UK Forestry Standard **Practice Guide**

Designing and managing forests and woodlands to reduce flood risk

Forestry Commission

Scottish Forestry
Coilltearachd na h-Alba

Cyfoeth Naturiol Cymru
Natural Resources Wales

Forest Service

Front cover: new woodland planting to help reduce downstream flooding and create new wildlife habitat. Upper Eden valley, near Kirkby Stephen, Cumbria, UK

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Forest Research

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Contents

Introduction . . . 1
- Aim and scope . . . 2

Flood risk management . . . 3

Designing new forests and woodlands . . . 6
- Site location . . . 6
- Scale of tree planting . . . 9
- Woodland design . . . 9
- Existing land use . . . 10
- Tree age . . . 11
- Size and nature of potential flood event . . . 11
- Planning new woodlands to reduce flood risk . . . 12

Forest and woodland management . . . 15
- Cultivation . . . 15
- Drainage . . . 16
- Roads and tracks . . . 18
- Felling and restocking . . . 19
- Planning felling and restocking to reduce flood risk . . . 20

Interventions to slow run-off . . . 22
- Installing leaky woody dams to reduce flood risk . . . 24

Monitoring . . . 27

Further reading and useful sources of information . . . 29

Appendix 1: Flooding authorities . . . 31
Appendix 2: Assessing and managing the scale of felling to minimise flood risk . . . 32
Appendix 3: Modelling impacts . . . 37

Glossary . . . 39

Introduction

Flooding is a major environmental hazard facing the UK, with at least six million properties at risk of flooding (Figure 1). Studies predict that this risk is likely to increase in the future due to climate change and urban development. The potential societal impacts and economic damages from flooding are expected to escalate, with major floods already costing multiple £billion. These concerns are driving a more sustainable approach to flood risk management involving greater working with natural processes. This has led to the concept of 'natural flood management' (NFM), in which natural features and characteristics are used to slow down and store more floodwater within upstream catchments (Figure 2).

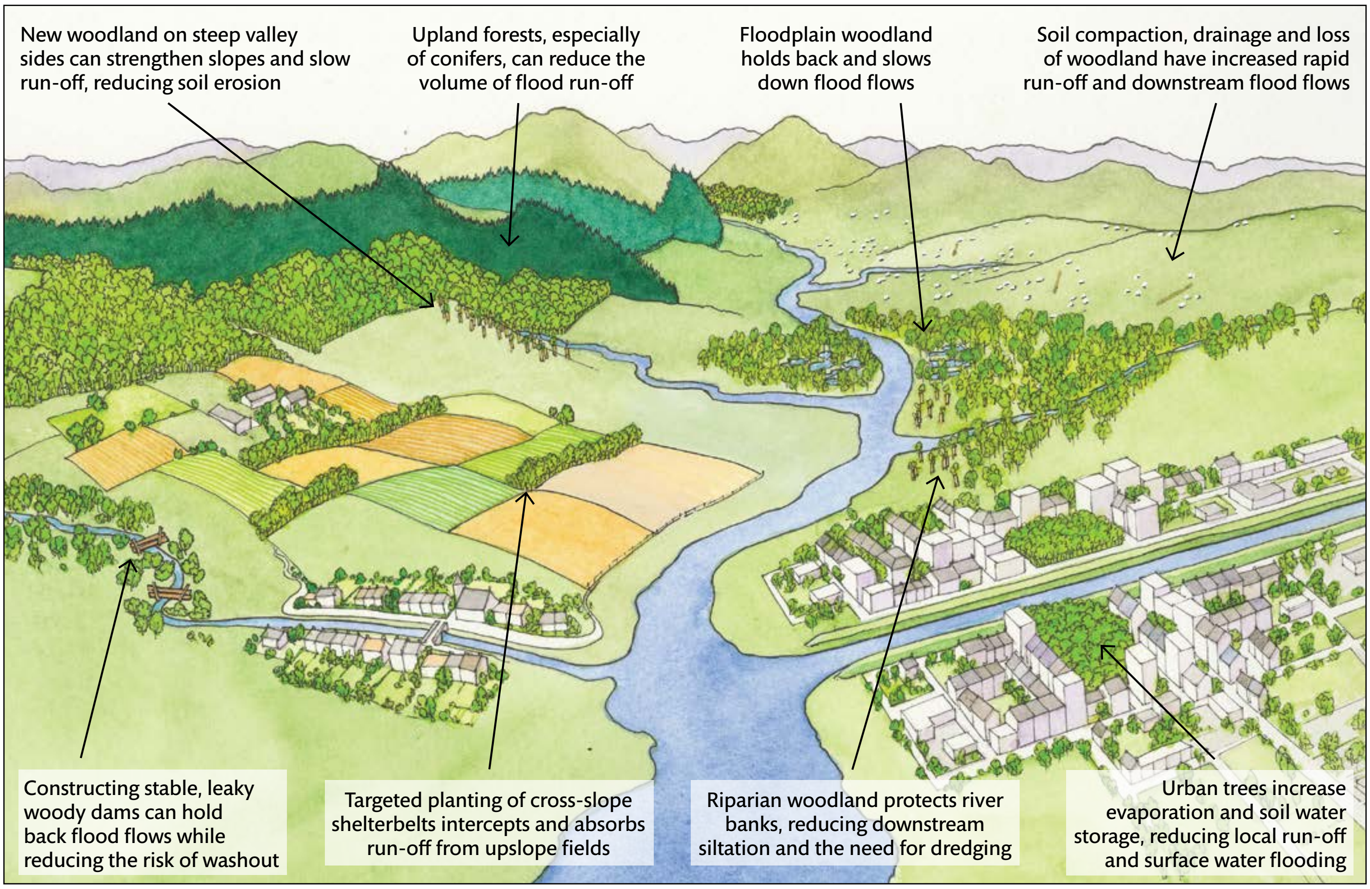
Forests and woodlands are known to reduce flood flows (Box 1) and can make an important contribution to NFM. On the other hand, forest operations such as cultivation, drainage, road construction and harvesting can have the opposite effect if not appropriately managed. The UK Forestry Standard (UKFS) recognises the potential of forestry to affect downstream flooding and includes a set of requirements and guidelines to ensure that forests, forest management and woodland creation make a positive contribution.

River and coastal flooding are the most serious natural hazards facing the UK today and both are expected to increase with climate change

This Practice Guide describes how to comply with the UKFS Good Forestry Practice Requirement that those planning woodland creation or the management and redesign of existing forests and woodlands in areas prone to flooding should consider how their activities could reduce flood risk. It describes how forestry affects the risk of flooding and provides practical advice on implementing the UKFS water guidelines on reducing peak flows and flooding. This includes how factors such as the location, scale and design of woodland creation influence its contribution to flood reduction; how to remedy drainage systems to delay run-off; how to phase felling to limit the temporary loss of woodland benefit; and opportunities to enhance water storage and slow run-off within forests.

Figure 1 Flooding affects millions of properties in the UK, causing misery to home owners and businesses. In 2007, more than 400 properties were flooded in Abingdon-on-Thames in Oxfordshire.

Figure 2 Natural flood management uses woodland and trees to slow the flow as part of a whole catchment approach to managing flood risk.



Aim and scope

This is the 'how to' Guide on woodland creation and forest management to reduce flood risk, and control the potentially adverse effects of forestry operations such as cultivation, drainage, road construction and forest felling. While it is primarily aimed at landowners, forest planners, managers and practitioners, it is also intended for use by the authorities responsible for managing flooding in the UK (flooding authorities, as listed in Appendix 1), some of whom may be unfamiliar with how forestry can help. A wide range of organisations are responsible for managing flood risk across the UK and rely on partnership working to develop a sustainable and integrated approach to protecting affected communities and assets from flooding.

The Guide comprises five main sections covering: flood risk management; designing new forests and woodlands; forest and woodland management; interventions to slow run-off, and monitoring. There are also three appendices, which describe the responsible flooding authorities in England, Scotland, Wales and Northern Ireland; the method for managing the scale of felling to minimise flood risk; and how to model the effects of forest measures on flooding. Other than the first section on flood risk management, each section starts with an introduction to the main factors affecting flood flows, followed by detailed guidance on planning and/or operational practice. Implementing the guidance as described will enable foresters to meet UKFS requirements and guidelines, and in so doing, promote working with natural processes to deliver a more sustainable, catchment-based approach to managing flood risk. By playing a stronger role in flood mitigation, it will also help the forest sector increase the resilience of downstream communities likely to be impacted by more frequent flooding due to climate change.

Flood risk management

Flooding is a natural occurrence but causes problems where it impacts on society. Because forests and forestry have the potential to reduce flooding (Box 1), it is important to consider and understand what is at risk of flooding when designing and managing forests. Much of the UK is affected by flooding but some areas have few or no impacts. Others are protected to varying degrees by engineered defences such as flood walls, embankments and washlands. Attention should focus on areas where communities and assets are at significant risk of flooding, as this is where forestry has the greatest potential to make a useful contribution.

Box 1 Trees reduce flood risk

There are several ways that trees can reduce flood risk. First, trees generally evaporate more water than other types of vegetation, which can reduce the volume of floodwater draining from the land. More evaporation reduces the amount of storm rainfall reaching the woodland floor, and results in drier soils that can store more of this water below-ground. Second, soils under woodland tend to be better structured than under other land uses, enabling more storm rainfall to enter and pass through the soil rather than quickly run-off the surface. This promotes the retention of floodwater within soils and delays its passage to watercourses. Third, trees, shrubs and deadwood, particularly along stream sides and within floodplains exert a greater drag on floodwaters, compared with grass, delaying flood flows. Lastly, tree cover protects the soil, decreasing soil erosion and the delivery of sediment to watercourses, which helps reduce siltation and thereby increases the capacity of main river channels to safely convey floodwaters downstream.

Forests and woodlands reduce the volume of floodwater at source by increasing canopy evaporation/interception.

Trees slow the rate of run-off from the land by increasing soil infiltration through rooting.

Trees and woody vegetation enhance floodplain storage and delay flood peaks by increasing hydraulic roughness.

Riparian woodland reduces siltation by protecting soils and river banks, increasing the capacity of the channel to contain floodwater.

Forestry has most potential to impact on surface water and river flooding. It has less influence on groundwater and coastal flooding

The UK is affected by four main types of flooding: surface water, river, groundwater and coastal (Box 2). Forestry has most potential to impact on the first two of these, with the magnitude of effect generally decreasing with increasing distance between the forest and the downstream community or asset at risk of flooding. Generally, as the size of the upstream catchment draining to the location at risk of flooding increases, the greater in extent the forest (or its removal) needs to be to make a significant contribution. Consequently, although forests are most often associated with reducing local floods generated by rapid run-off from small catchments (<10 km^2), there is evidence that effects can extend at least to medium-sized catchments (10–100 km^2). There is less scope for forests to reduce flooding in large catchments due to the generally smaller extent of forest cover and increasing importance of river channel processes and engineered flood protection downstream.

The flooding authorities (Appendix 1) are responsible for delivering flood-risk management strategies, plans and actions. In carrying out their duties, they are required to identify housing, businesses and other assets at risk of flooding and produce detailed maps to inform strategies to help protect them. Flood-risk management strategies specify the nature of flood impacts, the objectives for managing flood risk and proposed measures for achieving these objectives. They are designed to support local decision-making and promote engagement to try and ensure that flood risk is managed in a coordinated way across catchments or along stretches of coast. This necessitates a partnership approach so that measures can collectively make a difference.

Box 2 Different types of flooding

There are four main types of flooding: surface water or 'pluvial' flooding results from heavy rainfall rapidly running off compacted areas of land or hard standing such as roads and tracks. It is usually associated with causing local flash floods and affects more properties and parts of the UK than the other types of flooding. River or 'fluvial' flooding arises where run-off from large rainstorms overwhelms river channels, leading to water overtopping river banks and defences, spilling onto the floodplain. Around two million properties have been built on floodplains in the UK and thus are potentially at risk of river flooding if flood protection measures are overwhelmed. Groundwater flooding is restricted to certain geologies (e.g. sandstone and chalk) where prolonged periods of rainfall cause the groundwater table to rise to the surface and flood local, low-lying areas. Such flooding usually occurs days or even weeks after the cessation of heavy rainfall and potentially affects a few hundred thousand properties in the UK. Coastal flooding affects low-lying areas of land that are vulnerable to unusually high tides and storms overtopping sea defences. Some locations can be affected by more than one type of flooding and different types can occur at the same time, increasing the severity of the event.

Surface water run-off often causes problems in towns and cities because impervious areas (such as roads and pavements) do not allow water to soak into the ground.

Houses by the River Aire in Leeds during a flood in 2015. Rains over the Christmas period caused the river to swell and burst its banks, flooding many houses and other properties.

There is growing interest in using NFM alongside more traditional engineering techniques to reduce flood risk. Flood risk management strategies provide a framework for developing flood risk management plans or local flood risk management plans (terminology varies across the different countries in the UK), which increasingly consider the potential for NFM to help. These will be used to assign actions whereby combined measures can meet targets for the number of properties to be protected from flooding.

Different approaches have been developed by flooding authorities in each UK country to prioritise areas and communities for investing in flood protection, supported by a range of flood hazard and risk maps. Target areas and communities are increasingly being identified by flooding authorities, as well as the catchment areas draining to these. Across the board, it is increasingly acknowledged that NFM has an important part to play in managing flood risk within upstream catchments. However, levels of awareness and understanding of the potential contribution of NFM and the role of forestry varies between partners, and remains subject to significant uncertainty. Flood risk management plans will continue to evolve as new data and modelling techniques allow target areas and catchments to be better defined and improve quantification of the impact of NFM measures.

To facilitate flood risk management planning, indicative 'opportunity' maps (Figure 3) have been produced in some countries to identify potential areas where NFM measures can best contribute. These include opportunities for woodland creation and management to reduce downstream flooding. Woodland creation opportunity maps can be overlain with datasets for other factors to identify priority areas for potential planting to deliver multiple water and wider benefits. Spatial datasets and maps will continue to be developed in line with technical advances, including improvements to the way that flood models handle the effects of forests.

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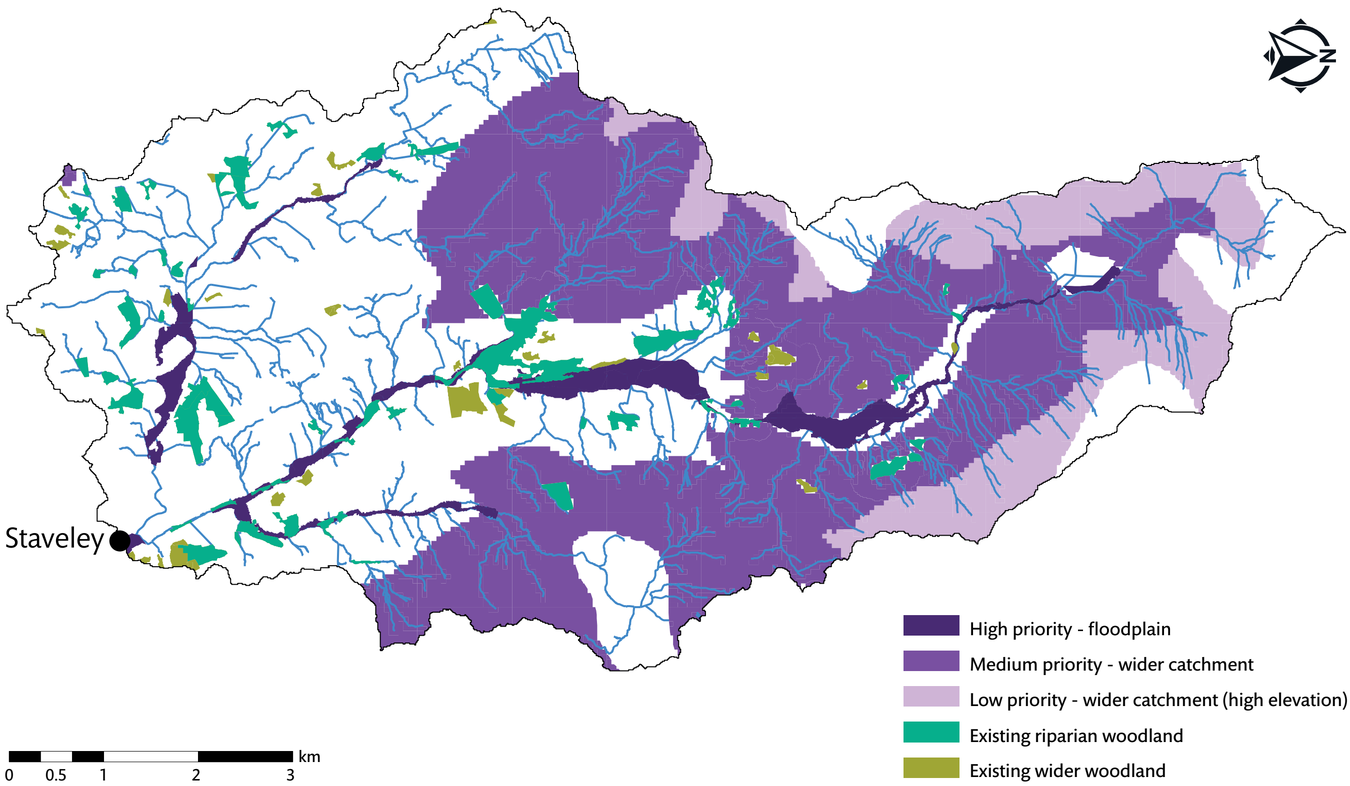
Woodland creation opportunity maps can be used to identify priority areas for tree planting to reduce flood risk, as well as to provide other water benefits

Figure 3 Opportunities for woodland creation to contribute to natural flood management within a pilot catchment in Cumbria.



Designing new forests and woodlands

Tree planting can significantly affect the volume, pathway and timing of water run-off from an area of land, all of which can act to reduce downstream flood flows. The size of reduction depends on several factors, the most important of which are location, scale and design of planting, the existing land use, tree age and the type and size of flood event. Associated management operations also have a role to play, and these are covered in the next section.

Site location

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The flooding authorities in each country of the UK (see Appendix 1) have identified the areas prone to flooding and can advise on the nature of the flood risk

The precise location of an area of land determines the nature of the flood risk, as well as climate, soil, geology and land use interactions. The first point to consider is whether any communities (e.g. houses and businesses) or other assets (e.g. critical infrastructure such as electrical sub-stations and key public highways) are at risk of flooding downstream; if not, there is little scope for tree planting to help and therefore the issue can be largely ignored. Potential exceptions where planting could still contribute are where new building developments are planned downstream within flood risk areas or existing developments are predicted to become flood prone due to climate change. The scope for woodland creation to reduce flooding on downstream farmland or protected habitats, should also be considered. The flooding authorities will have identified the areas prone to flooding and can advise on the nature of the flood risk. As knowledge and modelling improves, they and others may also be able to advise on the potential for NFM to help.

If a community or asset is known to be vulnerable to flooding, there is a need to consider the relative flood risk. Flooding authorities continue to invest in measures to protect many communities up to a fairly high standard of protection (e.g. against floods with a greater than one in 200-year chance (0.5%) of occurring in any year), whereas others and especially smaller communities may be largely unprotected. Woodland creation is likely to have a greater effect and thus potentially contribute most to the protection of smaller communities, although there may also be significant scope to integrate with and complement the protection of larger communities afforded by conventional flood defences (Figure 4).

Figure 4 By reducing flood flows, woodland creation can potentially enhance the level of protection afforded by conventional flood defences.

Another factor is the presence of downstream dams and river transfers, which can severely limit the scope for tree planting to affect flood risk.

Regional climate affects tree water use, both during a flood event in terms of the amount of water lost by canopy interception, and before a flood, by the degree of soil drying. The latter is also affected by soil depth and type, as well as soil condition. Planting in the wetter and windier uplands of the UK will maximise the contribution of storm-day, canopy interception loss to reducing flood flows, while woodland creation in the warmer and drier lowlands will potentially contribute more below-ground floodwater storage due to greater soil drying and higher soil moisture deficits. Note that the latter can exacerbate low flows in dry periods and pose an issue for water supplies and the wider freshwater environment. The impact of this potential trade-off needs to be considered where downstream waters and wetlands are sensitive to a reduction in water quantity (this is a UKFS Good Forestry Practice Requirement).

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> The Forest Research Ecological Site Classification tool (see Further reading and useful sources of information) provides guidance on which species would be most suitable for the local soil and climate

Geology exerts a strong influence on run-off pathways and the ability of tree planting to affect these. The more porous the geology, the less surface run-off and therefore the smaller the benefit from enhancing soil infiltration and hydraulic roughness. In some circumstances, greater soil infiltration could be a disbenefit on porous geologies (although could benefit water resources) by increasing recharge and groundwater flooding, depending on the extent to which this is offset by the higher water use by trees. Geology also affects soil type and in turn soil water storage capacity and tree water use; for example, on drought-prone soils, trees have the potential to increase soil drying at depth due to deeper rooting than shorter vegetation, while on soils overlying chalk, broadleaved trees have been shown to evaporate less water than grass.

The precise location of planting within a flood risk catchment also influences its ability to affect flood run-off pathways. It is helpful to target planting directly along or across run-off pathways, for example in the form of cross-slope shelterbelts or within riparian zones and on floodplains, where the drag or roughness effect of woodland will be greatest (Figure 5). In the same way, tree planting will increase the effectiveness of specific features designed to slow run-off such as swales, infiltration basins and sustainable drainage systems. A related benefit of slowing flood flows is to potentially increase groundwater recharge, which can enhance low flows and help to offset the impact of the higher tree water use on these.

Figure 5 Planting floodplain woodland can be particularly effective at holding back and delaying flood flows.

Planting on the floodplain will be less effective at reducing flood flows where the land is disconnected from the river channel, for example by the presence of flood embankments. This also applies to enclosed flood storage features such as washlands, where there is no flow-through of floodwater and thus benefit from increasing hydraulic roughness. Flooding authorities may view woodland creation on such features as a disbenefit by reducing the available flood storage due to the above-ground space occupied by the trees themselves. However, the reduction is likely to be compensated by the water use effect of the trees and woodland cover may provide a more economic use of the occasionally flooded land, compared with agriculture. The lost floodwater storage space is relatively small and can easily be calculated using the predicted stand basal area.

It is important to note that tree survival and growth can be significantly impacted by the nature of flood flows, with the potential for direct washout of trees in areas of turbulent flow, and tree death or damage where inundated by standing water. Newly planted and actively growing, young trees are the most vulnerable to damage, but the risk can be significantly reduced by planting more flood-tolerant tree species. Guidance on tree species selection for floodplains is provided by the 'FOWARA' project (see Further reading and useful sources of information).

While tree planting within the floodplain and within riparian zones can be a particularly effective location for reducing downstream flood risk, there are some cases where it can have the opposite effect. This includes locations where properties and assets are immediately adjacent to or upstream of the planted woodland and thereby potentially affected by the woodland delaying flood flows or diverting floodwaters onto adjacent ground. Floodplain woodland is known to raise local flood levels and create a backwater effect that can extend several hundred metres upstream, depending on channel gradient and the extent of the woodland. Backwater effects have the potential to increase the risk of flooding to upstream properties and therefore needs careful consideration when developing a woodland planting scheme (Figure 6).

A second issue is the risk posed by the washout of fallen tree trunks and branches, which can potentially block vulnerable downstream bridges and culverts, increasing local flooding. The risk is greatest for loose trunks and branches lying within watercourses, although these materials can also provide a flood benefit by slowing flood flows and pushing waters out onto the floodplain. Naturally accumulating large woody material is also an important part of river and stream habitat, and should therefore be retained where it presents no flood risk. See pages 22–26 for guidance on managing leaky woody dams within watercourses.

Lastly, concentrating planting within a specific tributary of a larger catchment can potentially affect the downstream phasing of the flood response. This has the potential to be positive or negative by desynchronising or synchronising flows from different tributaries. In theory, for tributaries that peak at the same time at a downstream flood point, delaying one of these over the other should lower the combined flood peak. The reverse also applies, with planting in a flashier tributary or closer to the community or asset at risk of flooding, increasing the scope for the woodland to bring flows into line with those from the rest of the catchment, increasing the flood peak and thereby flood risk. However, the flow response within individual tributaries also depends on the relative timing and spatial distribution of rainfall across a catchment, which are inherently very variable, changing between storms depending on wind direction and interactions with topography. This significantly limits the scope to manage the phasing of tributary flows through land use change. Flooding authorities may be able to advise whether the effect of planting on the phasing of tributary flows is an issue and should be considered.

Figure 6 Floodplain woodland can create a backwater effect, increasing the risk of flooding upstream properties.

Scale of tree planting

When considering the potential for woodland creation to reduce flood risk, this will depend on the location of the nearest vulnerable downstream community or asset. In general, the larger the extent of tree planting in the area draining to the community or asset (the upstream catchment), the greater the overall forest effect and thus expected reduction in flood flows. For riparian and floodplain woodland, which primarily act by increasing hydraulic roughness, it is both the width and longitudinal extent of planting within the riparian and active floodplain zones that determine the magnitude of the effect (increasing the width of planting across the floodplain tends to be more effective than increasing the longitudinal extent). Planting on both sides of the watercourse and floodplain will deliver a greater effect than planting on a single side, while a continuous width will reduce the scope for bypass or funnelling of flood flows.

Woodland design

Woodland shape and tree type, species and spacing can all affect the ability of planting to reduce flood flows. Consequently, these factors require consideration when planning woodland creation in catchments to reduce the risk of flooding to downstream communities and assets.

Woodland shape probably has the greatest effect upon floodplain woodland, where it can influence the direction and routing of flood flows across the floodplain, as well as the backing up of floodwaters. For woodland outside the floodplain, shape mainly affects the extent of woodland edge and thereby woodland water use, which is greatest at the exposed woodland edge. This is relevant to both external and internal edges, with the length of edge increasing as forests and woodlands become more diverse in species and age structure. However, the limited footprint of the edge effect means that it is likely to be 'lost' at the catchment scale.

Tree type has a marked effect on water use and thus the impact on flood volumes. Water use is generally much greater for conifers compared with broadleaves, especially in winter periods. Conifer canopy interception is typically twice that of broadleaves, resulting in larger evaporation losses during storm events and higher and more sustained soil moisture deficits, with a greater capacity for conifer soils to absorb rainwater and reduce flood run-off (but also to increase water shortages in drought periods). By contrast, soil infiltration rates tend to be similarly high under both tree types, provided woodland is well managed (e.g. avoiding ground compaction), while the hydraulic roughness created by trees and associated shrubs, ground vegetation and deadwood tends to be significantly greater under broadleaves, depending on tree age and the depth of floodwaters.

Tree species effects are generally small, especially within conifers. Differences tend to be greater between broadleaves, with the relatively high water use of willow and poplar species (when well supplied with water, such as in riparian and floodplain habitats) resulting in higher soil water deficits and a greater potential for below-ground floodwater storage. Tree species selection should be primarily driven by site suitability and habitat, but water impacts should be considered where significant.

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Coniferous woodland has a greater capacity to reduce flood run-off due to a higher interception loss compared with broadleaved woodland

Tree spacing has a direct effect on hydraulic roughness. Spacing wider than 5 m exerts little drag, with drag sharply increasing as spacing reduces from 2.5 m to 1 m. However, the negative relationship between spacing and drag is partly countered by the positive impact of increased tree spacing on the amount of ground vegetation and shrubs, which also contributes drag. Tree diameter, number of stems per tree, the amount of deadwood on the ground, the size of tree butts and the degree of microtopography created by surface roots and cultivation features, all influence the drag effect. Drag is only exerted by vegetation and structures within the depth of flooding and will reduce if vegetation becomes flattened or increasingly submerged.

Tree spacing also affects woodland water use. Open canopy, low density woodland intercepts less water and thus is likely to have wetter soils compared with closed canopy woodland, reducing potential below-ground floodwater storage. In addition, lower density planting can delay the recovery of soil infiltration on agriculturally compacted sites, resulting from the slower development and reduced extent of tree rooting.

The presence of fencing and tree shelters will interact with flood flows and can be easily damaged or washed out. Mesh fencing, fence corners and tall tree shelters are more likely to catch debris during flood events. Measures are available to reduce the risk of damage, such as designing appropriate weak points in fencing that are more easily repairable.

Existing land use

The type of land use being replaced by tree planting and the way that it has previously been managed will significantly influence the relative size of the woodland benefit for reducing flood flows. This partly reflects differences in water use between other land covers, which tends to increase in the order bracken>heather>grass>arable. It also depends on the propensity of the associated land management practices such as the use of agricultural machinery and livestock densities to compact or poach the soil and increase surface run-off, erosion and siltation within watercourses (Figure 7). Another factor is the presence and condition of existing drainage, with agricultural drains usually directly connected to watercourses and therefore benefitting from being disconnected and redesigned as part of

Figure 7 Cattle rearing can easily result in soil poaching, especially around feeding areas.

woodland creation schemes. The lower the water use, the more compact the soil, the more intensive the drainage and the lower the hydraulic roughness of the original land use, then the greater the net benefit of woodland creation for reducing flood flows. Consequently, woodland creation on arable and grassland is likely to reduce flood runoff to a greater degree compared with where it replaces bracken or heather.

Tree age

Tree age has a significant influence on water use, with canopy transpiration rates greatest for actively growing young stands and diminishing with old age. Interception losses steadily increase with age after planting and approach maximum rates once the woodland canopy closes, usually between 10 and 20 years of age, depending on tree type and growth rates. By contrast, soil infiltration benefits tend to develop rapidly after planting (within a few years), partly due to soil disturbance by cultivation, tree rooting and the removal of the machinery and livestock that may have caused soil compaction or poaching under the previous land use. The hydraulic roughness effect can be the slowest to establish, increasing with tree age and inputs of deadwood over multiple decades. The creation of roughness can be accelerated by the planting of closely spaced, faster growing tree species, by coppicing to produce multi-stemmed trees, or by management to promote the growth and establishment of shrubs and more upright, ground flora.

Size and nature of potential flood event

The ability of tree planting to reduce flood flows declines with increasing size of flood event. The longer the period and greater the volume of rainfall, the increased likelihood of soils being saturated, at which point the potential infiltration and soil water storage benefits of trees essentially cease. The effect of hydraulic roughness also tends to reduce with flood depth, with increased scope for deadwood and leaky woody dams to be submerged, displaced or washed out. By contrast, water loss by canopy interception continues throughout a flood event, regardless of event size, although it is likely to be less for more intense floods of a shorter duration. There is high confidence that woodland can reduce

> **!**
> There is high confidence that woodland can reduce small flood peaks, medium confidence in reducing medium flood peaks and low confidence in reducing large flood peaks

small flood peaks (a greater than one in 10-year (10%) chance of occurring in any year), medium confidence in reducing medium flood peaks (between a one in 10-year (10%) and one in 100-year (1%) chance of occurring in any year) and low confidence in reducing large flood peaks (less than a one in 100-year (1%) chance of occurring in any year).

Planning new woodlands to reduce flood risk

Those planning woodland creation should consider the nature of the local flood risk and where this is significant, the scope for amending plans in line with the above factors to reduce downstream flooding. The case for woodland creation to mitigate flooding may be an integral part of a woodland grant scheme or for separate funding support, which may already have identified target areas for planting. Alternatively, it could link to actions identified as part of flood risk management planning, or driven by a community-led project. Whatever the case, action is best taken in partnership with the relevant flooding authorities and other stakeholders. It is also important to remember that woodland creation needs to balance a wider range of objectives and potential impacts (including the potential for woodland creation to reduce low flows, increase water shortages and affect wetland habitats), as set out by the UKFS.

The scope for individual planting schemes to reduce flood risk will be greatest for communities and assets impacted by small and medium-sized floods in small catchments. Larger-sized schemes will generally exert a greater effect, but small (<10 ha) areas of planting can also reduce local flooding. For example, proposals targeting individual fields on steep or vulnerable hillslopes can reduce the generation of local 'muddy' floods, while narrow, extended planting along riparian zones can exert a catchment-scale effect.

The scope to reduce medium floods in medium-sized catchments is likely to require extended planting over a longer time period, most likely as part of a wider package of NFM measures. Individual planting schemes should aim to build on the contribution of existing woodland cover and other flood management measures, increasing the catchment-scale effect. A case can be made for reducing large floods, especially in small catchments, although there is a lack of observed data to underpin this.

Key points to consider when planning new woodlands are:

- Check whether country-level guidance is available and, if not, refer to flood maps, flood hazard maps and opportunity maps, as well as flood risk management strategies and plans, for information on downstream flood risk, NFM actions and target areas for woodland creation.
- Where information is lacking, contact the relevant flooding authority to determine if your site drains to a downstream community or asset at risk of flooding and, if so, the scope for woodland creation to contribute to flood protection; this is likely to be greatest for any nearby communities or assets.
- Where it is identified that households, businesses or other key assets are vulnerable to flooding and tree planting could help, consider modifying the design of the proposed planting scheme to increase the flood reduction benefit (e.g. by changing woodland type, placement and/or management practices).

The following measures will increase the ability of woodland creation to reduce flood risk, although these need to align with the wider principles of sustainable forest management as set out in the UKFS (including avoiding deep peat).

For wider planting within a catchment, outside of riparian zones and active floodplains:

- Increasing the spatial extent of planting so that woodland cover is >20% of the catchment draining to the nearest vulnerable community or asset (see Appendix 2 for how to determine the catchment area).
- Increasing the proportion of conifer but respecting the wider requirements of the UKFS.
- Targeting soils for planting that have a high propensity to generate rapid run-off, such as those damaged by or vulnerable to compaction and poaching.
- For delivering a quicker effect, planting faster growing species, including under a short rotation coppice or short rotation forestry system, subject to site suitability.
- Planting across or along pathways of surface run-off.

For planting within active floodplains:

- Increasing the extent/width of planting across the floodplain, including on both sides of the watercourse; consult with the relevant authority in England and Wales if considering planting next to Main rivers and flood defences and obtain the necessary consent (this is a legal requirement); restrictions may also apply on some watercourses in Scotland and Northern Ireland.
- Avoiding local pinch-points (Figure 8) where natural or man-made obstructions such as low bridges or culverts constrain and back up flood flows, especially where these are likely to submerge the upstream planted area.
- Blocking any existing drains and breaching or removing flood embankments (the latter subject to consent by the relevant flooding authorities).
- Restoring straightened sections of channel by re-engineering or aiding natural recovery (check river restoration plans for Sites of Special Scientific Interest ((SSSIs)) and priority river restoration maps where available), such as by installing leaky woody dams (until the woodland is established and able to form natural dams) to reconnect eroded/deepened channels with the floodplain and relic meanders (subject to consent; see page 23).
- Reducing tree spacing to 2 m or less within the wettest areas, where trees can most interact with and directly affect flood flows.

Figure 8 Low bridges constrain and back up flood flows, reducing the effectiveness of local upstream planting.

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Increasing the width and length of riparian woodland planting along watercourses will increase its contribution to reducing downstream flood flows

- Avoiding areas where upstream properties, assets and infrastructure could be flooded by diverted flows or raised water levels caused by water backing up behind the woodland; check the likely extent of the backing-up effect, which will depend on the channel gradient and existing surface roughness of the land.
- Design fencing to minimise the trapping of debris (e.g. avoid the use of mesh) and check and remove debris from fencing and water gates after flood events (Figure 9).

For native woodland planting within riparian zones:

- Increasing the width and continuity of planting across the riparian zone, including on both sides of the watercourse; the riparian zone is the area of land adjoining the aquatic zone and influenced by it (Figure 10).
- Increasing the longitudinal extent/length of riparian planting along the watercourse.
- Targeting level and gently sloping sections of watercourse (<2 degrees), especially those with wider functional riparian zones.
- Where appropriate, retaining existing woody material within watercourses and installing leaky woody dams or encouraging their formation, especially within headwaters, small streams and ditches where the channel is incised/deepened (subject to consent; see page 23).
- Where acceptable, planting on river banks (subject to consent on some watercourses and for certain types of planting, e.g. bank reinforcement); check with the relevant flooding authority).

Figure 9 Mesh fencing can easily fail as a result of trapping leaf litter and woody material during flood events.

Figure 10 Planting native woodland within riparian zones can be an effective way of slowing the flow, as well as providing other water benefits, including cooling water temperature.

Forest and woodland management

Forest and woodland management, including practices associated with woodland creation, also has a role to play in reducing downsteam flood flows. Operations such as cultivation, drainage and road construction all affect the volume, pathway and timings of water run-off. This section provides information on each of these factors, followed by guidance on how good practice can minimise risk and maximise the flood benefit of the woodland.

Cultivation

Soil cultivation for tree planting can both increase and decrease flood flows. The overturning or removal of ground cover reduces vegetation water use, increasing surface run-off from bare ground. In addition, the creation of linear channels and furrows such as by ploughing, can collect, direct and speed up surface run-off, especially on wetter soils and where furrows are aligned up-and-down slope (Figure 11). The effect of soil overturning is relatively short term until the vegetation regrows, while linear cultivation features can last for many years, especially if they are deep or start to erode. Measures that can help to reduce the impact on rapid run-off include selecting less intensive forms of cultivation (e.g. mounding), and restricting the length of downslope furrows or linear scrapes (e.g. by leaving regular breaks and installing drain-side buffers).

Cultivation can have the opposite effect on soils damaged by surface or deep compaction. The disruption of such layers can allow rainwater to percolate deeper into the soil, reducing topsoil wetness and surface or near-surface run-off (Figure 12).

Whatever the effect of cultivation, its impact on downstream flood flows will depend on the spatial extent of the cultivation operation. Appropriately designed, small-scale operations are less likely to have a measurable effect.

Figure 11 Long plough furrows accelerate run-off leading to higher peak flows.

Figure 12 Shallow ploughing and use of a tine can relieve soil compaction and reduce surface run-off.

Planning cultivation to reduce flood risk

Having selected an appropriate species mix to suit the nature of the site, the first step is to consider whether cultivation is needed. If it is, the least intensive and most appropriate cultivation method to successfully establish the planned woodland should be selected (Figure 13). Where appropriate, you will also need to consider the potential impact on flood risk. Key measures to minimise the risk of increasing flood flows when cultivating soils within catchments draining to nearby communities or assets at risk of flooding are:

- Avoid large-scale use of cultivation techniques that create linear channels, particularly ploughing; this includes allowing for the extent of recent (e.g. less than five years) linear cultivation on neighbouring land under different ownership.
- For small-scale use, limit lengths of linear cultivation channels by installing regular 2–5 m wide breaks, for example every 40 m on moderate (11–18 degree) slopes and every 70 m on gentle (6–11 degree) slopes.
- Check soil type and condition. If the topsoil is compacted or a pan or induration is restricting vertical drainage at depth, use cultivation to break/disrupt this layer but limit lengths of linear channels, as per small-scale use.
- Follow good cultivation practice as described by the UKFS and supporting guidance.

Figure 13 Mounding and screef planting minimise soil disturbance and avoid the creation of linear channels that can promote rapid run-off.

Drainage

The creation of drains can also increase or decrease flood flows. In most cases, drains will accelerate run-off by channelling and speeding up water flow. This will be greatest when drains are newly formed and usually declines with age as they become infilled with sediment and vegetation growth, depending on the degree of maintenance. The acceleration of run-off can be partly offset by restricting drain gradients and making sure drains discharge to buffer areas (generally 10–20 m wide, depending on the width of the watercourse or presence of a water body), rather than directly into watercourses.

In some cases, drains can have the opposite effect and reduce flood flows, particularly where they are effective at lowering the soil water table. This can result in the soil having a greater capacity to receive and store rainwater before run-off occurs during a flood event.

As with cultivation, the overall impact of drainage on flood flows will depend on the extent of drainage within a catchment, as well as on drain length and spacing, the nature of the soils and condition of existing drains. Small-scale operations are unlikely to have a measurable effect. The same factors apply to the impact of drain blocking, such as for peatland restoration.

Planning drainage to reduce flood risk

Having checked species selection and the nature of any required cultivation, determine whether there is a need for drainage to control run-off from cultivation channels or to aid woodland establishment. If so, you will need to consider the potential impact of drainage on flood risk. This includes assessing the presence of existing agricultural drains and the benefit of disconnecting these. Key measures to minimise the risk of drainage increasing flood flows within catchments draining to communities or assets at risk of flooding are:

- Avoid large-scale drainage operations, including allowing for the extent and nature of drainage on neighbouring land under different ownership.
- Avoid forest drains discharging directly into watercourses; drains should stop short of riparian buffer areas (Figure 14).
- Align forest drains to run at a maximum gradient of 2 degrees (3.5%) and lead them towards the heads of valleys.
- Do not drain wetlands, flushes or riparian zones; incorporate these into riparian buffer areas (Figure 15).
- Disconnect existing agricultural drains where it is safe to do so (if unsure, as in the case of main drains acting as significant watercourses, check with the relevant flooding authority) and replace with a drainage system that complies with UKFS Requirements and Guidelines.
- As soon as possible post-felling and prior to restocking, amend existing forest drains to slow down surface run-off.
- Where appropriate, correct any inadvertent water transfers between local catchments, after taking advice from the relevant flooding authority.
- Follow good drainage practice as described by the UKFS and supporting Guidelines.

Figure 14 Forest drains should not flow directly into watercourses, as shown here. Drains need to be disconnected from watercourses to slow down surface run-off.

Figure 15 Wetland flushes should not be drained, as shown here, as this will channel and speed up surface run-off.

Roads and tracks

Poorly designed roads and tracks can generate and accelerate run-off to watercourses, increasing flood flows. Their relative contribution may be greatest for summer floods generated by intense rainfall events. Rapid run-off from a network of road and track surfaces has the potential to cause local surface water flooding. This can be mitigated by disconnecting road drains from watercourses and using regularly spaced culverts to split and disperse road run-off onto adjacent slopes, slowing its flow and encouraging infiltration into the ground.

Planning roads and tracks to reduce flood risk

When planning the construction or upgrading of roads and tracks you will need to consider the potential impact on flood risk. Key measures to minimise the risk of works increasing flood flows within catchments draining to communities or assets at risk of flooding are:

- Ensure run-off from roads and tracks discharges to buffer areas and not directly into watercourses; disconnect existing road drains.
- Design road drains and culverts to avoid transferring run-off from one catchment into another catchment; do not overload drains.
- Ensure regular spacing of culverts (e.g. every 100 m) to split and divert road run-off, reducing drain flows and the risk of erosion.
- Consider changes in rainfall volumes predicted by regional climate change scenarios when specifying designs for road drains and culvert size.
- Where it is difficult to maintain an adequate camber, install regular bumps or gutters on long, steeply sloping sections of roads and tracks to reduce the build-up and speed of surface run-off (Figure 16).
- Avoid, move or strengthen sections of roads and tracks adjacent to watercourses to reduce the risk of undercutting and washout of embankments (obtain consent where appropriate).
- Follow good practice as described by the UKFS and supporting guidance, including controlling erosion and sediment run-off from roads and tracks.

Figure 16 Install regularly spaced culverts or cross-gutters to split and reduce road run-off. These will need to be maintained to remain effective.

Felling and restocking

Clearfelling will temporarily attenuate the forest benefit for reducing flood flows due to the removal of tree cover and resulting reduction in water use and re-wetting of soils. Soil compaction and rutting associated with poorly managed timber extraction can add to the problem by reducing the ability of rainfall to enter the soil and accelerating surface run-off, as well as by increasing soil erosion and siltation within watercourses. The retention of brash can help to reduce the loss of forest canopy interception and increase surface roughness, but only to a limited degree and for a limited period of time, depending on how it is managed.

Aside from implementing good harvesting practice or adopting other forest management systems such as conversion to continuous cover forestry (where suitable sites and species combinations allow and management objectives are compatible), the main way of controlling the impact of clearfelling is to limit the scale of the activity at the catchment level. Typical levels of clearfelling within well designed forests are likely to result in a small reduction of the flood benefit, especially at the scale of the catchment draining to most communities and assets at risk of flooding. However, larger-scale felling as part of the redesign of even-aged forests has the potential to significantly increase local peak flows due to the temporary loss of conifer water use (Figure 17). The locations affected are likely to be relatively few as first rotation forests have been progressively restructured over recent decades, resulting in smaller clearfells. Managing the risk in vulnerable catchments requires longer-term planning and balancing of other management objectives because restocking may be delayed by up to five years or more to control weevil damage and it can be a further ten years before regrowth of the trees largely restores canopy water use. The need for larger-scale sanitary felling to control forest pests or diseases has to be considered alongside the potential impact on flood risk. If there is little scope to vary the level of felling required, effort should focus on adopting other management measures to limit the risk, such as installing leaky woody dams.

> **!**
>
> Large-scale felling has the potential to increase local flood flows due to the temporary reduction in tree cover and evaporation

At one level, the temporary loss of the forest benefit by clearfelling could be viewed as simply returning to pre-afforestation conditions on previously open sites, and therefore of limited overall significance for flood protection, but this needs to be tempered by the potentially bare nature of clearfelled sites, the presence of cultivation channels, drains, roads and tracks, and the possibility that flood risk in the interim has increased due to climate change and

Figure 17 Avoid large-scale felling within catchments draining to local communities or assets at risk of flooding.

building development. This is mainly relevant to the protection of households, businesses and other key assets, and not to flooding of land in general, such as farmland, or minor infrastructure, such as culverts and local roads. It will also be offset (potentially resulting in a net gain compared with pre-afforestation conditions) from the flood benefit provided by any remaining standing forest in forested catchments subject to part felling.

Forest thinning and patch felling treatments have a much smaller effect than clearfelling. Woodland water use is largely unaffected until more than a third of the tree canopy is removed due to the resulting increased canopy ventilation compensating for the loss of the intercepting canopy.

Restocking will recover the benefits of a forest canopy for reducing flood flows, although the impact may be enhanced or reduced depending on changes to forest design and the nature of restocking practices. Loss of forest cover and conversion of conifer to broadleaved will reduce the existing flood benefit, while redesigning and disconnecting drains, and disrupting linear cultivation channels, will help to slow flood run-off. See the section on Creating new forests and woodlands (page 6) for more information on the effects of forest location, scale, design, tree age and forestry practices on flood flows.

Forest removal on peatlands may increase downstream peak flows, depending on the condition of the existing forest canopy. If the forest canopy is well developed the loss of the water use effect could exceed the benefit of drain blocking and re-vegetation in slowing surface run-off.

Planning felling and restocking to reduce flood risk

When planning felling and restocking within forested catchments draining to nearby communities or assets at risk of flooding, consider the potential impacts on flood risk. Key measures to minimise the risk of increasing peak flows are:

- Check whether local guidance is available and, if not, use flood maps, flood hazard maps and opportunity maps to determine if the forest drains to a downstream community or asset at risk of flooding and, if so, the scope for planned felling to increase the risk (Figure 18). This will depend on distance to the downstream community/asset and vulnerability to flooding.
- Where information is lacking, consult the relevant flooding authority. As a guide, the scale of felling is unlikely to be large enough to significantly increase the flood risk where there is less than 40% forest cover present within the upstream catchment of vulnerable communities or assets, allowing most catchments to be quickly screened out from further consideration.
- Where it is identified that households, businesses or other key assets are potentially at risk from large-scale forest felling, try to phase felling to minimise the impact on local flood flows (e.g. limit the extent of felling, resulting fallow land and restock <10 years old to <40% of the upstream catchment (see Appendix 2)).
- Where appropriate, minimise the fallow period between felling and restocking to shorten the felling effect.
- Consider the impact on flood risk of any planned large-scale conversion of conifer to broadleaves or loss of forest cover to open space, including for habitat restoration or wind farm development, and where significant, amend forest plans accordingly (e.g. by reducing the area of conifer removal or providing compensatory planting elsewhere within the catchment, e.g. Figure 19).
- Ensure machine working during felling and timber extraction does not divert surface water run-off to local housing or into a more vulnerable catchment.

Figure 18 Phased felling will minimise the risk of increasing peak flows.

- Where appropriate, restore any drained and planted wetlands or areas of wet woodland, create 'offline' leaky ponds, retain naturally accumulated woody material within watercourses, and where lacking, consider installing leaky woody dams to increase flood storage and slow flood flows (obtain consent; see page 23).
- When planning to install leaky woody dams, identify potential locations ahead of thinning or felling and leave appropriate lengths of log (to span the watercourse) on site for constructing leaky dams.
- Restore riparian zones and design and manage tree cover to maintain potential sources of woody debris and the natural formation of leaky woody structures in watercourses, as appropriate to location.
- When cultivating restock sites, restrict the length of spoil trenches to 30 m or less.
- As soon as possible post-felling and prior to restocking, amend drains to slow down surface run-off, including disconnecting existing forest drains from watercourses to create a suitable buffer area.
- Where disconnecting drains will back up water into an adjacent stand, plan to convert the area to wet woodland and incorporate it into a wider buffer area.
- Follow good practice as described by the UKFS and supporting guidance.

Figure 19 Consider the need for compensatory planting to maintain the forest flood benefit where forest removal is required for open habitat restoration or wind farm developments.

Interventions to slow run-off

Traditionally, efforts in forestry were directed at lowering soil water tables and removing excess water to improve conditions for forest growth and management. Deep ploughing and drainage of wet soils plus straightening of watercourses accelerated run-off from the land, increasing downstream flood flows. While these effects decrease over time with natural drain subsidence and infill, as well as by the developing forest water use, they can be temporarily reactivated by drain cleaning, tree felling and restock cultivation. Implementing good practice measures such as less intensive restock cultivation, blocking drains, retaining large woody material and leaky dams in drains and channels where appropriate, and restoring watercourses and riparian buffer areas, will help to manage these effects, as well as remedy past impacts.

In addition to implementing good practice, there may also be opportunities to install features to store more floodwater and/or slow run-off within woodlands and forests. This includes potentially using forest infrastructure such as roads, embankments and culverts to hold back flood flows, or installing formal flood storage features such as timber or soil bunds. Such features require considerable care and detailed design and management if they are to work effectively and not pose a local hazard (e.g. if they failed). They should therefore only be used under the direction of the relevant flooding authority, as part of a formal, funded NFM scheme or project.

> **!**
> Leaky woody dams are a natural and valuable feature of woodland streams that can help to retain and slow flood flows

Another option, which continues to attract much interest, is the use of leaky woody dams (Figure 20). Leaky woody dams are a natural and valuable feature of woodland streams (sustained by wood inputs from native riparian woodland) but are often removed because of concerns that they could be washed out and block downstream structures, or adversely affect fish movement. There is little evidence to support the latter but careful management of woody material is required within watercourses where downstream bridges and culverts are vulnerable to blockage, causing local flooding. It is also important that grates and screens designed to protect downstream culverts from blockage are adequately maintained by the

Figure 20 Leaky woody dams are a natural feature of woodland streams.

relevant authority. The construction of more stable dams may be possible in such watercourses to help slow flood flows while reducing the risk of washout. There is also an option of installing leaky woody dams within streams that do not have vulnerable downstream structures, as a means of accelerating the formation of natural woody dams within previously cleared streams or those recently planted with riparian woodland. A network of multiple leaky dams will exert a larger effect on downstream flood risk than one or two dams.

Installation of leaky woody dams for flood risk management requires great care to ensure that they are designed to deliver the desired effect, are appropriately maintained for this purpose and do not inadvertently increase flood risk (e.g. by the backing up of floodwaters or the release of woody material) (Figure 21). Such schemes should be delivered and managed in partnership with the relevant flooding authority, who will need to give consent, as well as involving local stakeholders and landowners. Larger woody dams are generally more cost-effective than smaller ones but can be less stable and pose a greater risk if they fail. Their lifespan will depend on the nature and species of tree used, as well as on their design and stresses placed on them.

Where stability is less of an issue, installed leaky woody dams should be left to naturally evolve providing they can be sustained by woody inputs from native riparian woodland. Joint guidance has been published by ADEPT on managing the potential hazards associated with installing leaky woody dams within watercourses, including on addressing issues of liability, design and maintenance (see Further reading and useful sources of information).

Figure 21 Leaky woody dams are most effective at high flow, when they hold back and push floodwaters onto the floodplain, increasing flood storage (left). However, 'weak' dams can be washed out at high flows (right), where the top log has broken and is likely to fail during the next flood event.

Installing leaky woody dams to reduce flood risk

When planning, designing, constructing and maintaining leaky woody dams to help reduce downstream flooding, there are a number of key points to consider.

Planning

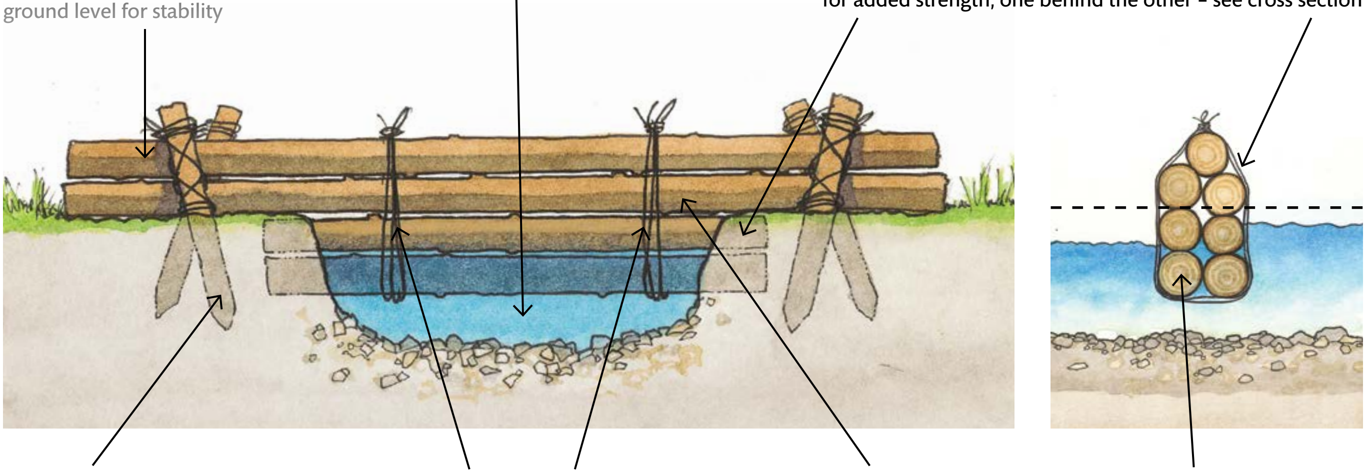
- Check the presence, condition and management of existing natural leaky woody dams and woody material within local watercourses (where appropriate, retain features), the ability of the riparian zone to sustain these, and the case for installing new leaky woody dams, including flooding authority and landowner support.
- Check the nature of the downstream flood risk and the scope for leaky woody dams to contribute to flood protection.
- Seek guidance on the appropriateness and type, number and size of leaky woody dams that would fit the location.
- If deciding to proceed, obtain consent from the relevant flooding authority prior to any work in or adjacent to a watercourse; this is a legal requirement.
- Integrate the use of leaky woody dams with other forest management objectives, access needs, constraints and opportunities for the timing of installation.
- Check with the relevant flooding authority if downstream structures (at least within 10 km) such as bridges and culverts are at risk of blockage from woody material and, if so, whether this would increase flooding to nearby property, assets or land. Where there is a risk of blockage and flood damage, avoid installing, or design structures to withstand washout.
- Check if leaky woody dams could back up or divert flows onto neighbouring land or affect access routes and, if so, seek agreement or reject the site.
- Select locations for building leaky woody dams that will be effective for storing flood waters and/or slowing the flow (e.g. wider, flatter sections of floodplain (<2 degree channel gradient) that will hold/store more floodwater, or incised/deeper water channels where dams will slow and push water out-of-bank).
- Only install structures in watercourses that are <5 m wide.
- Favour locations with bankside trees or riparian woodland, which will help to sustain and improve the stability of structures (e.g. by bracing logs against or securing to trees or stumps), increase their effectiveness (e.g. by inputs of deadwood) and trap washed-out material.
- Avoid sites where flood flows are already controlled/throttled by existing culverts and bridges, especially where the leaky woody dams would be 'drowned out' by floodwater backing up from these.
- Avoid steep watercourses and those with vulnerable or sensitive banksides where scour or undercutting could threaten bank stability and that of adjacent man-made structures and access routes.
- Avoid watercourses with a high sediment load (unless part of river restoration) as leaky woody dams can quickly fill or become blocked by sediment.

Design

- Follow published guidance on assessing the potential hazards of installing leaky woody dams within watercourses, including how to strengthen structures to reduce the risk of washout (see ADEPT guidance in Further reading and useful sources of information).
- Check accessibility of leaky woody dams to the public and where contact is likely, design structures to minimise the risk of accidental injury and install appropriate signage.

- Select a design that is appropriate to the location and leave a gap below the structure to allow low and moderate flows to pass unhindered (this will increase their effectiveness at reducing high flows, as well as aid fish passage).
- Consider the scope to increase the height and width of the leaky woody dam to increase the volume of flood storage; where appropriate, extend the dam across the floodplain on both sides of the watercourse.
- Where appropriate, secure structures in place by tying logs together and to adjacent trees or supporting posts (Figure 22); this will prevent logs floating and moving during high flows.
- Use appropriate fixings, informed by the expected lifespan of the structure, ease of maintenance and potential replacement, and hazard posed by washout.
- Do not overengineer dams; balance design and cost with flood volume stored (consider cost per cubic metre stored) and hazard posed by washout.
- Install leaky woody dams perpendicular to the watercourse to avoid flows being deflected into and undercutting stream banks, unless this is desired as part of river restoration and wider NFM.
- Where possible, use full length logs (rather than cut into short sections) to span the watercourse and floodplain as these are more stable and easier to secure.
- Use local trees to construct structures and favour available species that are more resistant to degradation, such as oak, sweet chestnut, beech, ash, willow and alder; where possible, use manual directional felling plus winching to aid construction.
- Where suitable local trees are not available, consider the scope to obtain trees from nearby planned thinning or felling operations.
- Do not use veteran, locally important, diseased or dead trees.
- Consider the use of 'live' dams where appropriate, formed by sprouting, split trees, partly felled across the watercourse.

Figure 22 Indicative design for constructing an engineered, leaky woody dam, suitable for watercourses <5 m wide and where downstream structures are vulnerable to blockage by woody debris.



- Construct a network of leaky woody dams to increase their contribution to reducing downstream flood risk; consider undertaking a cross-section survey along the watercourse to estimate the potential volume of flood storage.
- Design the spacing of individual leaky woody dams in a network so that upstream dams are not drowned out by floodwaters extending behind downstream ones (Figure 23).

Constructing and maintaining

- Minimise ground damage when constructing leaky woody dams; use machinery with great care as riparian soils are typically very wet throughout the year and very vulnerable to rutting and compaction.
- Consider an annual survey of installed leaky woody dams plus additional inspections after any significant flood events.
- Consider the need to repair or replace weakened or damaged leaky woody dams to maintain their effectiveness in reducing flood flows; naturally sustained and relatively stable dams that pose a low risk if washed out can generally be left unmanaged.
- Check the permeability/leakiness of woody dams and ensure they do not become a barrier to fish movement.
- Check with the relevant flooding authority before removing existing natural or installed leaky woody dams as their removal could increase local flood risk and adversely affect water quality and ecology.

Figure 23 Closely spaced dams as shown here are likely to be drowned out by the backing-up of floodwaters, reducing their overall effectiveness.

Monitoring

Monitoring the impact of forest measures can serve a range of purposes. First, it can be used to demonstrate the effectiveness of one or more measures and how this evolves over time, which may be a requirement of funding. Second, assessing the contribution that installed measures make to managing downstream flood risk will help inform future investment and an integrated approach. Lastly, monitoring will guide maintenance needs and when to eventually replace measures to secure their longer-term performance, which is especially important for interventions with a limited design life. An underlying requirement before undertaking any monitoring work is to set clear objectives and tailor monitoring to meet these.

In most cases, it will not be practical or affordable to quantify changes in flood flows in response to woodland creation or woodland management operations. Demonstrating such change requires an extended period of baseline measurements to capture several flood events, a long period of post-intervention measurements until the forest effect is established and several repeat events have been recorded, and an equivalent set of measurements for a comparable control site to allow for changes in background factors such as climate. This necessitates much investment and commitment to maintain robust measurements over many years or even decades, which is more suited to a longer-term research study (Figure 24).

A 'lighter-touch' approach will often be preferable for monitoring the effects of individual measures or schemes, such as using water level recorders to assess changes to peak height along a local section of watercourse. Alternatively, monitoring can focus on measuring changes to specific site factors or processes, with the data generated used to run models to predict changes to downstream flood flows. Measurements could include: changes to soil infiltration rates or soil water content within planted areas; the amounts of water used by canopy interception and/or transpiration by a growing woodland; how hydraulic roughness changes with tree growth; or estimating volumes of water stored behind features such as leaky woody dams. Time-lapse cameras can be combined with stage boards to capture the effects of individual measures on local water levels during flood events (Figure 25).

Figure 24 Large structures are required to contain and measure flood flows.

Figure 25 A camera and gauge board are used here to record how the timber dam affects high flows.

Monitoring of specific interventions such as leaky woody dams can range from regular observations of their general condition to more detailed but less frequent surveys of changes to their inherent strength and porosity.

If you have a desire to undertake monitoring of a forest measure or are asked to do so as part of an NFM project or scheme, the key points to consider are:

- Develop a monitoring plan and define clear and specific, measurable, achievable, relevant and time-bound (SMART) objectives.
- Consider whether the scale of woodland creation or management practice, or the number of interventions, is likely to have a measurable impact on flood peaks within the required timescale of the funded project or scheme; if not, monitoring is unlikely to be worthwhile.
- Check whether stream flow or water level baseline data are available for the location and, if not, there is a willingness to wait (a minimum of one to three years) for their collection before the scheme, practice or intervention is implemented; if there is not then the results of monitoring are less likely to be conclusive.
- Check whether a suitable control site is available to monitor and allow for background changes in rainfall and run-off; if not, monitoring data will be less robust and possibly inconclusive.
- If more than one intervention to slow down or reduce flood flows is planned, establish if there is a need to separate their effects; if so, design the layout of monitoring points accordingly.
- If the site and scheme is not conducive to monitoring impacts of the measure(s) on flood peaks, consider alternative measurements such as changes to soil infiltration rates, canopy interception or to hydraulic roughness, or whether a set of repeat images or site surveys will suffice.
- If the aim is to use monitoring data to inform modelling work, check the data requirements with modellers and ensure that the measurements are appropriate.
- Tailor monitoring of specific structures to the risk of their failure and expected degradation rates; for example, it is likely to take a number of years (5–10 years) before newly installed leaky woody structures start to degrade significantly, with their lifespan dependent on tree species and local conditions.

Further reading and useful sources of information

Forestry authority publications

- The UK Forestry Standard (FCFC001)

Guidance

- Managing forests in acid-sensitive water catchments (FCPG023)
- Managing forest operations to protect the water environment (FCPG025)
- An Ecological Site Classification for forestry in Great Britain (FCBU124)

Research

- Water use by trees (FCIN065)
- Forestry and surface water acidification (FCRN016)
- Ecosystem services and forest management (FCRN020)

The UK Forestry Standard and supporting guidance can be found on the Forest Research website at: **forestresearch.gov.uk/ukfs**. The full publications catalogue is available from **forestresearch.gov.uk/publications**.

Other publications

- Good Practice Guides (SEPA)
  - Bank protection
  - River crossings
  - Sediment management
  - Construction methods
  - Riparian vegetation management

- The natural flood management manual (C802F) Construction Industry Research and Information Association (CIRIA) - ciria.org
- Surface water alterations handbook (Department of Agriculture, Environment and Rural Affairs)
- Working with natural processes evidence directory, literature review and case studies - Working with natural processes to reduce flood risk - GOV.UK (www.gov.uk)
- Peatland catchments and natural flood management review - Commission of Inquiry on Peatlands Update 2017–20 (IUCN UK Peatland Programme)
- Assessing the potential hazards of using leaky woody dams for natural flood management: Natural Flood Management Programme - Assessing the risk (ADEPT).
- Guidelines for decision-makers, forest managers and landowners on forested water retention areas (FORWARA)
- Review of the impact of clearcutting on peak flows - Rainfall-generated stormflow response to clearcutting a boreal forest: peak flow comparison with 50 worldwide basin studies - ScienceDirect
- Natural flood management handbook: SEPA's Natural Flood Management Handbook For Practical Delivery

Websites

UK forestry authorities

- England: Forestry Commission – www.gov.uk/ukfs
- Scotland: Scottish Forestry – www.forestry.gov.scot
- Wales: Natural Resources Wales – www.naturalresourceswales.gov.uk
- Northern Ireland: Forest Service – www.daera-ni.gov.uk/forestry

Water regulatory authorities (most relevant to forestry and flooding)

- England: Environment Agency – www.environment-agency.gov.uk
- Lead Local Flood Authorities in England – www.local.gov.uk (see Local Government Association for local contact)

- Scotland: Scottish Environment Protection Agency – www.sepa.org.uk

- Wales: Natural Resources Wales – www.naturalresourceswales.gov.uk
- Lead Local Flood Authorities in Wales – www.gov.wales/find-your-local-authority

- Northern Ireland: Department for Infrastructure Rivers – www.infrastructure-ni.gov.uk

Other useful websites

- Joint Nature Conservation Committee (JNCC) – jncc.defra.gov.uk
- Association of Drainage Authorities (ADA) – www.ada.org.uk (to find your lead local flood authority)
- Natural England – www.naturalengland.org.uk
- NatureScot – www.nature.scot
- The Rivers Trust (to find your local rivers trust) – www.theriverstrust.org
- Water UK (to find your local water company) – www.water.org.uk
- Forest Research – Opportunity mapping - targeting woodland creation for water objectives
- Forest Research – Ecological Site Classification – www.forestresearch.gov.uk/tools-and-resources/fthr/ecological-site-classification
- JBA Trust interactive mapping for natural flood management – Working with Natural Processes: Home Page (jbahosting.com)

Appendix 1: Flooding authorities

Responsibility for managing flooding is shared between a number of authorities that differ between the four countries of the UK.

In England

In England, flooding authorities are known as Risk Management Authorities and include:

- Environment Agency
- Lead Local Flood Authorities
- District and Borough Councils
- Coast Protection Authorities
- Water and Sewerage Companies
- Internal Drainage Boards
- Highways authorities

The most relevant of these authorities for dealing with forestry and flooding matters are likely to be the Environment Agency (for main rivers and coast) and Lead Local Flood Authorities (for local flood risk arising from surface water, groundwater and ordinary (smaller) watercourses).

In Scotland

In Scotland, the authority responsible for managing flooding is SEPA, as the strategic flood risk management authority, supported by other 'responsible authorities', including local authorities, Scottish Water and the National Park authorities. Where this Guide advises consulting with the flooding authorities, in Scotland this refers to SEPA.

In Wales

In Wales, flooding authorities are known as Risk Management Authorities and include:

- Natural Resources Wales
- Lead Local Flood Authorities
- Water Companies and the Welsh Government Highways Authority

The most relevant of these authorities for dealing with forestry and flooding matters are likely to be Natural Resources Wales (for main rivers and coast) and Lead Local Flood Authorities (for local flood risk arising from surface water, groundwater and ordinary watercourses).

In Northern Ireland

In Northern Ireland, flooding authorities are:

- Department for Infrastructure (DfI Rivers, DfI Roads; DfI Water and Drainage (for policy matters))
- Local Councils
- NI Water
- NI Fire and Rescue Service

The most relevant of these authorities for dealing with forestry and flooding matters is likely to be the Department for Infrastructure (Rivers).

Appendix 2: Assessing and managing the scale of felling to minimise flood risk

This Appendix sets out the recommended approach to assessing the scale of planned felling within upstream catchments of nearby communities or assets at risk of flooding and how to phase felling to minimise impacts.

Information gathering

You should first check whether local guidance is available and, if not, use flood maps, flood hazard maps and opportunity maps to determine if the forest drains to a stream or river that causes flooding of local houses, businesses or other vulnerable assets that could be potentially impacted by a temporary increase in run-off due to forest felling.

> !
>
> If forest cover is less than 40% of the total catchment area, the scale of felling is unlikely to be large enough to significantly increase downstream flood risk

Where a community or asset is known to be at risk, efforts should be made to limit the scale of felling within the upstream catchment. This requires the catchment boundary to be identified and the area of planned felling within it to be determined. Where information is lacking, contact the relevant flooding authority (see Appendix 1).

Identifying the boundaries of water catchments

There may be country-level maps or guidance that have already defined the catchment areas of vulnerable communities and assets, in which case select the appropriate catchment. Failing this, you will need to determine the catchment boundary using a contour map or GIS.

Step 1 – Identify the catchment outlet

The catchment outlet is the location of the nearest property or asset known to be at risk from flooding, based on local knowledge or available flood maps. Starting from either side of the catchment outlet, draw a line upslope, perpendicular to the next contour, then continuing these two lines across consecutive contours until the highest points are reached (see the arrows in Figure A2.1). This process continues by following the edge of the natural drainage basin to link up consecutive high points, until the two lines meet, completing the catchment.

Step 2 – Calculate the catchment area and extent of forest cover

Where forest cover is less than 40% of the catchment, the scale of felling is unlikely to be large enough to significantly increase flood risk. This should allow most catchments to be quickly screened out from further consideration, because the majority will have less than 40% forest cover (see the worked example in Table A2.1, Catchment 3).

Where forest cover exceeds 40% of the catchment, check the forest management plan and determine how the scale of felling plus fallow land and young restocked trees (less than 10 years old) will change over the period of the plan. For ease of working, it is recommended that the assessment uses the standard five-year felling periods in forest management plans.

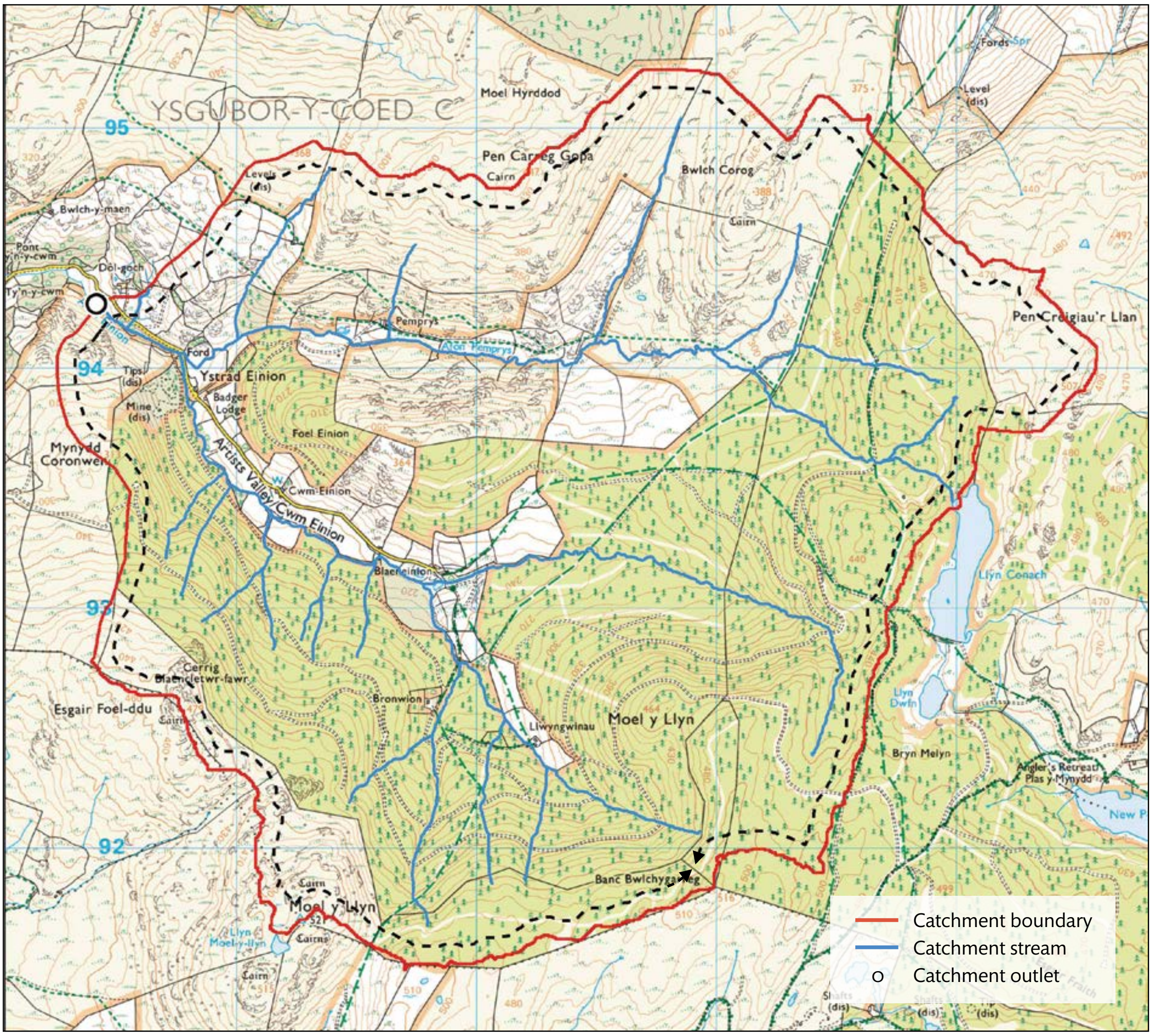
To account for the effect of any fallow period and the time taken for restocked trees to reach an age of 10 years, assume that the effect of felling extends over the full five-year period in which it occurs, plus the next two five-year periods. Note that the length of these time periods can be changed to suit local circumstances (e.g. where it is possible to have a shorter fallow period or site conditions will support faster canopy closure), subject to discussion and agreement with the forestry authority. Continue this rolling assessment for consecutive five-year periods over the duration of the forest management plan.

Assessing the scale of planned felling

Within any five-year period, if the total area of felling, fallow land and young restocked trees (less than 10 years old) is less than 40% of a catchment, then the effect on peak flows is likely to be small. However, as the proportion of the catchment affected increases beyond 40%, the loss of the forest benefit becomes more significant due to a greater potential rise in peak flows.

Large-scale felling poses the greatest risk of increasing peak flows and, therefore, where feasible, it is recommended that the total area of felling, fallow land and young restocked trees (less than 10 years old) within any five-year period should be less than 40% (Figure A2.2). Include any felling that is part of planned forest removal within the catchment, such as for wind farms or the restoration of open habitats.

Figure A2.1 Identifying the boundary of a water catchment (see Steps 1 and 2 opposite).



Felling by neighbouring owners

It is important to note that the 40% includes felling planned by any neighbouring owners in the catchment, which should be factored into the calculation. Because the felling plans of neighbours may not be known, the simplest way to proceed is to work out the proportion of the 40% that applies to your own forest, based on the proportion that this represents of the overall forest cover in the catchment (Table A2.1).

This should involve the following steps:

- Determine the proportion of the forest cover in the catchment under your ownership or management.
- Apply this proportion to the recommended 40% level to determine the percentage that applies to your own property; thus if you manage or own 60% of the forest area within a catchment, your fraction of the felling is 40 x 0.6 = 24%.
- Convert your fraction of the felling threshold to hectares by multiplying the total catchment area by your fraction; thus if the total catchment area is 1000 ha, your fraction of the felling threshold in hectares is 0.24 x 1000 = 240 hectares.
- For your forest ownership falling within the catchment boundary, take the planned felling rate for consecutive five-year phases and carry the effect of each forward for the subsequent two five-year phases, as described above and shown in Figure A2.2; where a felling coup straddles the catchment boundary only include the part that lies within the catchment.
- Compare these felling area totals with your fraction of the felling threshold to determine whether it is likely to be exceeded in any five-year period.

If the planned rate of felling keeps the loss of forest cover to below the 40% level, no further action is needed (Table A2.1, Catchment 1). If it exceeds the level in one or more five-year periods, consider the scope for adjusting the scale of the planned felling to meet the level across all five-year periods (Table A2.1, Catchment 2 and Figure A2.2).

Figure A2.2 Extent of loss of forest cover in Catchment 2 through time. Different coloured bars represent the area felled in each five-year phase and the effect of this is carried forward to the subsequent two five-year phases as fallow or young restock.

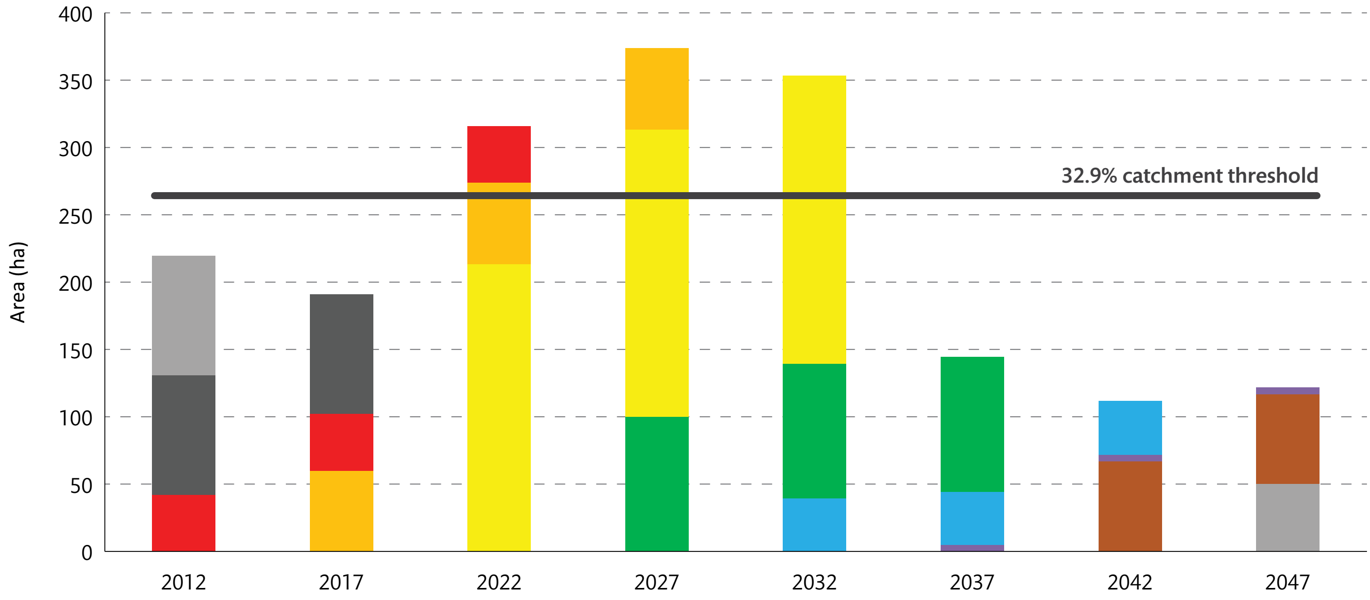


Table A2.1 Worked example of calculating the scale of planned felling and resulting fallow land and restock less than 10 years old in any five-year period of a forest plan (exceedances of 40% threshold applying to ownership highlighted in red); the changes to Catchment 2 are displayed in Figure A2.2.

Catchment assessment	Unit	Catchment 1	Catchment 2	Catchment 3
Total catchment area upstream of nearest property(ies) or asset(s) at risk of flooding	ha	708	800	2735
Total forest cover in catchment	ha	452	753	455
Proportion of forest cover in catchment (no consideration needed if <40%)	%	(452 ÷ 708) x 100 = 63.8	(753 ÷ 800) x 100 = 94.1	16.6
Forest cover under ownership	ha	452	620	
Proportion of forest under ownership in catchment	%	(452 ÷ 452) x 100 = 100	(620 ÷ 753) x 100 = 82.3	
Extent of 40% felling level applying to ownership	%	0.4 x 100 = 40.0	0.4 x 82.3 = 32.9	
Felling allowance for forest under ownership	ha	0.4 x 708 = **283**	0.329 x 800 = **263**	
Extent of felling within 5-year phases of the plan, the carry-over effect of fallow land and young restocked trees (less than 10 years old) over the next two phases (in brackets), and the total loss of forest cover (the effect of felling in the previous 10 years are carried forward to the first period of the new forest management plan, starting in 2012)				
2012–2016	ha	**61** + (56 + 56) = 173	**42** + (89 + 89) = 220	
2017–2021	ha	**66** + (61 + 56) = 183	**60** + (42 + 89) = 191	
2022–2026	ha	**40** + (66 + 61) = 167	**214** + (60 + 42) = 316	
2027–2031	ha	**16** + (40 + 66) = 122	**100** + (214 + 60) = 374	
2032–2036	ha	**0** + (16 + 40) = 56	**40** + (100 + 214) = 354	
2037–2041	ha	**67** + (0 + 16) = 83	**5** + (40 + 100) = 145	
2042–2046	ha	**67** + (67 + 0) = 134	**67** + (5 + 40) = 112	
2047–2051	ha	**50** + (67 + 67) = 184	**50** + (67 + 5) = 122	
Outcome of assessment for Catchments 1, 2 and 3		No action needed as planned felling never exceeds 283 ha (40%) limit	Need to explore scope to reduce scale of planned felling during 2022–36 because it exceeds the 263 ha (32.9%) level applying to ownership in this 15-year period. Check felling plans with other owners in the catchment in case no other felling is planned. If not, this could raise the level to 320 ha (40% limit). This would remove exceedance of the level in 2022–26 and reduce it to a smaller margin in the other two periods. Check if some felling can be delayed until 2037–41; if not, check vulnerability of properties and consider measures to reduce or slow run-off.	No assessment needed (<40% forest cover)

This should be relatively easy where it is only exceeded for one five-year period by a small margin but will be more difficult for larger exceedances over multiple periods (Catchment 2). If there is multiple forest ownership in the catchment and the exceedance only applies to a single ownership, check felling plans with other forest owners in the catchment in case there is scope to use the remaining capacity.

Where it is not feasible to amend the forest management plan to keep below the 40% level, for example due to the forest extent and age distribution, the presence of landscape and biodiversity constraints, or hazards such as the risk of windthrow, then discuss alternative options with the forestry and flood authorities. Actions will depend on the nature of the local flood risk and the margin by which the 40% level is exceeded. The presence of less vulnerable assets (e.g. properties that are protected from all but large floods) and small exceedances of the 40% level require less attention.

Possible measures that can be taken to offset the temporary loss of the forest benefit and increase in peak flows include interventions to slow and/or store run-off from felled and young restocked areas (see page 22). Woodland creation elsewhere within the catchment can also offset the felling effect, depending on the relative timing of planting. New planting 10 years before the peak in felling exceeds the 40% level would be of the most benefit, because then the new woodland canopy is more likely to be established and actively intercepting rainfall.

Appendix 3: Modelling impacts

Mathematical models are used to design traditional flood schemes to deliver a specified level of flood protection. The models focus on river hydraulics within well-defined channels and are well understood and accepted, giving relatively high confidence in the performance of the designed measures. This is not the case with modelling NFM interventions, which relies on a wider understanding of catchment hydrology and how the features will perform and change during flood events.

Growing interest in NFM and accompanying research continues to improve models, which are increasingly being used by research organisations and consultancies to inform the development and design of NFM schemes (Figure A3.1). They are also being coupled with economic models to evaluate the cost-benefit or flood regulation service of measures such as woodland creation.

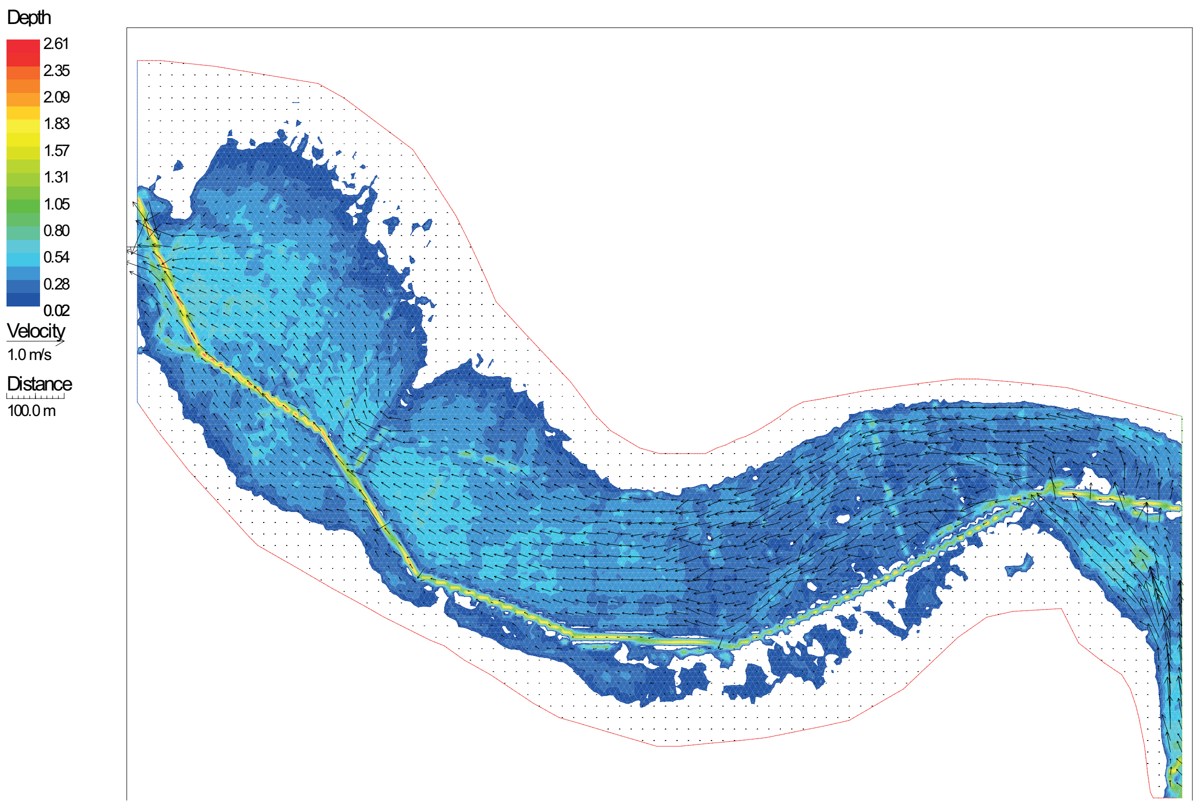
Most models are propriety software and the cost of purchase and licensing is high. They also need a high level of expertise and understanding of hydrology and hydraulics to be correctly applied. Model application is therefore best done by established companies or agencies, although some may not be well versed in adapting models to assess woodland or other NFM measures. Many towns and cities subject to flooding will already have an established hydraulic model but the boundaries of these models will usually not extend upstream of the urban area and simply treat upstream hydrology as a 'black box'.

If there is a desire to predict the potential impact of forest measures or if you are contributing to an NFM project or scheme that involves modelling work, the key points to consider and explore with partners or consultants are:

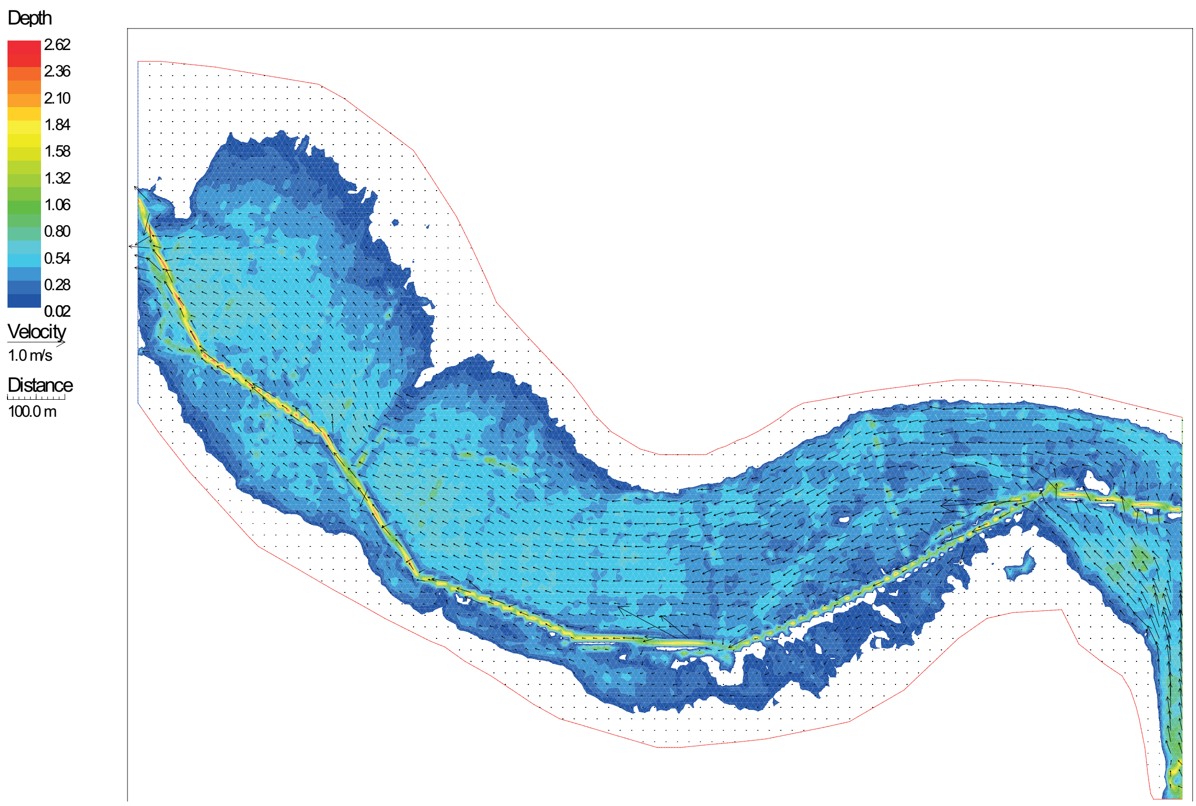
- Check with the relevant flooding authority whether there is an established model for the location or for a comparable site that can be adapted for use.
- Ask how the woodland measure(s) is/are represented in the model and which woodland effects are included (e.g. forest water use and canopy interception, soil infiltration benefits and/or changes to hydraulic roughness); note that the number of these processes included and the way they are represented in the model will have a large influence on the predicted woodland effect.
- Ask about the model calibration and check how well it reproduces flood peaks in the baseline period of observed flow or water level measurements.
- Check if the model is 'spatially distributed', which is preferred, and if so, correctly represents the location and design of the woodland measure(s) in the catchment; the catchment outlet for modelling should be the downstream community or asset at risk of flooding.
- Check if the modelling scenarios are sensible and include realistic and appropriate standards of downstream flood protection, as well as allow for the effects of forest management and climate change.

Figure A3.1 Planting 130 hectares of floodplain woodland along a 2.2 km reach of the River Cary in Somerset was predicted to increase the flood level for a 1-in-100 year event by 50–270 mm, temporarily storing up to an additional 120,000 cubic metres of floodwater*. Displayed colour relates to the depth of floodwater, while the length of the black arrows relate to the velocity of water/flood flows.

(a) Floodplain modelled with a cover of short grass.



(b) Floodplain covered by woodland.



*Source: THOMAS, H. and NISBET, T.R. (2006). An assessment of the impact of floodplain woodland on flood flows. *Water and Environment Journal*, **21**, 114–26.

Glossary

Active floodplain An area of land on either side of a watercourse that is regularly flooded during high flows.

Brash The residue of branches, leaves and tops of trees, sometimes called 'lop and top', usually left on site following harvesting.

Buffer area An area of land that protects the watercourse from activities on the adjacent land, such as by intercepting polluted run-off. The buffer area will usually include the riparian zone and may extend into the adjacent land.

Bund A constructed embankment designed to hold back floodwaters to create flood storage or to protect assets from flooding.

Canopy interception loss The proportion of rainfall that evaporates from the wetted surfaces of leaves, branches and tree trunks during and after rainfall.

Catchment The area of land from which precipitation drains to a defined point in a river system, or to a lake, reservoir or spring.

Cross-slope shelter belts A small/narrow band of woodland running across a hill slope to reduce rapid runoff from higher land, as well as create shelter.

Erosion The wearing away of the land surface by rain, wind, ice, or other natural or anthropogenic agents that abrade, detach and remove geological parent material or soil from one point on the Earth's surface and deposit it elsewhere.

Flooding authority The organisation(s) responsible for managing flooding (Appendix 1).

Flow throttle An obstruction (e.g. a culvert or bridge) that constricts the flow of water within a watercourse, holding back and slowing down flood flows.

Fluvial Conditions or processes relating to or occurring within a river.

Groundwater All water that is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil. This zone is commonly referred to as an aquifer, which is a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow a significant flow of groundwater or the abstraction of significant quantities of groundwater.

Hydraulic roughness The amount of frictional resistance created when water flows over land or river features, which acts to slow the rate of flow.

Infiltration (soil) The rate at which a soil surface can absorb rainfall and water can enter and move down into the soil – depends on factors such as surface compaction and sealing, soil wetness and rainfall intensity.

Infiltration basins A designated area of land that is used to receive surface runoff to temporarily hold the water to promote rapid infiltration into the ground. Can also be used to receive diverted river water during high flow to recharge groundwater aquifers and enhance water supply in summer dry periods.

Large woody debris Pieces of deadwood larger than 10 cm diameter and 1 m length, comprising whole trees, logs, branches and root boles that can accumulate within river systems.

Leaky woody dam A leaky barrier usually consisting of logs and branches, occasionally combined with some living vegetation, that naturally forms or can be placed or engineered in river channels, as well as on river banks and across floodplains. It acts to slow river flow and temporarily increase flood storage, including by pushing water out-of-bank and reconnecting rivers with their floodplains. Known by a wide range or terms, including leaky woody dams, leaky woody debris dams, large woody dams, coarse woody dams, in-stream structures, engineered log jams and beaver dams.

Main river (England and Wales) Usually larger rivers and streams that are designated on a statutory 'Main River Map' by the Environment Agency in England and Natural Resources Wales in Wales, who may carry out maintenance, improvement or construction work to manage flood risk. Other rivers not on the Main River Map are called 'ordinary watercourses'.

Morphology The spatial diversity of the physical characteristics of a water body and how they change dynamically over time due to natural and anthropogenic processes. Geomorphology refers to the size and shape of a water body and stream bed sediments; and Hydro-morphology refers to the flow regime.

Natural flood management A set of flood management techniques that aim to work with natural processes (or nature) to reduce the risk of flooding. They can be used in conjunction with more traditional engineering techniques.

Ordinary watercourse A watercourse that does not form part of a Main river and is not shown on the Main River Map in England and Wales. Lead local flood authorities, district councils and internal drainage boards may carry out flood risk management work on ordinary watercourses.

Patch felling Felling smaller areas (e.g. 1–5 ha) of even-aged forest to create a more varied structure consisting of a mosaic of age classes.

Pluvial The result of the action of rain, usually high rainfall.

Protected habitat or species Habitats or species protected by the Habitat Regulations.

Riparian Relating to or situated adjacent to a watercourse or water body.

Riparian woodlands Woodlands situated adjacent to a watercourse or water body.

Siltation Deposition of water-borne, mainly soil-derived, particles within a watercourse, other body of water, or wetland.

Soil moisture deficit The difference between the amount of water in a soil at a given point of time and the maximum it can hold after drainage has ceased by gravity.

Spatially distributed model A model that takes account of the spatial variation in physical properties across a land surface (e.g. topography, land cover, soil type, soil hydrology), rather than simply lumping these together, such as at a catchment scale. The spatial resolution depends on the nature of the model application and availability of data, and is often grid based.

Stage board A graduated board for measuring the depth of water within a water body or channel, usually with zero height being the bed of the water body or watercourse.

Stand basal area The cross-sectional area of all trees measured at breast height (1.3 m) per hectare of a woodland or forest; expressed as m^2 per hectare and often used to estimate stand volume.

Statutory flooding authorities The bodies with responsibility for managing flooding is shared between a number of authorities that differ between the four countries of the UK (see Appendix 1 for details).

Sustainable drainage system A more natural approach to managing surface runoff from the land by slowing, storing and reducing surface water before it enters watercourses, such as by using bunds, soakaways and permeable surfaces.

Swales A shallow, broad and vegetated channel designed to store and/or delay runoff, such as by enhancing soil infiltration.

Transpiration The evaporation of water through the pores or 'stomata' on the surface of leaves, supplied by water taken up by roots from the soil.

Washlands Areas of land adjacent to rivers that are formally used to temporarily store floodwaters to help reduce flooding downstream. These areas may be bunded, with the inflow and outflow of floodwater controlled by structures.

Water body The basic water management unit defined under the Water Framework Directive for which environmental objectives are set. Water bodies can be parts of rivers, lakes and estuaries, stretches of coastal water or distinct volumes of groundwater.

Watercourse Any natural or man-made channel through which water flows continuously or intermittently.

Water use The loss of water from vegetation by evaporation, principally by canopy interception and transpiration processes.

Wetlands Transitional areas between wet and dry environments, ranging from permanently or intermittently wet land to shallow water and water margins. The term can describe marshes, swamps and bogs, some shallow waters and the intertidal zone. When applied to surface waters, it is generally restricted to areas shallow enough to allow the growth of rooted plants.

Wet woodland Native woodland on wet soils in a variety of situations such as flushed slopes, wet hollows, valley floors and the riparian zone.

UKFSPG027/FR(ECD)/JTCP-0.5K/OCT22

Flooding is a major environmental hazard facing the UK and one that is expected to increase with climate change. Societal impacts and economic damages are likely to escalate, with major floods already costing multiple £billion. These concerns are driving a more sustainable approach to flood risk management involving greater working with natural processes to slow down and store floodwater within upstream catchments. Woodland creation can make an important contribution to reducing downstream flood risk, while forest operations such as cultivation, drainage, road construction and harvesting can have the opposite effect if not appropriately managed. This Practice Guide provides advice to landowners, forest and woodland managers, planners, practitioners and flooding authorities, on how forests, forest management and woodland creation can affect flood flows and flood water storage. Applying this guidance will help ensure that forests and woodlands make a positive contribution to natural flood management as part of a more sustainable and integrated approach to protecting communities from the damaging effects of future flooding.

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