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A novel multi-objective model calibration method for ecohydrological applications

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ABSTRACT

The reliability and applicability of hydrological models within ecohydrological frameworks are major concerns. Two multi-objective model calibration strategies were formulated to achieve a balanced representation of ecologically relevant hydrologic indices. Two approaches were employed: 1) a performance-based method constraining the targeted hydrologic indices and 2) an unconstrained signature-based method explicitly incorporating the targeted hydrologic indices into multiple objective functions. Both strategies were successful in representing most of the selected hydrologic indices within a ±30% relative error acceptability threshold while yielding consistent runoff predictions in a watershed. The performance-based strategy was preferred since it showed a lower dispersion of near-optimal Pareto solutions when representing the selected indices based on water balance and Flow Duration Curve characteristics. Still, the overall representation of low flow magnitude and timing, rise and fall rates, and duration and frequency of extreme flows was limited in terms of interannual variability due to the hydrological model structural inadequacies.

1. Introduction

The streamflow regime is widely acknowledged as a key determinant of the ecological integrity of riverine ecosystems (Poff et al., 1997; Sofi et al., 2020). Both climate and human-driven alterations to natural streamflow fluctuations affect the structure and functioning of these ecosystems, threatening biodiversity and restricting the provision of ecosystem services (Palmer and Ruhi, 2019; Vörösmarty et al., 2010). Therefore, understanding and evaluating the impacts of climate change and human interventions on the streamflow regime is critical to inform and prioritize environmental management alternatives (Hassanzadeh et al., 2017; Mittal et al., 2016).

A broadly accepted approach to characterizing streamflow regimes is to compute flow statistics from streamflow hydrographs. These statistics, also known as hydrologic signature metrics, streamflow characteristics (SFCs), or ecologically relevant hydrologic indices (ERHIs), generally represent five fundamental facets: magnitude, frequency, duration, timing, and rate of change of flows (Poff and Zimmerman, 2010). Currently, there are over 200 flow statistics relevant to stream ecology (Archfield et al., 2014; Olden and Poff, 2003; Vogel et al., 2007). These indices are usually employed in ecohydrological applications such as stream classification (Kennard et al., 2010; Mcmanamay et al., 2014), prediction of stream health or distribution of riverine species (Hernandez-Suarez and Nejadhashemi, 2018; Kakouei et al., 2017), and environmental flow determination (Mathews and Richter, 2007; Poff et al., 2010). Since these applications generally cover large spatial scales, statistical and hydrological models have been increasingly used, especially to predict regional changes in ERHIs due to climate and anthropogenic factors (Caldwell et al., 2015; Mittal et al., 2016; Yang et al., 2016).

Hydrological models are usually preferred over regional statistical approaches because they can explicitly consider modifications in land use, environmental conditions, and management practices (Hall et al., 2017; Shrestha et al., 2016). Moreover, some environmental flow frameworks recommend using hydrological models for predicting streamflow in poorly gauged or ungauged locations (Peters et al., 2012; Poff et al., 2010). However, there is a growing number of studies revealing important limitations of hydrological models in representing ERHIs, especially when these models are calibrated based on traditional performance metrics such as the Nash-Sutcliffe efficiency (NSE) (Murphy et al., 2013; Shrestha et al., 2014; Vigiak et al., 2018; Vis et al., 2015). These limitations include over or underprediction of low- and

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