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

Philippe ORBAN, Serge BROUYERE
Hydrogeology Group – University of Liège - Belgium

General context & Objectives

Context :

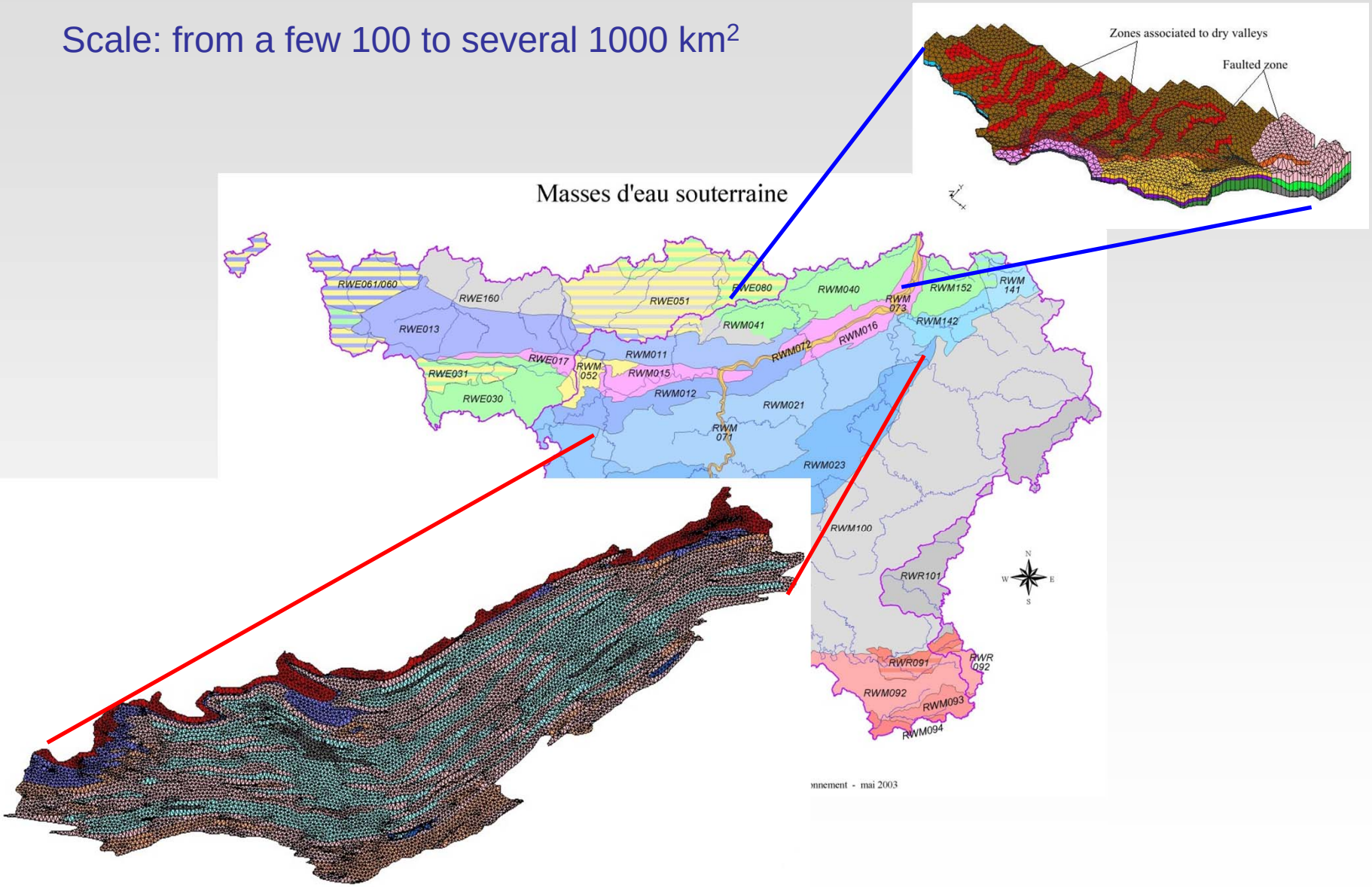
- Increasing deterioration of groundwater quality due to nitrate diffuse pollution
- Need for groundwater management to implement policy
- Statistical tools are generally poorly adapted to prediction
- Need to link changes in land use and groundwater quality trends

Objectives:

- Develop and apply modelling application for groundwater quality trend assessment and prediction at the regional scale

Challenges

Scale: from a few 100 to several 1000 km^2



Challenges

Parameterization/ Calibration of groundwater flow and transport at regional scale

- Conceptual model / objective function
  - Model complexity ←→ model objectives
  - Data requirements ←→ 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

Available modelling approaches

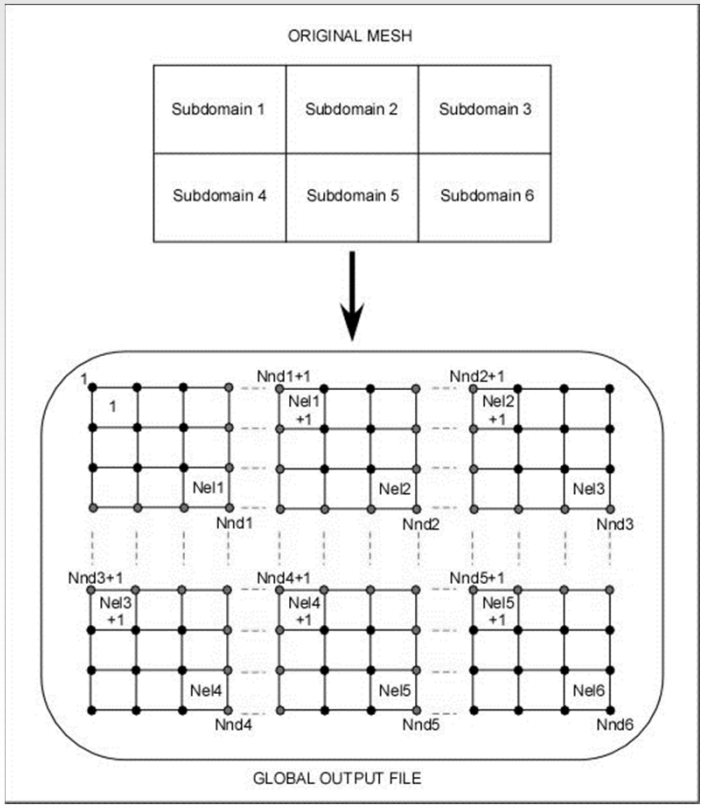
	Advantages	Disadvantages
Black box models	• Easily used • Few parameters	• Results not spatially distributed • Lower predictive capability
Distributed black-box models	• Easily used • Few parameters • Results spatially distributed	• Lower predictive capability
Distributed physically based models	• Results spatially distributed • Good predictive capability	• Large amount of parameters required

The Hybrid Finite Element Mixing Cell approach

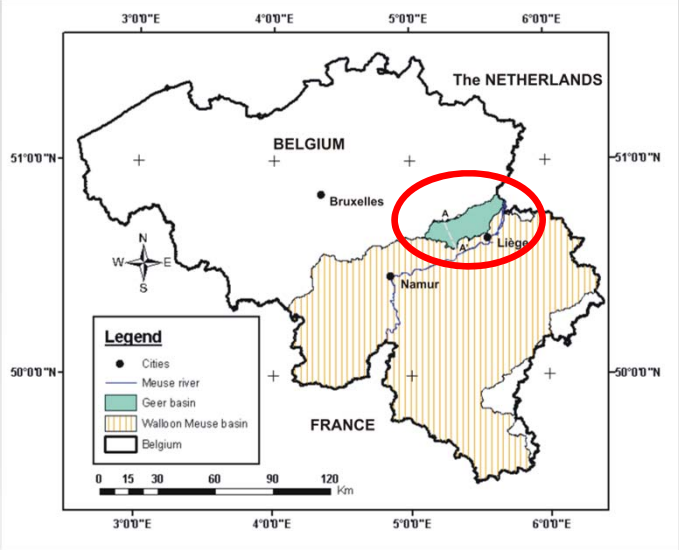
Physically-based, spatially-distributed, variably saturated subsurface model

- 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 (Hybrid Finite Element Mixing Cell approach)

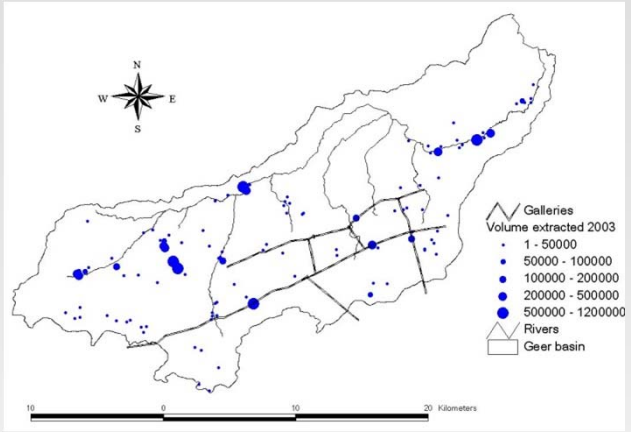
		TRANSPORT		
		Simple Reservoir (Linear…)	*Distributed Mixing Model*	*Advection-dispersion*
FLOW	*Simple Reservoir (Linear…)*	OK	impossible	impossible
	Distributed Reservoir (Linear…)	OK	OK	impossible
	Flow in porous media	OK	OK	OK



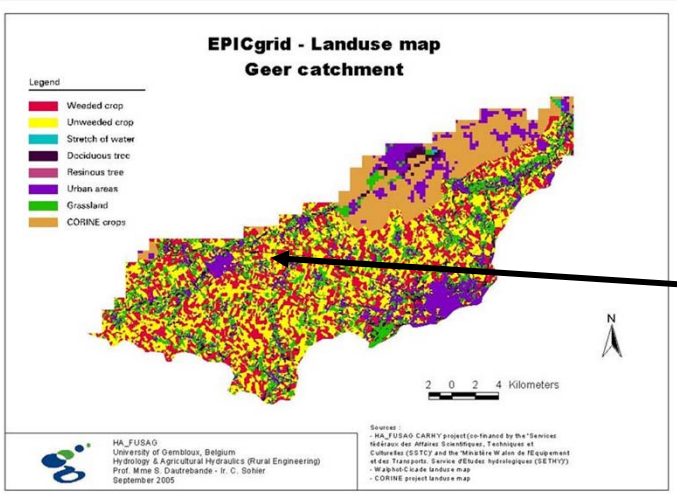
The Geer basin case study

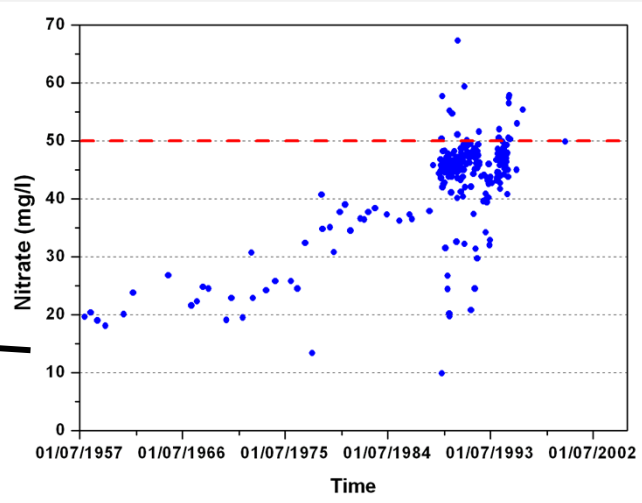


Groundwater quantity: 30 millions m³/year of drinking water to supply approx. 600,000 people in the region of Liège

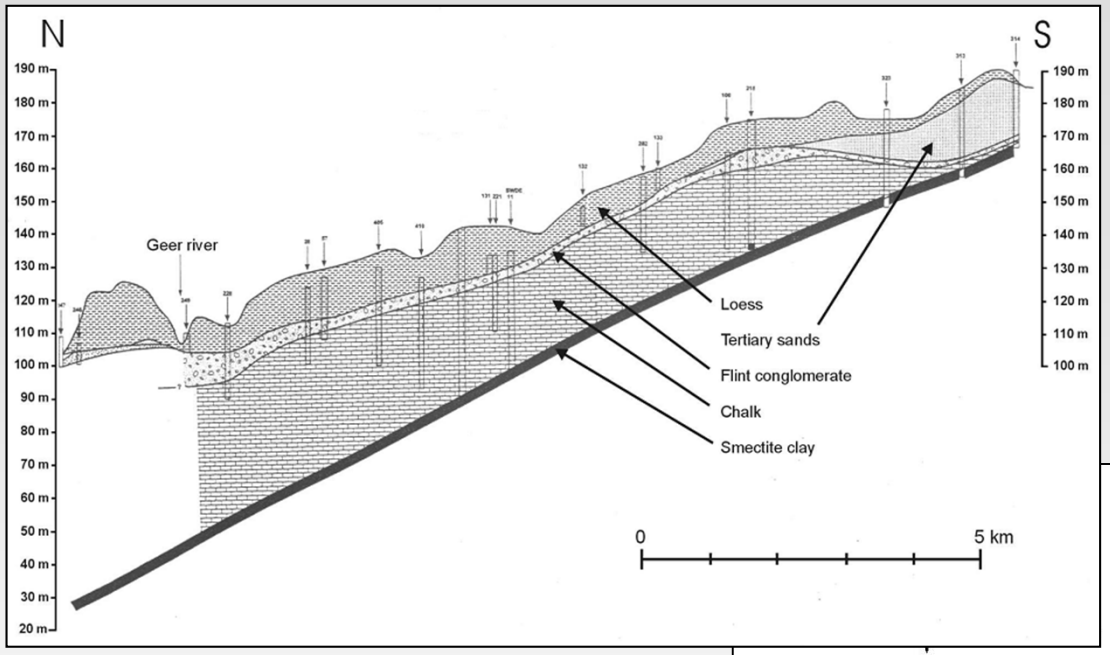


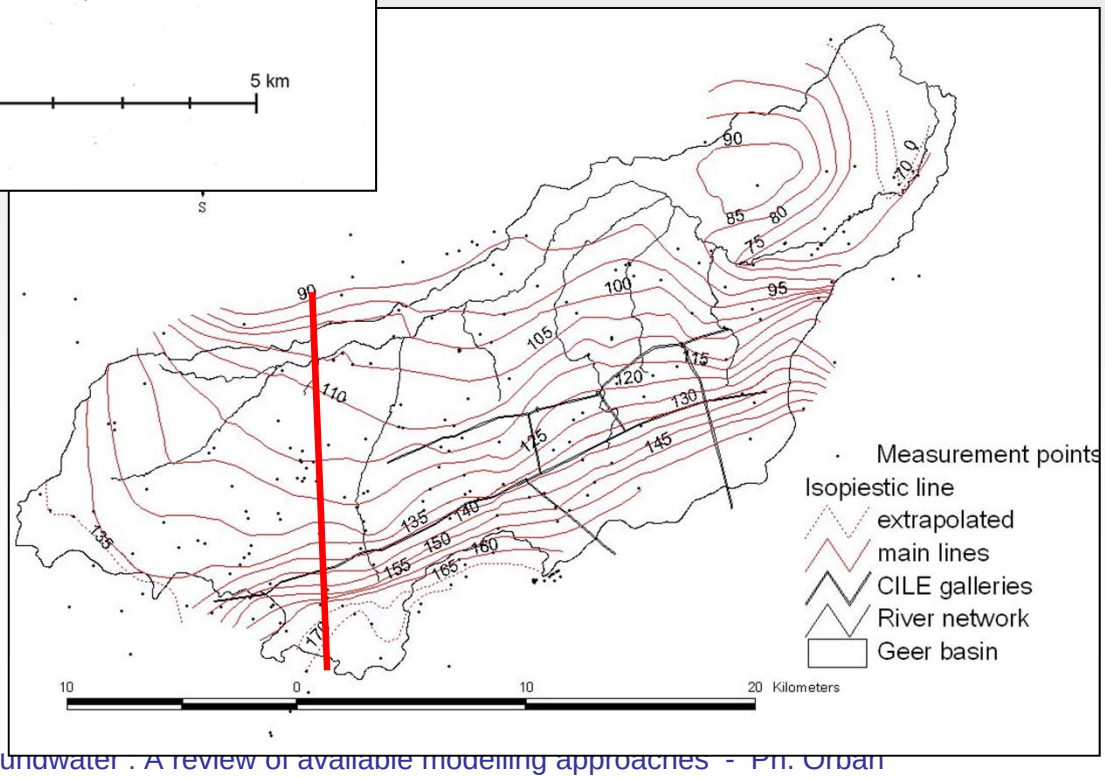
Groundwater quality: Intensive agriculture (65% of the basin) nitrate concentrations approach or are even above the drinking water threshold of 50mg/L NO_3



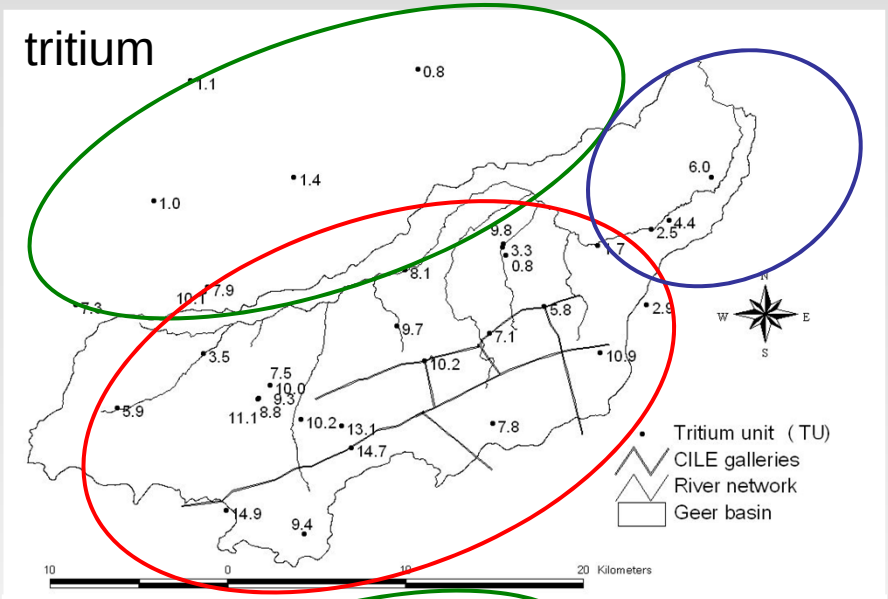


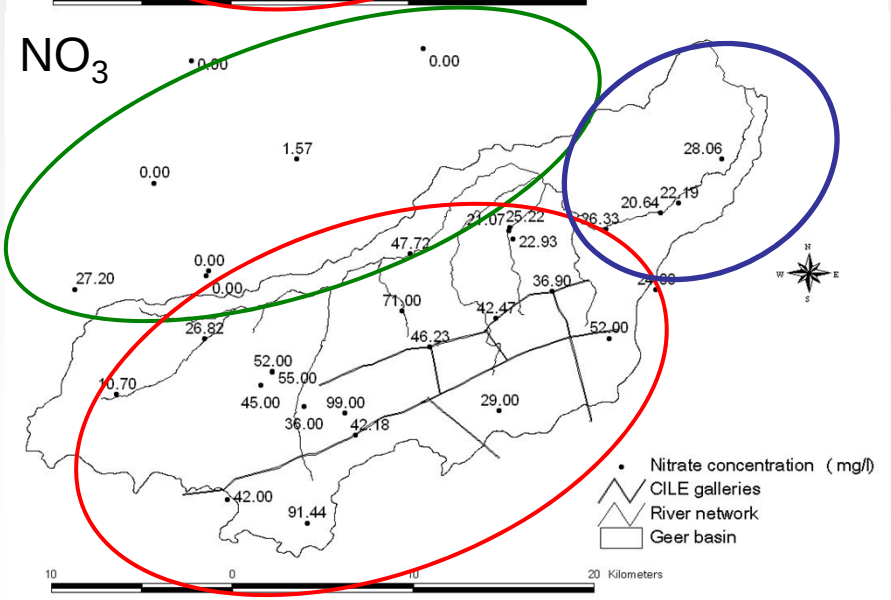
The Geer basin case study





The Geer basin case study





Spatial distribution of tritium contents

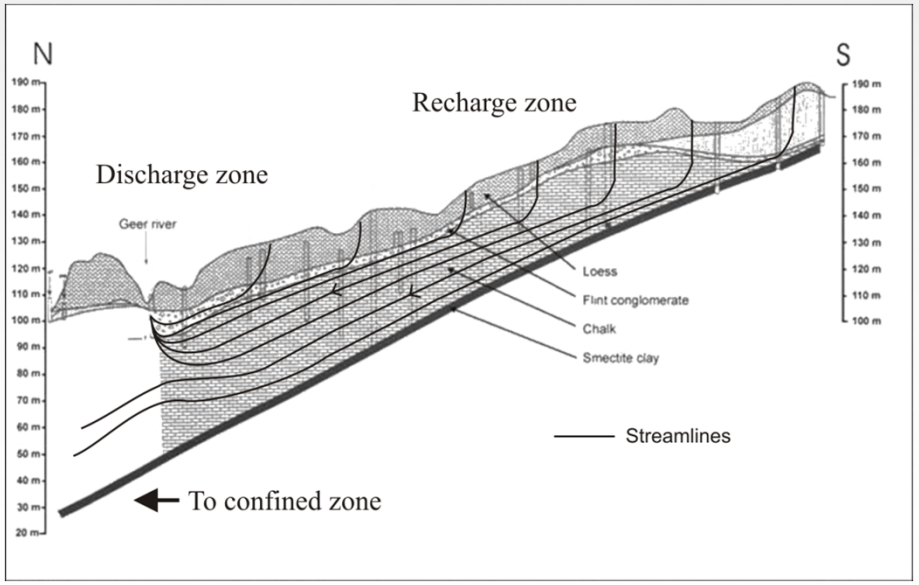
- N : TU =~ 1, old water
- S : TU =~ 10, young water
- E : TU =~ 5, mixing between old/young

Spatial distribution of nitrate contents

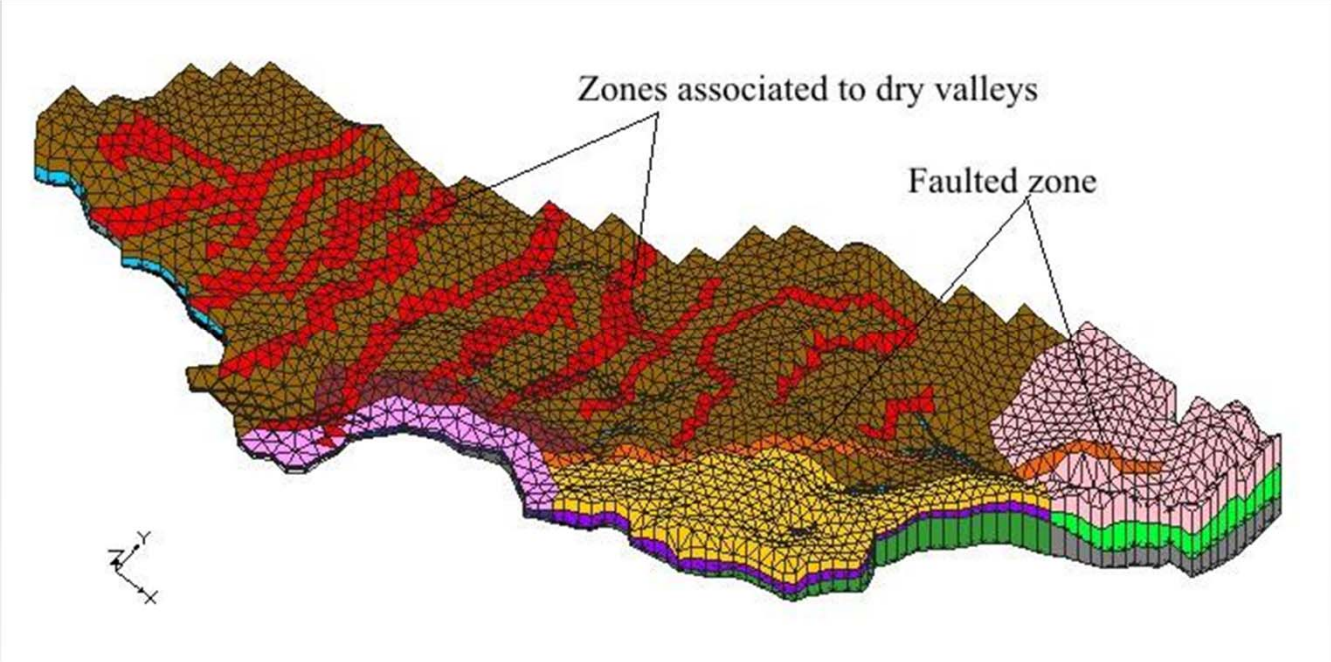
N : NO3 =~ 0 mg/L

S : NO3 =~ 30 – 90 mg/L

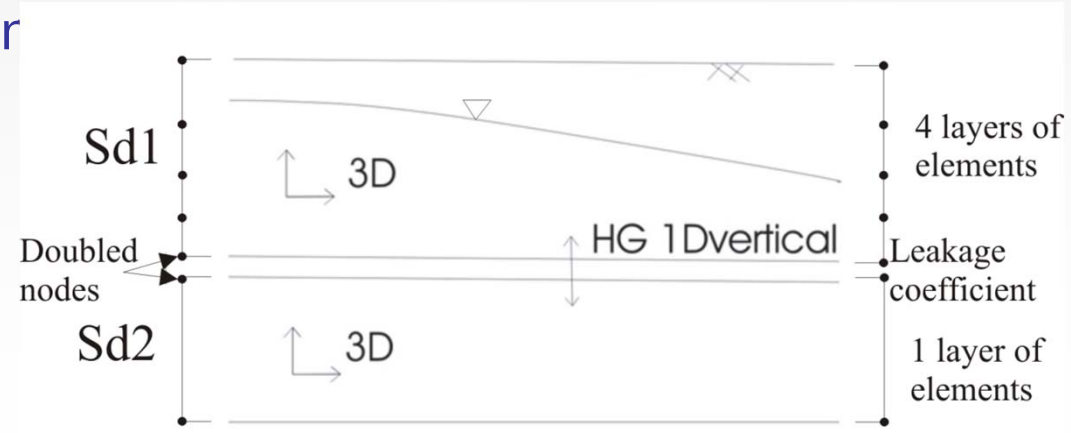
E : NO3 =~ 20 – 25 mg/L



Groundwater model



- Limits of the model similar to the limits of the hydrological basir
- 5 layers (2 loess, 3 chalk)
- Heterogeneity of the chalk



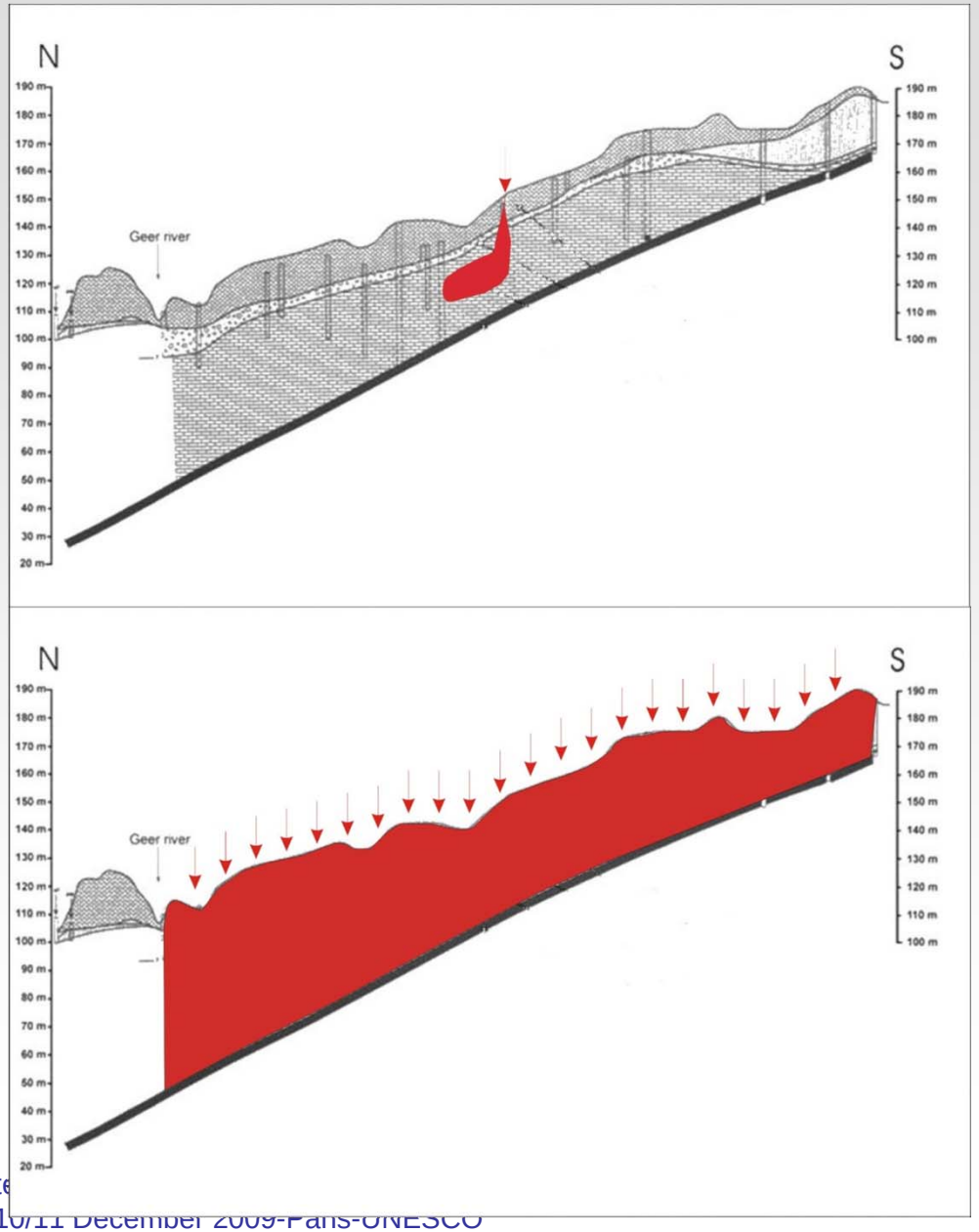
Groundwater model

Groundwater flow

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

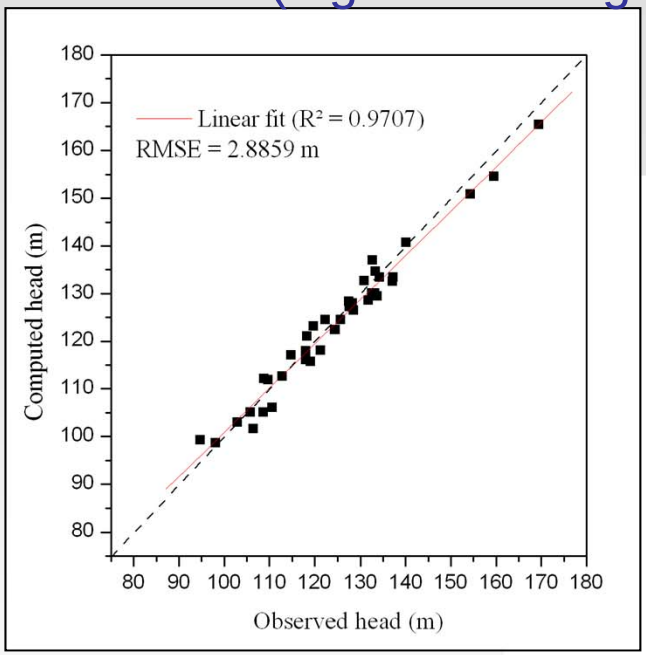
Solute transport

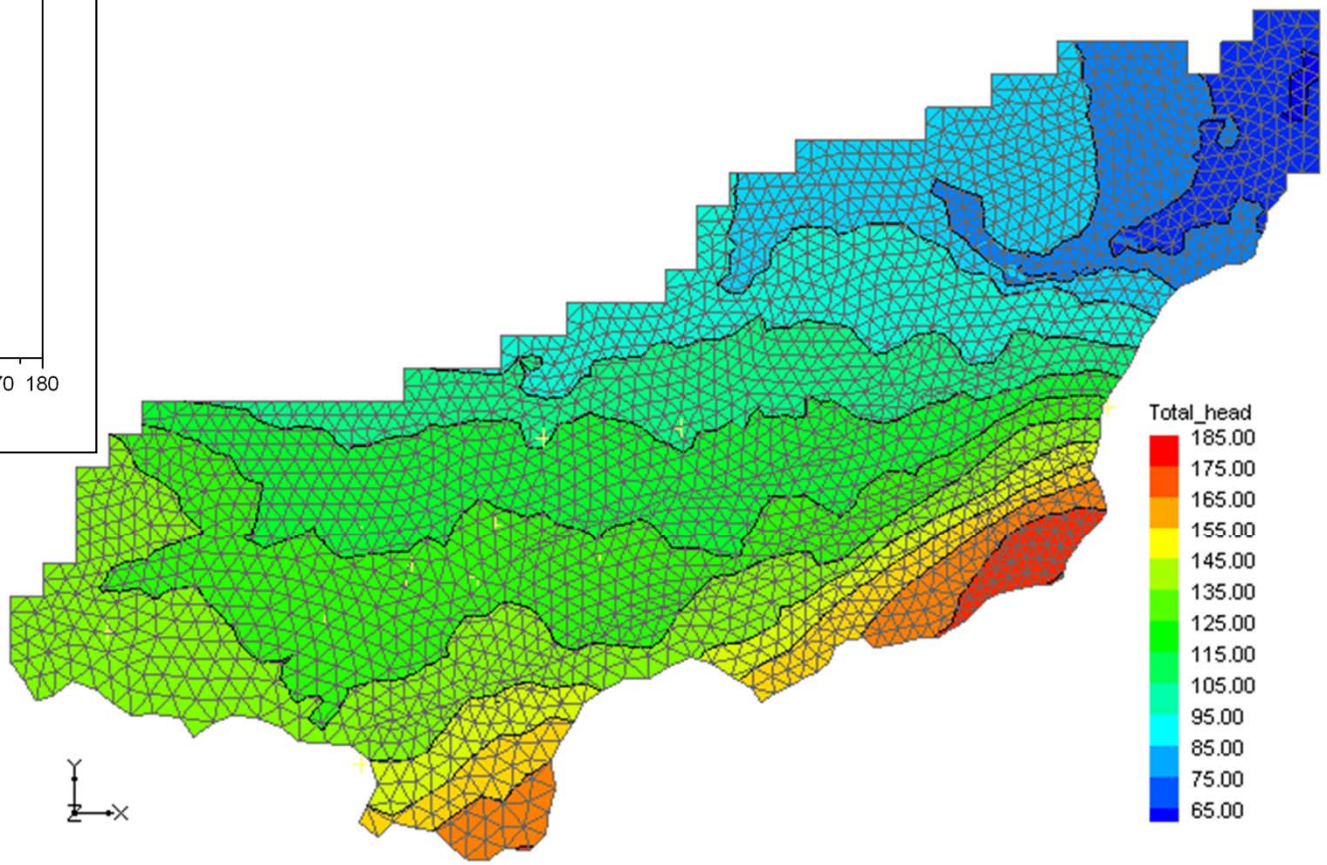
➔Dual-porosity concept
➔Distributed mixing cells



Groundwater model

Calibration of the groundwater flow model in steady-state on 2 contrasted datasets (high and low groundwater levels)



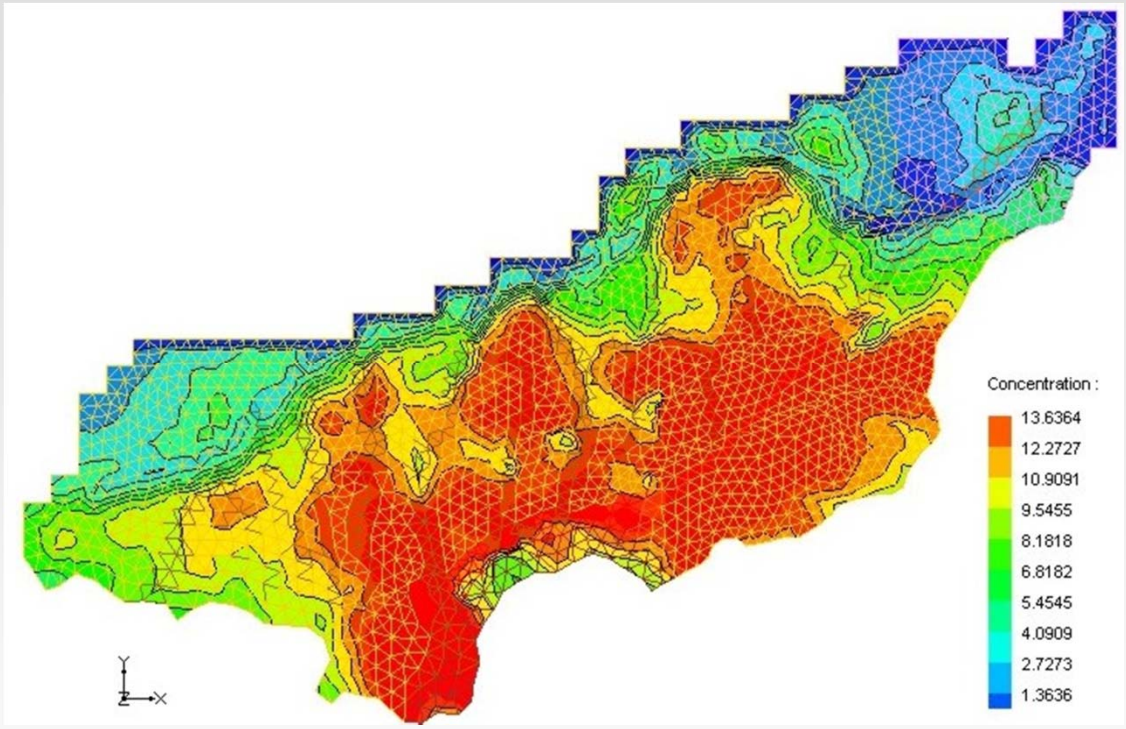


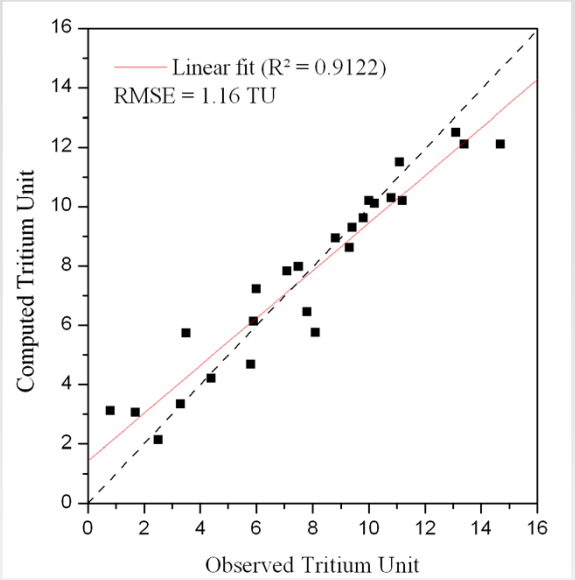
Groundwater model

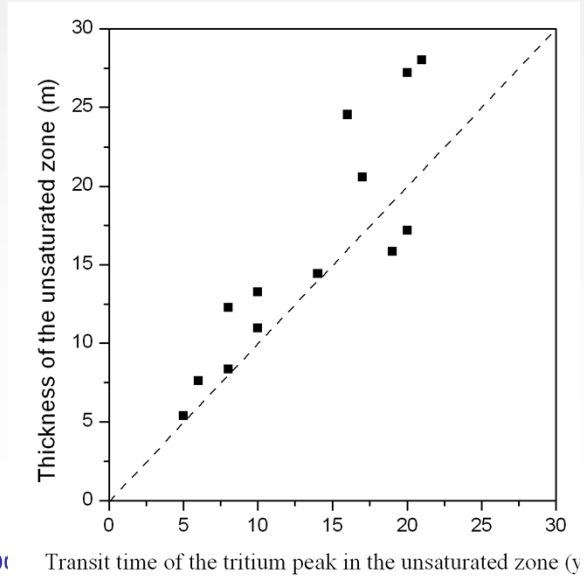
- Calibration of the solute transport model:
  - Groundwater flow in steady-state
  - Solute transport in transient conditions (period 1950-2008)
- Use of two datasets
  - Tritium data:
    - Input function is well known (Groningen measurement station)
    - Peak in the input function
  - Nitrate data
    - Input function difficult to estimate

Groundwater model

Calibration with ^{3}H data measured in 2004

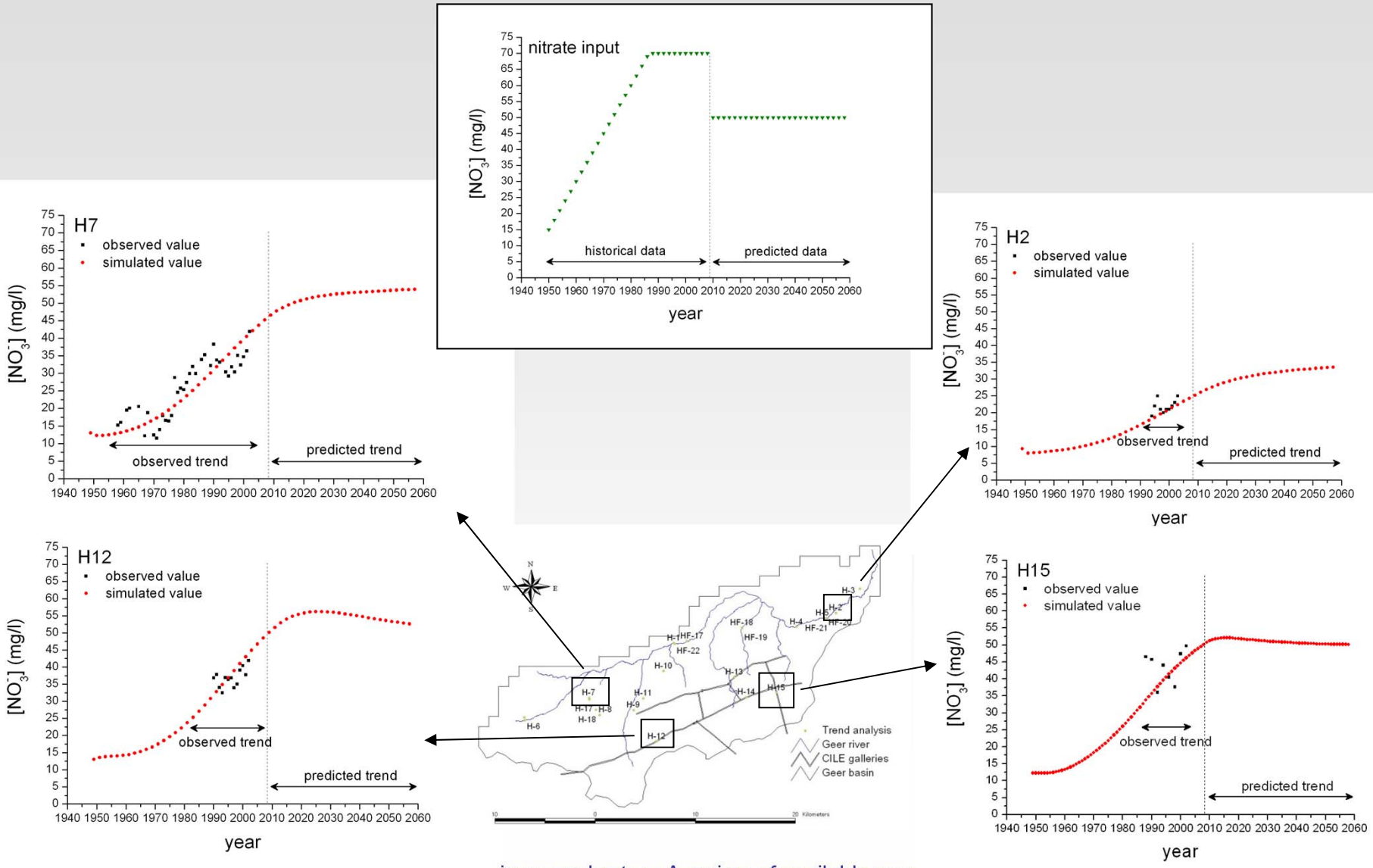






Mean observed velocity across the unsaturated zone=~ 1m/y

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

Acknowledgement

- FP6 AquaTerra EC and partners
- Walloon Region, Groundwater division
- Fonds National de la Recherche Scientifique of Belgium
- Aquapôle University of Liège
- Belgian Science Policy PAI Timothy

THANK YOU FOR YOUR ATTENTION !