Regional groundwater modeling for estimating the drained fluxes by the ET works and their impact

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Summary

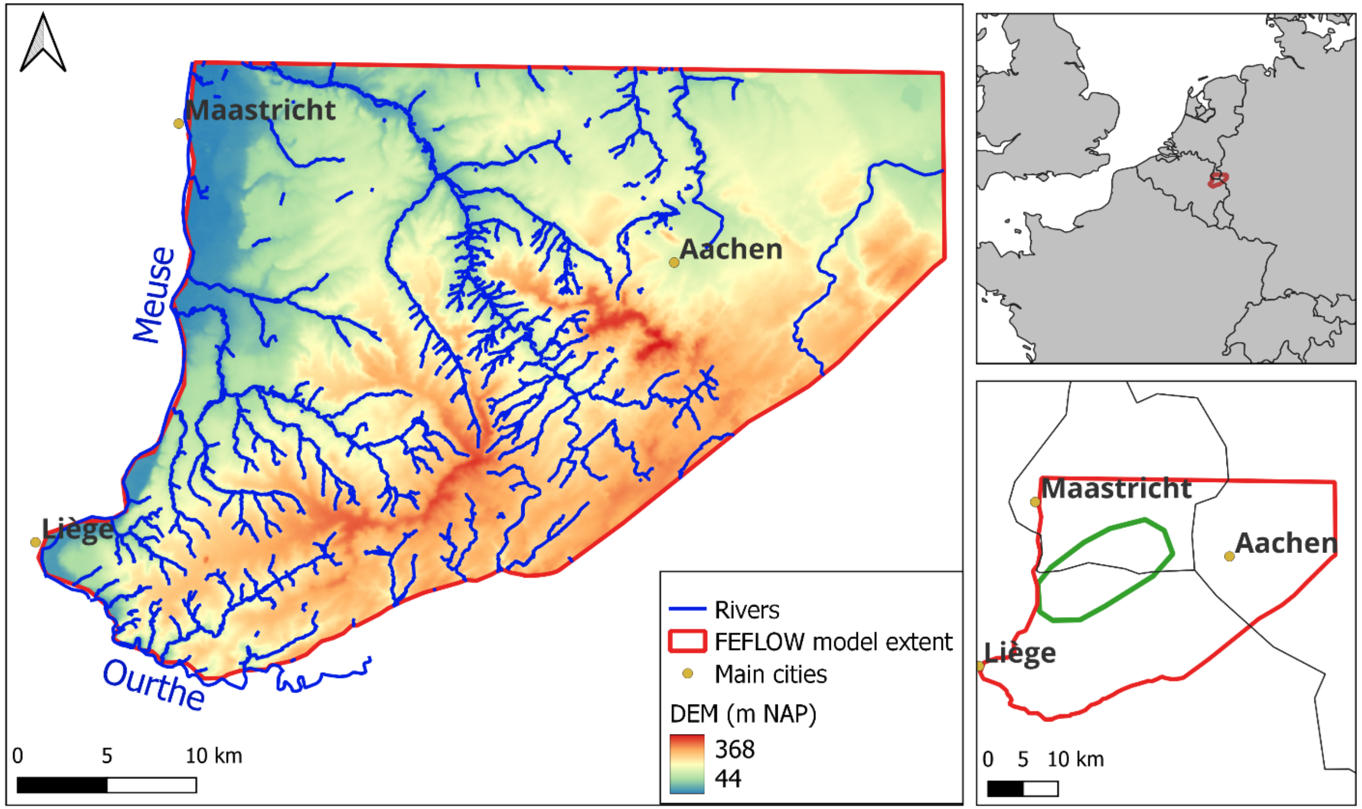
- Regional hydrogeological model
  - Objectives of the regional groundwater model
  - Conceptual model
  - Numerical model
  - Calibration
- Estimation of tunnels groundwater inflow and impacts to regional groundwater
- Conclusions & perspectives of the model

Objectives of the model

Open cross-border groundwater model for ecosystem services

- quantify quantitative impacts of ET tunnels implantations on groundwater
- estimate groundwater inflows in tunnels

Regional hydrogeological model extent



Aquifers

- all the aquifers are simulated until lower Famennian
- aquifers considered as connected
- with different hydrogeological properties

Ere	Système	Série	Etage	Groupe	Formation	Membre	Lithologie	Abréviation		Hydrogéologie
CENOZOIQUE	QUATERNAIRE	HOLOCENE			Alluvions Modernes		Sables et graviers	AMO		Aquifère alluvial
					Dépôts Tourbeux		Tourbières à sphaignes	TRB		Aquifère des tourbes
	PALEOGENE	OLIGOCENE			Dépôts Sableux		Sables quartzeux souvent micacés - Lentilles d'argiles sableuses	SBL		Aquifère des sables de remplissage
MESOZOIQUE	CRETACE	SENONIEN	Maastrichtien		Gulpen		Craies glauconieuses, craies blanches avec silex noirs - Conglomérat à silex (SX)	GUL		Aquifère des craies du Crétacé
			Campanien		Vaals		Sables, silts et argiles glauconieux, à horizons indurés	VAA		Aquifère - Aquitard de Vaals
			Santonien		Aachen		Argiles sitleuses et sableuses, silts argileux, sables blancs à niveaux indurés, localement lentilles graveleuses	AAC		Aquifère des sables du Santonien
PALEOZOIQUE	CARBONIFERE	NAMURIEN	Marsdenien	Houiller			Alternance de shales et de siltites, de grès argileux, de grès et de quartzites - Veines de charbon	HOU		Aquiclude à niveaux aquifères du Houiller
			Kinderscoutien							
			Alportien							
			Chokierien							
			Arnsbergien							
		VISEEN	Livien	Juslenville	Seilles		Calcaires - Niveaux à ooïdes - Cherts	SEI	JUS	Aquifère des calcaires du Carbonifère
					Lives		Calcaires - Nodules de cherts	LIV		
			Moliniacien	Bay-Bonnet	Moha		Calcaires grossiers généralement oolithiques - Cherts	MOH	BBN	
					Terwagne		Calcaires fins à grossiers	TER		
					Brèche de la Belle-Roche		Brèches calcaires	BBR		
		TOURNAISIEN	Ivorien	Bilstain	Dolomies de la Vesdre		Dolomies, dolomies crinoïdiques - Cherts et nodules siliceux	VES	BIL	Aquifère - Aquitard - Aquiclude de l'Hastarien
			Hastarien		Landelies		Calcaires fins à grossiers, crinoïdiques, dolomitisés au sommet	LAN		
					Pont d'Arcole		Shales, calcschistes avec nodules calcaires	PDA		
					Hastière		Calcaires moyens à grossiers - Calcaires argileux au sommet	HAS		
		SUPERIEUR	Famennien		Dolhain		Calcaires crinoïdiques et grès carbonatés - Intercalations de shales et siltites	DOL		Aquifère des grès du Famennien
					Monfort-Evieux		Grès micacés feldspathiques, grès carbonatés - Shales - Siltites - Nodules carbonatés	ME		
					Souverain-Pré		Calcaires argileux et noduleux	SVP		Aquitard du Famennien - Frasnien
					Esneux		Grès fins plus ou moins argileux	ESN		
					Hodimont		Siltites micacées - Nodules carbonatés	HOD	LH	
			Frasnien		Lambermont		Shales, siltites, calcaires, schistes nodulaires	LAM		
					Aisemont		Shales, calcschistes et calcaires organoclastiques	AIS		

- Cretaceous aquifers (sands, chalk)
- Houiller (Namurian) (shales, siltstones, sandstones)
- Visean and Tournaisian (limestones)
- Famennian (limestones-sandstones)
- Lower Famennian aquitard (siltstones)

Table of hydrogeological units
Hydrogeological map. RUTHY and DASSARGUES, 2009.

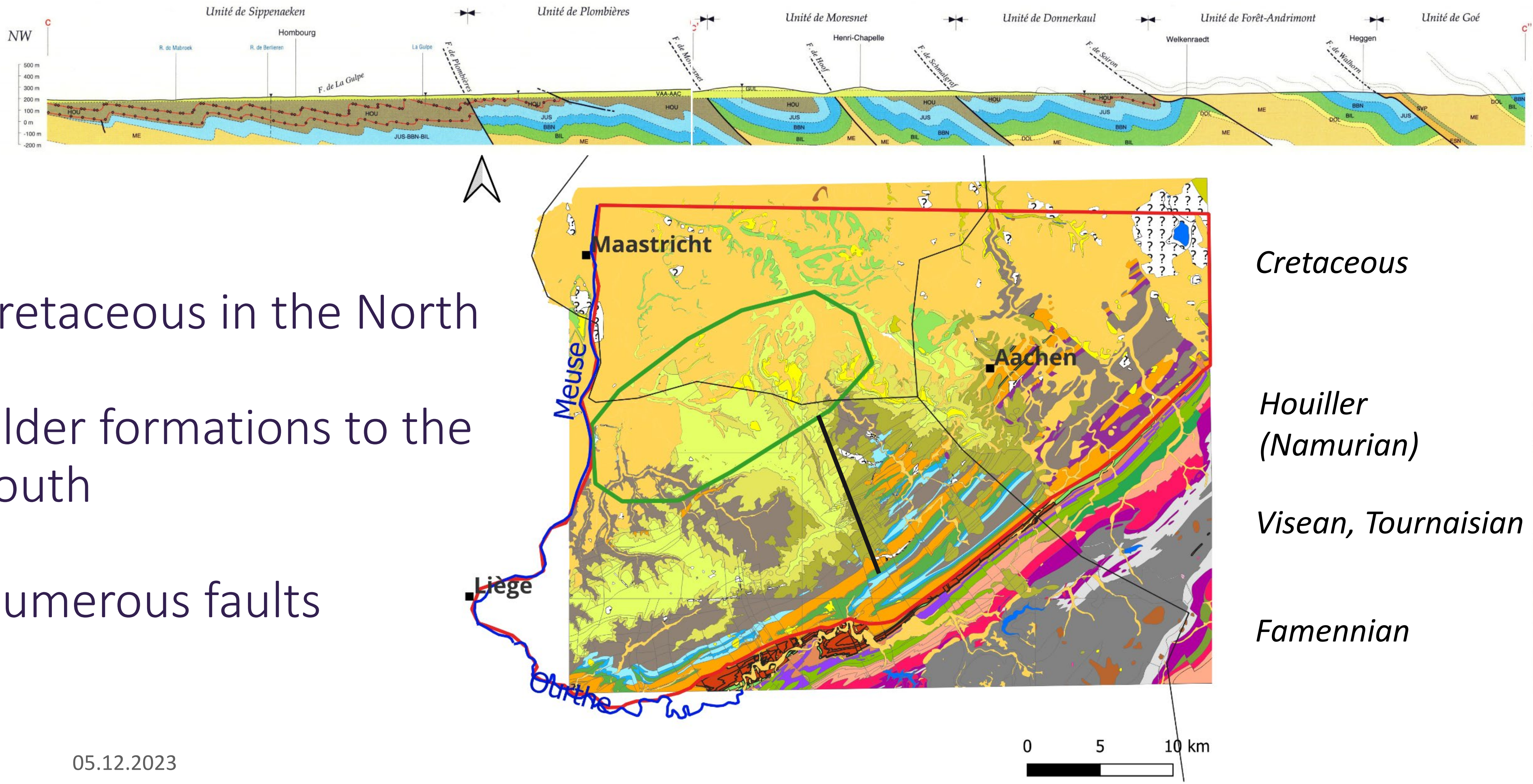
Geology

Wallonia geological map

Cretaceous in the North

Older formations to the South

Numerous faults

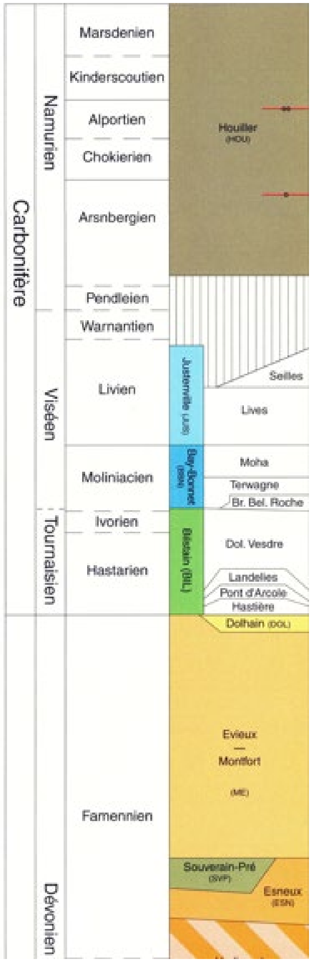


Cretaceous

Houiller (Namurian)

Visean, Tournaisian

Famennian



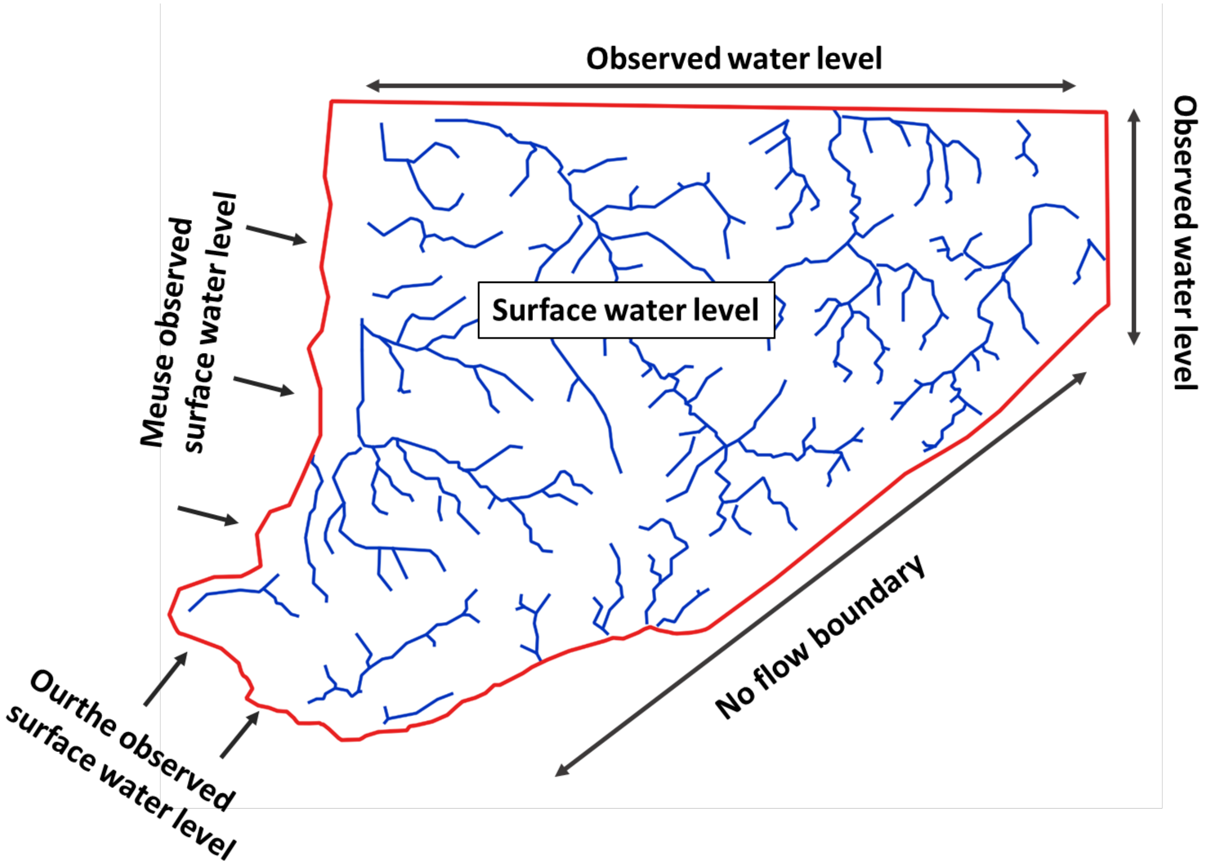
Conceptual model

natural boundaries of the model:

- based on geology
- rivers

North and East : no natural boundary

→ groundwater measurements set as prescribed heads BCs



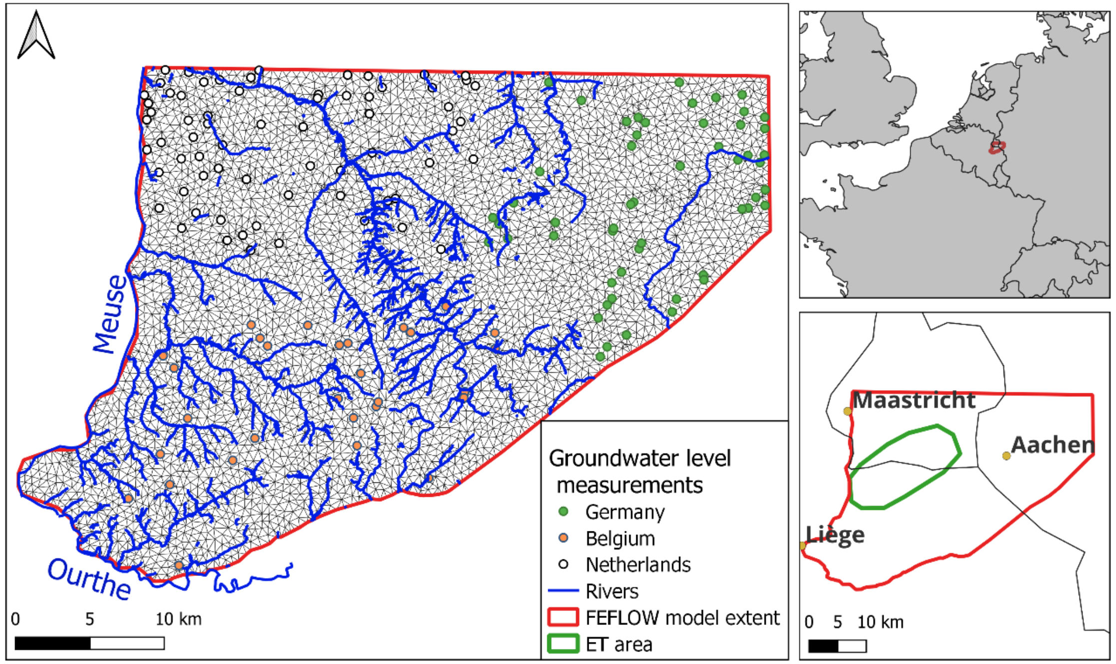
Numerical model

Feflow® hydrogeological flow model construction:

- finite element mesh
- steady flow model
- based on 2018 data

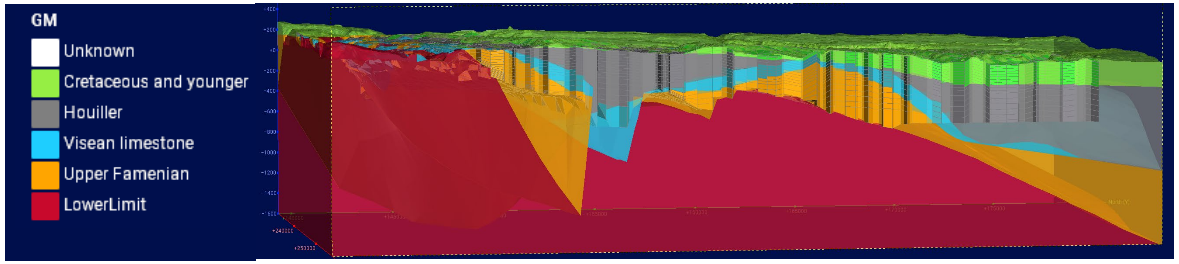
Regional database used in the model:

- groundwater water level observations, groundwater abstractions (Wallonia, Germany, The Netherlands)
- 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

Numerical model calibration

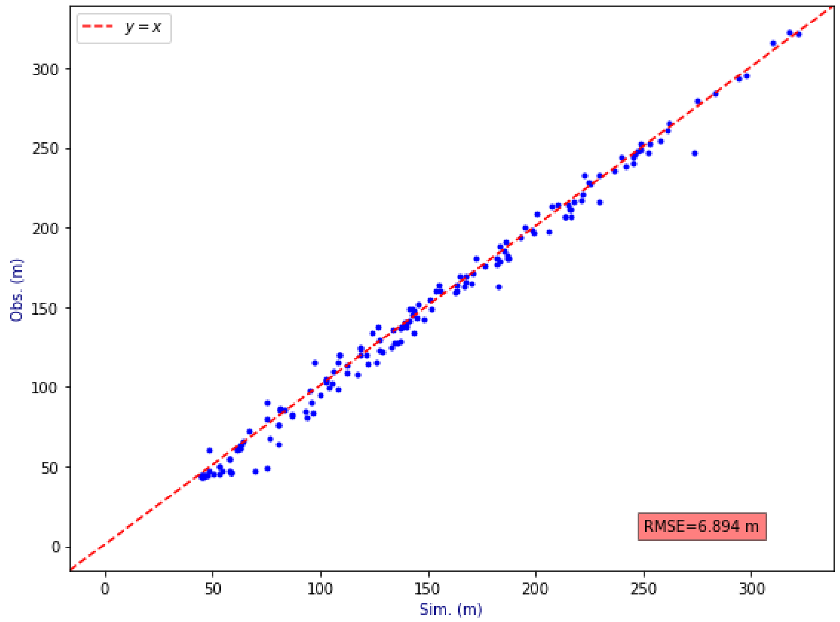
Groundwater levels calibration

Hydraulic conductivity ranges taken from previous studies in the region

	K m/s		K m/d	
Geology	min	max	min	max
Cretaceous	1.00E-07	1.00E-03	0.00864	86.4
Houiller	1.00E-08	1.00E-05	0.000864	0.864
Visean and Tournaisian	1.00E-07	5.00E-03	0.00864	432
Famennian	1.00E-07	1.00E-05	0.000864	0.864

Calibration with Pest software

50 pilot points/geological layers, considering prior hydraulic conductivities.



Plot of groundwater level observations and groundwater level simulations.

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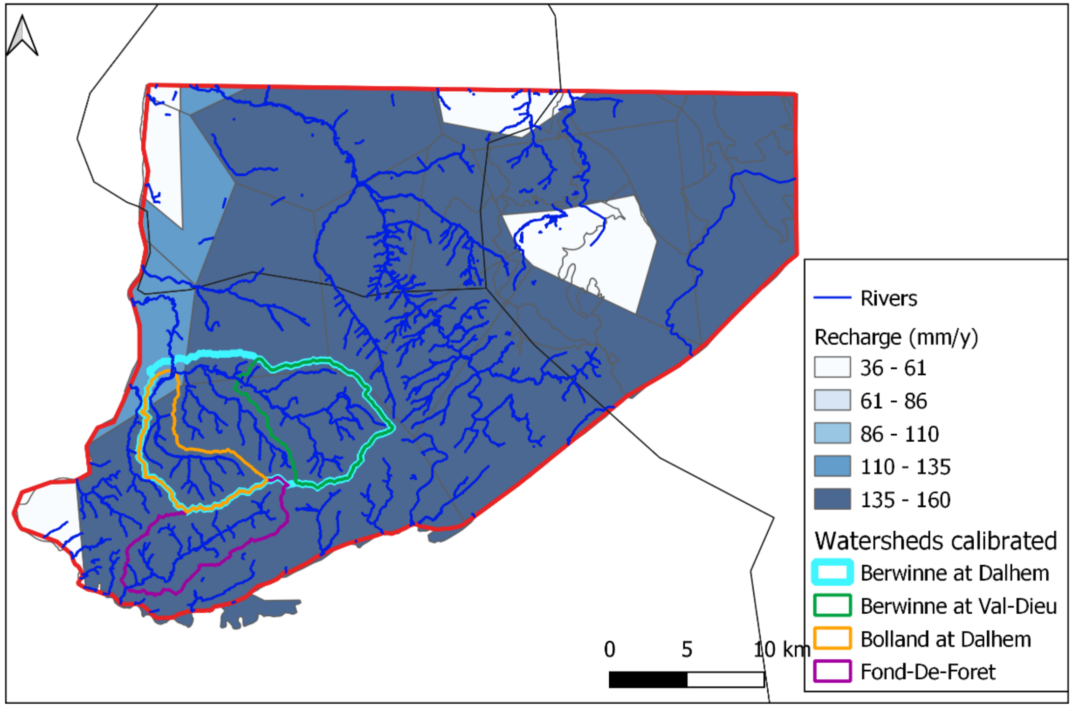
Numerical model calibration

Calibration of river base flows

	Area (km²)	Rainfall (mm)	Recharge (mm/y)	Observed base flow m³/s	Simulated base flow (m³/s)
Fond de Forêt	39	885	123	**0.17**	**0.19**
Berwinne Dalhem	119	885	123	**0.43**	**0.50**
Berwinne Valdieu	49	885	140	**0.20**	**0.24**
Dalhem Bolland	31	885	96	**0.14**	**0.12**
Veul Cottessen	123	929	166	**0.4***	**0.65**

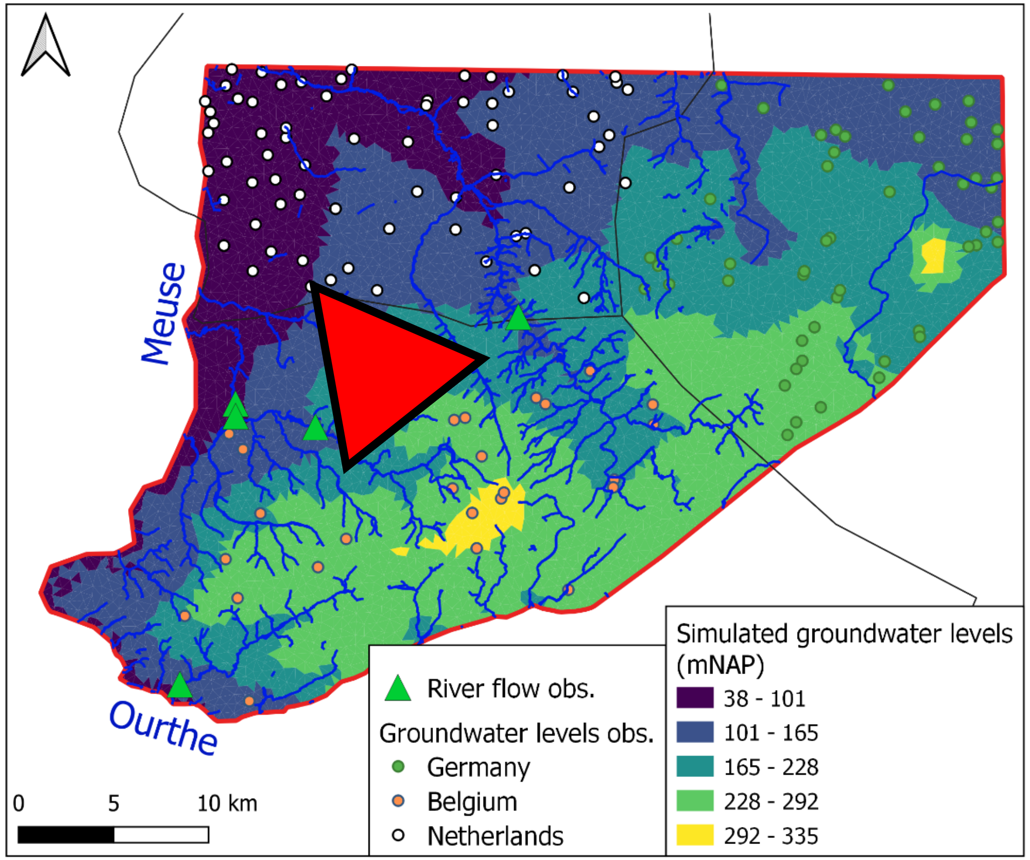
Measured base-flow are estimated with a classical statistical method applied to river hydrograms

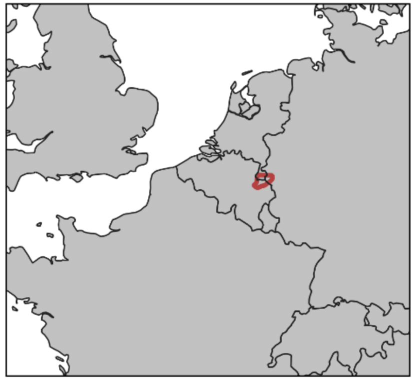
4 watershed with data for now

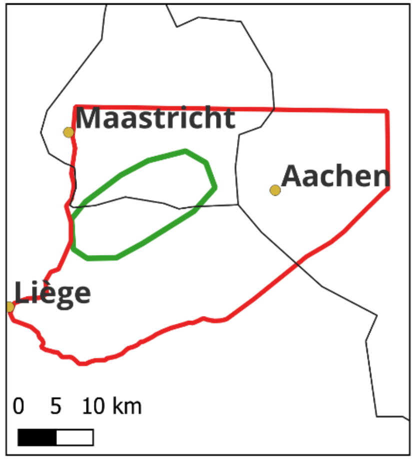


Map of natural groundwater recharge calibrated from groundwater contribution to river flow, according to subsurface geology, urbanization and rainfall observations

Simulated groundwater levels



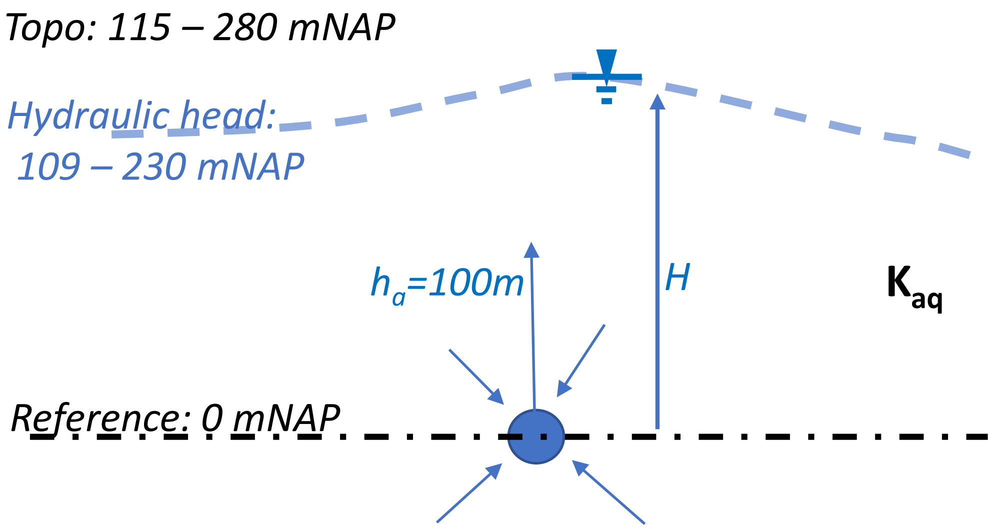




Estimation of tunnels water inflow and impacts to regional groundwater

Method:

- estimate analytically the inflow in the tunnels
- simulate the impacts with the groundwater numerical model



Tunnel surrounded by an impermeable lining

Kolymbas and Wagner (2007)

→ uniform drainage layer decreasing the water pressure at the tunnel to 10 bars = hydraulic head $\mathbf{h_a}$ **= 100 m**

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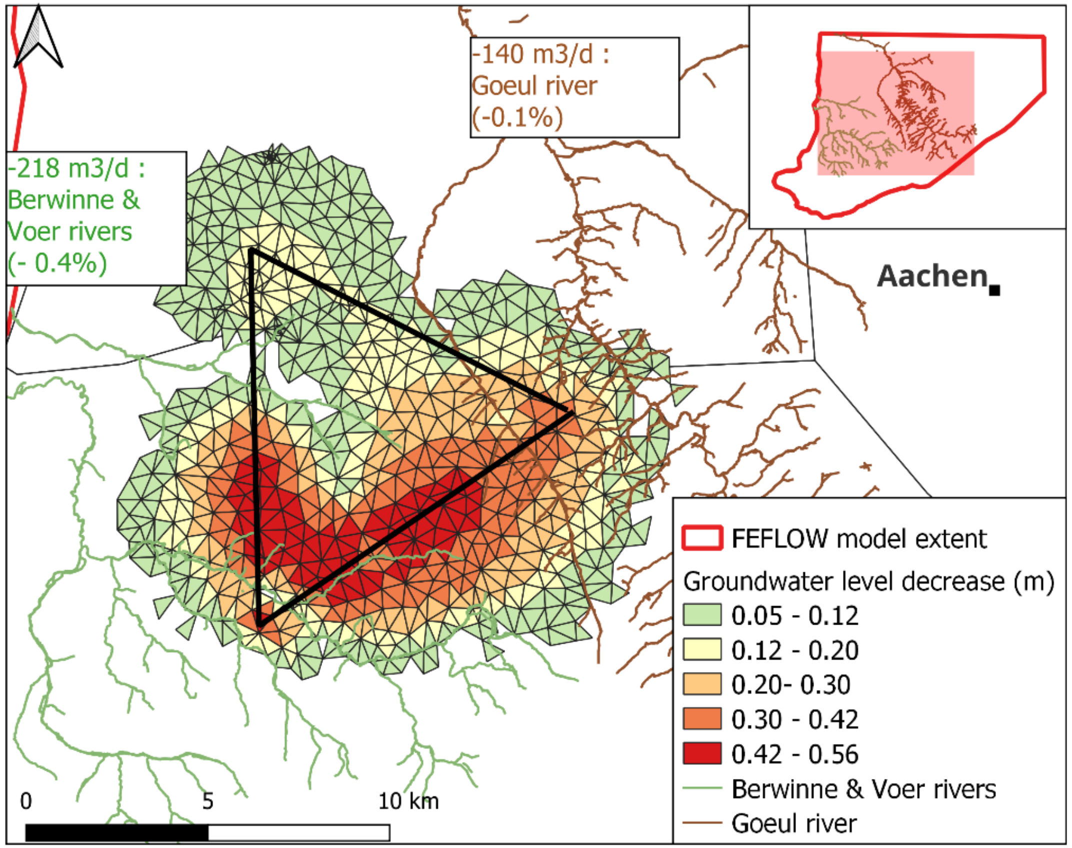
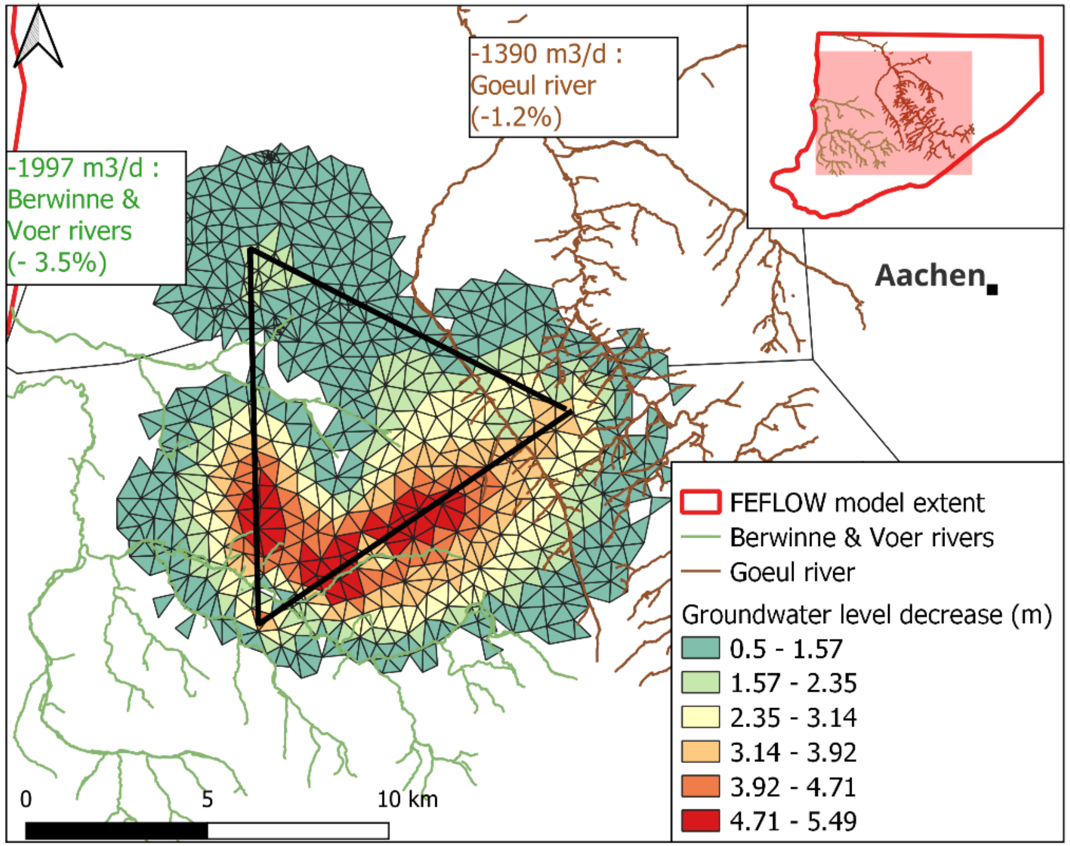
Inflow and impacts of groundwater drained by the tunnel on regional groundwater resources

In the case of $K_{aq}=10^{-8}$ m/s conductivity, calculations with analytical solution: **380 m³/d -> 4850 m³/d** (depending on H)



*for a **380 m³/d** tunnel water inflow*

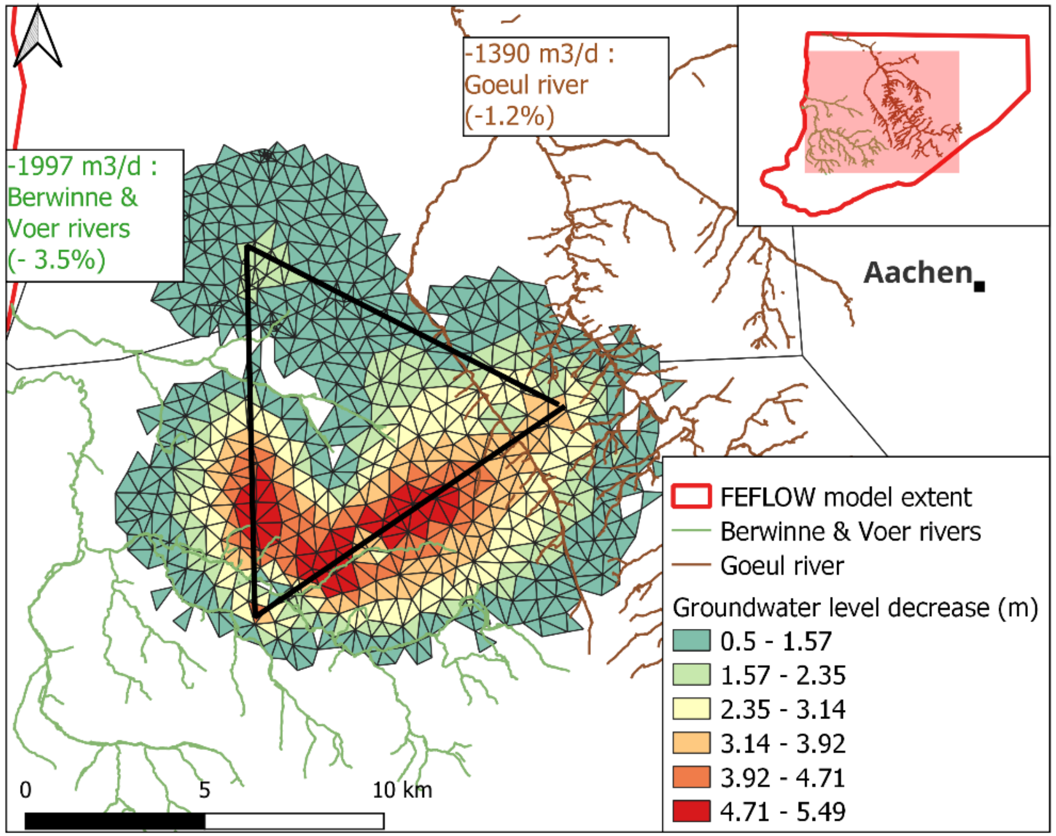


*for a **4850 m³/d** tunnel water inflow*

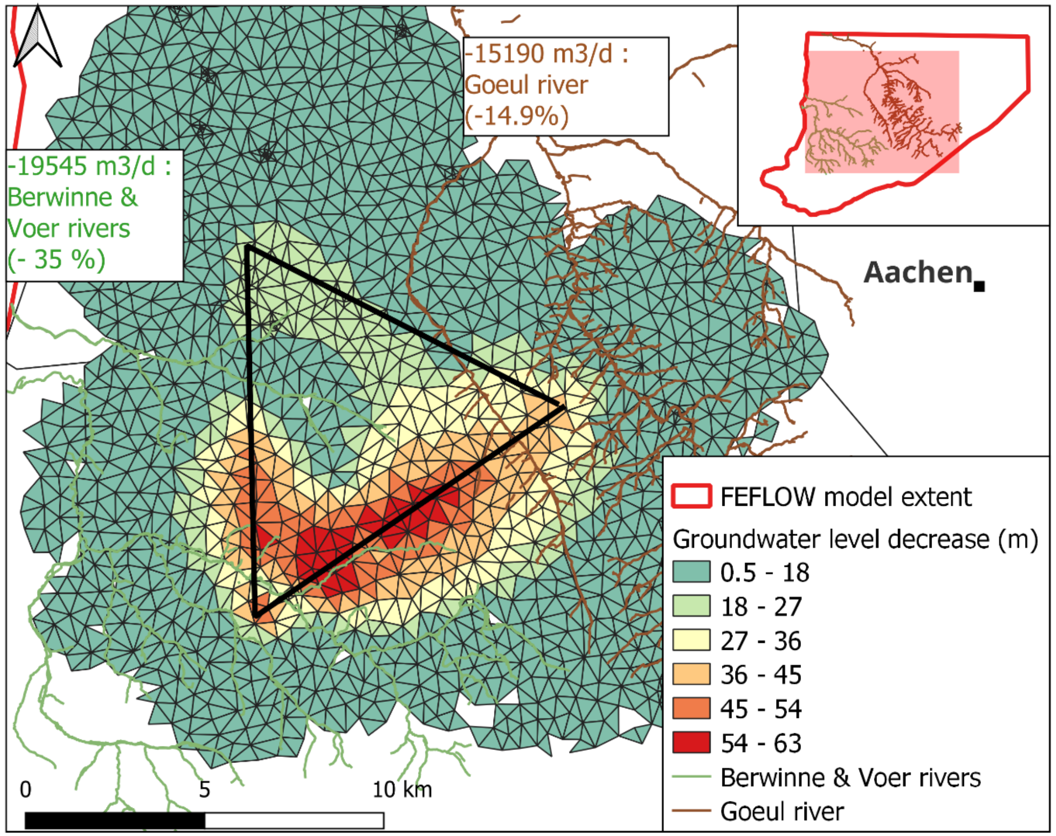
estimated impact

Inflow and impacts of groundwater drained by the tunnel on regional groundwater ressources

In the case of $K_{aq} = 10^{-7}$ m/s conductivity, calculations with analytical solution: **3800 m³/d -> 48500 m³/d** (depending on H)



*for a **4850 m³/d** tunnel water inflow*



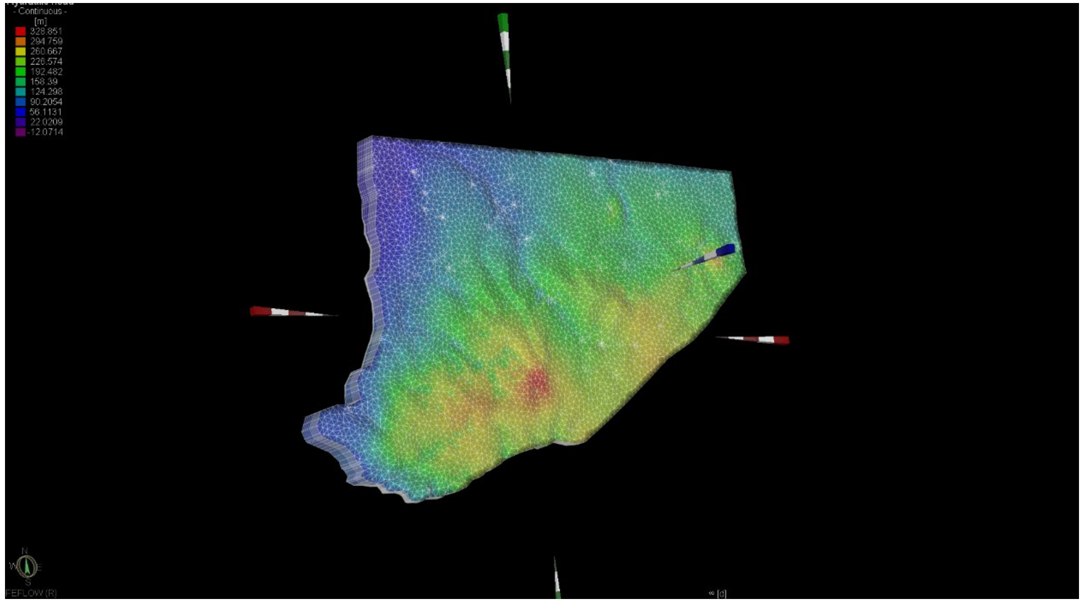
*for a **48500 m³/d** tunnel water inflow*

=> If $K_{aq} > 10^{-7}$ m/s, large amount of groundwater inflow and huge impact on regional groundwater

Conclusions

- Regional numerical model adapted to predict impacts of tunnels on regional groundwater resource

- Analytically calculated inflows and first estimation of the effects on the water table and base river flows
  - estimation of hydraulic conductivities near tunnels are needed.
  - if natural conductivities around tunnel $K>10^{-8}$ m/s, grouting is needed to reduce inflow rates



Feflow regional 3D groundwater model

Perspectives

- Numerical model improvements
  - new geological model data
  - additional hydro measurements for the robustness of the model
  - sensitivity of model results to hydraulic conductivity values (inflows, regional impacts)

- Further sub-models (local models) to be developed using regional model for BCs
  - fine discretization of tunnels, complex caverns, local heterogeneities
  - transient simulations of the tunnel drainage impacts, during excavations works

- The current numerical model can be used, as an ideal tool, for future design simulations of the tunnel

Thank you for your attention !

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