Estimations of flows drained by tunnels and impacts on the groundwater resources through regional numerical modelling and analytical solutions: application to the Einstein Telescope site

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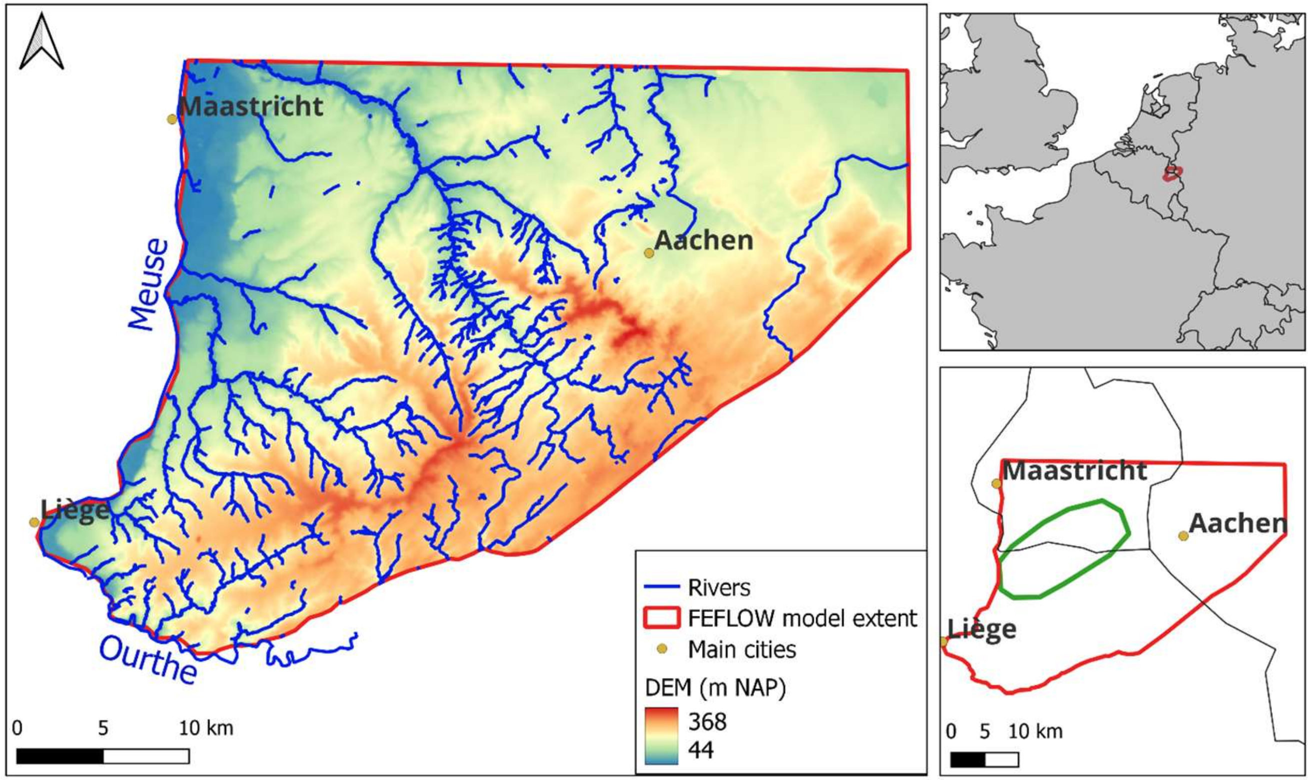
Einstein Telescope

Objectives of the regional hydrogeological model

- Understand and quantify regional groundwater flows, in relations with rivers

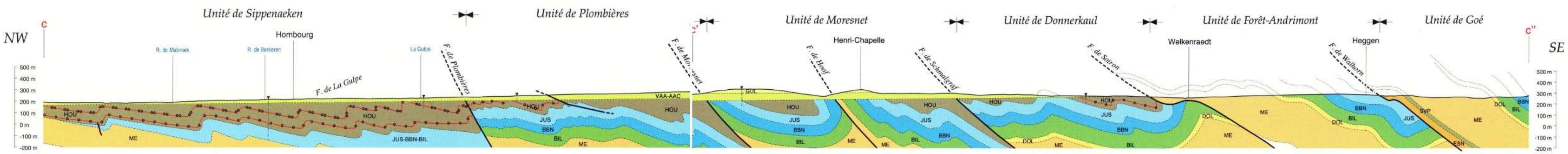
- Quantify ecosystem services impacts of the future tunnels : regional groundwater levels, rivers flows.



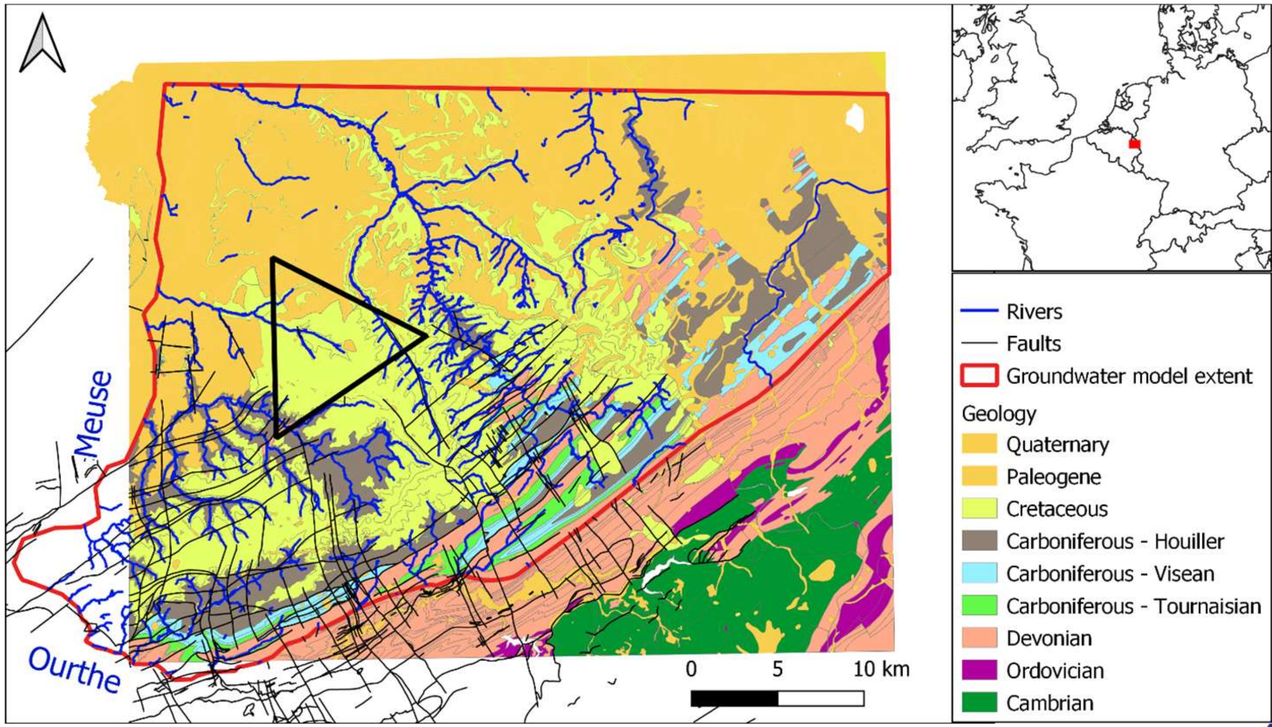
Regional hydrogeological model extent

Regional geology

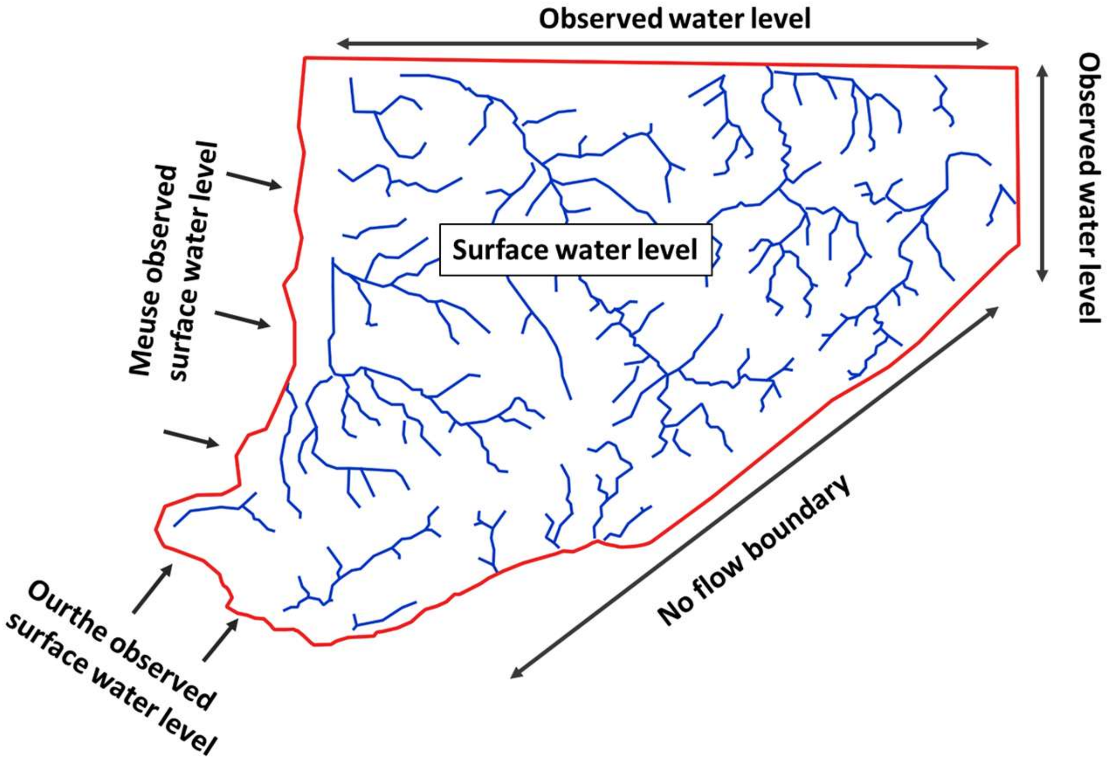
Wallonia geological maps



- Cretaceous, Quaternary formations in the North
- Older formations to the South
- Numerous faults



Conceptual model



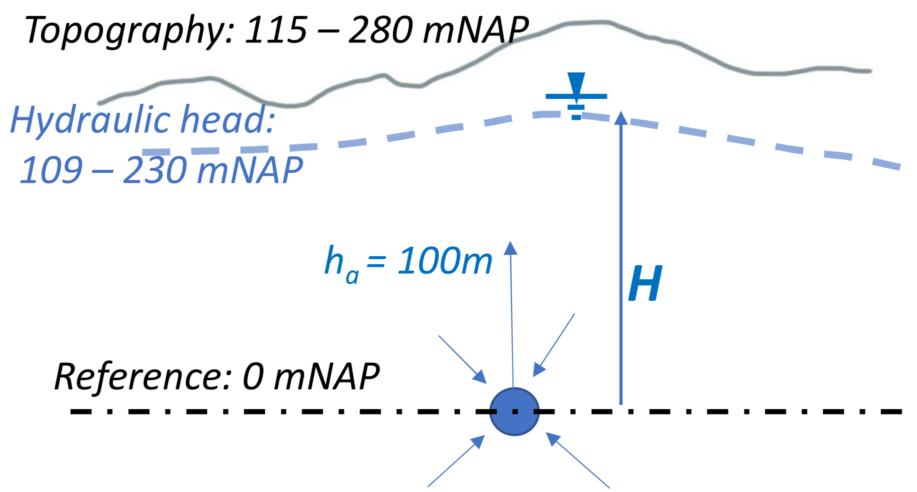
Natural boundaries of the model:

- based on geology
- rivers

North and East : no natural boundary

→ groundwater measurements set as prescribed heads BCs

Tunnel design used for the simulations



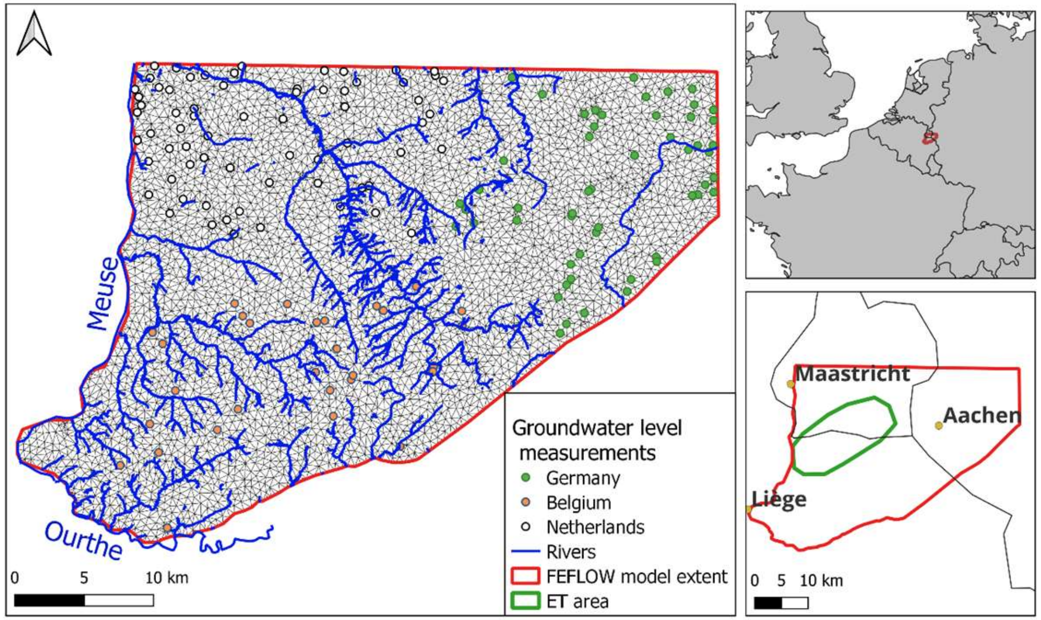
Tunnel surrounded by an impermeable lining & a drainage system at a pressure ha=100 m (above the tunnel)

- Heterogeneous hydraulic conductivity around tunnels
- Heterogeneous hydraulic head above tunnels
- Uniform drainage layer at a pressure of **100 m**

Numerical model

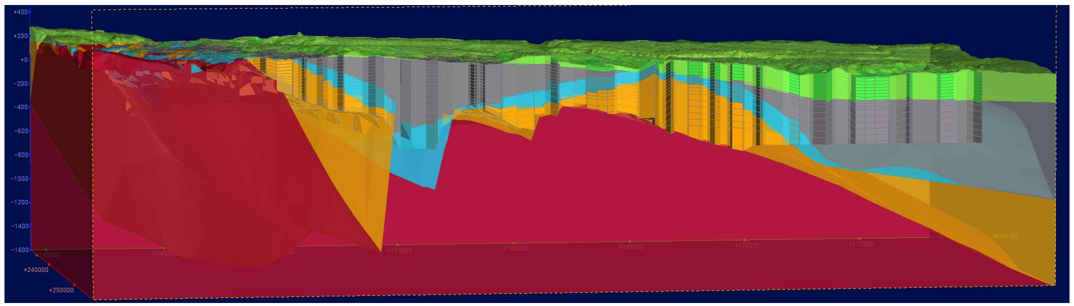
- Feflow® hydrogeological flow model construction:
  - finite element mesh
  - steady flow model (2018)

- Regional database used in the model:
  - groundwater water level observations, abstractions
  - hydraulic conductivities
  - topography, geology



River network, groundwater level measurements and mesh of the finite elements model

Mesh sizes about 500 meters length



Hydrogeological model according to regional geological model

Calibration of the hydraulic conductivities

- Optimization of the objective function

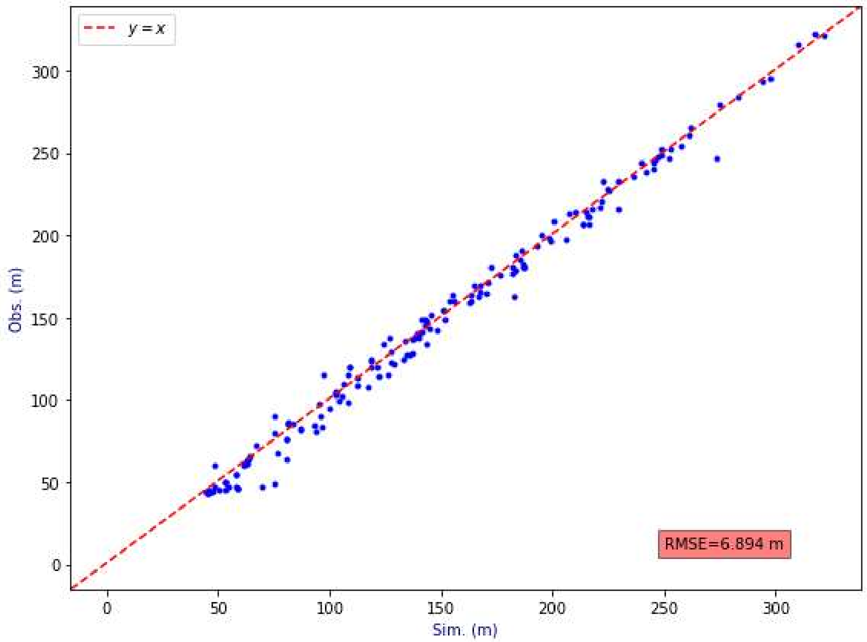
$$\Phi = \sum_i w_i (h_i^{obs} - h_i^{sim})^2$$

Calibration with Pest software 50 pilot points/geological layers, considering prior hydraulic conductivities.

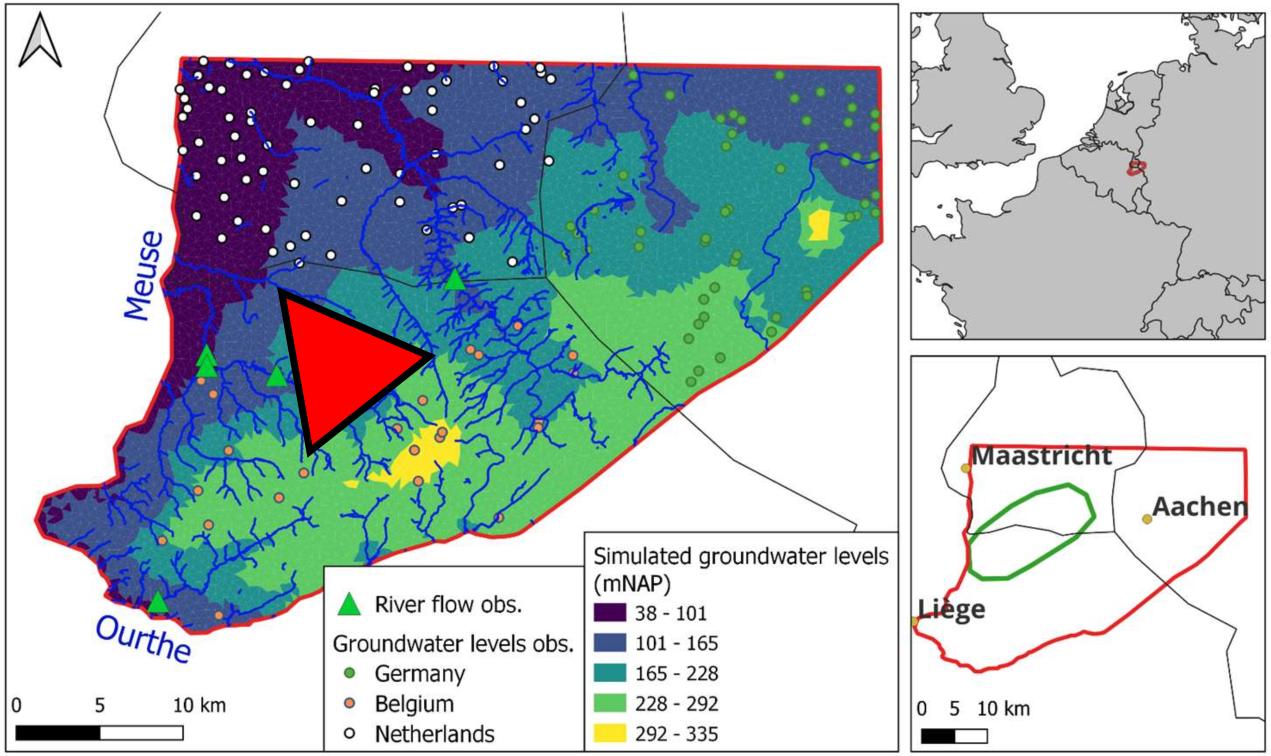
Ranges of hydraulic conductivity values estimations from expert knowledge and previous studies in the considered main geological unit allowed for the Pest estimation.

Geological unit	Lower Limit	Preferred values	Upper Limit
Cretaceous	$1.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-6}$	$1.0 \cdot 10^{-3}$
Namurian (Houiller)	$1.0 \cdot 10^{-8}$	$1.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-5}$
Visean and Tournaisian	$1.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-5}$	$5.0 \cdot 10^{-3}$
Famennian	$1.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-5}$

Calibrated numerical model



Plot of groundwater level observations and groundwater level simulations.

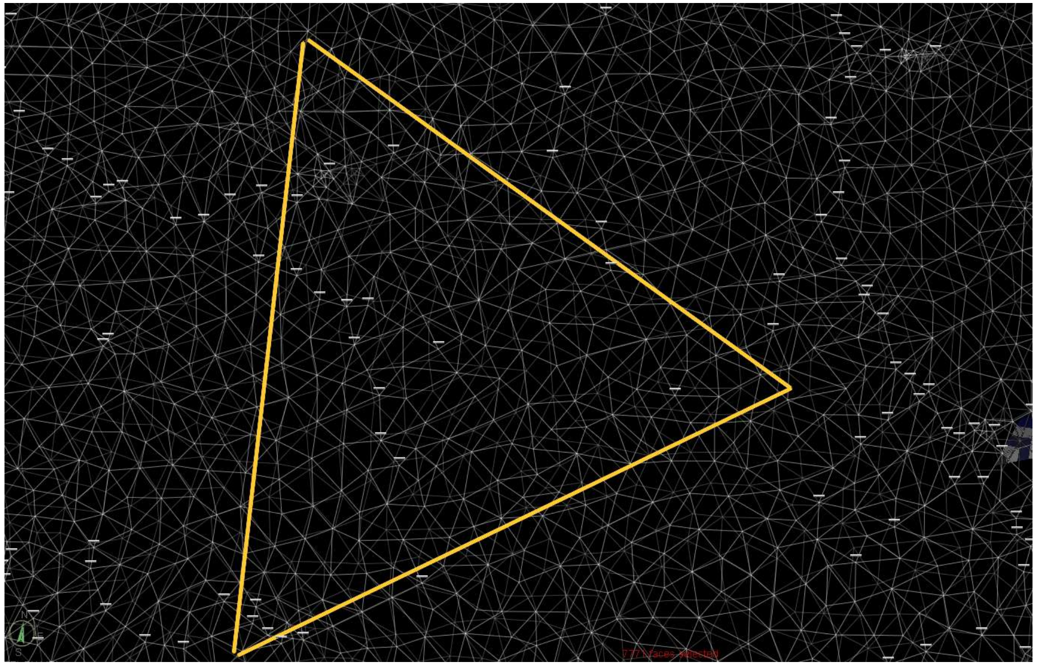


Simulated groundwater level

Calculations of the regional impacts

- Applications of 100 m NAP hydraulic head at the tunnels nodes:
  - No grouting mitigations
  - Considering simple geology
  - Considering simple tunnel design

- Calculations from the calibrated model (a single set of possible hydraulic conductivities)

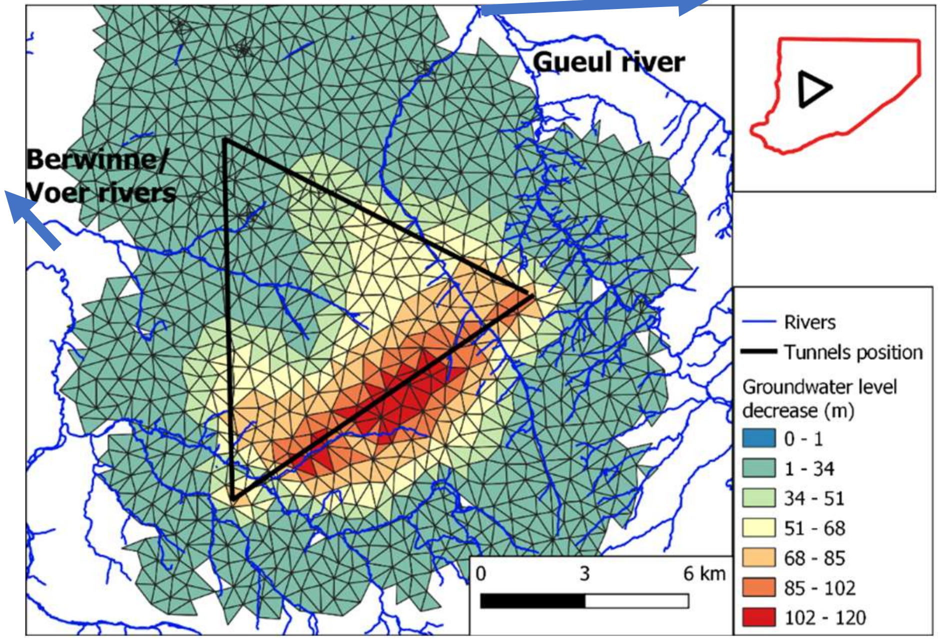


Feflow meshes & tunnel position

Estimated impacts of the long-term inflows on regional groundwater

19,959 m^3/d decrease (20 % of the base river flow)

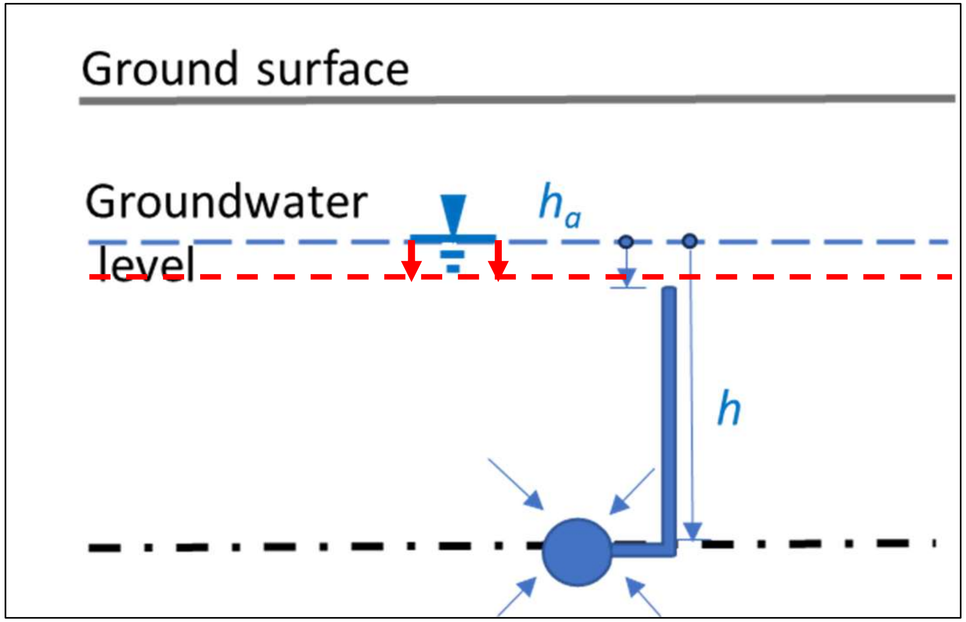
24,171 m^3/d decrease (57 % of the base river flow)



Simulated estimated impacts of the drainage into ET tunnels on hydraulic heads and watercourses flowrates

- Tunnel drainage inflow of 46,054 m^3/d
- Important impacts are assessed in term of :
  - Stream flow rates
  - Groundwater levels decreases

Existing analytical solution



Tunnel surrounded by an impermeable lining & a drainage system at a pressure h_a=100 m (above the tunnel)

$$Q = \frac{2\pi K(-h_a)}{\ln(\frac{h}{r} + \sqrt{\frac{h^2}{r^2} - 1})}$$

Kolymbas and Wagner (2007)

Estimations from the analytical solutions considering homogeneous:

- hydraulic head (165 m)
- conductivites ($1.5 \cdot 10^{-6}$ m/s)

=> Q are about 100,000 m^3/d

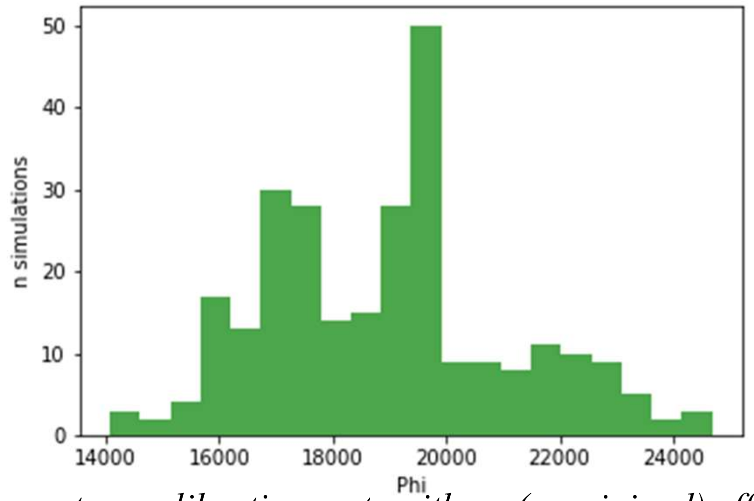
Large uncertainties about hydrogeological properties and tunnels designs

- Tunnels designs is simple, further discussions about the possibles tunnels designs should be considered for the impact as:
  - Drainage system after a first liner ?
  - Drainage system pressure (h_a) > 100m ?

- Considering the numerical model, the hydraulic conductivity is an important parameter driving the groundwater inflows.

Null-space Monte-Carlo

- Numerical hydrogeological models are commonly ill-posed problems
- Regularization achieves the estimation of a unique parameter set
- NS-MC: combinations of parameters that cannot be estimated on the basis of the calibration dataset (Doherty et al., 2010)



Parameters calibrations sets with no (or minimal) effects on model outputs fitting the field measurements

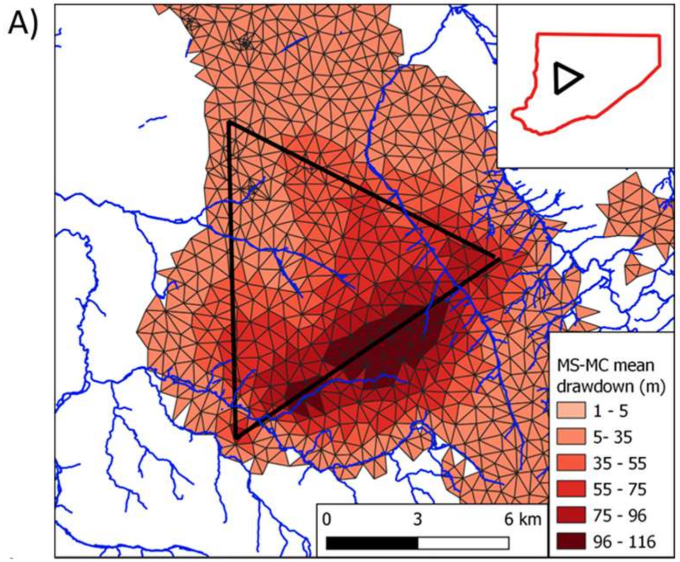
Geological zone	Mean K values (all elements) m/s	Mean variation factor [min – max] (all elements) (-)	Mean K values (around tunnels) m/s	Mean variation factor [min – max] (around tunnels) (-)
Cretace	$1.1 \cdot 10^{-5}$	**141 [3.4 – 7,561]**	-	-
Houiller	$3.9 \cdot 10^{-7}$	**52 [4.8– 879]**	$9.4 \cdot 10^{-8}$	**6.4 [6.1 – 7.6]**
Visean	$8.5 \cdot 10^{-6}$	**250 [4.6 – 33,216]**	$3.0 \cdot 10^{-6}$	**9.9 [5.9 – 34.1]**
Upper Fammenian	$6.5 \cdot 10^{-7}$	**36 [3.0 – 803]**	$6.3 \cdot 10^{-7}$	**43 [7.8 – 302]**

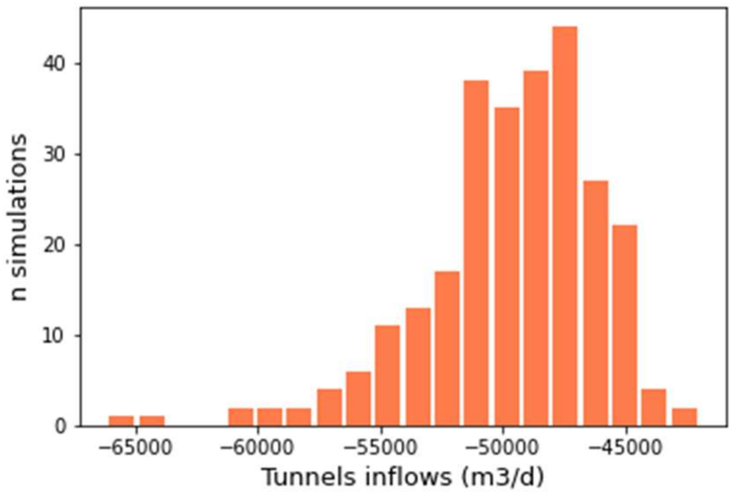
(K) values generated by the 270 Null-Space Monte-Carlo numerical models

Sensitivity analysis results

- Numerical estimations of:
    - Tunnel groundwater inflows
    - Groundwater level decreases

It is very likely that the long-term impacts will be very significant if the tunnels are located in this area **(given this tunnel design and no grouting mitigations measures)**





Results from on the 270 NS-MC simulations

- *Groundwater level drawdown*
- *Tunnels inflow estimations*

Conclusions & perspectives

- Considering the large assumptions (geology, tunnel designs), if no mitigations measures are planned, large inflows and impacts are expected.

- Simplifying assumptions were needed for:
  - The tunnel designs
    - We need to consider the possibles inflows mitigations measures
  - The geological considerations
    - We need to characterize the geology and especially considering discontinuities as karsts, fractures, etc.

Further data (pumping tests, geological characterizations) and further local models are coming …

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Thank you for your attention

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