Architecture of seepage zones combined with their residence time to constrain hydrogeological models

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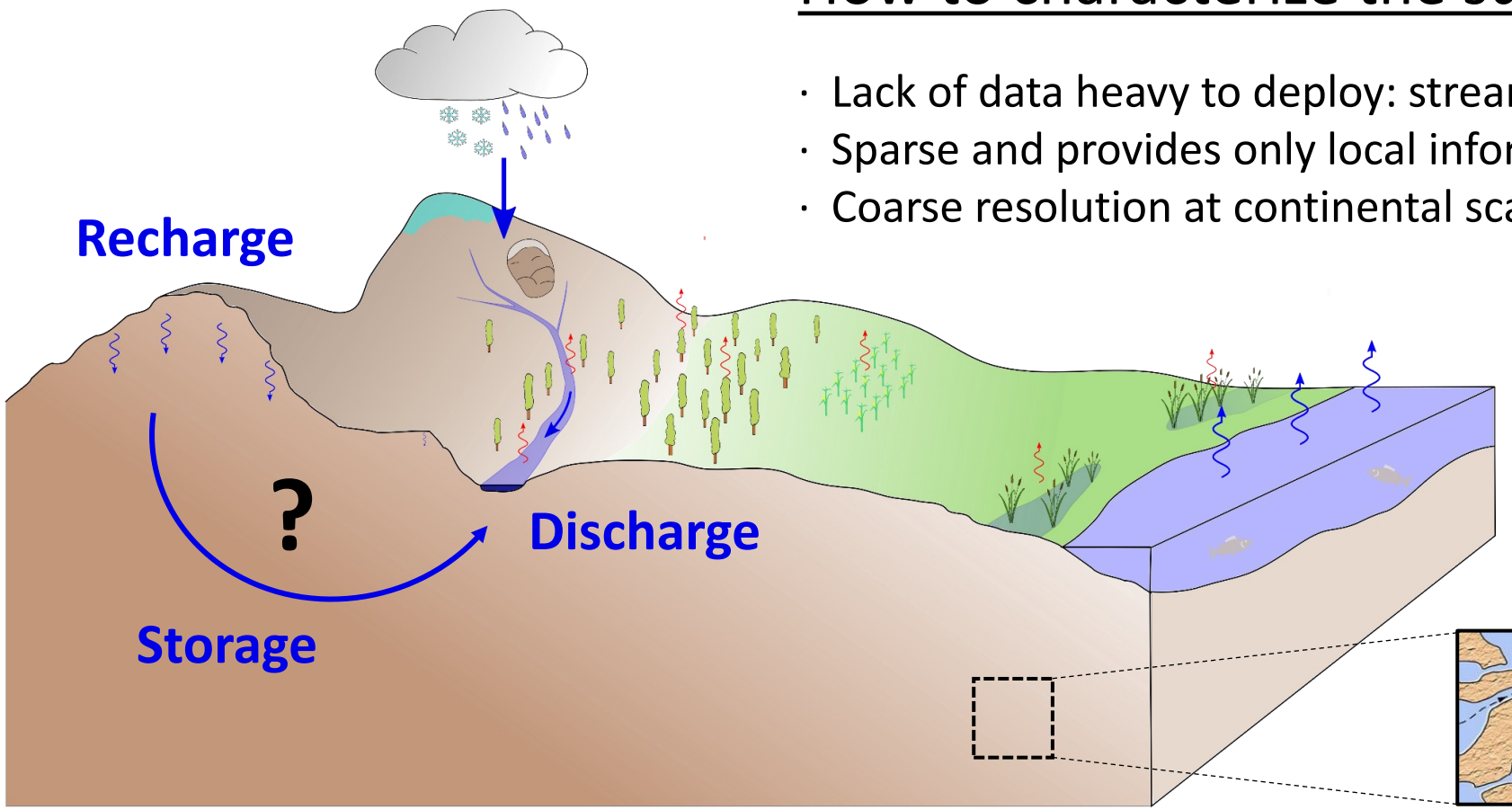
Objectives

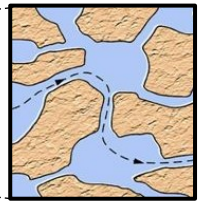
Need predictive model for ungauged basins *(Blöschl et al., 2019)*
representing processes at the hillslope/catchment scale *(Fan et al., 2019)*

How to characterize the subsurface ?

- Lack of data heavy to deploy: streamflow *(Cornette et al., 2022)*
- Sparse and provides only local information: boreholes *(Le Borgne et al., 2006)*
- Coarse resolution at continental scales: extrapolation *(Gleeson et al., 2014)*



Estimation of the aquifer hydraulic properties



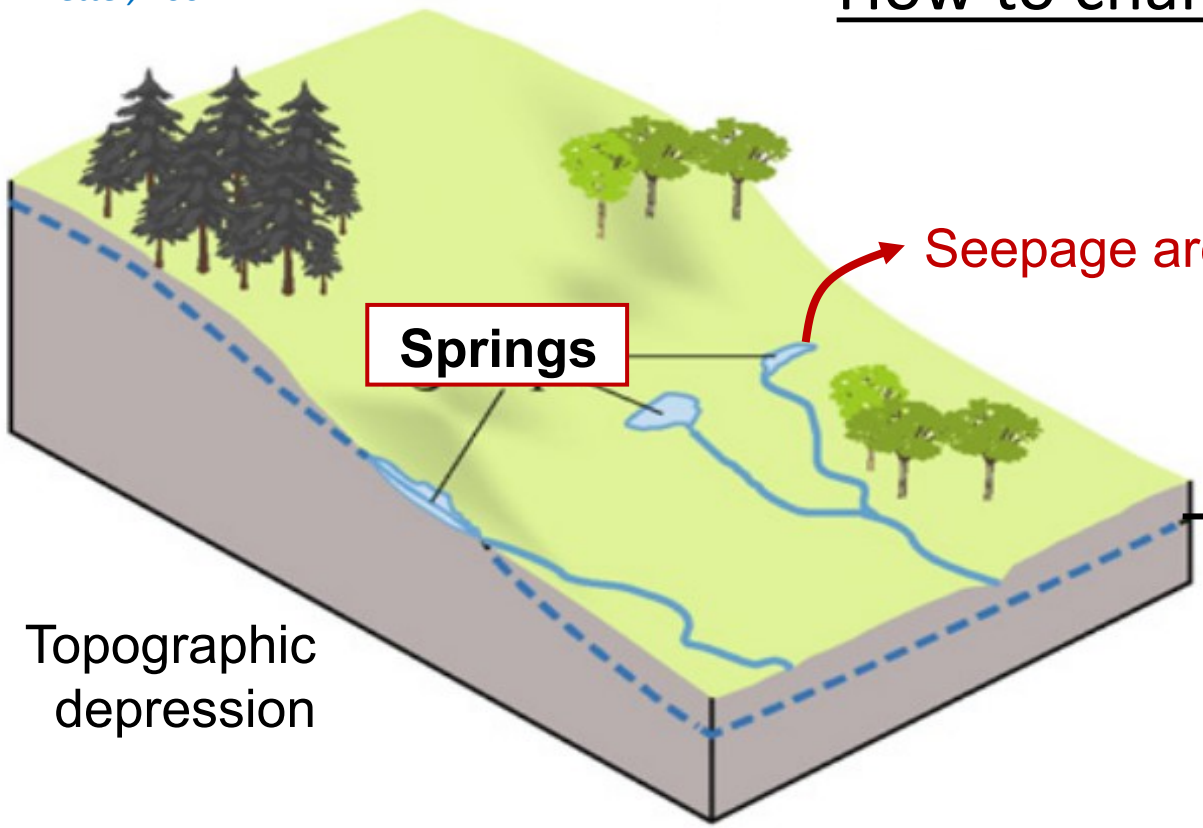
K hydraulic conductivity [m/s]

θ porostiy [%]

Objectives

Need predictive model for ungauged basins *(Blöschl et al., 2019)*
representing processes at the hillslope/catchment scale *(Fan et al., 2019)*

Kløve et al., 2011, from Fetter, 2001



How to characterize the subsurface ?

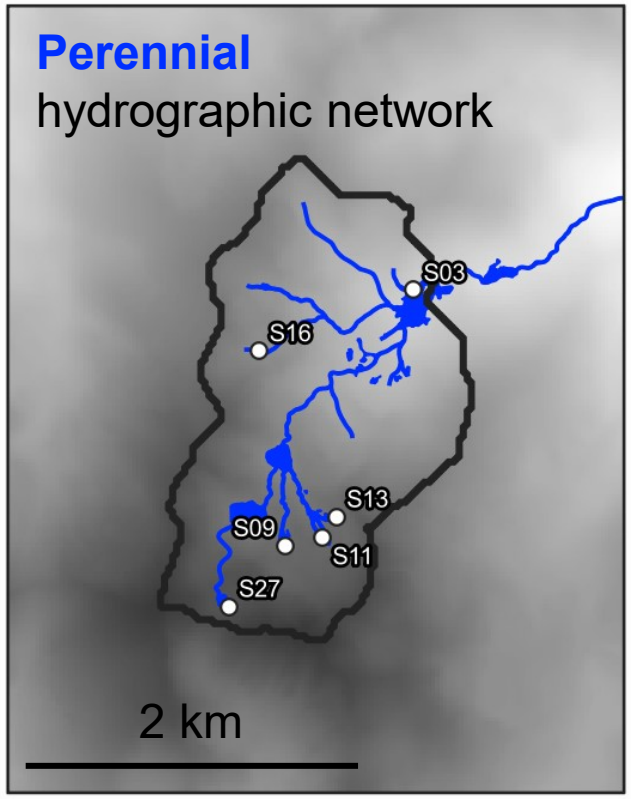
Hydrographic network *(streams/wetlands)*
Residence time

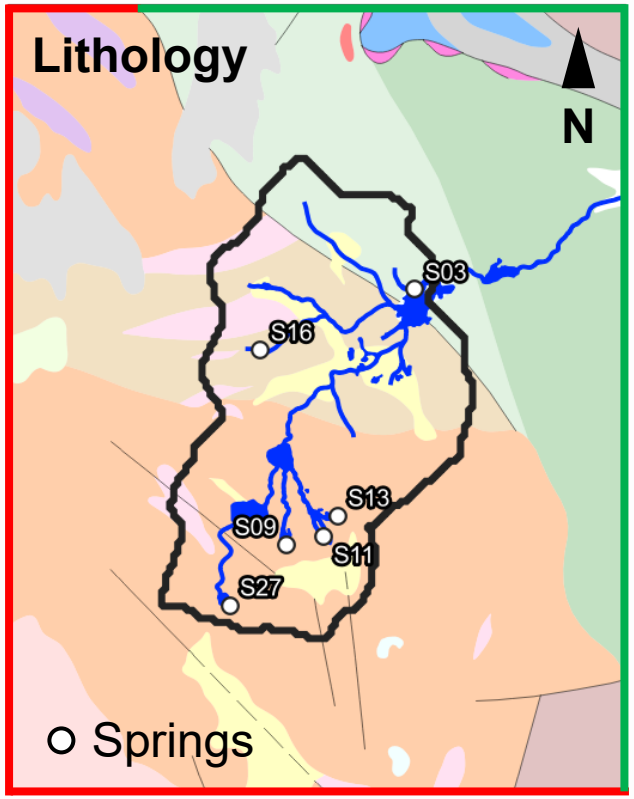
Can we gain insights into groundwater flow paths from hydrographic network and residence times at springs?

Study site

Pyrenees mountain range
“Lasset” catchment
3.7 km^2

Sedimentary rocks
(schist, sandstone, limestone)

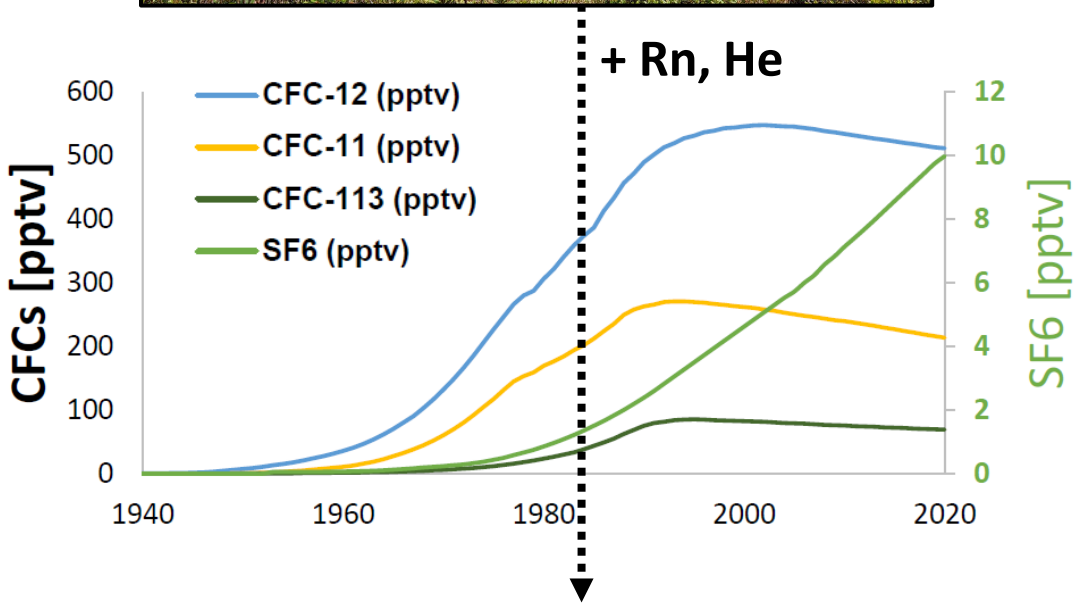




1100 Elevation [m] 2350

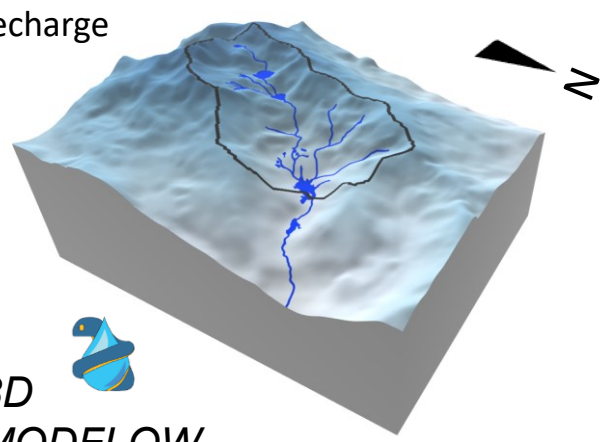
Metamorphic rocks
(gneiss, migmatite, micashist)

Measurement campaign in October 2021

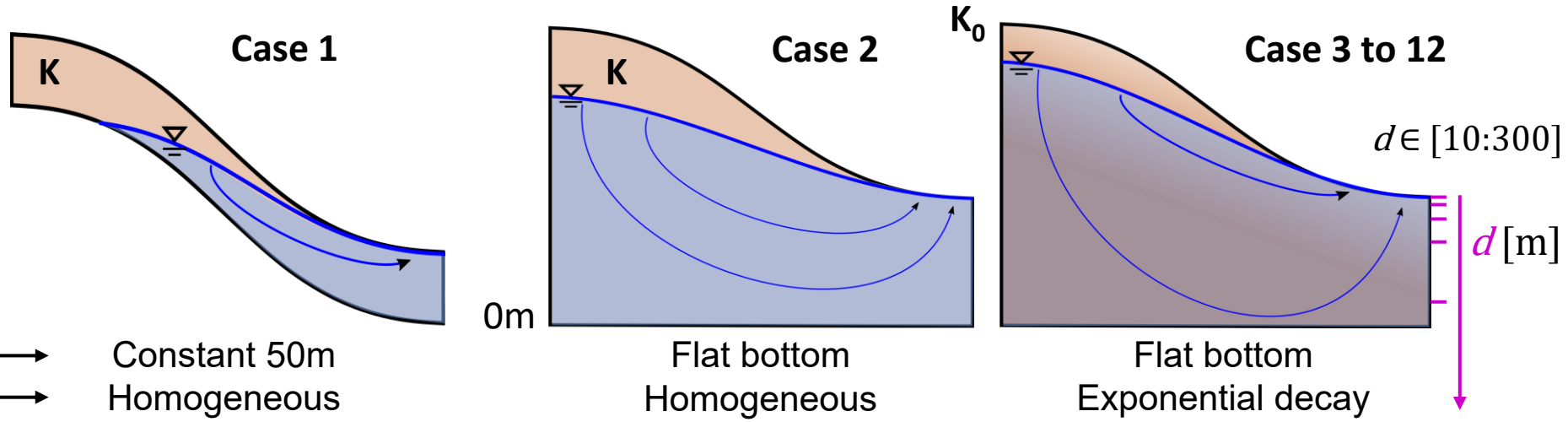


Residence times at springs

Calibration methodology workflow

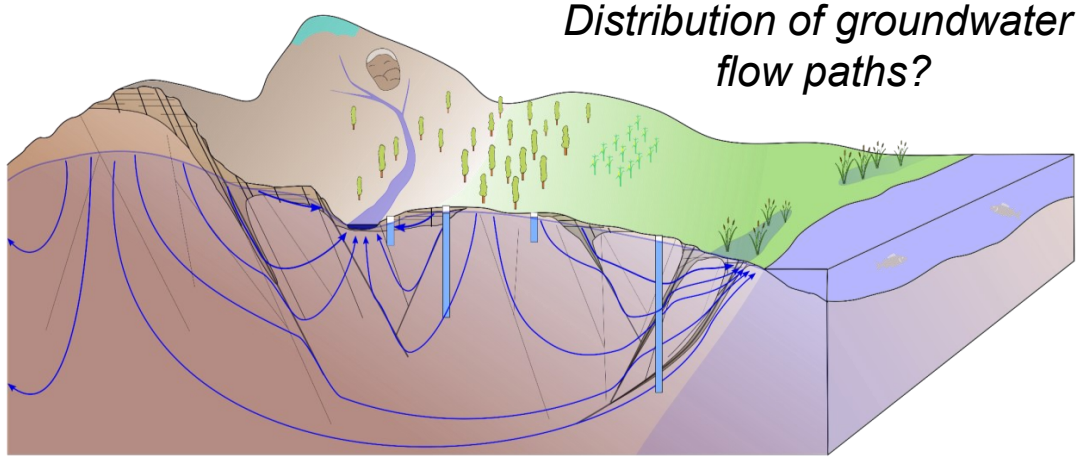


How to assess bedrock heterogeneity at the catchment scale?



Aquifer models		
	Geometry →	Constant 50m
	Hydraulic prop. →	Homogeneous
		Flat bottom Homogeneous
		Flat bottom Exponential decay

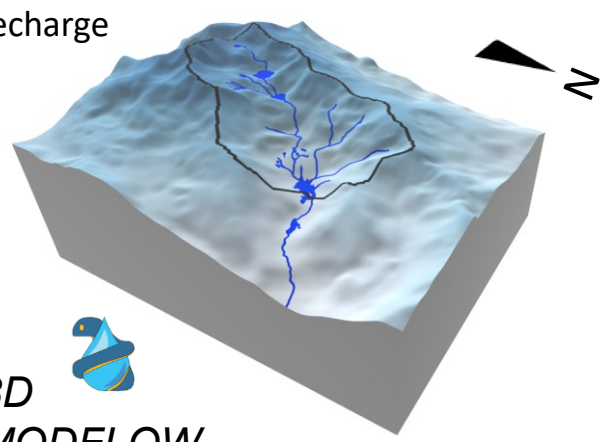
$$K_{(x,y,z)} = K_0 e^{-z_{(x,y)}/d}$$



For each of the **12 aquifer models**

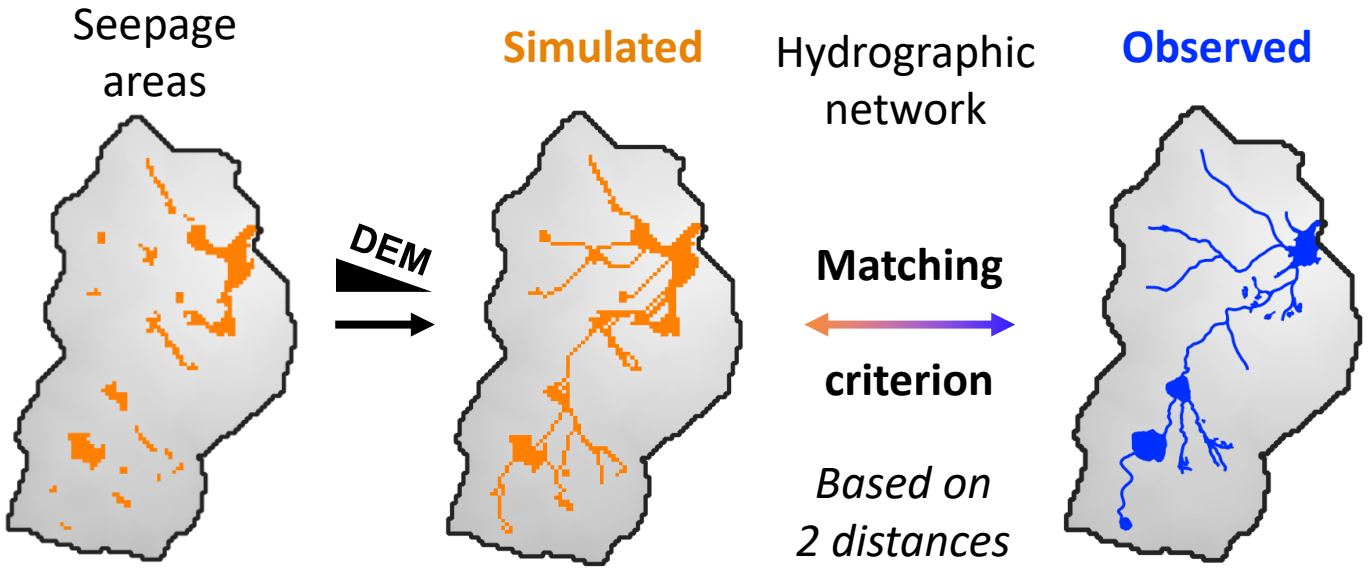
1. **Optimization of K from the hydrographic network**
2. **Optimization of θ from the residence times**

Optimization of K from the stream network

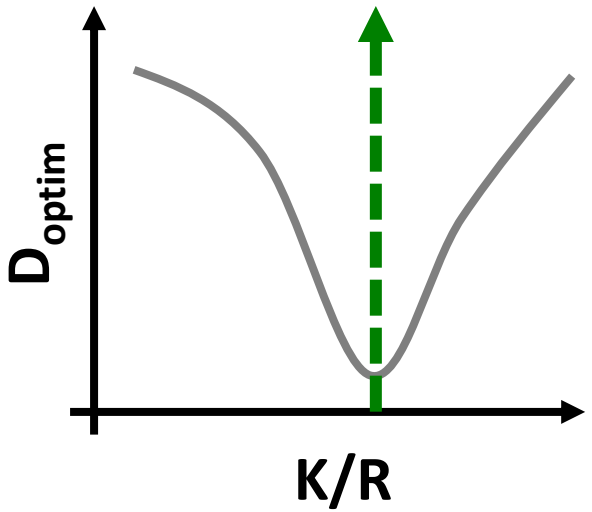


12 aquifer models

K/R values
[10^{-10} to 10^{-5} m/s]

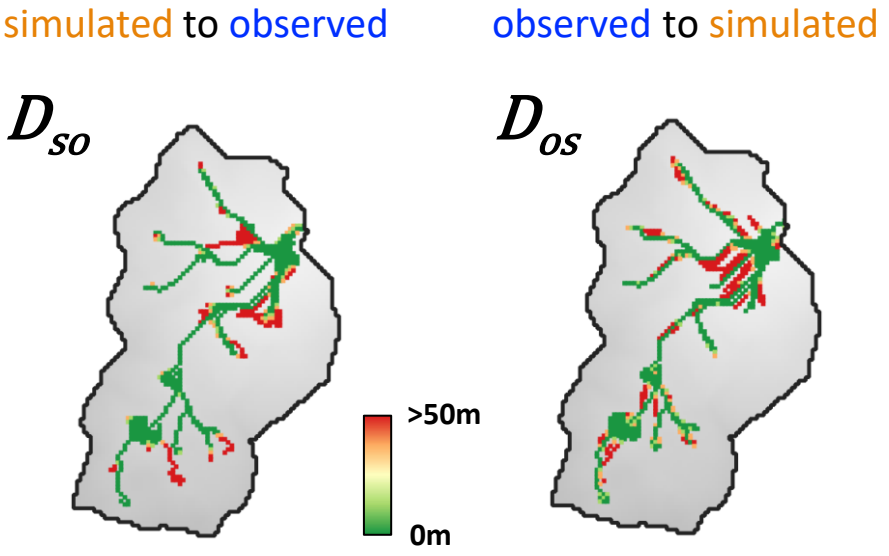


Optimal K value



$$D_{optim} = \frac{D_{so} + D_{os}}{2}$$

Reach the optimal K/R



Hydrology and Earth System Sciences Discussions
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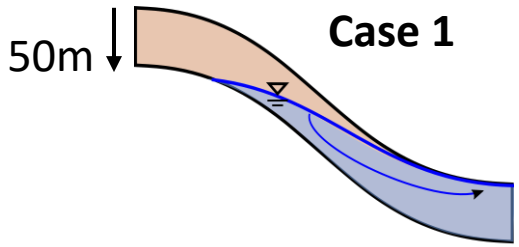
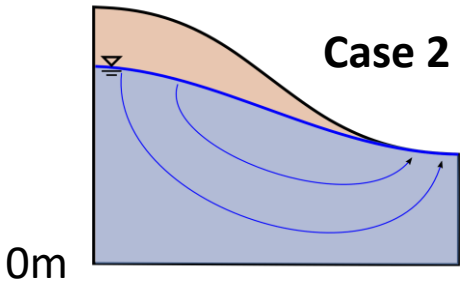
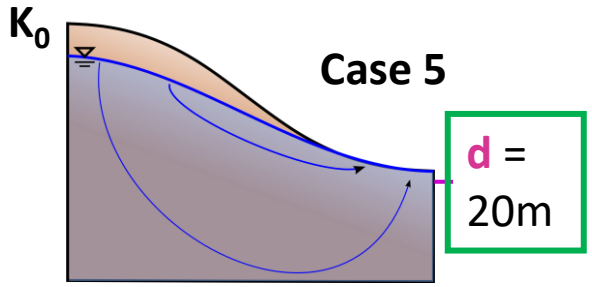
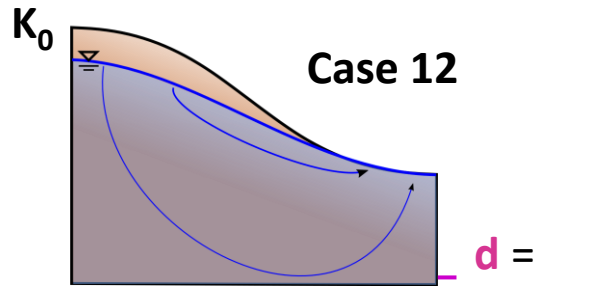
EGU
Abhervé et al., 2023

Estimation results of K

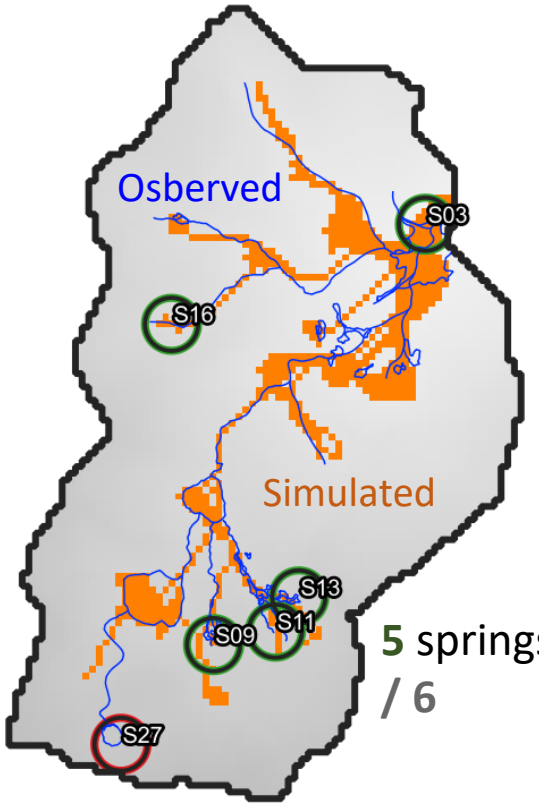


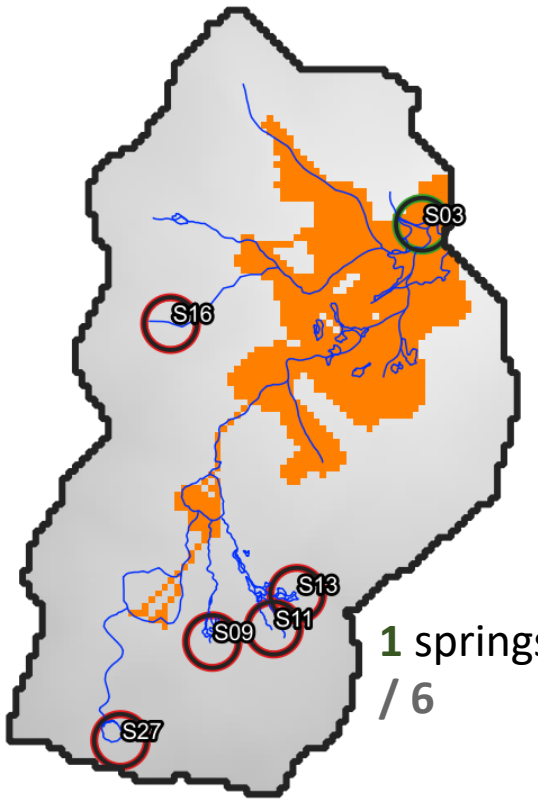


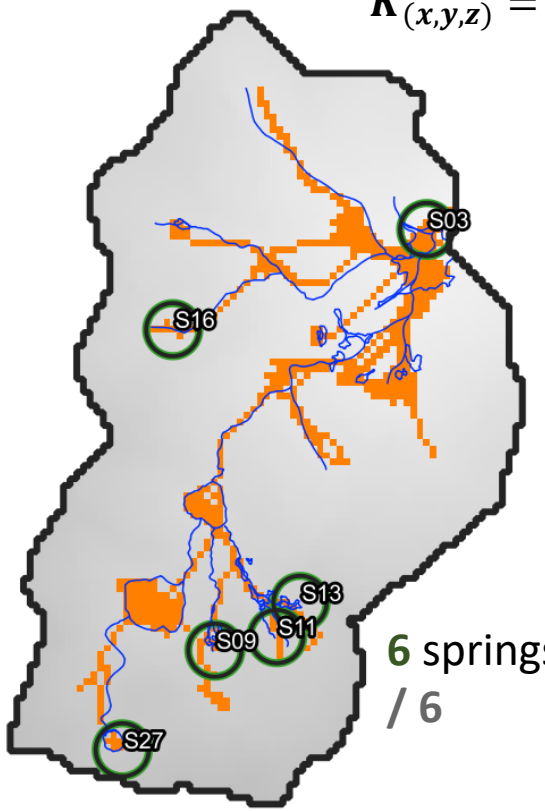


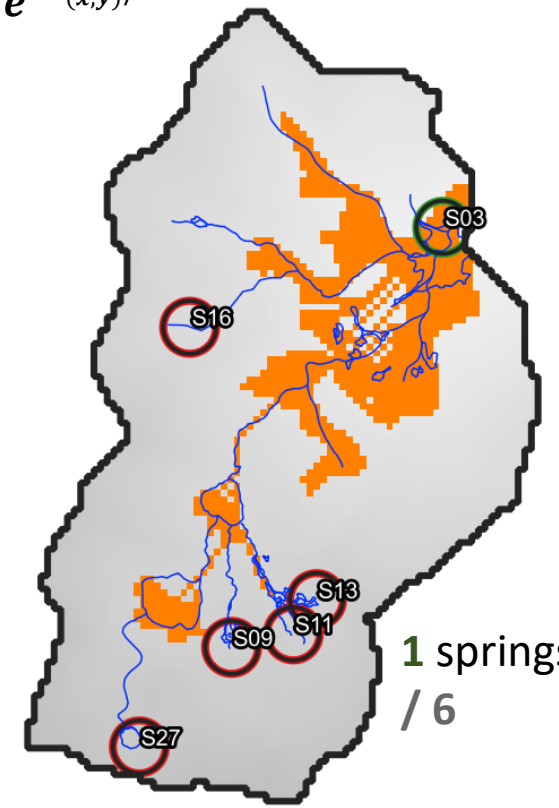


$$K_{(x,y,z)} = K_0 e^{-z_{(x,y)}/d}$$









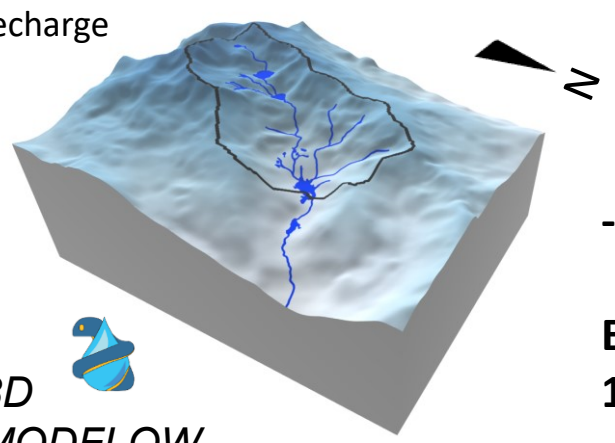
K = 7.0 x 10^{-7} m/s

K = 2.0 x 10^{-8} m/s

K_0 = 2.2 x 10^{-6} m/s

K_0 = 7.6 x 10^{-8} m/s

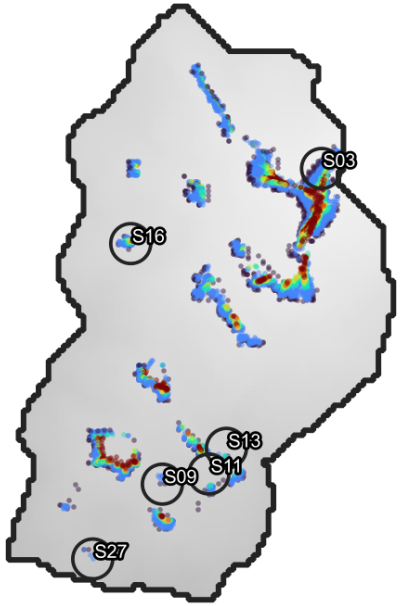
Optimization of θ from the residence times



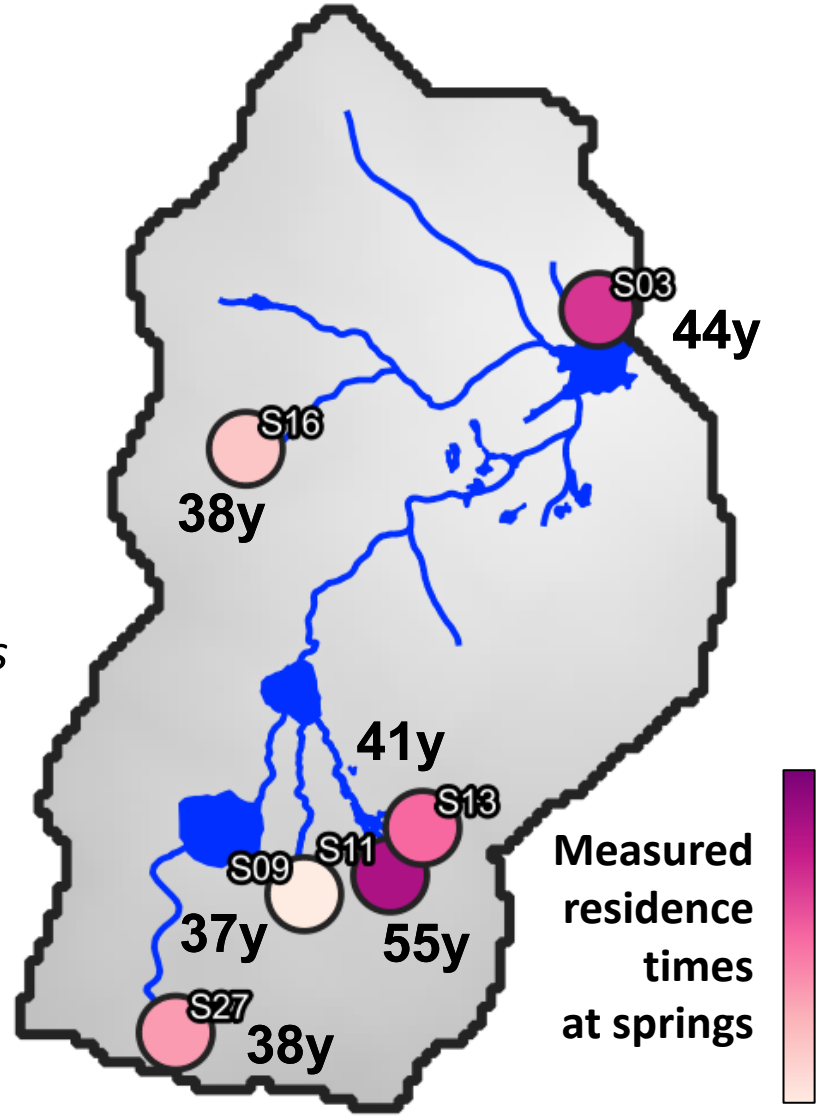
--> K value estimated

Exploration of θ
10 values [0.3 to 30 %]

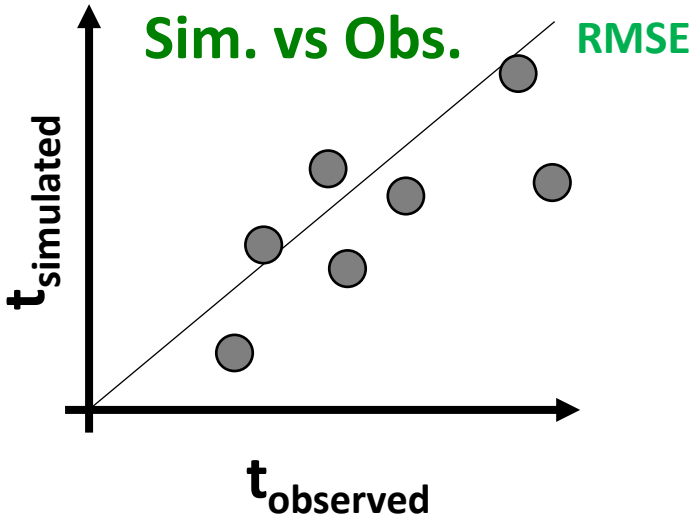
Simulated ⟷ **Observed**



Particle tracking results

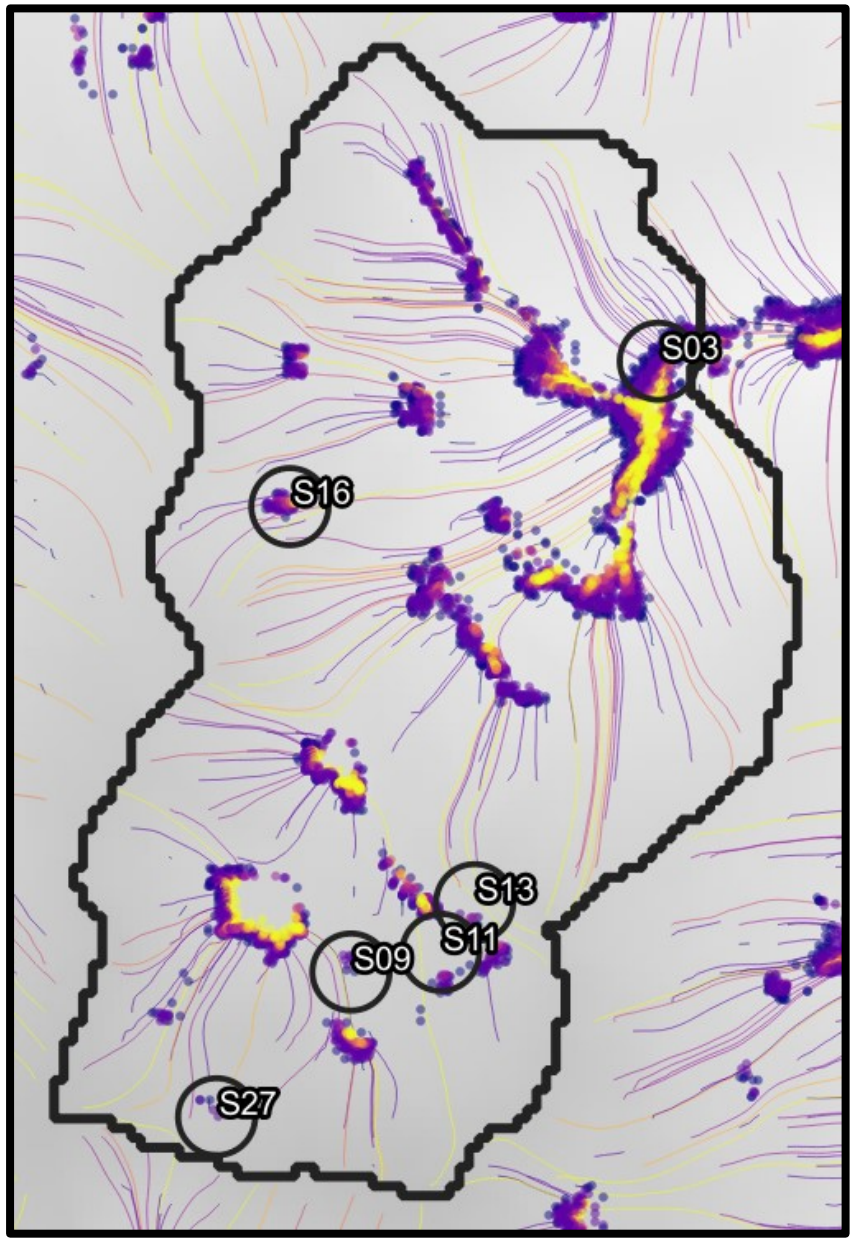


Optimal θ value

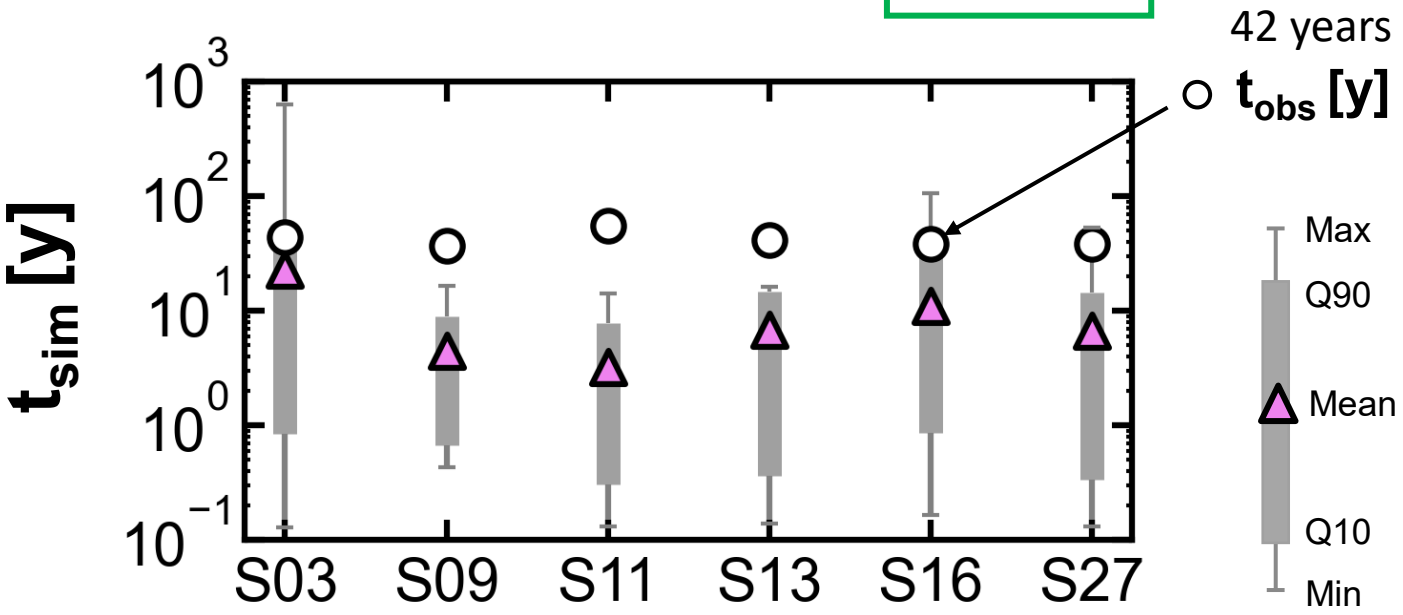


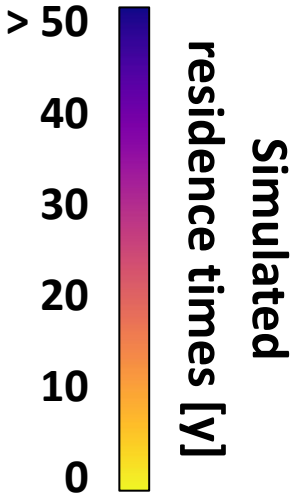
Mean apparent ages of
≈ **40 years**
suggests high storage capacity

Estimation results of θ



K = 2.2 x 10^{-6} m/s **d = 20 m** **θ = 4 %** Best RMSE

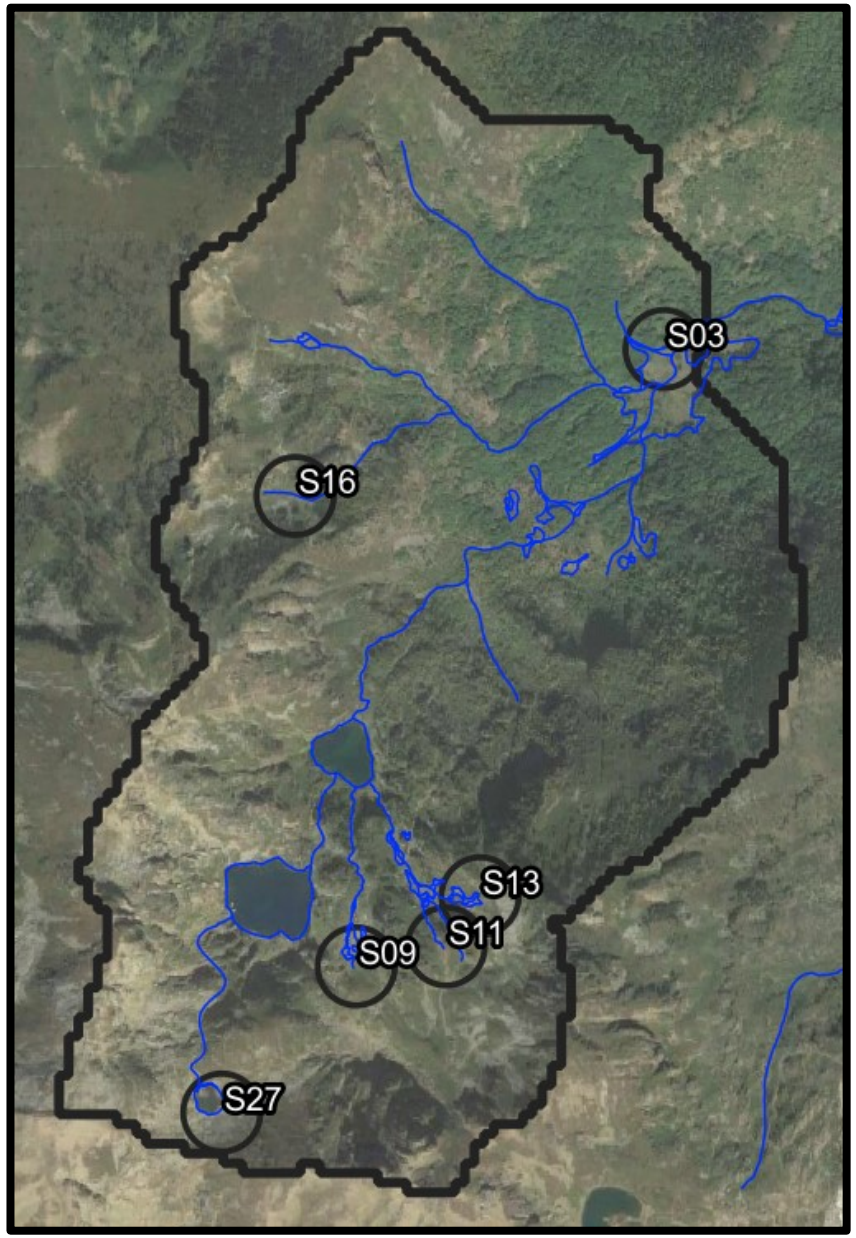




The optimal aquifer model

- Reproduce each springs
- Despite the underestimation of residence times

Estimation results of θ



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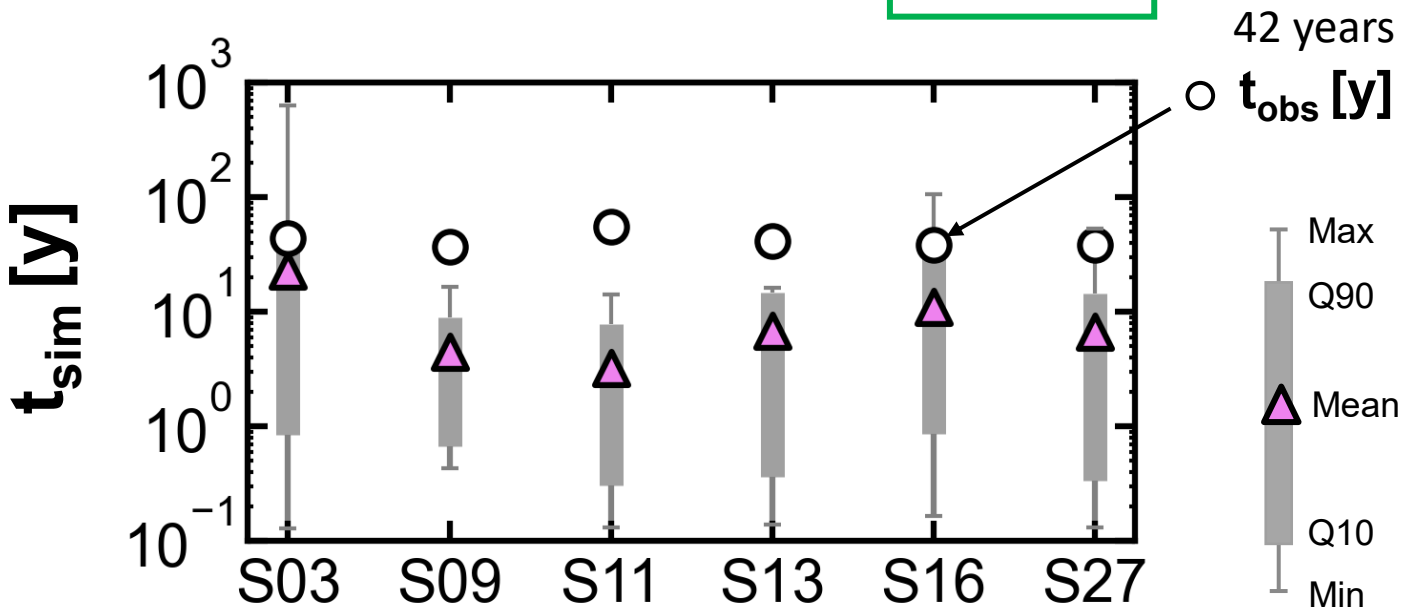


Model representation + measurement sampling

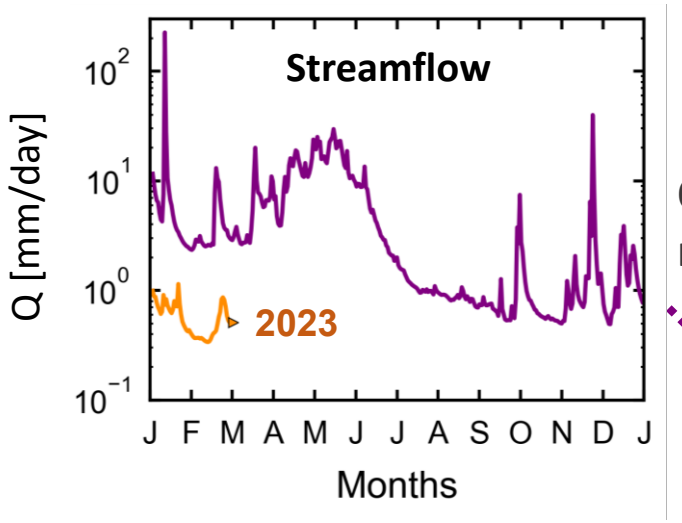
Complexity of the landscape

Lithological	bedrock, surface formations
Geomorphological	landslides, scree
Hydrographical	wetlands, peat bogs

CFC-based dating methods (t_{sim})

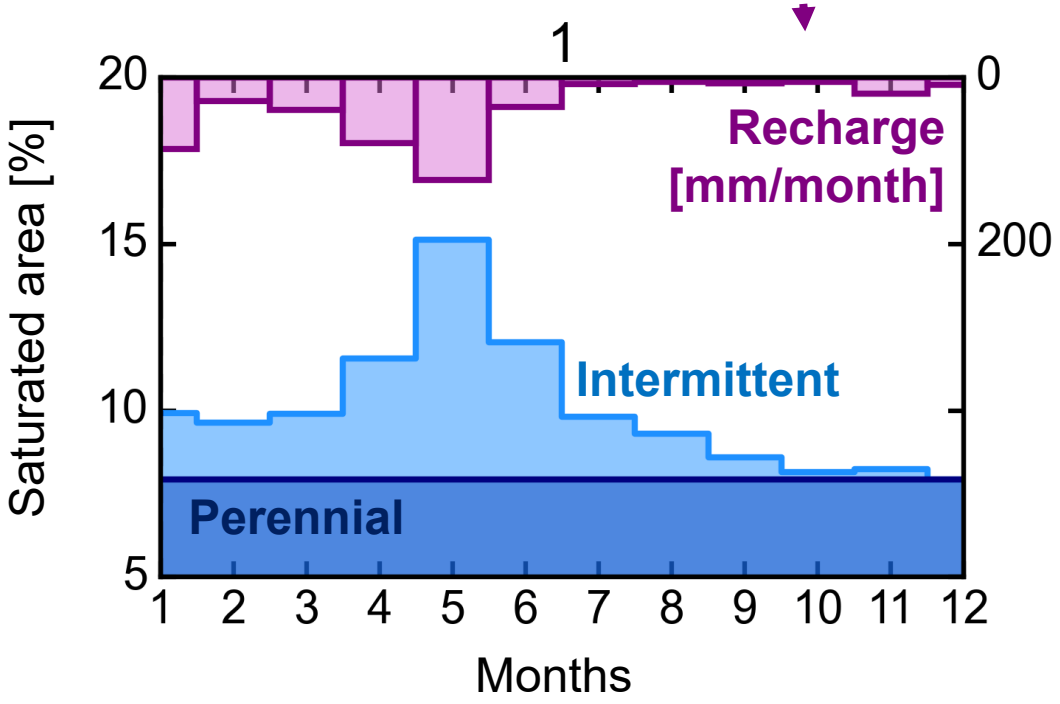
Insight about the geometry of groundwater flow paths

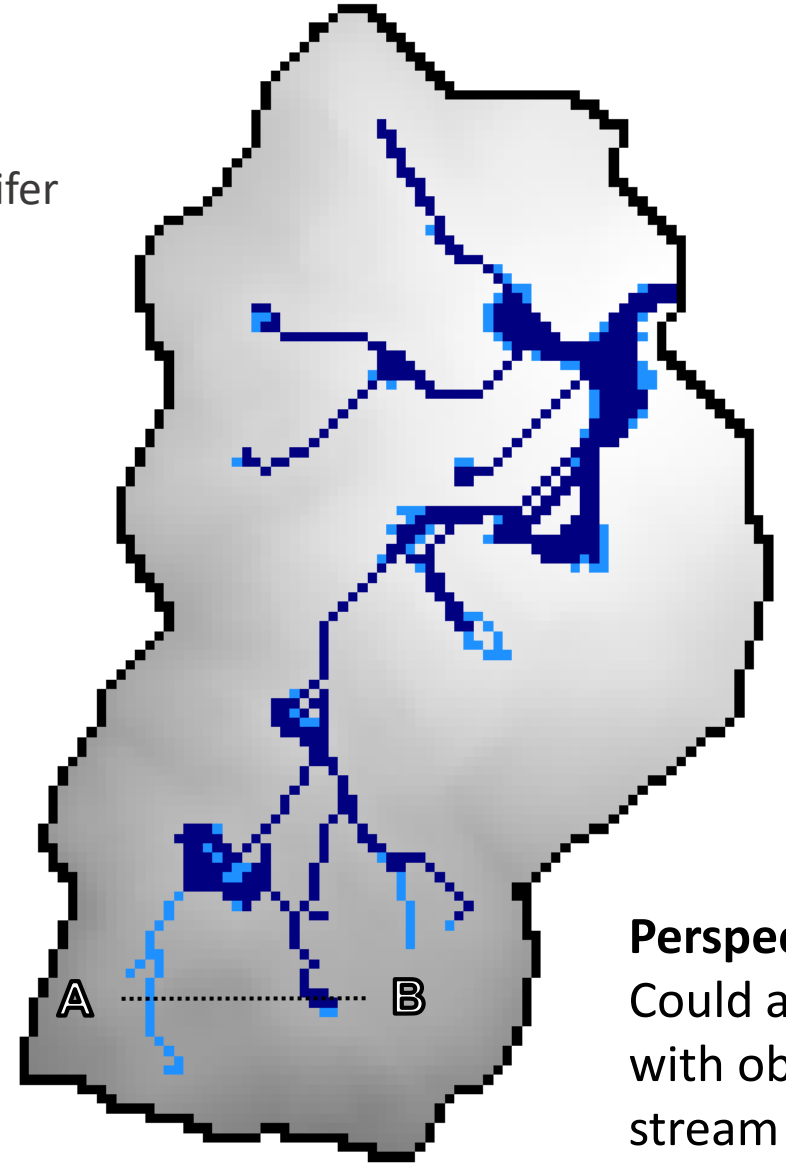
Validation of stream intermittency

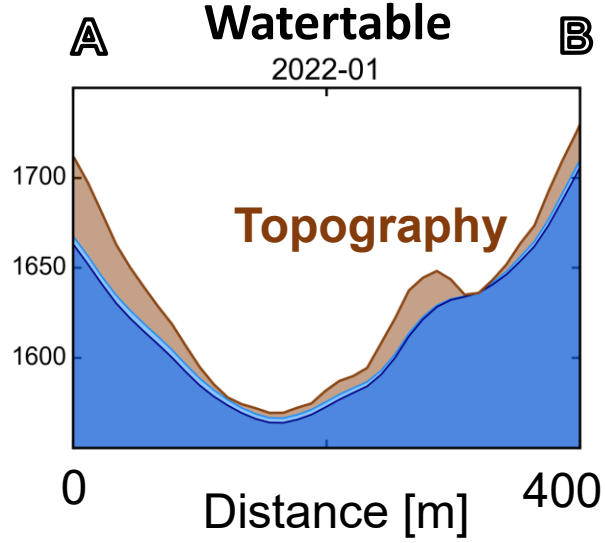


Q observed as the recharge of the aquifer

Year 2022







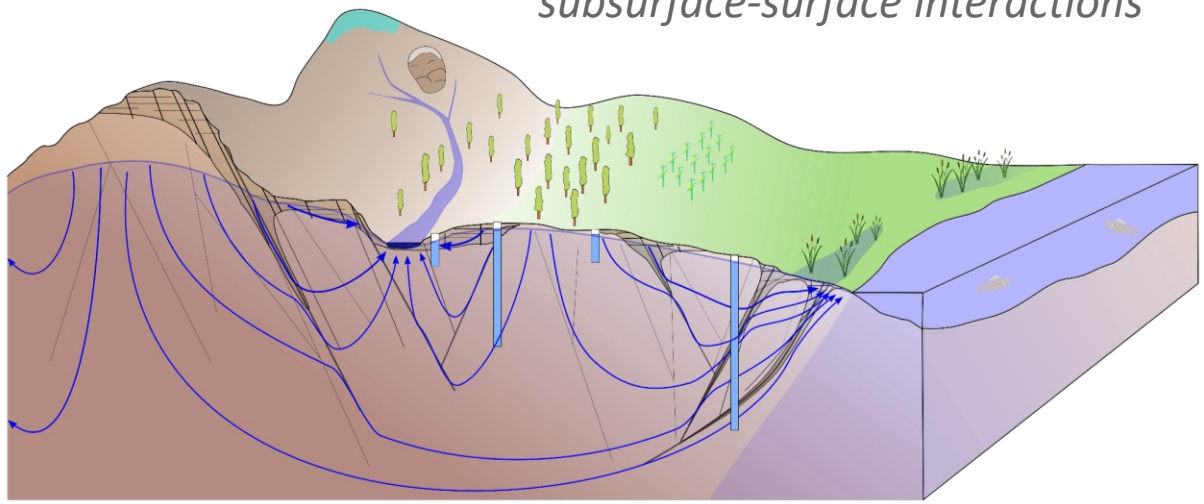
Perspectives

Could aquifer models be validated with observations of headwater stream expansion/contraction?

Conclusions

- Definition of geomorphic scenarios in which vertical heterogeneity is a key driver in the emergence of springs and induced residence times
- Model parametrization: need to define regional-scale hydraulic properties and aquifer geometries that properly capture the processes occurring at the hillslope scale
- Opportunity to assess relevant hydraulic properties and K e-folding depth solely based on surface information

unconfined aquifers with subsurface-surface interactions



Map of the hydrographic network

- alternative method for characterizing ungauged basins
- leverage in crowdsourcing and current innovations in remote sensing

Groundwater apparent ages

- estimation of the groundwater storage capacity
- insight about the spatial distribution and geometry of groundwater flow paths

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Thank you
for your attention

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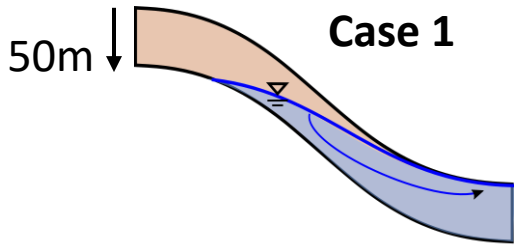
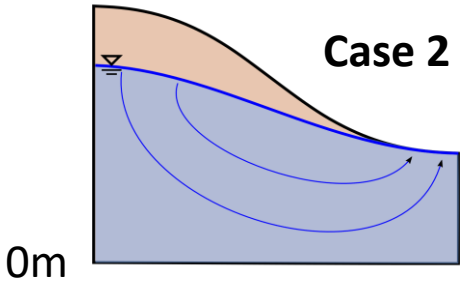
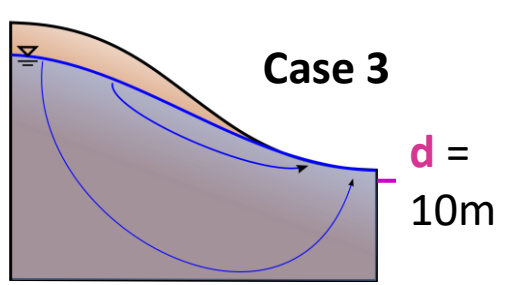
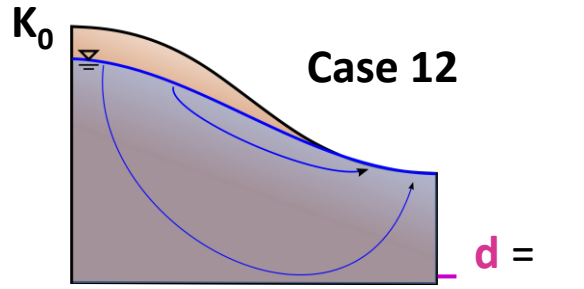
Estimation results of K









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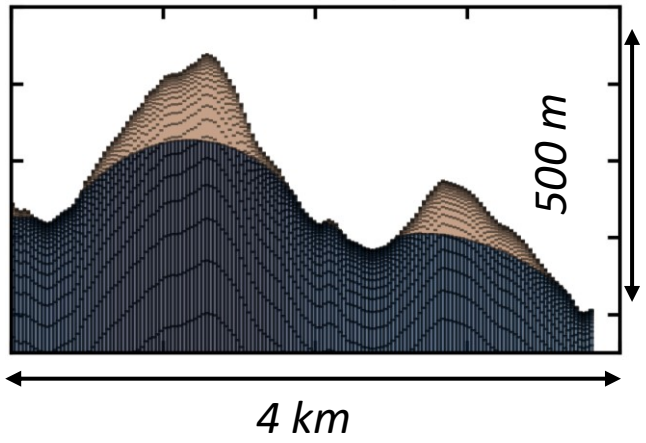
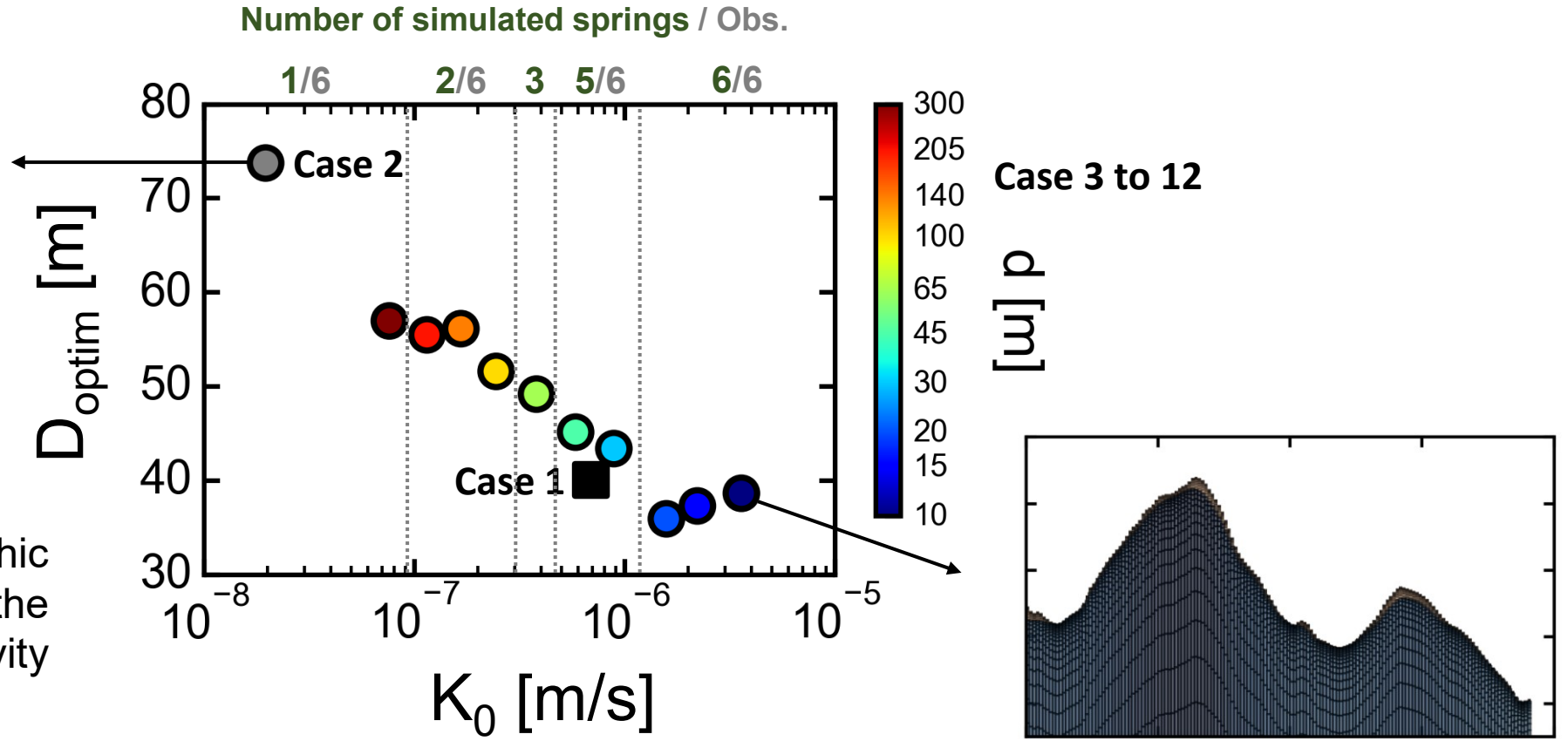
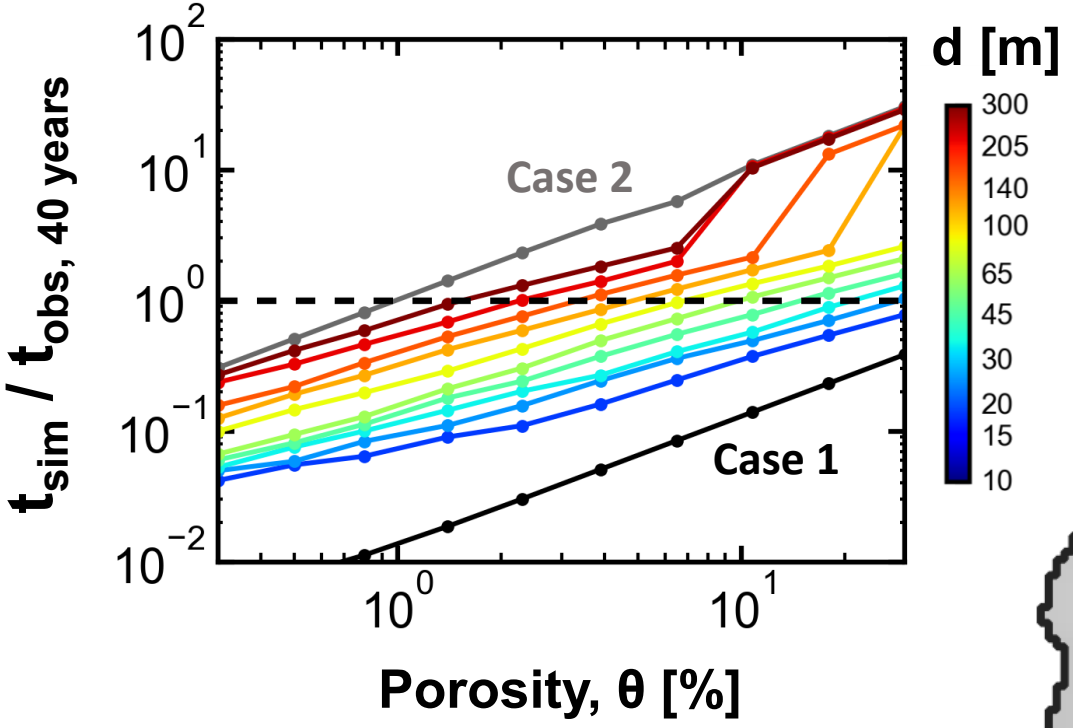


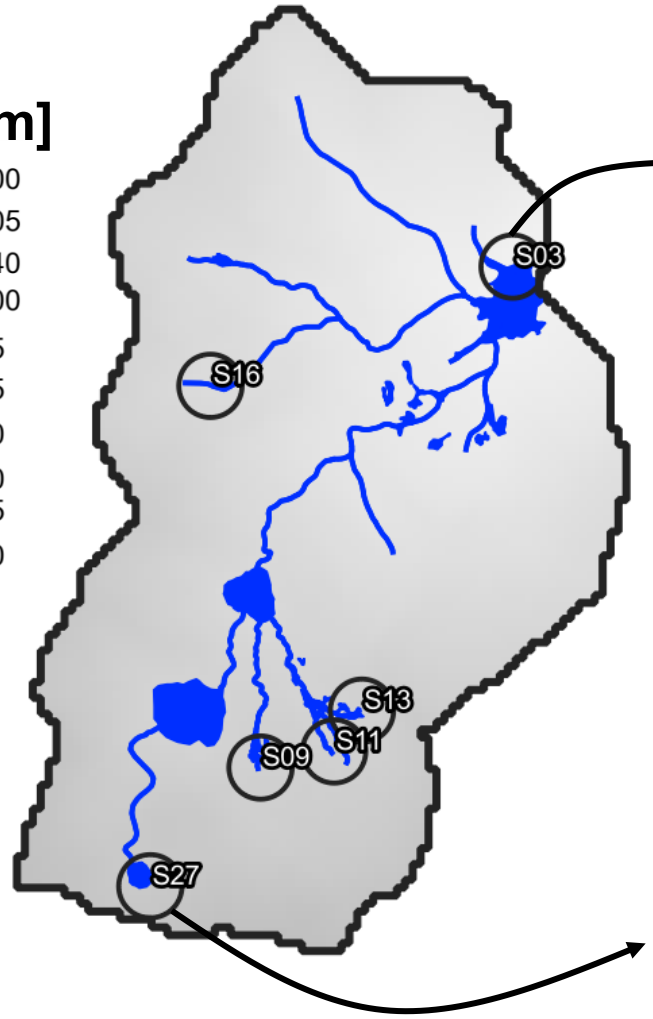


Spatial pattern of hydrographic network is highly sensitive to the decrease in hydraulic conductivity with depth

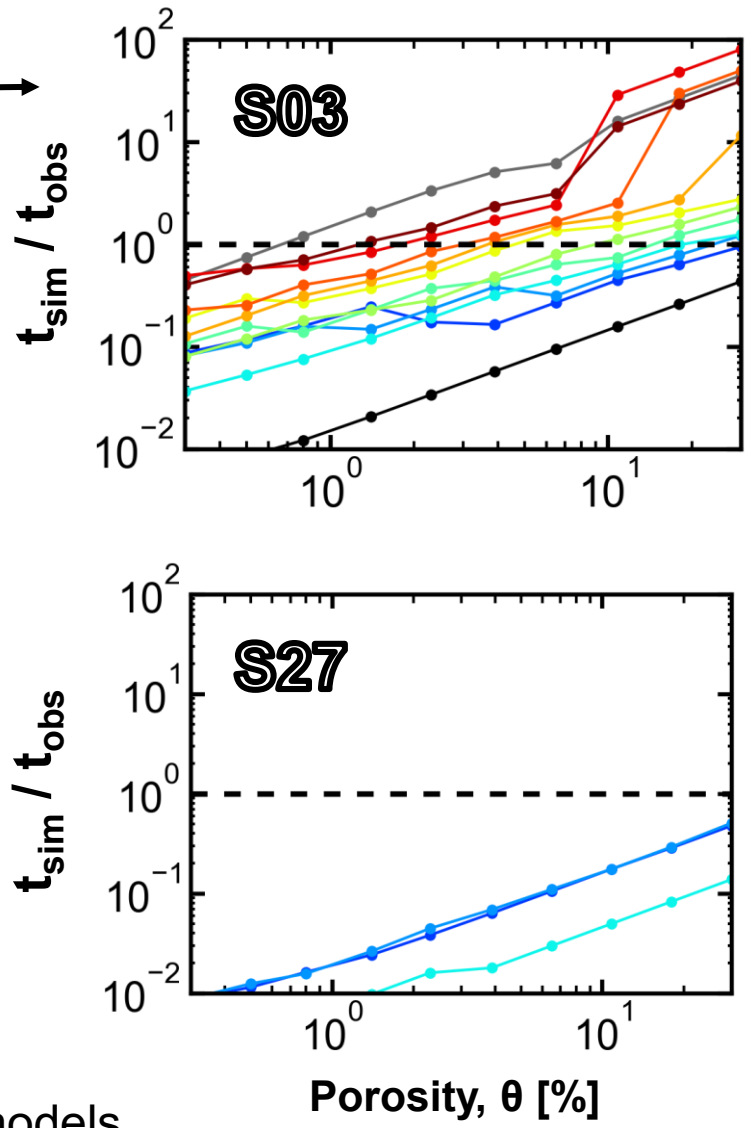
Estimation results of θ

For all the seepage areas





For 2 springs



- The groundwater storage capacity controls the residence times
- The spatial distribution of apparent GW age differs strongly among aquifer models