Sensitivity analysis of a distributed karst hydrological model at a Floridan karst aquifer

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Motivation & Objectives

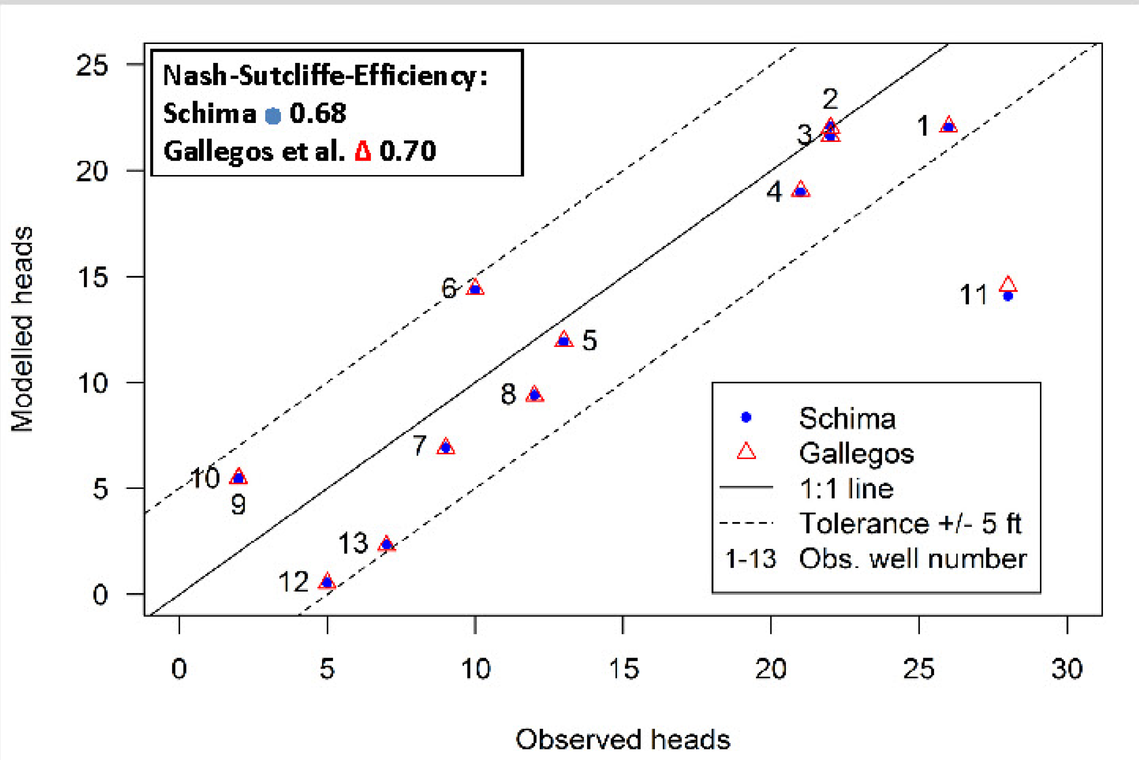
Karst aquifers are a significant source of drinking and irrigation water in many countries worldwide. For a proper water management, knowledge of the processes controlling the available amounts of water is crucial. A valuable to support water management are distributed simulation models. However, their input parameters are often subject to large uncertainties. Sensitivity analysis methods are able to analyze these uncertainties and to provide directions for uncertainty reduction. The aim of this study is to conduct a sensitivity analysis to rank the parameters according to their influence on the model performance. A spatial breakdown of the most influential parameters is supposed to additionally rank the most important regions of the simulation area.

Model & Data

The study uses an existing MODFLOW-CFP mode 1 model including discrete conduits and a porous matrix. It evolved over many years with several model versions by different authors. Input data and model parameters were derived from a steady-state model run by *Gallegos et al. (2013)* for one time period in 1991, published by *Kuniansky (2016)*. Observation data from three karst springs and 13 observation wells are available for that time.

Gallegos, J. J. , Hu, B.X., Davis, H. (2013): *Simulating flow in karst aquifers in laboratory and sub-regional scales using MODFLOW-CFP: Hydrogeology Journal, v. 21, no. 8, p. 1749-1760.*
Kuniansky, E. L. (2016): *MODFLOW and MODFLOW Conduit Flow Process data sets for simulation experiments of the Woodville Karst Plain, near Tallahassee, Florida with three different approaches and different stress periods: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7PK0D87*

Model evaluation

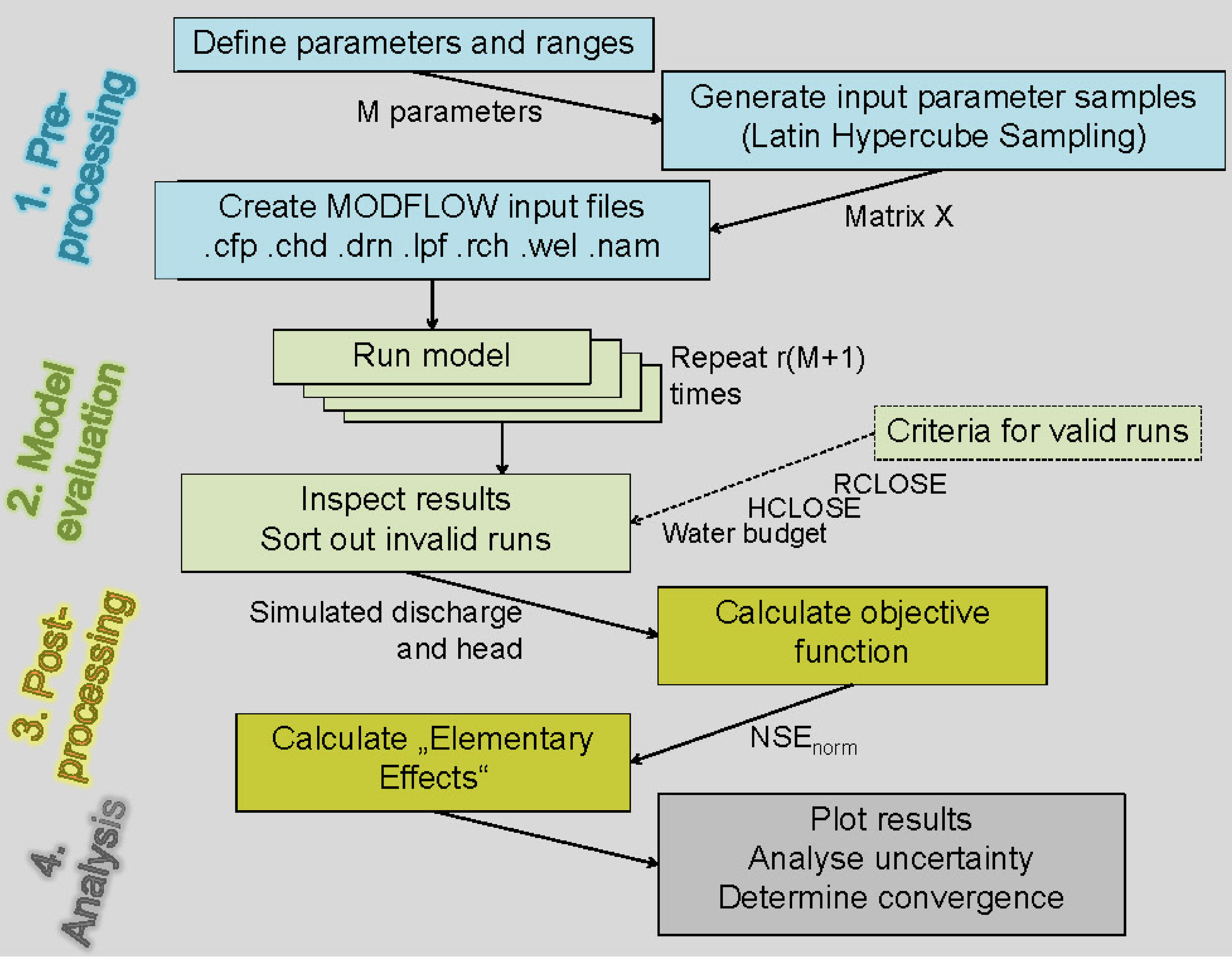


Method

With the given model and calibrated parameters, a sensitivity analysis was conducted using the *Elementary Effects* test (Morris' method). The sensitivity analysis results (hydraulic heads and spring discharges) were evaluated with the observations by the Nash-Sutcliffe-Efficiency (NSE). To compare both heads and discharges, their NSEs were standardized with their mean and standard deviation. With the resulting values NSE_{norm}, input parameter sets X for "initial" and altered points, and parameter range R, *Elementary Effects* EE of each parameter i were calculated:

$$EE_i = \frac{|NSE_{norm,i} - NSE_{norm,initial}|}{|X_i - X_{initial}|} \cdot R_i$$

The mean of all *Elementary Effects* for each parameter is the sensitivity index used for parameter ranking. Uncertainty ranges were derived with the bootstrapping method. The detailed workflow is given below:



Study site

The Woodville Karst Plain is located in northwest Florida, bordered by Tallahassee in the north and the Gulf of Mexico in the south. Topography is hilly with elevations not exceeding 200 ft. The general flow direction of the water is from the north to the Gulf of Mexico. The modelled layers represent the Upper Floridan Aquifer, which consists mostly of different limestones. Due to the geologic properties, there are many sinkholes, and an extensive submerged cave system and three major springs.

Woodville Karst Plain

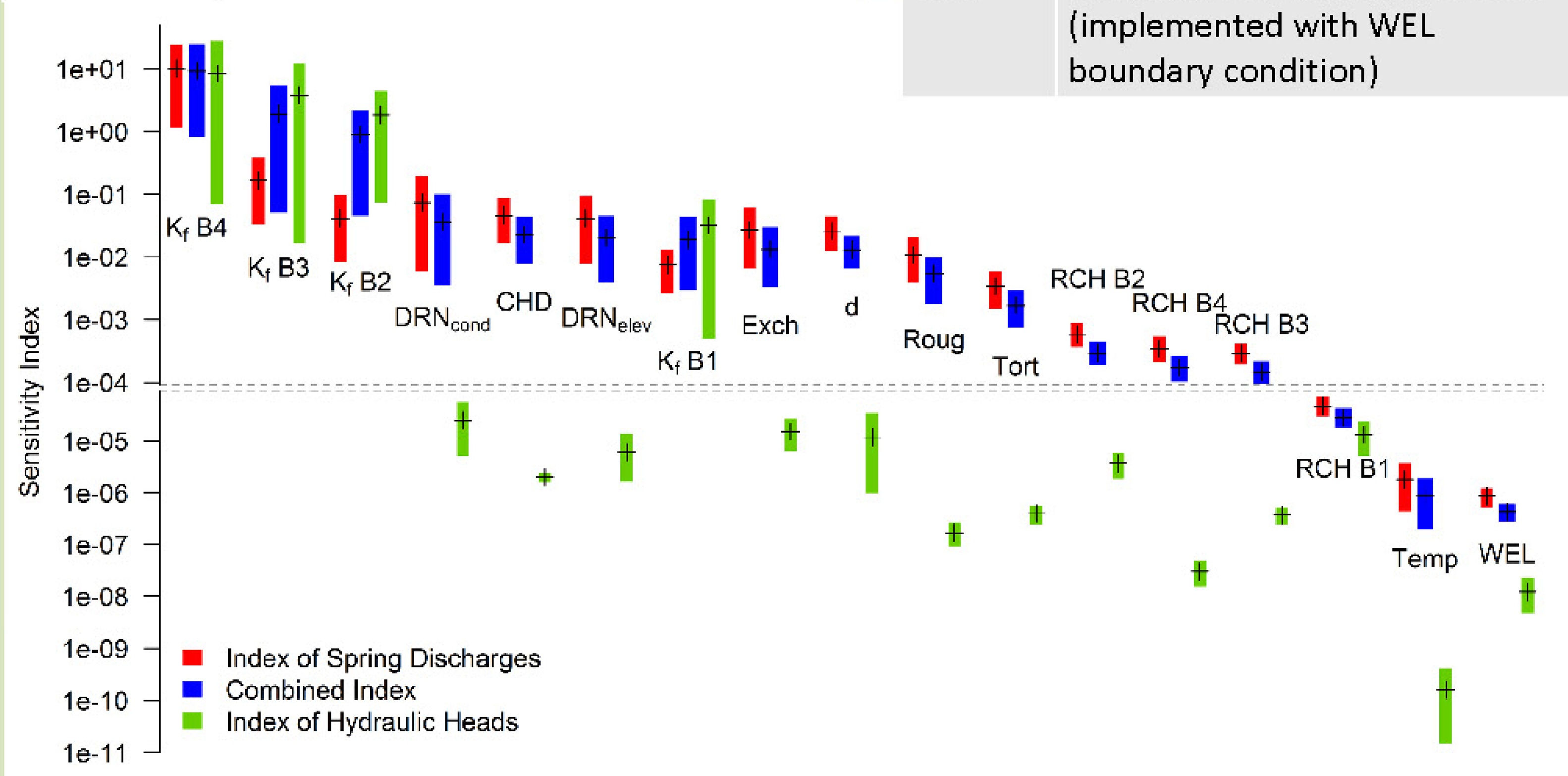
Open Street map, www.osm.org

Results

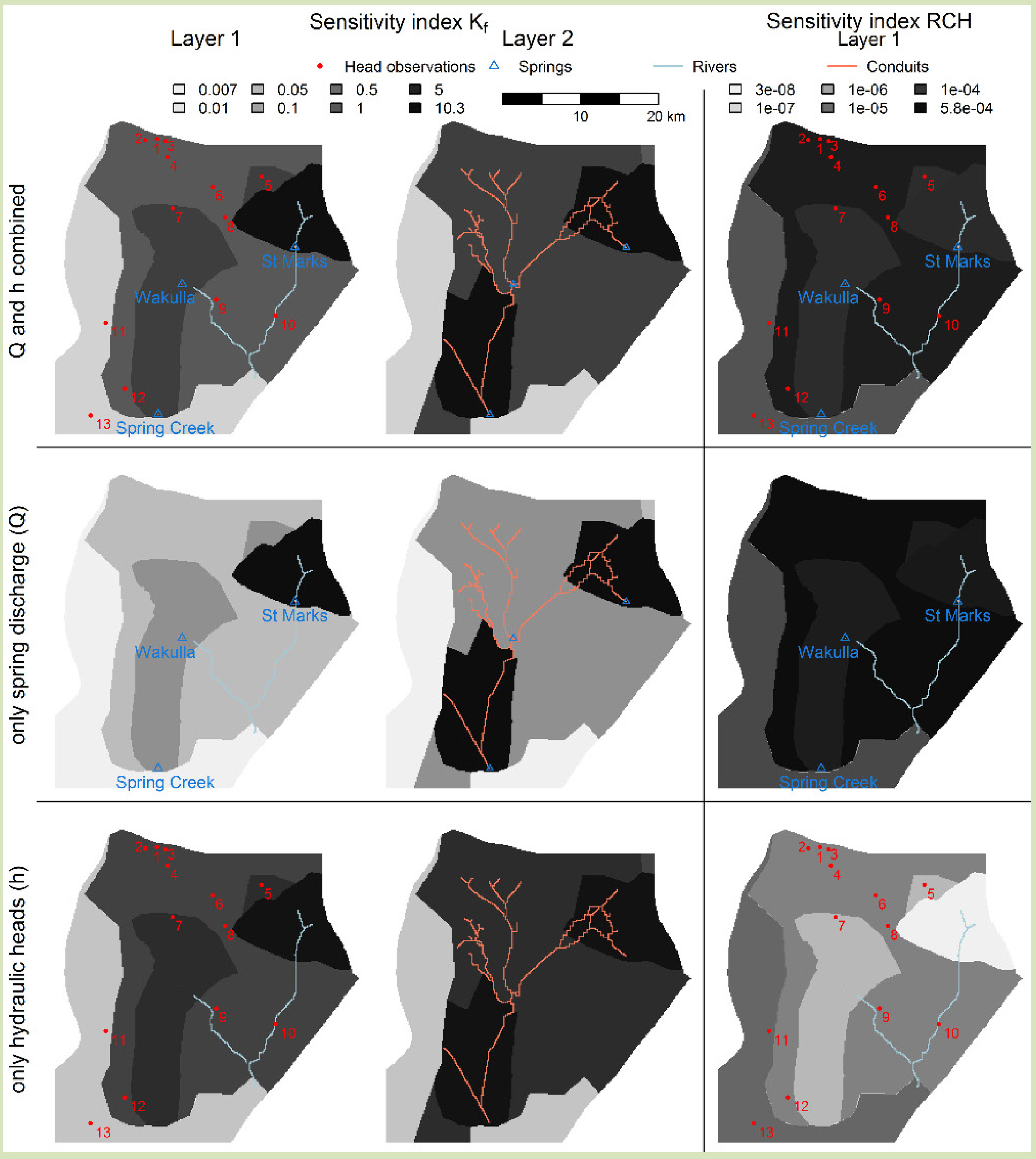
Pre-analysis showed that hydraulic conductivity (K_f) and groundwater recharge (*RCH*) were the most sensitive parameters over the entire area. Therefore, they were chosen to be split into four regions. Within the consequent spatial analysis, the most sensitive parameter for overall model efficiency is K_f in 3 regions, followed by the DRN and CHD boundary conditions. Parameters of the conduit system and recharge are less sensitive. While the ranking of discharge sensitivity is quite similar to overall sensitivity, the prediction of hydraulic heads is more strongly dominated by K_f, and less by RCH or CHD. Among the conduit parameters, Exch and d are most influential for hydraulic heads.

Variable	Explanation
K_f B1 – B4	Hydraulic conductivity in regions 1 to 4
RCH B1 – B4	Groundwater recharge in regions 1 to 4
DRN_{cond}	Conductivity of drains (representing rivers)
DRN_{elev}	Elevation of drains
CHD	Elevation of constant head boundary condition

Variable	Explanation
Exch	Exchange parameter between matrix and conduits
d	Conduit diameter
Roug	Conduit wall roughness
Tort	Conduit tortuosity
Temp	Water temperature
WEL	Various other recharge sources (implemented with WEL boundary condition)



Spatially distributed sensitivity indices of K_f and RCH for different output measures are shown below. The greater the K_f parameter value in one region is, the bigger is its sensitivity index. The hydraulic head sensitivity indices are generally higher than those for spring discharges. For RCH, sensitivity indices have a different pattern. Discharge indices are highest in regions that contribute to all springs' discharge, head indices are highest where model fit is worst.



Conclusion

The study shows that, under the assumption of steady-state conditions, hydraulic conductivity, boundary conditions and, to a lesser degree, certain conduit parameters are influential for the efficiency of a distributed groundwater model of the Woodville Karst Plain. Most notably, the contribution of different model regions varies. The spatial pattern of the regions' sensitivities strongly depends on the regarded output variable and the distribution of monitoring stations. **Consequently, the model performance obtained by NSE is dominated by the regions with high sensitivity and the capability of the model to provide reliable simulations at regions with low sensitivity remains questionable.**

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