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Keeping the secret: Insights from repeated catchment-scale tracer experiments under transient conditions

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Catchment-level tracer experiments are generally performed to identify site-specific hydrological response functions of the catchment. The existence and uniqueness of these response functions are hardly ever questioned.

Here, we report on a series of replicated tracer experiments in two small first-order catchments, G1 (0.6 ha, roofed) and F4 (2.3 ha, without roof) at Gårdsjön in SW Sweden. The soils in both catchments are shallow (< 50 cm) with the bedrock partly visible at the surface. In G1 (irrigated area approximately 1000 m^2), tracer experiments were conducted under a roof between 1993 and 2003 during steady state flow conditions. In contrast, in F4 (irrigated area approximately 500 m^2) the experiments were done without a roof mostly at transient conditions.

The catchment F4 was equipped with a sprinkler system with a watering capacity of around 38–45 m^3 day^{-1}. Natural rainfall comes in addition. A bromide tracer solution was injected to groundwater at a single location about 40 m upstream the weir over a period of less than an hour, and was monitored using a set of groundwater tubes and the weir at the outlet over the following 4 days. In addition, discharge was measured. The experiments were repeated each summer from 2007 to 2015.

While steady state conditions were guaranteed in G1, steady runoff has been achieved only four times in F4. We investigated tracer recovery rates against cumulated runoff since tracer application. Substantially different transit times and qualitatively different behaviour of the breakthrough curves were observed, even under steady state conditions. In G1, no single system response function could be identified in 5 replicates. Similarly, the catchment response functions in F4 under steady state differed between experiments. However, they remained in a similar range as in G1.

Based on these results, we question the identifiability of flow paths and system properties, such as saturated water content or hydrologic transmissivity, at the catchment scale using tracer experiments. Rather, the series demonstrate the utter importance of the initial and boundary conditions which largely determine the response of the system to inert tracer pulses.