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The Duration of Soil Saturation: Point Measurements Versus a Catchment-Scale Method

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Abstract

Almost two-thirds of the farms in southern Australia have a texture-contrast soil profile with sandy or loamy A and E horizons overlying clay B horizons. A common problem with some of these soils is the development of a perched watertable in winter, which causes severe reduction in crop yield and exacerbates land degradation. The aim of this study was to measure the extent of the variability in the duration of soil saturation in texture-contrast soils on slopes in a catchment in the Mount Lofty Ranges, South Australia. Furthermore, a method based on a topographic index was used to predict soil saturation at catchment scale, which was then compared to the conventional point-scale measurements.

In the relatively dry years of the study, water duration on the upper slopes was surprisingly higher than on the lower slopes but was rarely expressed at the soil surface. Furthermore, the cause of soil saturation on the mid- and upper slopes was different from that on the lower slopes. However, it was predicted that in wet years water would last longer on the lower slopes due to saturation by groundwaters. As the catchment-scale method was based on a topographic index, it should be useful for predicting the duration of saturation in wet years but not in dry years.

The information obtained on the variability and causes of waterlogging will be of benefit to farmers. It showed that the failure of some current management options to adequately control perched watertables on slopes is partly due to the lack of understanding of their causes and to inadequate prediction of their variability in catchments.

南澳几乎三分之二的农地土壤剖面质地不均，粘土层 B 之上有砂土或壤土层 A 和 E 覆盖。这类土壤的栖留水位冬天通常较高，导致作物大幅减产，加剧土地退化。本研究的目的是测量劳伏特山区一个坡地上土壤水分饱和状态持续时间的变动范围，采用地形指数法，预测整个流域范围内的饱和状况，然后将其与传统的点测结果相对比。

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在相对干旱的年份，坡地上部土壤饱和期竟然较下部的长，但在土壤表面很少表现出来。而且，坡地中上部和下部水分饱和的原因不同。不过在多雨年份，正如预期的那样，因地下水原因，坡地下部水分饱和最久。因流域尺度的方法基于地形指数，所以可对多雨年份的水分饱和期进行预测，但不适合干旱年份。

研究收集到的涝渍变动及成因材料对农户有用。这些材料也表明，现行的某些治理措施无法有效控制栖留地下水位，部分原因就在于对其成因缺乏了解，对其变化未能预报。

A COMMON morphological feature of texture-contrast (Chittleborough 1992) or duplex (Northcote 1979) soils of the agricultural lands of southern Australia (Fig. 1) is the strong contrast between the coarse textured A and E horizons and the fine textured B horizon. However, chemical, mineralogical and physical properties of the texture-contrast soils can vary (Tennant et al. 1992; McFarlane and Cox 1992). Texture-contrast soils are also common in other parts of the world (Chittleborough 1992). The B horizons of texture-contrast soils in catchments in Western Australia have been shown by Cox (1988) to have saturated hydraulic conductivities (*Ks*) as low as 0.002 m/day, whereas the A horizon is at least 10 times this value.

A common problem reported with some of these soils, due to a lack of vertical flow capacity in the B horizon, is the development of a perched watertable in winter (Cox and McFarlane 1995). On sloping land this results in significant throughflow to lower slopes, causing waterlogging (saturation of the root zone: see Fig. 2), reduction in crop yields and increased land degradation.

By comparison, the texture-contrast soils whose subsoils have a high *Ks* (up to 1.2 m/day in catchments in Western Australia; Cox 1988) have been termed ‘leaky’ (Cox and Fleming 1997); in these situations, throughflow in the A horizon is a minor component of the catchment water budget (Fleming and Cox 1998), with B horizon throughflow dominating (Stevens et al. 1999).

The aim of this study was to measure the causes and extent of waterlogging in texture-contrast soils on slopes in a catchment in the Mount Lofty Ranges, South Australia. A method based on a topographic index was used to predict waterlogging at the catchment scale, which was then compared to the conventional point-scale measurements. This information was necessary for advising farmers on better strategies to control waterlogging.

Figure 1. Location of texture-contrast soils in Australia (Chittleborough 1992).

Figure 2. Waterlogging of texture-contrast soils (Keynes catchment, Mount Lofty Ranges, 1993).

Materials and Methods

Site description

The study was carried out in the Keynes catchment near Keyneton in the Mount Lofty Ranges in South Australia. The Overview provides background information on the Mount Lofty Ranges. The climate is Mediterranean, with cool, wet winters and hot, dry summers. The long-term (91-year) average rainfall in Keyneton is 544 mm; evaporation is 839 mm.[1] Annual rainfall in the town is not significantly different from the catchment (Pritchard 1998). The long-term average data show that rainfall exceeds evaporation from April to October. During our study, monthly rainfall was measured by a tipping bucket pluviometer attached to a weather station (Monitor Sensors Pty Ltd). Potential evaporation was calculated using the Priestly–Taylor equation (Priestly and Taylor 1972).

Two toposequences with predominantly annual pastures (Cox and Pitman 2001) were chosen for this study: a 150 m convex toposequence (sites KH0 to KH9) and a 240 m concave toposequence (sites KV1–KV10). The sites were from flat (KH0, KV1) to crest (KH9, KV10) and thought to incorporate most soil types in the catchment and both diverging and converging water flow.

Pedology and soil physics

Soil horizons along each toposequence were hand-textured and described according to McDonald et al. (1990); they were classified according to US taxonomy (Soil Survey Staff 1996). Soil toposequences were drawn according to the method of Rinder et al. (1994).

A constant head well permeameter (Talsma and Hallam 1980) and the equation of Reynolds and Elrick (1991) were used to measure *Ks* of the A, E and B horizons in triplicate. Bulk density (ρ_b) was measured with depth by taking duplicate soil cores (4.7 cm wide and 5 cm thick) from soil pits dug at the end of the project. All soils were analysed by the method of Rayment and Higginson (1992).

Measurement and quantification of perched watertables

To measure point-scale water duration, dipwells were installed at eight sites (KH1–KH8) along the convex toposequence and 10 sites (KV1–KV10) along the concave toposequence. At each site, a hole was dug with an auger to 0.5–0.6 m; the hole was lined with 50-mm diameter PVC pipe and capped on the top and bottom. All dipwells were fully slotted below ground level and sand packed. Dipwell water levels were manually measured every week in winter and less frequently at other times for five years (1 January 1994 to 31 December 1998). In addition, at three sites along each toposequence—lower slope (KH1 and KV1); mid-slope (KH5 and KV5); and upper slope (KH8 and KV10)—a data-logger and capacitance probe were installed to electronically measure water levels.

Water duration was quantified by accumulating, over the monitored period, the depth of water between the soil surface and 0.5 m (average depth to

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[1] Point patched meteorological data: see http://www.dnr.qld.gov.au/silo

the B horizon); this was termed the water duration index (WDI):

$$WDI_{50} = \sum_{i=1}^{n} S_i \tag{1}$$

where n is the number of days in the analysis period and S_i is a statistic that is defined as:

$S_i = 50 - D_i$ for $D_i < 50$ cm

$S_i = 0$ for $D_i \geq 50$ cm

where D_i is the average depth (in centimetres) of the watertable below the soil surface on day i and $D_i > 50$ (the average depth of the B horizon in centimetres) means that the soil is not waterlogged. Cox et al. (1996) give a full explanation of the index.

Measurement and quantification of depth of saturation

Point scale

An aluminium access tube was installed to 2 m at five landscape positions on the convex slope — crest (KH9); upper slope (KH8); mid-slope (KH5); lower slope (KH1); and flat (KH0) — and three on the concave slope — upper slope (KV10); mid-slope (KV5); and lower slope (KV1) — using the method of Greacen (1981). Volumetric water content was measured every 15 cm (to 2 m) each 2 to 4 weeks for five years by a neutron moisture meter (NMM). Soil cores were taken on four occasions at each depth interval at each site and an NMM calibration was developed for each to determine volumetric water content and percentage saturation.

Catchment scale

To map the extent of soil saturation, a topographic index (Equation 2) was calculated for the study area to represent the geomorphic processes associated with soil water and its spatial distribution in the landscape. The variables of the index were evaluated on a cell-by-cell basis from a digital elevation model (DEM).

$$\ln (A_s/\tan \theta) \tag{2}$$

where A_s = specific catchment area, and $\tan \theta$ = local slope angle.

Results and Discussion

Rainfall

Annual rainfall was below average (544 mm), except in 1996 (Table 1).

Topographic index

Figure 3 shows a three-dimensional representation of the topographic index. The index indicated that:

- permanent or long periods of soil saturation occur on the flats and lower slopes;
- infrequent to very infrequent saturation occurs on the mid-slopes; and
- short to long periods of saturation occur on the upper slopes and crests (for example, the mid-slopes have the darkest shading in Figure 3, and are the driest).

Point measured waterlogging

Table 1 shows three contrasting examples of the severity of water duration as measured in the dipwells. Figure 4 shows variations in perched watertables along the convex toposequence. A perched watertable rarely formed on some of the texture-contrast soils, but other such soils were very susceptible, even in dry years. The shortest water duration was measured on the mid-slopes, which agreed with the prediction from the topographic index. However, longer water duration was measured on the upper slopes than on the lower slopes. The lower slopes and flats probably have a long water duration when groundwaters are highest (when rainfall is above average).

Table 1. Rainfall (mm) and water duration.

	1994	1995	1996	1997	1998
Annual rainfall (mm)[a]	304	468	548	404	426
Water duration (WDI_{50} cm/day)[b]					
Lower slope	0	71	330	0	0
Mid-slope	0	0	2	0	0
Upper slope	485	345	850	289	134

[a] Long-term average annual rainfall is 544 mm

[b] Water duration at 50 cm depth (cm/day)

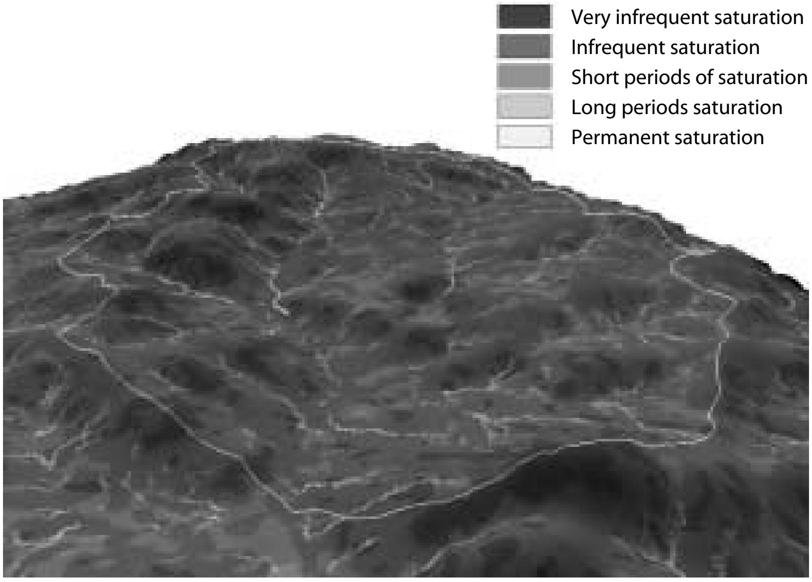

Figure 3. 3D representation of topographic index showing duration of saturation.

Figure 5 shows the relationship between the waterlogging and the annual rainfall less evaporation. Equation 3 expresses waterlogging as the average water duration severity over the hillslope:

$$\mathrm{WDI}_{50} = 0.0072\,(R - E)^{\,2.0374},\ r^2 = 0.914 \quad (3)$$

where WDI_{50} is the water duration index (cm/day), R is rainfall (mm), and E is evaporation (mm).

Neutron moisture meter data

Figure 6 shows the water status of three soils as determined from the NMM data. Soil saturation was sometimes due to the development and persistence of perched watertables and at other times due to groundwaters each winter, depending on the position in the landscape. Soils on the lower slopes were wettest each winter below about 1.5 m. Saturation was due to saline groundwater; the duration and severity were due to the height the groundwater rose each winter. Although the degree of saturation increased in the A horizon each winter, a perched watertable never developed on the boundary between the A and B horizons on the flats and lower slopes. Saturation of the soils on the mid-slopes was due to a perched watertable developing either on or within the clay B horizon. In addition, groundwaters contributed to saturation to within 1.0 m of the soil surface in 1995 and 1996. On the upper slopes, the lower A and B horizon soils became saturated each winter due to a perched watertable. In some soils the perching occurred at the boundary between the A and B horizons; in others it was deeper in the soil profile, nearer the boundary of the B and C horizons. In 1996, the wettest season, saturation extended into the upper C horizon.

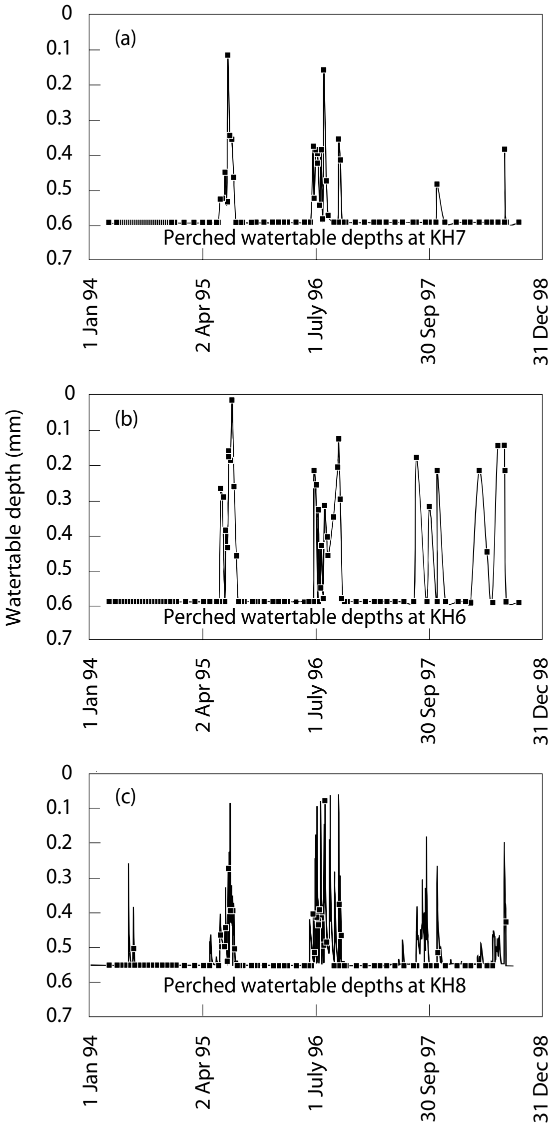

Figure 4. Examples of the development of a perched watertable along the convex toposequence.

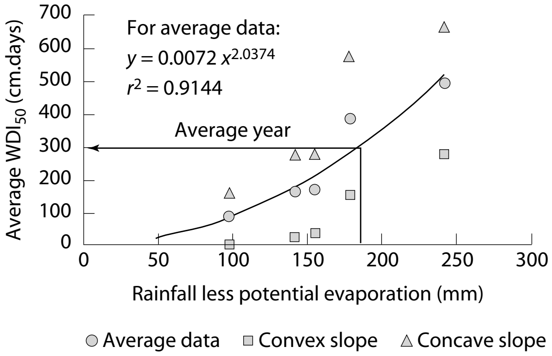

Figure 5. The relationship between rainfall less evaporation and waterlogging.

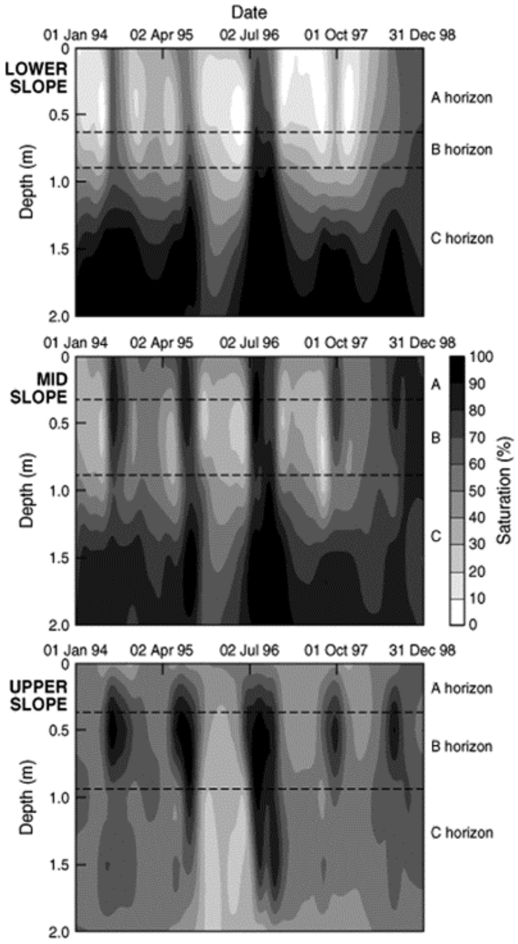

Figure 6. Examples of the degree of soil saturation at three positions in the landscape over five years.

Conclusions

In relatively dry years, water duration on the upper slopes of catchments in the Mount Lofty Ranges is higher than on the lower slopes. This is because the cause of soil saturation on the lower slopes is different from that on the mid- and upper slopes. It is predicted that the highest water duration on the lower slopes will occur in wet years (due to saturation by groundwaters); this is consistent with indications from a topographic index.

The failure of current management options to adequately control perched watertables on slopes is partly due to the lack of understanding of their causes and to inadequate prediction of their variability.

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