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Instrumenting an upland research catchment in Canterbury, New Zealand to study controls on variability of soil moisture, shallow groundwater and streamflow

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Hydrologists recognise the importance of vertical drainage and deep flow paths in runoff generation, even in headwater catchments. Both soil and groundwater stores are highly variable over multiple scales, and the distribution of water has a strong control on flow rates and timing. In this study, we instrumented an upland headwater catchment in New Zealand to measure the temporal and spatial variation in unsaturated and saturated-zone responses. In NZ, upland catchments are the source of much of the water used in lowland agriculture, but the hydrology of such catchments and their role in water partitioning, storage and transport is poorly understood. The study area is the Langs Gully catchment in the North Branch of the Waipara River, Canterbury: this catchment was chosen to be representative of the foothills environment, with lightly managed dryland pasture and native Matagouri shrub vegetation cover. Over a period of 16 months we measured continuous soil moisture at 32 locations and near-surface water table (< 2 m) at 14 locations, as well as measuring flow at 3 stream gauges. The distributed measurement sites were located to allow comparisons between North and South facing locations, near-stream versus hillslope locations, and convergent versus divergent hillslopes.

We found that temporal variability is strongly controlled by the climatic seasonal cycle, for both soil moisture and water table, and for both the mean and extremes of their distributions. Groundwater is a larger water storage component than soil moisture, and the difference increases with catchment wetness. The spatial standard deviation of both soil moisture and groundwater is larger in winter than in summer. It peaks during rainfall events due to partial saturation of the catchment, and also rises in spring as different locations dry out at different rates. The most important controls on spatial variability are aspect and distance from stream. South-facing and near-stream locations have higher water tables and more, larger soil moisture wetting events. Typical hydrological models do not explicitly account for aspect, but our results suggest that it is an important factor in hillslope runoff generation. Co-measurement of soil moisture and water table level allowed us to identify interrelationships between the two. Locations where water tables peaked closest to the surface had consistently wetter soils and higher water tables. These wetter sites were the same across seasons. However, temporary patterns of strong soil moisture response to summer storms did not correspond to the wetter sites.

Total catchment spatial variability is composed of multiple variability sources, and the dominant type is sensitive to those stores that are close to a threshold such as field capacity or saturation. Therefore, we classified spatial variability as ‘summer mode’ or ‘winter mode’. In summer mode, variability is controlled by shallow processes e.g. interactions of water with soils and vegetation. In winter mode, variability is controlled by deeper processes e.g. groundwater movement and bypass flow. Double flow peaks observed during some events show the direct impact of groundwater variability on runoff generation. Our results suggest that emergent catchment behaviour depends on the combination of these multiple, time varying components of variability.