Trees, water storage and flooding in upland agricultural landscapes

Healey, John; Smith, Andrew; Pagella, Tim; Ford, Hilary

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Trees, water storage and flooding in upland agricultural landscapes: why do we need to know more?

by **Hilary Ford, Andy Smith, Tim Pagella** and **John Healey**, Bangor University

Trees and flooding: it's obvious isn't it?

The potential use of trees to mitigate floods has been recognised for over 100 years[1], but has come to the fore in recent months following the extreme rainfall and associated flooding across the north of England and parts of Wales, during December 2015. It is increasingly acknowledged that hard-engineered flood barriers have largely reached their capacity to cope with the volume of water reaching the lowlands, so attention is switching to more natural methods of flood mitigation across the whole river catchment. The assertion that trees should be planted in uplands, riparian zones or on other marginal agricultural land in order to enhance water retention and reduce flooding downstream has recently been given serious consideration. But how good is the evidence that this will actually be effective? It would be a mistake for forestry to claim benefits that will not actually be delivered. Firstly, it is important to note that different forms of forestry vary greatly in their hydrological effects. Traditionally, planting conifer forests often involved extensive ground preparation. Whilst they provide an evergreen canopy cover for 12 months of the year (except for larch), open conditions are created at the end of the cycle through large-scale clear felling. In this article, we will focus on the other end of the spectrum: integration of small-scale tree planting, such as hedgerows and shelterbelts *(Figure 1)*, into the existing agricultural landscape. We review the scientific evidence of their impacts on water storage and flood prevention.

Some groups advocating tree planting to reduce flood risk have often supported their arguments by reference to experimental work that links deciduous trees planted in pasture land to enhanced water movement through the topsoil in summer. These studies, carried out in the Pontbren catchment of mid-Wales do show that soil water infiltration rates were up to 67 times greater in fenced-off land under trees than in adjacent pasture, and that surface run-off was reduced following tree planting[2,3,4]. However, those quoting this work have often extrapolated too far from its results by using it as evidence that trees of any species have the capacity to minimise water run-off and increase water storage in all seasons, thereby preventing winter flooding. Instead we recommend giving far more consideration to the impact of soil properties, land drainage, landscape topography, differences between tree species (e.g. in rooting depth and morphology) and the need to distinguish the effects of trees from the exclusion of livestock by fencing. In comparison, recently published work[5,6], showing much smaller changes in infiltration rates between land under trees and adjacent pasture has been largely ignored. This work, conducted on hill slopes in the Scottish borders, showed that infiltration rates[#] were 5-8 times greater in mature broadleaved or mixed woodlands than in adjacent intensely-grazed pasture. Subsequent work in the Cairngorms showed that soil infiltration rates were greater in mature Scots pine plantations (48 and 300 years old) than in either a younger plantation (6 years old) or neighbouring grazed pasture[6]. However, in another study they found no significant difference in soil infiltration rates between a Scots pine plantation and adjacent pasture[5].

How do trees modify water use and storage?

Trees modify water use by several mechanisms, including interception of rainfall, increased water infiltration into the soil matrix via channels created by roots, and evaporation of water via the root-stem-leaf pathway *(Figure 2)*. The trees' litter can also make an important contribution to soil organic matter and structure, especially if it increases the abundance of burrowing

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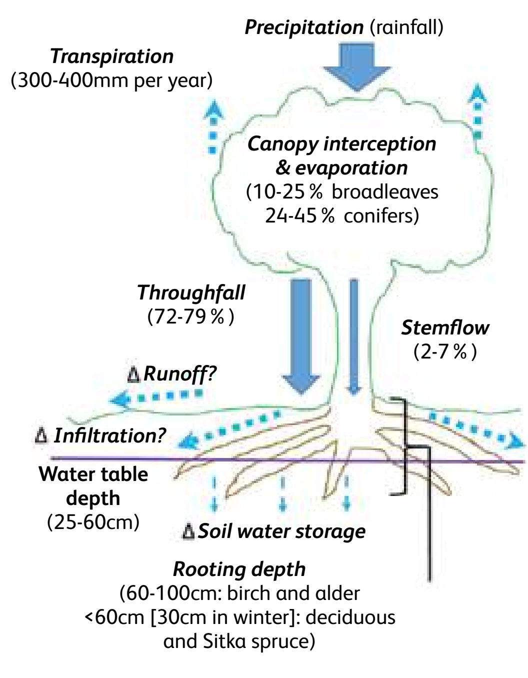
Fig 1. Examples of small-scale tree features, a hedgerow and shelterbelt at Pontbren, embedded in the agricultural landscape.



Precipitation is usually rain but can also be snow, sleet, hail or drizzle.
Stemflow is the portion of precipitation that is funnelled to the base of the trunk.
Throughfall is the portion that reaches the ground via gaps in the canopy, or drips from leaves, twigs, and branches.
Canopy interception & evaporation is the portion of rain that is stored in the canopy then evaporated, never reaching the ground.
Transpiration is the process of water moving through the roots and trunk and water vapour eventually exiting to the atmosphere via pores called stomata on the underside of the leaves.
Runoff is water that flows down hill slopes as surface water.
Infiltration is the process by which water on the ground surface enters the soil.
Water table depth is the level below which the soil is saturated with water.
Rooting depth is often restricted by water-logged soil conditions, particularly in winter when the water table is high and roots die back.
Soil water storage is the water held between soil particles and roots in the soil matrix. **It is uncertain how much water is stored under trees particularly when the water table is already high**

Fig 2. Effects of trees on the water cycle with implications for soil water storage. Quantification of canopy interception and evaporation, throughfall and stemflow[7,8,9] transpiration rates[10], water table depth[11,12] and rooting depth[13,14].

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earthworms that act to improve soil structure by altering soil particle aggregation and pore size. These mechanisms have been cited in support of the case for trees enhancing water storage and reducing flood risk. There will always be limits to the capacity of land to store water. Using the analogy of a sponge, prolonged rainfall will eventually completely saturate soil so that the rate of water flowing out equals the rate of water flowing in. Therefore, while tree planting can reduce the rate of water flow from the land into streams during short periods of rainfall, it does not necessarily mean that it will continue to do so during the long-duration rain events that can lead to the most serious floods.

How do soil properties and land use affect upland hydrology?

UK uplands have a high proportion of organic, podzol and gley soils. Land use can result in an O horizon of organic material at different states of decomposition which has a high water-holding capacity, an A horizon (topsoil), often compacted by sheep grazing (top 5 cm), or a plough pan at ~30 cm as a result of agricultural improvement, on top of a B horizon of variable depth, sitting on relatively impermeable bedrock. In addition, many upland areas contain field drains, designed to move water downstream as quickly as possible, reducing water holding capacity. These factors combine to increase the rate of water flow into streams under high rainfall leading to flash flood incidents.

It is possible that planting trees in the uplands where soil depth is sufficient could improve soil structure, water infiltration into deep soil, and water storage, but the gains achieved are likely to depend on interactions between a site's soil type and the rooting properties of the planted species. For example, tree roots have been shown to alter soil conditions in clay soils but may make little difference in sandier ones. In the un-enclosed uplands, data on soil depth is scarce, but in this heterogeneous landscape there will be areas of shallow soil adjacent to exposed rocky outcrops. Here it is not known how soil properties, such as depth, texture, bulk density* and porosity or slope, would interact with deciduous or coniferous afforestation to alter infiltration rates and water storage capacity. In order to see the benefits of increased infiltration rates under trees then the size of the riparian area, or the distance trees are planted away from the river's edge, are also likely to be key factors.

What about hydrological models?

Hydrological models are traditionally designed for flooding solutions downstream, therefore the parameters they include to characterise the upland part of the catchment are often broad, e.g. woodland is 'rougher' than grassland so will slow water more. However, Forest Research and the James Hutton Institute have been developing models that work at smaller scales and can incorporate natural flood management. Working at this scale would allow us to work out how trees of different types (position, age, species) influence water storage and flooding peaks. Initial research seems to suggest that natural flood management, including tree planting, might decrease flash flood peaks at the local scale, but it is unknown how they relate to flooding at larger scales.

What is the evidence from Pontbren and why can't we extrapolate from it?

Evidence from the upper Pontbren catchment in mid-Wales showed that soil surface runoff was reduced by 78 % in tree-planted plots after two years, compared with sheep-grazed pasture, by these kinds of mechanisms[4]. However, simply excluding livestock by fencing, without tree planting, caused a 48 % reduction. In addition, near-surface bulk density was significantly reduced and soil infiltration rates were 60-67 times greater in fenced plots planted with trees compared with grazed pasture[2,4]. Further work from a Pontbren hillslope reported significantly reduced runoff downslope under a 10-year-old shelterbelt compared with adjacent sheep-grazed pasture[3].

The work at Pontbren did not test the effect of tree species or soil type, which will be key factors in determining root morphology and depth, in turn altering infiltration rates, run-off and potential water storage in the B soil horizon. In the recent study[4] often quoted by those advocating afforestation of the uplands with production forests, plots were planted with a high diversity mix of native deciduous tree species that have a variety of contrasting rooting morphologies, whereas the shelterbelt study site used in the 2009 study[3] comprised a mix of five deciduous and two coniferous species. Despite this initial evidence the extent to which tree roots are able to access a potentially un-saturated B horizon is still unknown.

What is the way forward?

The Multi-Land project, funded by Welsh Government with researchers from Bangor University, Centre for Ecology and Hydrology (CEH) and Aberystwyth University, and involving the Woodland Trust, Coed Cymru, National Trust, Natural Resources Wales, Snowdonia National Park Authority and RSPB, aims to build on this preliminary evidence base and examine the link between upland tree features, water storage and flooding in more detail. We will consider: i) the impact of small-scale tree features in farmland on water movement; ii) whether this evidence can be linked to water storage and flooding and iii) best practice for the future.

Footnotes

infiltration rates were measured by field-saturated hydraulic conductivity in both Archer studies[5,6]. Hydraulic conductivity is a property of soils that describes the ease with which a fluid (usually water) can move through pore spaces or fractures.
* bulk density is defined as the dry weight of soil per unit volume of soil e.g. 1.5 g / cm^3.

For more information on the Multi-Land project please see **www.nrn-lcee.ac.uk/multi-land/** or contact Dr. Hilary Ford,
hilary.ford@bangor.ac.uk

References

1 McCulloch, J.S.G. and Robinson, M (1993). History of forest hydrology. *Journal of Hydrology*, 150, 189-216.

2 Carroll, Z.L., Bird, S.B., Emmett, B.A., Reynolds, B. and Sinclair, F.L. (2004). Can tree shelterbelts on agricultural land reduce flood risk? *Soil Use and Management*, 20, 357-359.

3 Marshall, M.R., Francis, O.J., Frogbrook, Z.L., Jackson, B.M., McIntyre, N., Reynolds, B., Solloway, I., Wheater, H.S. and Chell, J. (2009). The impact of upland land management on flooding: results from an improved pasture hillslope. *Hydrological Processes*, 23, 464-475.

4 Marshall, M., Ballard, C., Frogbrook, Z., Solloway, I., McIntyre, N., Reynolds, B. and Wheater, H. (2014). The impact of rural land management changes on soil hydraulic properties and runoff processes: results from experimental plots in upland UK. *Hydrological Processes*, 28, 2617-2629.

5 Archer, N.A.L., Bonell, M., Coles, N., MacDonald, A.M., Auton, C.A. and Stevenson, R. (2013). Soil characteristics and landcover relationships on soil hydraulic conductivity at a hillslope scale: A view towards local flood management. *Journal of Hydrology*, 497, 208-222.

6 Archer, N.A., Otten, W., Schmidt, S., Bengough, A.G., Shah, N. and Bonell, M. (2015). Rainfall infiltration and soil hydrological characteristics below ancient forest, planted forest and grassland in a temperate northern climate. *Ecohydrology*. doi: 10.1002/eco.1658.

7 Calder, I. R., Reid, I., Nisbet, T. and Green, J. C. (2003). Impact of lowland forests in England on water resources – application of the HYLUC model. *Water Resources Research*, 39, 1319-1328.

8 Neal, C., Robson, A. J., Hall, R. L., Ryland, G., Conway, T. and Neal, M. (1991). Hydrological impacts of hardwood plantation in lowland Britain: preliminary findings on interception at a forest edge, Black Wood, Hampshire, southern England. *Journal of Hydrology*, 127, 349-365.

9 Iroume, A and Huber, A. (2002). Comparison of interception losses in a broadleaved native forest and a *Pseudotsuga menziesii* (Douglas fir) plantation in the Andes Mountains of southern Chile. *Hydrological Processes*, 16, 2347-2361.

10 Nisbet, T. (2005). *Water Use by Trees, Information note*, Forestry Commission, www.forestry.gov.uk.

11 Ray, D. and Nicoll, B.C. (1998). The effect of soil water-table depth on root-plate development and stability of Sitka spruce. *Forestry*, 71, 169-182.

12 Dixon, S.D., Qassim, S.M., Rowson, J.G., Worrall, F., Evans, M.G., Boothroyd, I.M. and Bonn, A. (2014). Restoration effects on water table depths and CO2 fluxes from climatically marginal blanket bog. *Biogeochemistry*, 118, 159-176.

13 Christen, B. (2007). *Tree root influences on soil physical properties under shelterbelts on pasture: design and evaluation of an approach using dye staining*. MSc thesis, Bangor University.

14 Nicoll, B.C. and Coutts, M.P. (1998). Timing of root dormancy and tolerance to root waterlogging in clonal Sitka spruce. *Trees*, 12, 241-245.