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The influence of discharge variability on bedrock river incision on the Hawaiian island of Kaua'i

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Bedrock river incision occurs during floods that generate sufficient shear stress to strip riverbeds of sediment cover and erode underlying bedrock. Thresholds for incision can prevent erosion at low flows and slow down erosion at higher flows that do generate excess shear stress. Because discharge distributions typically display power-law tails, with non-negligible frequencies of floods much greater than the mean, models incorporating stochastic discharge and incision thresholds predict that discharge variability can sometimes have a greater effect on long-term incision rates than mean discharge. This occurs when the commonly observed inverse scalings between mean discharge and discharge variability are weak or when incision thresholds are high. Because the effects of thresholds and discharge variability have only been documented in a few locations, their influence on long-term river incision rates remains uncertain. The Hawaiian island of Kaua'i provides an ideal natural laboratory to evaluate the effects of discharge variability on bedrock river incision because it has one of Earth's steepest gradients in mean annual rainfall and it also experiences dramatic spatial variations in discharge variability, spanning a wide range of the conditions reported on Earth. Kaua'i otherwise has minimal variations in lithology, vertical motion, and other factors that can influence erosion. River incision rates averaged over 1.5 - 4.5 Myr timescales can be estimated along the lengths of Kauaian channels from the depths of river canyons and lava flow ages. We characterized discharge variability on Kaua'i using records from an extensive network of stream gauges spanning the past century and a stochastic hydrology model. The hydrology model incorporates rainfall, soil moisture, and catchment storage dynamics, as well as changes in El Niño Southern Oscillation over the duration of river incision on Kaua'i based on paleoclimate proxy records and modern observations. We used these characterizations to model long-term bedrock river incision along Kauaian channels with a threshold-dependent incision law, modulated by site-specific discharge-channel width scalings. In a time-averaged analysis and for transient river profile modeling, we tested a range of critical shear stresses and coefficients and exponents scaling excess shear stress to incision rates to find the parameters best able to reproduce observed incision rates. In these tests, we either assumed a spatially uniform critical shear stress or we used Shields' criterion and an empirical expression for median grain size to allow the critical shear stress to vary throughout the river network with channel and flow properties. In some tests, we also assumed that Shields number varies with channel slope. We found that models with spatially variable grain size and Shields number provide the best fit to observed long-term, time-averaged river incision rates, indicating that discharge variability and incision thresholds do leave a measurable imprint on patterns of river incision across Kaua'i. However, these models imply incision thresholds that should be frequently exceeded in Kauaian channels based on our discharge characterizations. Thus, our preliminary results indicate that variations in mean annual rainfall have greater influence on variations in river incision rates on Kaua'i than do differences in storminess across the island.