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Role of hydrological signatures in improving multi-objective calibration of SWAT model

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Multi-objective optimization of hydrologic models is widely adopted to achieve a suitable calibration level for the model through the optimization process. The method has been proven to be a promising approach in developing robust models essentially for the semi-distributed and physically based models that usually involve several decision variables. Inclusion of more than one criterion in the calibration process assists in suitably fitting various portions of the hydrograph, thus leading to a more realistic time series simulation. Statistical objectives primarily play the role of fitting the model-simulated variables with the corresponding observed values. This may sometimes inadequately predict some of the hydrological process represented by the model. Signature measures have been adopted in the very recent past to fine tune the model calibration process. In the present research signature measures are included as objectives in the multi-objective evaluation to improve the calibration results. Multi-objective evolutionary algorithms (MOEA) are well laid out tools for solving non-linear problems with conflicting objectives. Several MOEA's have been adopted by the hydrology community to arrive at feasible solutions for both conceptual as well as semi-distributed models. Borg multi-objective algorithm which is a fairly new but has been proven to be a powerful evolutionary algorithm capable of efficiently handling several criteria simultaneously, has been adopted in the current study. Borg incorporates design principles from existing MOEA's with several new characteristics that include ε-box dominance archive, ε-progress and an adaptive population sizing operator among others. Auto-calibration of the widely used physically based hydrologic model, Soil and Water Assessment Tool (SWAT), is carried out using Borg multi-objective algorithm. SWAT models for two snow fed southern Ontario catchments have been coupled with Borg to calibrate the model based on objective functions that include both statistical measures as well as flow signatures. The flow signatures based on the flow duration curve is assisting in proper distribution of flow levels whereas runoff coefficient objective function is balancing the total volumetric error in the simulation. For the two watersheds under study the maximum Nash-Sutcliffe efficiency (NSE) value obtained is 0.88 and 0.7, respectively for monthly and 0.68 and 0.53 for the daily simulations. It is also shown that routinely used statistical measures used as objective functions render a sub-optimal low flow simulation and poor overall volumetric bias in the SWAT model. Suitable combination of objective functions based on flow signatures is found to improve the overall flow simulation. Inclusion of signature measures shows an improvement of over 300% in the low flow fit which is measured through RMSE-standardized ratio (RSR). Similarly improvement is also found in percentage bias (PBIAS) of flow variable. Multi-objective formulation also aid in accessing the uncertainty in the overall process by the way of ensemble simulation of non-dominated Pareto solutions. Well calibrated models when applied for a future scenario would also assist in reducing the prediction uncertainty.