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Interpreting soil and topographic properties to conceptualise hillslope hydrology

J.L. Ticehurst [a,b,c,*], H.P. Cresswell [c], N.J. McKenzie [c], M.R. Glover [c]

[a] *Integrated Catchment Assessment and Management Centre, Australian National University, ACT, 0200, Australia*
[b] *Centre for Resource and Environmental Studies, Australian National University, ACT, 0200, Australia*
[c] *CSIRO Land and Water, Butler Laboratory, G.P.O. Box 1666, Canberra, ACT, 2601, Australia*

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Abstract

The sustainability of agricultural practices is enhanced when vegetation makes optimal use of natural hydrological processes. For example, planting tree belts where slope gradient sharply decreases can enable harvesting of run-on water. This can be beneficial for example in reducing water logging and enhancing tree production. There is a need for rapid and low cost identification of water flow paths and conceptualisation of hillslope hydrology so that local landuse planning can reflect such opportunities. The collection of detailed hillslope hydrological data is prohibitively expensive for such applications and so the use of soil morphology and visual observation of topography and surface condition is evaluated as an alternative.

At a study site in south eastern Australia the soil physical profile was described down a hillslope with additional measurements of the hydraulic conductivity, bulk density, cation exchange capacity, electrical conductivity, and particle size distribution of the key horizons. This data was used to identify the perceived significant hydrological flow paths down the hillslope. Measurement of the surface runoff, subsurface lateral flow, and the distribution of saturation measured in piezometers were subsequently used to test the conceptual hydrological model.

Soil morphology, particularly the soil colour and presence of redox concretions were useful in identifying the locations and depths where saturation and lateral flow occur. The morphology provides an integrated reflection of the dominant hydrological conditions, but care must be taken to ensure that the observations reflect the current hydrological environment and not relic conditions. Other collaborating information such as the history of geomorphological events at the site, a validation of plausible water sources for the potentially transmitting layers, surface soil condition and landholder observations give improved confidence. Combining soil morphological understanding with visual observations of other site characteristics enabled rapid conceptualisation of hillslope hydrological behaviour as needed for local landuse planning.

Keywords: Hillslope hydrology; Lateral flow; Oxidation–reduction; Soil morphology

1. Introduction

Knowledge of water movement and accumulation through the landscape is becoming increasingly important to the sustainability of Australia's agricultural systems. Waterlogging and salinity, caused by the accumulation of excess water not used by the annual, shallow rooting vegetation are evident in some locations (Dunin et al., 1999). Conversely changes in the regional climate have made severe drought conditions possible during moderate El Niño events (Suppiah, 2004), increasing risk of crop failure, tree mortality and insufficient pasture growth to support livestock. Vegetation patterns need to make optimal use of the natural landscape hydrology. For example, targeted perennial vegetation, such as tree belts oriented across-slope, have the potential to harvest and use excess water running from higher ground. Such a strategy might result in benefits from reduced waterlogging and salinity in wet periods, and less drought-induced tree mortality in dry periods.

Implicit in the identification of suitable locations in the landscape for a given landuse is knowledge of local hydrological processes. Conceptual models of hillslope hydrology, including lateral water flow paths, are required to support landuse planning decisions. However, field-based interpretation of hillslope hydrology needs to be relatively fast and inexpensive if it is to be used for targeting particular landuse options by farmers in this way.

Ideally, a conceptual model of the hydrological function of a hillslope would be developed using measurements of the surface

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[*] Corresponding author. Integrated Catchment Assessment and Management Centre, Australian National University, ACT, 0200, Australia.
E-mail address: Jenifer.Ticehurst@anu.edu.au (J.L. Ticehurst).

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and subsurface lateral flow, watertable fluctuations, and change in soil water content. However, such an approach is obviously expensive, time consuming and largely dependant on the weather conditions, particularly rainfall being 'typical' during the period of observation. Numerical modelling can provide more quantitative insight into hydrological processes, but this is not free of expense as the data requirements to run such models still require field measurements, and a conceptualisation of hillslope water flow pathways is a necessary precursor. Modelling is only likely to find application in the planning of large, high-value landuse change. Both the direct measurement of hydrological processes and simulation modelling are well outside the reach of the average Australian farmer planning landuse change on his or her property.

Soil morphological interpretation has been used, for example by Fritsch and Fitzpatrick (1994), to construct soil–water–landscape models. Given that lateral flow within a soil is most significant through the saturated parts of the profile (Weyman, 1973; Anderson and Burt, 1978; Hurley and Pantelis, 1985), and water is the main factor influencing soil development in most environments (Wysocki et al., 2000), soil water movement can be reflected by the redistribution of soluble compounds. For example trends in the electrical conductivity (EC) (e.g. Seelig and Richardson, 1994) or cation exchange capacity (CEC) (Duchaufour, 1982; Fritsch and Fitzpatrick, 1994) reflect salt concentrations and thus areas of water transmission and accumulation. Soil colour (e.g. Simonson and Boersma, 1972; Khan and Fenton, 1994), mottling (Dunne et al., 1975; Fritsch and Fitzpatrick, 1994) and redoximorphic features, such as iron and manganese concretions, can indicate poor drainage conditions, periodic saturation and leaching (Stace et al., 1968; Khan and Fenton, 1994). It has also been observed that an increase in the amount and size of mottles and concretions correlates to an increase in the duration of saturation (Simonson and Boersma, 1972; Khan and Fenton, 1994). Soil horizons with a massive structure and light texture has been identified as ones that readily transmit water (Duchaufour, 1982; Novak, 1994; Fritsch and Fitzpatrick, 1994), because the water movement removes the iron (Fe), degrades the soil structure and initiates clay eluviation to deeper horizons. Water movement through these horizons is even more likely where there is strong texture contrast between the conducting layer and the horizon below.

However, care must be taken when interpreting soil properties to indicate the hydrological environment. For example, Fe can be fixed by humic material, and therefore unavailable to precipitate into concretions, so the redoximorphic features may not reflect the water conditions (Duchaufour, 1982; Novak, 1994). Conversely, some organic matter is required to provide the energy for the bacteria to reduce the Fe (Fitzpatrick, 1988) so an environment too low in organic matter would not be able to reduce and mobilise the Fe. There can also be a lag period between the current hydrological environment and the observed soil properties (e.g. Cox et al., 1996).

This research tests the hypothesis that soil morphology can be used to identify significant lateral flow paths for water at a field site and thus can be integral to the development of low cost conceptual models of local scale hydrology. Soil properties, and observations of topography and surface condition, are used to construct a conceptual hydrological model for a hillslope in south eastern Australia. The model is tested using hydrological measurements at the site. The approach is evaluated in terms of its applicability for assessing specific locations for planting tree belts to harvest run-on water.

2. Materials and methods

2.1. Study area

The study area for this research covers 42.8 ha, located in southern New South Wales, Australia, centered at 35°49′41″S, 146°21′27″E (GDA 94) (Fig. 1). It is in the Billabong Creek catchment, which is subject to waterlogging and salinity (Baker et al., 2001). The site is typical of other steep granite derived hillslopes in south-east Australia. It was subject to deposition of aeolian material throughout the Pleistocene (Walker et al., 1988). The aeolian mantle once coating the upper slopes has

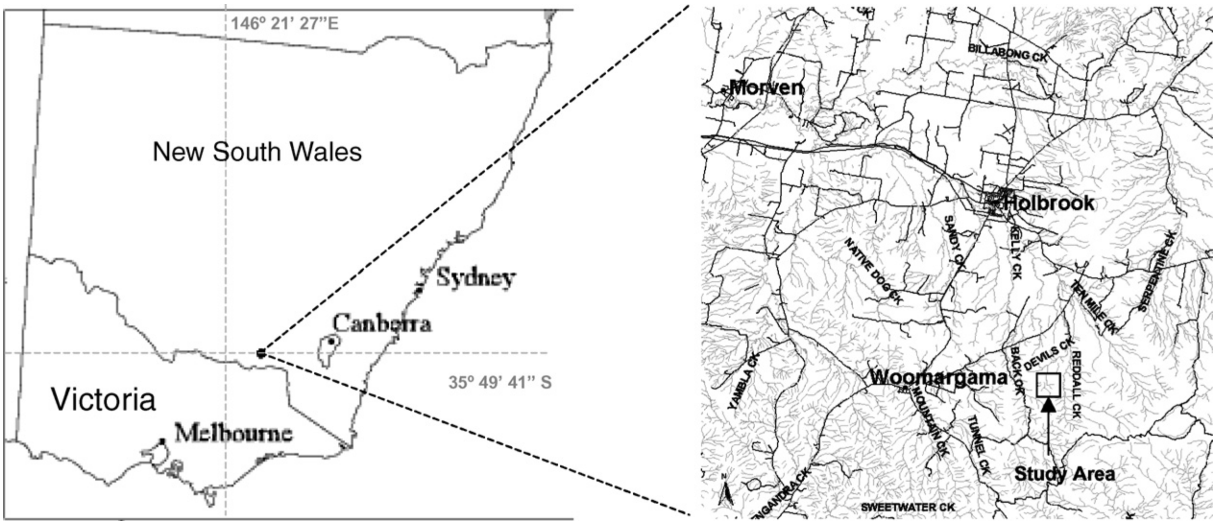

Fig. 1. Location of field study area in southern New South Wales, Australia. The right hand inset shows the major creeks (grey lines) and roads (black lines).