A hydrological classification of UK soils based on soil morphological data

Allan Lilly[A]

[A]Macaulay Land Use Research Institute, Aberdeen, Scotland, United Kingdom, Email a.lilly@macaulay.ac.uk

Abstract
Hydrologists are often required to predict river flows, for example, when designing flood protection or river management schemes. Where historical records exist, flow indices can be calculated statistically but where there are none, or few records, other methods need to be used. The Hydrology of Soil types (HOST) classification makes use of the fact that the physical properties of soils, and soil structure in particular, have a major influence on catchment hydrology. While it is recognised that the soil hydraulic conductivity, soil water storage capacity and the pathways of water movement through the soil are the most important, these attributes are spatially and temporally variable making them costly and time consuming to measure. However, many of the morphological attributes recorded during soil survey describe key features of soil hydrology. Through the use of pedotransfer rules and functions, these attributes were used to develop a UK soil hydrological classification capable of predicting river flow levels of ungauged catchments (r^2 =0.79, s.e.e =0.089 in the case of *Base Flow Index*) and can be used in predictions of water quality, land suitability and environmental assessments.

Key Words
Soil morphology, hydrology, pedotransfer, hydropedology.

Introduction

Hydrologists are often required to predict river flows, for example, when designing flood protection or river management schemes. Where historical records exist, flow indices can be calculated statistically but where there are none, or few records, other methods need to be used. Various catchment scale models have been developed which are capable of predicting river flows. Some predict flows according to the topography within a catchment while others take cognisance of the fact that the nature and distribution on soils within a catchment can greatly influence both the flood response and the base flow characteristics of its streams and rivers. Processed-based models attempt to model the soil hydrological process in three dimensions and at numerous points over the catchment. These models generally require large amounts of soil data such as soil moisture retention characteristics and hydraulic conductivities which are inherently spatially and temporally variable. Another approach is to utilise the vast store of soil morphological data that often resides in soil survey archives throughout the world.

This has been achieved within the UK where 3 national soil survey organisations collaborated with hydrologists to produce a soil hydrological classification based on soil morphological data. The classification is called HOST (Hydrology of Soil types) and groups all UK soils into one of 29 response classes capable of predicting base and flood flows in UK rivers.

Methods

Using existing pedotransfer rules (PTRs) and functions that were derived for earlier land evaluation schemes, a set of soil profile attributes were derived that were subsequently used to develop the HOST classification. These properties were:

- Depth to a slowly permeable layer
- Depth to gleying
- Integrated air capacity (volume of pores that drain under the influence of gravity)
- An assessment of hydrogeology of the underlying substrate
- Presence or absence of peaty surface layers
- Notional depth to groundwater
- Spatial distribution of soil properties within catchments

Much of the initial work that lead to the development of the HOST classification came from the derivation of regression-based pedotransfer functions (PTFs) to predict soil structural properties responsible for water storage and flow such as water retention (e.g., Reeve *et al.* 1973; Hall *et al.* 1977; Hollis *et al.* 1977) and from the use of morphological attributes to estimate packing density, air capacity (pores >60 µm), and

Available Water Capacity (e.g., Hodgson 1997). This work, and that by others such as Thomasson (1975; 1978) and Avery (1980), also led to the development of the PTFs and PTRs used in UK land resource evaluation systems for Scotland (Bibby *et al.* 1982) and for England and Wales (MAFF 1988). The latter publication in particular set out the PTRs that underpins much of the HOST classification where texture-based class PTFs were developed to predict Available Water Capacity (θ_5 - θ_{1500}) for each soil texture class and modified according to soil structure (type, size, and grade) and consistence such that moderate and poor structures were deemed to have less available water. There are also complex PTRs largley based on soil structure assessments to determine if a soil horizon is slowly permeable (*Ksat* <10 cm/day), which influences a range of hydrological properties of the soil. First, the physical properties of the soil such as ped type, ped size, texture, consistence, and the presence of biopores are assessed. A slowly permeable horizon is recognized from the various combinations of these properties (Figure 1) and its presence within the profile is confirmed by evidence of gleying in either that horizon or the one immediately above. Gleying is strictly defined in terms of soil colour, and the presence of mottling or gleying on ped faces (Avery 1980). Soils with high value but low chroma (grey and pale colours) are classed as gleyed.

<table>
<tr><th rowspan="2">PED SHAPE</th><th colspan="4">PED SIZE</th></tr>
<tr><th>Fine</th><th>Medium</th><th>Coarse</th><th>Very coarse</th></tr>
<tr><td>Granular</td><td colspan="2" rowspan="2">permeable</td><td colspan="2"></td></tr>
<tr><td>Subangular blocky</td><td colspan="2">slowly permeable if >18% clay and weakly developed structure</td></tr>
<tr><td>Angular blocky</td><td colspan="2">slowly permeable if >18% clay and weakly developed structure</td><td colspan="2" rowspan="3">slowly permeable if >18% clay</td></tr>
<tr><td>Prismatic</td><td></td><td></td></tr>
<tr><td>Platy</td><td colspan="2"></td></tr>
<tr><td>Massive</td><td colspan="4">slowly permeable if >18% clay or a silty loam, sandy silt loam or sandy loam texture and at least a firm consistence</td></tr>
</table>

Figure 1. Diagrammatic representation of the combinations of structure, texture and consistence which are characteristic of slowly permeable layers (*Ksat* <10 cm day^{-1}) in British soils (After MAFF 1988).

The rules and functions were applied to soil profile data held within the national soil databases in order to develop an attribute database of semi-quantitative soil properties from which the hydrological responses and flow pathways within UK soils could be predicted. Multiple regression analyses of these properties against two hydrological indices (Base Flow Index and Standard Percentage Runoff) were used to develop the soil hydrological classification through an iterative process that also involved conceptualising the dominant pathways of water movement through the soil and substrate (Figure 2).

Results

Through an iterative process of multiple linear regression of a hydrological index (Base Flow Index) against the proportion of these attributes within a catchment, a soil hydrological classification with 29 classes was developed for UK soils (Boorman *et al.* 1995). The resulting classification is capable of predicting river flow levels of ungauged catchments (r^2 =0.79, s.e.e =0.089 in the case of *Base Flow Index*) and can be used in predictions of water quality, land suitability and environmental assessments. More importantly, it has demonstrated the value of the soil morphological and observational data collected as part of normal soil survey activities for predicting hydrological responses. Table 1 shows the HOST framework and the values for the Standard percentage Runoff for a particular HOST class.

Conclusions

The development of the HOST classification has demonstrated the value of soil morphological data such as soil texture, structure and colour in predicting hydrological response and is also an example of how hydrology and pedology can be brought together to form a true hydropedological classification. HOST is now embedded in many hydrological software packages designed for applied hydrologists who are largely unaware of the extent of the soils component. As well as being useful to hydrologists, HOST has been used in modeling nitrate leaching, apportioning flow in biogeochemical models and predicting the potential for groundwater contamination by microbes.

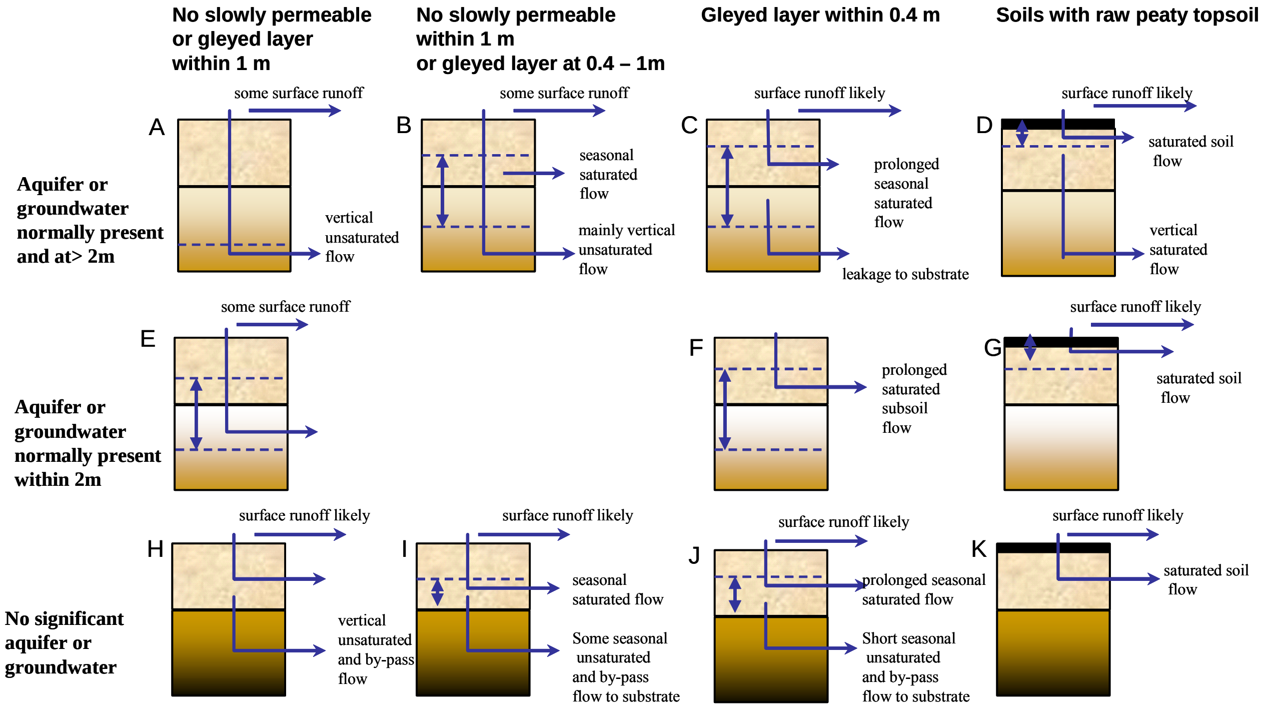

Figure 2. HOST conceptual response models used to classify soil cover (structural) units.

Table 1. The HOST framework with HOST class (black) and Standard Percentage Runoff index (brackets) for all UK soils.

Substrate hydrogeology	groundwater or aquifer	Mineral soils: No SPL or gleying	Mineral soils: SPL within 100 cm or gleyed within 40- 100cm		Mineral soils: Gleyed within 40cm		Peat soils	
Weakly consolidated microporous, by-pass flow uncommon	Normally present and at > 2m	1 (2); 2 (2)	13 (2)		14 (25.3)		15 (48.4)	
Weakly consolidated macroporous, by-pass flow uncommon		3 (14.5)						
Strongly consolidated, non - slightly porous, by-pass common		4 (2)						
Unconsolidated, macroporous, by-pass flow uncommon		5 (14.5)						
Unconsolidated, microporous, by-pass flow common		6 (33.8)						
					IAC<12.5	IAC>12.5	drained	undrained
Unconsolidated, macroporous by-pass flow uncommon	Normally present and at<2m	7 (44.3)			9 (25.3)	10 (25.3)	11 (2)	12 (60)
Unconsolidated, microporous, by-pass common		8 (44.3)						
			IAC>7.5	IAC<7.5				
Slowly permeable	No significant aquifer or groundwater	16 (29.2)	18 (47.2)	21 (47.2)	24 (39.7)		26 (58.7)	
Impermeable (hard)		17 (29.2)	19 (60)	22 (60)			27 (60)	
Impermeable (soft)			20 (60)	23 (60)	25 (49.6)			
Eroded peat							28 (60)	
Raw peat							29 (60)	

References

Avery BW (1980) 'Soil classification for England and Wales (Higher Categories). Soil Survey Technical Monograph no.14. Soil Survey of England and Wales'. (Lawes Agricultural Trust: Harpenden).

Bibby JS, Douglas HA, Thomasson AJ, Robertson JS (1982) 'Land capability classification for agriculture. Soil Survey of Scotland Monograph'. (The Macaulay Institute for Soil Research: Aberdeen).

Boorman DB, Hollis JM, Lilly A (1995) 'Hydrology of Soil Types: A Hydrologically-Based Classification of the Soils of the United kingdom. Institute of Hydrology Report No. 126'. (Institute of Hydrology: Wallingford).

Hall DGM, Reeve MJ, Thomasson AJ, Wright VF (1977) 'Water retention, porosity and density of field soils. Soil Survey Technical Monograph no.9. Soil Survey of England and Wales'. (Lawes Agricultural Trust: Harpenden).

Hollis JM, Jones RJA, Palmer RC (1977) The effects of organic matter and particle size on the water retention properties of some soils in the west Midlands of England. *Geoderma* **17,** 225-238.

Hodgson JM (1997) 'Soil Survey Field Handbook: Describing and Sampling Soil Profiles. 3rd Edition. Soil survey Technical Monograph No. 5'. (Soil Survey and Land Research Centre: Silsoe, England).

MAFF (Ministry of Agriculture Fisheries and Food) (1988) Agricultural land classification of England and Wales.

Reeve MJ, Smith PD, Thomasson AJ (1973) The effect of density on water retention properties of field soils. *Journal of Soil Science* **24,** 355-367.

Thomasson AJ (1975) 'Soils and Field Drainage. Soil Survey Technical Monograph No.7. Soil Survey of England and Wales'. (Lawes Agricultural Trust: Harpenden).

Thomasson AJ (1978) Towards an objective classification of soil structure. *Journal of Soil Science* **29,** 38-46.