A Bayesian Hierarchical Modeling Approach to Predicting Flow in Ungauged Basins

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Recent innovative approaches to identifying and applying regression-based relationships between land use patterns (such as increasing impervious surface area and decreasing vegetative cover) and rainfall-runoff model parameters represent novel and promising improvements to predicting flow from ungauged basins. In particular, these approaches allow for predicting flows under uncertain and potentially variable future conditions due to rapid land cover changes, variable climate conditions, and other factors. Despite the broad range of literature on estimating rainfall-runoff model parameters, however, the absence of a robust set of modeling tools for identifying and quantifying uncertainties in (and correlation between) rainfall-runoff model parameters represents a significant gap in current hydrological modeling research. Here, we build upon a series of recent publications promoting novel Bayesian and probabilistic modeling strategies for quantifying rainfall-runoff model parameter estimation uncertainty. Our approach applies alternative measures of rainfall-runoff model parameter joint likelihood (including Nash-Sutcliffe efficiency, among others) to simulate samples from the joint parameter posterior probability density function. We then use these correlated samples as response variables in a Bayesian hierarchical model with land use coverage data as predictor variables in order to develop a robust land use-based tool for forecasting flow in ungauged basins while accounting for, and explicitly acknowledging, parameter estimation uncertainty.

We apply this modeling strategy to low-relief coastal watersheds of Eastern North Carolina, an area representative of coastal resource waters throughout the world because of its sensitive embayments and because of the abundant (but currently threatened) natural resources it hosts. Consequently, this area is the subject of several ongoing studies and large-scale planning initiatives, including those conducted through the United States Environmental Protection Agency (USEPA) total maximum daily load (TMDL) program, as well as those addressing coastal population dynamics and sea level rise. Our approach has several advantages, including the propagation of parameter uncertainty through a nonparametric probability distribution which avoids common pitfalls of fitting parameters and model error structure to a predetermined parametric distribution function. In addition, by explicitly acknowledging correlation between model parameters (and reflecting those correlations in our predictive model) our model yields relatively efficient prediction intervals (unlike those in the current literature which are often unnecessarily large, and may lead to overly-conservative management actions). Finally, our model helps improve understanding of the rainfall-runoff process by identifying model parameters (and associated catchment attributes) which are most sensitive to current and future land use change patterns.

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