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The role of fragipan soils properties for hillslope subsurface flow dynamics

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In watersheds characterized by fragipan, soils runoff generation is traditionally assumed to be dominated by shallow subsurface flow perched by a nearly impenetrable, low-conductive, subsurface soil horizon. However, several irrigation studies have indicated that fragipan soils can conduct subsurface flow vertically in considerable amounts resulting from differences in fragipan properties (e.g., prism diameter, interprism cracks, etc). These fragipan properties remain difficult to measure at the hillslope and watershed scales and consequently are inadequately accounted for in hydrological models. In the present study, a geophysical survey using ground penetrating radar of a 0.5 ha hillslope in central New York, USA has shown that spatial variability of the continuity and depth of fragipan soils is more influential on subsurface flow pathways than the physical characteristics of the fragipan itself. The geophysical survey revealed that the depth to fragipan varied between 0.3 and 0.8 m, resulting in water table and subsurface flow dynamics similar to the 'fill and spill hypothesis'. The survey also indicated that the fragipan is interrupted by a higher conductive glacial sand lens that facilitates percolation of subsurface flow beneath the fragipan.

The effect of the spatial variability of fragipan soils on subsurface flow pathways and flux was examined in further detail by installation of a 1.5 m wide, 1.5 m deep and 12.5 m long trench at the base of the 125 m long hillslope. The trench was installed in a variable source area (VSA) that forms at the base of the hillslope. The trench was instrumented with a surface flow collector measuring runoff from the upper 5 cm of the soil, and two collector drains installed at the soil-fragipan interface in 0.4 m depth and at the base of the trench (1.5 m depth). In addition, water levels were recorded at 5-min intervals in a 10 m x 10 m grid at the upslope contributing area of the trench. Soils in the study site are characterized as channery silt loams with an average slope of 12%. Synoptic sampling of O-18 and geochemical tracers revealed a persistent heterogeneity in runoff contributions during storm events and baseflow conditions. During large storm events when the water table rose to the soil surface most water flow (56%) occurred as surface runoff from the spatially expanding VSA, while flow at the soil-fragipan interface and flow from underneath the fragipan accounted for 25% and 19%, respectively. During storm events water levels in the sand lens remained well below the soil surface indicating a "sink" or recharge behavior of the sand lens. During dry periods, when the water table in the hillslope recedes to the soil-fragipan interface, the flow ratio changes and total flow is dominated by lateral flow at the soil-fragipan interface (52%) and flow from beneath the fragipan (30%) while near-surface flow from the VSA accounts for only 18%. The role of this fragipan discontinuity will be further investigated through a simultaneous application of two tracers, one injected in the sand lens and one surface applied in the areas where the fragipan persists.

The results of this study emphasize the need to accurately quantify both the horizontal, perched water table flow component and interflow contributions from beneath the fragipan and its implications for the general understanding of chemical/nutrient transport in glaciated landscapes.