Uncertainties of low-flow indices estimation based on continuous simulation hydrological using data resampling.

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Estimating low-flow indices, seasonality and mean annual runoff is of paramount importance to manage water resources and risk assessments. These indices are derived from time-series of river discharges which are measured at gauged sites over long periods. Other strategy consists to use a rainfall-runoff model, taking into account climate variability and which parameters can be regionalized to provide simulated flows, from which any low-flow indices can be estimated at ungauged sites. The results of these different approaches are associated with uncertainties that are sometimes difficult to estimate due to the complexity of the method, especially for process simulation. Uncertainties coming from using hydrological model and from purely statistical approaches are compared.

This study was conducted on daily discharge data came from the French Hydro database (www.hydro.eaufrance.fr). They were chosen following different criteria: the nature of the catchment, the temporal availability of the data and the diversity of hydro-meteorological regimes. Therefore, we first retained natural catchments, or with limited human influences, whose sizes are hence small (lower than 8 000 km²). For our catchment set of interest in this study, the length of the discharge records for each catchment varied but they were generally available on the 1970-2013 period, which includes very humid years and very dry ones. Then, we intended to have long series of discharge, at least 30 years available between 1970 and 2013 to apply the sampling method and to calculate the low flow indices. A set of 644 catchments throughout France was built collected. These data were deemed good by the station-managers and a threshold of 10% of missing data per year was allowed. The diversity of the set can be representative of all hydrological regimes in France: pluvial (75% of the catchment set), snowmelt-fed (15%), uniform (7%), and mediterranean (3%) hydrological regimes. Meteorological data came from the distributed mesoscale atmospheric analysis system SAFRAN developed by Météo-France, which provides daily solid and liquid precipitations and temperatures data from everywhere in the French territory. The daily potential evapotranspiration was estimated using a temperature-based formula. These data were available on the period 1959-2013 over France.

Using a rainfall-runoff model to simulate long discharge records in order to derive low-flow statistics is an uncertain task and poses questions about the type of model, the calibration procedure and the uncertainties related to input and output observation data. The choice of the model to be used is often driven by data availability and/or the expert knowledge of the model user. We developed a conceptual daily rainfall-runoff model, LoiEau, combined with a regionalized model of snow storage and melt, to simulate low-flow indices at daily or longer time intervals through French territory. This model relies on two free parameters, which is sufficient to provide accurate enough estimates of low-flow indices, yet making easier the regionalization of the model. The model is flexible in the
sense that it is designed to fit to a wide variety of catchments and hydro-meteorological behaviors. The calibration procedure might be tricky since simulating low-flows is not a common usage of the rainfall-runoff model. Recently, we studied the identifying the best objective function to simulate low-flow indices in order to calibrate the parameter set of a rainfall-runoff model to estimates these statistics. We found that the mean of the KGE applied to the discharge and the KGE applied to the inverse of the discharge was sufficient. The robustness was dependent of the climate variability rather the objective function and the results were not sensitive to the model.

We analyzed only on the parameter uncertainty resulting from uncertainty in the forcing data (flow observations) and evaluate its impacts on the resulting streamflow simulations. The statistical indices analyzed are used by the water management agencies to manage water resource (flow indices at different time steps (daily, monthly and annual)). The data used for calibration model is bootstrapped while the model structure and the calibration process are held constant. The bootstrap procedures have already been used for the estimation of hydrological parameter uncertainty. So, one hundred independent calibrations were made over 25 years sub-periods, identified through a block-bootstrap method. Blocks are constituted by assembly single years, the interannual autocorrelation of precipitations, temperatures and streamflow series are keeping. However, the long-term hydroclimatic autocorrelation is not preserved in this approach. As the hydrological model is continuously, it runs over the entire period but only the selected single years are considered for the calculation of the objective function. After each calibration, the model was run on the whole period in order to enable calculations flows indices on all test sub-periods. We can also compare them against flow indices simulated with the parameter set calibrated over the complete period. The carrying out 100 simulations using parameter set sampling provided 100 daily flows series, from which the estimations of flow indices are calculated. Based on these distributions, the median, and 5% and 95% prediction bounds were calculated for each flow indices to determine a 90% confidence interval. The uncertainties obtained under the same sampling conditions by fitting classical probability distributions were also investigated.

The main results showed that the uncertainties on flow indices calculated with hydrological model (LoiEau) were lower than those associated with methods based only on the use of flows. Using a hydrological model enables to take into account the non-linearity of the hydrological processes; it models the fact that the low-flows are influenced by dry rainfall periods and reduces the uncertainties compared to the methods based only on the use of flows. Finally we propose a confidence interval of flow indices (low-flows, annual and monthly flows) on the gauged catchments.