Predicting reservoir inflows with an advanced SWAT+ model calibration in the Tagus River headwaters (Spain)

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Abstract

The headwaters sector of the Tagus River in central Spain has been modelled with SWAT+, addressing a novel multi-spatial and multi-variable calibration process. The basin was divided into three geological regions, with Hydrologic Response Units (HRUs) parameterized independently for each of them. A soft calibration process was used to achieve realistic values for two crucial hydrological indices: the runoff coefficient and the groundwater contribution to streamflow, evaluated across eight subbasins. Satisfactory results from this phase were the basis for a subsequent hard calibration, aiming for both statistical adequacy and maintenance of hydrological indices within realistic ranges. Streamflow values were aggregated for reservoirs' watersheds, subject to double validation, revealing remarkable accuracy and realistic representation of hydrological processes in the catchment. This comprehensive approach, integrating detailed calibration and validation while considering spatial disaggregation at both geological and subbasin levels, ensures robust simulation of hydrological processes, particularly in geologically heterogeneous basins.

Introduction

The Tagus River, the longest in the Iberian Peninsula, faces significant management challenges due to high population density and water transfers to southeast Spain. The study focuses on the headwaters sector, starting from the Entrepeñas-Buendía-Bolarque reservoir system (Fig. 1). With a 50% inflow decrease over recent decades, largely due to climate change, understanding hydrological behaviour and predicting reservoir inflows are crucial for sustainable water management and thus we decided to apply the SWAT+ model (Bieger et al., 2017) in this region.

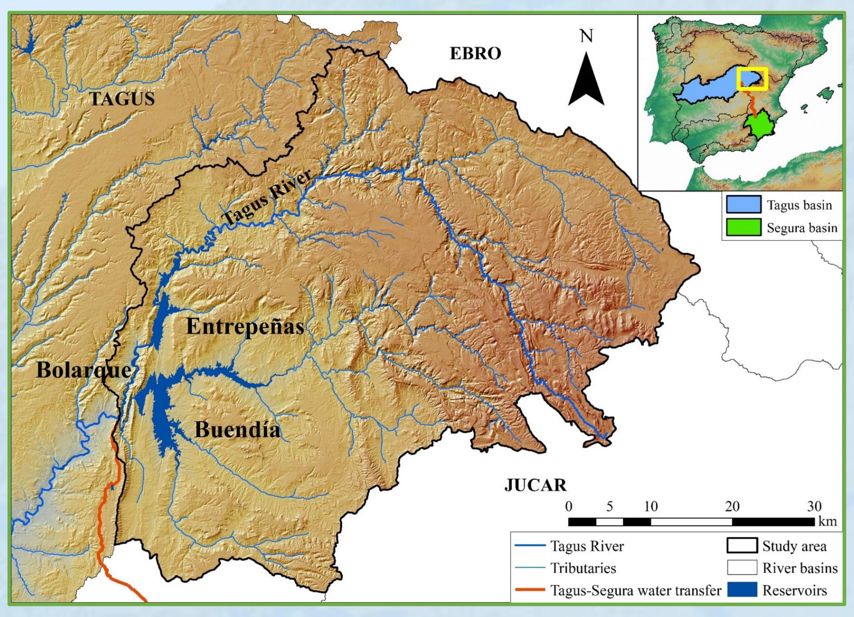


Fig. 1: Location of the headwaters of the Tagus River

Methodology

Subbasins and the stream network were delineated using a 25x25 m DEM, resulting in a model with 36 subbasins, 390 LSUs, and 197 channels. For HRUs definition, land use and soil type data were obtained from SIOSE, CORINE Land Cover, and DSOLMap, respectively, thus having 5463 HRUs (Fig. 2).

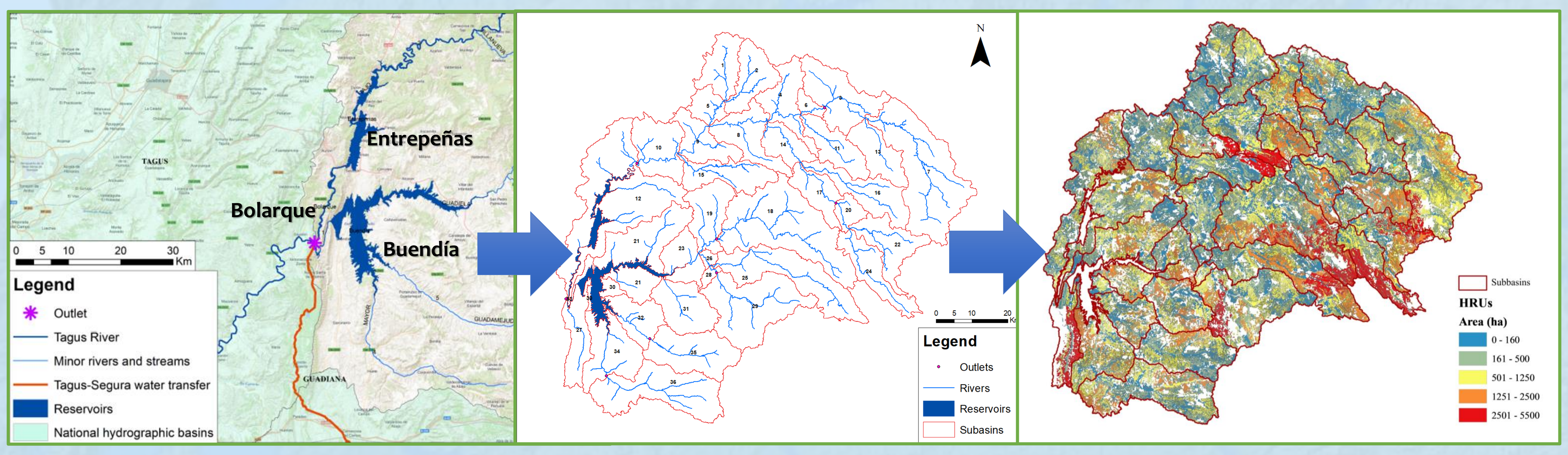


Fig. 2: Set-up scheme the SWAT+ model in the Tagus River headwaters

Eight subbasins were selected for model calibration. Five of them are in the Buendía Reservoir watershed and three in the Entrepeñas Reservoir watershed (Fig. 3). Each subbasin was assigned to a geological region (CRB: Carbonates, D-H: Detrital-High permeability and D-L: Detrital Low-Permeability. In addition, two key hydrological variables, runoff coefficient (RC) and groundwater contribution (GC, in fraction), were calculated for each region subbasin based on Sánchez-Gómez et al. (2024) (Table 1).

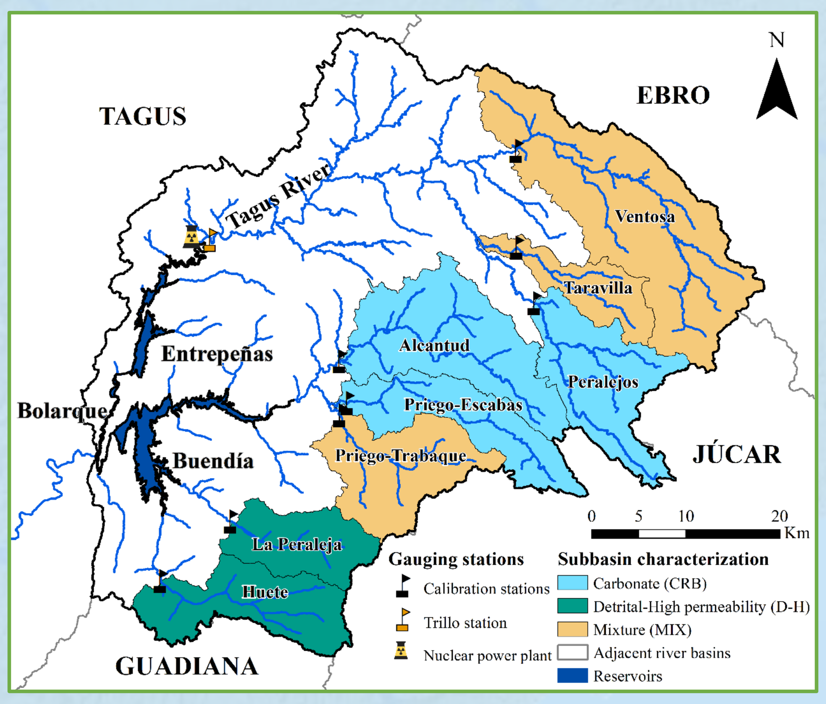
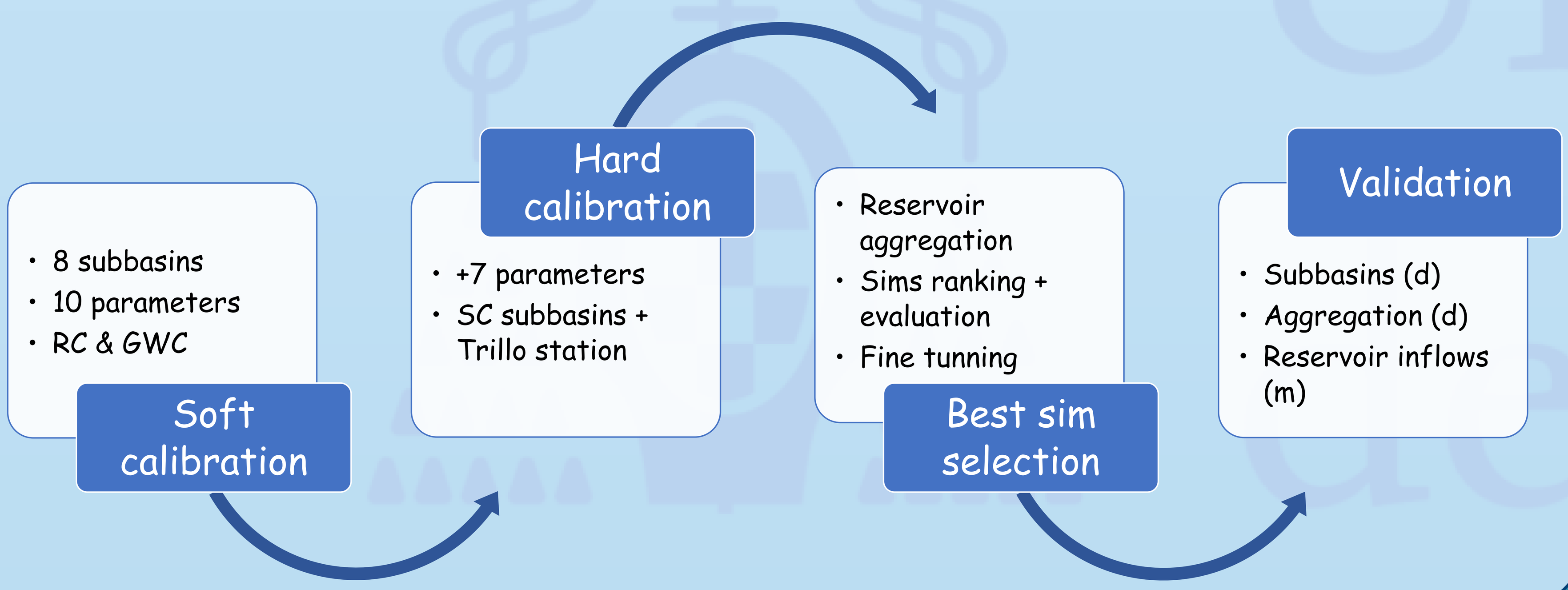


Fig. 3: Subbasins selected for analysis and their dominant geological region

Table 1: Estimated values of runoff coefficient and groundwater contribution for the geological regions

	CRB	DEA	MIX
RC	≈ 0.30	≈ 0.05	≈ 0.10
GC	≈ 0.50	≈ 0.35	≈ 0.50

Then, a zonal soft calibration was performed, which involved adapting parameters for each geological basin independently to achieve realistic values for the hydrological indices estimated. This was followed by the hard calibration on the streamflow records, checking performance metrics and ensuring also that the hydrological indices stayed within adequate values (Moriasi et al. 2015). The model was further evaluated on daily streamflow values aggregated for the reservoirs' watershed, and final best simulation was chosen based on overall performance, performing a double validation on monthly reservoir inflows.



Results

Figure 4 shows an example of parameter restriction during soft calibration for sensitive parameters in the three geological regions. Soil available water capacity (awc), perco (per) and parameters related to the curve number were the most sensitive for both indices.

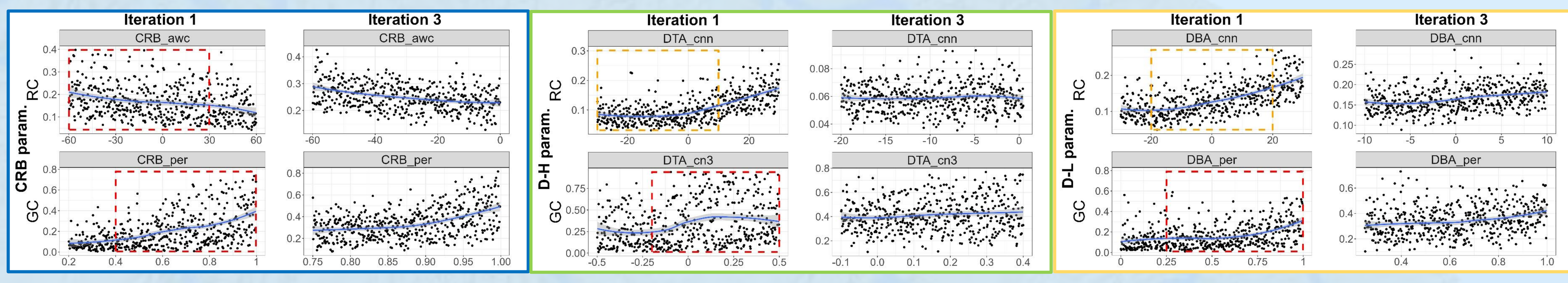


Fig. 4: Scatterplots of hydrological indices for soft calibration iterations 1 and 3 showing ranges restrictions for sensitive parameters

The soft calibration allowed to reach parameter ranges that simulated realistic values of the two hydrological indices in all the subbasins, thus becoming an ideal starting point for the subsequent hard calibration.

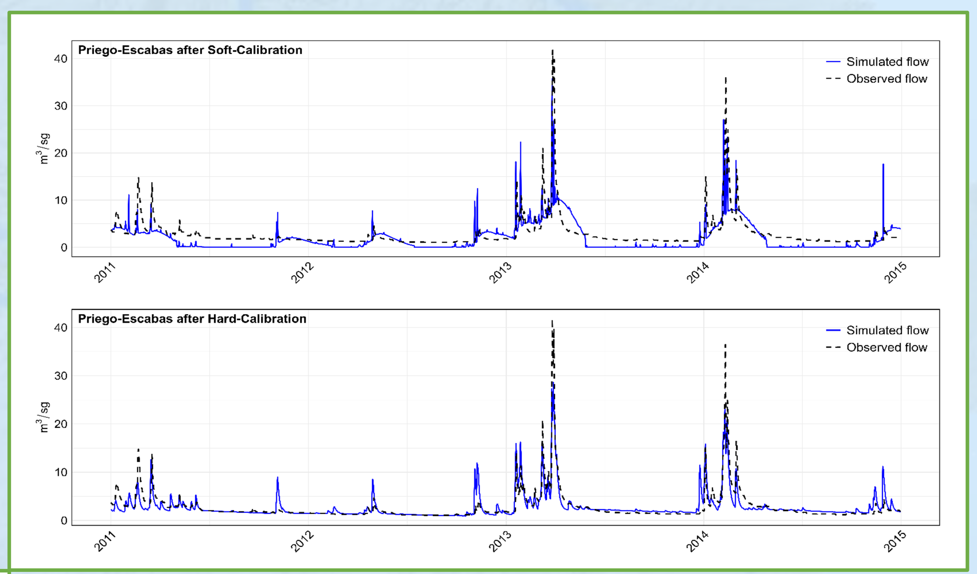


Fig. 5: Simulated flow in Priego Escabas (CRB subbasin) after soft calibration (above) and after hard calibration processes (below).

Satisfactory results were achieved after the hard calibration, ensuring that hydrological indices kept within realistic values and yielding a satisfactory streamflow adjustment in each subbasin (Fig 5).

Following thorough evaluation, 10 simulations were chosen based on performances in each sub-basin, and their evaluation on aggregated daily streamflow for the reservoirs' watershed yielded good results (Fig. 6).

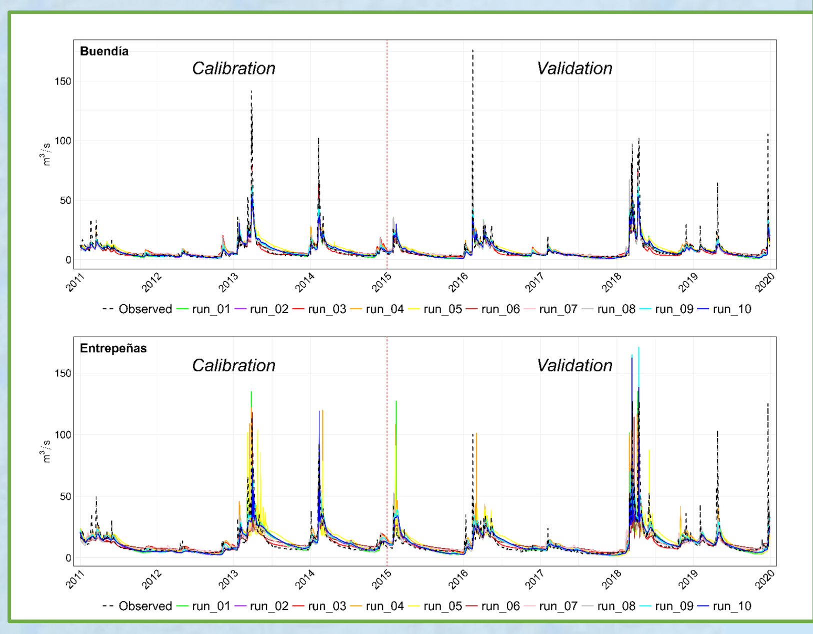


Fig. 6: Simulated hydrographs for 10 selected simulations for calibration and validation in Entrepeñas y Buendía

A final simulation that yielded both satisfactory metrics and a realistic simulation of the groundwater contribution to streamflow was chosen (Fig. 7). Afterwards, the double validation on monthly reservoirs' inflows showed very good performances (Fig. 8), yielding NSE, R^2 and PBIAS values for Entrepeñas of 0.86, 0.88 and 2.5%, respectively, and 0.89, 0.91 and -8.5% for Buendía, reinforcing the robustness of the calibration approach, which is innovative and has been proven useful to provide a realistic model in a geologically heterogeneous catchment. This innovative approach goes beyond previous modelling applications in the area, and could be helpful to guide future water management.

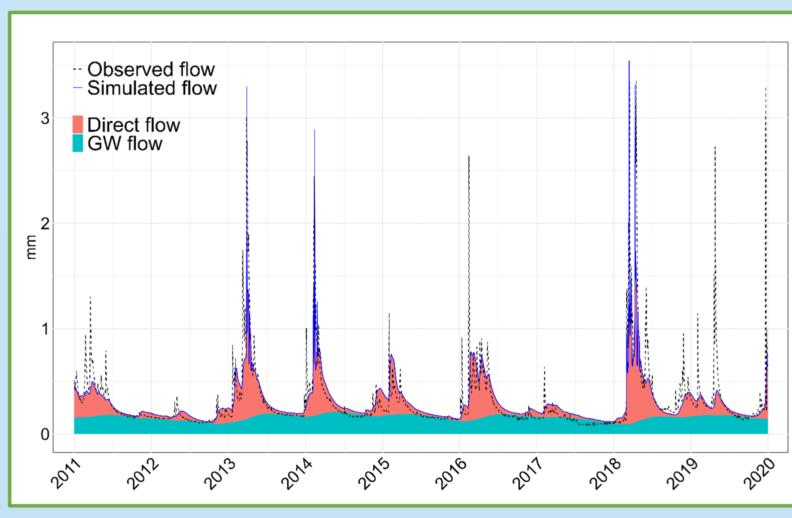


Fig. 7: Simulated hydrograph components after final validation of the model at the Trillo station.

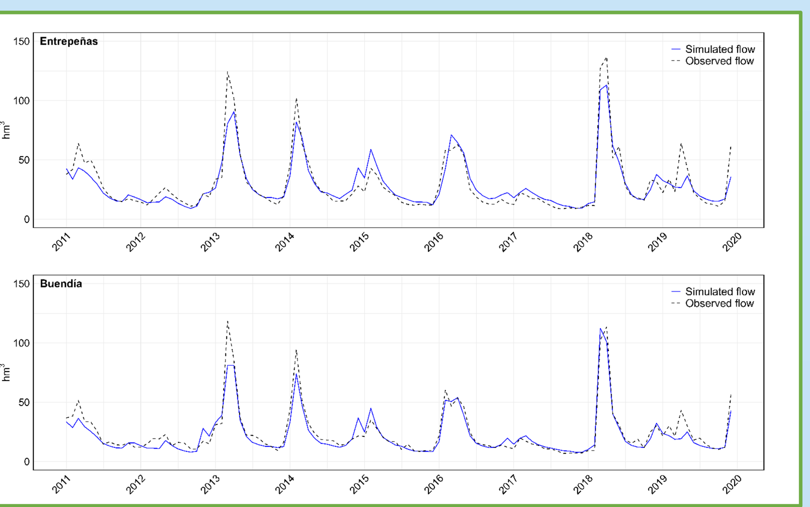


Fig. 8: Observed and simulated monthly inflows into Entrepeñas and Buendía reservoirs.

Conclusions

- A highly detailed SWAT+ model has been built for the Tagus River headwaters
- A complex calibration procedure has been designed, discretizing 3 geological regions to achieve a more realistic simulation
- Soft calibration optimized parameters towards realistic values of RC and GC
- Hard calibration was addressed for each subbasin and a best simulation was selected
- Double validation was performed and a robust and realistic model was achieved

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