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Alluvial aquifer modeling with MODFLOW in the case of a well-field facing global change (AUVERWATCH Project)

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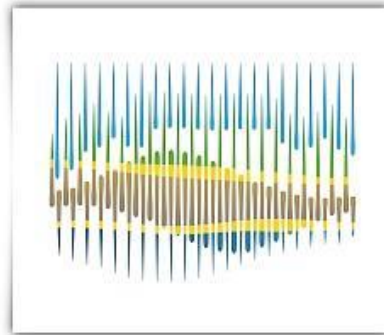
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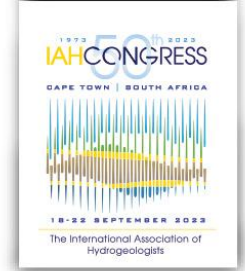
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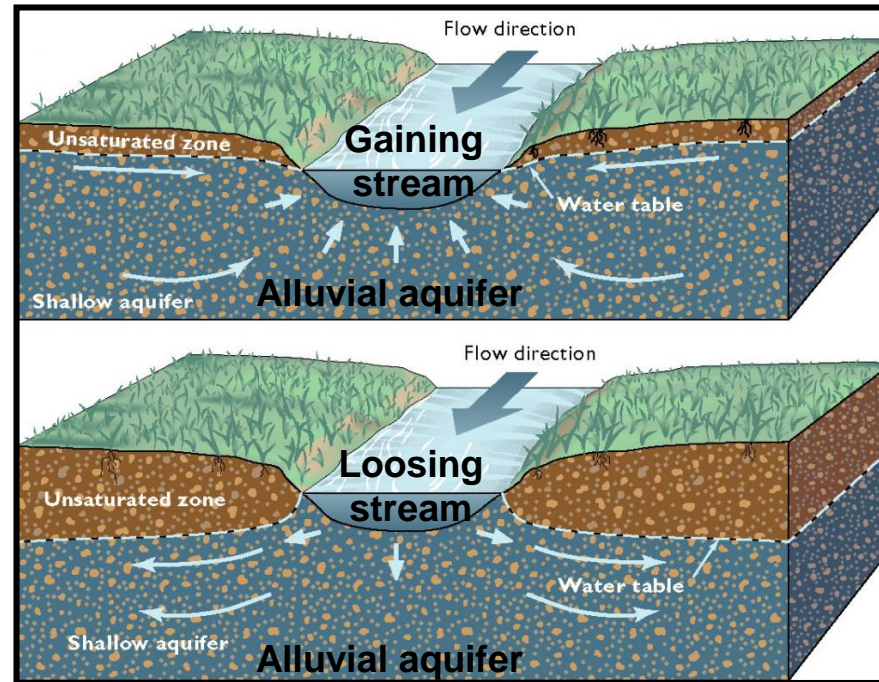
Alluvial aquifer modelling with MODFLOW in the case of a well-field facing global change (AUVERWATCH project)



CONTEXT: the importance of alluvial aquifers as a water resource



1) Shallow groundwaters in relation to rivers/streams



2) Unconsolidated sediments

Groundwater abstractions worldwide:
67% Irrigation
22% Domestic
11% Industries

Smith et al., (2016)

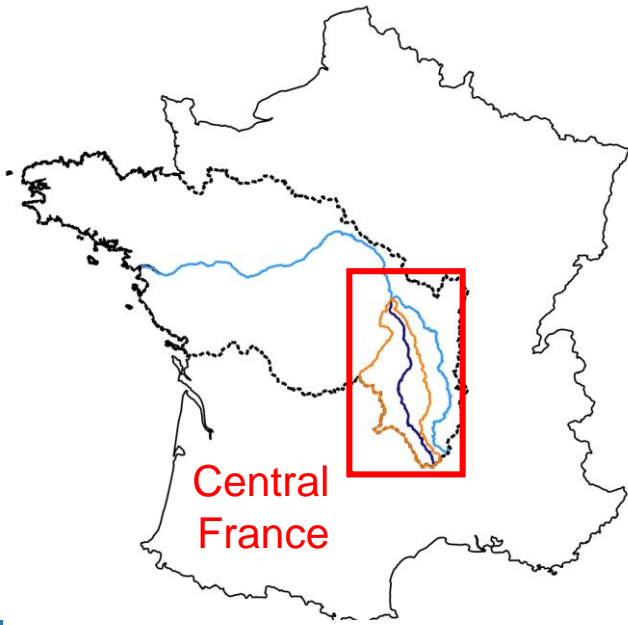
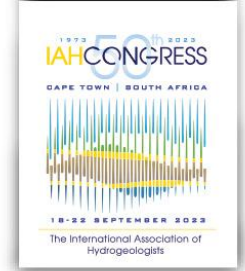
In France:
45% of groundwater use
come from alluvial aquifers

Maréchal et Rouillard, (2020)

<https://waterknowledge.colostate.edu>

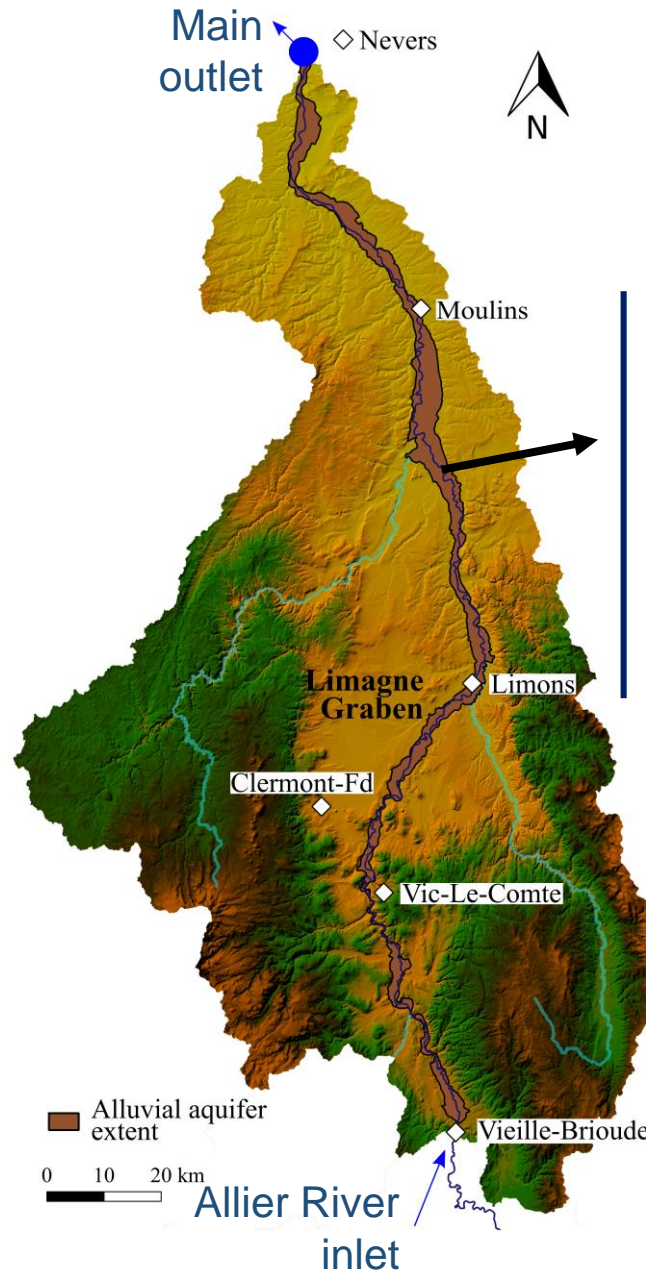
3) Important transmissivities
(provide high yields)

CONTEXT: the case of the Allier River watershed (Central France)



Central France

Downstream part of the Allier River Watershed
11,100Km²



Main outlet
◇ Nevers



◇ Moulin

◇ Limons

◇ Clermont-Fd

◇ Vic-Le-Comte

◇ Vieille-Brioude

Alluvial aquifer extent

0 10 20 km

Allier River inlet

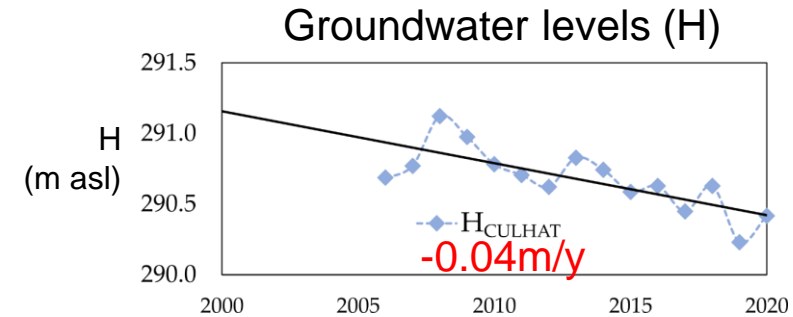
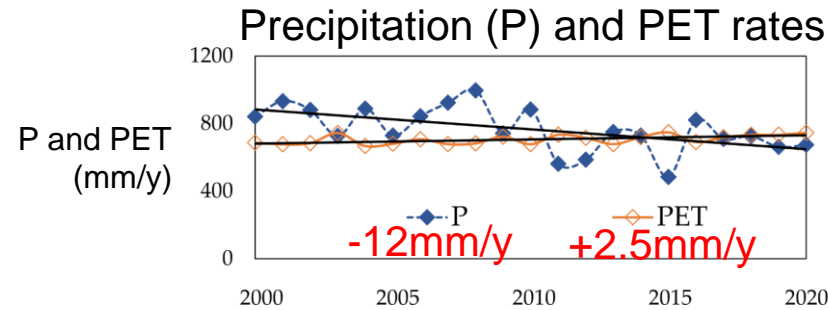
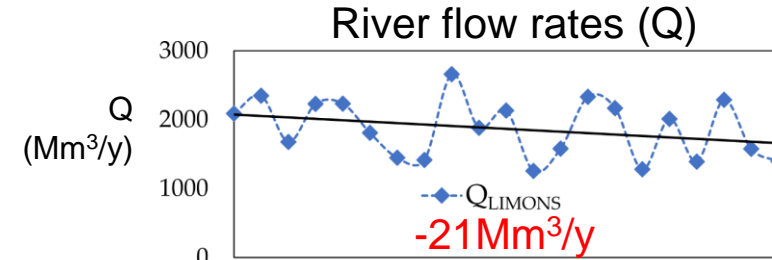
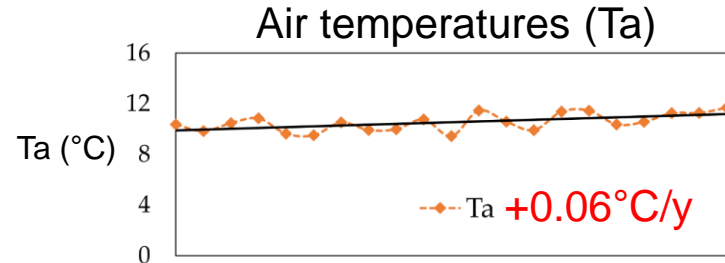
Allier River and its alluvial aquifer:
460km²

70% of the domestic water needs

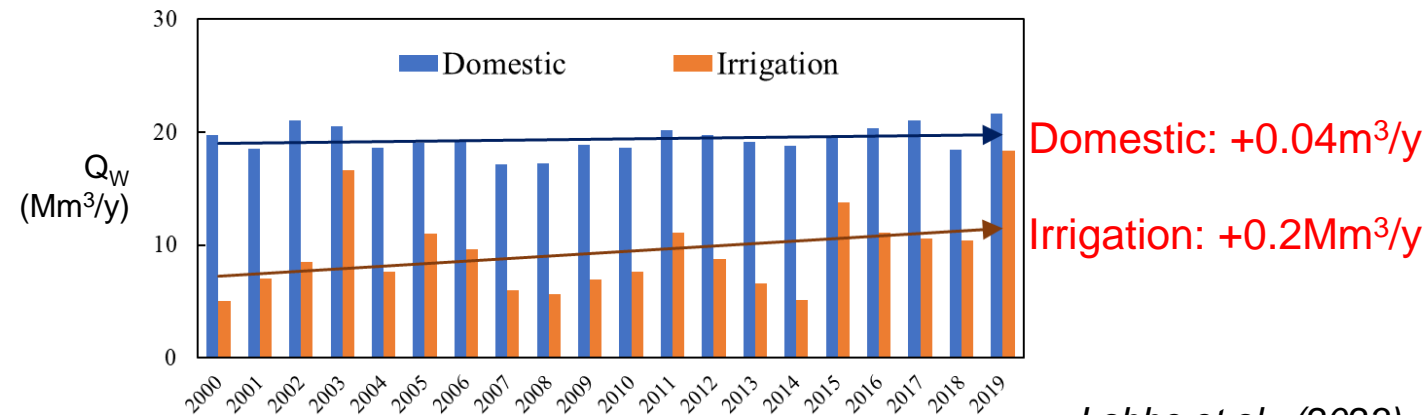
Elevations (m asl):

- 100
- 400
- 600
- 900
- 1200
- 1500
- 1700

Distinctive trends at the watershed scale



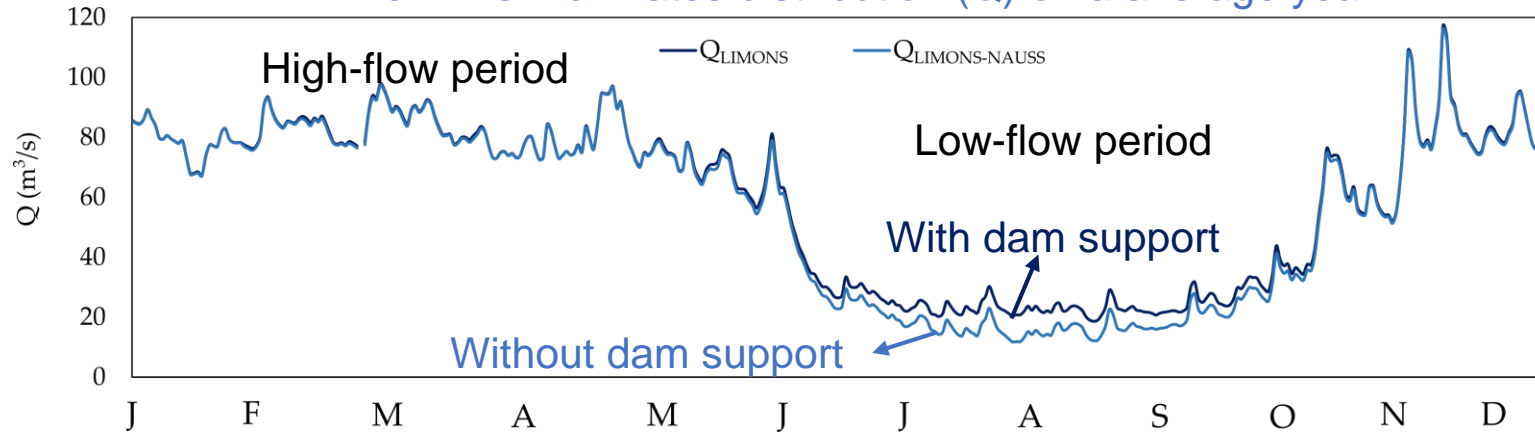
Water abstractions (Q_w) over the alluvial hydrosystem



Labbe et al., (2023)

The Allier River: known for its recurrent and intense summer droughts ($Q < 10 \text{ m}^3/\text{s}$)

Allier River flow rates distribution (Q) on a average year



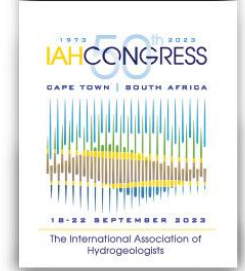
Labbe et al., (2023)

The dam of Naussac:

- Located in the upstream watershed
 - 185 Mm³ of stored water
- Supports the Allier River low-flows (from June to October)

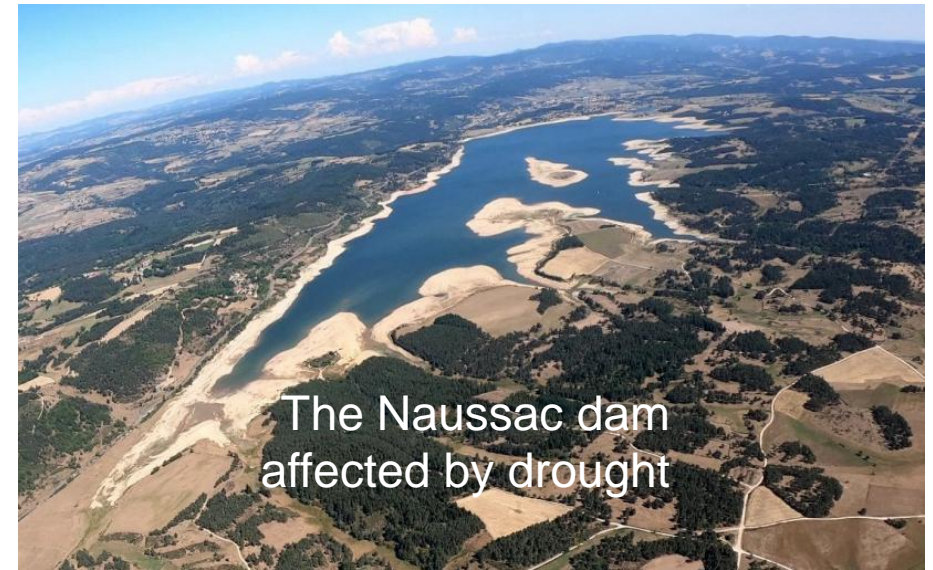


The general question



But the winter rainfall is less and less abundant and the dam is hardly refilled....

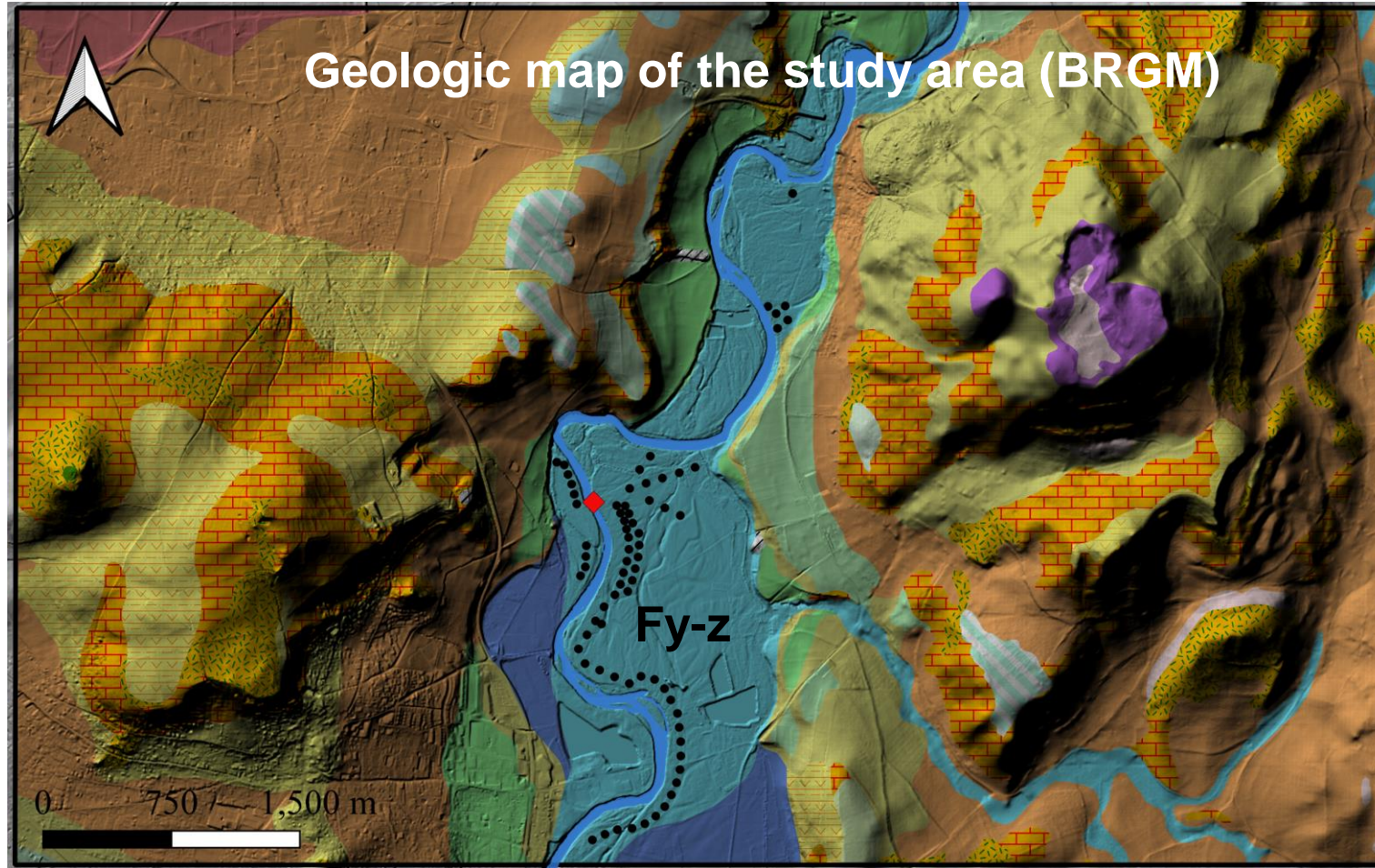
...Considering the regional importance of the Allier alluvial hydrosystem for **irrigation**, **industries** and **domestic supply** – Water stakeholders are wondering:



<https://www.zoomdici.fr>

How extreme low-flows affect groundwater levels of an exploited alluvial aquifer?

Taking the case of a municipal well-field:

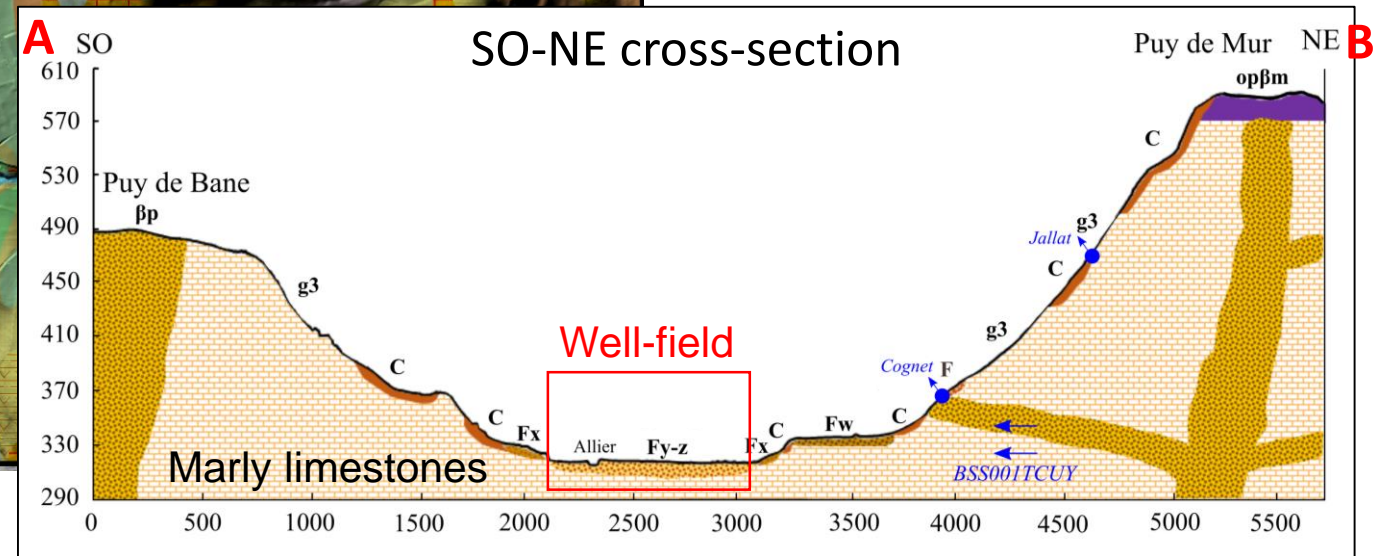
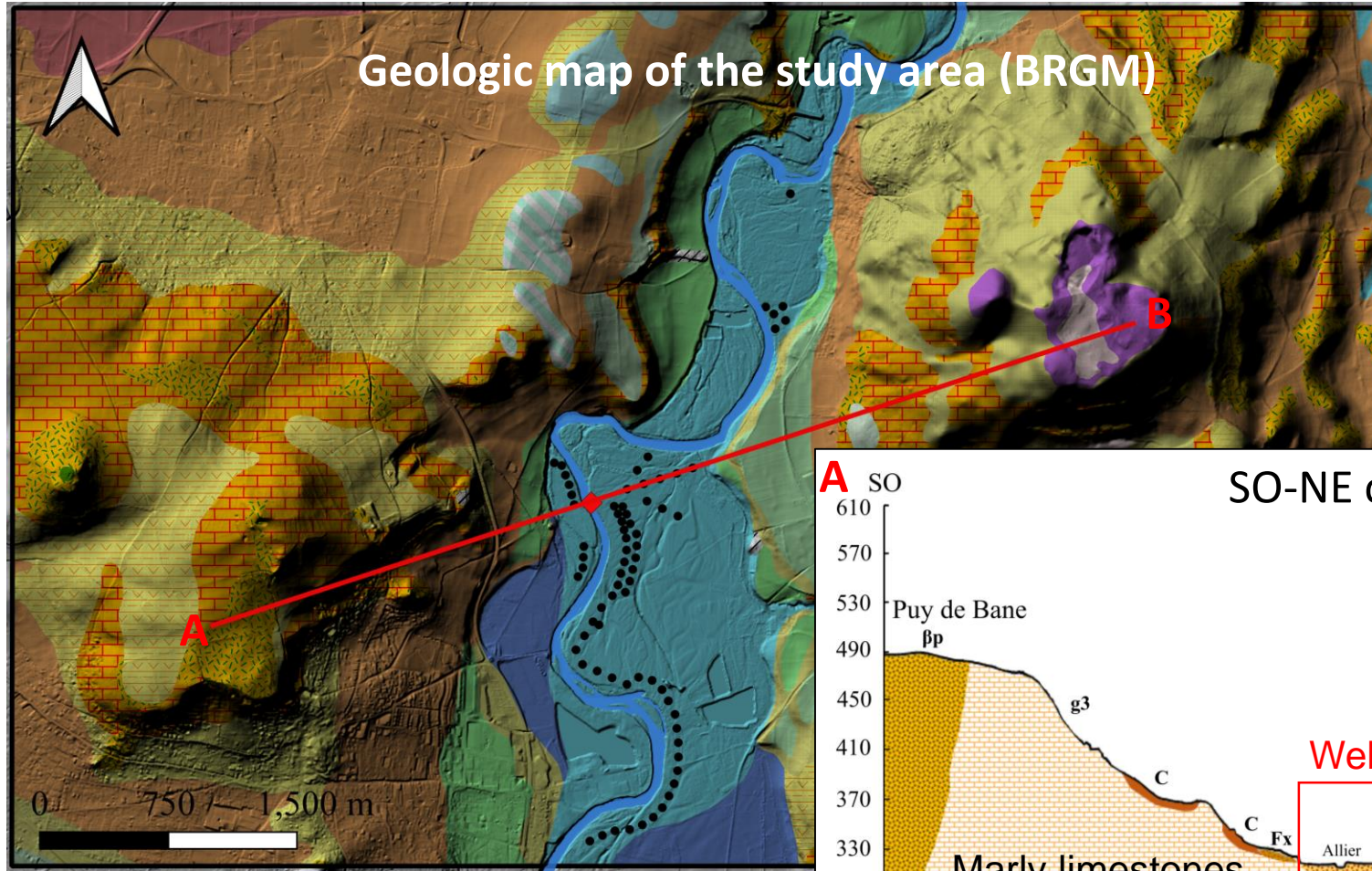


The Val d'Allier well-field:

- 71 pumping wells
- 8 millions of m³ per year for the 100,000 inhab. of the Clermont-Ferrand municipality
- On the recent Allier River terrace (Fy-z)

Studied site: the Val d'Allier well-field

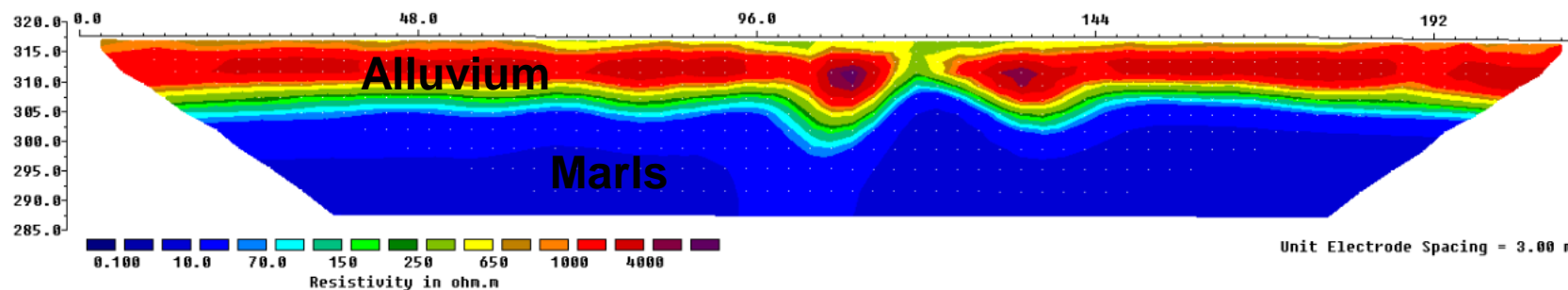
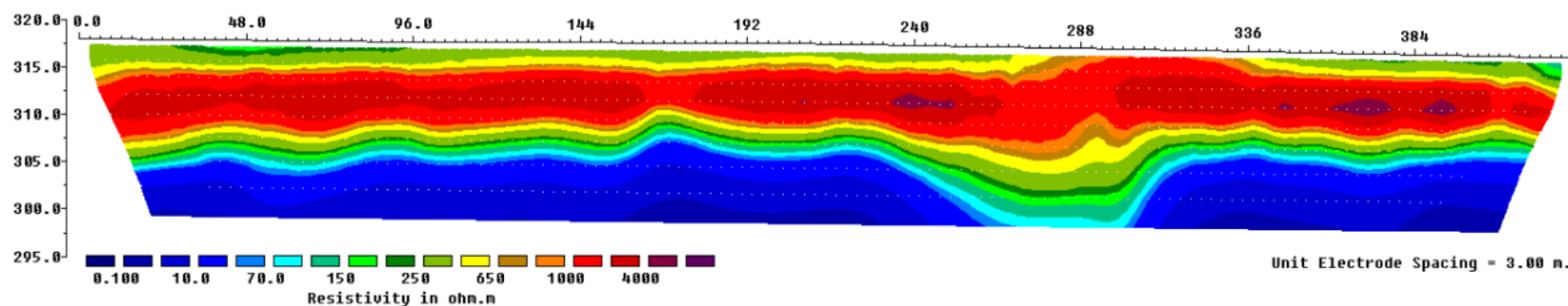
Taking the case of a municipal well-field:



Groundwater Vistas 8 (MODFLOW-2005)

Model based on:
Geological investigations
Groundwater/River levels monitoring
ERT surveys

Imaging the interface between marls and alluvium

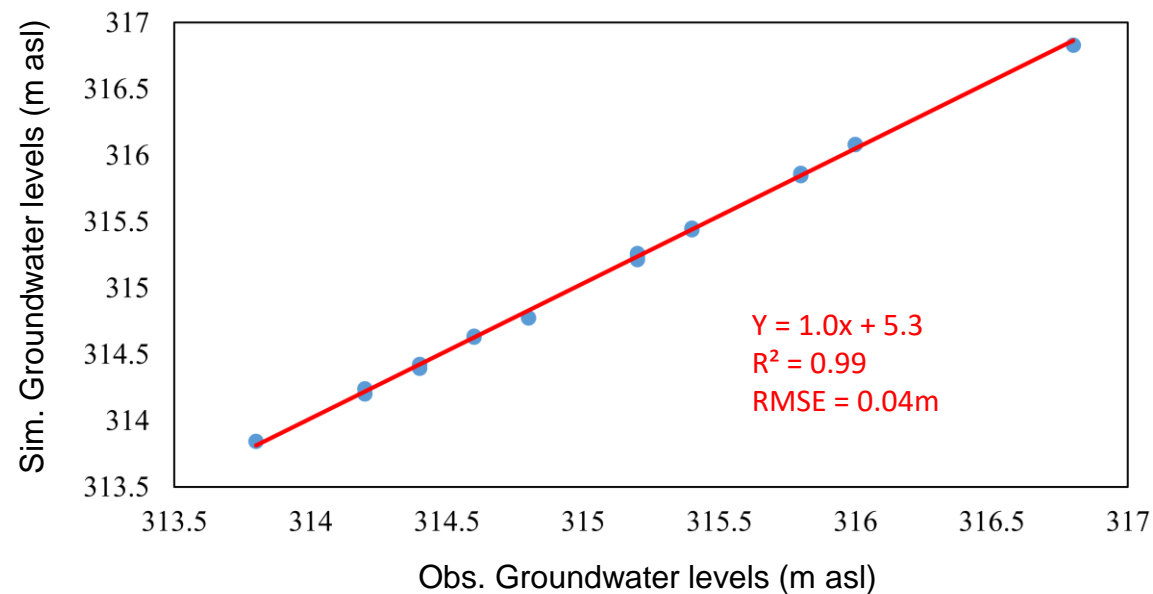


Groundwater Vistas 8 (MODFLOW-2005)

Model based on:
Geological investigations
Groundwater/River levels monitoring
ERT surveys

Steady-state calibration
(PEST & pilot points)

Calibrate the model in natural flow conditions (no change in hydraulic heads over time)

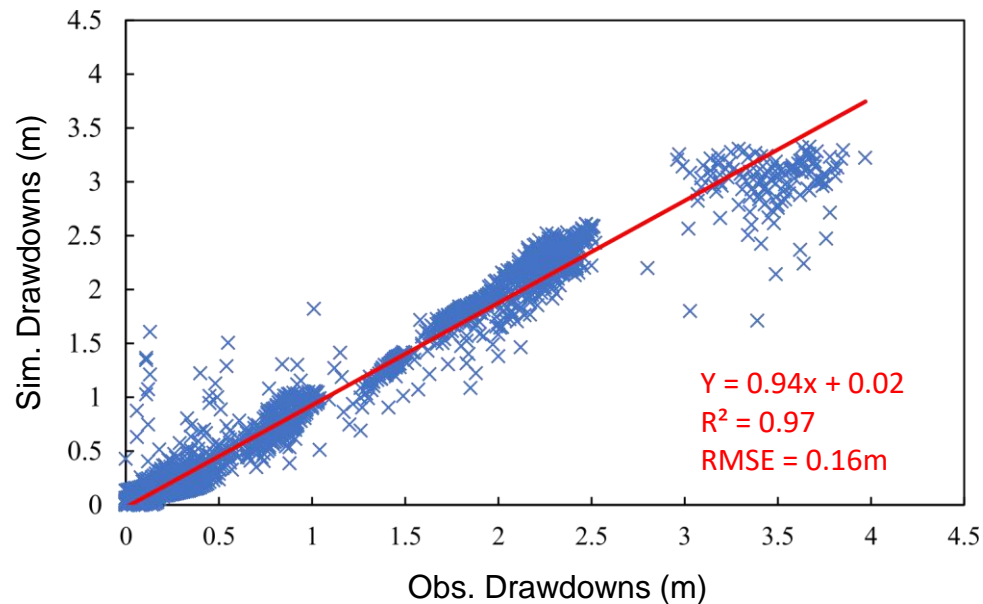


Allocate the hydraulic conductivities (K_x , K_y) over the modeled area

Groundwater Vistas 8 (MODFLOW-2005)

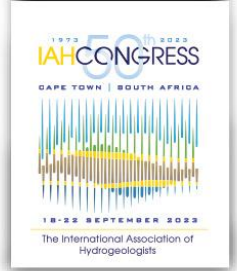


Calibrate the model in forced flow conditions (hydraulic heads may vary over time)

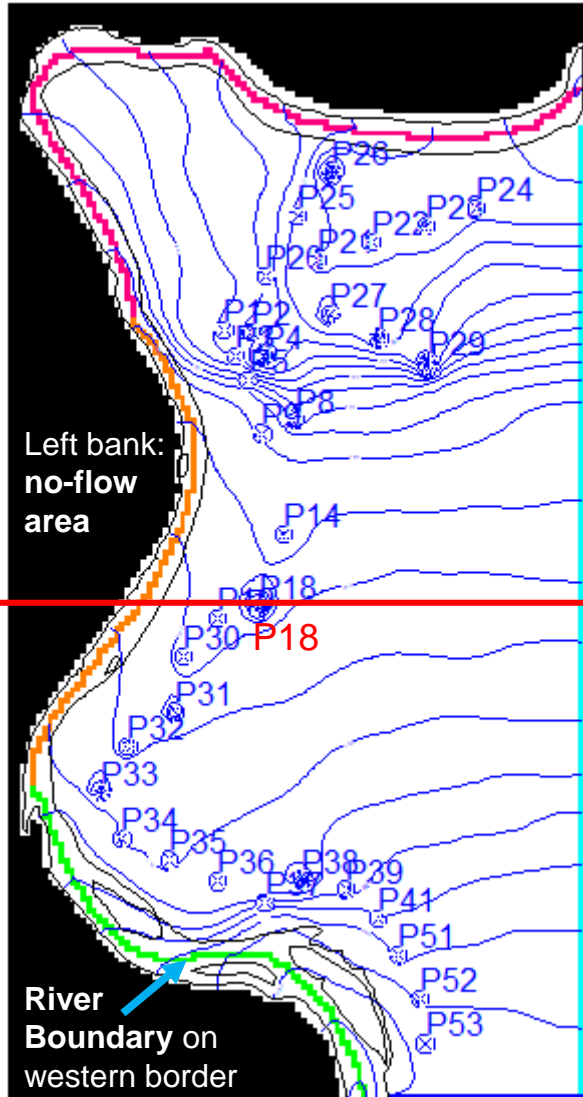


Allocate the specific yield S_y over the modeled area

Results: reactivity of groundwater levels with extreme low-flows



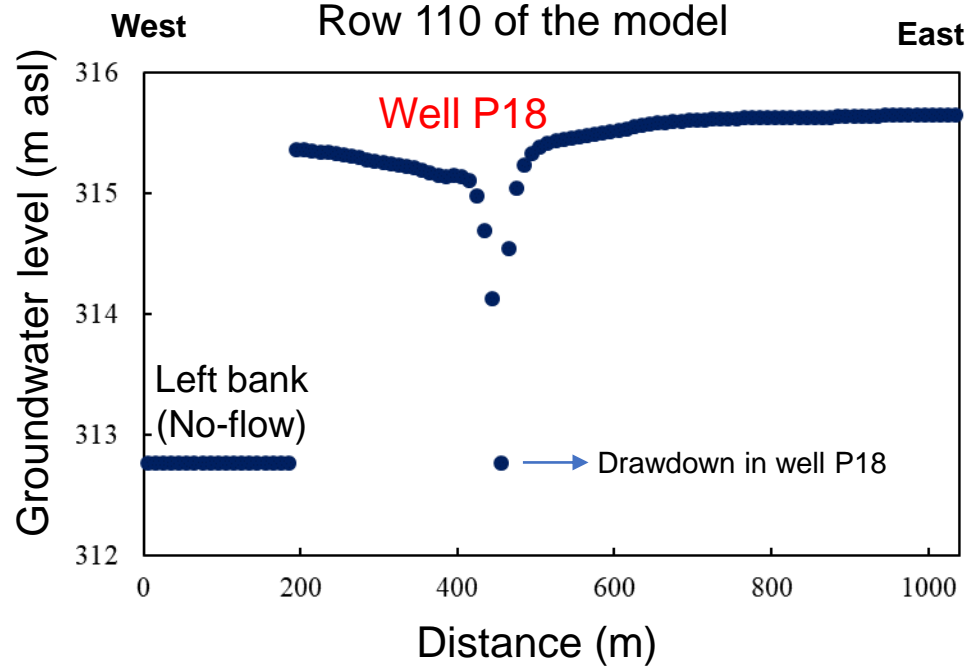
West Model grid extent East



General Head Boundary (GHB) on eastern border

Constant head on southern border

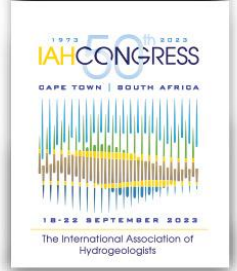
West-East profile of the water-table level



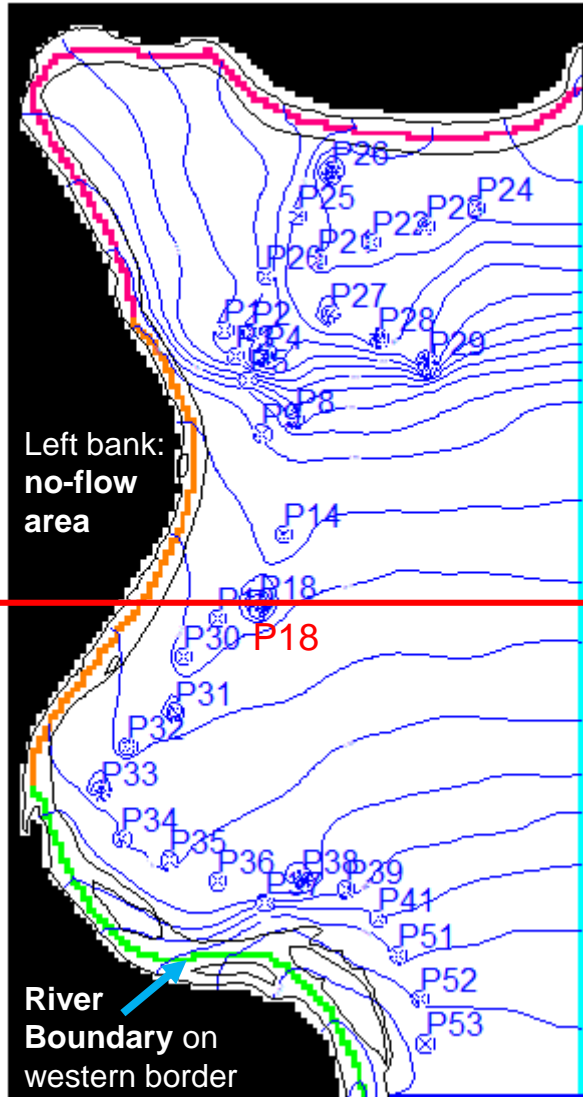
For 2 months:

- 1) Normal flow conditions
- $Q_{\text{RIVER}} = 30\text{m}^3/\text{s}$
- Pumping schedule:
 - 12h pumping
 - 12h recovery

Results: reactivity of groundwater levels with extreme low-flows



West Model grid extent East



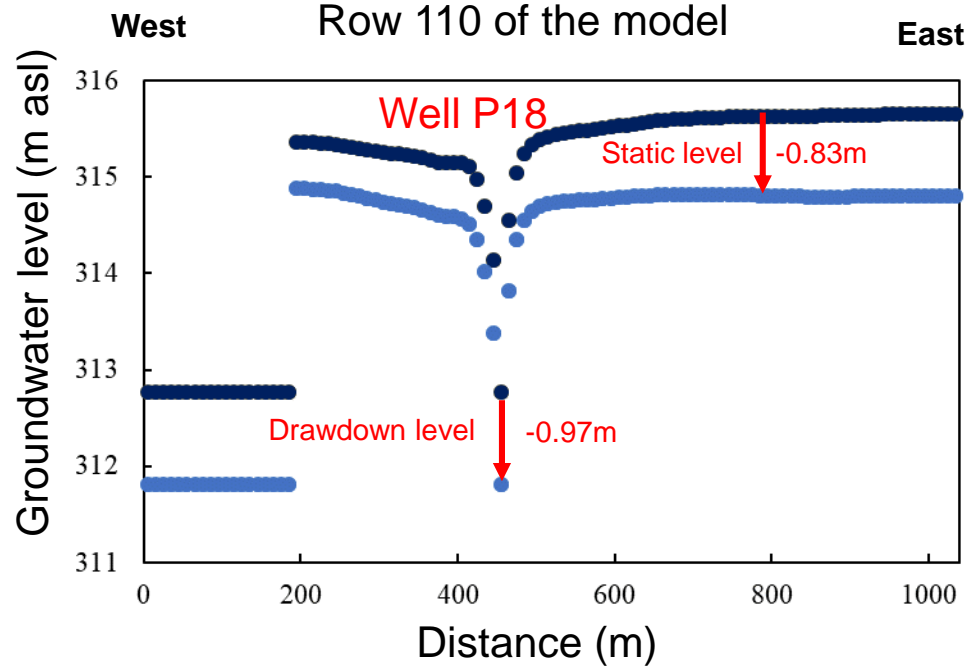
Row 110

General Head Boundary (GHB) on eastern border

River Boundary on western border

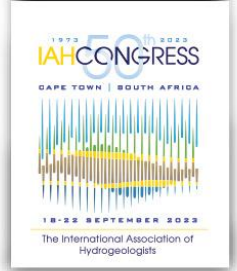
Constant head on southern border

West-East profile of the water-table level

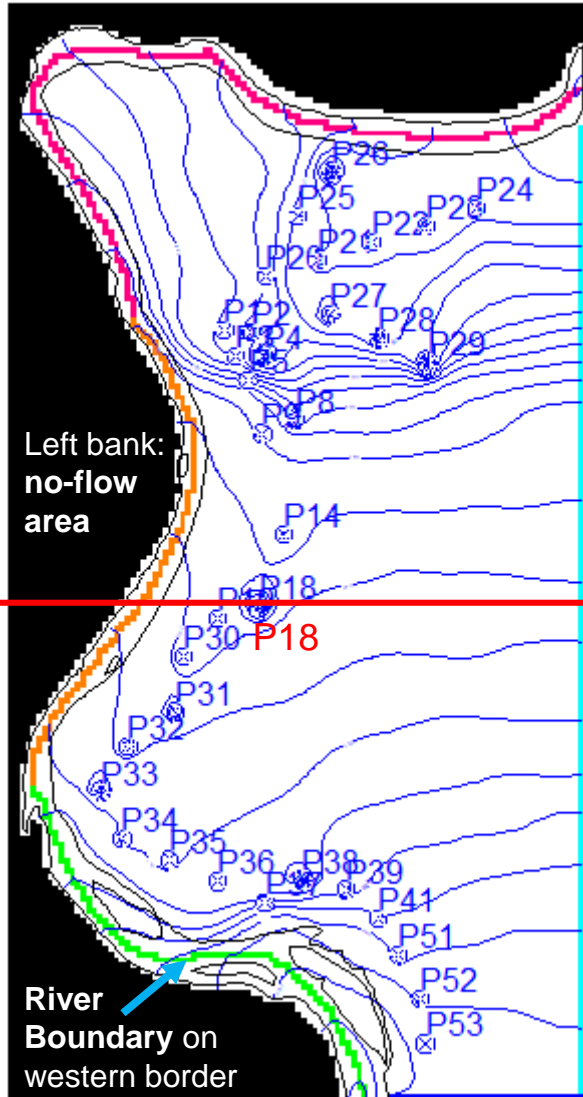


For 2 months:
 2) Extreme low-flow conditions
 $Q_{RIVER} = 2m^3/s$
 Pumping schedule:
 12h pumping
 12h recovery

Results: reactivity of groundwater levels with extreme low-flows



West Model grid extent East



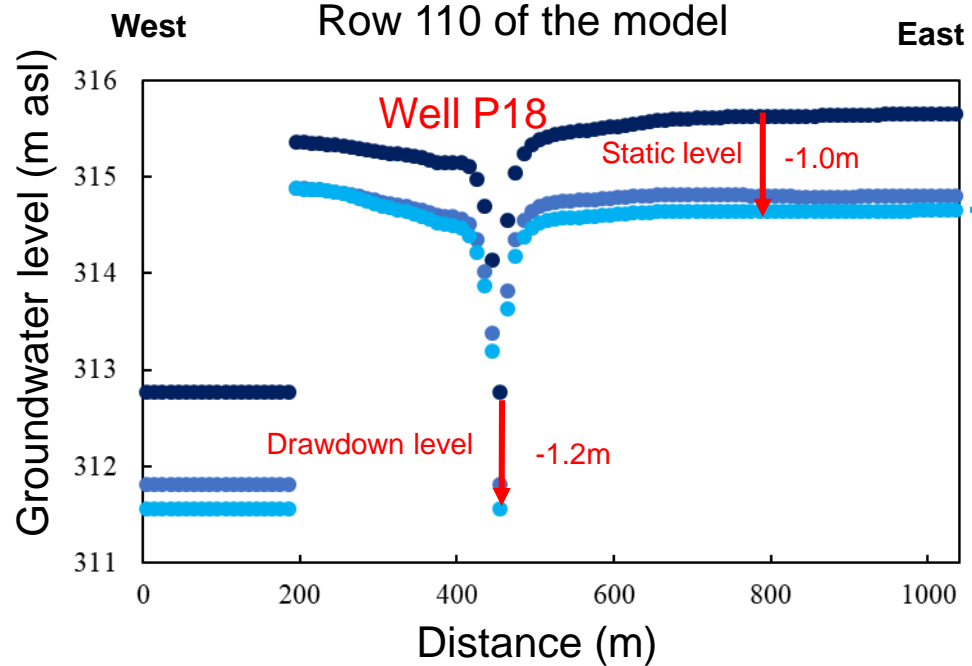
Row 110

General Head Boundary (GHB) on eastern border

River Boundary on western border

Constant head on southern border

West-East profile of the water-table level

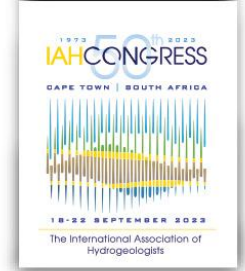


For 2 months:

- 2) Extreme low-flow conditions
- $Q_{\text{RIVER}} = 2\text{m}^3/\text{s}$
- Pumping schedule:
 - 20h pumping
 - 4h recovery

(to anticipate higher domestic water needs)

Conclusion and study outlook



- Low-flows are a major issue for connected hydrosystems such as River/alluvial aquifers
- Extreme low-flows in the River also affect the groundwater levels (static & drawdown levels are decreasing)
- Could be a threat for drinking water production
- Provide more accurate answers to water stakeholders and to give them some tools to anticipate future potential water crisis

Limits:

- The model still needs to be improved:
 - i) it is calibrated in transient conditions on a daily basis,
 - ii) it needs to be calibrated and validated on a monthly time-scale to consider the alternance of low/high flow periods

Thank you for your attention

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