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# Assessing the impact of stress–dependent hydraulic properties on hillslope-scale groundwater flow and transport

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The occurrence of springs and their connectivity within stream networks is typically associated with three key controlling factors: climate, topography and the distribution of hydraulic properties. In crystalline media, this distribution is often related to lithology and the presence of fractures. In addition, tectonic and topographic stresses can modify properties through compressive and extensional forces acting on the rock mass and fractures. However, these controls are rarely considered for hillslope scale applications. The aim of this research is to investigate the effects of stress on bedrock hydraulic properties and their implications for groundwater flow and transport at the hillslope scale. A numerical experiment has been designed that combines linear poroelasticity to simulate the distribution of permeability and porosity, together with groundwater flow and transport simulations. Different slope and stress conditions are examined, providing a comprehensive sensitivity analysis framework.

Our results show that vertical stress leads to a decrease in permeability and porosity at depth, following an exponential-like trend. Increasing the proportion of lateral stresses relative to the total vertical stresses reduces the mean permeability and porosity and increases the variance in the distribution along the hillslope. For high values of lateral stress, a low permeability domain develops downslope at the valley bottom due to the accumulation of compressive stresses, while the extensive regime at the crest provides higher permeabilities. As expected, groundwater flow simulations revealed that the partitioning of flow paths is strongly influenced by such heterogeneous stress-induced permeability and porosity fields. As stress increases, groundwater flow becomes more channelized in the near subsurface, strongly deviating from the classical Dupuit model. We also found that the distribution of normalized groundwater discharge rates shows higher values in the upper part of the seepage zone than in the lower part. By analyzing the results of particle tracking simulations, we found that mean residence times increase with higher external stress due to a decrease in mean permeability. In addition, the shape of the residence time distribution is strongly modified by the channeling of groundwater flow with increasing lateral stress, with the probability of shorter residence times increasing as stress increases. We discuss the implications of these fundamental results for our understanding of the role of stress in groundwater-dependent systems, with important insights into the recharge, storage and discharge mechanisms that may control the resilience of landscapes to the effects of climate change.