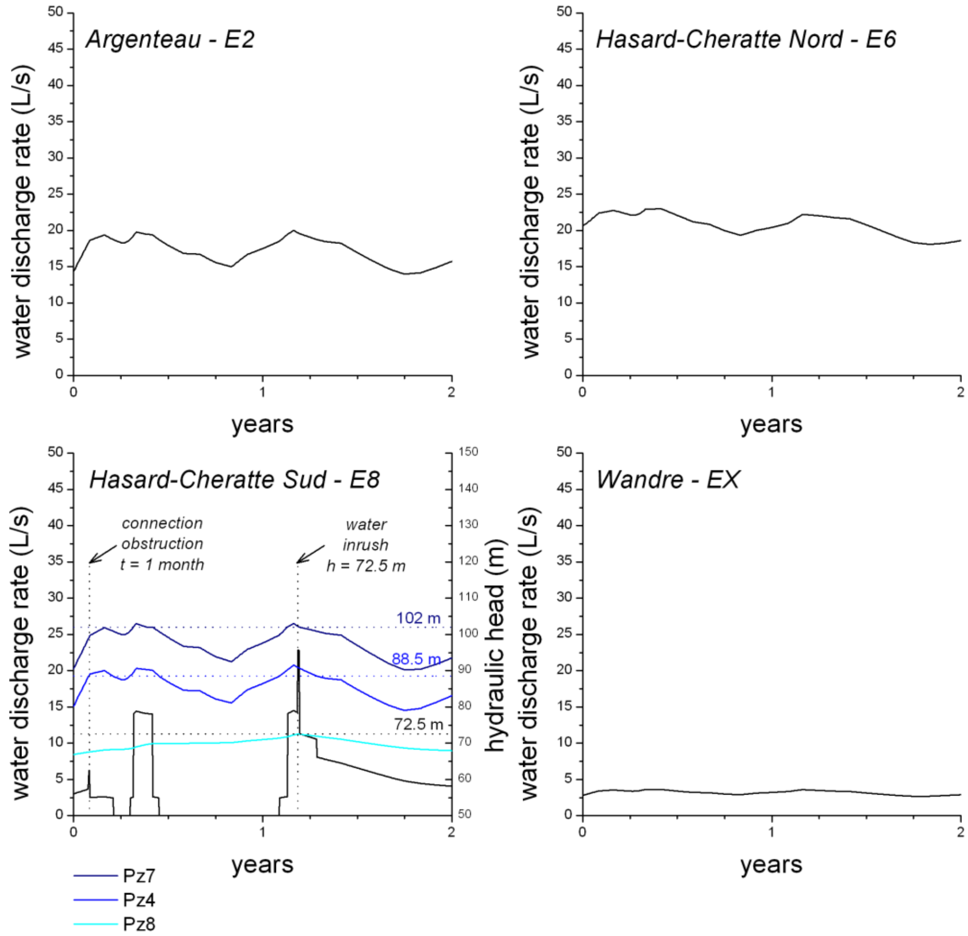
Water inrush

- 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)

Scenarios

Very rainy winter

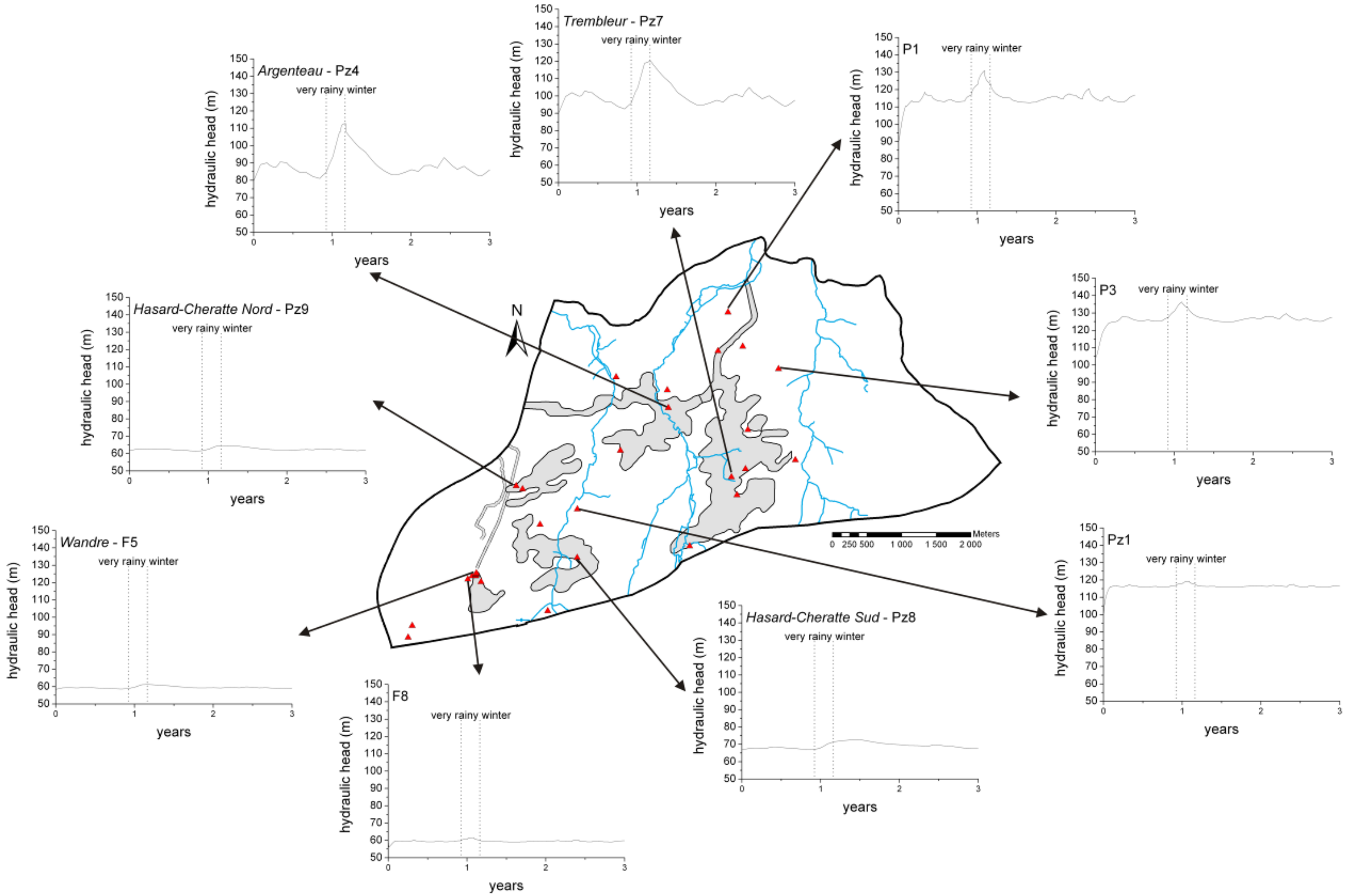
Very rainy winter

- Goal:
  - Predict system response in case of a very rainy winter

- Simulation:
  - 3 years
  - Very rainy winter at the end of the 1st year
  - Recharge, computed from a water budget for the period 2004-2006 (except for the very rainy winter), varies monthly

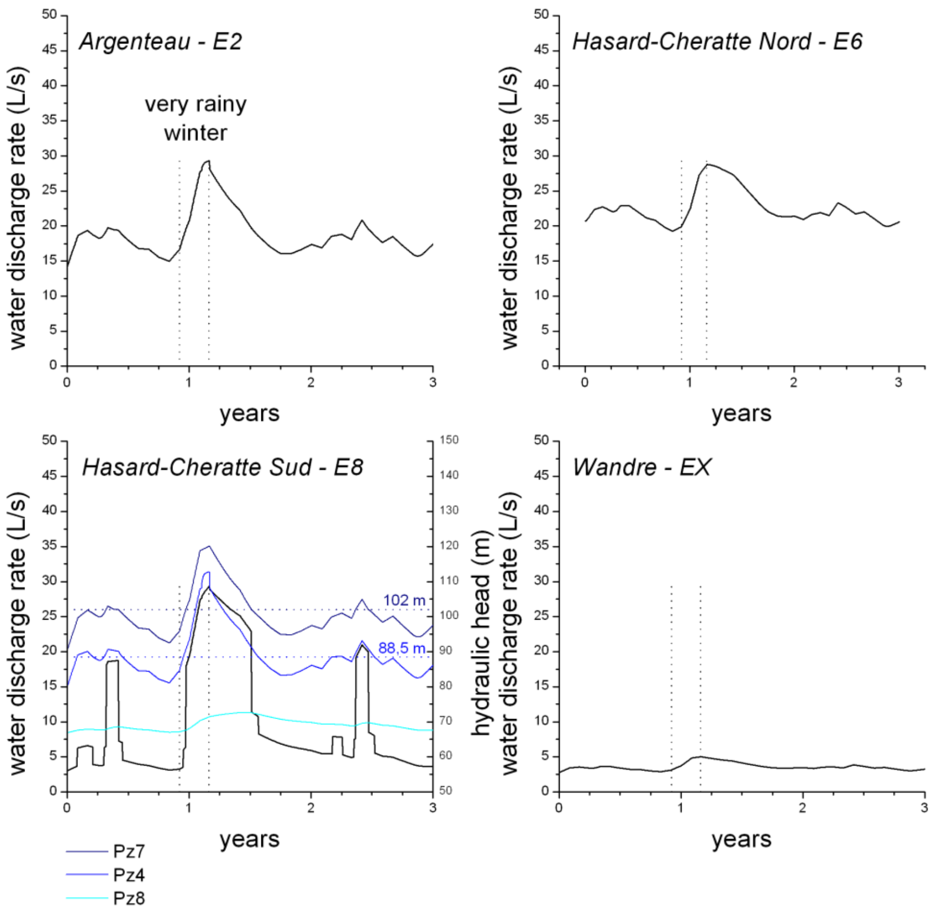
Very rainy winter

- Hydraulic heads



Very rainy winter

- Water discharge rates



Very rainy winter

- Conclusions:
  - Very rainy winter could cause:
    - A strong increase in water levels in *Trembleur* and *Argenteau*
    - A strong increase in associated drainage galleries
  - *Hasard-Cheratte Sud*, via E8, is the most sensitive zone

BUT

the model does not consider the possibility of old dewatering galleries reactivations

Conclusions and perspectives

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 the calibration (UCODE_2005 or PEST)
    - Uncertainty analysis (UCODE_2005 or PEST)

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Thank you for your attention!

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