Forestry Commission

Environment Agency

Woodland for Water: Woodland measures for meeting Water Framework Directive objectives

Summary of final report from Forest Research to the Environment Agency and Forestry Commission (England)

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Miranda Kavanagh

Director of Evidence

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- To provide a firm base of scientific evidence for effective policy and practice;
- To ensure effective dissemination of knowledge;
- To develop a cadre of forest researchers characterised by excellence and connectivity to the wider scientific community.

Wilma Harper

Head of Corporate and Forestry Support

Foreword

Woodland is very much a part of our farmed environment and has long served our countryside with the provision of fuel, timber, recreation and a valuable habitat for wildlife. However, this report recognises that woodland offers further services to water regulation and land management.

The next decade will be a critical period for the farming and forestry sectors because it will coincide with a fundamental review of the Common Agricultural Policy in 2013, delivery of Kyoto emission reduction targets, and the end of the first cycle of river basin planning for the Water Framework Directive (WFD) and planning for the second cycle.

We will need a range of measures and approaches for tackling diffuse pollution and water management based on good advice, incentive and regulation. Woodland can play a significant role in mitigating some of the environmental impacts of man's activity. Until now the potential for utilising woodland to help meet WFD objectives has been largely unrecognised.

The evidence presented in this review will help promote effective woodland planning and be part of the solution to achieving good water status. It is timely, as it follows on from the establishment of the Woodland Carbon Task Force which aims to realise Government's desire for increased woodland planting in England to help meet greenhouse gas emissions reduction commitments. Similarly, in Wales, the recently announced *Glastir* scheme provides additional incentive for woodland creation.

This is a summary of the final report from Forest Research to the Environment Agency and Forestry Commission (England) - an in-depth scientific review undertaken by Forest Research and ADAS UK Ltd, which is available from Forest Research.

Thanks are due to all those who contributed to and reviewed this comprehensive study and for the advice provided by the Countryside Council for Wales, Scottish Natural Heritage, Natural England and the Scottish Environment Protection Agency.

Paul Hickey Head of Land and Water Quality, Environment Agency

Laura Jones Director Forest Services, Forestry Commission England

Executive summary

This review considers the key issues relating to the use of woodland measures for meeting Water Framework Directive (WFD) objectives. It focuses on native woodland creation, but also considers the impact of new conifer woodlands and bioenergy plantations in light of climate change and renewable energy policies.

- There is strong evidence to support woodland creation in appropriate locations to achieve water management and water quality objectives.

- Woodland contribution to tackling diffuse pollution includes both a barrier and interception function. They help to trap and retain nutrients and sediment in polluted runoff.

- The benefits of riparian and floodplain woodland for protecting river morphology and moderating stream temperatures are well proven, while a good case can also be made for mitigating downstream flooding.

- Targeted woodland buffers along mid-slope or downslope field edges, or on infiltration basins appear effective for slowing down runoff and intercepting sediment and nutrients, but the evidence base is limited.

- Wider targeted woodland planting in the landscape can reduce fertiliser and pesticide loss into water, as well as protecting the soil from regular disturbance and so reduce the risk of sediment delivery to watercourses.

- Evidence from Europe and further afield provides a range of examples of effective action plans and incentive schemes for water-related woodland services, which have succeeded in achieving woodland creation and a reduction in nutrients reaching watercourses.

- The evidence presented here supports the use of woodland measures in helping to meet water quality objectives in future River Basin Planning cycles.

Evidence into practice

- It is important to be aware of all the additional services and benefits woodland can bring to water. There is potential for woodland to benefit water management through River Basin and Catchment Flood Management Plans.

- There is a strong case for woodland solutions to be delivered through catchment level planning and then to local farm and field planning. To achieve this, woodland measures should be considered within relevant land management advice and guidance, WFD Programmes of Measures and agricultural best management practice handbooks.

- A re-evaluation of the advice and guidance on woodland creation and management for farmers, landowners and land management advisers could, potentially, encourage appropriate woodland creation. Local demonstration sites could help to communicate how woodland can help to tackle issues such as diffuse pollution and flood risk.

- The scope for woodland planting remains limited by constraints on land use and financial viability of schemes for land managers. Solutions to these barriers should be explored in view of the additional services woodland can provide besides the value of timber.

- Evidence gaps, relating to how woodland can be best integrated with agriculture and urban activities to deliver benefits to water resources and the wider environment, need to be addressed.

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1. Introduction

1.1 Context

The Water Framework Directive (WFD) applies to all inland surface waters (including lakes, streams and rivers), groundwater, wetlands that are dependent upon surface or groundwaters, estuaries and coastal waters out to one mile from low-water. Water management within the WFD is based on River Basin Districts. Nine River Basin Districts have been defined in England and Wales and one in Scotland as management and reporting units, together with two cross-border districts with Scotland. For each River Basin District, there is a statutory requirement to produce and regularly review a River Basin Management Plan. The majority of water bodies in the UK currently fail to meet the target of good ecological and chemical status due to a range of pressures, including diffuse pollution. River Basin Management Plans have been developed to deliver a Programme of Measures to improve and restore failing water bodies. The programme is a set of measures within each management plan to achieve environmental objectives. Within the first cycle of river basin management, the Programme of Measures must become operational between 2009 -2012, and will be reviewed with the production of each new River Basin Management Plan.

1.2 Background and scope

The report considers the key issues relating to woodland and the WFD in England and Wales, but has application to Scotland and Northern Ireland. The review focuses on native woodland creation but also considers the impact of new conifer woodlands and bioenergy plantations in light of climate change and renewable energy policies. Emphasis is given to the literature from UK and Northern European studies.

Well planned and managed woodland can be of significant benefit to the local and global environment. It can act as a sink for, or protect against, potential sources of diffuse pollutants, may play an active role in rehabilitating degraded and/or contaminated land and, arguably, reduce flood risk. However, environmental problems can arise if woodland is poorly managed or planted in unsuitable locations. In considering any expansion of woodland cover, the environmental impact of the displaced land use is as important as the impact of the woodland itself, and it is the net effect of new woodland that is most relevant.

At 13% of land area, woodland cover in the UK remains one of the lowest in Europe. UK national governments have acknowledged the need for more woodland for the multiple benefits provided, which is helping to push woodland higher up the hierarchy of land use. The ecosystem services provided by woodland are increasingly recognised[1], including the potential to deliver WFD objectives, through reducing the impact of diffuse pollution from agriculture and urban activities, as well as assisting the management of flood risk.

Public funding for the planting of new woodland is mainly through Rural Development Programmes (RDP). In the future, the next review of the Common Agricultural Policy (CAP) may provide further opportunities for woodland management and creation.

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[1] UKNEA (2011)

There is a need to know the relative attributes and interdependencies between woodland and water to better target new woodland schemes to help achieve WFD objectives. Climate change brings a number of new drivers to the potential expansion of woodland, from biomass supply for energy to sequestering carbon in the growing timber, the potential after use and in the organic matter that is created in the soils. Delivery of some of these benefits, however, may involve trade-offs for water.

The implementation of the EU RDP regulations is set out in Defra's UK National Strategy Plan (2006), which recognises that sustainable and competitive agriculture and forestry sectors are a prerequisite for improving the environmental quality of the countryside. The plan identifies common elements that run through the RDP strategies of each country (Scotland, England, Wales, and Northern Ireland), which include the protection and enhancement of natural landscapes in rural areas.

Realisation of woodland benefits for water will depend on working with farmers and other landowners to change land use and plant the right tree in the right place. However, there are many barriers to woodland expansion on farmland that will need to be addressed if this approach is to succeed. The recently published Natural Environment White Paper calls for a review of how we use advice and incentives for farmers and land managers, to create a more integrated, streamlined and efficient approach that yields better environmental results[2].

Woodland planting still remains limited by wider land-use constraints and by financial considerations, such as the long time-frame of returns on investment from eventual harvesting of timber. Land use has many conflicting demands made upon it including the need for both food security and biodiversity. For example, large areas of the country are designated for preserving extensive open grassland, heathland and wetland habitats.

The climate change agenda may act as a catalyst for a renewed focus on woodland creation. The UK Low Carbon Transition Plan outlined Government support for a new drive to encourage private funding for woodland creation, which is being taken forward through the work of the Forestry Commission-led Woodland Carbon Task Force. The Scottish Government also plan to use woodland creation to help meet carbon budgets, and increasing annual woodland planting to 10-15,000 ha by 2015 is set as a key milestone in the Scottish Government's Climate Change Delivery Plan. As part of the Climate Change Strategy for Wales, the Welsh Assembly Government has set a target of 100,000 ha of new woodland to be created over the next 20 years to be delivered through the Glastir Scheme.

[2] HM Government (2011)

2. Aims of the woodland and Water Framework Directive review

This review had three key aims:

- To collate existing scientific research and policy options to increase our understanding of how woodland can be used to improve water quality and water management to help meet WFD objectives of achieving ‘good ecological and chemical status’ in all water bodies, where possible;
- To provide a robust evidence-base for developing woodland and environmental approaches; and
- To review relevant studies that could inform the development of a cost-benefit analysis of proposed measures, summarising available valuations of those ‘ecosystem services’.

3. Main findings of review

3.1 Diffuse pollution

Using woodland to reduce diffuse water pollution

Environmental and forestry policies promote targeted woodland planting in areas where trees can contribute environmental benefits, including reducing diffuse pollution – *the right tree in the right place*. Local targeting of woodland to act as nutrient soaks on farmland and riparian woodland buffer strips could be regarded as options which satisfy this principle. Existing economic incentives for buffer strips are country specific and mainly based around grass buffer strips, with no direct targeted support for creating riparian woodland.

Forestry Commission (FC) England's Woodland Creation Grant offers support for woodland planting for multiple benefits but has only recently started to target water benefits. Broadleaved woodland, which provides the greatest benefits to water quality, receives the highest payments.

The new woodland creation elements under the Glastir Scheme in Wales offer planting and management support for multiple benefits, including water quality, and are available to all landowners with more than 0.25 hectares of land which has been assessed by Forestry Commission Wales (FCW) and conservation bodies in Wales as suitable for new planting. Native woodland and mixed woodland receive the highest payments with specifications designed to encourage greater tree species diversity, better woodland structure and appropriate management regimes.

Stronger incentives are available in other parts of Europe and have led to co-operative agreements between stakeholders to promote afforestation/reforestation for the protection of water quality. As a consequence of a series of Action Plans (AP) imposed since the mid-1980s, Denmark has been one of the most successful countries within the EU to reduce nitrogen surpluses and losses, while still benefiting from increasing animal production and economic gains. Subsidies to encourage woodland creation on up to 20,000 ha of farmland and to establish 16,000 ha of wetlands were provided, specifically designed to reduce demand for nitrogen fertiliser and decrease nitrate leaching through denitrification. Further economic incentives for woodland and wetland establishment were provided in the mid-term evaluation of the second Action Plan for the Aquatic Environment in 2000, alongside recognition of the importance of wetlands in reducing phosphate export to water bodies resulting in a policy to establish 4,000 ha of wetlands and 20,000 – 25,000 ha of new woodland.

A study looked at the effectiveness of land management measures on modelled nitrate leaching within 86 catchments across Denmark between 1990 and 2003. It revealed that the average reduction was 33%[3]. This was directly comparable with the measured decline in the stream total N concentration and load. The conversion of farmland to mainly broadleaved woodland has become the most commonly adopted measure of land use change for the protection of aquifers in Denmark.

[3] Anon (2005)

Woodland’s role in protecting vulnerable sites from harmful affects of ammonia deposition

Carefully sited, the use of "sacrificial planting” of woodland could be considered as a means of improving air quality for the benefit of downwind locations, or to encourage nitrogen deposition in areas that are less at risk from acidification and/or diffuse pollution to water. An example of this approach is the spatial targeting of woodland around pig farms to reduce the high level of local ammonia emissions (Figure 1). Tree shelterbelts around farms can help capture ammonia emissions at source (e.g. from animal houses or manured and fertilised fields), while the turbulence created by their canopies can reduce deposition to the immediate surroundings (dispersal). Wider strips of woodland appear to be more efficient for pollutant capture, with 7.1% of local ammonia emissions recaptured by a 60 m wide tree belt compared to only 2.1% for a 15 m wide belt (based on emissions from a 2 m high source located at 5 m distance from the woodland edge, and 10 m high trees[4]). As a mitigation measure, this can be more efficient than conventional abatement techniques and may provide significant cost benefits. However capture and release to water has been shown to be as high as 24 kg N ha^{-1} at a lowland site with Scots Pine adjacent to an intensive pig farm at Thetford in East Anglia[5].

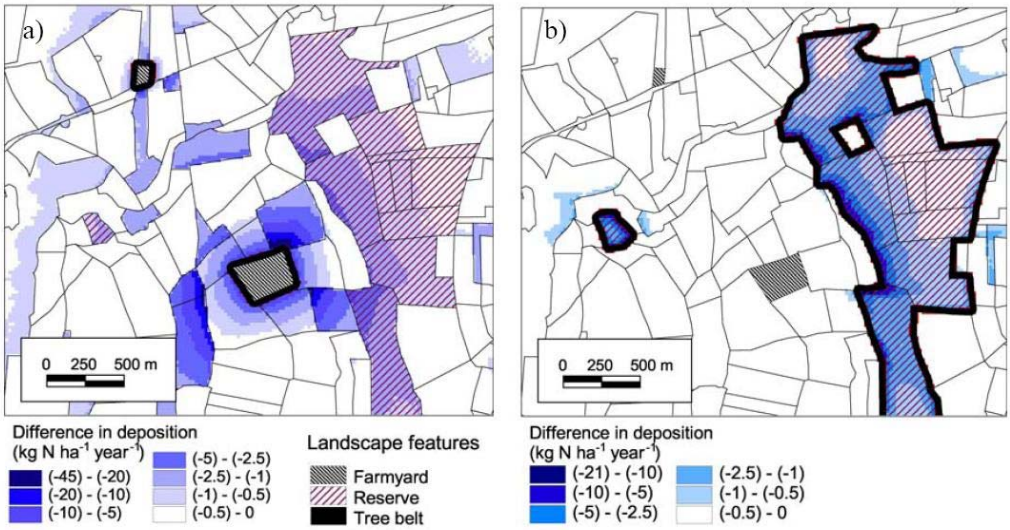

Figure 1. Woodland can be very efficient at capturing and removing pollutants from the atmosphere. Maps show model predictions for the effectiveness of a 50 m wide woodland strip placed either (a) around a farm or (b) around a nature reserve in reducing downwind ammonia deposition (From: Sutton *et al*., 2004). © International Association for Landscape Ecology (UK).

Tackling diffuse nitrate pollution in water

Agriculture is the predominant source of nitrate in surface and groundwaters. About 60 per cent of nitrate entering rivers in England and Wales is from farming, while the rising trend in nitrate concentrations across much of Europe has been linked to an expansion in arable land use. Agricultural apportionment of nitrogen losses is even higher in Scotland at 74%, compared to only 1.2% from forestry[6]. Nitrate leaching losses from woodland are typically much lower than those from different types of arable land use (Figure 2). Analysis of the final results of the Nitrate Sensitive Areas (NSA) scheme, which ran from 1989 to 2003,

4 Theobald et al. (2004)
5 Vanguelova et al. (2010)
6 Anon (2006)

concluded that agricultural land management practices alone would be insufficient to meet good water status, and that targeted land use change should be considered.[7]

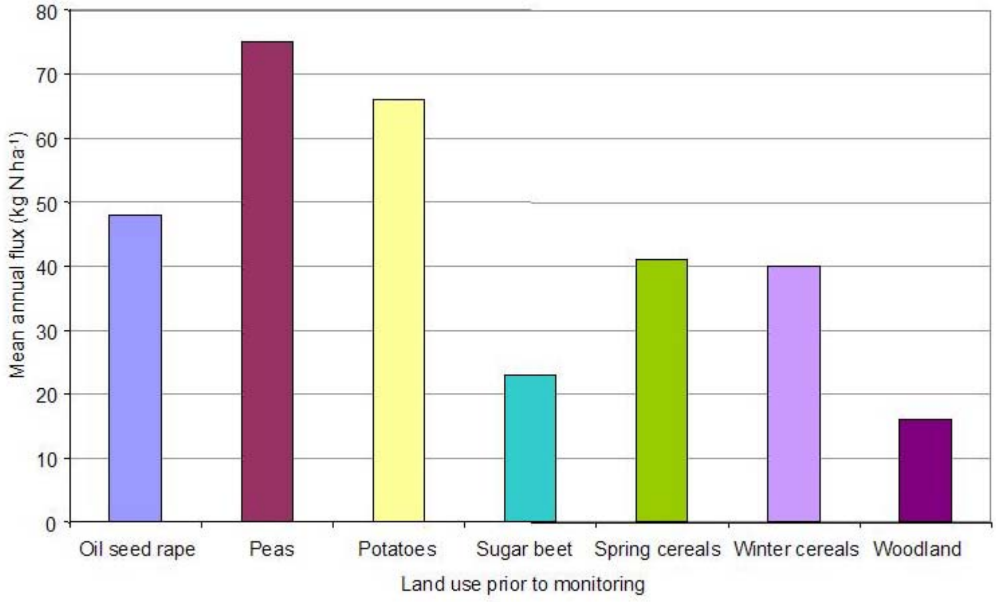

Figure 2. Over-winter nitrate leaching is significantly lower beneath woodland compared to a range of arable crops (From Silgram *et al*., 2005).

Simulations of land use change in the Netherlands and afforestation in a Danish catchment showed substantial reductions in nitrate leaching where land had been converted to woodland. Furthermore, in a study of nine afforested sites in Denmark, nitrate concentrations in groundwater reduced substantially over a 10 year establishment period (Figure 3). A number of long-term investigations in Poland have shown woodland bio-geochemical barriers (woodland strips/tree shelterbelts) to be effective at reducing nitrate leaching and run-off from adjacent fields and thereby exerting a purification effect on the chemistry of groundwaters.

There is evidence to suggest that nitrogen loss from poorly drained soils can be reduced through afforestation[8]. Woodland planting has also been suggested as an effective measure to reduce nitrate leaching from well drained sandy soils, where agricultural production is reliant on recurrent large nitrogen fertiliser inputs due to the inherently nutrient-poor status of these soils. Concentrations of nitrate in groundwater within shelterbelts, or pine and birch woodland patches, adjacent to cultivated fields were reduced by 76-98% of the input[9]. The efficiency of nitrogen removal by shelterbelts was found to be influenced by woodland age, width of strip, season and depth to water-table. Alder is a nitrogen-fixing species and therefore more likely to promote nitrate leaching due to nitrogen supply exceeding demand, especially in areas receiving moderate to high nitrogen deposition.

[7] Silgram *et al*. (2005)
[8] Addy *et al*. (1999)
[9] Ryszowski and Kędziora (2007)

Use of woodland as nutrient soaks

The establishment of riparian woodland buffer strips can act as potential nutrient "soaks" near surface waters[6]. However, it is not clear if nutrient removal by woodland exceeds that of wet grassland. More productive species like some willow and poplar hybrids will enhance nutrient uptake. Multi-species riparian buffers reduced nitrate concentrations by more than 80% between adjacent fields and a stream in Central Iowa in North America[10]. It has been suggested that a 10-20 m width of riparian woodland would be sufficient to remove the majority of nitrate and phosphate pollutants present in surface runoff[11].

Use of woodland in Nitrate Vulnerable Zones (NVZs)

There is scope for encouraging woodland planting and other land use measures within NVZs to reduce nitrogen loadings, as part of the NVZ Action Programme. This could include uncultivated buffer strips (grass, scrub and trees) adjacent to surface waters and targeted woodland creation. The general absence of fertiliser inputs to woodland and low nitrate concentrations in drainage waters, especially under broadleaved woodland, mean that woodland creation could be an effective local measure for reversing the rising nitrate levels in some groundwaters. Land use change to woodland would be particularly effective when targeted to land near to boreholes, on soils susceptible to nitrate leaching, or surface water pathways of nitrate movement to streams, such as within riparian buffer zones.

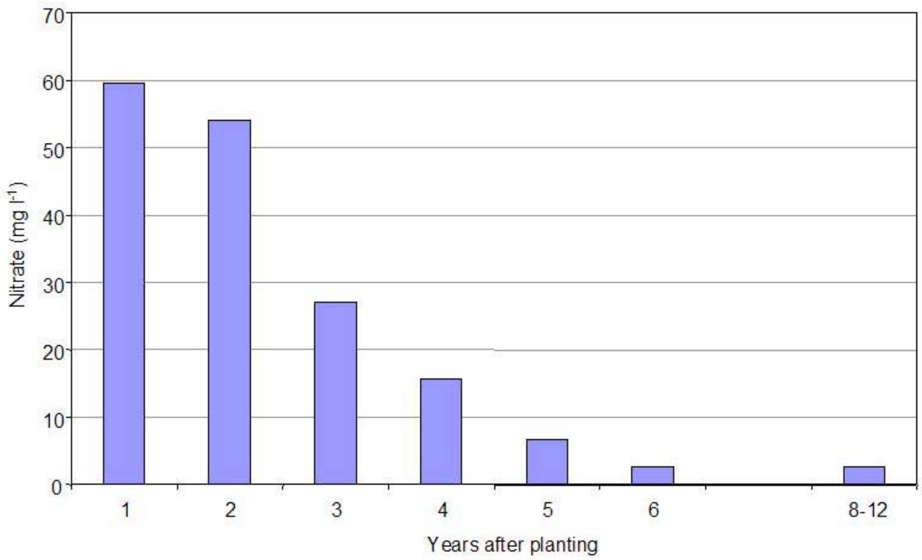

Figure 3. Woodland planting can be very effective at reducing nitrate levels in groundwater. The plot shows average response in nitrate concentrations in water draining through the soil profile at 75-90 cm depth in the soil following afforestation of former arable land at nine sites in Denmark (from Hansen *et al*., 2004).

Energy woodland crops such as Short Rotation Coppice (SRC) could be a particularly attractive option for mitigating nitrate leaching in NVZs by maximising nitrogen uptake and providing a high yielding crop for farmers. However, SRC requires regular nitrogen additions to maintain productivity with potential high losses of nitrate in the establishment

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[10] Schultz *et al*. (1995)
[11] Vought *et al.* (1994)

and removal years. Nonetheless, losses are very low when averaged over the whole life-span of an SRC crop (15-30 years), with a Swedish study showing nitrate concentrations leaving the root zone to average less than 0.20 mg l^{-1} during the main growth phase[12].

The high water use of conifer woodland can indirectly threaten water quality due to an evaporation-concentration effect, with the low rate of recharge leading to greater nitrate concentrations in groundwater. The graph in Figure 4 shows high nitrate concentrations in soil drainage waters beneath a Corsican pine stand at Clipstone Forest in the Midlands, which sharply decline following clear felling in 2000. Data are compared with nitrate concentrations under a grass ley, which show a rising trend following the farm's withdrawal in 2000 from a moratorium on N fertiliser applications (under the NSA scheme). Also shown, are nitrate concentrations under oak woodland, which remain low throughout the monitoring period. To minimise the risk of woodland creation increasing nitrate leaching, the Forests & Water Guidelines[13] recommend avoiding large scale new planting of conifers within NVZs receiving less than 650 mm annual rainfall.

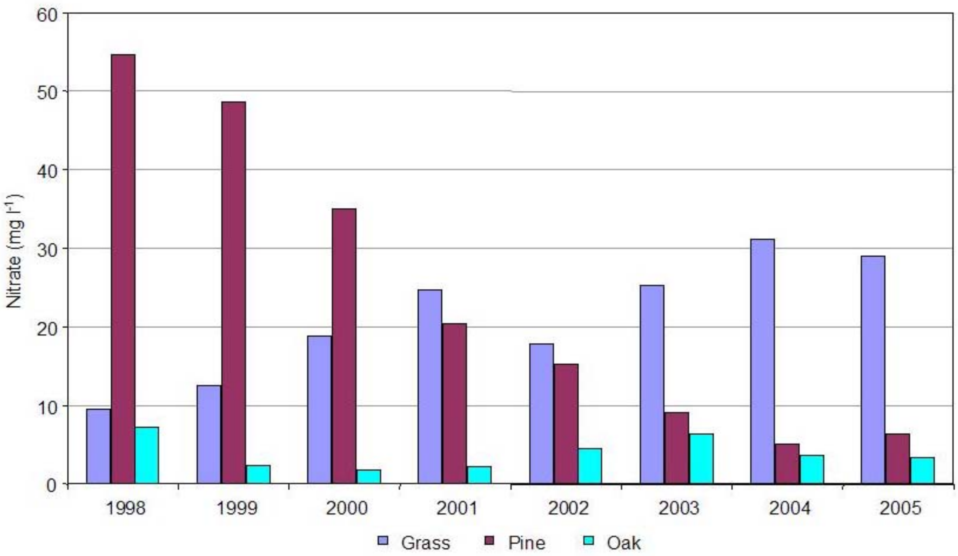

Figure 4. High nitrate concentrations can occur beneath conifer woodland in dry areas (from Calder *et al*., 2002).

Use of woodland in final treatment systems on farms

Ongoing research suggests that the purification functions of SRC and Short Rotation Woodland (SRW) can be exploited for final water treatment on farms, with the potential to couple wastewater management with renewable energy production[14]. Species such as willow, poplar and eucalyptus appear to be well adapted to "wastewater polishing" systems based on woodland buffer strips or infiltration zones[15]. Less certain, is the ability of SRC or SRW buffers to remove pathogens and faecal indicator organisms.

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[12] Aronsson *et al.* (2000)
[13] Forestry Commission (2003)
[14] Sugiura *et al.* (2008b)
[15] Sugiura *et al.* (2008a)

Tackling the risk of diffuse pesticide pollution

Woodland generally poses little risk of pesticide pollution due to the relative small and infrequent amounts of pesticide applied and the continuing drive to develop and promote alternative non-chemical forms of pest control. Thus woodland creation can be used as a measure to reduce the greater threat of diffuse pesticide pollution from agriculture. This includes the establishment of edge of field woodland shelterbelts to reduce spray drift, riparian woodland buffer areas to intercept pesticides in runoff, and constructed wooded wetlands to treat contaminated waters. The use of shelterbelts can be a highly effective measure, achieving reductions in spray drift of between 60 and 90% (Figure 5).

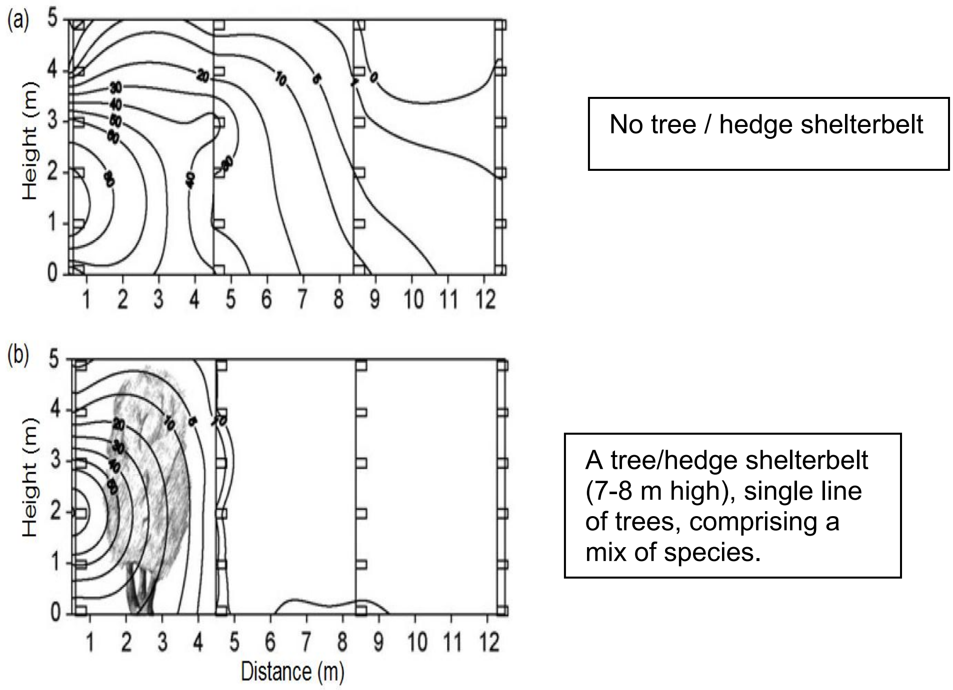

Figure 5. Woodland shelterbelts can be very effective at reducing pesticide spray drift. Plots compare pesticide deposition levels (mg/run/m^2) downwind of a pesticide application to a field bordered with or without a tree / hedge shelter belt. Reprinted from Lazzaro *et al.* (2008), Copyright (2008), with permission from Elsevier.

Riparian woodland buffer areas can also provide effective protection for streams and groundwaters from pesticide applications on adjacent land by intercepting aerial drift of pesticides and trapping pesticides bound to sediment in runoff. Pesticide residues may be removed from drainage waters through a number of natural processes within woodland soils, including by tree uptake. Both a mature, managed woodland buffer (50 m wide) and a newly restored woodland buffer (38 m wide) have been shown to achieve almost complete pesticide retention[16].

Use of woodland to reduce sediment delivery

There are a number of options for using woodland to control runoff and reduce soil erosion and sediment delivery. These include targeted woodland planting to protect erosion sources, the use of woodland shelterbelts or buffer areas to interrupt the transport and delivery of sediment to watercourses, and the restoration of riparian and floodplain woodland to protect river banks and enhance sediment retention by slowing down the flow

[16] Vellidis *et al*. (2002)

of flood water. Recommended widths for buffer areas range from 3-200 m, with 5-15 m most commonly adopted[17]. Particle size affects trapping efficiency, with one model predicting an efficiency of 47% for clay sediment in a 15 m length of vegetated filter strip, compared with 92% for silt[18]. Research found that a combination of woodland and grassland buffers (as an understorey or adjacent strip) enhanced sediment removal. Measurements generally display consistently lower sediment losses for watercourses draining woodland compared to other land-uses (Figure 6). Studies show if correctly targeted in the landscape, these measures can be very effective as part of a whole-catchment approach to tackling sediment problems.

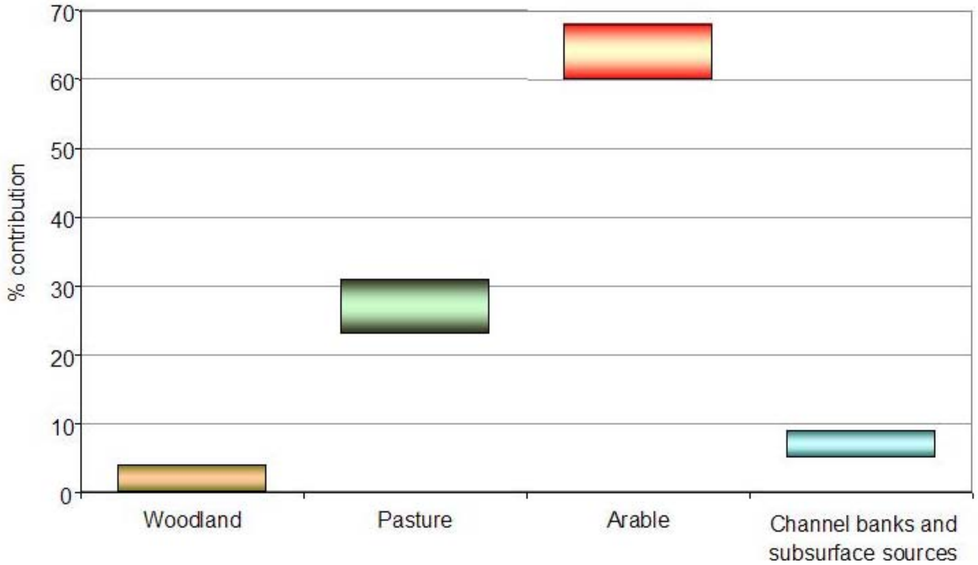

Figure 6. Well managed woodland is usually associated with low sediment losses. The plot shows the relative contribution of different sediment sources (land uses) to sampled fine sediment from the bed of the River Frome in Southwest England (after Collins and Walling, 2007).

Role of agri-environment schemes in encouraging woodland planting

Buffer strips are recognised within the Environmental Stewardship (ES) scheme options, but only for grass strips, with no reward for the establishment of woodland buffers. Points are awarded irrespective of location within the landscape.

The Higher Level Stewardship (HLS) scheme has regional aims to increase woodland cover. There is, however, no incentive to target new woodland creation to where it can most benefit the water environment. Future stewardship schemes could consider:

- Incentives (points or payments) for the creation of tree shelterbelts, hedgerows and riparian woodland buffer areas;
- Weighting of the points system to favour the targeting of these measures to the most effective location within farm landscapes.

The Scottish Rural Development Programme (SRDP) includes support for a number of woodland based Land Managers and Rural Priority options. In Wales, the Glastir Scheme is still under development but will support the creation of water interception strips (shelter belts) and streamside woodland/hedgerow planting and management. Within Glastir Woodland Creation (open from November 2010) there are currently no plans to target

[17] Edwards (2003)
[18] Abu-Zreig (2001)

woodland creation at a strategic scale but the most effective tree planting actions will be incorporated into the design of individual schemes.

Woodland as a potential source of diffuse pollution

Woodland can pose a risk of diffuse water pollution, especially when involving more intensive management practices on sensitive soils. The risks are greatest for conifer forest crops on poor upland soils, where cultivation, drainage, fertiliser and pesticide applications, road construction and harvesting are potential sources of water pollution.

Most pollution incidents resulting from forestry are associated with harvesting operations, usually linked to poor practice in timber extraction. Ground damage due to machinery can lead to soil erosion and increased sediment delivery to watercourses. Clear felling also presents a risk of both phosphate and nitrate contamination of watercourses. Soil type is a key factor with clear felling on peaty soils most at risk of phosphate leaching.

The more intensive practices associated with SRC pose greater risks than in conventional forestry, such as higher application rates of fertiliser. However, experimental results[19] from a willow plantation showed that despite a high peak concentration of nitrate loss following fertiliser application in the establishment period nitrate losses over the whole crop rotation were significantly less than from a neighbouring standard arable crop.

These pollution risks are addressed by good practice measures under the Forests & Water Guidelines. Implementation of the Guidelines has been shown to be generally successful in controlling diffuse pollution.

Forests can also interact with acid deposition and promote surface water acidification. This is mainly due to the increased capture or ‘scavenging’ of acidic sulphur and nitrogen pollutants from the atmosphere by their aerodynamically rough canopies. The lower scavenging ability of broadleaves compared to conifers and longer time to reach canopy closure means that this type of woodland creation is less likely to contribute to water acidification. Emission control policies appear to be succeeding in promoting the continued chemical recovery of acid-sensitive waters across the UK, although there is scope for further improvement as emissions continue to decline and soils re-equilibrate to a lower pollution climate. Evidence of biological recovery is weaker and more variable. This is not unexpected in view of lag effects, including the continued impact of acid episodes and slow recolonisation. This is especially evident where populations have been lost or barriers have affected species migration.

Despite being more impacted by acid deposition, chemical time series do not reveal any major dissimilarity in recovery between forest and moorland streams[20]. Figure 7 shows that acidified streams draining forested and moorland catchments appear to be recovering at a similar rate in response to ongoing emission reductions, suggesting that existing measures may be controlling the contribution of forestry to acidification.

[19] Goodlass, *et al.,* 2007
[20] UKAWMN (2010)

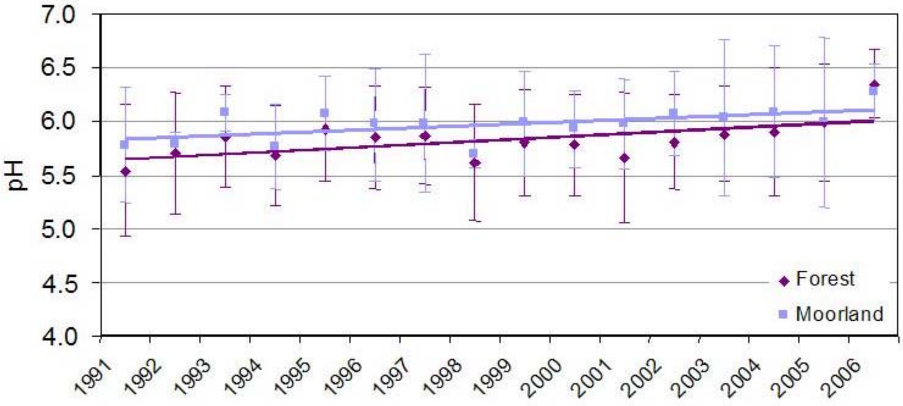

Figure 7. Comparison of the mean response of stream pH in ten forest and two moorland, acid sensitive, catchments in upland Wales (Forest Research: unpublished data).

The longer-term effects of atmospheric N deposition are less certain, with the possibility of nitrate loss in certain circumstances. Woodland management has an important role to play through its effect on nitrogen release by soil disturbance, uptake by tree growth and removal in harvested products. Concern has been raised that the amount of N retained within woodland biomass and soils remains high and potential future disturbance such as clear felling could lead to nitrate release and pose a risk of increased acidification.

Opportunities still exist for promoting native riparian woodland as a means of aiding the biological recovery of acidified waters. The clearing back of dense conifer shading and opening out of stream sides to encourage the restoration of native riparian woodland has been shown to greatly enhance aquatic and riparian habitats; this could aid upstream fish migration and the biological recovery of these streams.

Continued monitoring is essential to demonstrate that sustainable forest management underpinned by best practice measures in the Forests & Water Guidelines is controlling the contribution of forestry to acidification and will continue to do so in the future. Since forest streams tend to be more impacted by acid deposition and thus more acid than moorland ones, the time scale for achieving a chemical status capable of supporting acid-sensitive species may be longer. This has implications for the achievement of WFD objectives.

3.2 Water resources

Trees can use more water than other types of vegetation but whether they do and by how much is dependant on many factors, including tree species, location and local climate, soil and geology, woodland management and design, scale of woodland, and the type of land cover being replaced (Figure 8). The higher water use is mainly due to the interception and subsequent evaporation of rainwater by their aerodynamically rougher canopies, but also to potentially higher transpiration rates sustained by deeper rooting on drier sites.

For upland conifer plantations in the UK, their higher water use results in a potential 1.5 to 2% reduction in water yield for every 10% of a catchment covered by closed canopy forest[21]. Conifer woodland has a disproportionately larger effect in drier lowland areas, amounting to a 7 to 10% reduction in water yield for a 10% land cover. The impact of broadleaved woodland is more variable, ranging in different studies from a 1.4 to 3.2% reduction in groundwater recharge to an increase of 1.3 to 2.5% for every 10% of an aquifer covered by established woodland, compared to grass. The difference in results is thought to be due to soil/geology and species-related factors.

An evaluation of the planned three-fold expansion of broadleaved woodland (from 9% to 27% of area) to create the Greenwood Community Forest in Nottinghamshire predicted this would lead to a maximum reduction in groundwater recharge of between 3 and 6%, assuming all planting involved oak on sandstone[22]. Another assessment concluded that the impact of an increase in native broadleaved woodland cover from 4% to 40% of the public water supply catchment on the average annual water yield at Loch Katrine in central Scotland, would not be significant (+1% to – 4%)[23].

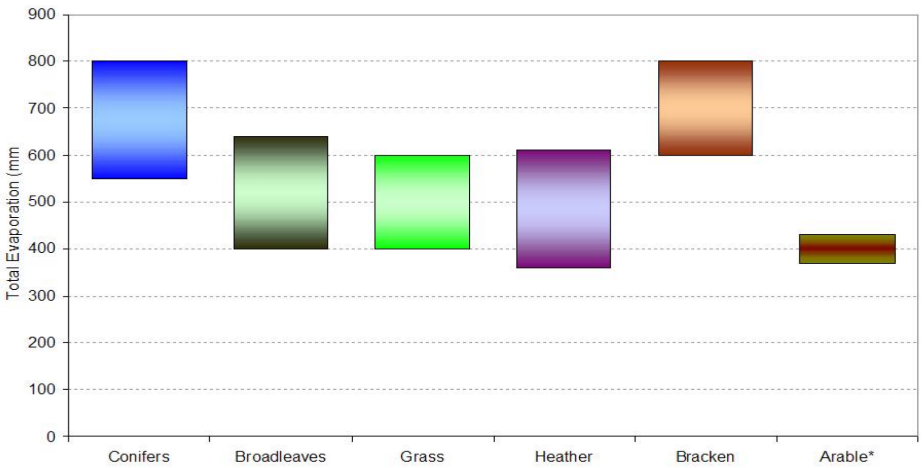

Figure 8. Trees generally use more water than other types of vegetation. The graph compares the typical range of annual evaporation losses in mm for different land covers receiving 1000 mm annual rainfall in UK (from Nisbet, 2005). * Assuming no irrigation.

3.3 Flood alleviation

There are three mechanisms whereby trees can help alleviate flooding:

1. Through greater water use. The higher water use of conifers and related extra capacity of soils to adsorb water offers some scope for reducing flood runoff but the effect is expected to decline with size of flood event. Losses for individual large storms are likely to be <10% for completely conifer forested areas[24].

2. The higher infiltration rates of forest soils. Studies at Pont Bren[25] in Wales found that infiltration rates were up to 60 times higher within young native woodland shelterbelts compared to grazed pasture (Figure 9). Recent modelling predicts that planting shelterbelts across the lower parts of grazed grassland sites could reduce peak flows

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[21] Nisbet (2005)
[22] Calder et al. (2002)
[23] Price (2005)
[24] Calder (1990)
[25] Bird *et al*. (2003)

by between 13 and 48%[26]. These benefits could apply to woodland planting as a part of future sustainable drainage systems.

3. The greater hydraulic roughness of floodplain and riparian woodland. The increased hydraulic roughness associated with planting native floodplain woodland along a 2.2 km grassland reach of the River Cary in Somerset was predicted to reduce water velocity by 50% and raise the flood level within the woodland by up to 270 mm for a 1 in 100 year flood (Figure 10). Temporary flood water retention increased by 71% and the downstream progression of the flood peak was delayed by 140 minutes. Riparian woodland acts in a similar way to floodplain woodland but on a different scale. In addition to the hydraulic roughness associated with bankside and adjacent trees in the riparian zone, the presence of large woody debris (LWD) dams within stream channels acts to delay flood flows, promote out-of-bank flows and increase flood storage. Studies show that these porous dams can significantly delay flood peak travel time, although the effect reduces with size of event and condition of the dams.

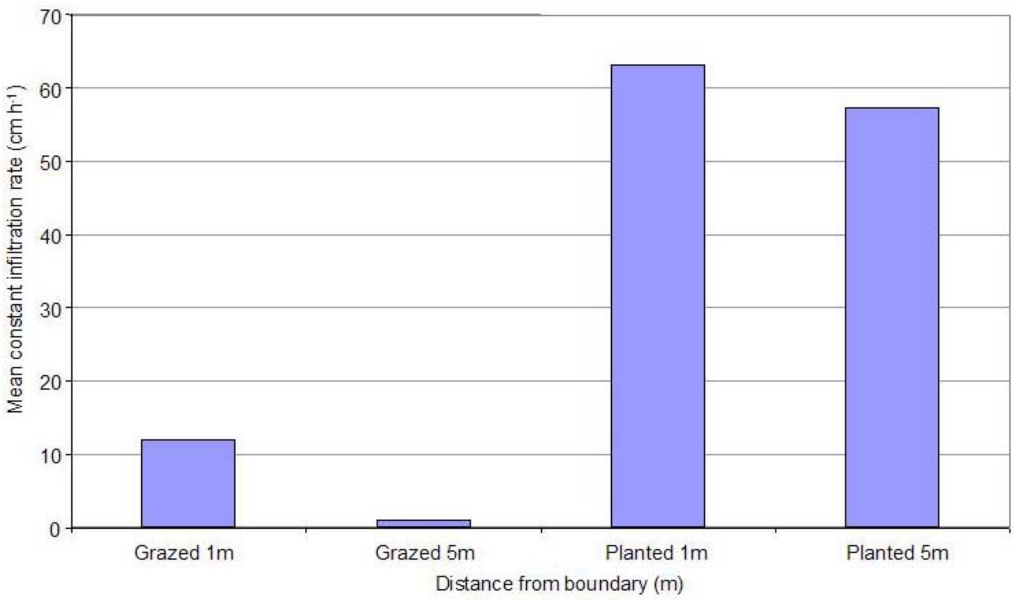

Figure 9. Woodland can help to increase the entry of rainwater into the soil, reducing rapid surface runoff. The graph compares mean soil infiltration rates along a transect, between sheep grazed pasture and a recently planted woodland shelterbelt (2-7 years after planting) at Pont Bren in mid Wales (from Caroll *et al*., 2004, Soil Use and Management, with permission from Wiley).

Modelling studies predict that floodplain and riparian woodland have potential for attenuating large floods within downstream towns and cities[27]. Their ability to delay flood flows offers significant scope for desynchronising flood peaks and providing more time for issuing flood warnings. There is sufficient evidence to promote floodplain and riparian woodland planting to reduce flood risk in appropriate locations, especially when other benefits are factored into the calculation. These include enhanced biodiversity, reduced diffuse pollution and improved hydromorphology.

Woodland's main role in flood risk management is likely to be in helping to climate proof present and new defences. They also provide a sustainable option to assist the protection of smaller communities at risk of future flooding where it is unlikely that they would receive Flood Risk Management Grant-in-Aid to build new flood defences. Strategic planting of SRC or SRW may provide a rapid impact on hydraulic roughness and therefore offer

[26] Jackson *et al*. (2008)
[27] Thomas and Nisbet (2006)

greater flexibility for flood management, as well as providing a high yielding crop generating wood fuel.

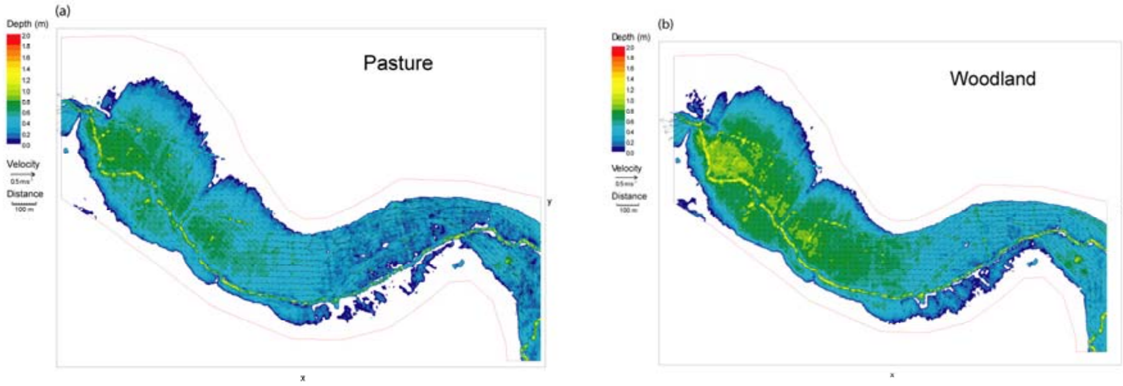

Figure 10. Floodplain woodland can be effective at delaying flood flows, potentially reducing downstream flood risk. The two maps compare model predictions of flood depth and water flow velocity for a 2.2 km reach of the River Cary in Somerset under floodplain woodland versus grassland; (from Thomas and Nisbet, 2006).

Adding to flood risk

There are some circumstances where it would not be suitable to plant floodplain or riparian woodland to manage flood risk. These are:

- Locations where the backing-up of floodwaters upstream of the woodland could threaten local properties. Modelling work shows that the effect typically extends over a distance of 300-400 m, although the enhanced flood depth gradually declines over this distance from being greatest at the woodland edge. The risk can be controlled by carefully siting woodland to avoid locations where properties or infrastructure lie within the affected zone.
- Where there is a risk of woody debris being washed downstream and blocking key structures such as bridges and culverts. Until studies are able to properly evaluate this risk, a precautionary approach is warranted and catchments with known pinch points in downstream towns and cities should be avoided for any major upstream planting in the floodplain.
- Woodland on land adjacent to engineered flood defences, designed for fast water flows to relieve potential flood risk. Banks could be weakened and debris hinder the flow of water.
- Catchments with insufficient water to maintain ecological flows or water demands may be unsuitable due to the potential high water use of woodland, although this can be largely controlled by appropriate species selection. The need to protect open wetland habitats also restricts the scope of woodland planting, as will the presence of buried archaeology.

3.4 Riparian management

Riparian woodland can potentially play an important role in mitigating a range of pressures acting on the water environment and thereby help to achieve good ecological status. Benefits include:

- The binding action of tree roots, which can help to strengthen and stabilise river banks, reducing erosion and bank collapse.
- Intercepting sediment entrained in surface runoff from the adjacent land. The action of herbaceous vegetation and dead wood in slowing down runoff and trapping sediment, combined with the high infiltration rates of woodland soils, helps to reduce sediment delivery to watercourses. There is also considerable nutrient removal by tree uptake and through microbial processes within riparian woodland soils. For riparian woodland to be most effective in reducing diffuse pollution, however, land drains from the adjacent land need to terminate before the woodland edge to maximise contact between drainage waters and riparian soils.
- The ability of riparian woodland to moderate the stream microclimate. Some species of fish such as salmon and trout are very sensitive to water temperature and thus are believed to be at risk from climate warming. A study in the New Forest in southern England found that shade provided by trees reduced water temperature by up to 5.5°C on hot summer days compared to open grassland sections, preventing it from rising above the lethal limit for brown trout (Figure 11).
- The benefit of shading in controlling weed and filamentous algal growth, and possibly the spread of invasive weeds. Algal growth has been implicated in the poor status of some freshwater pearl mussel populations, while mussel densities have been found to be positively related to the level of riparian woodland shade.

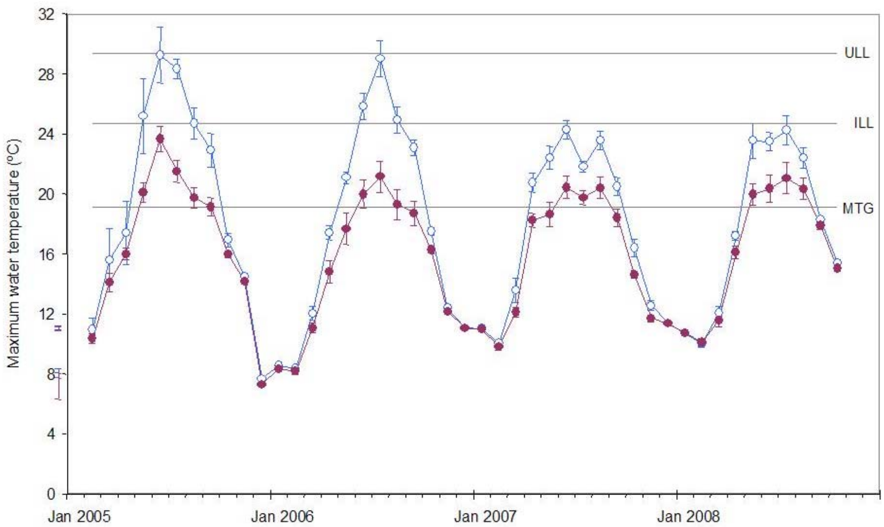

Figure 11. Woodland shade is expected to become increasingly important for reducing thermal stress to fish. Plot compares measured annual variation in water temperature between shaded (solid symbols) and open (open symbols) stream reaches in the New Forest in southern England: ULL = Ultimate lethal limit; ILL = Incipient lethal limit; MTG = Maximum temperature for growth (from Broadmeadow *et al.,* 2010).

Riparian woodland has also been associated with some negative impacts on stream ecology. These include:

- Excessive shading, mainly associated with conifer plantations planted too close to streamsides. This can lead to bare stream banks, increased erosion and siltation, and channel widening, resulting in impoverished stream habitat.
- LWD dams forming a barrier to migrating fish. However, studies increasingly show LWD to be very beneficial to stream ecology and dams only restrict fish movement if they become sealed with sediment and fine wood material.

- The potential high water use of some riparian tree species. In particular, willow and poplar trees can maintain high evaporation losses when well supplied with water and therefore could contribute to the cessation of summer low flows along smaller streams and rivers.

The benefits of riparian woodland are best secured, on main watercourses, by establishing a minimum of a 20 m wide riparian strip on each bank comprising a mosaic of five vegetation habitat types: open ground, occasional large trees, trees with open glades, scrub thicket and closed canopy woodland[28]. In general, the level of shade should be sufficient to allow the development of a more or less continuous cover of ground and bankside vegetation, which is best achieved by aiming for a 50% cover of dappled shade from trees and shrubs. Regular management of riparian woodland is required to sustain the optimum vegetation structure for supporting good ecological status.

Rural Development Programmes in some EU Member States provide financial support for planting riparian woodland. All of these schemes, however, receive 'standard' woodland grant payments and there remains scope for exploring additional funding contributions to help promote and target planting to where water benefits are greatest.

Use of energy crops to increase effectiveness of riparian buffers

SRC can increase the effectiveness of riparian woodland buffers by enhancing tree growth and thereby nutrient uptake, and by increasing hydraulic roughness and delaying flood flows. The planting of high yielding willow and poplar clones has been shown to be very effective at removing nutrients and reducing the oxygen demand of sewage effluent[29]. SRW offers similar benefits to SRC for promoting nutrient uptake but is probably less effective at delaying flood flows due to the lower hydraulic roughness associated with single stemmed trees.

Some negative impacts of energy crops include the potential increased water use which can reduce water resource availability and the maintenance of ecological flows in rivers. This could be managed by species choice. A recent modelling study suggests that ash could generate greater groundwater recharge than grass[30]. Planting of exotic species associated with a high water use, such as Eucalypts, on any sizeable scale is probably best avoided in locations where water demand is expected to exceed available supply. Southeast England is most at risk, with guidelines recommending that only a small proportion of a catchment should be planted where the annual precipitation is less than 600 mm[31].

3.5 Climate change

Adaptation

Climate change is likely to have a marked impact on the freshwater environment, affecting both the timing and volume of river flows and extent of groundwater recharge, with knock-on effects for water quality and stream water ecology. Drier summers and more days with temperatures above 30^0C will lead to more droughts, while wetter winters and increased intensity of rainfall will increase the risk of flooding. Opportunities provided by woodland creation to help attenuate local and larger-scale flooding are likely to become increasingly

[28] FC (2003)
[29] Britt *et al*. (2002)
[30] Calder *et al*. (2009)
[31] Hall (2003)

attractive in appropriate locations and best addressed within Catchment Flood Management Plans (Figure 12). Species choice can be an important consideration for enhancing the effectiveness of woodlands for reducing flood generation or conveyance by affecting water use and vegetation roughness.

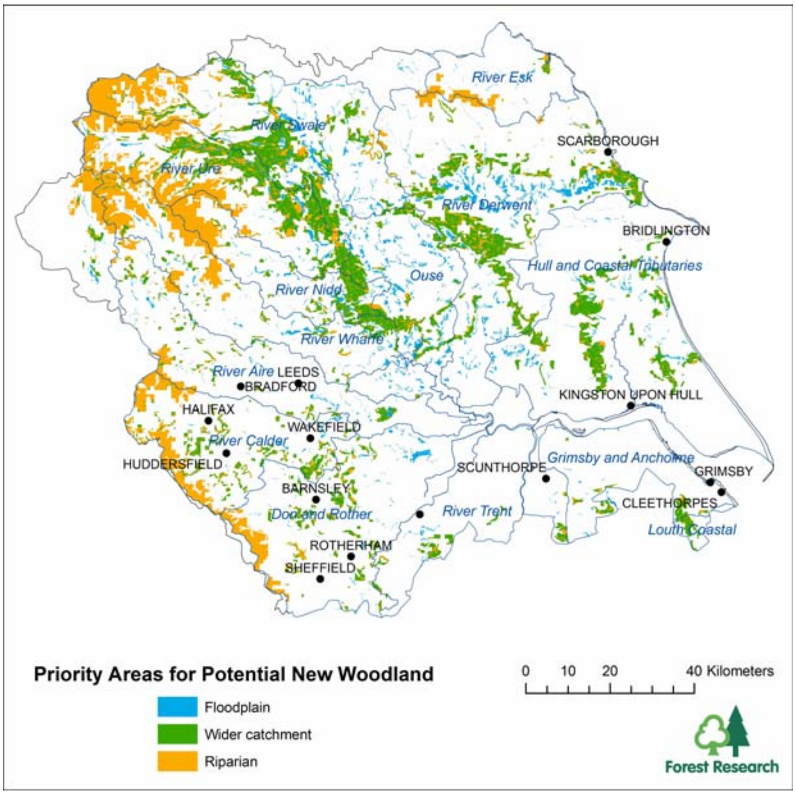

Figure 12. Regional mapping has been used to identify opportunities for planting floodplain, riparian and other woodland within the Yorkshire and Humber Region to deliver a range of water benefits, including improved flood management (from Broadmeadow and Nisbet, 2010).

Species choice is expected to be even more important when addressing the impact of climate change on water supplies. The high water use of conifer woodland can cause a disproportionately large reduction in river flows and groundwater recharge in drier regions of the country due to the smaller quantity of rainfall and thus effective drainage. Since reductions in water supply of 7% or more are possible for every 10% of an aquifer where conifer replaces grass or arable land, large-scale planting of new conifer woodland should be avoided within areas of low water availability[32].

The lower water use of broadleaved woodland means that it poses less of a risk to water supplies, except where planting involves energy crops or occurs on a large scale within a given catchment or aquifer. Modelling suggests that short rotation energy crops of Eucalyptus or southern beech could reduce water resources by up to 9% for every 10% of an aquifer covered in areas receiving <800 mm rainfall[33]. However, planting native ash was predicted to have the opposite effect and increase water yield by a margin of 1.5 to 20.2% per 10% cover, compared to grass.

Riparian woodland shade can play an important role in alleviating the predicted rise in water temperatures and increased risk of thermal stress to freshwater life. Smaller streams and rivers in southern Britain are probably most at risk from temperatures exceeding lethal limits for sensitive fish species such as trout and salmon.

[32] Nisbet (2005)
[33] Calder *et al*., 2009

Mitigation

Since most forests and woodland promote carbon sequestration, new woodland planting will generally help to mitigate climate change. Sequestration is potentially greatest for higher yielding conifer species or broadleaved species grown under short rotation systems. In contrast, woodland benefits for water are likely to be greatest for native broadleaved woodland and therefore this type of planting tends to be more complementary to meeting both WFD and climate change mitigation objectives.

Measures designed to expand riparian and floodplain woodland probably offer the greatest synergy by reducing flood risk, retaining diffuse pollutants, improving river morphology, mitigating rises in water temperature and increasing carbon storage, as well as providing a number of other benefits, especially for biodiversity.

3.6 Land contamination and waste

When planted and managed as part of a controlled programme, trees and woodland can play an important role in the rehabilitation of derelict land, including landfill sites. Benefits include visual remediation, reducing 'fit for use' restoration costs, reducing mobilisation and leakage of contaminants and, in some cases, treatment of contamination. Woodland can also have a positive role to play in reclaiming ex-mineral and brownfield land, promoting revegetation and soil protection.

It is estimated that up to 300,000 ha of land may be affected by contamination in England and Wales[34], some of which may have the potential to impact surface water and/or groundwater. Trees could assist remediation in a number of ways:

- by enriching the soil with organic matter, which is important for immobilising many contaminants;
- by providing a semi-permanent land cover, reducing the risk of soil disturbance and erosion;
- by reducing surface runoff/groundwater recharge and thus the potential for leaching of contaminants to water;
- by the active uptake of contaminants and fixation in woody biomass.

There is also a role for planting woodland adjacent to contaminated land, which can help to reduce the offsite migration of contaminants by intercepting polluted runoff and by reducing wind erosion and trapping airborne contaminated soil. At a more basic level, woodland provides an effective way of screening contaminated sites and discouraging access.

Although woodland offers potential in helping to manage and remediate contaminated land, it may not be suitable for all sites. For example, the tendency for some types of woodland to acidify the soil could enhance the mobilisation of certain metal contaminants within inadequately buffered materials. Heavy shading could pose a problem by restricting the growth of ground vegetation and exposing bare soil to increased erosion. The risk of fire releasing and spreading contaminants may also be a concern. Good woodland design and management practices will be necessary for effective remediation.

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[34] Environment Agency, 2005a

4. Review of cost benefit analyses

A review of 25 case studies in the 'Woodland for Water' Science Report provides a good knowledge base to inform the future development of payments for water-related forest services in the UK (Figure 13). Where there are water trade-offs in terms of the potential for woodland to reduce water yield, these can be managed by attention to woodland type, design and scale. There are significant opportunities to extend such payment schemes to wider areas and incorporate other benefits, including flood reduction and nature conservation.

A higher level of financial incentive is required to persuade landowners to plant woodland on higher value farmland, or to provide funding for land purchase. A start has been made by using locational premiums to raise the value of woodland grants to encourage land use change where water benefits are potentially greatest. Improved assessments of the economic value of water and other forest services are required to gain recognition in relevant policies and strategies that promote forests for water.

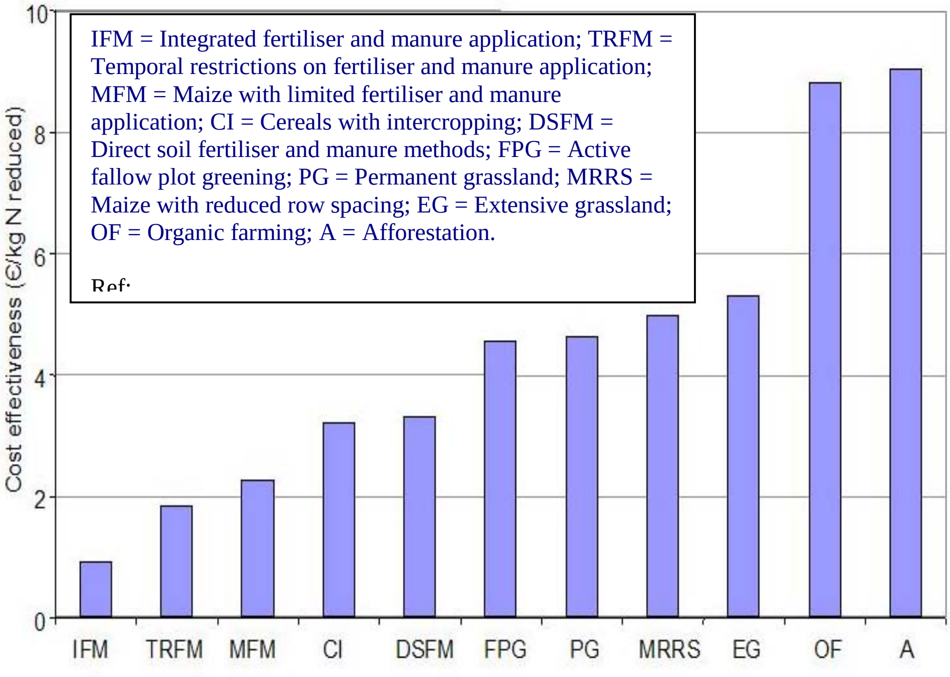

Figure 13. A number of payment schemes for water-related forest services have been developed in Europe. The bar chart compares the cost effectiveness of different groundwater protection measures for reducing nitrate pollution (from WaterCost Inter-reg, 2008).

5. Opportunity mapping

Opportunity mapping offers considerable potential for identifying where woodland creation should be targeted in the landscape to help meet the objectives of the WFD. A GIS-based mapping methodology has been developed and applied to a case study involving the Bassenthwaite Lake catchment on the River Derwent in Northwest England. The method can be applied across a range of scales from assessing opportunities for planting at a strategic regional or river basin level down to the practical farm/field scale. The main output from the opportunity mapping is a set of maps describing catchment sensitivity, constraints and opportunities for woodland planting, an example of which is given in Figure 14.

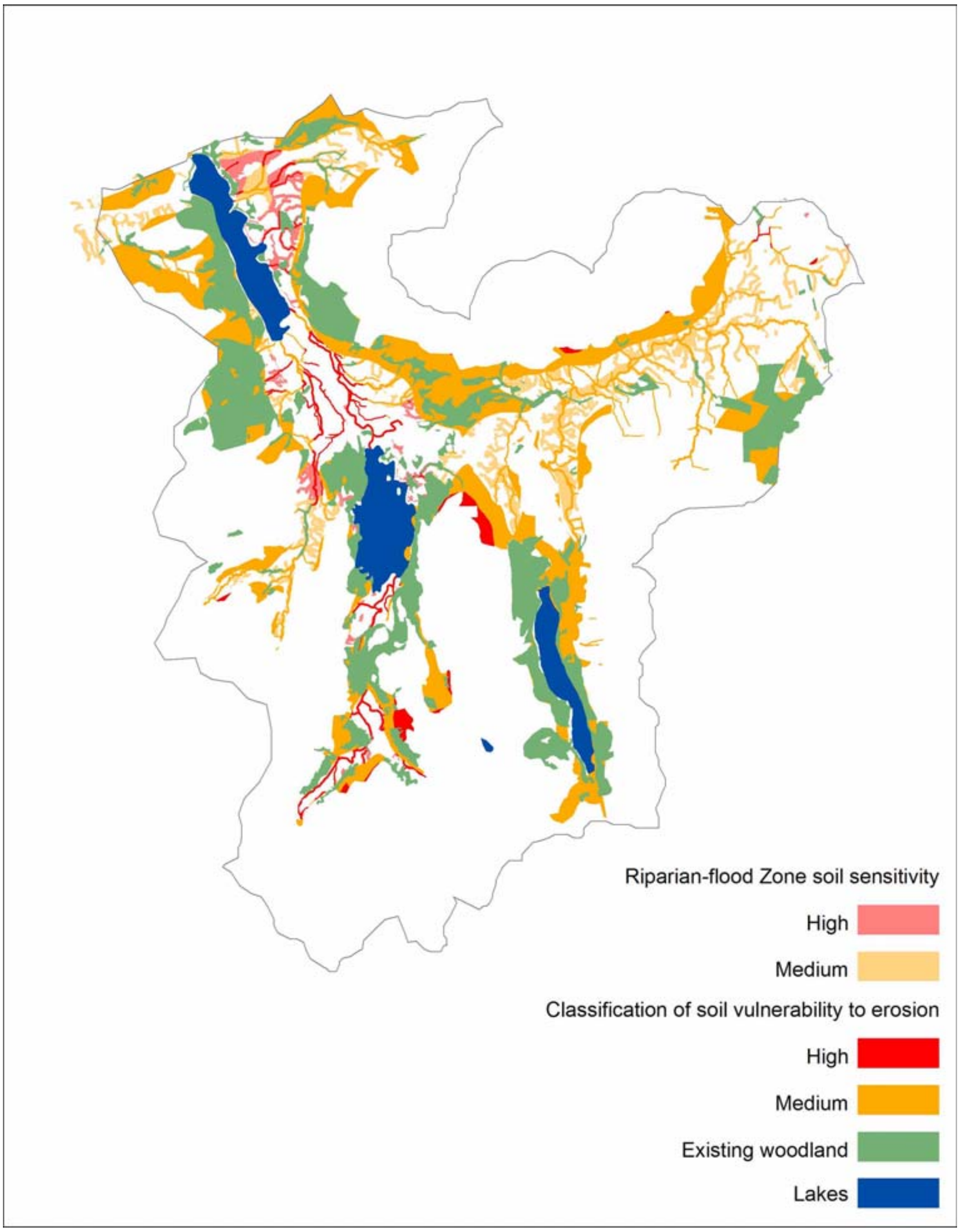

Figure 14. Opportunities for woodland planting to reduce sediment delivery and peak flood flows in the catchment draining to Bassenthwaite Lake.

6. Evidence gaps

There are remaining gaps in the evidence base for the use of woodlands for delivering water benefits. River Basin Planning requires effective and beneficial measures to help reduce pollution, and any potential for land use change would need to be supported by sound science. The following five research recommendations would help to secure a better understanding of woodland benefits at a catchment scale.

1. Establish case studies to evaluate through measurement and modelling the costs and effectiveness of different woodland measures for water protection, including planting riparian buffer areas, mid-slope shelterbelts, infiltration basins and Sustainable Drainage Systems (SuDS). Also, to assess the practicability of integrating their use into the UK farming environment.

2. Evaluate the effect of woodland design (e.g. width, structure and species choice) and management factors (e.g. thinning, coppicing and felling) on the efficacy of woodland measures for diffuse pollution control and flood alleviation. This will help to improve advice and guidance to maximise woodland benefits.

3. Continue long-term monitoring of streams draining acid sensitive forested catchments to establish whether existing measures remain fit for purpose and guide the need for future revisions to best practice guidance.

4. Extend measurements and model testing of the impact of woodland creation on flood generation, including floodplain and riparian woodland, SRC and SRW, and assess the effectiveness of measures designed to trap large woody debris.

5. Further develop the opportunity mapping approach and support model development to aid local targeting of measures at the field and catchment scale.

7. Conclusions

This review provides strong evidence to support new proposals to expand woodland in appropriate locations for soil and water benefits. Main drivers for woodland expansion include sustainable flood management, water bodies remaining at risk of failing good water status despite improvements in agricultural land practices, and the need to mitigate the effects of climate change.

The benefits are potentially greatest for the planting of riparian and floodplain woodland, which can help to reduce diffuse pollution, protect river morphology, moderate stream temperature and aid flood risk management, as well as meet Biodiversity Action Plan targets for the restoration and expansion of wet woodland.

The contribution to tackling diffuse pollution includes both a barrier and interception function, where the presence of trees reduces the risk of direct contamination by agricultural activities on the adjacent land, and helps to trap and retain nutrients and sediment in polluted runoff. Riparian and floodplain woodland benefits for protecting river morphology and moderating stream temperatures are well proven, while a good case can also be made for mitigating downstream flooding. Planting SRC or SRW in these locations could help to maximise some benefits but also presents some risks.

Targeted woodland buffers along mid-slope or downslope field edges, or on infiltration basins also appear effective for slowing down runoff and intercepting sediment and nutrients but the evidence base is limited. Wider woodland planting in the landscape is known to reduce potential pollutant inputs compared to agriculture in the form of fertiliser and pesticide loadings, as well as protecting the soil from regular disturbance and so reducing sediment delivery to watercourses.

Woodland planting is limited by economic and wider land use constraints. Landowners and farmers are likely to be resistant to land use change unless it is economically attractive. Planting on better quality land can result in a reduction in land value, a loss of agricultural subsidies and a reduction in income. Experience from Europe and further afield provides a range of examples of effective payment schemes for water-related forest services, which have succeeded in achieving woodland creation for water protection.

Realising woodland solutions to water management issues is best achieved through River Basin and Catchment Flood Management Plans, including farm and field-level targeting. To achieve this, woodland measures should be considered within relevant land management advice and guidance, WFD Programmes of Measures and agricultural best management practice handbooks. Woodland creation may also have an important role to play in mitigating longer term water pollution problems such as reducing nitrate pollution.

Agricultural advisers have an important role in the provision of good advice on land management. Guidance on the best woodland options and local demonstration sites could help to communicate how woodland can contribute to tackling issues such as diffuse pollution and flood risk.

The report highlights the evidence gaps in our understanding of how woodland can be best integrated with agriculture for water and wider environmental benefits, while minimising any water trade-offs. Spatial mapping offers significant potential for promoting integrated catchment management and delivering new woodlands where they can best benefit society. 'Opportunity mapping' has been developed to help direct woodland onto preferred sites for protecting sediment sources, intercepting the pathways of diffuse pollutants, reducing rapid run-off and to enhance flood storage.

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