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Design of small hydropower plants under uncertainty: from the hydrological cycle to energy conversion

Panagiotis Pagotelis[1,2], Konstantinos Tsilipiras[1,2], Antonis Lyras[1,2], Anastasios Koutsovitis[1,2], Georgia-Konstantina Sakki[1], and Andreas Efstratiadis[1]
[1]Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Greece
[2]Contributed Equally

We investigate the design of small hydropower plants under multiple sources of uncertainty and contrast it with the conventional deterministic practice that leads to a unique solution. In particular, we emphasize three sources of uncertainty, referring to: (a) the rainfall process, (b) the rainfall-runoff transformation, and (c) the flow-energy conversion. The first is due to the natural (i.e., hydroclimatic) variability, and is represented through stochastic approaches. Regarding the rainfall-runoff uncertainty, this arises from inherent structural shortcomings and poor parameter identifiability across the calibration procedure. In fact, hydrological model parameterizations using only historical data are often insufficient for accurately predicting catchment behavior over the long term, as they may not capture the full range of hydroclimatic conditions that the catchment may be subjected to. To address this issue, we use synthetic time series as drivers to parameterize the model and validate it against observed data. This approach preserves the probabilistic properties and dependence structure of the observed data while also providing a much wider range of hydroclimatic conditions for model training. In addition, it allows for assessing and quantifying the total model uncertainty. The final source of uncertainty is depicted by means of probabilistic efficiency curves. This Monte Carlo simulation-optimization framework is formalized as a modular procedure, where the different sources of uncertainty, as well as the full context, is tested through the design of a small hydropower plant in Epirus, Western Greece.