Stochastic frameworks for predicting the flow duration curve are simple but powerful tools for understanding the first-order dynamics that occur between natural systems and anthropogenic processes. These frameworks, however, are derived under restrictive assumptions about stationary climate, catchment storage dynamics, and streamflow generation processes. Extensive validation of these frameworks across catchments with varying degrees of conformity to these assumptions is yet to be undertaken, but would inform the more widespread use of these models. We performed a set of model suitability analyses to determine whether the idealized assumptions implied by these frameworks are appropriate for a variety of climate and geomorphic typologies across the United States. In each suitability analysis, the stringent assumptions about climate and storage dynamics are relaxed for one of several variations on the stochastic framework, potentially broadening their applicability. Existing catchment classification schemes provided the basis for our model suitability analyses, which we extended by the including more nuanced treatments of climate and seasonality. The results provide insight into the accuracy of these minimalistic frameworks, with implications for their utility in studies of natural-human system feedbacks.