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Stronger ground motion promotes stream discharge responses to earthquakes

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Following earthquakes, it has long been noted that the amount of water discharged at Earth's surface can increase. The magnitude can exceed 1 km3 of excess discharge in streams, and elevated discharge can persist for many months. Even dry streams may begin to flow.

The mechanisms responsible for increased stream discharge remain uncertain. Coseismic contraction may squeeze water out of aquifers, subsurface hydraulic barriers may break, (near-)surface material may consolidate, soil water may be mobilized or permeability may be increased. Testing these hypotheses is limited, because observations are restricted to the response of one or more streams to a single earthquake. Documenting responses to multiple earthquakes has proven insightful in showing that at least some springs and streams do not respond to coseismic volumetric strains. Instead, dynamic strains from seismic waves must be responsible for changes in discharge. However, it remains unclear whether the magnitude of responses scales with the magnitude of ground motion, or whether the response is binary – changes occur if ground motion is large enough, but the magnitude of response is independent of the ground motion beyond some threshold.

Here we take advantage of the large number of earthquakes in Chile and the dense hydrological monitoring network to document the response of many streams to numerous M$\geq$8 earthquakes. In total, there are daily discharge records from 716 gauging stations and daily precipitation records from 802 rainfall gauges. We manually identify responses in hydrographs by searching for coseismic and postseismic changes to the 1960 M9.5 Valdivia, the 1985 M8.5 Valparaiso, and 2010 M8.8 Maule earthquakes that we cannot attribute to rainfall. We characterize ground motion by the peak ground velocity (PGV) from USGS shakemaps because this measure of ground motion predicts best whether or not streams respond to earthquakes (e.g., Mohr et al., 2017). In order to extract the total amount of excess discharge, we use a one dimensional groundwater flow model in which excess water is estimated, either by changing vertical permeability or releasing water from storage.

We find that PGV as small as 0.3 cm/s may trigger streamflow responses under favorable conditions. But we could neither find a catchment nor earthquake specific scaling. Our data does not support a scaling relationship between PGV and magnitude of response. Instead, our data shows a binary response. Ground motion of approx. 12.0 cm/s is needed to trigger streams to respond (n=110). Streams respond to multiple earthquakes confirming a recovery of hydraulic properties during the inter-seismic periods, at least for most cases, which in turn excludes a quasi-permanent change in permeability due to ground motion. Instead, the modeling suggests spatially varying contributing areas (fraction of the catchment responding to the shaking), consistent with co-seismic recharge in the elevated areas. Our study support enhanced vertical permeability as the governing seismo-hydrological process explaining our streamflow observations.