Variable climate elasticity curves across streamflow regimes

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Climate elasticity of streamflow describes the sensitivity of streamflow to changes in climatic variables. It is defined most frequently as the percent change in mean annual streamflow resulting from a 1% change in a given climate variable (Shaake, 1990). Potential evaporation (PET) and precipitation are key variables of interest due to their direct relationship with streamflow. The relationship between climatic and hydrological change across the annual flow distribution is important for understanding the spectrum of hydrological behavior and potential non-stationarity under climate change. We may expect these elasticities to vary since flows of different magnitudes are likely to be more or less influenced by different environmental conditions, such as ground water contributions. To date, studies have reported widely on the climate elasticity of streamflow at the annual scale (e.g., Chiew et al., 2006; Sankarasubramanian and Vogel, 2001; Tang et al., 2020; Milly et al., 2018; Berghuijs et al., 2017), and more recently, the aggregated multi-annual scales (Zhang at al., 2022). However, the question of how the sensitivity of streamflow to climate varies from low to high flows and across different flow regimes has not been adequately addressed.

In this study, we estimate average elasticity of streamflow to precipitation and PET in United States rivers across different segments of the streamflow hydrograph using a causally-constructed panel regression model. This results in the generation of a series of "elasticity curves" which represent the relationship between streamflow and climate across the segments of the streamflow hydrograph. Then, building on existing literature, we address the question of how the shape of the climate elasticity curves varies for different streamflow regimes and the extent to which it is well described by the hypotheses outlined in previous elasticity research. In particular, we consider the flashiness, annual snow fraction, climatological divisions, and ground water contribution.

We show that average climate elasticity estimates are consistently largest for high flows and smallest for low flows across all examined divisions of hydrologic similarity. We demonstrate clear differences in hydrologic response across the percentiles of the hydrograph and generate distinctive elasticity curves which characterize the varied nature of hydrologic response to changes in precipitation and PET dependent on the climatologic and geological features of a catchment. For instance, catchments where evaporative demand and storage are high are less responsive to changes in precipitation, to the extent that low flow elasticity is less than 1, while low flow elasticities in flashier catchments are much larger, even approximating 2 in more extreme cases (e.g., 2% change in annual low flows corresponding to a 1% change in precipitation). Meanwhile, high flow elasticities show greater convergence across regions with estimates between 2 and 2.5. We suggest that more complete consideration of the hydrograph is essential in the context of interpreting the hydrological implications of climate change.

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