The UK Forestry Standard

The governments' approach to sustainable forestry

Forestry Commission
Scottish Forestry
Coilltearachd na h-Alba
Cyfoeth Naturiol Cymru
Natural Resources Wales
FOREST SERVICE

9. Forests and Water

Sustainable forest management is essential to ensure the supply of good quality fresh water, provide protection from natural hazards such as flooding or soil erosion, and protect aquatic species.

Water and climate change

Having forests that are well planned, designed and managed as regards their impact on the water environment is more important than ever. Climate change is expected to have a marked impact, with wetter winters and more extreme rainfall events affecting the timing and volume of river flows and the extent of groundwater recharge, in turn increasing the risk of flooding and soil erosion and the consequent negative impacts on water quality and ecology. Reduced summer rainfall coupled with increased demand for water may have potentially serious implications for water supplies and ecosystem flows, while increased water temperatures will threaten the survival of salmonid fish and other sensitive freshwater life. Greater soil drying will exacerbate the decomposition of soil organic matter and the release of dissolved organic carbon, in turn affecting freshwater ecology and increasing the treatment costs of public water supplies. Many current water management systems are historic and preserve important heritage features such as sluices and weirs. As well as being important irreplaceable features, they add significant value and character at a landscape level.

Forests and forest management practices can help to moderate these impacts and so there is a need to develop appropriate strategies for managing and redesigning forests for water protection and enhancement. Forests that are well designed and managed can reduce the effects of acid deposition, avoid eutrophication, decrease sediment delivery and help manage local flood risk. In turn these will help improve the quality of aquatic habitats and support aquatic species, improve ecological status and enhance fish populations and dependent fisheries.

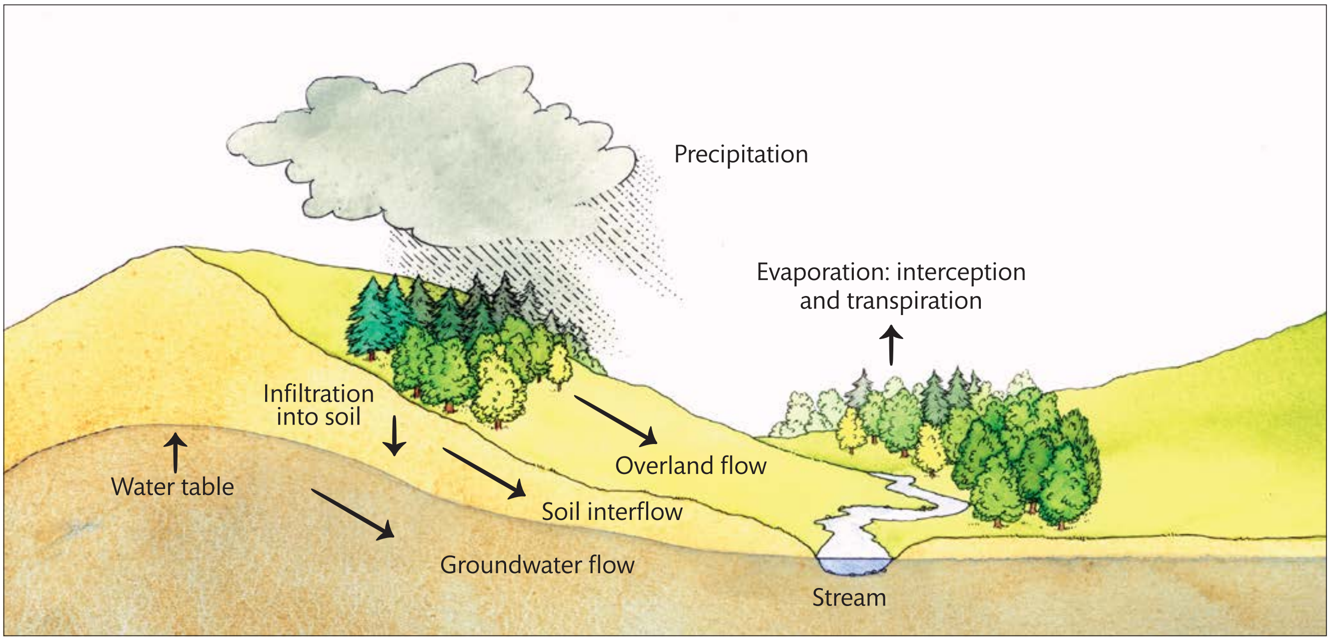
Where drinking water is abstracted, good forest management can reduce water treatment costs and help maintain the high quality of public and private supplies. The low usage of pesticides and general absence of contamination within well-managed forests means that woodland creation can help to offset the pollution threat from more intensive land uses. In particular, targeted woodland creation on farmland can help protect watercourses from pesticide spray drift and leaching, and pesticide run-off after crop applications.

Water catchments and drainage pathways

A water catchment is a defined area of land from which a proportion of the precipitation falling on it runs off or drains to a given collection point (Figure 9.1).

Trees and vegetation within the catchment can exert a strong influence on the quantity of water reaching the ground as some precipitation is intercepted and evaporated back to the atmosphere, and also on water quality, because evaporation can concentrate chemicals present in the atmosphere, which adds to chemical interactions within the vegetation layer. Having passed through the vegetation layer and into the soil, some water is taken up by

Figure 9.1 The water cycle. Water can follow a number of different pathways through a river basin.



vegetation and returned to the atmosphere through the process of transpiration, while the rest is either retained by the soil or drains away.

The amount of water following each of these routes is influenced by the catchment's vegetation and soil, and therefore by land-use practices. Interception and transpiration losses vary between different types of forest and non-forest vegetation, and are strongly affected by rainfall amount and pattern. Removing vegetation because of harvesting will reduce evaporation and result in more water leaving the soil as drainage, until the vegetation is restored.

Drainage water takes different pathways over and through the soil and bedrock to the river basin outlet, reflecting geology, topography, soil and human intervention. These pathways will have a marked influence on the timing, volume and quality of water travelling through the catchment into watercourses and water bodies:

- Rapid run-off in response to precipitation is characterised by superficial pathways and occurs on steep slopes, poorly draining or compacted soils, and shallow, impermeable bedrock. Superficial waters tend to be low in base cations, brown (due to high dissolved organic carbon) and acidic, reflecting their short passage through the upper organic soil horizons.

- Slow run-off in response to precipitation is characterised by deeper pathways leading to a delayed and moderated response, reducing flood flows and increasing groundwater recharge. This occurs on gentle slopes, freely draining soils, deep drifts and porous bedrock. Waters following deeper pathways tend to have higher base cation levels and be clearer and more alkaline, due to the longer period in which rainfall is in contact with soil and rock minerals and is able to react with them.

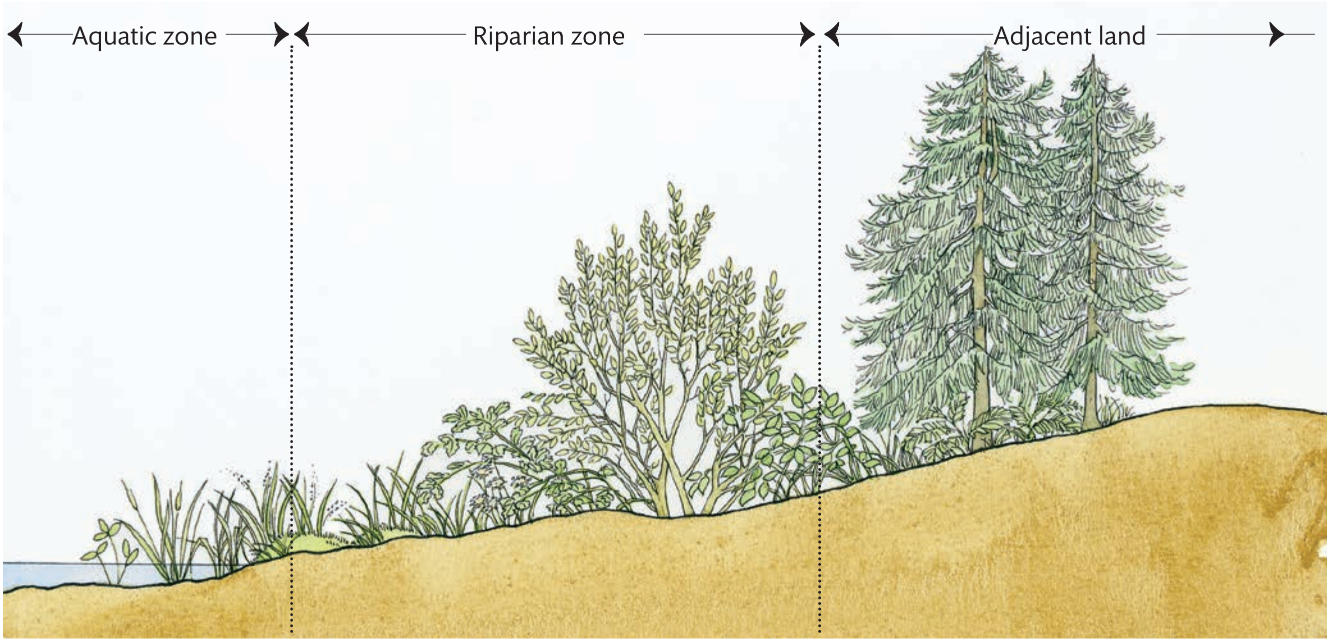
Groundwater

Where the geology is porous, water drains to the underlying water table, forming groundwater. Groundwater is important for public and private water supplies, maintaining river flows in drier months, and sustaining wetlands. Groundwater bodies with both a high porosity and high permeability are defined as aquifers. They are very sensitive to contamination such as from diffuse pollution: pollutants may not reach a river or borehole abstraction point for several decades, but once groundwater is contaminated, it may be difficult or impossible to restore good water quality.

Riparian zones

When drainage waters eventually emerge from the soil and bedrock they pass through the riparian zone before forming the aquatic zone. The riparian zone is the area of land adjoining the aquatic zone and influenced by it, which includes the riverbank but not the wider floodplain (Figure 9.2). Riparian woodlands are therefore the wooded areas of land adjacent to waterbodies such as rivers, streams, lakes, marshlands and reservoirs. Riparian landowners are responsible for maintaining the bed and banks of the watercourse and the trees and shrubs growing on the banks.

Figure 9.2 Diagram showing the transition from the aquatic zone through the riparian zone to the adjacent land.



Riparian zones can be ecologically rich, with long and convoluted edges that host a wide variety of habitats. They can also link other ecologically-rich habitats and offer migration corridors for invertebrates, birds and mammals. In places where natural flooding occurs, large tracts of wet woodland habitat may extend from the riparian zone across the floodplain. These wet woodlands are now rare throughout the UK and are identified as priority habitat types in country biodiversity strategies.

Aquatic zones

The aquatic zone is frequently or permanently under water, forming streams, rivers, ponds, lakes, wetlands, estuaries and coastal waters, as well as canals and reservoirs. Aquatic zones can be divided into discrete water bodies, each with a defined water catchment area. These water bodies – and their assemblage into river basins – are recognised in law as being the units for how pressures on the water environment from human activity are managed through environmental objectives and standards set to protect and improve their quality.

Forests and freshwater ecology

Streams, rivers, lakes, ponds and wetlands all provide habitats for a wide range of plant and animal species, and forests play a major role in the ecological functioning of the freshwater environment.

The ecological requirements of freshwater plants and animals differ from species to species, encompassing a natural range in water chemistry, temperature, oxygenation, flow velocity, depth and substrate type. Some of the broad ecological requirements of organisms and how forests and forest management can help sustain these are shown in Table 9.1. The needs of protected and priority species such as the otter, water vole, Atlantic salmon and freshwater pearl mussel require particular attention.

The spread of invasive non-native species is an increasing problem, which, if unchecked, has the potential to degrade riparian and freshwater habitats and lead to a loss of native species and increase the risk of bank erosion. Co-ordinated action between landowners and authorities will be required to control the spread of invasive animal and plant species such as the North American signal crayfish, Japanese knotweed and Himalayan balsam.

Small streams, including those less than 1 m wide, can form very important spawning habitat for salmonid fish. Their protection is therefore fundamental to the sustainability of fish populations and downstream fisheries, as well as for maintaining other freshwater life.

Estuarine and coastal waters are less influenced by forestry due to dilution and other factors, but some water bodies are very sensitive to disturbance, such as designated shellfish waters in shallow marine lochs. Shellfish and salmon farms could be adversely affected by increased sediment and nutrient inputs associated with larger-scale forestry operations.

Flooding

Flooding is a serious issue in many areas of the UK and flood events are expected to increase in frequency and severity with climate change. To address this, recent years have seen a more sustainable approach to flood risk management involving greater working with natural processes. This has led to the concept of natural flood management, in which natural features and characteristics are used to slow down and store more floodwater within upstream catchments.

Table 9.1 Broad requirements of aquatic wildlife and how forests can help sustain them.

Ecological requirement	Forest contribution
Well-oxygenated water free of contaminants or containing contaminants at a concentration that is not harmful.	Well-designed and managed forests protect the soil and can act as a trap or sink for contaminants. Riparian woodland and riparian buffer areas form an important habitat and help to protect and enhance the freshwater environment, including by intercepting sediments, nutrients and pesticides draining from adjacent land.
Adequate light reaching the water to support aquatic plants and algae and to maintain temperatures suitable for animal metabolism.	A variable density of tree cover is a key component of riparian habitat, although open areas are also important for light-demanding species. A forest canopy can provide the right balance of light and shade and help control temperature extremes – this is increasingly important for fish survival as climate change progresses, because some species are very sensitive to water temperature.
A range of natural features and habitats, such as pools, riffles, gravel bars, fringing wetlands, ponds and backwater channels; dry river terraces; alluvial floodplains connected to the river and banks that are steep, shallow or undercut.	The binding action of tree roots helps to strengthen and stabilise riverbanks, reducing erosion and bank collapse. Tree stumps and underwater tree roots also provide important refuges for fish and other aquatic wildlife, including white-clawed crayfish; they can also provide nests or holts for otter. Natural accumulations of woody debris increase habitat diversity in rivers and streams.
Vegetation appropriate to the site, such as algae and mosses on stony beds; rooted plants in the silt or sand of less turbulent waters; also bankside trees, shrubs and ground vegetation.	Native riparian woodland generally provides an ideal cover for protecting river morphology. Floodplain and riparian woodland can link disconnected habitats to form an extended forest habitat network, benefitting the movement and dispersal of wildlife.
Natural range in acidity and alkalinity.	As the pH falls below 6.0, the physiology and growth of fish, invertebrates and other freshwater life are increasingly affected. Forest canopies, especially conifer, can increase the capture of acid pollutants in the atmosphere and thereby reduce stream pH where acid geology renders waters susceptible to increased acidity. Forest restructuring can help to reduce pollutant capture by increasing open space and species diversity, and by reducing the area of closed canopy.
Appropriate inputs of organic matter and nutrients.	The variety and seasonality of leaf litter inputs and microbial processes in the root zone are critical to maintaining energy and nutrient flows and the effective ecological functioning of aquatic ecosystems. Twigs, leaves and terrestrial invertebrates that fall from forest canopies into the water provide an important source of food for aquatic organisms.
Natural range in water flow and depth.	Reduced water flows can impede fish access and decrease available habitat for freshwater life. Under certain circumstances and conditions some forests can reduce water flows, but this effect can be ameliorated by good forest design and management.

Forests are known to reduce flood flows and can make an important contribution to natural flood management. Trees tend to use more water than other vegetation types (including via interception loss during major rainfall events), and they protect soil and increase water infiltration and storage. Trees and the natural accumulations of deadwood slow flood flows by increasing flow resistance, and also reduce downstream siltation, increasing the capacity of river channels to hold and convey floodwaters. On the other hand, forest operations such as cultivation, drainage, road construction and harvesting can have the opposite effect if not appropriately managed.

The UKFS supports the concept of working with natural processes to deliver a more sustainable, catchment-based approach to managing flood risk. The composition and location of a forest, and the way it is managed, will influence the ability of its trees to affect flood flows. The UKFS Practice Guide *Designing and managing forests and woodlands to reduce flood risk* explains how to meet the UKFS Requirements and Guidelines on flooding.

Climate change itself is also likely to have an impact on how forestry affects flooding, water yields and flows. Forest interception losses are likely to increase, emphasising the difference in water use between forest and non-forest land cover. However, the impact on water supplies could be offset in some areas by higher winter rainfall, while increasing carbon dioxide concentrations could increase the efficiency of water use by trees and reduce water losses.

UKFS Requirements for Forests and Water

The water environment

UK and country legislation provides a comprehensive system for the protection, improvement and sustainable use of the water environment, including the development of River Basin Management Plans. There are controls over water abstractions, impoundments and engineering activities in or adjacent to watercourses that may have impacts on river and lake hydromorphology. A number of protected and priority conservation species rely on the water environment, and the potential adverse effects of forestry operations can extend over a considerable distance downstream.

Note: the definition of 'in or adjacent to watercourses' is dependent on regional byelaws, but often refers to within 7 or 8 m of a watercourse.

1 Prior authorisation must be obtained from the relevant authority for building, engineering and other activities in or adjacent to watercourses that affect river hydromorphology; this includes water abstraction, impoundments, constructing culverts and extracting river gravel. Authorisation for gravel extraction may also be required from the relevant nature conservation authority if the river is designated as, or flows through, a Special Area of Conservation, Special Protection Area, Ramsar site or Site of Special Scientific Interest (Area of Special Scientific Interest in Northern Ireland).

2 In Scotland, all forestry operations must meet relevant General Binding Rules and any divergence must be licensed or registered with the Scottish Environment Protection Agency (SEPA).

3 In Wales, all new developments where the construction area is 100 m^2 or more must have sustainable drainage systems (SuDS) for surface water, designed and built in accordance with published standards, and relevant approvals obtained before construction work begins. This is relevant to any forest infrastructure construction work including roads, stacking areas and quarries.

4 In-stream work involving the use of plant or machinery (or other works nearby that may release sediment into watercourses) must not be carried out when fish are spawning in the affected surface water, or in the period between spawning and the subsequent emergence of juvenile fish. If in doubt about these times, contact the responsible authority or advisory body for advice.

5 Any plant, vehicles or equipment must not be operated in any watercourse or waterbody if there is a reasonable likelihood that there are protected species in the same or a connected watercourse.

1 Any damage caused by the operation of machinery to the bed and banks of a waterbody should be repaired, including re-establishing vegetation on any areas of bare earth on the banks resulting from the operation, by using green engineering techniques.

Pollution control

Under country legislation it is an offence to cause or knowingly permit the entry of poisonous, noxious or polluting material into any controlled waters (all streams, rivers, lakes, groundwaters, estuaries and coastal waters to three nautical miles from the shore).

Regulations also specifically protect groundwater from pollution caused by the disposal of potentially harmful and polluting substances. Under these regulations, permission or prior authorisation is needed from the relevant authority to dispose of 'listed substances' (or, in Scotland, any pollutant) to ground, including sprayer washings. Furthermore, some areas are designated as having groundwater that is nitrate-vulnerable, and restrictions on applying fertilisers within these areas may apply (details are given in country guidance).

The Control of Pesticides Regulations 1986 (as amended) in Great Britain and 1987 (as amended) in Northern Ireland provide details of pesticides subject to control, and prescribe approvals required for their supply, storage and use (including aerial application). Authorisation is not required for normal use of pesticides covered by relevant codes of practice, except in Scotland, where authorisation is given subject to General Binding Rules. In all cases, users are required to take all reasonable precautions to protect the health of humans, animals and plants, safeguard the environment and, in particular, avoid the pollution of water. The Health and Safety Executive Code of Practice for Using Plant Protection Products defines what is meant by a certified person in this regard.

Forestry operations frequently involve the permanent or temporary storage of oils and fuel, including containers, mobile bowsers and drums. Country legislation imposes requirements aimed at preventing leakage and pollution.

! 6 The entry of poisonous, noxious or polluting material into the water environment must not be caused or knowingly permitted (unless authorised by the relevant authority).

! 7 Any water containing fish, or any tributary of that water, must not be rendered poisonous or injurious to fish, their spawning grounds, fish spawn or the food of fish (unless authorised by the relevant authority).

! 8 Groundwater must be protected from harmful and polluting substances, including sprayer washings; the relevant authority must be consulted regarding the disposal of such substances to land.

! 9 Where a designated site or priority habitat or species might be affected, appropriate regulators and conservation agencies must be consulted prior to the aerial application of pesticides and the use of pesticides in or near water, and, where appropriate, authorisation obtained.

! 10 All those employed to use pesticides must be trained to the required standard and have an appropriate certificate of competence; operators must comply fully with instructions on pesticide product labels.

11 Oil and fuel must be stored and managed in a way that minimises the risks of leakage and pollution.

12 In Wales, nitrogen fertiliser must not be spread on land if there is a significant risk of it getting into surface water, taking into account the slope of the land, any ground cover, the proximity to surface water, weather conditions, soil type, ground conditions including if the soil is waterlogged, frozen or snow covered, and the presence of any land drains.

2 Fertiliser and pesticide applications should match the needs of the stand and should be planned with careful attention given to buffer and storage areas, weather and ground conditions, and the risk to water supplies. Contingency plans should be in place in case of a spillage.

Water supplies for human consumption

Country regulations set standards for the quality of all public and private water supplies, to protect human health by ensuring that water intended for human consumption is wholesome and clean. Drinking Water Protected Areas have been established to reduce levels of water purification treatment required for public supply.

Country water regulatory authorities ensure that the water in the environment meets certain standards to enable it to be used for human consumption, and country drinking water authorities regulate public and private water supplies. Private water supplies are particularly vulnerable to disturbance because they often undergo limited or sensitive forms of water treatment and there may be little scope for finding replacement sources in the event of pollution.

13 Forestry operations must not lead to harmful or polluting substances contaminating public or private water supplies.

Water quality and buffer areas

Water quality can be maintained or enhanced through good forest planning and management, and in particular through the identification and management of buffer areas. Buffer areas are the minimum working distances from a waterbody, set aside to help buffer any potentially adverse effects of adjacent land management. Special measures apply to buffer areas in terms of forest planning and operations, and these measures ensure that soil disturbance, siltation and the risk of pollution are minimised.

A buffer area is fundamental to woodland creation and the management of existing forests, and needs to include the riparian zones next to watercourses, springs and flushes which form run-off source areas, and their dependent terrestrial ecosystems. Key aspects of the design of the buffer area are width, structure, choice of species and management regime. In general, the aim in buffer areas is to establish and maintain a variable cover of riparian woodland comprising species native to the location and soils. It is important, for landscape and water environment reasons, to avoid parallel-sided corridors and design the margin in response to the landform.

Factors such as climate, altitude, slope and soil type all have a bearing on the effectiveness of the buffer area and therefore on the desired width, which is why only minimum widths are given. The width of the buffer area depends on the width of the watercourse and forest managers will need to use their professional judgement on the width beyond the minimum that is needed in a given situation (e.g. on ground that is sloping). In addition, where there are sensitivities in the aquatic zone, such as salmonid spawning beds or the presence of the freshwater pearl mussel, wider buffer areas may be required.

Table 9.2 sets out the recommended **minimum** widths of buffer areas from the bank top of the waterbody or the edge of standing water. These minimum widths apply to all forestry activities, except for:

- hinge mounding;
- inverted mounding;
- direct planting of native trees and shrubs and other ecologically appropriate broadleaved trees to create riparian woodland.

Table 9.2 Minimum buffer widths for forestry activities (other than the exceptions listed above) from forest edge to watercourse, waterbody or abstraction point.

Buffer width	Situation
10 m	Along permanent watercourses with a channel less than 2 m wide.
20 m	Along watercourses with a channel more than 2 m wide and along the edge of lakes, reservoirs, large ponds and wetlands.
50 m	Around abstraction points for public or private water supply, such as springs, wells, boreholes and surface water intakes.

These buffer widths and precautions apply on both sides of the watercourse and around the whole perimeter of the waterbody, and apply to all waterbodies, including connected ditches and drains, wetlands, large ponds, lakes and reservoirs. Ditches and drains that are disconnected from a watercourse and so do not carry water into them do not require a buffer area.

The minimum buffer widths, or minimum working distances, given in Table 9.2 are recommended as part of the Good Practice Requirements of the UKFS, but wider buffer areas might be required by a regulatory body as a condition of consent or permit (and this might be to address other interests such as a nearby priority habitat, private water supply, designated site or historic environment feature).

Narrower widths of buffer area might be appropriate along minor watercourses with a channel less than 1 m wide, especially on steep ground. The UKFS takes this pragmatic approach for minor watercourses to accommodate situations where, on the one hand, they could be valuable habitats such as spawning streams, but in other situations they may be ephemeral drains leading to a watercourse.

3 The buffer widths in Table 9.2 should be observed.

4 Woodland creation and management should be planned and undertaken in a way that protects or restores the quality of the freshwater environment and reduces the impact of more intensive land management activities and environmental change.

5 All watercourses, including connected drains/ditches (whether dry or running), water bodies, wetlands and flushes, should be identified and appropriate buffer areas established and maintained to protect the water environment and riparian zones from adjacent activities.

6 Forest drainage (including road drains) should be planned and, where necessary, existing drains should be realigned and disconnected from waterbodies to ensure that water is discharged before the edge of a buffer area, and never directly into a waterbody.

7 Forest operations should be conducted to prevent watercourses being affected by sediment or discoloured; monitoring should be carried out during forestry works and any incidents involving contamination of the water environment reported to the relevant authority without delay; remedial action should be taken immediately if pollution starts to occur.

8 Where extensive fertiliser applications are being planned within the same catchment, phasing should be considered to ensure impacts on downstream waterbodies are limited.

9 Where felling is planned, and there are potential risks to water quality, activities should be phased to reduce those risks.

Acidification

Despite ongoing recovery due to the control of emissions, acidification continues to impact water quality in some parts of upland Great Britain. The contribution of forestry through the scavenging of acid deposition has declined but can still pose a threat to vulnerable waters. A range of measures and assessment procedures therefore remain in place to protect vulnerable waters from adverse effects.

10 Where new planting or restocking (or regeneration) is proposed within the catchments of water bodies at risk of acidification, an assessment of the contribution of forestry to acidification and the recovery process should be carried out; details of the assessment procedure should be agreed with the relevant authority.

Flooding and water resources

Flooding is a serious issue in many areas of the UK and flood events are expected to increase in frequency and severity with climate change. Forests can help reduce damaging flood flows in a number of ways: trees tend to use more water than other vegetation types, and they protect soil and increase water infiltration and storage. Trees and natural accumulations of deadwood slow flows by increasing flow resistance, and also reduce downstream siltation, increasing the capacity of river channels to hold and convey floodwaters.

The composition and location of a forest, and the way it is managed, will influence the ability of trees to affect flood flows. However, if left unmanaged, woody debris can wash downstream during heavy rainfall causing blockages, which can result in flooding.

On some watercourses in England and Wales, particularly those designated as a ‘main river’ for flood protection purposes, periodic access for maintenance is required. In such access areas, consent may be required from the relevant authority to plant trees within 7 m of the watercourse. Restrictions may also apply on selected watercourses in Scotland and Northern Ireland.

Forestry practitioners also need to be aware that, in certain circumstances, there is the potential for woodland creation and management to reduce water supplies, especially in the light of changed weather patterns resulting from climate change. In some areas of the UK there is a growing imbalance between water demand and supply that can lead to water shortages, diminish aquatic habitats and concentrate waterborne pollutants.

14 The relevant authority must be consulted when planning new woods next to main rivers and flood defences, and the necessary consents obtained.

11 Where communities or assets are vulnerable to flooding, woodland creation or the management and redesign of existing forests in relevant upstream water catchments should be considered as a way of mitigating flood risk.

UKFS Guidelines on Forests and Water

Acidification

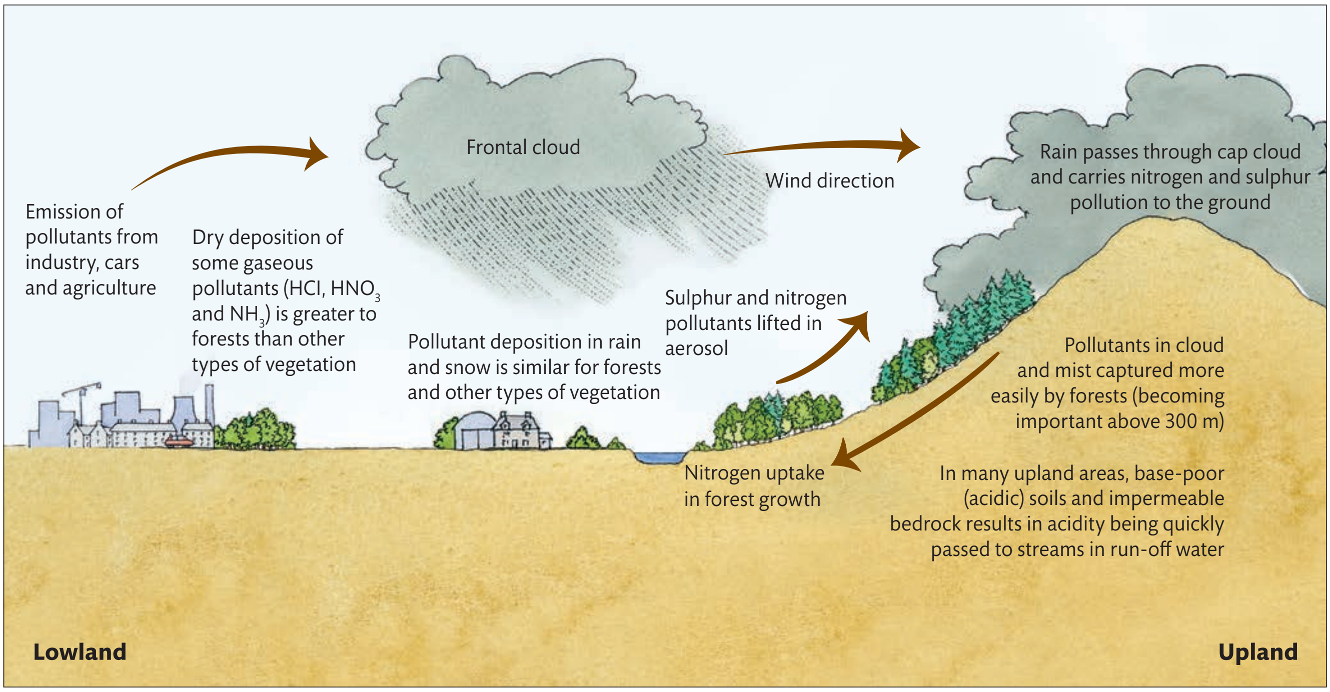
The most acidified areas in the UK are in the uplands, where base-poor, slow-weathering rocks and soils have coincided with high pollutant inputs in the form of large volumes of moderately polluted rainfall (Figure 9.3). Emission control has resulted in major reductions in pollutant inputs, although modelling and monitoring data predict that soil recovery may take decades and could be further delayed by nitrate leaching and climate change.

The starting point for forest managers is to assess where new planting or restocking (or regeneration) could contribute to increased acidification or delay recovery, and the agreed approach is to undertake a catchment-based critical load assessment for waters that are failing or at risk of failing good status due to acidification.

The UKFS Practice Guide *Managing forests in acid sensitive water catchments* offers guidance on how to assess whether the freshwater critical load is exceeded and, if so, ways to reduce pollutant capture, such as restructuring closed canopy conifer stands. This Guide also explains how to carry out a site impact assessment to determine the potential impact of clearfelling operations, and provides helpful measures to reduce the risk of nitrate leaching enhancing acidity.

Note: Guidelines 1–5 apply to catchments of water bodies identified by the water regulatory authority within River Basin Management Plans as failing or at risk of failing good status due to acidification.

Figure 9.3 Interactions between forests and acid deposition.



1 Where the area of new planting or restocking (or regeneration) could contribute to increased acidification or delay recovery, undertake a catchment-based critical load assessment.

2 Avoid new planting or restocking (or regeneration) where catchment assessments based on critical load calculations and relevant supporting information indicate this will lead to deterioration in water body status or prevent recovery to good status.

3 Where an area to be felled will exceed 20% of the acidified catchment in any three-year period, undertake a site impact assessment.

4 Co-ordinate the phasing and timing of felling of conifers in riparian zones and encourage the transition to a variable cover of native woodland to promote the ecological recovery of watercourses.

5 Limit the planting of alder to less than 10% of the area within all riparian zones.

Sediment delivery, cultivation and drainage

Well-managed forests protect the soil from disturbance and improve soil structure due to high inputs of organic matter and the action of tree roots. These conditions enhance soil infiltration pathways and water storage capacity, thereby reducing direct surface water run-off, erosion and downstream siltation. New woodland can therefore help to reduce the higher rates of sediment delivery and resulting turbidity and siltation that are associated with more intensive land uses such as arable cropping. A reduction in sediment delivery will also reduce soil carbon loss. The bare cultivated soils associated with autumn-sown winter cereals and spring cropping are particularly at risk of soil loss by heavy rainfall and strong winds, respectively. Strategically placed tree cover in the form of shelterbelts or riparian zones can help to intercept run-off from such sites and reduce sediment delivery to watercourses.

Conversely, poor forest management can lead to large quantities of sediment entering surface waters; this can cause unacceptable turbidity levels, introducing high levels of nutrients, carbon, metal (such as iron and manganese) and pesticides. This will impact on local and downstream drinking water supplies, aquatic habitats and species.

Large inputs of coarse sediment can also have a significant impact on hydromorphology. This can de-stabilise stream beds and channels, reduce the depth of watercourses and reservoirs, as well as block pipelines and water intakes. Shallow coastal waters can also be vulnerable to siltation, especially where these support shellfish populations.

The financial consequences of such incidents can be significant and may require the construction of new treatment works and payment of fines issued by the relevant authority. Following the UKFS guidelines on water management during cultivation, drainage, harvesting, road building and quarrying will help avoid these problems.

Guidance on planning and undertaking good practice sediment management is in the UKFS Practice Guide *Managing forest operations to protect the water environment*.

6 Prior to clearfelling, assess the drainage system, identify watercourses, and plan restoration work to reduce the risk of erosion and sediment delivery.

7 Where there is a need for drainage, design drains so that they discharge before the edge of a buffer area and never directly into a waterbody.

8 Consider the influence of slope when installing drains; align forest drains to run at a maximum slope gradient of 2° (3.5%) and lead them towards the heads of valleys.

9 When culverts are to be installed, site them at the point where a watercourse is intercepted by a road or track to avoid discharging the watercourse into the roadside drain.

10 Ensure the installation of bridges or culverts does not present barriers to fish movement or promote channel erosion or bank collapse.

11 Assess whether existing drains, culverts or other structures are de-stabilising the banks or beds of watercourses, or forming a barrier to fish access; if so, plan for their replacement or removal.

12 Avoid clearfelling more than 20% of the catchment of an area that drains to a public water supply, fish farm or waters supporting freshwater priority species or habitats within any three-year period.

13 During forestry operations, keep streams and buffer areas clear of brash as far as practicable; avoid felling trees into watercourses and remove them or any other accidental blockages that may occur.

14 Avoid fording streams and rivers, unless there is an existing purpose-built ford and measures are taken to minimise the potential risk to the water environment.

Nutrient enrichment

The leaching and run-off of phosphate and nitrate from the land represents a loss of soil fertility and can reduce surface water and groundwater quality. Of principal concern are naturally nutrient-poor upland waters in which biological activity is usually limited by phosphorus. Enrichment can lead to unwelcome ecological changes and a reduction in water status. In extreme cases, phosphorus enrichment can produce excessive algal growth, resulting in dissolved oxygen fluctuations and disruption of the ecosystem. Excess phosphate may result in increased water treatment costs and may require improvements to water treatment works.

Forests can be an effective land use to intercept and remove excess nutrients from agricultural land, helping to protect water quality and freshwater ecology. This is especially beneficial in catchments of water bodies at risk from diffuse nutrient pollution, particularly within Nitrate Vulnerable Zones (NVZs) and Source Protection Zones (SPZs). The main exception is conifer forest in polluted and drier areas, where there is evidence that the enhanced capture of nitrogen pollutants from the atmosphere can lead to concentrated nitrate levels in groundwater.

High nitrogen inputs can result where forests are downwind of local pollutant sources, such as intensive pig and poultry rearing units, although this effect can be used to protect more vulnerable habitats from nitrogen deposition, providing local groundwater supplies are not affected. In general, these require that neither organic nor inorganic fertiliser be spread on land if there is a significant risk of it getting into surface or groundwater.

Organic pollution of watercourses can occur following the spreading of organic wastes, and this can result in microbial contamination, bacterial growth and oxygen depletion, which in some cases may kill fish.

15 When planning and cultivating restocking sites, seek to minimise the amount of brash placed into mounding spoil trenches

16 Where water bodies are sensitive to nutrient enrichment, including shallow coastal waters designated for shellfish, limit any clearfelling to less than 20% of the catchment in any three-year period.

17 Within Nitrate Vulnerable Zones (NVZs), ensure any fertiliser applications or organic soil amendments adhere to NVZ regulations.

18 Ensure fertilisers are only applied when the weather and ground conditions are appropriate.

19 On restock (or regeneration) sites in catchments of water bodies sensitive to nutrient enrichment, avoid applying fertiliser until sites have re-vegetated.

20 Apply fertiliser according to prescriptions that are based on an analysis of foliar nutrient levels compared with reference values for target species.

21 Consider opportunities for woodland creation to reduce nutrient or pesticide spray drift, leaching and run-off from adjacent land to watercourses and groundwater.

Pesticides

Pesticide use (in the form of herbicides, insecticides and fungicides) in UK forestry is very low and is declining in response to policies and plans for chemical reduction. The approach of the UKFS is to:

- restrict pesticides to those approved by international agreement;
- seek alternatives to pesticide use;
- confine necessary usage to the absolute minimum.

This involves rigorous attention to legal requirements in relation to pesticide usage, storage, disposal (including waste packaging) and aerial applications, and to good working practices, avoiding adverse effects such as off-site drift and contamination from discarded planting bags, and contingency planning for spillages. Further guidance on planning and undertaking good practice pesticide use is in the UKFS Practice Guide *Managing forest operations to protect the water environment* and the UKFS Practice Guide *Reducing Pesticide Use in Forestry*.

22 Only apply pesticides if the weather and ground conditions are suitable.

23 Prior to spraying pesticides, check that the drainage channels in the area to be treated do not discharge directly into watercourses; extend buffer areas to incorporate individual drains where they are not separated from watercourses.

24 Only fill pesticide sprayers with water taken directly from the water environment if a device preventing back-siphoning is fitted, or the water is first placed in an intermediate container.

25 Do not store or soak pesticide-treated planting stock in any surface water or wetland prior to planting.

26 Avoid applying pesticides onto or over impermeable surfaces, infrastructure, roads and railway lines that drain directly into a surface water drainage system unless measures are taken to minimise the risk of pollution.

Water yield and low flows

The water yield (or average streamflow) from a forest needs to be considered so that low water flow is avoided. A forest can affect water flow if it has a high water use, which in turn could result in a low water yield.

Water yields from newly planted, young or felled forests are unlikely to differ significantly from moorland catchments until canopy closure is achieved. However, once that point is reached, water yields from upland catchments with significant proportions of closed-canopy conifer forest are lower than those from moorland or grassland catchments, due to higher interception losses. Interception losses are greatest in the wetter and windier parts of the UK and increase with forest height and canopy development. Research suggests there may be a 1.5–2% reduction of potential water yield for every 10% of a catchment under mature conifer forest.

In lowland areas, the drier and less windy climate reduces interception loss in absolute terms, but tree transpiration rates may be higher due to roots reaching deeper soil water reserves. The net effect can be a marked reduction in potential water yield, amounting to as much as 7% for every 10% of a catchment under mature conifer forest. This can have important implications for the quality and quantity of lowland groundwater resources and the maintenance of river flows.

Annual evaporation from mature broadleaved forest is generally much less than from conifers due to reduced interception losses during the leafless period. Therefore, planting broadleaved forest can help to protect and may enhance chalk groundwater resources. However, recharge under broadleaved forest on drier sandy soils is likely to be reduced compared with grass. This is because the deeper rooting of trees enables transpiration to continue unaffected by water stress for a longer period during the summer than for grass.

Fast-growing species such as poplar and willow used in short rotation coppice systems, and novel species sometimes used in UK forestry such as *Eucalyptus* or hybrids of *Paulownia* are able to sustain high transpiration rates, resulting in a greater reduction in potential water yield in covered parts of the catchment when compared with grassland.

Adequate summer baseflows in rivers are critical for wildlife, water supply and the dilution of effluent. Research suggests that the reduction in water yield due to upland conifer forests has a relatively small effect on these flows. However, large areas of lowland conifer forest or short rotation forestry could cause a significant decline in summer baseflows. This is due to the greater potential reduction in water yield and because baseflows often form a much larger proportion of the annual run-off.

Climate change could exacerbate the effect of forestry on water yields and low flows. Forest interception losses are likely to increase, accentuating the difference in water use between forest and non-forest land covers. However, the impact on water supplies could be offset in some areas by higher winter rainfall, while rising carbon dioxide concentrations could increase the efficiency of water use by trees and reduce water losses.

27 Where there is a risk of low water flow, consult the relevant authority before planning large-scale woodland creation – especially involving a high proportion of conifer or fast-growing broadleaved species used in short rotation forestry with a high water use; consider the projected impacts on future water yield, including the effects of climate change.

Flood risk management

Forestry has great potential to impact on surface water and river flooding, with the magnitude of effect generally decreasing with increasing distance between the forest and the downstream community or asset at risk of flooding. Woodland creation can reduce flood risk depending on the location of the nearest vulnerable downstream community or asset. Target areas and communities are usually identified by flooding authorities, and the catchment areas draining to them. Coniferous forest has a greater capacity to reduce flood run-off due to a higher interception loss compared with broadleaved forest.

Forest felling can have the opposite effect and temporarily increase flood flows until trees are replanted and regrow. As a guide, the scale of felling is unlikely to be large enough to significantly increase flood risk where there is less than 40% forest cover present within the upstream catchment of vulnerable communities or assets. The UKFS Practice Guide *Designing and managing forests and woodlands to reduce flood risk* gives more detail on how to apply these Guidelines.

28 Consider opportunities to restore riparian and floodplain woodland, create ponds and install leaky woody dams to increase flood storage and slow flood flows, ensuring the consent of the relevant authority is obtained if needed.

29 Where downstream communities and assets are vulnerable to flooding, consider opportunities for woodland creation and management to reduce flood risk; this includes their use as part of sustainable urban and rural drainage systems.

30 Where it is identified that households, businesses or other key assets are potentially at risk from large-scale forest felling, phase felling to minimise the impact on local flood flows.

31 When restocking or allowing regeneration, reassess requirements for forest drainage and wherever possible disconnect existing forest drains from watercourses.

Riparian zones

Ideally the riparian zone will be managed to develop a rich herb and shrub layer, with a light and broken tree canopy. Dappled shade, such as that provided by broadleaves, helps keep summer water temperatures down, which can be important for aquatic life, particularly salmonid fish. The occurrence of lethal temperatures is likely to become more commonplace as climate change progresses.

The best combination of shade and shelter is usually provided by a cover of predominantly native woodland. Too much canopy, especially of conifers, can shade out the lower layers of vegetation and result in bank erosion. For this reason, prioritising the clearance of riparian conifers and linking cleared sections with new native broadleaved woodland to create a network of wet woodland habitat will promote the recovery of fish and aquatic invertebrate populations.

Riparian zones present a major opportunity to enhance forest biodiversity by linking permanent habitats and establishing native trees, shrubs and ground flora. However, they can also facilitate the rapid spread of invasive species such as Japanese knotweed and giant hogweed, so control measures and careful management are required in areas where invasive species may be a problem. Water can often act as a pathway for spreading invasive non-native species. Where this is the case, consideration should be given to their distribution within a catchment and measures should address them at appropriate spatial scales, as far as possible tackling them higher in the catchment to prevent re-infestation.

In addition to providing shade, riparian vegetation can influence the condition of watercourses by providing an effective filter and buffer, which helps to trap sediment and absorb nutrients, thereby reducing the delivery of pollutants to watercourses. Riparian woodland will also provide a source of woody debris to watercourses, which is important for aquatic life and slowing flood flows. Identifying and establishing an effective buffer area is fundamental to the protection of the riparian zone and aquatic habitats; the wetness of the soils and the characteristic instability of stream banks mean that the zone is particularly sensitive to disturbance. Buffer areas will also help to protect watercourses from any potentially adverse effects of adjacent land use.

32 Aim for a mix of shaded and lightly shaded habitat within the riparian zone, guided by local objectives and the requirements of priority species.

33 Remove dense stands of conifers from riparian areas and from the edges of ponds and lakes; control excessive conifer regeneration and encourage the transition to a variable cover of native woodland.

34 Design and manage riparian woodland along watercourses to provide a source of leaf litter and woody debris; retain this within watercourses unless it poses a significant risk of damaging or blocking downstream structures.