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Shallow lateral flow from a forested hillslope: Influence of antecedent wetness

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Abstract

A 5-m-wide soil pit at the base of a forested hillslope in coastal British Columbia was instrumented for studying subsurface flow processes during rainstorms. Three typical, low-intensity autumn rainfall events with different antecedent moisture conditions are assessed. Outflow from the organic horizon was captured and measured by a single trough, and outflow from the mineral horizon (above compact glacial till and bedrock) was measured separately for three adjacent sections of the soil pit. For two storms that were preceded by dry conditions, lateral outflow from the organic horizon occurred, although the water table did not rise up to the organic horizon. However, the calculated effective contributing area was small (<0.7 m^2) and the effective contributing slope length was short (<0.15 m). Furthermore, volumes of outflow from the organic horizon during these storms were more than 400 times less than during a later storm with wet antecedent conditions. During this later storm, a portion of the outflow from the organic horizon may have been generated as saturated overland flow due to the rising water table. The calculated effective contributing area (>170 m^2) and the effective contributing slope length (>36 m) were substantially greater for the “wet” antecedent storm compared to the “dry” storm events. Shallow lateral flow over unsaturated soil is therefore unlikely to be a significant contributor to storm runoff at such forested sites. Flow at the organic horizon–mineral soil

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interface may contribute to interconnected preferential flow pathways during wetter antecedent conditions.

Keywords: Forest hydrology; Subsurface flow; Contributing area; Antecedent moisture; Preferential flow; Organic horizon

1. Introduction

Headwater catchments play a fundamental role as source areas and transient sinks for water, nutrients, sediments, and biota, and these functions are controlled by hillslope stormflow processes and pathways (e.g., Mosley, 1979; Pearce et al., 1986; Tsukamoto and Ohta, 1988; Wilson et al., 1990; McDonnell et al., 1991; Peters et al., 1995; Sidle et al., 1995, 2000; Tani, 1997). In the past 40 years, much research has been conducted on the mechanisms of storm runoff generation in forested drainage basins (e.g., Whipkey, 1965, 1969; Weyman, 1970, 1973; Mosley, 1979; Tanaka et al., 1988; Tsukamoto and Ohta, 1988; Pearce, 1990; Wilson et al., 1990), but few studies have specifically focused on contrasting stormflow response during periods of dry and wet antecedent conditions.

A number of field investigations have noted that downslope flow in shallow hillslope soils occurs mainly in a transiently perched saturated zone located above a relatively impermeable layer at the base of the soil profile; thus, any outflow from the upper soil layers is generated by a rising water table (Wilson et al., 1989; 1990; Chappell et al., 1990; Mulholland et al., 1990; Jenkins et al., 1994). This concept provides the basis for many computer models of catchment hydrology, including TOPMODEL (Beven and Kirkby, 1979), DHSVM (Wigmosta et al., 1994), and TOPOG (O'Loughlin, 1986). However, several studies have indicated that shallow flow paths through the organic horizon over an unsaturated mineral soil layer can be important for stormflow generation. McDonnell et al. (1991) described a pseudo-Hortonian overland flow process, where large differences in saturated hydraulic conductivity at the organic-mineral soil boundary generate lateral flow in the shallow organic horizon. Brown et al. (1999) concluded that lateral flow in the organic horizon was more important in dry conditions as evidenced by transport of natural tracers. One possible explanation for this inferred phenomenon is the development of a hydrophobic layer near the base of the organic horizon that would induce preferential flow (Sevink et al., 1989). In contrast, studies in Japan using direct hydrometric measurements showed that subsurface stormflow from the organic horizon generally increased significantly with increasing antecedent wetness; for drier conditions, flow in the organic horizon was low or non-existent (Sidle et al., 1995; Noguchi et al., 2001). Staining tests during moderately dry conditions revealed that lateral shallow flow paths at the base of the organic horizon were generally limited to about 0.6 m before water infiltrated into the mineral horizon or connected with other preferential flow paths (Noguchi et al., 1999). Thus, lateral flow in the organic horizon may be important as part of a linked network of preferential flow pathways, especially during wet conditions (Noguchi et al., 1999; Sidle et al., 2001).