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Theoretical models regarding factors influencing switching regimes and the hydrological and erosional significance of hydrophobicity

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The influence which soil hydrophobicity may have on hillslope hydrology and erosion in any location will depend on the proportion of storm events in which it is spatially contiguous. This in turn is dependent upon (a) the speed and three-dimensional pattern with which it disappears in wet weather and (b) the speed, three-dimensional pattern and degree of re-establishment of hydrophobicity in dry weather following hydrophilic or partially hydrophilic episodes. This paper draws upon results of laboratory and field investigations of changes through time in hydrophobicity, as well as recent advances in knowledge of switching mechanisms, to develop theory relating to hydrophobicity, its three-dimensional temporal dynamics and controls and its influence on overland flow and slopewash. Particular attention is given to modelling temporal change following fire. Use is made of key findings from (1) a field study of changes over a 4.2-year period January 2009 to March 2013 in hydrophobicity at two 10 m x 10 m grids (270 points, surface and 5 cm depth) on heather moorland in Central Portugal, where one grid was burned by an experimental fire in February 2009 and the other was an immediately adjacent unburned control; (2) a laboratory study of three-dimensional change in hydrophobicity with wetting (by an 8 mm simulated rainfall) and at different stages in an 80-hour drying phase of three different but initially equally hydrophobic soils, each of which comprising variants with and without artificial vertical routeways (simulated roots or linear cracks) and with or without drainage impedance at 2.5 cm depth.

A series of theoretical models are presented addressing 1) factors and mechanisms influencing post-fire temporal change in hydrophobicity and (2) factors and mechanisms controlling the significance and temporal dynamics of hydrophobicity influence on overland flow and erosion (i) in unburned terrain and (ii) following fire. The field evidence from Portugal suggests a three-phase response in hydrophobicity following fire. An initial tendency for more rapid re-establishment of repellency after wetting and more frequent highly hydrophobic conditions in the burned grid, resulting in part from more rapid drying of the bare surface, is replaced by progressively less intense hydrophobicity due to lack of replenishment of hydrophobic substances. The third phase is one of hydrophobicity recovery towards unburned grid levels with rising replenishment rates as vegetation regenerates. Of critical importance more generally will be the propensity of constituent species comprising the vegetation to generate hydrophobic substances. The laboratory experiments demonstrated the key importance of roots and cracks (if present in sufficient density) and the presence/absence and depth of any impeding layer in influencing the degree and pattern of switching and wetting of soil during rainstorms and hence also the speeds of decline and disappearance and subsequent persistence and re-establishment of hydrophobicity. It is argued that significant overland flow and slopewash enhancement is only likely if hydrophobicity is (1) surface or near-surface, (2) spatially contiguous and persistent, (3) vertically extensive without a shallow subsurface impeding layer, (4) on terrain with a low density of preferential routeways and (5) has effective replenishment mechanisms.