

HRU definition in the model

According to the SWAT multiple HRU definition, threshold values are defined for the land use, soil, and slope data that are used to decide on the number and variety of HRUs in each sub-basin. Thresholds are used to eliminate minor land uses in each sub-basin. The remaining area is redistributed proportionally so that 100% of the land area in the sub-basin is modelled once the thresholds have been defined. The creation of HRUs as a function of the threshold area of soil and land use separation results in the omission of some important combinations that can have a major impact on hydrological processes in the catchment, such as surface runoff. This makes the model perform poorly and take a long time to calibrate. In contrast, a large number of HRUs can deal with a wide variety of land cover types. The use of small and comparatively homogeneous HRUs reduces the rate of error due to clustering effects (Geza and McCray, 2008). However, it results in a more complicated cost function and thus an increased probability of becoming stuck in local minima. In addition, the required computational time increases non-linearly with HRUs. In this study, the hierarchical HRU division approach was used to increase performance and reduce computational complexity simultaneously (Ozdemir et al. 2017). For hierarchical optimization, each sub-basin is divided into two HRUs and optimized with respect to some important parameters expected to significantly affect hydrological processes in the catchment. Each HRU is then further divided into two. Each of the child HRUs will inherit the optimal parameters of the parent HRU as its initial values. In this way, a reduction in the overall calibration time and a solution that is closer to the global minimum of the cost function are expected. To achieve this, based on some important parameters that have a significant impact on the water cycle, such as curve number, available water capacity, or bulk density, a completely different HRU generation algorithm was developed. HRU types were generated using MATLAB scripts by combining the standard curve number, standard soil hydraulic conductivity, and soil classification. In order to understand the performance of the HRU-type model, SUFI-2 was chosen as the calibration procedure. Model performance was controlled according to the Nash–Sutcliffe objective function. The number of HRU types was increased until acceptable results or a steady state was reached, depending on the assessment of NS and r^2 values. (Fig. 1)

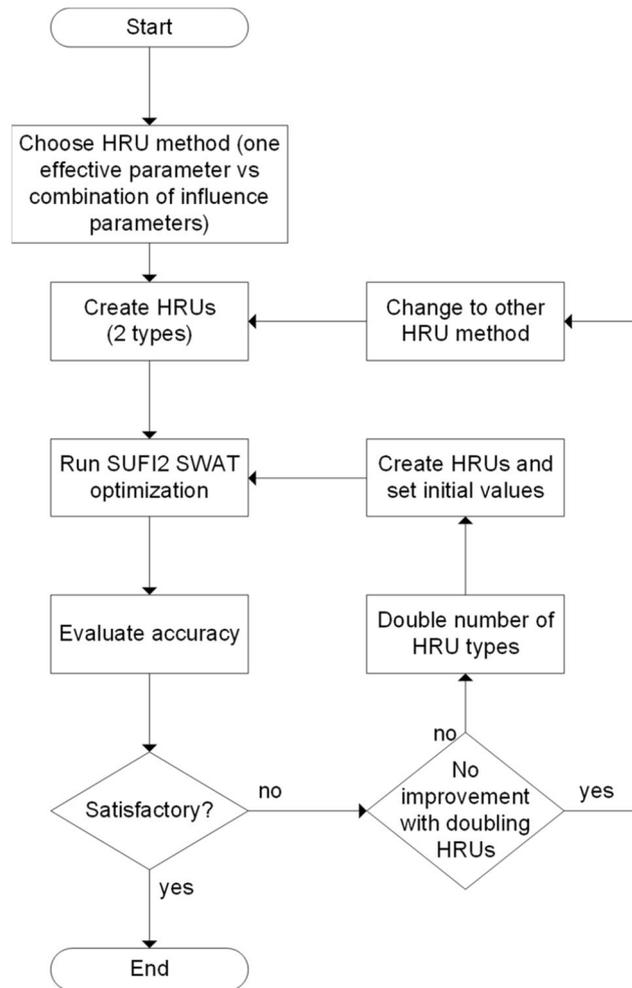


Figure S1. General concept of the hierarchical methodology (Ozdemir et. 2017).

Model setup and calibration

The current HRU creation method implemented in SWAT was used as the baseline to be compared to the hierarchical HRU division approach depending on the total HRU number in thirty-three sub-basins. Firstly, 187 HRUs in total were obtained (one in each sub-basin) using the dominant land use/land soil and slope combination approach. The uncalibrated model's performance, $r^2 = 0.49$ and $NS = -0.93$, improved to $r^2 = 0.66$ and $NS = -0.11$ after calibration. When the total HRU number was increased to 447 by using 20/20/60% threshold values for the land use/soil/slope combination, the performance of the uncalibrated model, $r^2 = 0.47$ and $NS = -0.94$, improved to $r^2 = 0.67$ $NS = -0.13$ after calibration. Finally, when 10/10/80% threshold values for the land use/soil/slope combination were used, the total number of HRUs was 1866. The performance of the uncalibrated model, $r^2 = 0.48$ and $NS = -0.97$, improved to $r^2 = 0.68$ and $NS = -0.13$ after calibration.

In order to find reasonable model results, after trying several different parameter combinations to generate HRUs, CN2, slope value, and soil-saturated hydraulic conductivity (SOL_K) parameters were used to generate the HRUs based on the basin's own properties (Fig. 2). The average standard deviation and median statistical values for CN2, slope class, and soil-saturated hydraulic conductivity were used to decide the classification of HRUs. The combination of $CN2 > 70$, $SOL_K > 10.15$, and a slope class of less than 45% formed the first HRU type. The second type of HRU was generated via combination with another value of these values. The

first HRU type was divided into two subtypes by merging the values of $CN2 \geq 80$, $SOL_K > 33$, and $slope_class < 15$, as well as the opposite values of these parameters. For the second category, the HRUs were further subdivided into two groups. This process continued until the optimum HRU types were identified in a hierarchical manner, as shown in Figure 4. The model was calibrated based on HRU type using FACT with 200 simulations per iteration.

Using this method, each of the thirty-three sub-basins was divided into two HRUs (two-HRU type). Sixty-six HRUs were obtained. The performance of the uncalibrated model, $r^2=0.42$ and $NSE = 0.114$, improved to $R^2=0.45$ and $NSE=0.40$ after calibration.

In the second step, each of the two HRUs above was further divided into two HRUs (four-HRU type) resulting in a total of 129 HRUs. The performance of the uncalibrated model, $r^2= 0.40$ and $NSE=0.35$ improved to $r^2=0.45$ and $NSE=0.43$ after calibration.

In the third step, the four-HRU-type model was run with the calibrated parameters of the two-HRU-type model (eight-HRU-type; 187 HRUs were obtained) and obtained initial results, $r^2=0.45$ and $NS=0.36$, that improved to $r^2 = 0.43$ and $NS = 0.42$ after calibration.

In order to find the optimum HRU number, the HRUs in the eight-HRU-type model were further divided into two HRUs, resulting in the sixteen-HRU-type model. The accuracy of the sixteen-HRU-type model without including calibration processes was initially $r^2=0.39$ and $NS=-0.032$, which was calibrated to produce $r^2=0.33$ and $NS=0.19$. Introducing the calibrated parameter values of the four-HRU model into the eight-HRU model, the initial run gives $r^2=0.43$ and $NS = 0.42$, and the calibration gives $r^2 = 0.33$ and $NS = 0.19$, showing that they do not improve on the previous results (Table 1). When we compared the results, eight HRUs gave us optimum HRU numbers (Table 1). Furthermore, when the calculated nutrient loads were compared with the observed measurements based on the hierarchical HRU division methodology, eight HRU types presented the best simulation results.

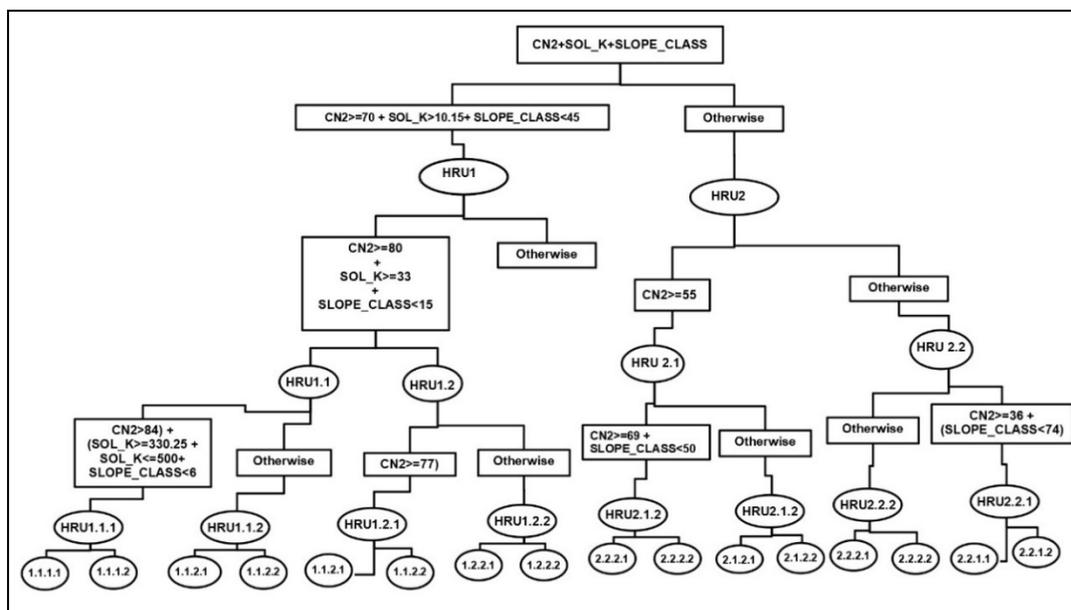


Figure S2 HRU generation by combining CN2, soil hydraulic conductivity, and slope classification.

Table S1. Summary flow results of HRU division for the Gordes Dam.

Method	Total # of HRUs	Initial model R², NSE	After Calibration R², NSE
Arcswat (dominant land use/slope/soil)	187	0.49; -0.93	0.66; -0.11
Arcswat (20/20/60% threshold values for land use/soil/slope)	447	0.47; -0.94	0.67; -0.13
Arswat (10/10/80% threshold values for land use/soil/slope)	1866	0.48; -0.97	0.68; -0.13
2 HRU types	66	0.34;0.11	0.45;0.40
4 HRU types	129	0.41;0.35	0.45;0.43
8 HRU types	187	0.45; 0.36	0.43;0.42
16 HRU types	274	0.39; -0.032	0.33;0.19
32 HRU types	447	0.30; -0.021	0.28;0.14

The model's performance is good in the hydrological processes when the hierarchical approach for HRU division in SWAT is used. Land use/land cover in the basin with similar hydrological properties was generalized in this approach. However, the study aimed to identify appropriate crop patterns in drinking water basins. Therefore, the hierarchical approach and current SWAT HRU definitions were combined to reduce computational time and to not ignore crop patterns when defining HRU numbers in SWAT. After applying the hierarchical approach to HRU division based on the method of Ozdemir et al. (2017), eight HRUs (eight-HRU type; 187 HRUs were obtained) gave us the optimum HRU number. Thus, the target total number of HRU types in ArcSWAT was assigned as 187, and nine crops (CORN, POTA, TOBC, WWHT, WBAR, POPY, CUCM, SGHY, and SESA), pastures, forest areas, and olive trees were defined as land use threshold exemptions. After defining the crop types in the HRU generation in the ArcSWAT, a total of 764 HRUs were created for 33 sub-basins.

The initial model results for hydrological processes are NSE=0.54 and R²=0.76 between 1979 and 1996 (Fig. 3a). The initial model results for nutrient transport are NSE=0.54 and R²=0.54 between 2000 and 2013 (Fig. b).