Uncovering the hillslope scale flow and transport dynamics in an experimental hydrologic system

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Hillslope scale water flow and transport dynamics have been extensively studied (Burt & McDonnell, 2015; Hewlett & Hibbert, 1963), but observing those internal dynamics in high spatial and temporal resolutions remains challenging. In this study, we uncover internal water flow and transport dynamics in an artificial hillslope in the Landscape Evolution Observatory (LEO), Biosphere 2, University of Arizona, Tucson, USA, using the experimental dataset collected in December 2016. Complete information about the hillslope and experiment can be found elsewhere (Pangle et al., 2015; Till H. M. Volkmann et al., 2018); Here, we only summarize some relevant information.

The first part of the animation describes the experimental system and setup (time 00:12 – 04:14 in Animation S1). The LEO hillslope is 330 m^3 (30 m long, 11 m wide, and 1 m deep) sloping soil lysimeter. The hillslope is primarily made up of loamy-sand textured basaltic tephra, and the most downslope 5.5 m^3 is filled with gravel-textured basaltic tephra. A custom irrigation system supplies reverse osmosis filtered water onto the LEO surface. The downslope boundary is exposed to atmospheric pressure, creating the seepage face boundary condition. The sensor networks (including pressure transducers and volumetric water content sensors) and the water isotope sampling locations and intervals (7 hrs to 101 hrs) are illustrated in Animation S1 (time 02:09 – 03:01). The isotope composition of subsurface water is obtained from laser-based online measurements of vapor that is extracted via custom gas probes through equilibrium calculation (T. H.M. Volkmann & Weiler, 2014). The irrigation sequence of this experiment was designed to generate a periodic steady state, which allows the application of the PERidoic Tracer Hierarchy method (Harman & Kim, 2014) for the observation of the time-variable transit time distributions and the StorAge Selection functions. Deuterium-labeled water was irrigated during the first two irrigation events.

The second part of the animation shows the dynamics of the perched water table and soil water content (time 04:15 – 06:53). The extent of the saturated zone was estimated using the pressure transducer data and Delaunay triangulation (Delaunay, 1934). The experimental data show the saturation from below mechanisms—wetting up from the bedrock surface into the soil profile (McDonnell, 1997)—and the saturation from downslope to upslope. The water table profile forms a wedge-like shape, which is a characteristic of hillslope with a high hillslope (Peclet) number (Berne et al., 2005; Brutsaert, 1994). The hillslope Peclet number of the LEO hillslope during the experiment is high (> 10) (Kim et al., 2020). Significant time delays in the water table dynamics are observed at some upslope locations (e.g., at 13 m upslope), which is mostly due to the delayed water supply from the convergent upslope area. The water content data indicates that the convergent upslope water content began to decrease around the timing of the water table peak at 13 m upslope.

The third part of the animation shows the tracer dynamics (from time 06:43). The animated experimental data reveal two notable water transport dynamics. First, the vertical tracer movement is faster at the upslope. This faster movement at the upslope is, in a sense, counter-intuitive because the upslope region is drier than the downslope. This is due to the lateral flow in the saturated zone and the tension saturated zone, that are thicker at the downslope. While water velocity is higher at the downslope, the direction of velocity is not vertical but rotated towards the downslope in those zones.Second, the animated data illustrate that old water is present only at the downslope. This observation is a characteristic of hillslope with a high hillslope number, in which old water is preferentially discharged (Kim et al., 2020). Indeed, the observed SAS function in this hillslope is concave (Kim et al., 2020), indicating that the hillslope preferentially discharges old water that is stored at the downslope.

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