Woodland in the mountainous Derwent catchment, Cumbria.

The significance of wet-canopy evaporation

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Following devastating floods in Cumbria in the last two decades, natural flood management has certainly come up the agenda. As part of the response, the Woodland Trust has been facilitating some large-scale woodland creation schemes in places such as Tebay and Mallerstang, and is working with Lancaster University to research the resulting impacts on water through wet-canopy evaporation.

In Cumbria, several centuries of intense grazing pressure in upland habitats has denuded them of pretty much any tree cover over vast areas. This has left a legacy which people seem to value highly despite the lack of wildlife and ecological resilience. The debate about the role our uplands could play where planting trees might be the answer – for climate, biodiversity and people – is challenging and polarised, often along cultural or farming lines; hence, the reason why the Woodland Trust is seeking common ground in Cumbria based on good science.

There are still many questions regarding the science underpinning natural flood management (NFM) effectiveness; for example, what size of flood event is relevant when assessing this effectiveness? Here we discuss the potential flood-mitigation effects of wet-canopy evaporation from new tree planting, based on our research as part of the Q-NFM project[1]. Estimation of NFM intervention effects is being carried out for three large river catchments in Cumbria; the River Kent, Derwent and Eden all caused major flooding downstream in Kendal, Cockermouth and Carlisle in 2015.

What is natural flood management?

'Nature-based solutions' that are able to significantly mitigate flood risk are often referred to as 'natural flood management' (NFM) in the UK[2]. NFM can involve storing flood water on slopes or in channels, increasing evaporation during storms, or enhancing infiltration – all with the objective of reducing flood risk by working with natural processes.

NFM can be both active, where specific interventions such as tree planting are made, or passive, where intensive management is halted and natural regeneration allowed. More specifically, NFM employs measures that have the potential to significantly modify the shape of a flood hydrograph to reduce the risk of overtopping channels and flooding homes and businesses.

How trees provide NFM

Trees have the potential to alter various hydrological processes. Tree growth can lead to increased soil-infiltration capacity, and so may reduce the rapid pathway of overland flow. Trees and other vegetation such as hedges may also impede water movement within inundated areas and thereby increase surface storage (often referred to as 'slowing the flow'). Evaporation from leafy and woody surfaces during storms, and longer-term effects of transpiration that make catchments drier at the start of storms, also attenuate the effects of the flood rainfall.

Wet-canopy evaporation

Evaporation from leafy and woody surfaces during rainstorms is known as ***wet-canopy evaporation*** or *interception loss*. For trees, this includes the leaves, stems, branches, and trunks. Many things control the amount of water that evaporates from wet surfaces, but the relative humidity of the air and the wind speed are particularly important during large and extreme rainfall events. Higher wind speed mixes more air from the atmosphere with the canopy airspace, and the drier the air the more evaporation can occur. As woodland promotes more mixing than, for example, intensively grazed grassland, it has the potential for higher evaporation.

The significance of wet-canopy evaporation for flood mitigation is not well known; it has received little attention in most NFM studies[3]. It is, however, possible that during some large rainfall events, enough water could be evaporated to make a difference – water that evaporates from wet surfaces goes back into the atmosphere and does not reach the ground, so does not contribute to flooding locally.

Our research aimed to fill this evidence gap, focusing particularly on storms where more than 50mm of rainfall occurred. We collated all available data from studies in temperate climates around the world to gain greater insight into how evaporation loss changes with rainfall-event size. The results indicate that although evaporation reduces with event size, significant evaporation can occur during large and extreme events[4]. Far fewer studies provide estimates for deciduous forest than coniferous forest, particularly during larger events. What does exist, however, suggests that less evaporation occurs during winter months when there are fewer (or no) leaves, but may still be significant.

Nick Chappell

Relative humidity sensor at the Bessy conifer evaporation plot.

New observations in Cumbria

We are undertaking new field research to increase our knowledge of wet-canopy evaporation during large rainfall events that typically occur in Cumbria during autumn and winter. This involves measuring ***gross rainfall*** (the rainfall that is received by the canopy) and ***net rainfall*** (the rainfall that reaches the ground). Wet-canopy evaporation is simply the difference between the two. Rainfall reaches the ground by falling through gaps in the canopy and when it drips from the stems and leaves (known as ***throughfall***). Rainfall also reaches the ground by running along tree branches and then down trunks (known as ***stemflow***) – see diagram. Throughfall is measured using throughfall gauges, which may be similar in design to rain gauges (or may take the form of troughs or large plastic sheets). Collars attached to tree trunks capture stemflow and direct it into collectors (see photos). This data will improve our knowledge of the amount of evaporation that takes place during rainfall events that are large enough to flood communities in Cumbria.

Stemflow collar and tank.

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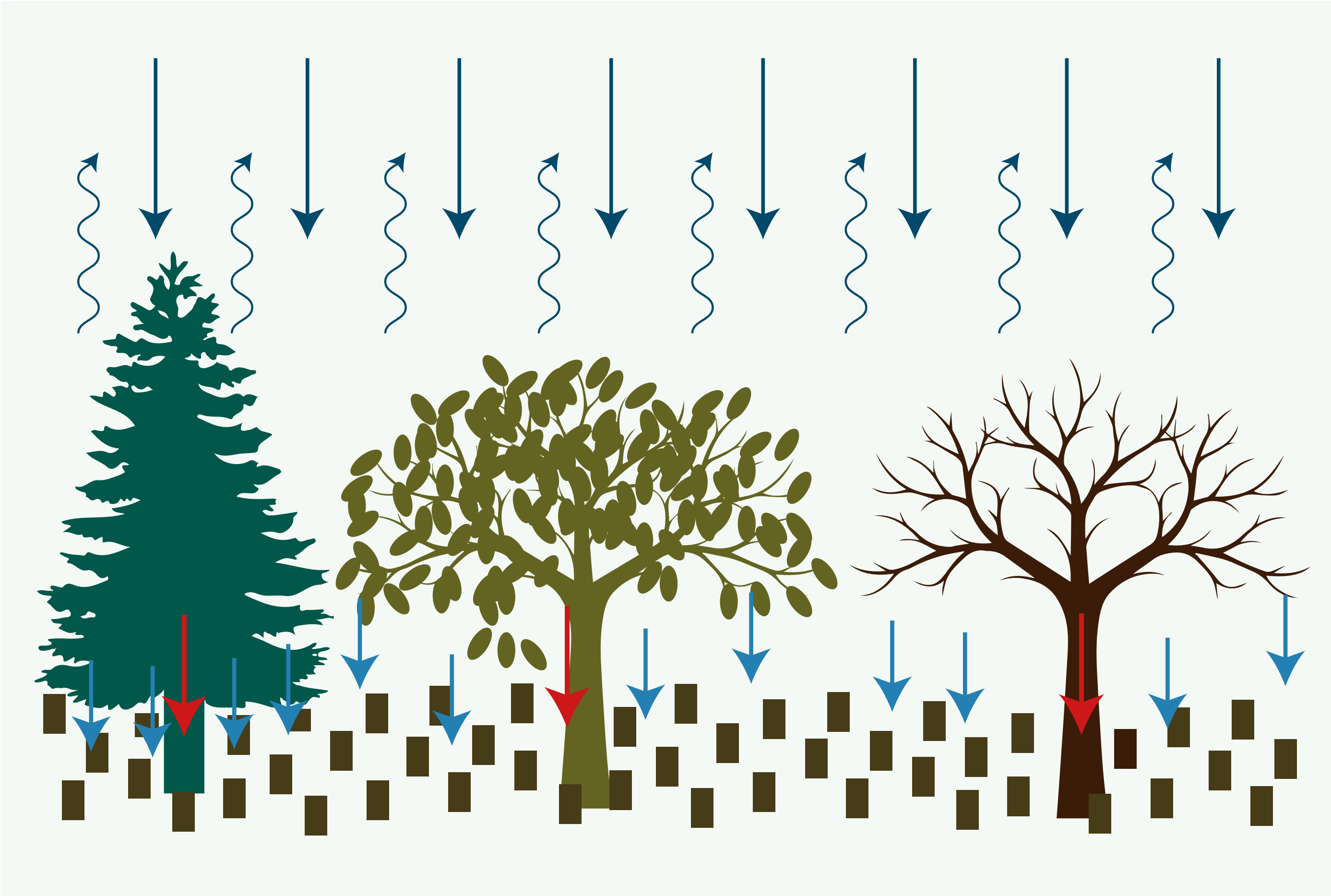
Experimental site within a small deciduous woodland.



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Schematic diagram of a wet-canopy evaporation experiment.

LEGEND
Evaporation from vegetation surfaces
Rainfall outside wood
Throughfall
Throughfall collector
Stemflow

How effective is deciduous woodland?

In the mountainous county of Cumbria, many native deciduous trees have been planted in the last decade, and more are needed to meet the ambition of creating connected vital habitats. Deciduous trees have seasonal variation in canopy structure because of variations in leafiness, and this affects the amount of water that can be captured by the canopy and the exposure of surfaces to the wind. Even when trees are completely leafless, because the branches and stems are more exposed to the wind (compared to a fully leafed canopy), the effective surface area may remain very large. This is particularly the case where there is a well-developed woodland understorey or complex age structure.

What does this mean for trees and NFM?

Trees, if numerous enough, have the potential to remove a significant amount of flood-event rainfall from a catchment by wet-canopy evaporation. The amount of water lost will vary at different locations and between flood events with different meteorological conditions. For example, for three extreme rainfall events in Cumbria that led to widespread flooding, we found that in some locations, prevailing meteorological conditions were consistent with a significant potential for evaporation, whereas in others the air was already saturated (100% relative humidity), and no evaporation would have occurred.

It is possible, however, to identify certain locations where evaporation is likely to be highest; for example, areas of rain shadow with respect to the dominant prevailing wind, such as the Eden Valley. Such areas tend to have a lower relative humidity, as can local valleys downwind of mountains. As the amount of evaporation is also related to canopy surface area, to make a significant difference to a flood hydrograph a large proportion of a river catchment upstream of an at-risk community would need to be planted with trees to be effective. Other forms of vegetation that have higher rates of evaporation compared to intensively managed pasture, such as hedges and scrub, should be considered too.

The next step for the Q-NFM project is to estimate the amount of evaporation during flood peaks in three notable periods of flooding in Cumbria over the last 20 years. Various scenarios of vegetation change are being considered to produce estimates of the effects of elevated wet-canopy evaporation rates on flood hydrographs using our catchment-scale hydrological modelling.

Science informing policy and practice

This work is timely and adds very positively to the upland debate. There are huge social, economic and environmental challenges in the uplands, so understanding the benefits for water of landscape-scale change – using the right trees and restoring peat bog and other mixed habitats – could be a game changer, coupled with changes in social and land management policy.

To mitigate major rainfall events we need large-scale interventions which reconnect habitats at a grand scale – even bigger than the 400 hectares of scrub that the Woodland Trust helped plant in Mallerstang valley in Cumbria's southeastern corner. We will need landowners and managers on board; if livestock grazing is removed or reduced, future jobs will be needed for those whose roles may be lost and livelihoods changed. It's a big debate, but understanding the science significantly helps these discussions along.

References

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4. Page, T., Chappell, N.A., Beven, K.J., Hankin, B., and Kretzschmar, A. (2020) Assessing the significance of wet-canopy evaporation from forests during extreme rainfall events for flood mitigation in mountainous regions of the United Kingdom. *Hydrological Processes*, 34: 4740–4754.

Nick Chappell

Almost leafless tree canopy showing a high density of woody canopy.

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