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# Using ancient and recent soil properties to design a conceptual hydrological response model

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ABSTRACT

Morphology (ancient) and chemistry (recent) were used as indicators of hydrological response and used to construct a conceptual hydrological response model with new insights into hydropedological interpretations of easily accessible soil data. Soil chemistry is hypothesised to be equilibrated with the recent water regime. Profiles of three soil types on the soilscape with descriptions, analyses, long-term soil water content and water tension data are discussed and 15 auger observations with descriptions and MIR data are used to develop a conceptual response model. Morphology was able to identify the primary response of soils. The deep interflow Cambisol on the midslope has a vertical flowpath through the first subsoil, indicated by the red apedal morphology, which combines with interflow in the second subsoil, indicated by stagnic colour patterns. The responsive Gleysol on the footslope is a storage mechanism, indicating permanently saturated conditions. The responsive Luvisol at the toeslope has interflow in the Albic horizon while the subsoils act as a storage mechanism. pH and base saturation were used to indicate leaching (flowpath), ferrolysis (fluctuating watertable), acid weathering and accumulation (water saturation). Iron and Mn were used as indicators of reducing conditions to infer the duration of saturation. Soil response was verified by water contents and tension data. Pedological processes were correlated to horizons and hydrological response. Chemistry was more sensitive to water regime change than soil morphology. Therefore soil chemistry was successfully used in designing a conceptual hydrological response model and improved identification of hydrological processes.



## 1. Introduction

The hydrological response of catchments is determined by the combined response of individual soilscapes (Sivapalan, 2003). Soilscape response, in turn, is mainly controlled by soil distribution patterns which are the buildings of catchments (Soulsby et al., 2006), and is therefore a first order control of water movement (Park et al., 2001; Soulsby et al., 2006). Soil distribution patterns control the hydrological processes such as flowpaths, residence times and storage mechanisms (Soulsby et al., 2006) which influence the quantity and chemical composition of the water exiting the soilscape (Jacks and Norrström, 2004). Soils have specific hydrological functions (Van Tol et al., 2010; Kuenene et al., 2011) and can be divided into horizons with specific hydrological functions (Kuenene et al., 2011; Van Tol et al., 2013).

Traditional pedotransfer functions from soil survey data have been developed using analytical data (Bouma, 1989; Elsenbeer, 2001), but soil morphology has been shown to serve as a pedotransfer function to infer the hydrological response of soils (Elsenbeer, 2001; Fritsch and Fritzpatrick, 1994; Van Tol et al., 2010; Kuenene et al., 2011). Soil physical and hydrometric data are commonly used to determine hydrological processes within soils. Gathering this data is however tedious, time consuming and often unreliable (Park and Burt, 1999). Soil morphological data is more accessible than soil physical and hydrometric data and can play an important role in conceptualising soilscape hydrology and assist in assigning the correct model structure in soilscape hydrological models (Lorentz et al., 2007; Van Tol et al., 2011). Soil morphology is a visible indicator of the interaction between water and parent material and the resultant variation indicates soil water regimes. Soil morphology was successfully applied by Fritsch and Fritzpatrick (1994); Soulsby et al. (2006); Ticehurst et al. (2007); Van Tol et al. (2010) and Kuenene et al. (2011) to develop conceptual hydrological response models of soilscapes and catchments. These interpretations are however often criticized as soil morphology reacts slowly to changes in soil water regimes and the formation of some morphological features are difficultly reversed.

Indeed, the process of soil formation is relatively long ($10^2$–$10^4$ years). Soil morphology related to drainage e.g. cutans, structure, soil colour and the delineation of master horizons is unlikely to change

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in a lifetime, but soil chemistry alternatively is less buffered (MacEwan and Fitzpatrick, 1996; MacEwan, 1997) and provides a more recent environment of soil formation.

Hydrology therefore plays an important role in resultant soil chemistry. Chemical weathering cannot take place without water and water is the mediator in further chemical reactions (Essington, 2004). Specific geochemical indicators are related to hydrological processes (McDaniel et al., 1992; Park and Burt, 1999) but using soil chemistry to infer pedological processes could transform the procedure of soilscape modelling by reducing the time required for physical measurements. It can improve the quality of hydrometric and isotope interpretations, which without the support of other data could produce erroneous predictions (McDonnell et al., 2007). Therefore soil chemical properties commonly reported in soil surveys can indicate recent hydrological response.

Developing a conceptual response model should be the first step in hydrological modelling. Although hydrometric measurements do reveal the current hydrological regime, conceptual interpretations of these point scale data might be erroneous when applied to whole soilscapes. The transference value between soilscapes of point data is also minimal. It is hypothesized that soil chemistry, a sensitive, equilibrated product of recent water/soil interactions can be used to: (i) reveal the recent hydrological behaviour of a particular horizon and (ii) due to their relationships with horizon morphology can be extrapolated from point scale hydrometrical measurements to soilscape scale. The aim of this paper is to establish the relationship between ancient (morphological) and recent (chemistry) soil indicators of soilscape hydrology and to verify whether this relationship reflects the current hydrological regime using hydrometric measurements. Point scale interpretations of the interactive relationship amongst soil morphology, chemistry and hydrometry are also extrapolated to derive a conceptual hydrological response model for the soilscape.

## 2. Materials and methods

### 2.1. Site description

The Weatherley catchment is situated southwest of Maclear in the Eastern Cape Province of South Africa (Fig. 1). The catchment is 160 ha (Lorentz, 2001) and forms part of the Mooi River catchment, which is a quaternary catchment of the Umzimvubu basin. It is situated at an altitude of approximately 1300 m above sea level and has a mean annual precipitation (MAP) of 1000 mm and mean annual potential evapotranspiration (ET) of 1480 mm (BEEH, 2003). The catchment was initially covered by Highveld sour grass (Acocks, 1975) with a basal cover of 50–70% (Esprey, 1997). About half of the soilscape was afforested in 2002. The catchment consists of mudstone and sandstone of the Elliot formation above 1320 m a.s.l., sandstone of the Molteno formation below 1320 m a.s.l., and a dolerite dyke dissects the soilscape (De Decker, 1981). A soilscape in the western side of the catchment consisting of three profiles, a Molteno sandstone shelf and a dolerite dyke, was selected for this study.

Many studies in the Weatherley catchment contribute to the understanding of the Weatherley catchment. Lorentz and Esprey (1998) found that water accumulation at the toe slope was dependant on soil properties, surface and bedrock topography. A large component of quick flow was ascribed to near-surface macropore flow (Lorentz et al., 2004). Some concepts and data were obtained from a comprehensive hydropedological study (Van Huyssteen et al., 2005).

### 2.2. Materials and methods

Four steps were used to design the conceptual hydrological response model: (i) morphology was used to infer hydrological response of the horizons and soil types; (ii) chemical data was interpreted to establish the relationship between morphology and pedological processes; (iii) tensiometer data and long term soil water content measurements

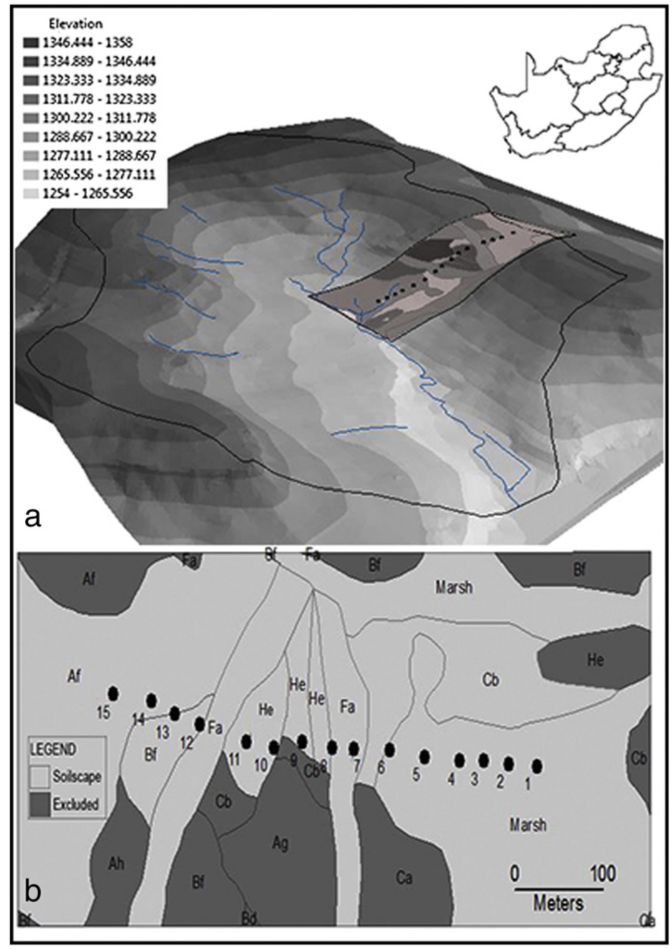


Fig. 1. A) Location of the Weatherley catchment in South Africa and indicating the soilscape and B) transect of observations representing the soilscape (adapted from Roberts et al., 1996).

were used to verify the interpretations; and (iv) a conceptual model was designed using more detailed morphological observations.

Firstly profile descriptions and chemical analyses of three profiles (Van Huyssteen et al., 2005) were used to establish the relationship between soil morphology and soil chemistry. The profiles were classified according to IUSS Working Group WRB (2007) and Soil Survey Staff (1999). Long term water contents were measured using neutron moisture metre (NMM) over a period of 6 years on a weekly basis. The NMM measures a 300 mm circumference around the probe. Separate on site calibration equations were done for different soil groups: A horizons ($R^2 = 0.96$), B horizons ($R^2 = 0.92$), C and E horizons ($R^2 = 0.79$) and G horizons ($R^2 = 0.71$) (Van Huyssteen et al., 2005). Water contents are expressed as annual duration of saturation ($ADs_{>0.7}$) which is defined as 70% saturation of porosity and proposed by Van Huyssteen et al. (2005) that reduction occurs before 100% saturation. Smith and Van Huyssteen (2011) found that significant reduction occurred at 70% of saturation and that almost complete reduction at 80% saturation. The chemical properties were used as indicators of pedological processes to verify if the soil morphology was in phase with the recent soil water regime. Tensiometer and soil water content data was used to verify the deductions made from the morphology and soil chemistry. Sensors were positioned in each horizon to identify horizon response. March 2001 was selected for the tension evaluation period as the onset of evaluation followed a number of days without any precipitation followed by a few rainy days. This pattern allows a wetting and a drying sequence which gives a good indication of fluctuations in the water regimes of the profiles.