Describing Lateral Preferential Flow Experimentally

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Introduction
In steep, forested landscapes, hillslopes are the fundamental landscape unit. A rainfall threshold before lateral subsurface flow initiates is a ubiquitous feature seen at trenches hillside sites. After this threshold is reached, preferential flow is a similarly prevalent feature of lateral subsurface flow, whether macropore flow, fingering, or flow along the soil and bedrock horizon boundaries. Despite the prevalence of preferential flow, it remains poorly characterized. This set of experiments is designed to identify and characterize the following:
1) Preferential subsurface flow types and locations
2) Particle velocities
3) Pressure velocities
4) Flow path connectivity and extent

Methods
At the Woods and Rowe hillslope, the topographic hollow and area of highest flow convergence (Trench sections 11-12), was chosen for the experiments. Stream water pumped and applied as a line source to the soil surface 400 cm upslope of the collecting trench until steady state conditions were reached. Flow types, locations and relative intensity were recorded. ~20 cm of soil was removed, after which the flow characterization was repeated. Every 2-3 slices, bromide was added while the system was at steady state. 125 cm above the trench, repeat injections were run at increasing irrigation rates to determine intensity effects. A subset of the injections coincided with high intensity irrigation pulses to test the pressure wave velocity. The experiment was repeated above all trench sections 13-14, with water applied in a pit dug to the soil bedrock interface 80 cm upslope.

Subsurface Flow Identification and Mapping
While some macropore and matrix flow were noted during slicing, the majority of flow was at the soil bedrock interface, in distinct rivulets. Rivulets were routed by features in the cemented gravel bedrock, and often accompanied by fine and medium live and dead roots. Between 40 cm downslope of the injection point, macropores and sub-vertical cracks in the soil matrix. Between 30 and 100 cm downslope, some water flowed overland in topographic depressions.

Flowpath Connectivity and Extent
Flow path connectivity was determined through combined thin slicing, burrowing and brilliant blue dye staining. Flow paths were found to be continuous for the length of excavation ~4 meters for trench sections 11-12 and 9.7 meters for trench sections 13-14 (see map and slicing to left). Irrigated water flowed along the soil surface for <1 meter, until it intersected a series of subvertical cracks and macropores which funneled the water to the soil bedrock interface. Flow paths remained within 5 cm of the bedrock, with no evidence of flow into the bedrock or soil matrix. Some branching and convergence was seen in the flow paths, generally controlled by flow around and between protruding stones in the cemented bedrock. Flow appeared to be routed and mapped topography.

After excavation was complete, while irrigating at steady state on the bedrock surface above trench sections 13-14, brilliant blue dye was added (see series of photos below, taken at 2 second intervals). Convergence and branching patterns are seen, qualitatively similar to those seen with the soil. Quantitative analyses of flow paths with and without soil are in progress.

Previous Research at Catchment 208, Maimai, New Zealand
1978-1982 – Mosley finds rapid hillslope and catchment response to rainfall along with high tracer and water velocities during natural storms. A variety of subsurface flow paths are identified, including flow along the soil and bedrock horizon boundaries, through soil matrix and macropores. 1980 – Pearce, Sklash and Stewart used combined isotopic and hydrometric methods to show that while response is rapid, exfiltrated water is old, with new water contributions to lateral subsurface flow between 2-25%. Authors question importance of preferential flow in subsurface flow. 1980 – McDonnell uses vadose zone tracer studies of lateral subsurface flow at Maimai, where rainfall vertically bypasses soil matrix via vertical cracks, back ups & mixes with soil water at the soil bedrock interface, then travels preferentially via pipe network downslope. McDonnell concludes that preferential flow paths are important conduit of old water to stream.
1996 – Woods and Rowe build a long (60m) trench to capture subsurface flow at the base of a representative hillslope in the M8 catchment. Analysis of flow during from each trench section demonstrates that flow varies across slope, controlled by surface or subsurface topography.
1996 – Branner et al apply a line tracer 30m upslope of the Woods and Rowe trench. Tracer velocities were calculated using a selective probe. Travel times were estimated as the time to peak concentration.

Particle Velocities
At 8 slices above trench sections 11-12, with 0, 50, 99, 125, 153, 192, 215 and 320 cm of soil removed, a bromide tracer was added to irrigation water. Concentration breakthrough was monitored at the upslope raise with an ion selective probe. Travel times were estimated as the time to peak concentration.

Pressure Velocities
0.0 cm upslope of trench sections 11-12, while irrigating at steady state, a concurrent bromide injection and irrigation rate spike were added to a pit dug to bedrock. The hydrometric response was rapid, with peak discharge after 5 minutes. Pressure breakthrough was delayed, with peak bromide concentration after 154 minutes. Hydrometric and tracer velocities were 2.66 and 0.25 cm/s (96 & 9 m/hr) respectively. This experiment was repeated above trench section 11-12 with a surface application, with similar results.

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