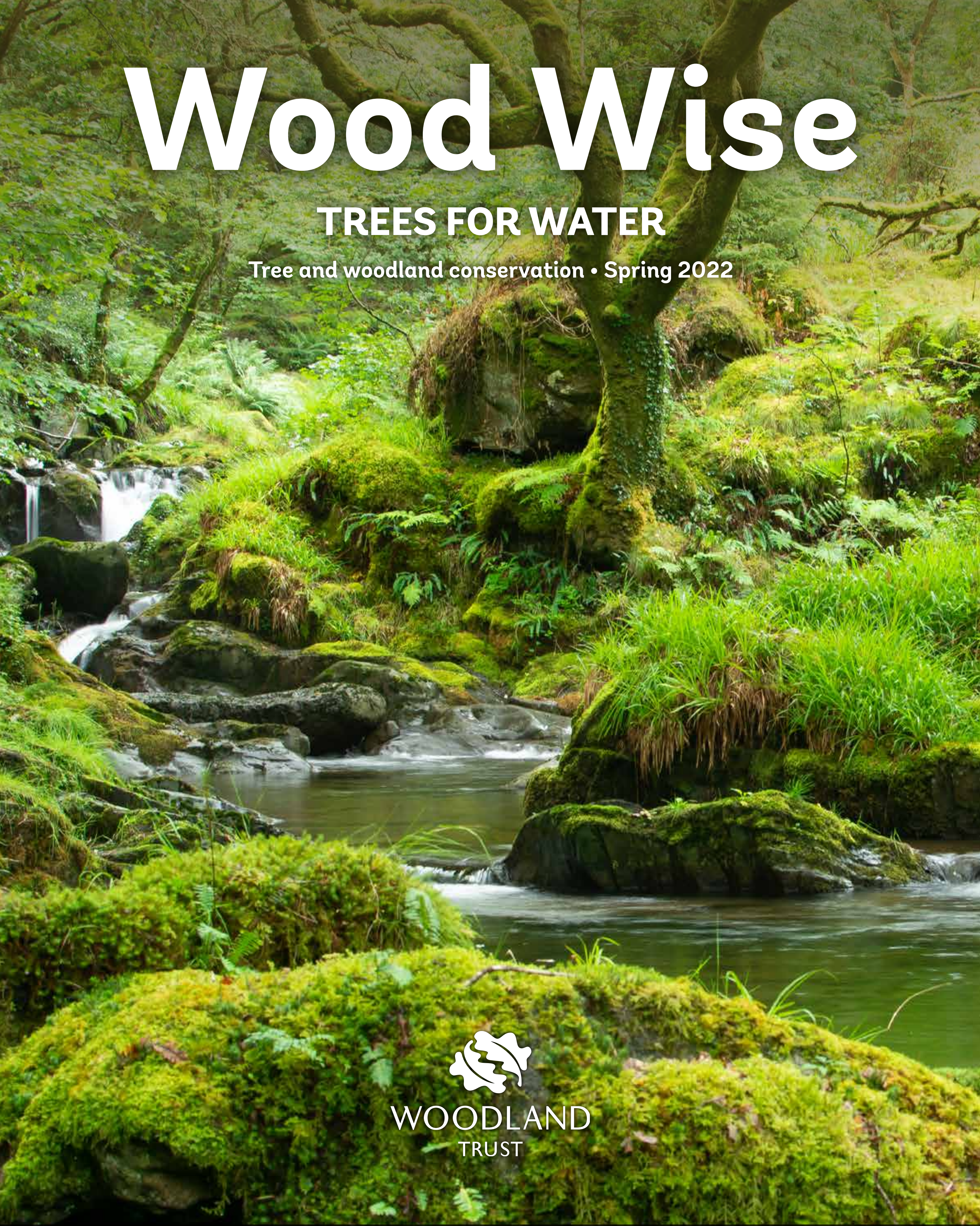
Wood Wise

TREES FOR WATER

Tree and woodland conservation • Spring 2022



WOODLAND TRUST

WET-CANOPY EVAPORATION

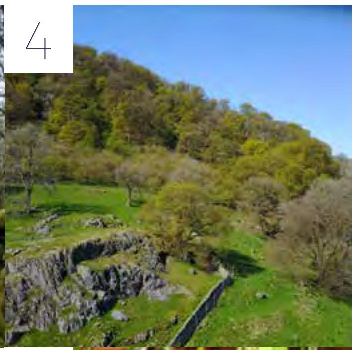
WHY RIVERS NEED TREES

SLOWING THE FLOW

BEAVER ENGINEERS

CONTENTS

3

4

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20

24

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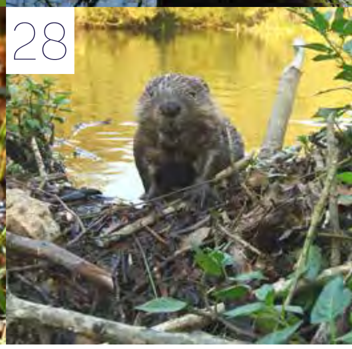
32


3 The power of trees

4 How broadleaf woodland alters flood risk

10 The significance of wet-canopy evaporation

16 Catchment-scale collaboration

20 Riverwoods – how trees create healthy river systems

24 Hold back the water

28 Beavers, trees and the freshwater environment

32 Plantation forestry impacts on water quality

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The power of trees

Abi Bunker

Trees have extraordinary powers. The most well known is their ability to capture and store carbon, providing an essential service as rates of greenhouse gas emissions threaten to push our climate beyond critical tipping points. But, unlike most superheroes, trees don't just have one special power. This is never more evident than in all the ways trees benefit freshwater environments.

Trees reduce flood risk, improve water quality and regulate the temperature of rivers, while woody material deposited in rivers slows the flow and provides habitat for aquatic wildlife. These are just a few of the benefits.

Fortunately, recognition of these hitherto underappreciated services provided by trees is increasing, and the environmental sector is forging the way to restore the damaged relationship between trees and water. Organisations are joining forces to work across whole catchments – the scale at which such natural processes operate. They are doing so armed with the latest science and technologies, and are innovating along the way – collecting data and evidence for what works, how, and why.

The Woodland Trust is one of the organisations leading the way in restoring treed landscapes to re-establish hydrological processes for the benefit of people and the environment. Around the UK we are involved in several initiatives. Through the Grow Back Greener programme, funded by Defra's Nature for Climate fund, we are partnering with the Ribble Rivers Trust to create 80 hectares of woodland by 2025 for multiple benefits for water. We also joined forces with the National Trust, Rivers Trust and Beaver Trust to form the Riverscapes partnership which is managing the £2 million Defra-funded Woodlands for Water project. This project aims to help landowners plant 3,150 hectares of riparian woodland by 2025. In Northern Ireland, we're collaborating with the Loughs Agency on the TREES project, helping farmers to put trees back into the landscape to provide shelter and shade for livestock, alleviate floods and prevent soil erosion in the Foyle and Carlingford catchment areas. And in Scotland we are partnering in the Scottish-Wildlife-Trust-led initiative 'Riverwoods', aiming to create a network of riparian woodland and healthy river systems throughout Scotland. Such initiatives provide inspiration and exemplars that we hope will be emulated and scaled up to bring the environmental improvements needed to prevent further natural catastrophes.

This issue of *Wood Wise* explores the relationship between trees and water through both lenses of science and practice. We hear from a range of scientists conducting innovative research into how trees benefit water, as well as potential disbenefits and how to mitigate them. Practitioners from the Woodland Trust and National Trust showcase how they are harnessing this evidence to utilise the power of trees for good through real-world examples. These large-scale partnership projects demonstrate the benefits for water of landscape-scale restoration – using the right trees and restoring peat bog and other habitats – and the need for changes in land management practices. This landscape-scale change requires the right policies and incentives as well as willing landowners.

Trees are, of course, simply one component of naturally functioning ecosystems, and catchment restoration requires restoring other key habitats, such as blanket bog, and bringing back other missing elements like the iconic beaver – a keystone species that does a far better job of engineering rivers to create dynamic wetland habitats than we ever could. Experts from the Beaver Trust describe what beavers do to our rivers and the benefits they can bring. Finally, we hear from a biogeochemist from the UK Centre for Ecology and Hydrology on the latest evidence relating to the impacts of upland conifer plantations on water quality.

Abi Bunker is director of conservation and external affairs at the Woodland Trust, providing strategic leadership across the Trust's conservation, campaigning and external advocacy work.

Mature broadleaf woodland in Cumbria.

How broadleaf woodland alters flood risk

Felicity Monger, Dominick Spracklen and Mike Kirkby



Felicity Monger is a PhD researcher studying woodlands and flooding, **Dominick Spracklen** is Professor of Biosphere Atmosphere Interactions, and **Mike Kirkby** is Emeritus Professor of Physical Geography – all at the University of Leeds.

Despite well-known connections between trees and water, the exact benefits of woodlands on flooding are still debated. Through our research – in which we compare woodland and grassland catchments in the uplands of the Lake District – we explore the ways that broadleaf woodlands reduce the risk of downstream flooding.

Flooding is a major risk to communities across the UK. In England, flooding causes £1.3 billion of damage to property each year. Climate change is expected to cause even more intense rainfall, further increasing the risk of flooding. Until recently, efforts to reduce flood risk mostly relied on concrete and hard engineering. In many cases, this is no longer sufficient to protect communities, and new approaches are needed to reduce the risk of flooding in the face of climate change. Another way of reducing flood risk is working with nature and natural processes to store more water and slow the flow of water across the land[1]. This is known as natural flood management (NFM) and includes planting trees and creating woodland, restoring rivers, and installing woody-debris dams.

Trees and woodlands can reduce downstream flooding in several ways. Woodlands increase water infiltration into the soil, increase soil water storage, and reduce the amount and speed of surface water runoff. Trees, woodland and hedgerows planted across a slope (cross-slope woodland) increase infiltration and interrupt surface water flow. Woodlands next to streams and watercourses (riparian woodland) increase water storage and the roughness of the watercourse, slowing the flow of water. Floodplain woodland (woodland and trees which are subject to regular flooding) contribute to reductions in river-flow velocity and help to desynchronise flood peaks of adjacent tributaries. When trees fall (or are placed) into a stream, woody-debris dams can form which further increase water storage and slow the flow of water. Together, these can reduce flood peaks and flood frequency.

Our research

While it is accepted that woodlands reduce flood risk during smaller flood events and for small catchments, the effects in larger storms and at larger catchments are less certain[2]. Furthermore, most previous UK research on woodlands and flooding has focused on conifer plantations, and there is relatively little work on broadleaf woodlands. Our research aimed to fill this gap.

We made detailed measurements of stream flow in small (less than 20 hectare) catchments dominated by upland broadleaf woodland, and compared them to catchments dominated by sheep-grazed grassland – a land use which covers large swathes of the UK's uplands. Working at RSPB Haweswater, we established v-notch weirs (see photo) and installed automated data loggers to measure the streamflow at five-minute intervals. This allowed us to compare how streams in woodland and grassland catchments responded to storm events. We also made detailed measurements of soil moisture and of how quickly water was able to permeate into saturated soils.

Measurements were taken of streamflow over a 13-month period (including the UK's wettest February on record) in three woodland and six grassland catchments. During this period, there were 28 storms, including Storm Ciara, a one-in-10-year storm. Peak stream flow during these storms was up to 60% lower in the woodland catchments compared to the grassland catchments (Figure 1)[3]. Crucially, we found that woodlands reduced the peak stream flow even in the biggest storms we measured.

Felicity Munger

Weir and equipment to measure streamflow in a small upland catchment.

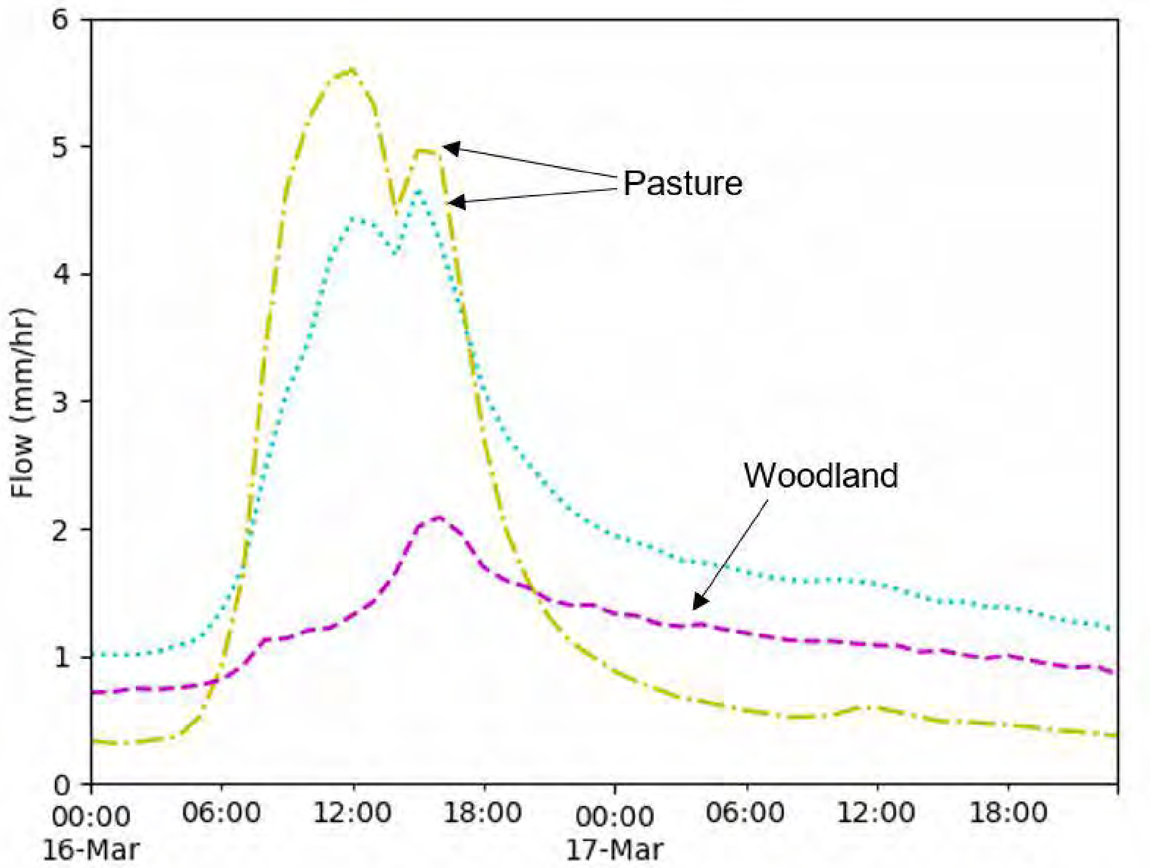

Figure 1. Streamflow during a storm event with lower peak discharge in woodland compared to pasture streams.

Effect of soil and vegetation structure

To explore the reasons behind the different responses of woodland and grassland catchments we took detailed measurements of soil properties. We found that broadleaf woodland soils had top-soil permeability (measured as saturated hydraulic conductivity, i.e. the ease with which pores of a saturated soil permit water movement) up to 20 times greater than grassland soils. Tree roots alter the structure of soils, creating a more porous structure that allows water to enter the soil more quickly.

During big storms or after long periods of rain, soils become saturated and can't hold any additional water. At this point, water starts to flow across the land. The rate at which it travels depends on the type and structure of vegetation. We measured the rate of overland flow across a range of different habitats. Lightly grazed grasslands, ungrazed woodlands and wood pasture had denser vegetation sward and significantly slower overland flow compared to more heavily grazed grasslands[4,5]. A slower rate of overland flow changes the timing of the flood peak and can reduce its size.

Woodland creation scenarios

Computer models can be used to explore the flood-mitigation benefits of woodlands in more detail. Models can be compared for a range of different woodland scenarios to simulate the impacts of landcover on larger flood events that are harder to measure. We used TOPMODEL – a new version of the rainfall-runoff model – to explore how different woodland scenarios might alter peak streamflow during a one-in-50-year storm event in a 260-hectare catchment in Cumbria. We found that increasing woodland cover from 0% to 65% reduced the peak stream flow during this storm by up to 16%[6]. Streamflow reduced by about 2% for each 10 percentage-point increase in woodland cover across the catchment (Figure 2). This demonstrates that woodlands provide flood mitigation benefits even in larger catchments and for some of the largest storm events. We also used the model to compare different types of woodland. Creating woodlands along streams and water courses (riparian woodland) and across the slope (cross-slope woodland) provides the biggest flood mitigation benefit (Figure 2).

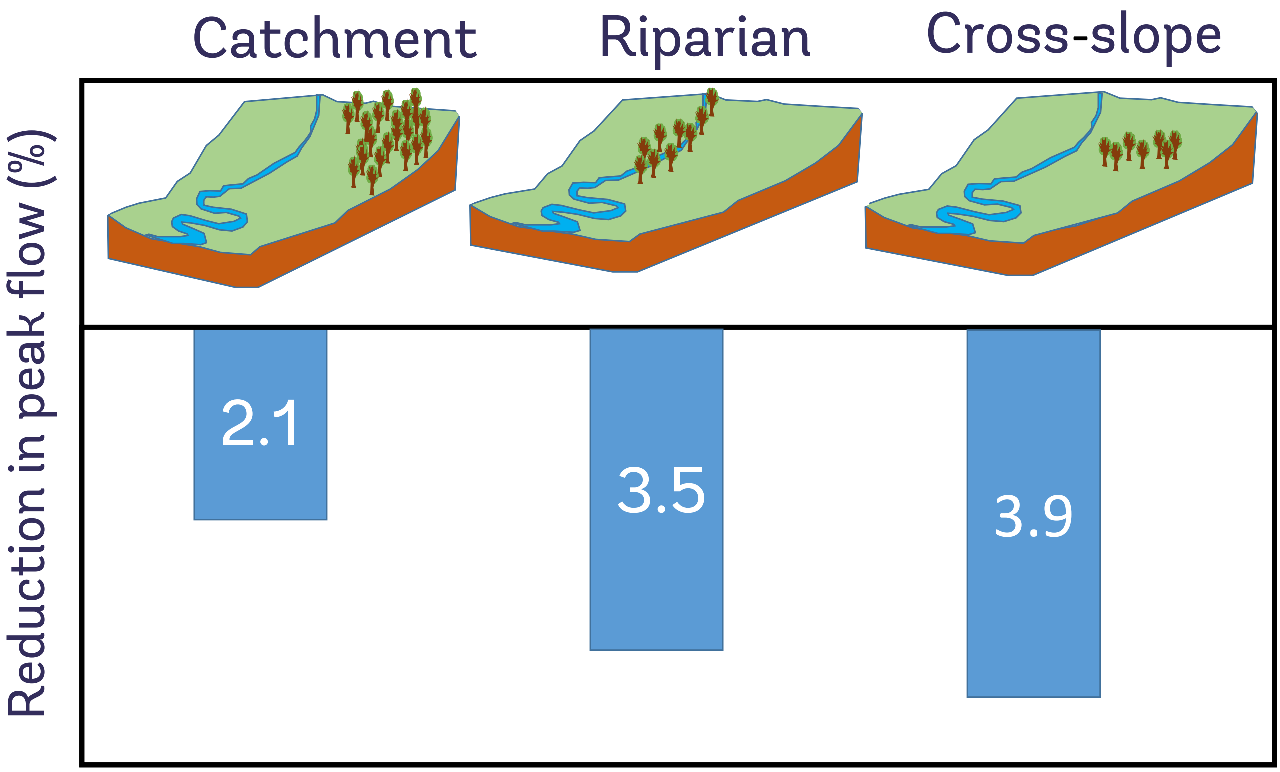

Figure 2. Simulated reduction in peak flow during a one-in-50-year storm for a 10-percentage point increase in catchment, riparian and cross-slope woodland cover in a 260-hectare upland catchment in Cumbria.

Land managers also want to know how quickly new woodlands will impact soil functioning and reduce flood risk. Recent work has shown that soil permeability can double within 15 years of tree planting[7], suggesting newly planted trees quickly alter soil properties and start to provide benefits for flood mitigation. A realistic woodland planting scenario reduced simulated overland flow for a one-in-30-year storm by up to 30%[8]. We estimated that a planned woodland at Haweswater by RSPB and United Utilities could reduce peak streamflow in a one-in-50-year storm by 10%. Together, these studies suggest that natural flood management benefits develop quickly in newly planted woodland.

Of course, creation of new woodlands needs to account for a wide range of objectives in addition to reducing flood risk. The Woodland Trust's *Woodland creation guide*[9] provides advice for the creation of new native woodlands to achieve a wide range of objectives for people, nature and climate. Woodland creation can be combined with the restoration of other habitats, such as rivers and blanket bogs, to provide even larger flood-mitigation benefits. The Woodland Trust's new site at Snaizeholme in the Yorkshire Dales National Park provides an example of how plans to create and restore a mosaic of woodland, grassland and upland blanket bog can combine benefits for biodiversity, carbon storage and climate mitigation with reduced flood risk and improved water quality. The Landscape Recovery scheme – the top tier of the new environmental land management scheme in England – provides an exciting opportunity for farmers and landowners to help create and restore habitats at a landscape scale to support nature recovery and reduce flood risk, alongside food production. However, it is still early days, so the success of this scheme is currently unknown.

Future work

There are still many things we don't know about woodlands and water. The impact of land cover, such as broadleaf woodlands or grasslands, at the largest scales is still uncertain. A recent modelling study suggested that afforestation had little impact on peak stream flow for large (> 10,000km$_2$) catchments[10]. More work examining the impacts of land cover at these large scales is needed.

A negative consequence of trees intercepting and evaporating water (which helps reduce flood risk) is that less rain makes it to rivers during periods of drought, exacerbating low river flows. This suggests a potential management trade-off between mitigating floods and maintaining drought resilience. However, trees also increase soil infiltration, thereby increasing soil and groundwater recharge, and so there may be an optimum tree cover that reduces flood peaks and maintains or increases low water flows[11]. More work is needed to try to disentangle these complex interactions.

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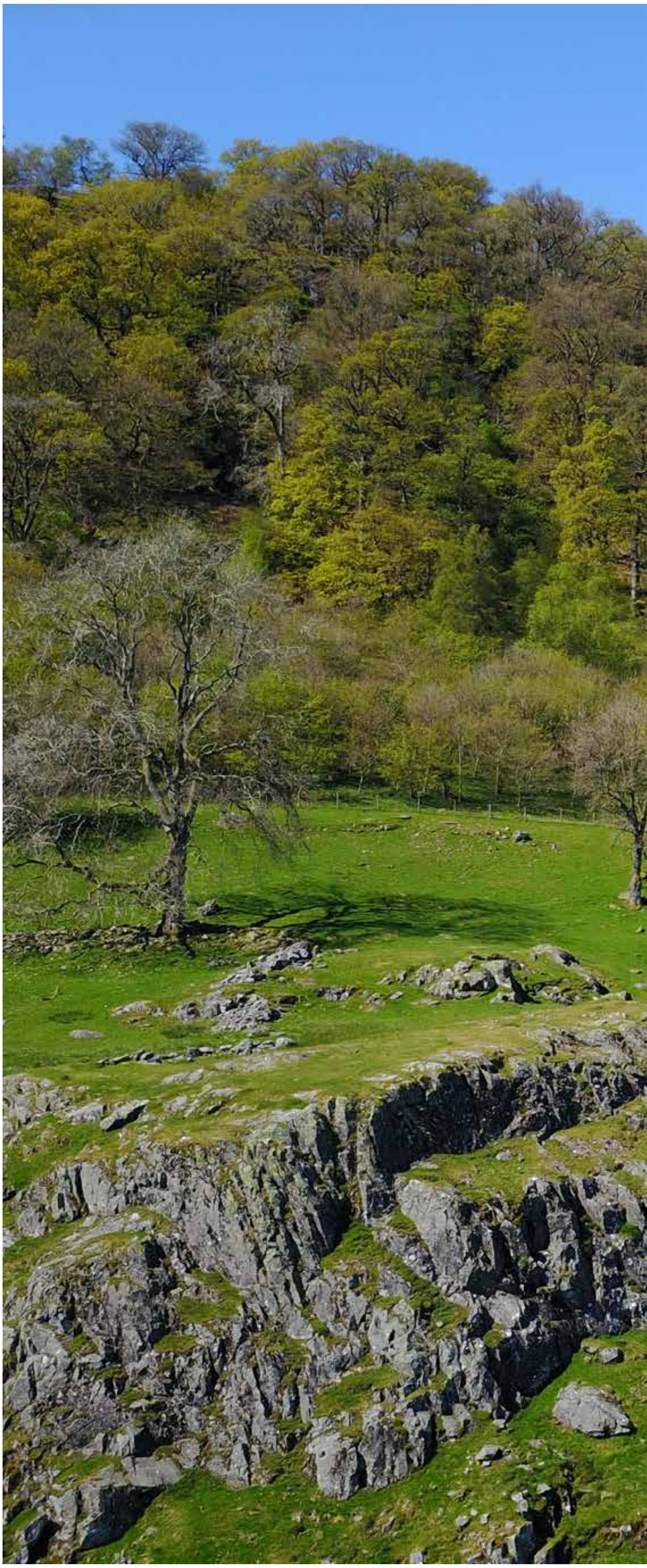


Broadleaf woodland and open wooded habitat in Naddle Valley, Cumbria.

Woodland in the mountainous Derwent catchment, Cumbria.

The significance of wet-canopy evaporation

Trevor Page, Nick Chappell and Peter Leeson

Trevor Page is a researcher at Lancaster University specialising in environmental modelling. **Nick Chappell** is a hydrologist at Lancaster University and interested in forest hydrology and evaluating hydrological aspects of nature-based solutions. **Peter Leeson** is partnerships manager for the Woodland Trust. Peter works with landowners and farmers to promote tree planting, regenerative agriculture and rewilding in Cumbria.

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.

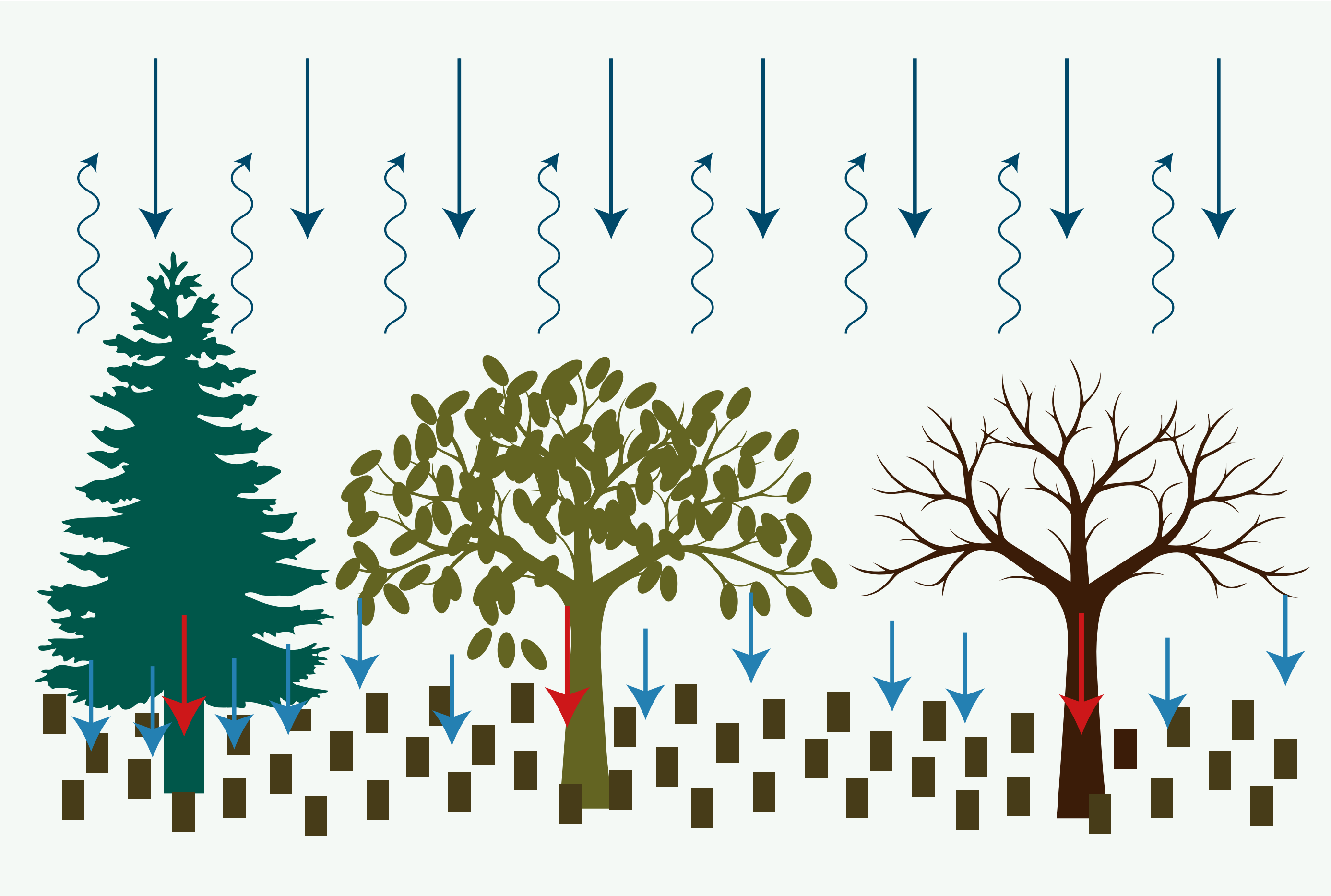
New observations in Cumbria

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.

Trevor Page

Experimental site within a small deciduous woodland.



Trevor Page

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.

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Nick Chappell

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

Catchment-scale collaboration

Doug Edmondson

Dave Connolly

Flooding at Sowerby Bridge in Calderdale, West Yorkshire in 2015.

Doug Edmondson is one of the outreach advisers for the Woodland Trust in the North of England. He has worked with the Trust for around ten years, and before that, in the Forestry Commission and with England's Community Forests.

Across the Leeds City Region, homes and businesses have been subjected to severe floods in the last decade – including those of December 2015 – which have had a devastating impact on people's lives and livelihoods. While the causes – and thus also the solutions – of flooding are complex, one key element is land use in the upland areas of catchments that have major rivers running through population centres. For land use change to be effective, it must be addressed at a catchment scale, and this cannot be done without a partnership approach.

The National Trust and Yorkshire Water are both major landowners in the South Pennines area, and have been working together through a partnership called Common Cause. Their aim is ecosystem restoration at a catchment scale – delivering for nature, customers and visitors. The landscapes concerned also lie within the Northern Forest, an ambitious project to increase tree cover across a swathe of land from Liverpool to Hull, extending north and south well into the Pennine landscapes in which Yorkshire Water and the National Trust are working.

The Northern Forest is a partnership between the Woodland Trust, the Community Forest Trust, and four community forests, including the White Rose Forest which covers North and West Yorkshire. The result is an innovative collaboration between multiple partners and stakeholders which over time could transform large areas of the Pennine landscape: restoring habitats, storing carbon, reducing flood risk, improving water quality, and importantly, raising the profile of natural flood management (NFM).

Delivering at scale

One of the first schemes to reach completion from this collaboration is at Gorpley Reservoir, which lies near Todmorden above the flood-prone Calder Valley. Here, a 104-hectare scheme has been co-created and delivered by the partnership, including Yorkshire Water, the National Trust, the Woodland Trust, and the White Rose Forest. It had been four years in the planning and over a year in delivery. It was only possible through the clear, shared vision of the partners contributing to the co-design of the project, and their ability to bring their skills and resources to the table as needed.

Gorpley was one of three sites in the Calder and Colne Valleys where the scoping work and delivery of the NFM programme was funded by the West Yorkshire Combined Authority through the Growing Resilience initiative. This brought significant additionality to the partnership, complementing grant aid from the Forestry Commission and direct investment from Yorkshire Water.

The vision for Gorpley was to create a mosaic of interconnected and robust natural habitats that would transform the valley into a visually stunning experience for visitors, while providing increased biodiversity and other ecosystem services as a model of upland management, using woodlands as a catalyst for change.

The South Pennines is characterised by swathes of open sheep-grazed hills, with woodland generally surviving as fragments in steep-sided valleys or 'cloughs'. The National Character Area profile for the Southern Pennines identifies the opportunity to manage existing woodlands and extend broadleaved woodland cover in appropriate locations to: help with climate change mitigation, improve water quality and supply, increase biodiversity, provide biomass, and strengthen landscape character.


Victoria Holland

Woodland creation at Gorpley Reservoir.

Management should include:

- Restoring, expanding and linking existing fragmented areas of broadleaved woodland and wood pasture, especially on valley sides.
- Encouraging creation of upland woodland and wood pasture on valley sides, in cloughs and gills, to stabilise banks, reduce erosion, capture carbon and increase wildlife value.
- Ensuring that new woodlands are created in suitable locations and include native species that are suitable for the physical location; thus contributing to the biodiversity resource, making the habitats more resilient to climate change, avoiding damage to historic features and strengthening landscape character.

It can be challenging to create new woodland at scale in this landscape, given the need to protect existing habitats and species of value and at the same time take advantage of the opportunities afforded by willing landowners. To ensure the right trees were planted in the right place, extensive habitat and species surveys were conducted, and a wide-ranging consultation was held.

The land at Gorpley Reservoir is owned by Yorkshire Water, and on this occasion was brought into the Woodland Trust on a short-term lease. The opportunity here was to bring together the aspiration of Yorkshire Water for large-scale woodland creation (as part of their Million Trees aspiration) with the woodland creation expertise of the Woodland Trust to deliver improvements to the water environment. It also harnesses the ability


Victoria Holland

Woodland creation on valley sides and in cloughs and gills can stabilise banks, reduce erosion, capture carbon and increase wildlife value.

of the National Trust to manage a natural flood management programme – all under the umbrella of the White Rose Forest as a facilitating partnership.

Habitat creation and restoration

At Gorpley, the partnership has delivered 41 hectares of moorland improvement and over 63 hectares of new native woodland creation, along with improved management of mosaics of other habitats. Individual habitat features were mapped and assigned a specific management prescription under the programme of NFM interventions.

The woodland design plan started with the UK Forestry Standard, which was then complemented with the clough woodland creation guiding principles that were pioneered by Moors for the Future[1], as a cornerstone to the design process. The most floristically rich areas of pasture were retained, cliffs were preserved as an open landscape feature/habitat, and Molinia was controlled on acid grassland with the possibility of creating hay meadow or heathland. Wet grasslands were developed through digging scrapes and blocking drains, and acid flushes were retained and enhanced.

A moorland assessment was undertaken to recommend restoration works for three areas within the catchment of Gorpley Reservoir. Given the absence of sphagnum moss in most of the peat moorland, restoration involved sphagnum reintroduction as well as using techniques to help re-wet the moor, such as the creation of wetland scrapes and the construction of earth dams.

Natural flood management interventions included the construction of 91 stone dams, 239 turf dams, 105 willow dams and 1,800 willow fascines; the planting of 56,250 sphagnum plugs and 13,000 gorse and broom plugs; and the creation of seven shallow scrapes. Where possible, material from derelict and irreparable stone walls was reused to construct some of the NFM interventions. The partnership strove to innovate wherever possible and create specifications, designs and concepts that could be easily replicated across similar locations and programmes.

The project design respected and retained historic field boundaries. Woodland blocks were carefully designed and positioned to reflect the cultural landscape character of the area, and followed historical field pattern. A range of native tree species was planted, with the woodland created in accordance with the National Vegetation Classification (NVC) appropriate to the site (mainly NVC community W17: upland oak-birch woodland with bilberry). Species were matched to the appropriate NVC classification, taking local site variation into account, such as soil type, soil moisture level and exposure. The Ecological Site Classification (ESC) tool was used to inform species choice. The planting took place during the winter of 2019/20 and was a challenge to deliver, given the difficult, steep terrain and exposed conditions on the site. A five-year maintenance contract is in place, but so far the survival rate is good. However, dealing with unauthorised livestock incursion continues to be a significant issue.

Going forward

The woodland creation and NFM interventions at Gorpley Reservoir cost somewhere in the region of £1.4 million, including maintenance and monitoring. The partners continue to work together to manage the site and monitor the impacts. Leeds University is undertaking part of the monitoring and evaluation for the project, with interim reporting due shortly.

As the partnership goes forward into the next portfolio of projects across the estates of both Yorkshire Water and the National Trust, we are actively responding to the difficulties of delivering at a landscape scale. The next round of schemes could amount to over 1,000 hectares of woodland creation in conjunction with moorland restoration. We are looking to work across the designated landscape of the South Pennines, across West Yorkshire and into the Dales and Peak District National Parks.

Working with the partnership across West Yorkshire for almost a decade has stripped bare the very evident challenges that must be resolved – and compromises reached – to effectively enable trees and woods to play their part in addressing the climate and biodiversity crises. This is amplified in designated landscapes in the uplands. We must rise to the challenge of delivering multiple benefits through working in partnership – recognising the urgent need for change in these landscapes. Change must come.

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For fantastic footage from the project go to youtube.com/watch?v=tE0QWe1AS2c.

Scrub and pioneer woodland in the floodplain (Middle Rhine).

Riverwoods – how trees create healthy river systems

Stewart Clarke

There is growing interest in targeting new trees and woodlands near rivers for the many benefits they bring. Trees and rivers are old friends and if we reunite them, the impact will be significant.

Stewart Clarke is the National Trust's national specialist for freshwater and catchments. He is a freshwater ecologist committed to an evidence-led approach to nature conservation and catchment management.

There are many good reasons for increasing native tree cover along riverbanks (as riparian trees) and in the floodplain (best defined as the wet-weather river channel). Trees have positive benefits for rivers and help reduce flood risk by slowing the flow of water and increasing infiltration (woodland soils are better structured and more permeable), all while providing nature-rich river corridors (surely a quick win for nature recovery networks). Given commitments to increase woodland cover, this flood-prone land is an obvious place to create new woodland, converting from other land uses that are affected by, or can exacerbate, regular flooding.

A missing habitat

A few years back I was lucky enough to spend a few days exploring some wonderful species-rich meadows in the Middle Rhine in Germany. As well as flowery meadows ringing with the sound of birds rarely heard in the UK (wrynecks, golden orioles, bluethroats), one of the most lasting impressions was of a densely wooded nature reserve. In the crook of an old meander, this reserve represented something completely lost from our UK river systems – a floodplain forest pioneered by black poplar and succeeding to oak and ash where conditions were drier. The trees were giants, fed by nutrient-rich floodwaters and well-watered by growing on river sands and gravels. It was a wild and unfamiliar landscape, made incongruous by glimpses of heavy industry in the distance and large river barges chugging by on the wide river.

In the UK we have all but lost our floodplain forests, particularly along larger lowland river systems. For too long, the drainage engineers' desire to control all aspects of river and wetland systems has seen riverside trees removed to facilitate navigation, for agriculture on rich soils, or to manage perceived flood risk. The latter has had the greatest impact in recent decades. The fear, admittedly sometimes justified, of trees or branches blocking bridges and culverts, has led to overzealous management of all trees; in some districts no bankside tree could be tolerated. And with this loss of trees, we have lost a fundamental relationship between rivers and trees – a relationship which shapes the health of our rivers and all the benefits they can provide.

Why rivers need trees

The science of fluvial geomorphology (the forms and processes of rivers) was initially conceived as an interaction of water and sediment movement[1], but increasingly river scientists have recognised the importance of vegetation, including trees. Work since the 1990s has clearly demonstrated the influence of floodplain, riparian (riverside) and in-stream plants on the movement of water and sediment, and the feedbacks that occur. Now, the significant role of vegetation in shaping most river systems is widely accepted[2].

Trees in particular play a key role in structuring channel forms and dynamics. When rooted, trees can stabilise riverbanks, bars and islands, thereby maintaining channel widths or establishing important habitat heterogeneity, such as when roots bind sands and gravels to stabilise in-channel features. Studies of large, near-natural gravel-bed rivers, such as the Tagliamento in Northern Italy, have shown how stranded trees can create new islands that then become colonised by more trees until large floods sweep everything away and the cycle starts again. When riverside trees fall or drop branches into the channel, the wood traps sediment and diverts the flow of water – creating important variability in flow and habitat. The power of woody material to shape in-channel habitat and create cover for fish and conditions for aquatic plants has led to a huge growth in projects that use wood for river channel restoration. The use of large wood, or large woody debris (LWD) as it is often called, has become a standard method in the river restoration toolbox (see later article ***Hold back the water***).


Gemma Harvey

Resprouting, flood-deposited black poplar initiating island development on a gravel-bed alpine river (Tagliamento, Italy).

While physical habitat, and in particular its variety, is important for river wildlife, trees also benefit rivers in other ways. Leaf litter is an important source of organic material, fuelling many stream food webs, and the shade from riparian trees has an important role in cooling rivers. This cooling effect is becoming more important as cold-water species, such as salmonids, are threatened by climate change. Increasing riparian tree cover could also improve resilience by increasing energy inputs to streams (via leaf litter), with resultant increases in invertebrate biomass and diversification of functional groups[3].

Towards functioning river systems

While adding woody material into rivers and streams to assist with physical habitat restoration is often a good approach, it misses the full range of benefits associated with the tree-river relationship and is arguably not sustainable. A better way of realising these benefits is to restore natural processes – a philosophy that underpins much contemporary nature conservation practice. This means recreating the floodplain and riparian woodland that will supply the woody material to the rivers and all the other things that trees can provide. Geomorphologists have described restoring a 'natural wood regime'[4] in which there is recruitment, transport and storage of woody material.

The tree-river relationship is one of feedback – trees can only truly fulfil their role if there is some dynamism to the channel and they are allowed to fall and remain in the channel. Too many of our rivers have been straightened and over-deepened or isolated from their floodplains by raised floodbanks. Simply planting or allowing trees to grow on riverbanks will not be enough – we also need to free our rivers and create the space for trees, sediment and water to work together.

A further component long missing from our river systems may hold the key to making this more sustainable. There are now more than 20 sanctioned beaver reintroduction projects in the UK which demonstrates the growing recognition of the role that these ecosystem engineers can play in restoring wetland systems to the benefit of a range of other species. Through their tree felling and feeding activity, beavers create open space in wet woodland,


Mike Dodd

High nutrient supply from the river feeds vigorous tree growth – floodplain forest, Middle Rhine (Lampertheim).

letting light into river channels where aquatic plants can thrive. They create the sort of structural diversity that woodland managers would love to emulate. By building dams, beavers initiate the process of channel restoration, trapping sediment and raising the riverbed which ultimately allows the channel to reconnect with the floodplain (see later article on ***Beavers, trees and the freshwater environment***).

The opportunity

Restoring riparian and floodplain land could bring nature, carbon and flood/drought resilience gains, as well as improve river health by buffering against diffuse pollution and displacing some of the most intensive land uses from the most vulnerable locations. Floodplains are naturally complex mosaics of periodically and permanently wet habitats in which open water, swamp, grassland, scrub and woodland ebb and flow with the prevailing weather and grazing pressure. Recent work in England to redefine the 'Coastal and Floodplain Grazing Marsh Priority Habitat' as 'Floodplain Wetland Mosaic' is an attempt to recognise these features and encourage their restoration; it is hoped this revised definition will be adopted soon.

Restoring our rivers to more natural systems will require one thing above all – space. Research shows that 90% of UK floodplains no longer function as they should[5]. They cannot store water and sediment and are often disconnected from the channel, meaning that large volumes of water are conveyed downstream at speed rather than spreading out and slowing down.

There is a huge opportunity to replace inappropriate floodplain use, such as arable farming (which will become harder and harder in some locations as floods become bigger and more frequent), with semi-natural habitats that work for nature, climate resilience and people. Incentives for farmers to 'move back' from the riverbank, and instead plant trees or allow natural regeneration (some lowland rivers already have a rich source of seeds and propagules), could be an easy win for nature recovery and climate resilience.

Such 'farming back' opens the door to rivers behaving more naturally – allowing them to move and adjust to changing flows. It will also create valuable habitat and space for land managers to live alongside beavers and their engineering behaviour. With 1.6 million hectares of floodplain in England and Wales, there is plenty of room for this type of restoration. Our floodplains have room for trees to soak up carbon and slow floodwaters, for wildflower-rich meadows that can work with modern farming systems, and for complex wetlands that are home to, and created by, the charismatic beaver. And perhaps we can restore some of our lost floodplain forests like those I saw in the Rhine.

Riverscapes and the Woodlands for Water initiative

As with most conservation efforts, partnership working is key to success. The Riverscapes partnership is an alliance of organisations (the National Trust, the Woodland Trust, the Rivers Trust and Beaver Trust) who recognise the value of riparian woodlands and habitats and the importance of giving rivers the space they need to function properly. Our first project is the Woodlands for Water initiative which seeks to help landowners and managers realise the benefits of riparian trees and woods and helps them access funds from government and the private sector to create riparian woodland. The partnership will continue to explore ways to create more dynamic and complex river corridors in partnership with those managing land next to rivers. Our vision is for a broad network of green corridors snaking through our countryside, linking existing natural habitats and reaching into our cities and towns.

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Hold back the water

Jonny Walker

In the West Pennine Moors above Bolton, natural processes are being used to reap many benefits for the wildlife that lives there as well as the people living downstream.

Historically, engineered structures have been used to alleviate flood risk in the British Isles. While engineered structures still have their place, other ways to reduce flood risk are increasingly being recognised. As described in previous articles, natural flood management (NFM) is the use of natural processes to hold water back in the landscape, slowing its flow over land and in streams and rivers. This slowing reduces water levels at peak flow when a river is most likely to burst its banks.

Jonny Walker is a site manager for the Woodland Trust. He helped to deliver the Smithills Estate NFM project and now works across the Trust's woods in North and East Yorkshire.

Demonstration day with intervention shown on right of photograph.

There are a range of NFM methods, including:

River and floodplain restoration – restoring rivers to their natural, sinuous and multi-streamed courses, de-culverting, and allowing them to flow onto their floodplains in high river levels (e.g. moving back flood embankments).

Leaky dams – leaky barriers in streams, ditches or across contours to hold back water within a channel or encourage it to spread out onto banks or across floodplains. There are many types of leaky dam, including stacked timber, timber planks, plastic piling, piped peat dams, stone check dams and clay core-pipe bunds.

Tree planting – trees, and the associated vegetation growth promoted by reduced grazing, intercept water before it hits the ground. This increases surface roughness and allows water to percolate into the soil. Short willow-crop rotation has the same benefits as tree planting, with the addition of trapping flood debris and sediment.

Moorland restoration – blocking grips and historic drainage gullies raise the water table of moorland, re-creating conditions for sphagnum growth and peat creation. Sphagnum mosses can hold up to 20 times their own weight in water, and so contribute greatly to water storage.

Flood attenuation – offline storage areas, whereby water is diverted from the river channel and temporarily stored, are dry for most of the time, but fill up during peak flow. After the peak has passed, water is released slowly back into watercourses. Examples include retention basins, ponds and scrapes.

Agricultural land management – looking after soils by avoiding compaction, using cover crops, ploughing along contours, etc., slows the flow of water (and resulting soil erosion) into watercourses.

NFM trial at Smithills Estate

In Northwest England, on the slopes of Winter Hill, the Smithills Estate is the Woodland Trust's largest site in England, covering almost seven square kilometres of upland fringe. Water was historically significant for the estate, powering much industry across and downstream of its mosaic of water, moorland, blanket bog, woodland and grazing land. Now that the industry has gone, we're left with its legacy – drained moorland and incised, straightened and culverted watercourses. While these rivers, ditches and ponds are important habitat for the wildlife of the estate, there was more the Trust could do.

As a part of the Trust's National Lottery Heritage Fund (NLHF) project to restore and enhance the Smithills Estate, the Trust took part in a regional trial of NFM. Over three years, funded by the NLHF and Environment Agency, led by Mersey Forest with monitoring by the University of Liverpool, a number of interventions were installed at around 25 locations across the Dean Brook catchment. The aim was to reduce the risk of flooding for the communities downstream.

Several measures were employed across the 690-hectare estate, including large woody barriers planted with young willow, stone check dams on the moorland, and over 100,000 trees planted. It is estimated that 12,000 cubic metres of water – a volume equivalent to the capacity of almost five Olympic-sized swimming pools – will be attenuated during a one-in-100-year flood event.

What impacts have they had?

Examining the impacts of these interventions was a key part of the project. A reservoir, decommissioned in the 1840s, formed the main study site as it is an ideal location to attenuate flood flow due to its broad, flat bed.

Jonny Walker/the Woodland Trust

Creation of offline temporary storage area in progress.

Rain gauges and water-level stations, as well as wildlife cameras recording time-lapse images, were installed across the decommissioned reservoir prior to the installation of five large woody barriers crossing the full width of the reservoir (Figure 1). The woody barriers were constructed of timber with young willow trees planted on the downstream side. The timber will sink over time, plugging any gaps that appear. The willow, which will be cut annually by volunteers to promote growth at the base, will form a living barrier in the years to come when the timber has rotted away.

The time-lapse photos (and first-hand experience of standing in the rain, staring at gushing water) showed water was getting trapped behind the barriers. Success!

Data collected at comparable precipitation events pre- and post-barrier installation were analysed[1]. While each rainfall event is different, the data indicates water is being stored during events, with a release of water after the peak flow has passed. Further analysis of the water level and discharge data described an average discharge reduction in peak flows of 27.3% post- compared to pre-installation.

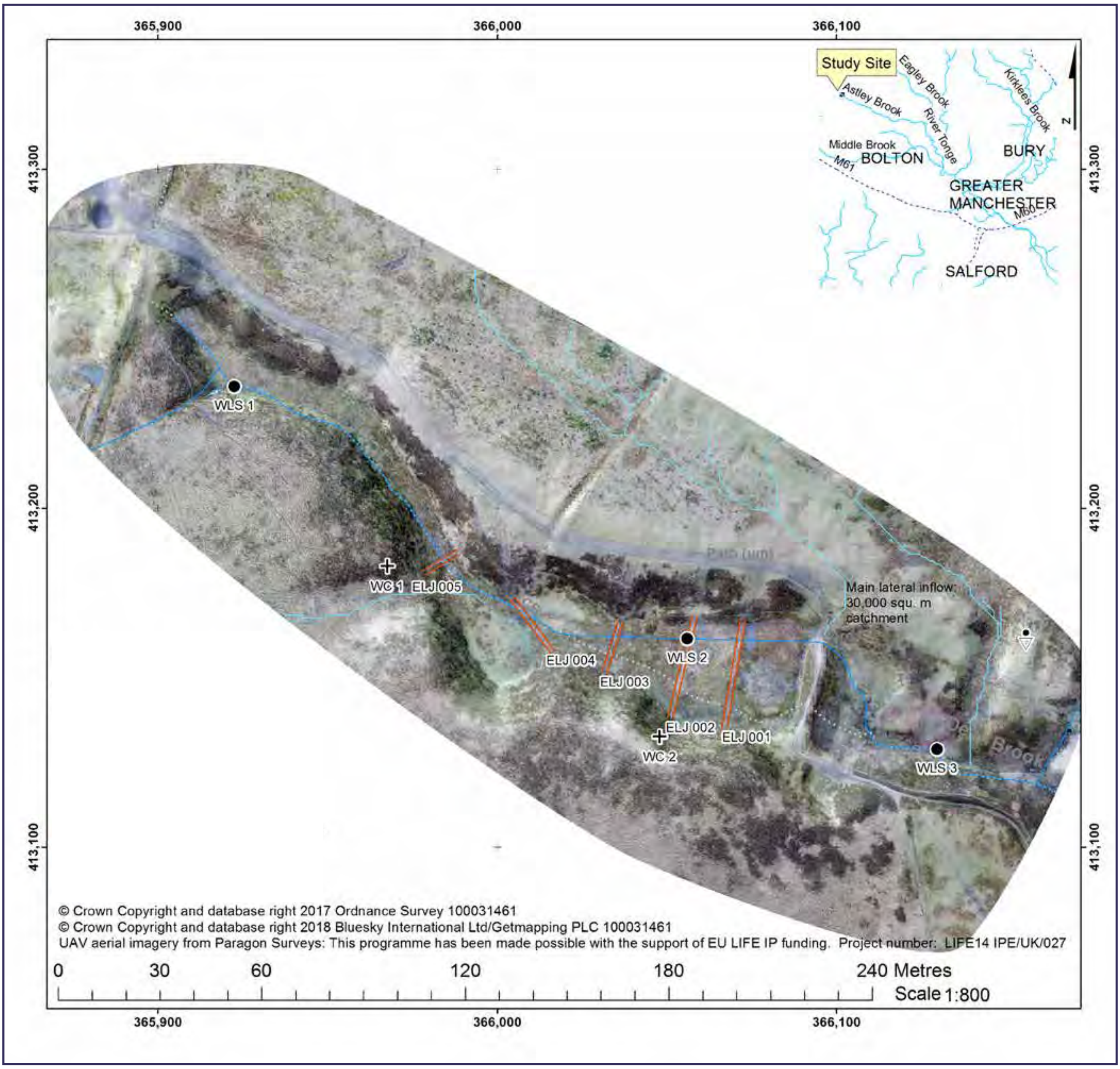

Figure 1. Study site showing monitoring equipment in relation to the woody barriers. WELJs = Willowed Engineered Log Jams, WC = Wildlife Camera, WLS = Water Level Station. Credit: Figure 1 in Norbury et al., 2022[1].

Keeled skimmer, *Orthetrum coerulescens*, at Sugarloaf leaky dams.

This was just one set of interventions in the catchment. The impact varies from intervention to intervention, and not all were studied, but if this approach was implemented across the upper reaches of a whole river catchment, the impacts would be considerable.

Additional benefits

The benefits of NFM are not restricted to flood reduction. The wet areas created in a landscape that had been extensively drained over centuries provide valuable habitat, clean water and carbon storage and have an aesthetic appeal. Not long after the completion of the log jams below Sugarloaf (a hill shaped like a sugar loaf!) a keeled skimmer dragonfly was seen using the pools – the first ever record of this species for Greater Manchester.

Volunteers and community groups were involved in planting trees and installing many of the woody barriers – reaping the benefits of volunteering outdoors and spending time in nature.

The Moors for the Future Partnership has also been hard at work on Smithills Moor – blocking grips and reprofiling eroding peat to help restore the blanket bog. Together, the moorland restoration and NFM interventions will ensure that the watery environment at the Smithills Estate is well on its way to a healthier future.

This research was conducted through a partnership between the Universities of Liverpool, Cardiff, Newcastle and Birmingham, with support from the Environment Agency and the Woodland Trust.

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For more information about Smithills and footage of the site, go to: youtube.com/watch?v=fwsVIQMGXi0

Beaver kit crossing a dam at Cornwall Beaver Project.

Beavers, trees and the freshwater environment

Chris Jones and Josh Harris

Chris Jones is the community and land director at the Beaver Trust and **Josh Harris** is the community beaver officer.

Beavers are famous for coppicing and pruning trees to build dams that store water, manipulating the environment to meet their needs. In doing so, beavers provide enormous benefits for other plants and animals, not least through their effects on water.

Fresh water is a fundamental requirement for all terrestrial life. People need enough of it all year round to drink, grow food and process our waste. There must also be sufficient water in rivers, even at times of drought, for aquatic biodiversity such as fish and invertebrates. An additional dimension is the need for flow regulation, ideally by natural means, so that flood risk is minimised. Step up the beaver. Beavers can have quite dramatic effects on the way our rivers work, bringing huge benefits to both people and the environment.

What do beavers do to our rivers?

Firstly, what is meant by a river system? Increasingly, practitioners are considering whole catchments – in other words, all the land on which rain falls and ends up flowing into a river. Rivers can be seen as transport systems which move dissolved chemicals, solids, and suspended solids from land to sea (or in some cases, to lakes). Most of a river catchment is dry land, over and through which water moves into aquifers and surface channels.

Rivers across the original range of beavers *cannot* be considered to be in good ecological health if the species is absent. In headwaters in particular, beaver dams turn what we think about the naturalness of streams on its head. Our understanding of headwaters is that they are shallow, fast flowing and stony or gravelly in substrate.

When beavers occupy headwaters, they must build dams to create the depth of water for them to swim through their territory and, most importantly, have submerged entrances to their burrows and lodges. This is fundamental for the species, while benefiting other wildlife and people in several ways: they slow the flow[1]; build drought resilience[2]; remove fine solids within dams[3]; improve water quality[3]; improve existing habitats and create new ones[4]. Each of these is looked at in more detail in this article.

Slowing the flow

Beavers build dams in headwaters. These dams are leaky, but effective enough to create ponds. As the dam increases in height it can reconnect the stream with its floodplain, and as the water is braided through the floodplain it is subject to greater friction which further attenuates the flow. In the Cornwall Beaver Project, beavers have created eight dams, each of which is connected to the floodplain. There are now four streams compared to just one before the beavers arrived, with peak flows reduced by a quarter compared to pre-beaver peak flows[5]. The floodplain has become a complex and dynamic wetland.

Building drought resilience

The issue of drought is slowly rising up the agenda in Britain. Many people can remember back to the very serious drought of 1976, but there have been several national droughts since then – 1985, 1995, 2005, 2014 and 2018 – and even more on a regional scale[6]. One of the consequences of this has been ever greater reliance on groundwater, and somehow water supply has always (just about) been available for people (albeit with occasional local hosepipe bans and water rationing). For aquatic wildlife on the other hand, drought has often been devastating – it needs plentiful fresh water to survive and prosper. We can go without a clean car for

A dam at Cornwall Beaver Project.

a few months, but fish must have water to survive. The effect in headwaters of beaver presence is to hold water, both on the surface in channels and ponds, and also below the surface. Beavers create wetland which acts like a sponge, collecting lots of water during periods of rainfall, and releasing it slowly during periods of drought. Beaver wetlands may also help to recharge groundwater by holding it inland for long enough for some of it to migrate downwards into subsurface geology[7].

Removing fine solids

Beaver dams slow the flow of water. Water's ability to transport solids is directly related to the velocity and turbulence of the stream. As a dam is built, a pond is formed and the current slows, the water loses energy, and fine suspended solids settle out. These solids are often related to agricultural runoff containing nitrates and phosphates, as well as organic matter, making this an incredibly important beaver service. Water passing through a beaver territory becomes cleaner as it goes through and around a series of dams[3]. This effect can extend right out to coastal waters and could even lead to positive economic impacts; for example, the Falmouth oyster beds would benefit from cleaner fresh water entering the Carrick Roads from the River Fal. Bathing water quality would also improve.

Improving water quality

As well as the removal of fine solids mentioned above, the reduction of loading with nutrients is another very important result of beaver dam building[3]. Nitrates and phosphates can cause algal blooms that are anathema for a lot of aquatic life. These nutrients tend to be taken up by macrophytes around the edges of the pond, and phytoplankton in the water.

Improving habitats

Beavers are very general herbivores, consuming a wide range of aquatic and terrestrial plants. Famously they fell trees, and where this is part of closed-canopy woodland, beavers open up the canopy, allowing light in which then stimulates growth in the shrub and ground layer. This in turn creates habitats for other species not previously present. Clearly, the volume of deadwood in a beaver landscape increases dramatically. Deadwood in our generally over-tidy landscape is a rare resource. An indication of the variety of habitats, and thus biodiversity and abundance of wildlife at the Cornwall

James Wallace

Beaver coppiced willow *Salix capraea*.

Note the amount of space allowed for tree growth.

Beaver Project site, is the presence of up to 11 species of bat, 17 species of Odonata (dragonflies and damselflies), and nine new bird records.

Mitigating beaver impacts

While beavers provide all the above-mentioned benefits, they can also cause issues locally. The direct impacts of beaver presence can be summed up as localised flooding, bank destabilisation and tree felling. Any of these could be most unwelcome if they occur in a place where it negatively impacts on amenity or income. Context is of course everything – localised flooding where it doesn't have a negative impact may reduce flood risk in a place where it does matter.

An area of mixed broadleaved plantation was selected for the Cornwall Beaver Project, which was historically used occasionally for cattle and pigs, and for firewood. The beavers have felled c120 trees now, mostly willow and oak, but also some alder and ash. Some of the felling has amounted to group felling in one patch and thinning across the remainder of the area. None of the trees (except for ash) are of timber quality, so there is no economic loss. However, simple preventative measures have been taken on a small sample of trees, either by painting with a mix of PVA glue and sand, or by applying a guard of weldmesh (see photo). These methods have been successful and are widely used in Tayside and Europe. Critically, most tree impacts occur within 20 metres of water, which has implications for species choice – placing the right tree in the right place for beaver co-existence.

Where beaver dams are causing unwelcome localised flooding, dams can be removed or their level reduced (both licensable activities). Again, these are actions widely practised across the animal's range.

It is clear that beavers can, through their everyday activities, have significant impacts on our rivers and riparian zones. While these are sometimes antithetical to people (or some people anyway), in many circumstances the impacts are beneficial or neutral in effect. It is also clear that protection or mitigation of these impacts is not unduly expensive or onerous. Can society learn to understand beavers and adopt a strategy that enables co-existence with this extraordinary species? Can we know a good thing when we see it?

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Plantation forestry impacts on water quality

Jennifer Williamson

Jennifer Williamson is a peatland biogeochemist working for the UK Centre for Ecology & Hydrology and based in Bangor, north Wales. Her research interests are focused around quantifying the impacts of land use change on water quality and greenhouse gas emissions.

Nathan Callaghan/UKCEH

A stream within the conifer plantation that has instruments installed to monitor stream flow and water chemistry.

Following the end of the Second World War, large areas of the UK's uplands, which at the time were considered to be of low productive value, were planted with conifers. Coinciding with this, over the past 40 years, river and lake water in the UK has been getting browner, particularly in the uplands and areas with peat-dominated soils. Here, we explore the link between the 'brownification' of fresh water and plantation forestry.

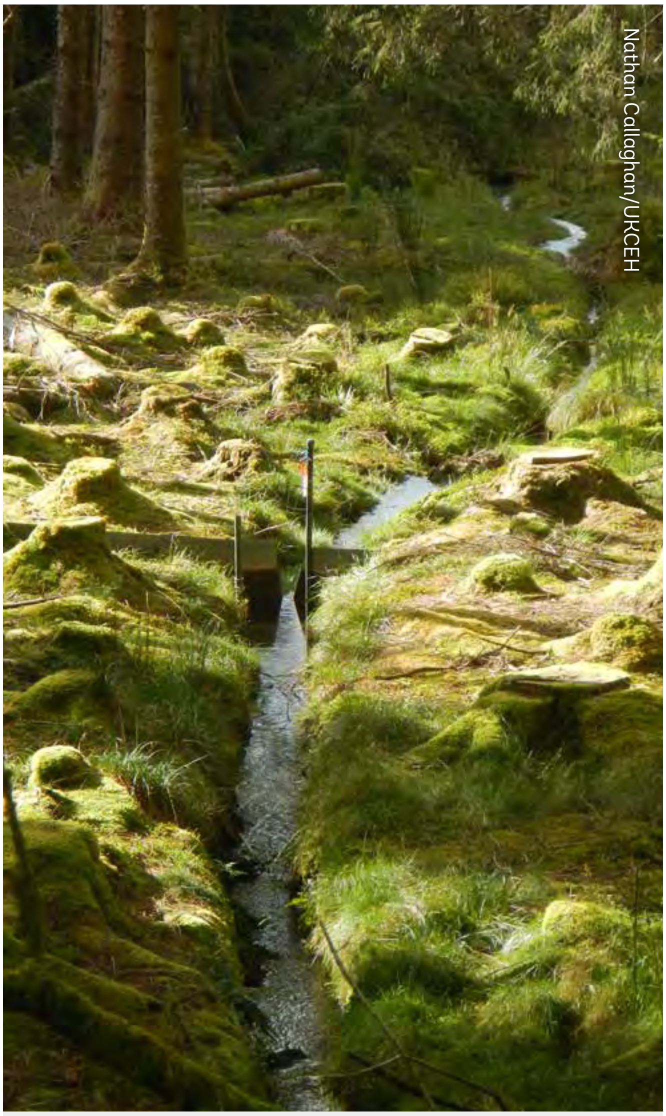
Much of the brown colouration in fresh waters can be attributed to dissolved organic matter (DOM). DOM includes a spectrum of organic molecules ranging from colourless simple sugars to highly complex humic structures (organic compounds found in humus) which are responsible for the brown colour seen in affected waters. DOM contains approximately 50% carbon, along with hydrogen, oxygen and a range of other macronutrients, including nitrogen and phosphorus.

Increasing discolouration of fresh waters is a problem on many levels, from water purification (dissolved organic matter must be removed during drinking water treatment) to impacting on carbon cycles. Globally, it is estimated that 1.7 petagrams* of carbon per year is washed into rivers and lakes from the soil – a quantity similar to the net uptake of carbon by vegetation[1]. Thus, if through careful land management we can reduce the loss of carbon from our soils into rivers, we can increase carbon sequestration in our landscapes. [* 1 petagram = 1 trillion kilograms].

Impacts of plantation forestry

It is now well recognised that conifer plantation forestry management can negatively impact water quality[2,3]. Conifer plantations are often on organic and organo-mineral soils which were drained prior to planting. Drainage of organic soils leads to emissions of carbon dioxide from decomposition of previously waterlogged peat, as well as leaching of dissolved organic carbon (DOC) from the soil into surrounding streams and rivers. Management by clearfelling has also been linked with large increases in DOC[4].

There are now measures in place to minimise these impacts, including the *Forest and Water Guidelines* which state, for example, that no more than 20% of a catchment should be felled in any three-year period[5], and the overarching *UK Forestry Standard* which prohibits planting trees on peat deeper than 50cm[6]. Guidance for England has also been developed to support decisions on applications for the new England Woodland Creation Offer and new Peat Restoration Grants[7]. Despite these measures, a recent study has suggested that river catchments with large areas of forestry and organic soils, and particularly those with plantation forestry on organic soils, export proportionally more DOC per unit area than any other land use and soil combination across the UK[8].


Nathan Callaghan/UKCEH

V-notch weir with sensors to measure water flow and particulate matter.

A Welsh experiment

At Cwm Mynach, a Woodland Trust-owned site near Dolgellau in North Wales, UKCEH have partnered with the Woodland Trust to monitor the impacts of forest management on water quality. A paired catchment approach is being followed, and instruments to measure stream flow were installed in small streams draining the two catchments. Both are currently under conifer plantation, but have different management approaches: one of the catchments is being managed as a plantation forest, while the other is being gradually converted to native broadleaf woodland using a continuous cover management approach. Since 2014, water samples have been taken each month, creating a long-term dataset to compare the effect of changes in management. In the winter of 2021/22, a weather station was installed at the site and the river flow downstream of the catchment is also being recorded to allow the downstream impacts to be measured.

We aim to test the potential for continuous-cover forest management to reduce carbon export from soils into the aquatic systems. Ongoing monitoring will also allow us to understand the interactions between forest management and other pressures, such as storms and atmospheric deposition, and how they affect water colour in streams draining forest catchments in the uplands.

Early findings

There are already some interesting findings from this study on the effect of soil type on water quality. The western catchment contains areas of peat soil and wetland vegetation, whereas the eastern catchment has shallower organo-mineral soils. Higher concentrations of DOC were found in streams in the western catchment and concentrations show a seasonal cyclical pattern similar to those seen in streams that drain blanket bogs. Concentrations of dissolved iron and sulphate also show seasonal cycles, suggesting the soil is waterlogged in winter. In the eastern catchment, DOC concentrations are lower and do not show the same seasonal cycle in concentration, and the water chemistry data suggests that this catchment does not experience the same degree of waterlogging.

This catchment monitoring has also brought to light an interaction between ionic strength (concentration of ions) and DOC concentrations, particularly in the catchment with peat soil. In February 2014, a large storm resulted in the deposition of sea salt across most of North Wales, causing an increase in chloride concentrations in the streams at Cwm Mynach of 15 milligrams per litre (mg L^{-1}). At the same time, the peak DOC concentrations in the western stream declined by almost 10mg L^{-1}, a pattern also seen in other water quality monitoring sites across the region. Since 2014, chloride concentrations have gradually reduced to the levels seen prior to the storm, and DOC concentrations have increased.

These findings show that water quality, particularly with regards to concentrations of DOC, varies both between and within years, and that the impacts of any felling and replanting should be reported in the context of soil type and antecedent weather conditions. The stream draining the sub-catchment with the peaty soil has higher DOC concentrations and was more affected by the change in chloride concentrations.

Forest-to-bog restoration

Recently, attention has turned to restoring bogs that have had trees planted on them. Although still limited in extent within the UK, bog restoration has been carried out for 18 years in the Flow Country in northern Scotland, and national policies on peat restoration may

Ed Midmore

Weather station at Cwm Mynach.

lead to more forest-to-bog restoration in future. Recent research found that the initial impacts of forest-to-bog restoration were similar to those reported during clearfelling, but as bog vegetation regenerated, DOC concentrations returned towards those seen in forest control areas[9]. Complete recovery to pre-planting levels had still not occurred, however, 17 years post restoration.

The extent to which plantation forestry has contributed to the increases in water colour seen across the UK and further afield is difficult to quantify due to the huge variation across sites, including weather, soil type, geology and plantation management. However, recent studies suggest that the presence of plantation forestry on organic soils increases the export of DOC from the soils to the aquatic system[7], hence the brownness of the water.

While the reasons for this are not completely clear, it is likely to be related to drainage of previously wet soils to allow trees to grow. When returning these areas to a more natural array of plant species, thereby increasing the diversity of the landscape, we should also consider incorporating measures to increase the water table in areas with organic-rich soils. This will reduce emissions of carbon dioxide through decomposition as well as the export of DOC from soils to rivers.

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