# Large Scale Groundwater Modelling in the Scope of the EU Water Directive

AquaTerra

## Challenges and first steps in the Walloon part of the Meuse basin

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# General context

- EU Water directive
  - IWRM at the scale of main EU water districts (e.g. Rhine, Meuse...)
  - (ground)water body = management unit
  - Focuses more on diffuse pollution problems (e.g. nitrates)
  - Short terms deadlines (2015…) and ~strict rules and regulations
  - All territories to be covered (no « gaps »)

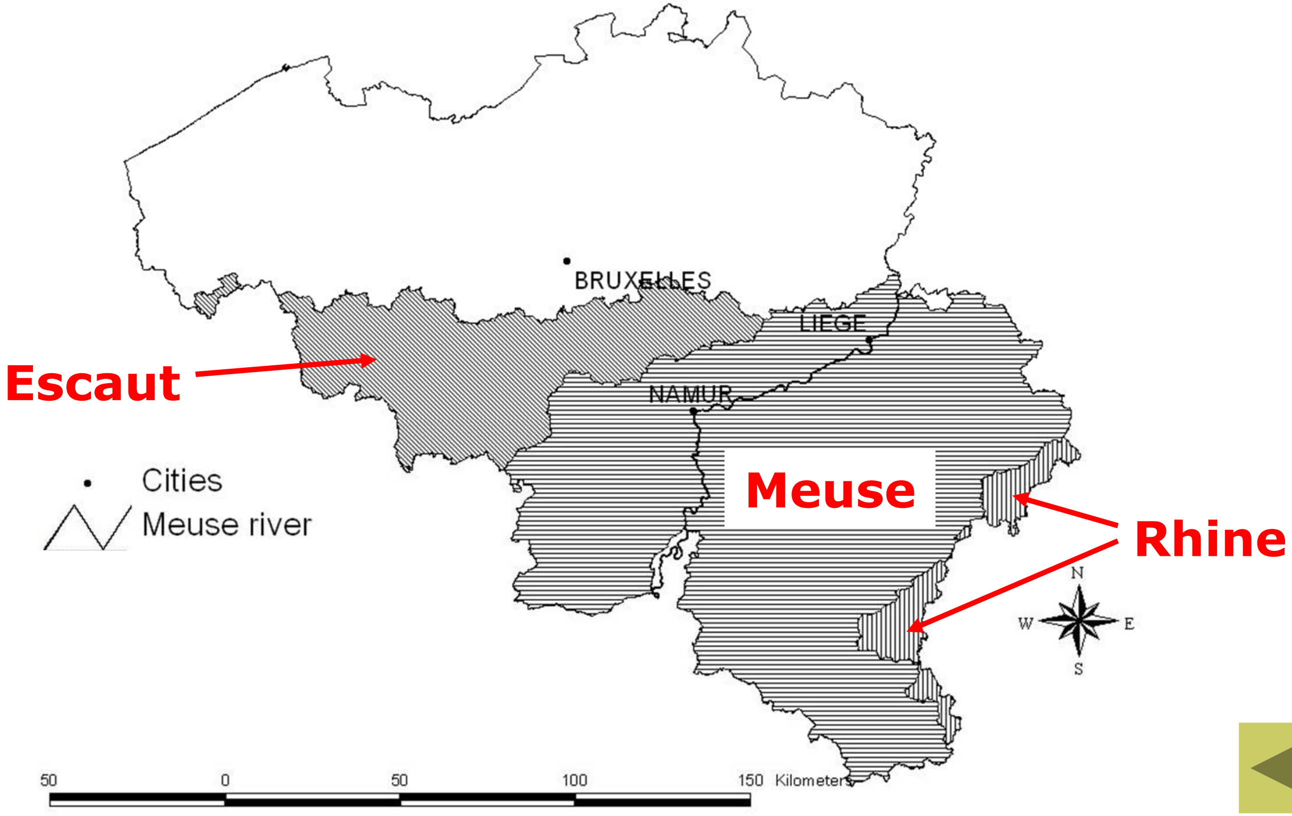
# Challenges

- Developing a large-scale groundwater modelling approach is challenging:
  - Working scale: GW body → Water district
  - Large variability in geological and hydrogeological contexts
  - Large variability in the assessment of hydrogeological conditions and complexity of processes
  - Data requirements and handling
  - Integrated modelling approach in perspective
  - Computation requirements and accuracy of results

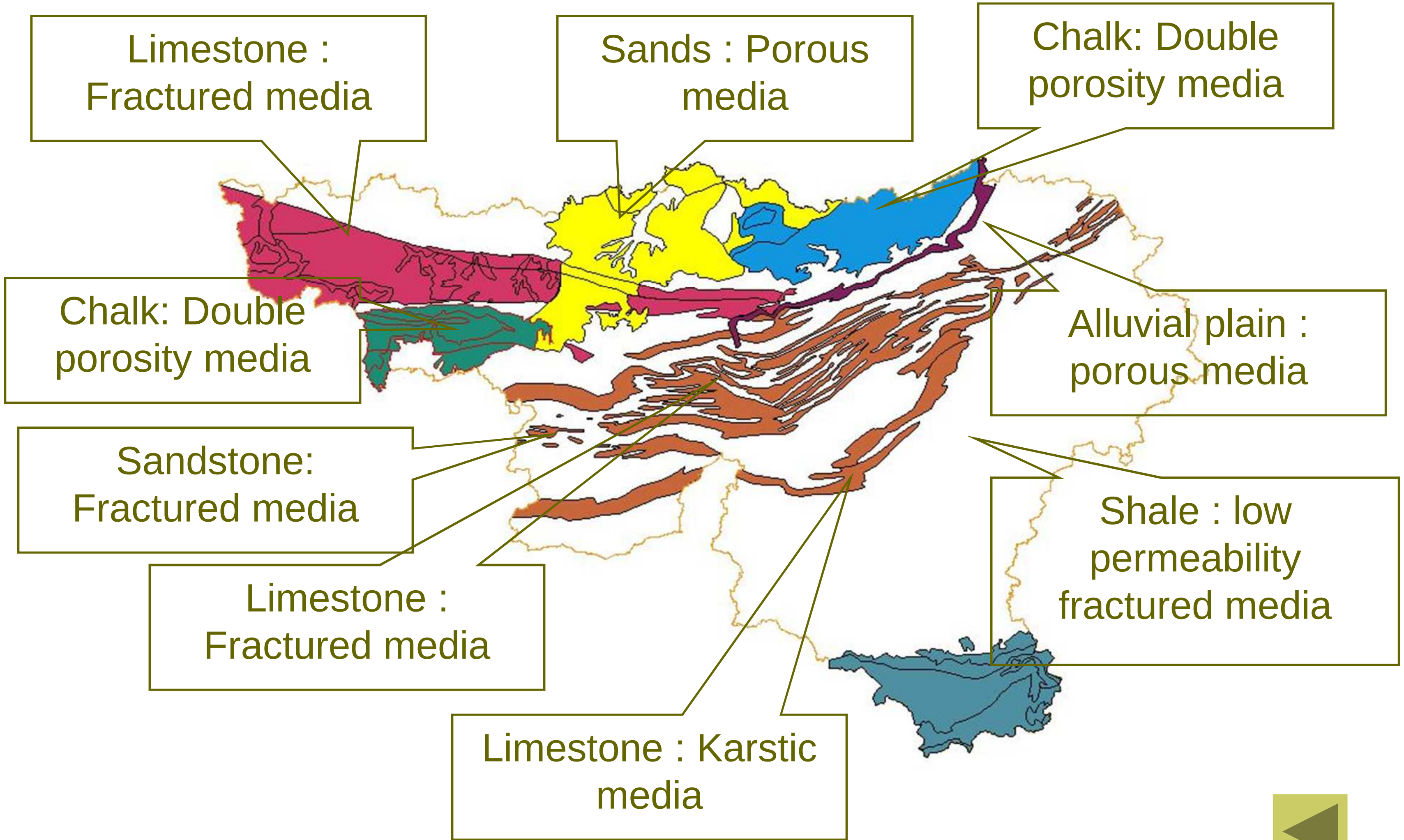
# Working scale in the Walloon region

WFD : Management of water by hydrological districts

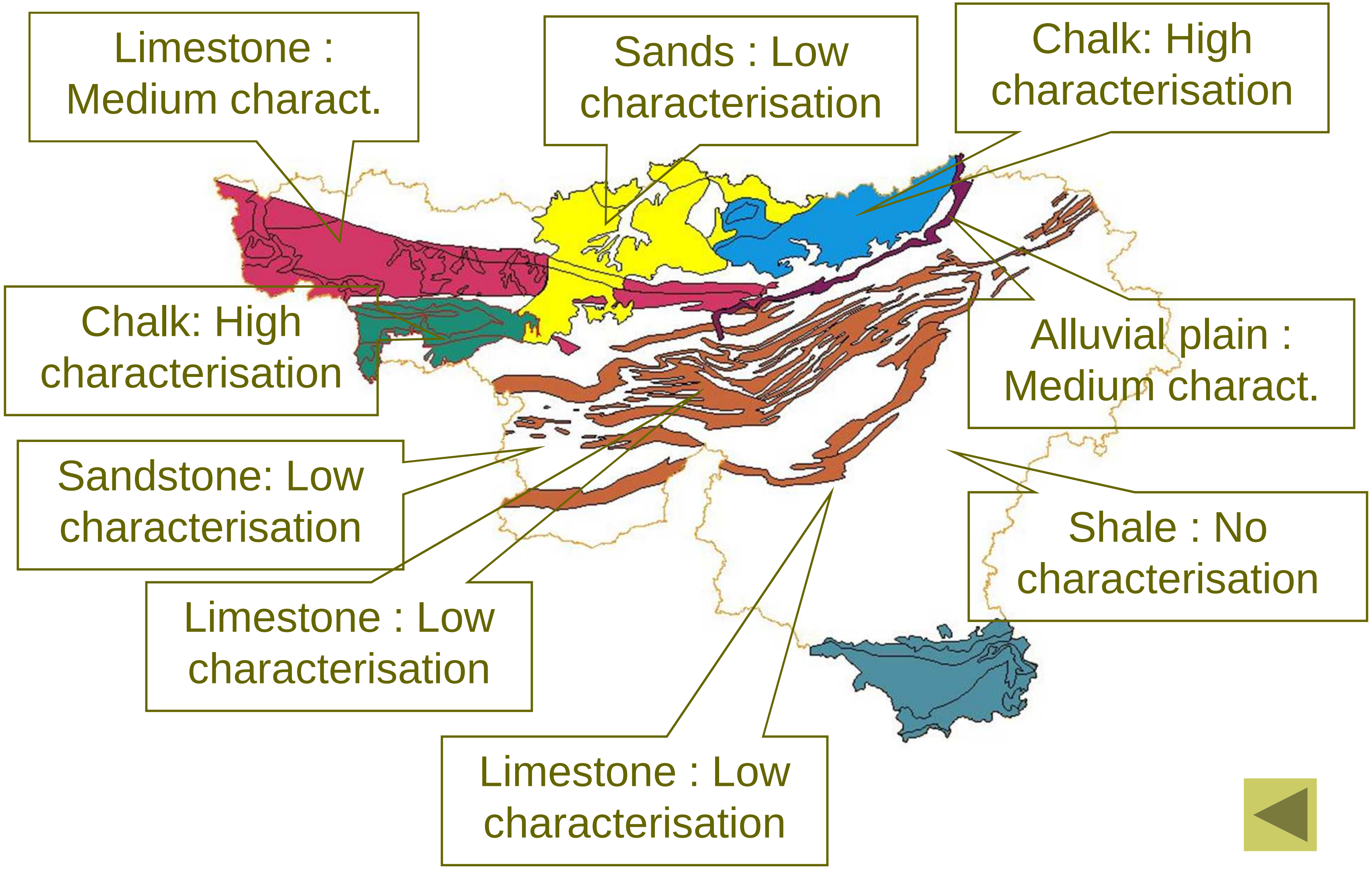
=> In the Walloon region, 3 hydrological districts



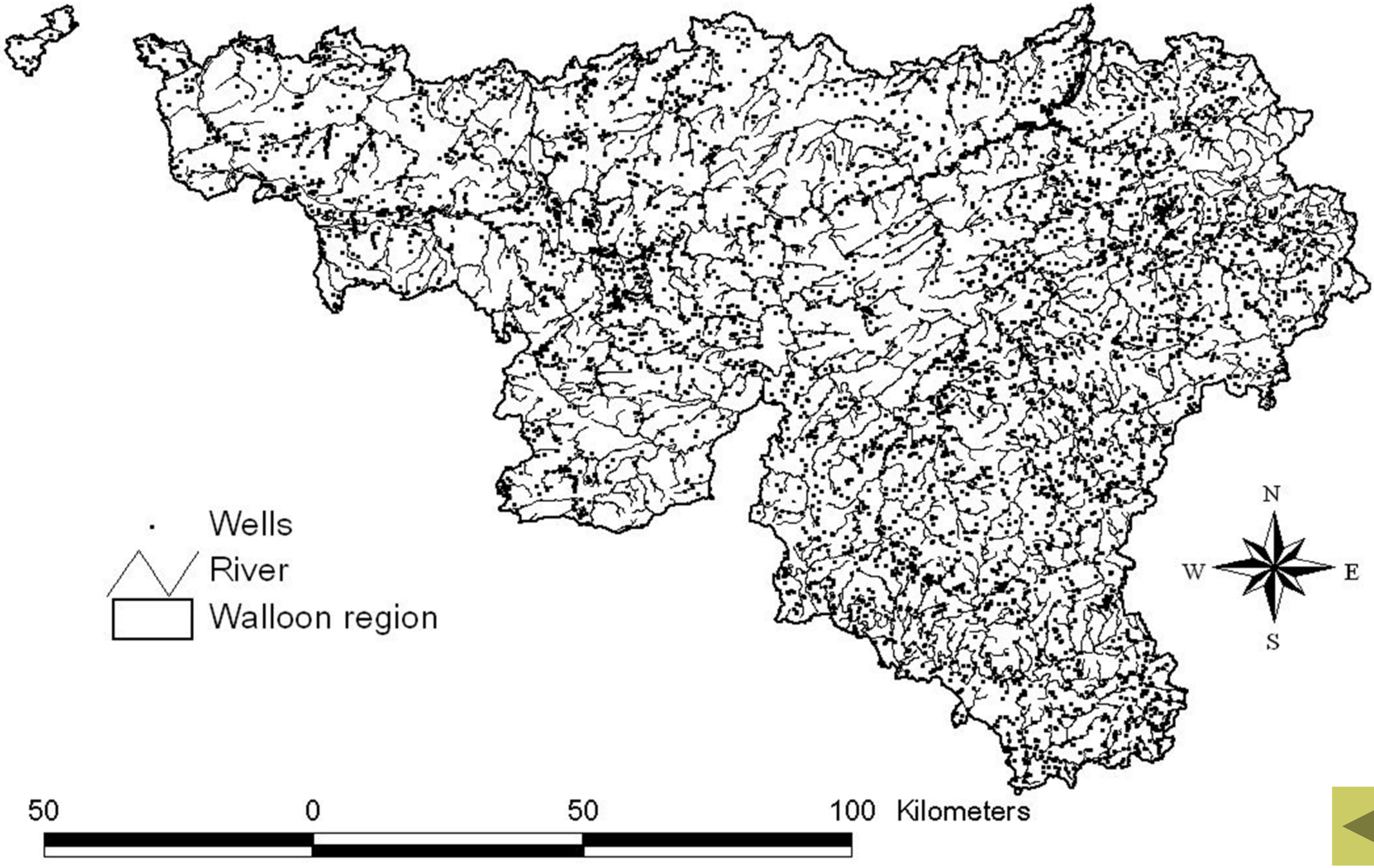
# Variable geological contexts



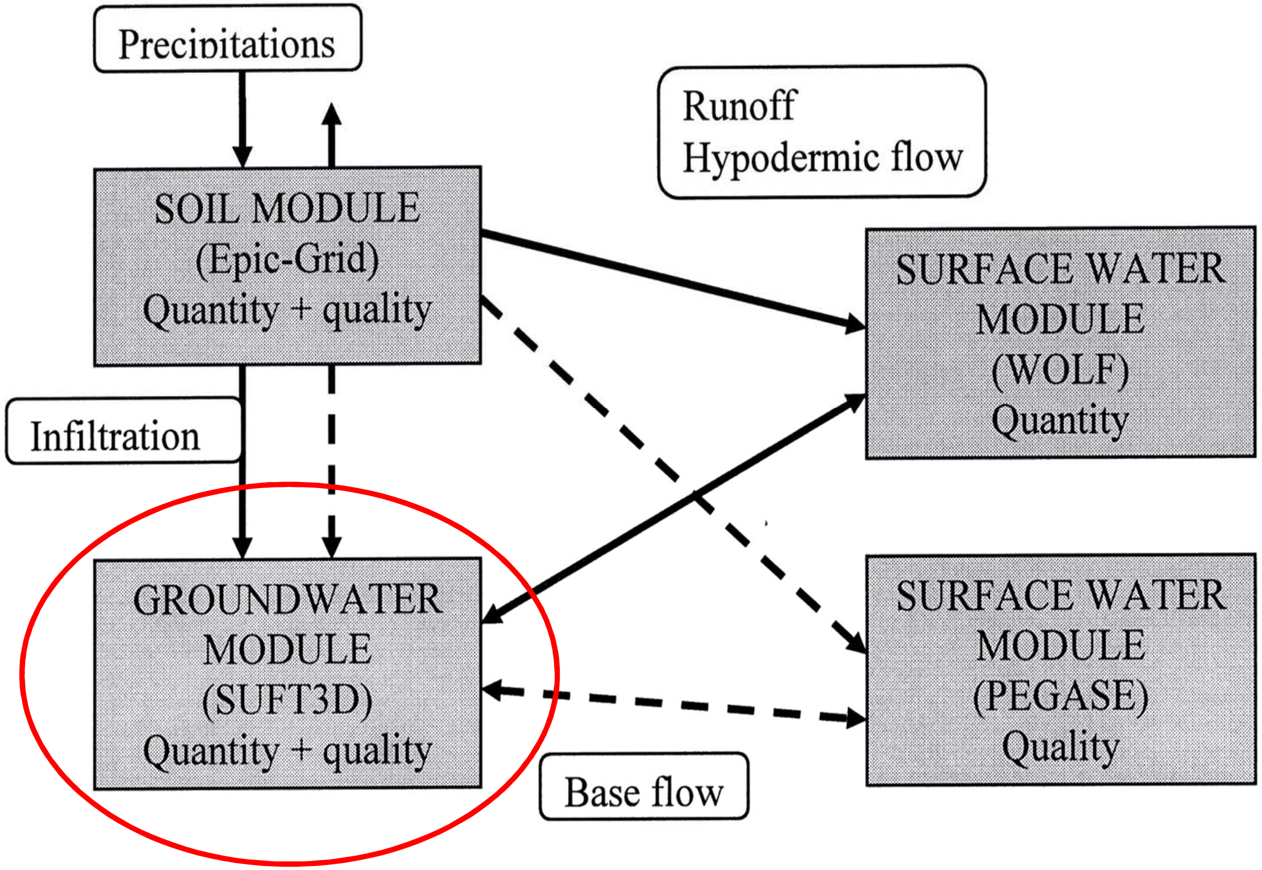
# Variable knowledge on hydrogeological conditions



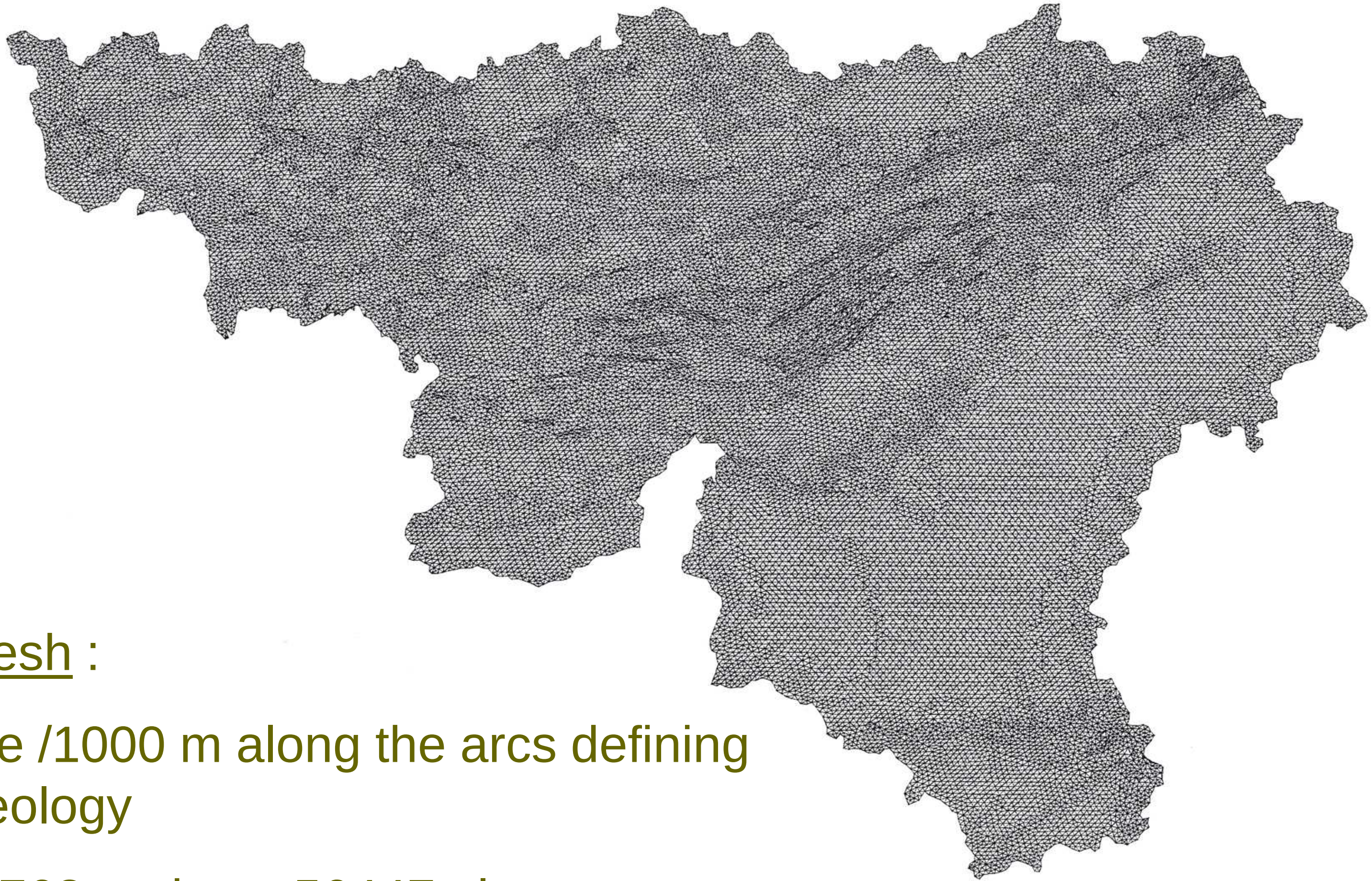
# Data requirements and handling



# Integrated Modelling of the Water cycle



# Computational requirements

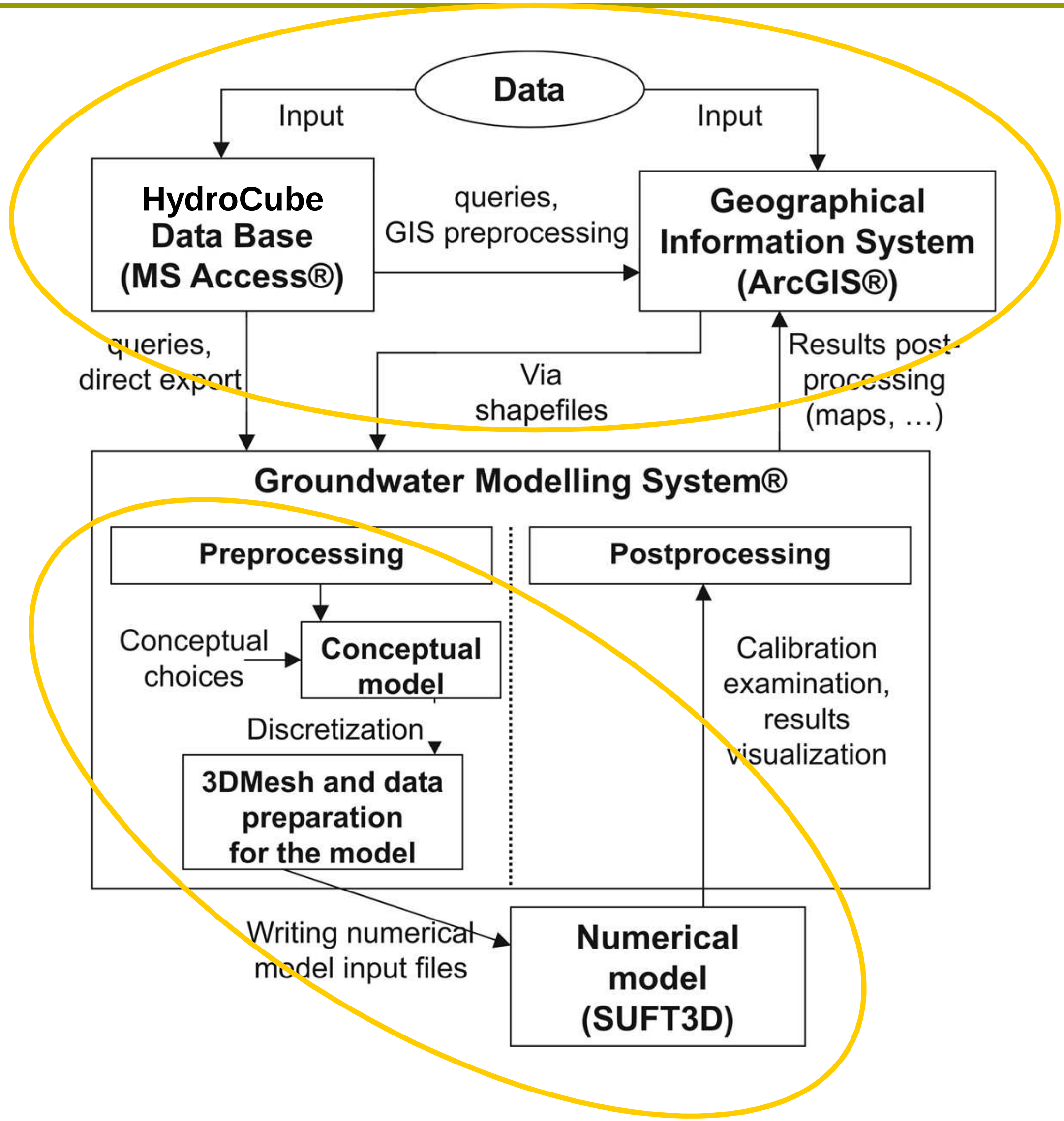


2D Mesh :

1 node /1000 m along the arcs defining the geology

=> 28768 nodes – 56447 elements

# General methodology for GW Modelling



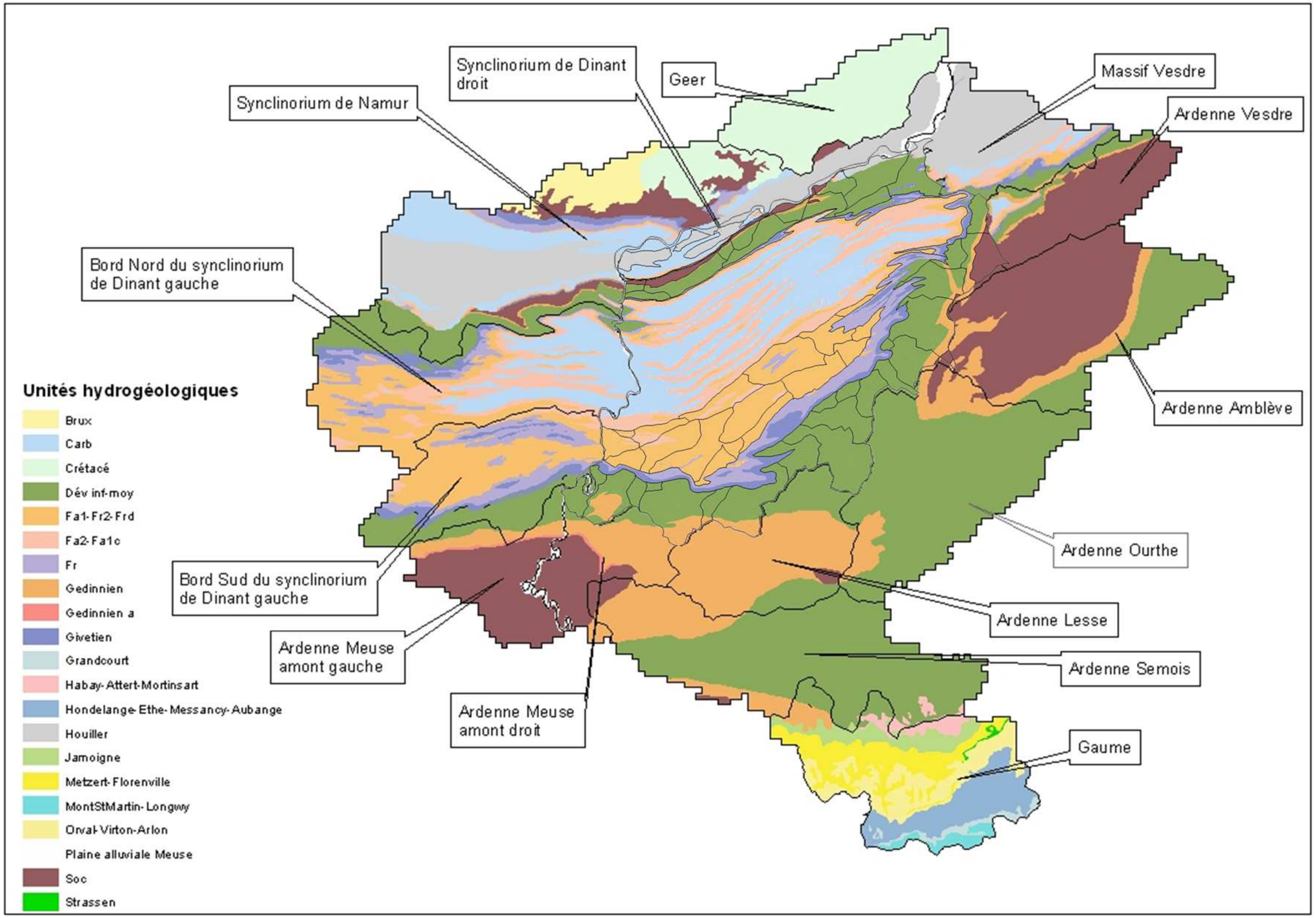

Data management :
Database and GIS

Model :
Conceptualisation
Equations

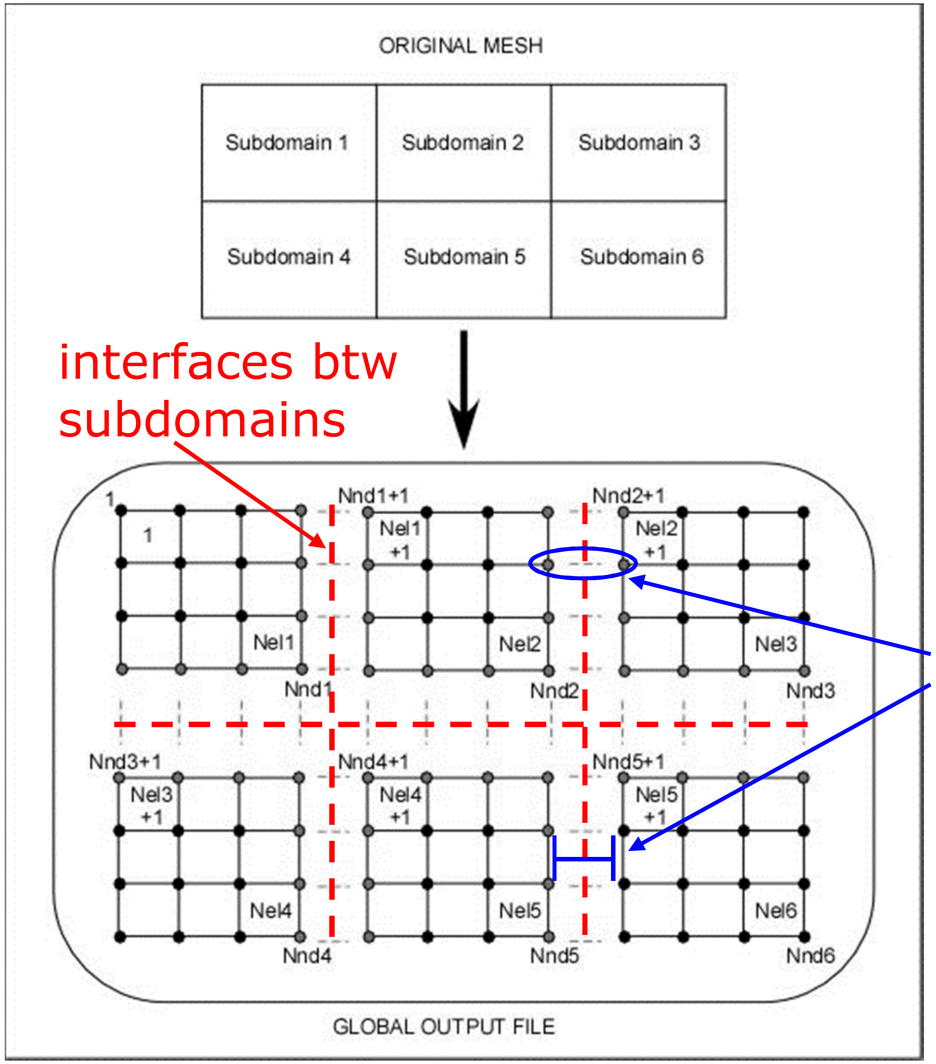
# Geometrical discretization choices

- Global Model = ∑subModels(subDomains)
  - SubModel = hydrogeologically independent subregion of a hydrological basin or district
    - no water exchanged between subModels
    - Exchange of water and contaminants through “external” boundaries only
  - SubDomain = subdivision of a subModel with:
    - “Given” degree of hydrogeological assessment (rough, detailed…)
    - Similar hydrogeological conditions (karst, porous media…)
    - Appropriate set of more or less complex flow and transport equations selected
    - Separated by “zero-D” interfaces = “internal” boundary conditions, across which water and contaminants can be exchanged (e.g. thin confining units not explicitly considered in the 3D discretization)

# SubModels and subDomains in the Meuse basin



# Mesh renumbering with subDomains




node-node or face-face internal BCs

3Dmesh =>

$$\begin{pmatrix} 1 \\ \dots \\ ne_1 \end{pmatrix} = SD_1 = 3DMesh_1$$

$$\begin{pmatrix} ne_{1+1} \\ \dots \\ ne_2 \end{pmatrix} = SD_2 = 3DMesh_2$$

$$\begin{pmatrix} ne_{2+1} \\ \dots \\ ne_3 \end{pmatrix} = SD_3 = 3DMesh_3$$

=> Potentials for parallel computing, sub-modelling…

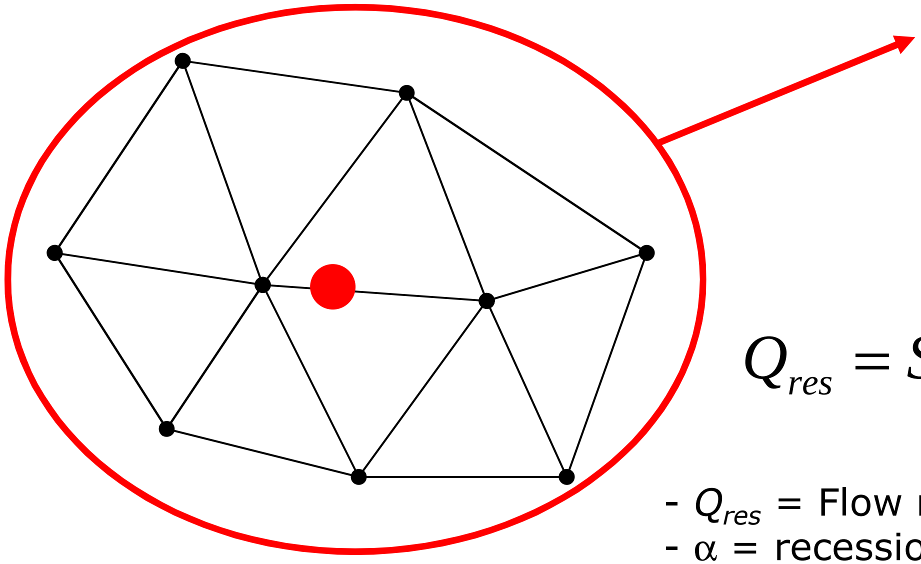
# Mathematical and numerical solutions

- SUFT3D: Saturated – Unsaturated Flow and Transport in 3D
  - Control volume finite element method (CVFE)
  - For large scale applications
    - Flexible discretization / meshing approach
    - Progressive evolution to a OO approach + Full dynamic allocation of arrays
    - Mathematical models of various (increasing) complexities for flow and transport (Hybrid Mixing Cell Finite Element 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 |

# Mathematical and Numerical solutions

- Simple (linear) reservoir



N nodes but 1 unknown
e.g. the mean water level
In the reservoir

$$Q_{res} = S A_{res} \frac{d\overline{H}}{dt} = -\alpha_{res}\left(\overline{H} - H_{ref}\right) + Q_{\pm}$$

- $Q_{res}$ = Flow rate entering or leaving the reservoir
- $\alpha$ = recession coefficient
- $H_{ref}$ = reference (drainage) level
- $Q_{\pm}$ = lumped pumping rate in the reservoir

- Ex: modelling a karstic basin of unknown geometry

# Mathematical & Numerical Solutions

- Distributed reservoir
  - Generalization of the simple linear reservoir to the case of multiple interconnected reservoirs (along the 3 dimensions)

$$\frac{\partial V_{w,I}}{\partial t} = S A_{res,I} \frac{\partial H_I}{\partial t} = \sum_{J \in \eta_I} \alpha_{IJ} \left( H_J - H_I \right) + Q_I$$

    - Reservoirs = FE control volumes

- « Classical GW flow equation based on Darcy's law (CVFE formulation)

$$V_I \frac{\partial \theta_I}{\partial t} - \sum_{J \in \eta_I} \left( H_J - H_I \right) \int_V \underline{\nabla} N_I \cdot \underline{\underline{K}} \cdot \underline{\nabla} N_J \, dV - Q_I = 0$$

# Mathematical & Numerical Solutions

- Simple (linear) reservoir for transport

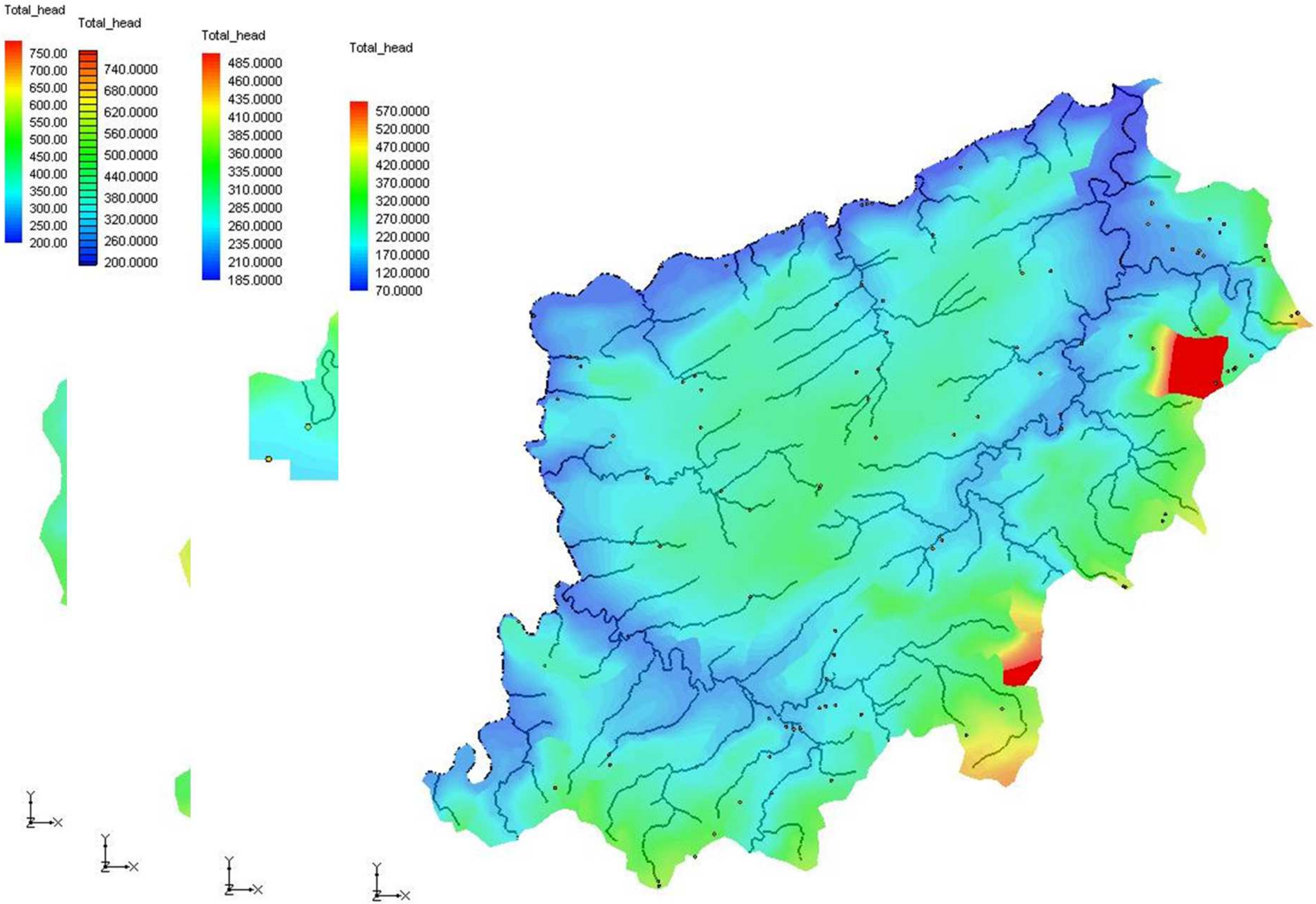
$$\frac{\partial\left(V_{eff,res}\overline{C}\right)}{\partial t} = Q_{in}C_{in} - Q_{out}\overline{C}$$

- Distributed mixing cell approach

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

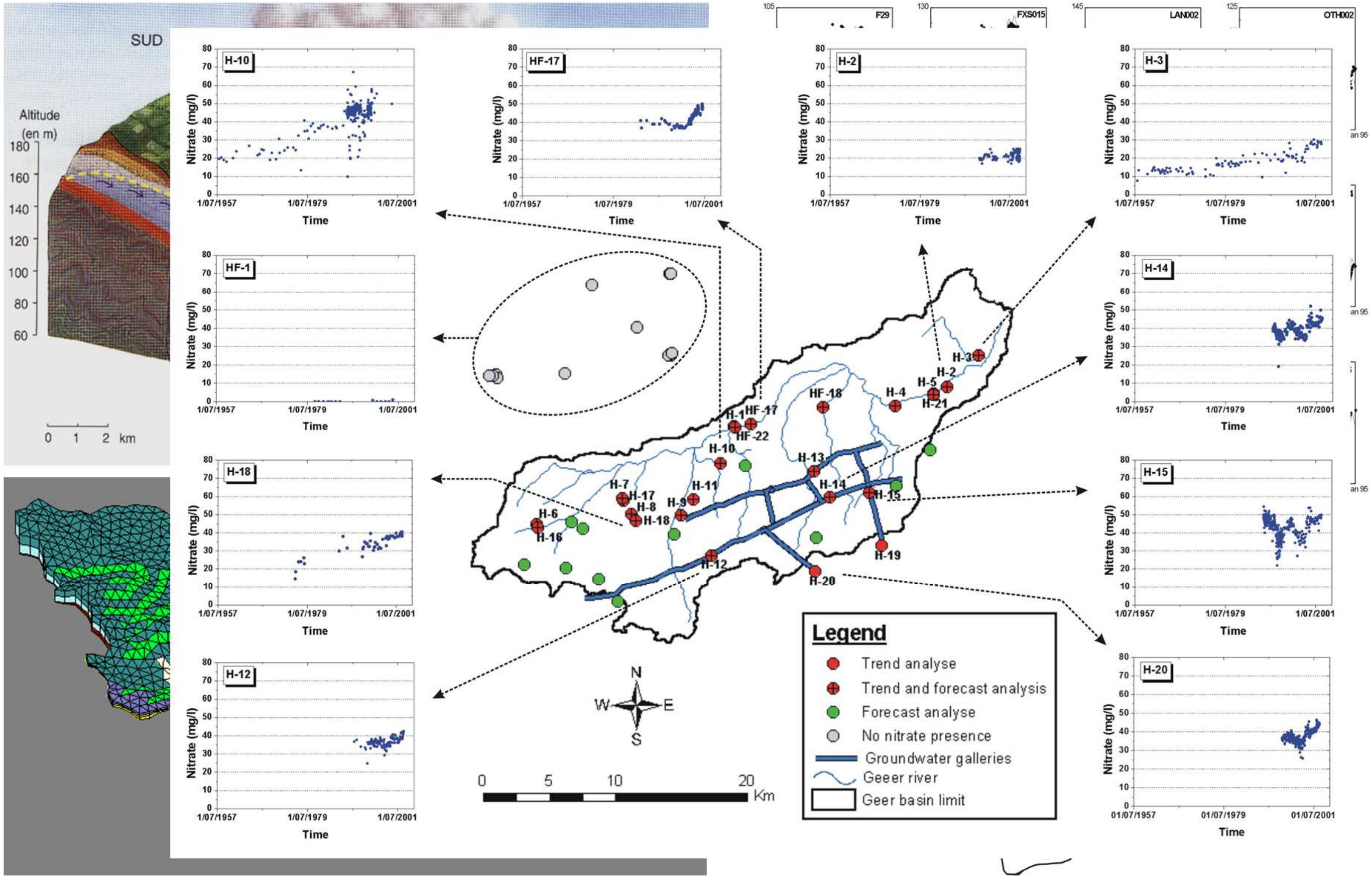
  - Unconditionnaly stable
  - Dispersion governed by the size of the mixing cells only; however, for diffuse pollution, the spatial dispersion of the source is dominant
- « Classical AD transport equation

# Preliminary results for the Meuse basin



# Preliminary results for the Meuse basin

- Nitrate trends in the Geer sub-basin



# Perspectives & Conclusions

- Further steps
  - Finalize the coding of some concepts
  - Calibration and validation for the Walloon region Meuse basin
  - Integration in the integrated model
- Possible applications
  - Impact of land practices (e.g. agricultural manure) and contaminant trend forecasting (e.g. nitrates)
  - Impact of climate changes on (ground)water resources at regional scale
  - Modelling regional GW systems (isotopic data…)

Thank you!

# Boundary conditions

- External boundaries
  - Recharge : Flux-type (Neumann) BC
  - Pumping wells : Element-based source/sink
  - Exchanges with rivers: Head dependent flux node/face (Cauchy) BC
- Internal boundaries
  - Nodal prescribed head or nodal/face head dependent (Cauchy) flux