Journal of Hydrology (2006) **329**, 16–25

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jhydrol

Four-year comparison of water contents beneath a grass ley and a deciduous oak wood overlying Triassic sandstone in lowland England

Julian C. Green [a,*], Ian Reid [a,1], Ian R. Calder [b,2], Thomas R. Nisbet [c,3]

[a] *Department of Geography, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK*
[b] *Centre for Land-use and Water Resources Research, University of Newcastle, Newcastle upon Tyne NE1 7RU, UK*
[c] *Forest Research Agency, Forestry Commission, Alice Holt Lodge, Farnham GU10 4LH, UK*

Received 30 November 2004; received in revised form 1 February 2006; accepted 3 February 2006

KEYWORDS
Sandstone aquifer;
Soil moisture;
Forestry;
Grass ley;
Oak woodland;
Preferential flow

Summary Differences in the seasonal water dynamics of a sand soil overlying Triassic sandstone have been investigated to a depth of 9 m beneath both a grass ley and a pendunculate oak woodland within Clipstone Forest, Nottinghamshire, England. Fortnightly measurements with a neutron-probe over a four-year period allowed a comparison of the soil–rock water content to depths rarely reported. In spring, the rate of decrease of water content of the uppermost 2 m of soil was much greater under grass than oak woodland. In contrast, the rate of decrease under oak was greater after leafing out in May, while the rate of rewetting in early autumn was lower for this land-use until senescence and leaf-fall in late autumn. In the uppermost 2 m of soil – a depth that includes all plant roots – the soil moisture minima were between 47 and 58 mm lower under oak than grass in each year of monitoring. As a result of both these drier conditions and the comparatively late leaf fall of this species, penetration of the winter-season wetting front to 2 m was delayed by between one and three months at the oak site relative to grass in years of near-average rainfall. Rewetting at 9 m lags by 10–12 months, compared to the surface, giving an average penetration rate for the wetting front to this depth of 25–30 mm day^{-1}, with little observable differences between the land-uses. Preferential flow is evident under both sites, affecting the profile to 3 m in all years and to at least 6 m following winters experiencing exceptional rainfall.

* Corresponding author. Tel.: +44 0 1509 222751.
E-mail addresses: j.c.green@lboro.ac.uk (J.C. Green), ian.reid@lboro.ac.uk (I. Reid), i.r.calder@newcastle.ac.uk (I.R. Calder), tom.nisbet@forestry.gsi.gov.uk (T.R. Nisbet).
[1] Tel.: +44 0 1509 222791.
[2] Tel.: +44 0 191 2226428.
[3] Tel.: +44 0 1420 526203.

0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2006.02.004

Introduction

Protracted deforestation means that the British Isles are amongst the least wooded parts of Europe (Environment Agency, 1998). England has been particularly affected, with only 8% of its territory under forest at the close of the 20th Century (Smith, 2002). Consequently, in 1995, the UK Government proposed a doubling of the area of woodland by the year 2045 (Her Majesty's Stationery Office, 1995). However, while the amenity, biodiversity and landscape benefits of this intention are undeniable, questions were raised concerning the possible impacts on water resources of such a large change in land-use (House of Commons Environment Committee, 1996). The negative impact of evergreen conifer afforestation on the quantity of runoff from upland British catchments that receive high annual rainfall had already been demonstrated conclusively (e.g. Law, 1956; Calder and Newson, 1979). Studies of the effects of deciduous broadleaved species on water-relations elsewhere in the world suggested that, relative to pasture, higher transpiration and interception reduces soil water recharge (e.g. Guevara-Escobar et al., 2000). However, available information about the impact of an intended increase in broadleaved deciduous woodland on components of the water-balance in drier areas of lowland Britain was both limited and contradictory. For example, studies by Harding et al. (1992) and Roberts et al. (2001) suggested that recharge beneath beech and ash woodland on shallow soils overlying Cretaceous chalk is similar to, or greater than, that under grass. Meanwhile, Finch (2000), in a comparison of mixed deciduous woodland and grassland overlying sands and gravels of the Tertiary Reading Formation, suggests the opposite within the same geographic province. Compounding the problem of understanding the effects of land-use change on the soil moisture regime was that there was only limited information available about evaporation from woodland growing on drought-prone sand soils overlying Triassic sandstone (Ragab et al., 1997) — the UK's second most important aquifer (Kinniburgh, 1999). Yet, much of the planned increase in woodland might take place in the English Midlands on this type of soil.

In light of this knowledge-deficit and given the ever-increasing pressures on groundwater resources to satisfy the needs of both irrigated agriculture and public water supply, the Department of the Environment, Transport and the Regions, supported by the Forestry Commission and the Environment Agency, commissioned a field study of water use by evergreen pine forest, deciduous oak woodland, grassland and heath at Clipstone Forest in Nottinghamshire, England (Fig. 1), of which data for the oak and grassland sites will be reported here. Clipstone Forest is part of the wider Greenwood Community Forest, within which it is planned to expand woodland from the current nine percent to 27% by the middle of the 21st century. The aim of the study was to assess the impact of different vegetation types on groundwater recharge of the Triassic Sherwood Sandstone through examination of water contents to a depth of 9 m. In support of this, soil and rock water content data were collected between February 1998 and April 2002. The depth of the soil—rock profile from which data were gathered is considerably greater than in most other studies

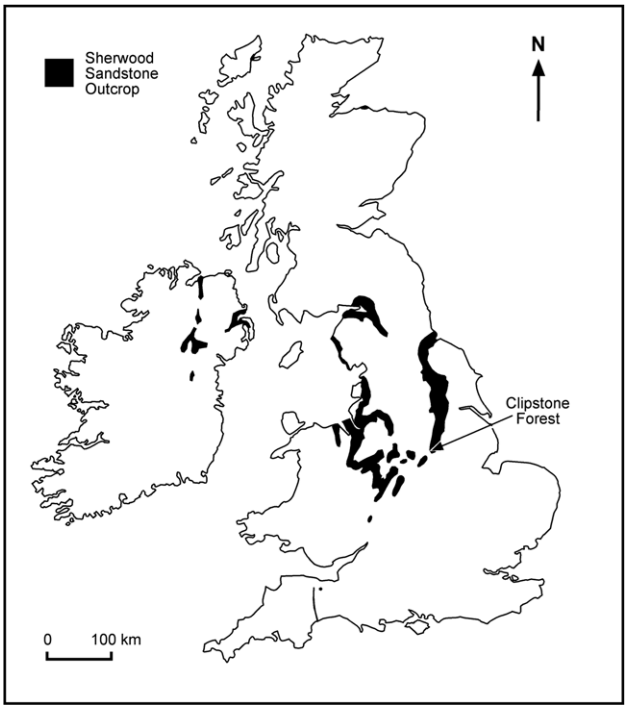

Figure 1 Outcrop of Triassic Sherwood Sandstone in the British Isles and the location of Clipstone Forest (centred upon UK grid reference SK 6162; 1°05′W, 53°09′N).

(c.f. Bréda et al., 1995; Granier et al., 1999; Guevara-Escobar et al., 2000). The length of the record — four years — is also only rarely matched by other studies. It has allowed us to assess changes in the soil—rock water profile not only during periods of near normal amounts of rainfall, but also in years of comparatively unusual weather.

Experimental sites

The study was located within Clipstone Forest, a relatively large woodland in the midlands of England. Extending over an area of approximately 5×5 km, the forest is characterized predominantly by commercial plantations of Corsican pine (*Pinus nigra* var. *maritime*), but within it are sizeable tracts of deciduous woodland and heathland. All experimental sites were located within 2.5 km of each other on land sloping at <2° and at an altitude of 95 m above sea level.

Daily rainfall data from a non-recording UK Meteorological Office Mark II rain gauge at Gleadthorpe (UK Grid Ref: SK 593701; 1°07′W 53°13′N), 9 km north of the forest, provide a long-term (1971—2000) annual mean of 628 mm. Weekly estimates of potential evapotranspiration for grass, obtained from the UK Meteorological Office Rainfall and Evaporation Calculation System (MORECS), which uses a modified form of the Penman—Monteith equation (Meteorological Office, 1992), provide an equivalent long-term annual mean of 608 mm for the 40×40 km grid square within which Clipstone Forest lies. The small difference between annual rainfall and annual potential evapotranspiration (20 mm) raises concern over the sustainability of water resources where land-use changes might be instrumental in instigating significant shifts in water-balance.