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Assessment of aquifer recharge and groundwater availability in a semi-arid region of Brazil in the context of an inter-basin water transfer scheme

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S1. Hydrological model parameterization

The use of WASA (Model for Water Availability in Semi-Arid Environments) allows representation of the temporal variability of infiltrated rainfall by calculating rainfall infiltration and soil moisture redistribution at a daily time scale. This model also permits sub-dividing the study area into spatially-distributed modelling units, including different soil-land cover patterns, to account for the spatial variability of the hydrological behavior within a watershed.

WASA was parameterized by Costa et al. (2013) for the whole state of Ceará in Brazil. The model parameterization was organized through five different scales in cascade, as follows: sub-basin, landscape unit, terrain component, soil-land cover component and soil profile (Güntner and Bronstert 2004). It also considered the major reservoirs located at sub-basin outlets and the impact of small reservoirs on the simulated runoff within the sub-basins (Güntner et al. 2004). Costa et al. (2013) delineated 215 sub-basins for the state of Ceará based on the location of 155 major reservoirs, 13 streamflow gauges and major river confluences.

Their parameterization was adopted in this study. The area of the Medium Aquifer is covered by three WASA sub-basins (sub-basin IDs: 170, 172 and 186, Figure 3 in the main article). There is a streamflow gauge at the outlet of these WASA sub-basins. There are predominantly eight land-cover and eight soil types in these sub-basins (Costa et al. 2013), which produce a complex mosaic of soil-land cover patterns. Note that there are upstream sub-basins that can flow into the sub-basins 186 and 172 (Figure 3 in the main article). The inter-basin hydrological connectivity happens if the reservoirs at the outlet of these upstream sub-basins release water downstream. Reservoir releases occur during the dry seasons in order to allocate water downstream or during very moist rainy seasons due to uncontrolled spill overflow. Both processes were simulated by WASA in this study.

S2. Hydrological model calibration

For the three aforementioned sub-basins covering the area of the Medium Aquifer, WASA was run from January 1990 to December 2016, using the first five years as the model warm-up period. As the aim of the study was to model the regional groundwater flow over time periods of several years, the calibration of WASA primarily focused on the monthly time scale. Data available were daily discharge time series, measured at streamflow gauges located at the outlet of the sub-basins. Thus, the average river flow simulated by WASA was compared to the average river discharge at the streamflow gauge on a monthly basis.

The model was then calibrated to fit the simulations to the observations, by adjusting the saturated hydraulic conductivity and the porosity of the soil profiles in a manual trial-and-error process. These parameters are the most sensitive for WASA (Güntner 2002). It was expected that WASA would produce more runoff than that observed in the study area, since the state of Ceará is mainly composed of low permeability crystalline rocks, unlike the sedimentary formations comprising the Medium Aquifer. The soil parameters could therefore be adjusted to fit the hydrological conditions in the study area by gradually increasing the soil saturated conductivity and the porosity, generating more infiltration and less runoff.

The performance of WASA in simulating the monthly surface water processes was evaluated using the Nash-Sutcliffe efficiency (NSE), calculated for each sub-basin (170, 172 and 186). The best fit is the simulation resulting in the highest NSE (close to 1) for at least the two largest sub-basins, which cover the majority of the Medium Aquifer. After calibration, the simulated water balance was assessed to ensure that the model results were hydrologically realistic. Given the fact that the study area is located in the semi-arid region of Brazil, it was expected that about 70 to 80% of rainfall would be lost by evapotranspiration, 10 to 15% by runoff and about 5 to 10% lost as deep percolation into the deeper groundwater system (Ponce 1995).

S3. Outputs of MODFLOW parameter sensitivity analysis

Fig. S1 The head difference (m) between the simulation with adjusted hydraulic conductivity and without any parameter change at the end of simulation. Multiplied parameter factor equal to 0.1 (a), 0.25 (b), 0.5 (c), 0.75 (d), 1.25 (e), 1.5 (f), 1.75 (g), and 2.0 (h).

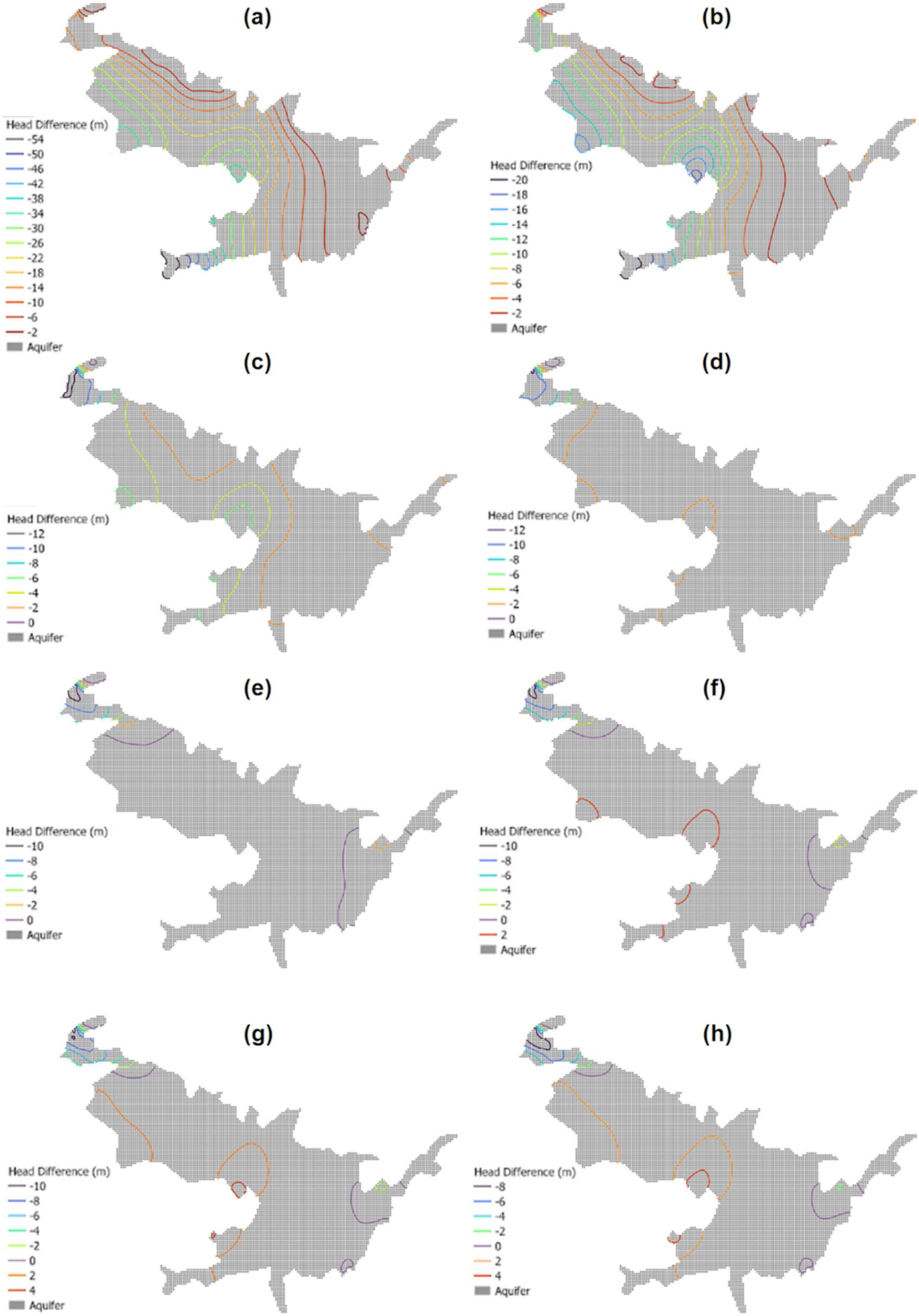

Fig. S2 The head difference (m) between the simulation with adjusted specific yield and without any parameter change at the end of simulation. Multiplied parameter factor equal to 0.1 (a), 0.25 (b), 0.5 (c), 0.75 (d), 1.25 (e), 1.5 (f), 1.75 (g), and 2.0 (h).

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