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Evaluation of drainage system effects on slope stability using numerical modeling of variably-saturated flow in a steep coastal bluff along Puget Sound (Edmonds, Washington, USA)

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Shallow landslides on steep ($> 25°$) bluffs along Puget Sound have resulted in the occasional loss of life and costly damage to property during intense or prolonged rainfall. As part of a larger project to assess the landslide hazard in the Seattle area, the U.S. Geological Survey instrumented two coastal bluff sites in 2001 to observe the subsurface hydrologic response to rainfall. The instrumentation at one of these sites, near Edmonds, Washington, consists of two rain gauges, two water-content probes that measure volumetric water content at eight depths between 0.2 and 2.0 m, and two tensiometer nests that measure soil-water suction at six depths ranging from 0.2 to 1.5 m. Field observations from these instruments were used to test one- and two-dimensional numerical models of infiltration and groundwater flow. Capillary-rise tests, performed in the laboratory on material collected at the Edmonds site, were used to define the soil-water characteristics for the wetting process. The field observations of water content and suction showed an apparent effect of porosity variation on the hydraulic response to rainfall. Using ranges of physical properties consistent with our laboratory and field measurements, we performed sensitivity analyses to investigate the effects of variation in physical and hydraulic properties of the soil on rainfall infiltration, pore-pressure response and, hence, slope stability. For a two-layer system in which the hydraulic conductivity of the upper layer is at least ten times greater than the conductivity of the lower layer, and the infiltration rate is greater than the conductivity of the lower layer, a perched water table forms above the layer boundary potentially destabilizing the upper layer of soil. Our modeling result indicate that the addition of a simple

trench drain to the same two-layer slope has differing effects on slope hydrology depending on the initial pressure-head conditions: for hydrostatic pressure conditions, the depth of the water table is only significantly reduced near the drain; however, for transient, vertical infiltration in a partially saturated soil, conditions which are similar to those observed during monitoring at the Edmonds site, the drain decreases the depth of a perched water table by a lesser amount, but over a much greater radius of influence.