COMPARISON OF THE VARIANCES OF A LUMPED AND SEMI-DISTRIBUTED MODEL PARAMETERS

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The accurate modelling of discharges in catchments plays an important role in solving a large variety of water management tasks. Three basic errors may affect the outputs modelled: the quality of the input data, uncertainities about the parameters, and the structure of the model. This paper is focused on a comparison of the performances of the lumped and semi-distributed versions of the conceptual TUW rainfall-runoff model, which represents two different model structures. The comparison took place on 180 Austrian catchments, which have variable morphologies, altitudes, land uses, etc. We focused on the variability of the efficiencies and parameters of both types of HBV models, which were calibrated based on discharges in the period from 1991 to 2000. Whether the morphology and mean elevation of the catchment affect the calibration results was also take in account. Finally, we realized that the semi-distributed version of the TUW model gave better results as to the calibration efficiencies, when we calibrated the model for discharges; at the same time, the variations in the model parameters also gave better results in the semi-distributed version of the TUW model.

KEY WORDS: HBV model, model parameters, model efficiency, Austrian catchments

Introduction

Hydrological models are a useful tool for estimating various hydrological phenomena. Due to the continuing development of computer technologies in recent decades, models have become an important tool in hydrology and water management practice (Jeníček, 2012). However, with the increasing number of hydrological models, there is an ongoing problem concerning the right choice of the type of the model. Many authors have discussed this problem, see (e.g. Jeníček, 2005; Beven and Freer, 2001; Buchtele, 2002; Kulhavý and Kovař, 2002; Bergström, 1995, etc.).

Hydrological modelling involves multiple steps, each of which can be associated with uncertainties in the calibration of the model. There are three main errors, i.e., the model´s structure, uncertainties about the parameters, and uncertainties about the input data, that influence the correct selection and operation of the model. In our study, we compared two types of HBV models with different structures to determine which model structure better fits the selected region. We have also focused on the hypsometric characteristics of the catchments and how they affect the calibration of lumped and semi-distributed rainfall-runoff models.

In this paper, we calibrated the conceptual lumped version of the "Technische Universität Wien" (TUW model) and the dual-layer semi-distributed TUW model. We calibrated the models for the instrumental period of 1991–2000. We have compared the efficiencies between the lumped and semi-distributed versions of the TUW model, and we also observed the variances in the parameters and how the hypsometric characteristics of the catchments affect the results of the calibration.

Methods

In the study, we applied the two types of HBV model, i.e., the lumped TUW model and the semi-distributed TUW model (Parajka et al., 2007; 2009). The main difference between the lumped and semi-distributed versions is that the inputs in the semi-distributed version are divided into 200-meter hypsometric zones (1. Zone 0–200 m a.s.l., 2. Zone 200–400, etc.). In Fig. 1 we can observe the structure of the TUW model.

The TUW rainfall-runoff model is frequently used for solving many hydrological problems (e.g., flood predictions, estimations of droughts, or duration of floods). Input data for rain, the air temperature, and potential evapotranspiration were used to calibrate both models. The model consists of three submodels: a snow submodel, a soil submodel, and a runoff formation submodel. The snow submodel simulates the accumulation of water from melted snow and contains the following parameters: snow correction factor-(SCF), degree day factor-(DDF), and threshold temperature limits for rain-(Tr), snow-(Ts), and melting snow-(Tm). The soil submodel simulated the processes in the soil part of

the catchment. This submodel contains the following parameters: limit of potential evaporation-(Lprat), field capacity-(FC), and (BETA)-non-linear parameter for the formation of runoff (Table 1).

The runoff formation submodel simulated the surface and underground runoff. This submodel contains the following parameters: (K0, K1, and K2): parameters for the surface, underground and base runoff; (Bmax)-maximum base at low flows; (Lsuz)-threshold for the storage state, i.e., the very fast response start if the Lsuz is exceeded; and the (Croute)-free scaling parameter. The Deoptim differential evolution algorithm (Sleziak et. al., 2017), was used for the calibrations in this work. The range of the model for the parameters was estimated by Merz (Merz et al., 2011) using a daily time step.

Input data

The calibration was run on the 180 catchments selected for the whole territory of Austria. The catchment areas varied from 14.2 km^2 to 6214 km^2. The runoff in these catchments is not affected by dams, canals, or any other transformations from another catchment. For the lumped TUW model version we used input data (rainfall, runoff, potential evaporation, air temperature) in daily time steps from the period 1.1.1991 to 31.12.2000. These data were interpolated from measurement stations across Austria (Sleziak et al., 2017). The rainfall data were interpolated from 1091 stations by the method of external drift kriging. The runoff data were from 180 gauged stations (Austrian Hydrographical Service). The potential evapo-
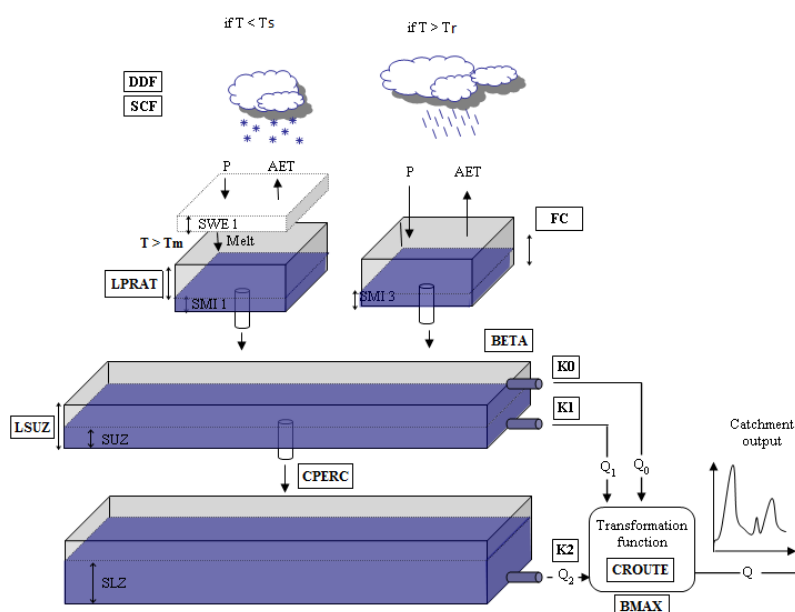

Fig. 1.   Schematic description of the TUW model (Sleziak, 2017).

Table 1.   TUW model parameters (Merz et al. 2011)

Abbreviations	Description of the model parameters	Range
1. SCF	snow correction factor	0.9–1.5 [-]
2. DDF	degree day factor	0.0–5.0 [mm degC^{-1} day^{-1}]
3. Tr	threshold temperature above which precipitation is rain	1.0–3.0 [degC]
4. Ts	threshold temperature below which precipitation is snow	-3.0–1.0 [degC]
5. Tm	threshold temperature above which melting starts	-2.0–2.0 [degC]
6. Lprat	parameter related to the limit for potential evaporation	0.0–1.0 [-]
7. FC	field capacity, i.e., max soil moisture storage	0–600 [mm]
8. BETA	the non-linear parameter for runoff production	0.0–20.0 [-]
9. K0	storage coefficient for a very fast response	0.0–2.0 [days]
10. K1	storage coefficient for a fast response	2.0–30.0 [days]
11. K2	storage coefficient for a slow response	30.0–250 [days]
12. lsuz	threshold storage state, i.e., start of the very fast response if exceeded	1.0–100 [mm]
13. cperc	constant percolation rate	0.0–8.0 [mm day^{-1}]
14. bmax	maximum base at low flows	0.0–30.0 [days]
15. croute	free scaling parameter	0.0–50.0 [days^2 mm^{-1}]

ration data were calculated with the Blaney-Criddle method (Parajka, 2009).

The rainfall and air temperature input data for the semi-distributed TUW model version were from the Spartacus database (Hiebl et al., 2016) and were interpolated into the hypsometric zones by 200 vertical meters, also potential evaporation was calculated with the Blaney-Criddle method in hypsometric zones by 200 m. The runoff data were the same as the input data for the lumped TUW model version; we used the discharge data from the 180 gauged stations, which were provided by the Austrian Hydrographical Service. The calibration period was set for the period 1991–2000 because of a data overlap.

For a better comparison of the results, we finally divided the catchments into two groups (Sleziak, 2017). The first group includes catchments where the major contributor to the runoff is water from rain; this group we called the "Lowland" type. The second group includes catchments where there is a significant part of runoff from water from melted snow or glaciers; we called it the "Alpine type". In Fig. 2 we can observe selected catchments, divided by hypsometric characteristics.

Results and discussion

One of the major difficulties of calibrating rainfall-runoff models is that these models generally have a large number of parameters that cannot be directly obtained from measurable quantities of catchment characteristics; this is especially true when we have a large area of interest or want to calibrate more catchments at the same time. This is why we focused on comparing the variability in parameters between both the lumped and semi-distributed versions of the TUW model. We compared all 15 model parameters. In Fig. 3 we can see the variance in the parameters that affect the snow submodel of the TUW model. As can be seen, the semi-distributed version of the model gives us better results with regard to the parameter variances.

Fig. 4 represents the variance in parameters that affect the soil submodel of the TUW model. We can again observe that the variance of the semi-distributed model is smaller and that the model gives us better results than the lumped version of the TUW model.

In Fig. 5 we can observe the differences in the values of the parameter variances of the flow submodel. However, we can observe that parameters K1 (the storage coefficient for a fast response) and croute (free-scaling parameter) give us better results in the lumped version of the TUW model. The other five parameters showed less variance in the semi-distributed version of the TUW model as in the snow and soil submodels.

The objective function was used to select the best set of the parameters. Nash-Sutcliffe efficiency (NSE) and Nash-Sutcliffe efficiency logarithm (logNSE) criteria were used to determine the runoff model efficiency (RME) of the model´s performance. NSE is sensitive to high peaks, log NSE for lower discharges, and the RME represents the average of NSE and log NSE.

In Table 2, we can see the RME results, which show that the semi-distributed version of the TUW model gives us better results for the calibration efficiencies, due to the hypso-metric characteristics of the catchments. We can observe that the average improvement in RME is 0.137 in the Alpine catchments and 0.119 in the lowland catchments.

Fig. 6 represents the spatial distribution of the catchments; the circles represent catchments with lowland characteristics, and the triangles represent catchments with Alpine characteristics. As can be seen, the red colour points are catchments with a RME value lower or equal to 0.60, and the green points are catchments with a RME value higher than 0.60.
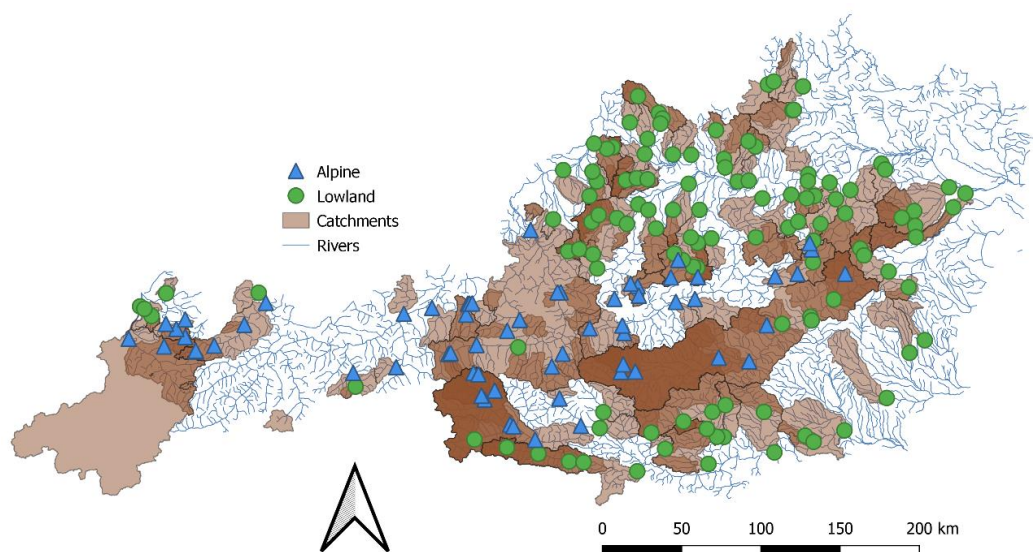

Fig. 2.   Selected Austrian catchments, Blue – alpine, and green – lowland catchments.
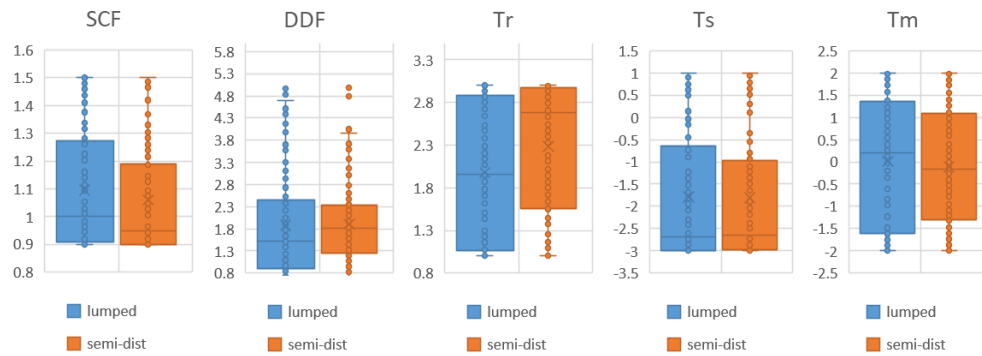
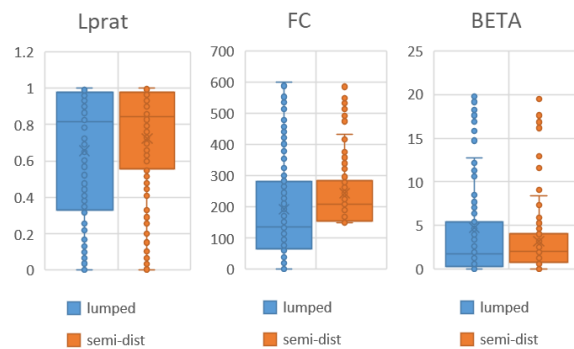Fig. 3.   *The variance in parameters belonging to the snow submodel.*

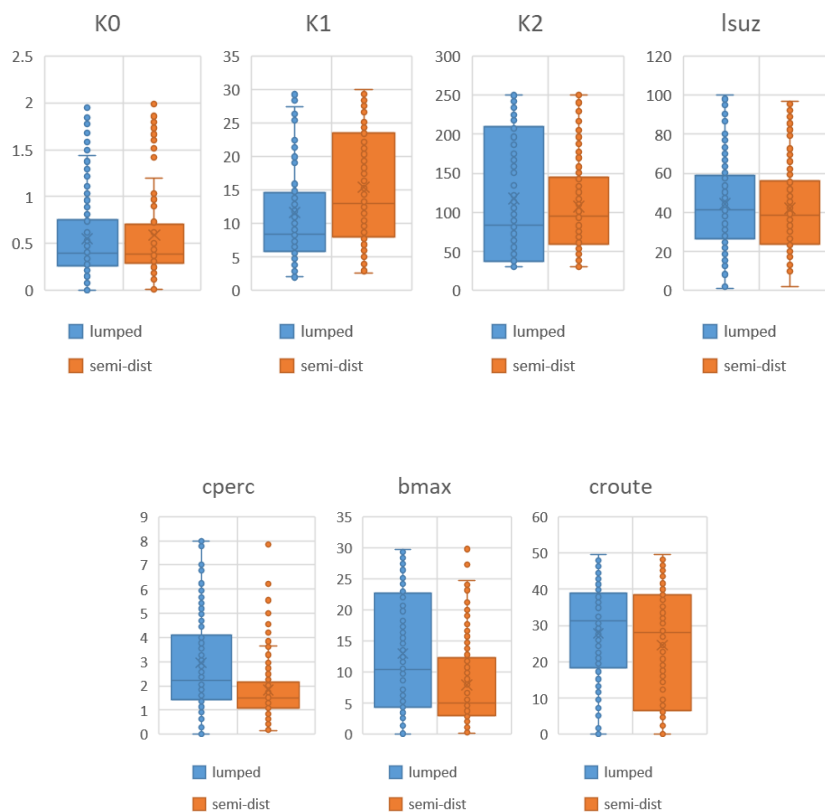Fig. 4.   *The variance in parameters belonging to the soil submodel.*

Fig. 5.   *The variance in parameters belonging to the flow submodel.*

Table 2.   Results of the calibration efficiencies

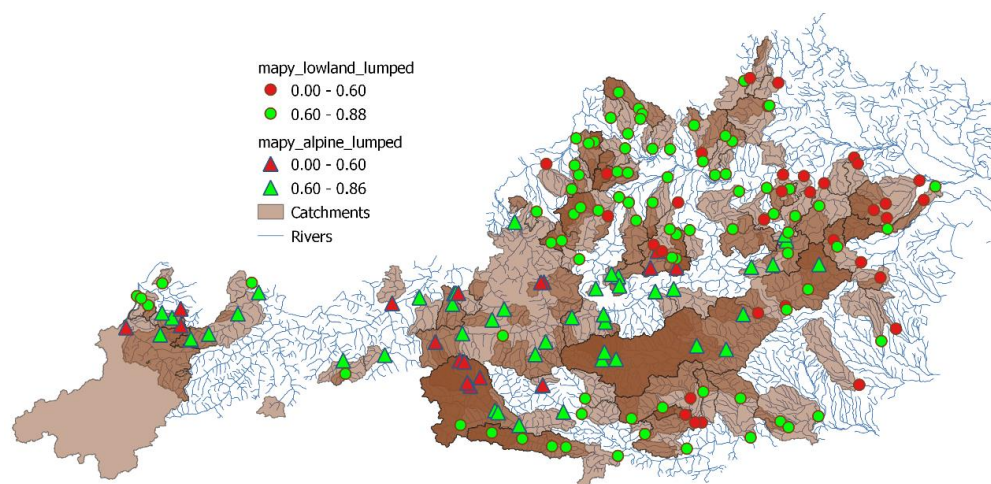| 180 catchments (1991-2000)	Lumped	Semi-distributed
RME median	0.650	0.787
RME median Alpine	0.673	0.833
RME median Lowland	0.642	0.761

Fig. 6.   Results of the calibration efficiencies, circles – lowland catchments, triangles – alpine catchments, RME ≤ 60 => red, RME > 60 => green colour

Conclusion

In this study, we focused on the calibration of two versions of the TUW model. We tested the performance of both models on 180 Austrian catchments in which discharges are not affected by hydraulic structures or other anthropogenic impacts. After the calibration of the model, we compared three indicators of the model´s performance:
-   Model efficiencies
-   Parameter ranges
-   Differences in model efficiencies due to hypsometric characteristics.

We determined that the semi-distributed version of the TUW model gave better results for all the criteria tested. We achieved better results in the model efficiencies and parameter resolutions, and we also determined that the semi-distributed version provided better modelling results in the Alpine (79%) catchments rather than the lowlands (65%). The main reason could be in the spatial distribution by elevation zones of the semi-distributed model, which provided a better and more detailed resolution of the input data than the input data in the lumped version of the model.

Due to the results achieved, we recommend the use of the semi-distributed version of the TUW model in this geographical area. In the future we plan to focus on the performance of the model in the validation period.

Acknowledgment

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