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Using regression heteroscedasticity to model trends in the mean and variance of floods

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Changes in the frequency of extreme floods have been observed and anticipated in many hydrological settings in response to numerous drivers of environmental change, including climate, land cover, and infrastructure. To help decision-makers design flood control infrastructure in settings with non-stationary hydrological regimes, a parsimonious approach for detecting and modeling trends in extreme floods is needed. An approach using ordinary least squares (OLS) to fit a heteroscedastic regression model can accommodate nonstationarity in both the mean and variance of flood series while simultaneously offering a means of (i) analytically evaluating type I and type II trend detection errors, (ii) analytically generating expressions of uncertainty, such as confidence and prediction intervals, (iii) providing updated estimates of the frequency of floods exceeding the flood of record, (iv) accommodating a wide range of non-linear functions through ladder of powers transformations, and (v) communicating hydrological changes in a single graphical image. Previous research has shown that the two-parameter lognormal distribution can adequately model the annual maximum flood distribution of both stationary and non-stationary hydrological regimes in many regions of the United States. A simple logarithmic transformation of annual maximum flood series enables an OLS heteroscedastic regression modeling approach to be especially suitable for creating a non-stationary flood frequency distribution with parameters that are conditional upon time or physically meaningful covariates. While heteroscedasticity is often viewed as an impediment, we document how detecting and modeling heteroscedasticity presents an opportunity for characterizing both the conditional mean and variance of annual maximum floods. We introduce an approach through which variance trend models can be analytically derived from the behavior of residuals of the conditional mean flood model.

Through case studies of urbanizing watersheds, we demonstrate that accounting for trends in both the mean and variance can yield substantially different estimates of time-dependent extreme flood quantiles than only considering trends in the mean. When applied to risk-based optimization, considering trends in the variance strongly influences the flood magnitude for which flood control infrastructure should be designed over a given planning horizon. We demonstrate that this approach can easily be extended to multivariate regression equations that employ physically meaningful covariates, such as impervious cover and extreme precipitation events. Finally, we introduce a statistical tool that enables decision-makers to examine the effects of particular gradually implemented watershed management actions on an annual peak flow probability distribution.