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Identifying distributions of response times in karst aquifers

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In karst catchments, aquifer recharge occurs through a composite mosaic of subsurface flow paths. Precipitation infiltrates in the subsurface and flows along a complex network of fractures – that are characterized by different sizes and degrees of saturation – before eventually reaching the catchment outlet. The discharge of a karst spring is the result of the contributions of these flow paths, that may differ widely in terms of lengths, velocities, and travel times. Monitoring the spring discharge can thus provide information about flow within the aquifer. In particular, the spring discharge signal can be interpreted as the lagged response of the aquifer to precipitation inputs over the catchment, with the aquifer being characterized by a distribution of response times that relates input (precipitation) to output (discharge). Identifying these response times is not a trivial task as the input-output problem is often mathematically ill-posed, which leads to amplification of the errors and may prevent finding a physically meaningful solution.

In this work we propose a method to evaluate the distribution of response times of a karst aquifer. The method, that was originally developed to deal with ill-posed problems in geostatistical applications, relies on a probabilistic description of precipitation inputs and discharge outputs, and it provides an estimate of the response time distribution and of its uncertainty. The method is here tested through the application to two datasets collected in two cave systems in Northern Italy (the Bossea system and the Vene/Fuse system) with different hydrogeological properties. The results demonstrate that the method successfully identifies different response time distributions that reflect the differences in aquifer characteristics of the two systems. Furthermore, differences among response time distributions relative to different precipitation events in each system provide valuable insights on seasonal variations in aquifer recharge and fracture saturation. The method can hence be applied as a tool for the indirect investigation of karst systems.