Assessing annual streamflow response to forest disturbance in the western US: A large-sample hydrology approach

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Forested watersheds across the western US have experienced recent widespread disturbance and tree mortality due to a combination of heat, drought, and epidemic insect and disease outbreaks. Hydrologic response has included both increases and decreases in the fraction of annual precipitation that is partitioned to streamflow versus evapotranspiration (ET). We used a large-sample hydrology approach to address two questions: First, how have water budget components changed during this period of high forest disturbance, and second, does streamflow response vary with disturbance severity, incoming solar radiation, and/or aridity? From previous studies, streamflow and runoff ratio are expected to increase with forest disturbance due to reduced ET, and conversely increases in forest density are expected to reduce streamflow. We statistically evaluated whether these expectations were met, and where and why contradictory responses occurred, using trend and regression analysis. We constructed annual water budgets for 211 watersheds in the western US from daily observations in the CAMELS dataset, which includes streamflow and climate data as well as watershed characteristics such as mean incoming solar radiation and aridity (i.e., ratio of mean annual potential ET to mean annual precipitation, or PET/P). Forest disturbance was quantified as percentage change in live tree volume and mean annual rate of tree mortality, using data collected by the US Forest Service's Forest Inventory and Analysis program. While most water budget components and forcing variables did not exhibit consistent trends, many watersheds experienced significant increases in temperature and PET. Unexpected trends in runoff ratio occurred in two scenarios: First, runoff ratio decreased following forest disturbance in many water-limited watersheds (i.e., PET/P>1) of the southwestern US; and second, both runoff ratios and forest densities increased in some energy-limited watersheds of the Pacific Northwest. Water-limited watersheds and those with high solar radiation experienced more forest disturbance than energy-limited watersheds. We used hydrologic time trend analysis to quantify the magnitude of streamflow change. A linear regression model including precipitation and temperature as inputs was calibrated and validated using the pre-disturbance time period (1980-2006, odd years and even years, respectively; $r^2_{\text{val}}=0.954$), and then applied to the post-disturbance time period (2007-2019), where model residuals are assumed to represent change in streamflow due to factors not included in the model, i.e., forest change. Among the 65 watersheds with significant streamflow change, the magnitude of change was moderately correlated with both disturbance severity and solar radiation. Decreased post-disturbance streamflow occurred mainly
in watersheds with low to moderate tree mortality and high incoming solar radiation. We used multiple linear regression to identify important predictors of streamflow change. Pre-disturbance streamflow, change in precipitation and PET, solar radiation, and the interaction of solar radiation and tree mortality were all highly significant predictors (p