A new modeling and calibration approach considering time variant recharge areas in karst systems

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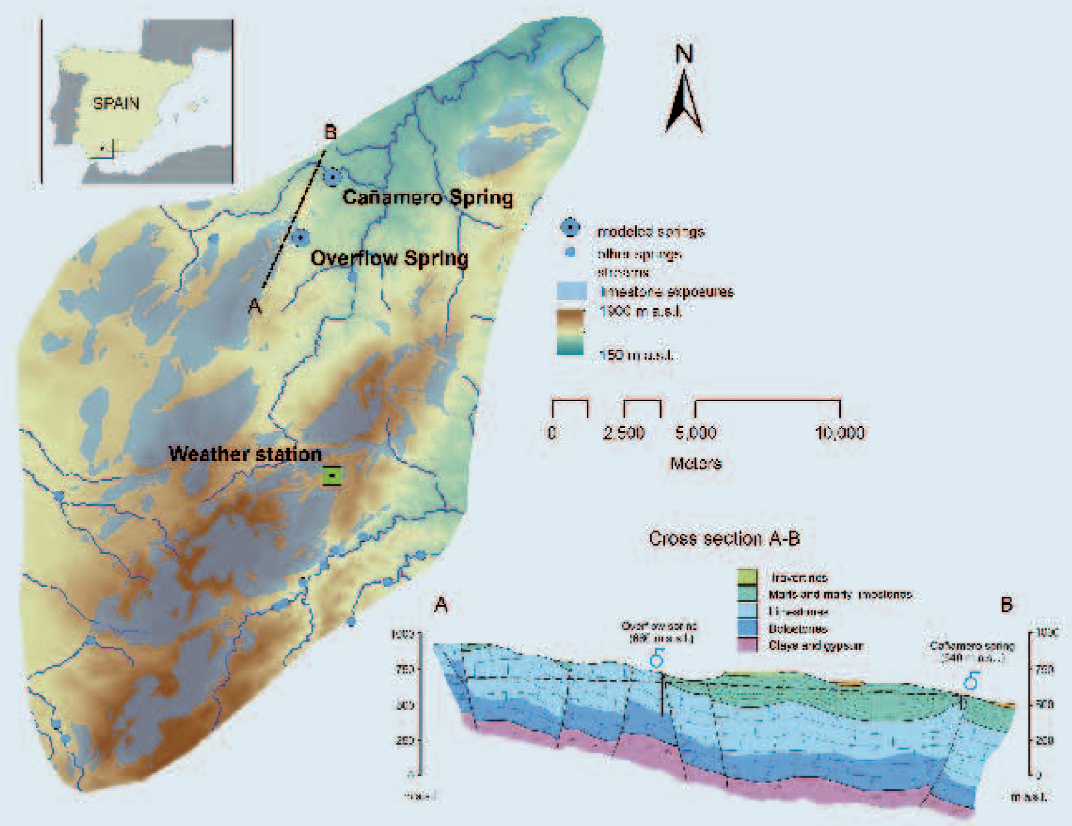
HYDROLOGY

1. Introduction

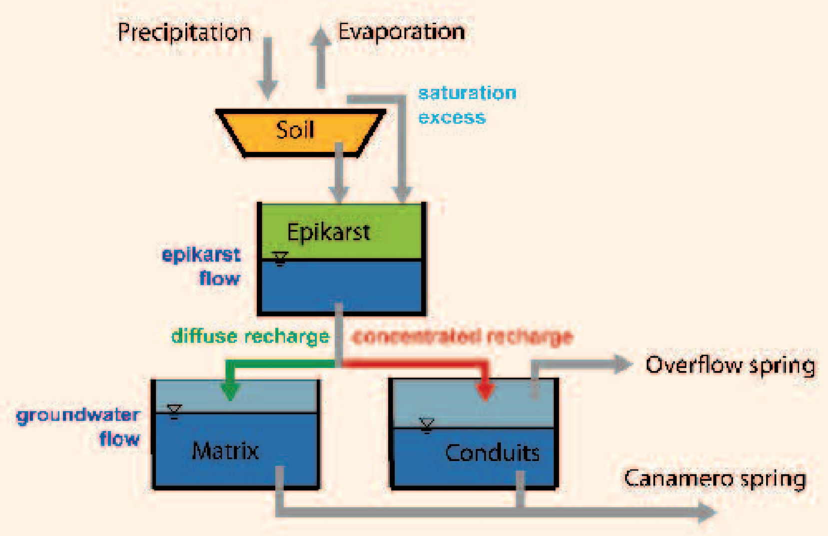
Time variant recharge areas are a particular characteristic of karst systems. Despite many field studies, that investigate processes causing variations of the recharge area, there are only few attempts to them into modeling. In this study we present a new process-based karst model that considers time variant recharge areas by including the variability of karst system properties. Applying a novel calibration strategy we compared the new model with a classical reservoir model at a well-studied karst system in Southern Spain.

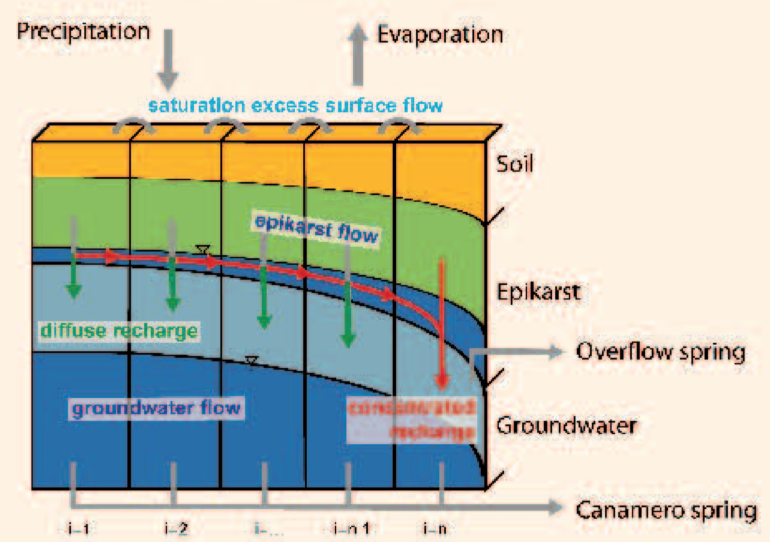
2. Study site



The spring "Manantial Cañamero" is located in Southern Spain in the Northwest of the city of Málaga. The aquifer is composed of Jurassic dolostones and limestones with a thickness of more than 500 m. Developed karst features like karrenfields and dolines can be found all over the area. In addition to the main spring, an overflow spring can be found about 120 m higher than the main spring.

3. The models





The calssical reservoir model consists of a combination of reservoirs that represent the karst system. The newly developed process-based model includes the variability of system properties by distribution functions considering the spatial variability of soil and epikarst depths, epikarst hydrodynamics, recharge separation (diffuse / concentrated) and groundwater hydrodynamics. The area contributing to recharge varies soil and epikarst storages are exceeded.

4. Calibration strategy

For calibration we used an automatic routine (SCEM) and the Kling-Gupta-Efficiency (KGE), which is defined as:

$$KGE = 1 - \sqrt{(r-1)^2 + \left(\frac{\sigma_S}{\sigma_O}-1\right)^2 + \left(\frac{\mu_S}{\mu_O}-1\right)^2}$$

In a **first step**, the hydrodynmic behavior of the system was calibrated by a modified KGE:

$$KGE_{cr} = 1 - \sqrt{(r-1)^2 + \left(\frac{\sigma_S}{\sigma_O}-1\right)^2}$$

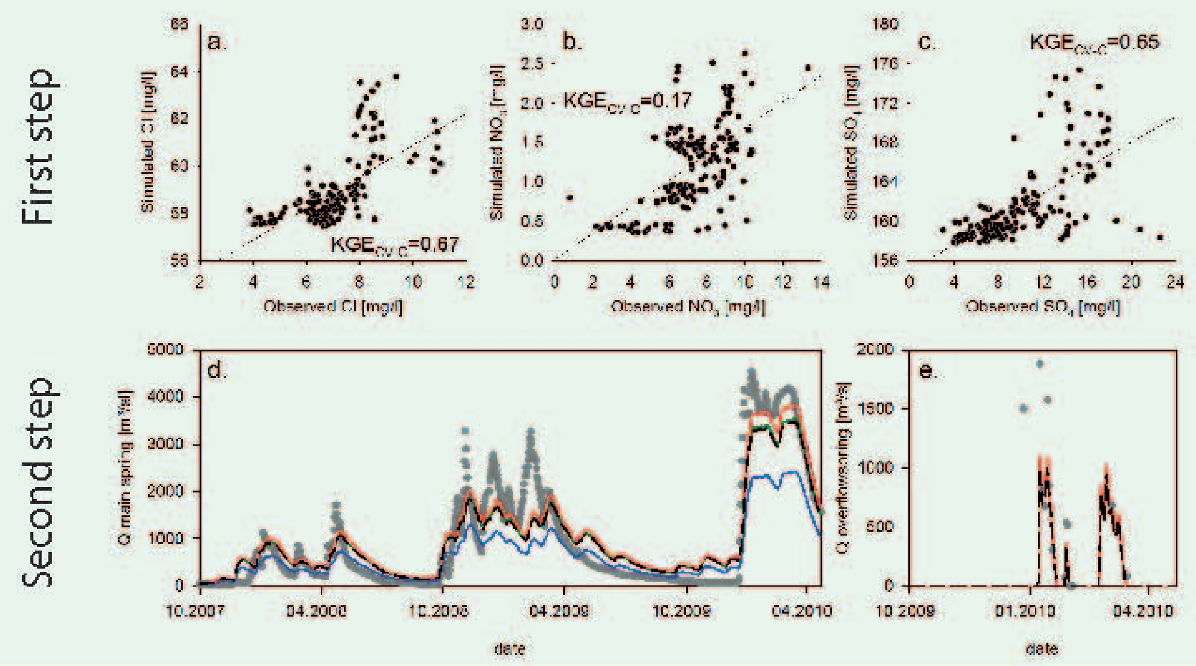
where r is the correlation coefficient and σ_S and σ_O are the standard deviations of simulations and observations. This was done simulatebously by discharge and selected solutes (Cl, NO_3 and SO_4) to improve parameter identifiability.

Modifying KGE again in a **second step**, the recharge area was found by: $KGE_\beta = 1 - \frac{\sigma_S}{\sigma_O}$

where μ_S and μ_O are the means of simulations and observations. That way, the parameter representing the recharge area was determined for individual years and once for the entire time period. For validation we applied the models and calibrated parameters on an additional time series of discharge observations beyond the calibration period.

5. Calibration results

Reservoir model

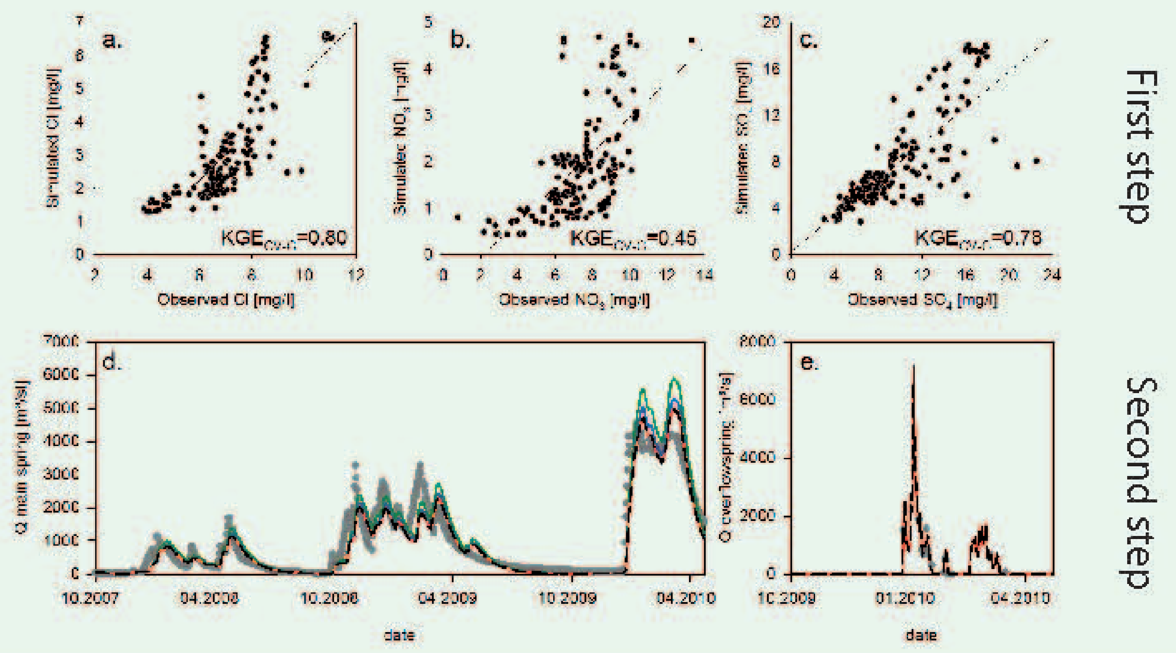


In the first step of the calibration, the performance of the reservoir model was much lower than the efficiency of the variability model when discharge and the selected solutes were considered. This indicated that the reservoir model had structural errors that prohibited the simultaneous simulation of discharge and hydrochemistry.

The second step of the calibration revealed that for the classical model the parameter representing the recharge area varied up to ~20 km² when individual years were considered. The new model showed much less variation in the recharge area (only up to ~10 km²).

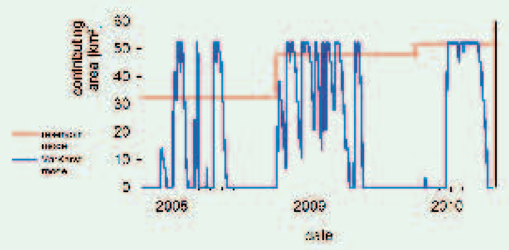
Hydrological year	Reservoir model		Variability model	
	A [km²]	KGE_β	A [km²]	KGE_β
1s year	32.8	0.57	49.3	0.94
2nd year	47.8	0.98	55.0	0.84
3rd year	51.7	0.91	46.1	0.98
whole period	46.9	0.81	46.1	0.96

Variability model



6. Simulation of variable recharge area

The variable model showed different variations of the water balance components than the reservoir model, especially in the second and third year. For instance, infiltration to the model compartments with deeper soil and epikarst storages was much more pronounced in the third year, as well as concentrated recharge.



The variable model achieves a better representation of the variable recharge area, because the deeper model compartments provide recharge only provide recharge under extremly wet conditions. During average conditions they hold the water and finally release it by evapotranspiration.

7. Model validation

For the validation period the variability model showed only a small decrease of performance compared to the calibration time period. The reservoir model failed completely during validation. Only when the recharge area of the driest year of the calibration period was used, a moderate performance was achieved.

A derived from	VarKarst model	Reservoir model			
	all years	all years	1st year	2nd year	3rd year
KGE (calibration)	0.90	0.72	0.42	0.74	0.77
KGE (validation)	0.78	0.00	0.42	-0.03	-0.18

8. Conclusions

This study compared the newly developed variability model with a reservoir model of similar complexity using observations of discharge and selected soultes, and a novel calibration approach. It revealed that

(1) it is possible to consider system dynamics and a variable recharge area separately when an adapted calibration strategy is applied,

(2) the new process-based model that includes the variability of karst system properties is superior to a classical conceptual model in terms of hydrological and hydrochemical system dynamics, as well as in reproducing the variations of the recharge area,

(3) a karst model that is not able to consider the effects of a variable recharge area may completely fail to predict future periods. The new model proved to be highly flexible under changing climatic conditions.

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