Geophysical Research Abstracts
Vol. 21, EGU2019-2581, 2019
EGU General Assembly 2019

Monitoring landslide hydrology across the United States: Insights into variable controls on landslide activity from shallow to deep and rainfall to snowmelt triggering

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The U.S. Geological Survey's Landslide Hazards Program and our cooperators maintain a landslide monitoring network across a broad range of hydroclimatic and geographic regions. Many years of rainfall and climatic forcing data, and the attendant pore-water pressure, volumetric water content, and water-table response dynamics reveal insights into a variety of controls on landslide initiation. This presentation takes a brief tour of these sites with a few examples that highlight the value of in-situ monitoring for improved quantitative understanding of landslide hydrology. Decades of monitoring of a large, deep-seated landslide in the California's Sierra Nevada Mountains have revealed relations between rainfall, pore-water pressures, and landslide activity, as well as different rainfall conditions that lead to shallow debris flows along the margins of the slide. In the Colorado Rocky Mountains, piezometer responses helped confirm that snowmelt from previous years can impact remobilization of a deep-seated, seasonally active landslide. In contrast, burned areas in southern California are subject to sometimes deadly and destructive runoff-generated debris flows during relatively common winter rainfall events, without any correlation to antecedent moisture. Paired hillslope monitoring near Seattle, Washington, illustrates that recent landslides drain less efficiently between storm events than neighboring vegetated hillslopes, which can explain the positive-feedback cycle driving frequent landslide recurrence in this area. Monitoring data have also facilitated improved estimates of unsaturated soil-hydraulic properties and better model calibration and evaluation for landslide forecasting. Whereas some landslides may occur in partially saturated materials, monitoring data from the San Francisco Bay area (California), Puerto Rico, and western North Carolina reveal substantial positive pore-water pressures at the soil-bedrock interface absent shallow landslide movement, which provides important feedback for measurement-based alert systems. Data displayed in near-real time on the USGS website currently provide situational awareness in a variety of settings and have helped inform new hydro-meteorological thresholds for the development of landslide warning systems. Challenges maintaining monitoring sites include difficult to access locations, maintenance of clogged rain gages, cavitating tensiometers, and power systems, as well as abrupt data interruption due to vandalism by animals and humans and even the occasional damaging slope failure. Despite the challenges and considerable expense, in-situ monitoring has facilitated new insights and advances in landslide science across the United States.