Journal of Hydrology 364 (2009) 342–348

Contents lists available at ScienceDirect

Journal of Hydrology

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

Flow through macropores of different size classes in blanket peat

Joseph Holden *

School of Geography, University of Leeds, Leeds LS2 9JT, UK

ARTICLE INFO

Article history:
Received 10 March 2008
Received in revised form 13 June 2008
Accepted 10 November 2008

Keywords:
Peat
Macropores
Runoff
Infiltration
Tension infiltrometer
Effective porosity

SUMMARY

Blanket peats are important source areas for runoff in many northern European headwaters. The upper peat layer (20 cm) is dominant in producing flow in blanket peat catchments. However, little information exists on the relative roles of different size classes of macropore in water movement in this upper peat layer. This study uses results from tension infiltrometer experiments to assess the role of different size class of macropores in runoff generation. Infiltration measurements were performed under four surface cover types (bare, *Eriophorum, Calluna* and *Sphagnum*-dominated), at four soil depths (0, 5, 10 and 20 cm) and at four water tensions (0, −3, −6 and −12 cm). Macropore flow was found to be an important pathway for runoff generation. Only 22% of the flow in the upper 20 cm of peat occurred in pores smaller than 0.25 mm in diameter. The remaining portion of flow was equally divided between those pores between 0.25 mm and 1 mm in diameter those pores greater than 1 mm in diameter. Most of the flow in upland blanket peat was generated from only a small volume of the peat. At the surface around 80% of flux was generated through only 0.26% of the peat volume while at 5 cm depth, while percolation rates were an order of magnitude slower than at the surface, 85% of the flux was generated from only 0.01% of the peat volume. Infiltration and effective porosity both declined by over two orders of magnitude over the top 20 cm of the peat. The variability in flow and effective porosity was found to be similar between different pore size classes.

Introduction

Peat covers 3% of the world's landmass but is much more important in terms of its role in delivering water and sequestering carbon (Holden, 2005b). Research on blanket peats has shown that runoff production tends to be very flashy and dominated by quick-flow response with very little baseflow (Burt, 1995; Holden and Burt, 2003a,b; Price, 1992). Flow production is controlled by the saturated state of the peat mass and the low hydraulic conductivity of the lower peat layers such that near-surface and saturation–excess overland flow dominate (Evans et al., 1999; Holden and Burt, 2003b; Holden et al., 2007).

While saturation–excess overland flow and near-surface flow dominate the runoff response of blanket peat catchments, it has also been shown that bypassing flow is an important process in these systems (Holden, 2005a,c, 2006; Holden and Burt, 2002; Holden et al., 2001; Ingram et al., 1974; Jones, 2004). Natural soil pipes (generally considered to be larger than 1 cm in diameter) have been shown to contribute 10% of discharge to the stream in deep peat catchments (Holden and Burt, 2002) while flow in pores larger than 1 mm in diameter has been shown to contribute approximately 30% to the infiltration process (Holden et al., 2001). Blodau and Moore (2002) found, using a tracer in Ontario peats, that 20–50% of the tracer was recovered from depths at which the tracer would have been absent if preferential flow had not occurred. Others have shown that macropores can locally impact the rate of water transmission through peats (Chanson and Siegel, 1986; Ingram et al., 1974). Baird (1997) studied a fen peat with a tension infiltrometer finding that macropore flow contributed between 51% and 78% of the flow at the peat surface.

Little research has been done on the comparative roles of macropores of different sizes in conducting water through peats. Porous media physics would suggest that it is likely that the larger pores play a significant role in transporting water through peats rather than the smaller pores but field and laboratory determinations have been rare. Carey et al. (2007) employed tension infiltrometer measurements and image analysis on subarctic organic soils to assess the role of different pore sizes in peat water transmission. They found that total effective porosity was 1.1×10^{-4} which accounted for only 0.01% of the total soil volume with macropores (defined as those pores larger than 1 mm in diameter) accounting for approximately 65% of the water flux at saturation. Effective porosity is the interconnected pore volume that contributes to fluid flow. This compares to total porosity which is the proportion of the soil mass that is filled by pore spaces as opposed to solid material. Values of effective porosity have been well reported for agricultural soils. For example, Azevedo et al. (1998) found that

* Tel.: +44 113 343 3317; fax: +44 113 343 3308.
E-mail address: j.holden@leeds.ac.uk

0022-1694/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhydrol.2008.11.010

86% of the flow in a loamy agricultural soil occurred through 0.02% of the soil volume. It may be that similar values occur in blanket peats but this has hitherto not been determined. While Carey et al. (2007) examined water flows through pores of different sizes in subarctic organic soils, to the author's knowledge there has been no work to examine water flux or effective porosity related to pores of different size classes in intact blanket peats. Most of the research carried out on macroporosity in blanket peatlands has been done on mined peat stockpiles for power stations in order to determine the most productive water retention and rewetting characteristics. Holden and Ward (1996) found that in some rewetted milled peat stores the water content at depth in the profile was greater than near the surface, suggesting a short-circuiting of water flow through them. Some evidence came from 'wet fingers' that were observed in the field (Holden and Ward, 1997). Further evidence came from Holden (1998) who examined air-dried milled peat from the surface of a drained bog. From core samples, outflow was similar to the spray rate and little water accumulated in the peat. Bypassing flow paths appeared to form readily.

Macroporosity is important for transport characteristics of solutes (Ours et al., 1997; Reeve et al., 2001) and indirectly influences peatland gas exchange (Siegel et al., 1995). Since most of the runoff in blanket peatlands is generated within the upper peat, these layers will also be important in terms of solute production. Runoff emerging from blanket peat catchments suffers from several water quality problems, including high concentrations of dissolved organic carbon which is associated with discolouration. In the UK, which hosts 15% of the world's blanket peat deposit, the headwater blanket peats are sources for large quantities of solutional discolouring organics, which are an expensive and growing problem for water supply companies (Mitchell and McDonald, 1992, 1995; Mitchell, 1990; Worrall et al., 2003, 2006). Understanding flow through differently sized peat pores would enable us to improve our transport models, and our understanding of dissolved organic carbon production and solute transport. This is because the flow pathway, pore sizes, tortuosity and continuity will have an impact on water residence time and the interactive surface area that the solution can come into contact with (Allaire et al., 2002a,b).

Blanket peat is formed from the residue of vegetation that grows on it. For this reason its structure is likely to be partly affected by the surface vegetation. The structure of plant roots and litter produced by living vegetation will also interact with the upper peat layer to impact its structure and the potential for bypassing flow. Furthermore, bare peats often suffer from desiccation in dry spells and frost-heave in cold spells (Gilman and Newson, 1980; Tallis, 1973). Thus, unprotected peats may have a different structure in the upper layers due to these physical processes. It would be expected that the vegetation cover type would have some control over the proportion of flow moving through different pore size classes. Additionally Bradley and Van Den Berg (2005) examined infiltration in a flood-plain wetland peat formed largely from reeds and found large changes in water flow through large and small pores with depth. As peat properties can change rapidly with depth it is also expected that depth will control the proportion of flow moving through different pore size classes in blanket peat.

This paper aims to examine the role of a range of pore sizes in the infiltration and percolation process in blanket peat and to assess whether the flow in the different pore size classes is affected by vegetation cover type and distance from the peat surface. Unpublished data collected during the course of experiments performed by Holden et al. (2001) will be examined for the first time in this paper. It is hypothesised that (i) flow through small pores (<0.25 mm in diameter) plays only a small role in infiltration and percolation in the upper 20 cm of blanket peat; (ii) that the vegetation cover type controls the proportion of water that flows through different macropore size classes and (iii) that effective porosity will be effected by vegetation cover type.

Some authors have classified pores into macropores, mesopores and micropores, where the latter corresponds with the small pores associated with the soil matrix (Luxmoore, 1981). Definitions of the size of such features vary. In this paper four pore size classes with the ranges <0.25 mm, 0.25–0.50, >0.50–1.00 mm and >1.00 mm are investigated. In order to avoid confusion these pore sizes classes are not given descriptive terms here.

Study site

The experiments were performed at the Moor House National Nature Reserve, North Pennines, England (54°41'N, 2°23'W). This is one of the largest areas of blanket bog in the UK and as a UNESCO Biosphere Reserve is recognised for its worldwide importance. Lower Carboniferous sequences of interbedded limestone, sandstone and shale provide a base for a glacial till (Johnson and Dunham, 1963). The overlying glacial till has resulted in poor drainage which has led to the development of a one to four metre thick deposit of blanket peat on around 70% of the reserve. Peat formation began in the late Boreal as bog communities began to replace birch forest, macro-remains of which are commonly found at the base of the peat (Johnson and Dunham, 1963). The vegetation is dominated by *Eriophorum* sp. (cotton grass), *Calluna vulgaris* (ling heather) and *Sphagnum* sp. (moss). There are also some areas of bare peat, although many of these areas are now revegetating (Evans and Warburton, 2005). The upper 5 cm of the intact vegetated soil is generally poorly humified, graded H2–H3 on the Von Post (1922) scale, with a black–brown coloured peat with living roots. Below this to 10 cm depth the peat is a slightly humified (H3–H4) brown peat overlying darker brown *Eriophorum–Calluna–Sphagnum* peat (H4). The peat, then, very gradually becomes more humified with depth, with decomposition almost complete by 1.5 m depth (H9). Further details on the peat at the study site are provided in Johnson and Dunham (1963) and Holden et al. (2001). Dry bulk densities range from 0.15 g cm^{-3} at the surface to 0.18 g cm^{-3} at 20 cm depth gradually increasing to 0.27 g cm^{-3} at 50 cm depth. Total porosity of the blanket peat at the site is typically within the range of 90–97% which corresponds well with total porosity for blanket peats reported elsewhere (Bozkurt et al., 2001).

Methods

A tension disk infiltrometer similar to that designed by Ankeny et al. (1988) was used in the study during summer 1999. A 100 m $\times$ 100 m area was used for sampling and contained the four most common surface types found at the field site (*Calluna, Eriophorum, Sphagnum* and bare peat). Infiltration measurements were taken at eight randomly chosen sites for each cover type and at four depths (0 cm, 5 cm, 10 cm and 20 cm) at each site. At each location vegetation was carefully cut back to the peat surface and a fine layer of moist silica sand was applied to smooth out irregularities and improve contact between the base of the porous disk of the infiltrometer and the soil surface. The instrument was supported with a clamp–stand structure to prevent the weight of the instrument compressing the peat surface and was shaded to prevent sunlight heating the water reservoir. Infiltration measurements were performed until steady-state was achieved. The measurements were performed with supply heads of −12 cm, −6 cm, −3 cm and 0 cm. According to capillary theory, infiltration at these soil water tensions will exclude pores of equivalent diameter greater than 0.25 mm, 0.5 mm and 1 mm, respectively, from the