Pedological criteria for estimating the importance of subsurface lateral flow in E horizons in South African soils

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Abstract

E horizons formed in soils by reduction and eluviation are considered to be an indicator of subsurface lateral flow (SLF) between the A and B horizons – a hydrological process important in generating streamflow. There is, however, uncertainty in the interpretation of the hydropedological behaviour of some E horizons. This study used a physical index (SLFI) to estimate the importance of SLF in profiles with E horizons, where SLFI is $\frac{K_{sc}}{K_{si}} \times (\tan\beta \times L)$. Data were obtained from the South African Land Type database. For criteria development, 156 profiles were used and an additional 80 profiles were used to validate the criteria. SLFI values were determined for the 156 profiles and then divided into 3 groups, with high, medium and low values. The basic hypothesis was that the individual quantifiable and qualitative soil and landscape properties influencing the pedogenesis of E horizons, and their integrated pedogenetic expression in soil forms, would be most and least strongly expressed in the profiles of the 'high' and 'low' SLFI groups, respectively. This concept was employed in a unique way to allocate numerical values expressing the estimated importance of the criteria with regard to SLF. In order to validate the pedological criteria the 80 test profiles were subjected to a similar procedure to that used to develop the criteria, resulting in an integrated pedological criterion value for each profile, which was then correlated against its SLFI value. Selected measured properties, i.e. organic matter, Fe, Mn and clay content, of the test profiles were also correlated against their SLFI values in the validation process. The results provide supporting evidence for the validity of the pedological criteria.

Keywords: hydrological behaviour, interflow; Land Type database; PUB; soil properties

Introduction

The identification, definition and quantification of the pathways and residence times of components of flow making up stream discharge need to be captured in hydrological models for accurate water resource predictions; estimating the hydrologic sensitivity of the land for cultivation, contamination and development; and for quantifying low-flow mechanisms (Uhlenbrook et al., 2005; Lorentz et al., 2007 and Wenninger et al., 2008). These hydrological models can best be developed using measurements of hydrological processes and parameters. Such measurements are however expensive and time consuming, since most hydrological processes are dynamic in nature with strong temporal variation (Park and Van de Giesen, 2004; Ticehurst et al., 2007). The need for predictions of hydrological processes is becoming increasingly important, especially in predictions in ungauged basins (PUB) (Sivapalan 2003; Sivapalan et al., 2003). An 'ungauged basin' is defined as a basin or catchment with inadequate hydrological observations to enable calculation of hydrological variables (water quality and quantity) for spatial and temporal scales at an accuracy acceptable for practical applications (Sivapalan et al., 2003). The reliable interpretation of soil morphological features related to hydrological processes should therefore be of considerable value in PUB activities.

There is an interactive relationship between soil and hydrology. Water is the primary agent in soil genesis, resulting in the formation of soil properties containing unique signatures of the way they formed, and soil influences and governs hydrological processes such as the preferred flowpath and residence times (Park et al., 2001 and Soulsby et al. 2006). Soil properties are in the short term not dynamic in nature and their spatial variation is not random (Webster, 2000). The correct interpretation of spatially-varying soil properties associated with the interactive relationship between soil and hydrology can serve as indicators of the dominant hydrological processes (Ticehurst et al., 2007 and Van Tol et al., 2010), and improve the understanding of the hydrological behaviour of catchments (Lin et al., 2006).

In a vast range of catchments subsurface lateral flow (SLF) is considered a dominant streamflow generation process (Lorentz, 2001; Retter et al., 2006), not only during the recession limb of flow events, but also for peak and low flows (Harr, 1977; Mosley, 1979; Whipkey and Kirkby, 1979). SLF occurs either through the soil matrix (inter-granular pores or small structural voids) or through larger voids (macropores or pipes) (Atkinson, 1979). According to Whipkey (1965), SLF in the matrix occurs especially when 'i) the land is sloping, ii) surface soil is permeable, iii) a water-impeding layer is near the surface, and iv) the soil is saturated'. In support of Atkinson's hypothesis, Hopp and McDonnell (2009) state that the saturated hydraulic conductivity (K_{sc}) of the conducting layer in relation to K_{si} of the impeding layer (anisotropy) plays a first-order control in the generation of SLF. Phillip (1991); McCord, Stephens and Wilson (1991) and Jackson (1992) all report on studies concerned with SLF close to the surface in hillslopes. Their studies show that the hydrologic processes involved are complex; even in the case of deep soils that are vertically isotropic with regard to hydraulic conductivity, SLF can occur. Anisotropy, both vertically and parallel to the

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