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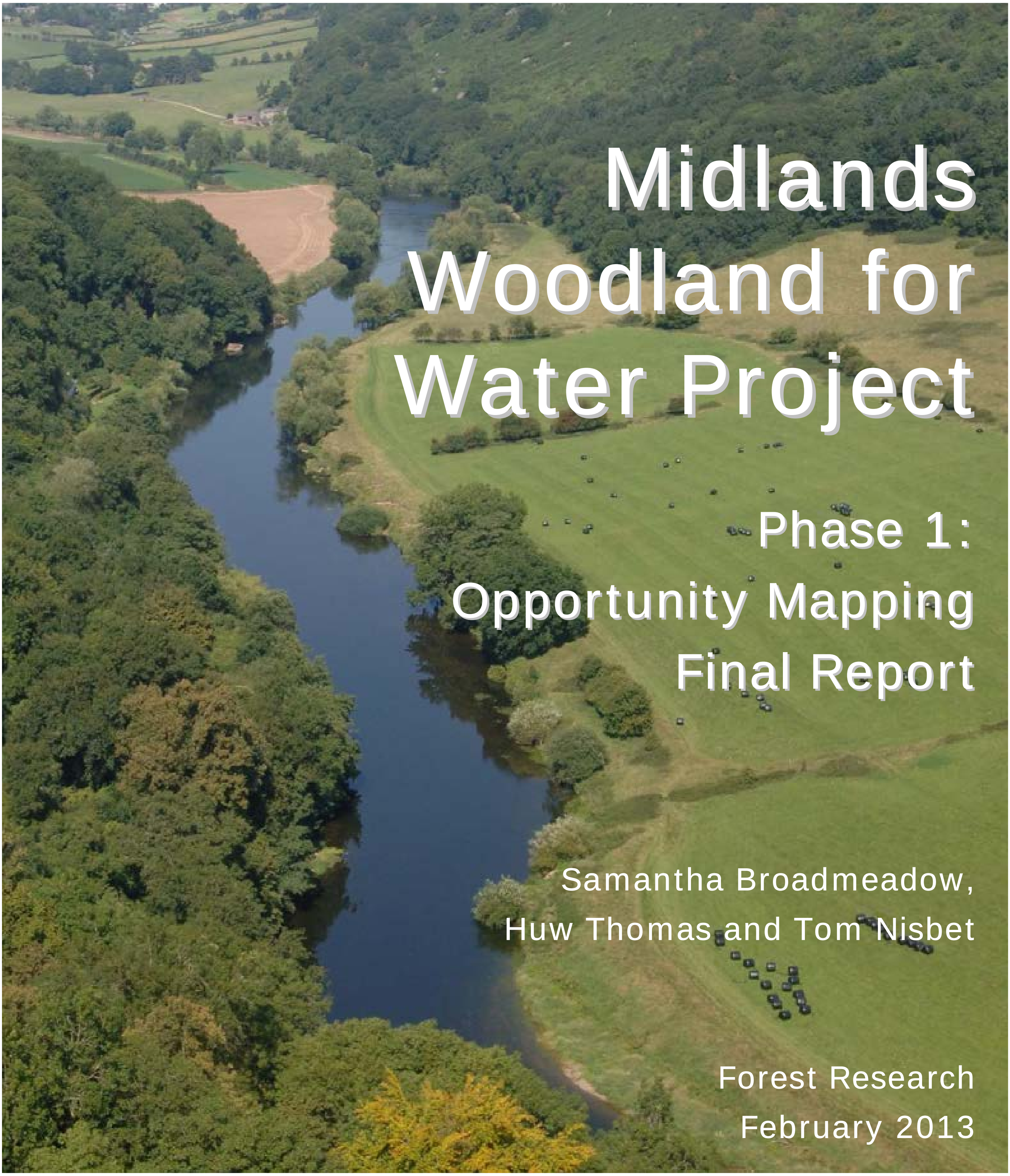

Midlands Woodland for Water Project

Phase 1: Opportunity Mapping Final Report

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Executive Summary

The Midlands Region faces a number of major water issues, with over 100,000 properties at significant risk of flooding and 85% of river waterbodies currently failing to meet the target Good Ecological Status required by the Water Framework Directive. A number of recent publications provide strong evidence of the ability of woodland creation to help tackle these pressures by reducing and delaying flood waters, limiting pollutant loadings and retaining diffuse pollutants. Ongoing studies designed to improve our understanding of the effects of woodland on flood flows have been reviewed and the findings found to further strengthen the supporting evidence base. A significant caveat, however, is the need for care in site selection to ensure that planting does not increase flood risk by synchronising, rather than desynchronising downstream flood flows.

The main aim of this study was to identify priority areas for woodland creation and the improved management of existing woodlands to reduce downstream flood risk and achieve the objectives of the Water Framework Directive. A wide range of spatial datasets were accessed from partners, particularly the Environment Agency, and used to generate a large number of maps and supporting GIS shapefiles showing priority areas potentially available for planting. The results provide a strong basis for developing and refining regional objectives, initiatives and projects to deliver new woodlands where they can best contribute to FRM and meet WFD targets, in addition to generating many other benefits for society.

There are extensive opportunities across the region for woodland creation or the improved management of existing woodlands to mitigate downstream flood risk and improve water quality (Map 39), including:

- 5,189 km^2 (24% of region) of priority sites for woodland planting to reduce downstream flood risk, comprising 4,349 km^2 of wider woodland, 623 km^2 of riparian woodland and 217 km^2 of floodplain woodland

- 4,670 km^2 (22% of region) of high priority land in failing or vulnerable waterbody catchments subject to one or more diffuse agricultural pollution pressures (phosphate, nitrate, pesticides and sediment)

- 1,919 km^2 (9% of region) of priority land where woodland planting could tackle both flood risk and one or more diffuse agricultural pollution pressures; 18% (341 km^2) of this land is free from all sensitivities

- 737 ha of priority land where woodland planting could reduce both flood risk and all four identified diffuse agricultural pollution pressures; 81% (599 ha) of this land is free from all sensitivities

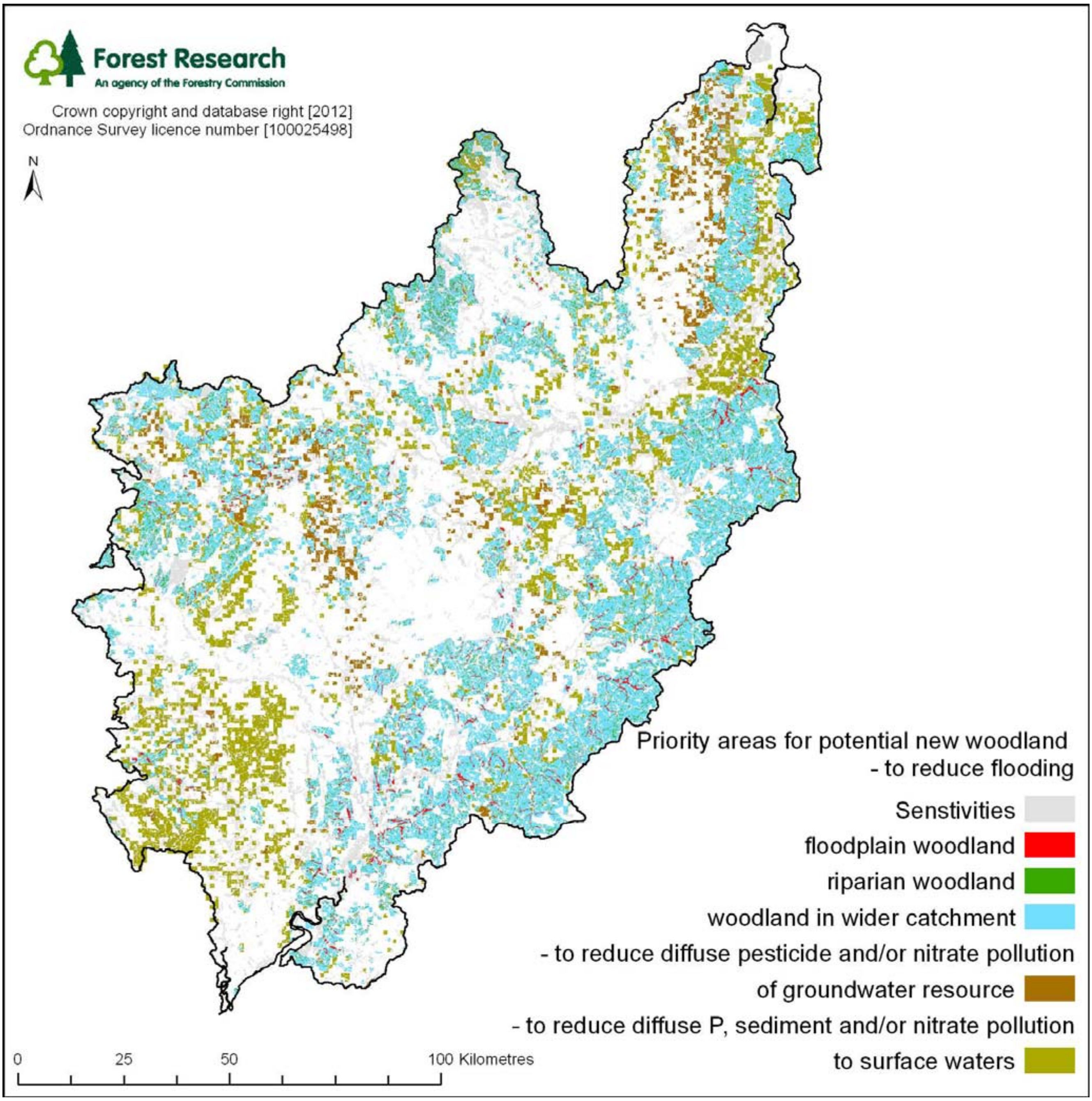
- 112 (>100 ha) sub-catchments with >20% conifer forest cover where the scale of felling could potentially increase local flood risk or reduce water quality, including seven within areas vulnerable to acidification; 2,795 ha of riparian land where conifer woodland remains within 20 m of the river network; and ~100 sub-catchments with >20% forest cover where further conifer planting could potentially pose a risk to future water resources due to the higher water use of trees.

These opportunities are reasonably widely distributed across the region, although there are notable ‘hotspots’. The greatest scope for multiple water benefits arise in the northern parts of the River Severn catchment and in a relatively narrow band along the eastern boundary of the region, stretching from the Warwickshire Avon to the Lower River Trent (Map 40). There is a large degree of overlap between the identified priority land for woodland creation and the many existing regional strategies, plans and projects designed to promote land use change or improve land management to mitigate flooding and diffuse pollution, including Catchment Flood Management Plans and England Catchment Sensitive Farming Delivery Initiative Priority Catchments. A significant proportion of the priority land is subject to sensitivities that may restrict the scale and character of any woodland creation.

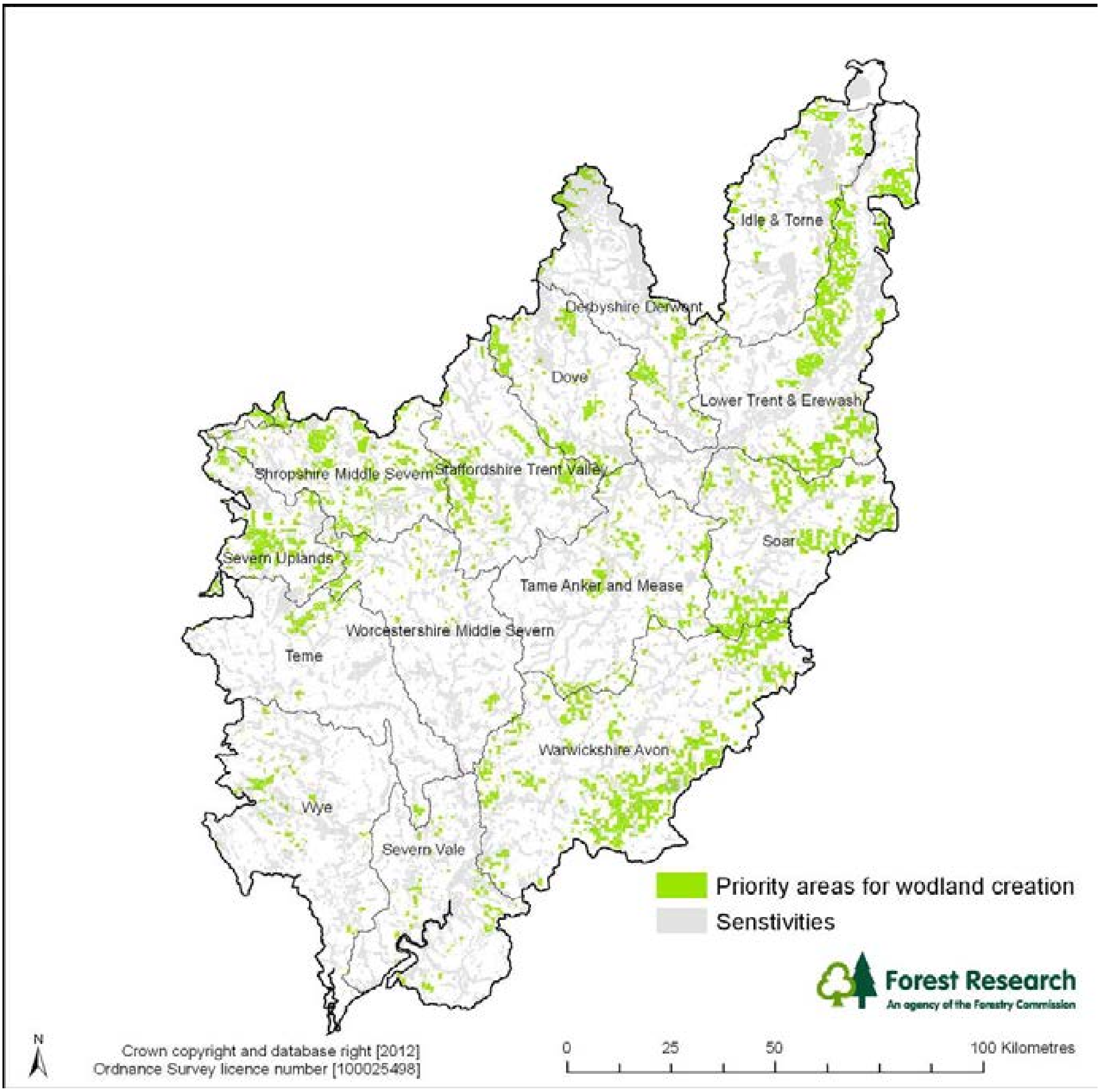
It is recommended that partners and other regional stakeholders use these maps and spatial data to target locations where woodland planting can provide the greatest benefits to water at the catchment scale. This includes using the identified opportunities to better integrate woodland into existing and new catchment initiatives to improve the chances of success and help secure longer-term performance. There is also significant scope to overlay the maps with those of other woodland values such as the provision of recreation and health benefits, so that opportunities to further widen the range of potential benefits from planting can be realised.

Woodland planting is limited by economic and other considerations. In particular, landowners and farmers are likely to be resistant to land use change unless it is economically attractive. The study notes that while recent progress has been made in raising the value of woodland grants to promote better targeting of woodland creation for water, more will need to be done to achieve the required level of planting to make a difference at the catchment scale. This is especially the case for tackling agricultural diffuse pollution pressures, which tend to be greatest on arable land. While land values and crop prices will greatly constrain woodland creation on such land, it is thought that small scale planting targeted to riparian buffers and along pollutant pathways could make a significant difference, while having a limited impact of agricultural incomes. There is scope for better integrating available incentives to secure greater land use change, as well as encouraging water companies to help fund woodland creation for water.

Finally, it is recommended that one or more pilot studies are established within the region to demonstrate and help communicate the value and benefits of woodland creation for water. Ideally, any such study should be incorporated within one of the existing pilot catchment sites that have been set up to examine the effectiveness of agricultural best practice measures, but failing this a new site should be sought guided by the opportunity maps. The report provides guidance on the monitoring and evaluation of woodland benefits to provide a more robust local evidence base.



Map 39 Distribution of high priority areas for woodland creation for Flood Risk Management (FRM) in relation to those for reducing one or more diffuse pollutants to surface waters or groundwater



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1. Background

The Water Framework Directive (WFD) poses a big challenge for the Environment Agency and its partners. To meet the objectives set out in the first River Basin Management Plans (RBMP) will mean tackling some of the more intractable water quality issues, such as mitigating diffuse pollution from rural and urban sources. Another major issue is to manage the risk of flooding to householders, with over 100,000 properties at significant risk in the Midlands Region. The Catchment Flood Management Plans for the River Severn, Severn Tidal Tributaries and River Trent set out policies for managing flood risk over the next 100 years, including where there are opportunities for greater working with natural processes.

In the last few years a number of reports have identified the positive benefits woodlands can have on WFD and Flood Risk Management (FRM) (see Appendix 4; Nisbet et al., 2011a). These publications provide strong evidence and support for better targeting of woodland creation for water. However, to make use of this evidence we need to identify and map the locations where woodlands will be most effective.

This work attempts to fill that gap and provide the basis for future delivery phases of the Midlands Woodlands for Water project. The report describes the methodology used to generate opportunity maps for woodland creation to deliver water services in the Midlands Region. The approach comprised three strands: identifying constraints and sensitivities to woodland creation; assessing the scope for woodland planting to reduce flood risk; and identifying opportunities for woodland creation to address diffuse pollution pressures affecting river waterbodies and groundwater resources. Account was also taken of potential water trade-offs associated with woodland creation and where changes to the design and management of existing woodland could benefit FRM and WFD. A series of maps and tabulated data are provided that identify priority areas for woodland creation to benefit water. The report concludes with a summary of delivery mechanisms to promote woodland planting in preferred locations and provides a number of recommendations on next steps. The final section updates the Woodland for Water Review (Nisbet et al., 2011a) by summarising ongoing and new case studies, followed by a consideration of developments in hydraulic modelling and a methodology for monitoring and measuring the short and long-term water benefits of woodland creation.

2. Objectives

To provide GIS spatial datasets and maps which identify priority areas for woodland creation and improved management of existing woodlands to benefit FRM and help achieve the objectives of the WFD.

3. Study area

The extent of the Midlands Woodlands for Water project is defined by the EA Midlands regional boundary (Map 1). The region covers 21,475 km^2 extending from the Humber in the north to the Severn Estuary in the south. It comprises two main river systems, the River Trent draining the more densely populated north-eastern half, and the River Severn in the south-west.

Due to the presence of extensive coalfields the River Trent catchment has a long history of industrialisation and settlement. It is now home to 6 million people and contains the sprawling metropolitan areas of Birmingham, Derby, Leicester, Nottingham and Stoke on Trent. Landform, geology and soils vary considerably across the catchment, ranging from the uplands of the Peak District characterised by carboniferous limestone and gritstone moors, steep-sided valleys and thin soils; via the softer mudstones, glacial deposits and rich loamy soils of the Tame and Trent Valley; to the thick clay soils of the broad lower floodplain of the River Trent and the intensely drained Humberhead Levels (Maps 2, 3 & 4). Above the Trent floodplain lie outcrops of porous sandstone and pebble beds that were deposited by ephemeral braided rivers during the Triassic period. These give rise to the free draining soils of Sherwood Forest and Cannock Chase.

The south-west half of the region comprises of the more rural catchments of the River Wye and River Severn, in which 2.3 million people live in a predominantly agricultural landscape. The major urban centres are typically discrete market towns and small cites such as Shrewsbury, Ludlow, Coventry, Leamington Spa, Warwick and Worcester. While the source of the catchment lies in the Cambrian Mountains in Wales, the highest ground in the region is formed by the Shropshire Hills in the Teme catchment and the Black Mountains on the Welsh border. To the north-east is the relatively flat Shropshire, Cheshire & Staffordshire plain, from which the River Severn flows through The Wrekin and Wenlock Edge into the Mid-Severn sandstone plateau, and then onto the broad floodplain of the Severn and Avon Vales (Map 2). The soils of Shropshire, Warwickshire and Worcestershire are typically deep and fertile, with local variability reflecting the nature of the underlying glacial sediments (Map 4).

Agriculture is the dominant land use across the region, with a relatively even split between improved grassland and arable (Map 5). Urban is the next major land use at 12% (Map 6), while existing woodland is less than the national average, at only 9% (Map 7). This is relatively evenly distributed, with sizeable woodlands limited to the Dean, Wyre, Cannock Chase and Sherwood Forests. There are many important habitat and wildlife areas, including 30 Special Areas of Conservation, 5 Special Protection Areas, 28 National Nature Reserves and 759 Sites of Special Scientific Interest, of which 198 are waterbodies or water dependant priority habitats. A total of 44 of the 724 river waterbody catchments in the region are protected under the EU Habitats and Species Directive. The Severn Estuary and its surrounding area are afforded a high level of protection under European wildlife law for their bird populations, wetland habitats and migratory fish species. There are two National Parks and four Areas of Outstanding Natural Beauty.

Both the River Trent and River Severn catchments have a long history of flooding, including both fluvial and tidal floods (Map 8). Around 23,000 and 29,000 properties (both residential and commercial) and 45,000 and 60,000 people are at risk from a 1% flood event in the Trent and Severn catchments, respectively. These figures are expected to rise significantly in the next 50 to 100 years due to climate change. The most recent severe flooding was experienced in 2007 in the River Severn catchment, when a period of prolonged, intense rainfall led to major pluvial flooding, followed about three days later by extensive fluvial flooding. The smaller tributaries of the Severn to the east of Cheltenham and Gloucester inundated their floodplains very quickly, resulting in considerable flood damage to housing, business and infrastructure.

The water environment is under considerable pressure within the region, reflecting its intensive use by agricultural and urban activities. Of the 724 WFD river waterbody catchments, 612 (85%) are currently failing to meet the target Good Ecological Status (GES), 471 (65%) due to diffuse pollution. Groundwater resources are also at risk, with 40% of the region underlain by groundwater with less than good water quality and another 8% where the present good status is subject to a deteriorating trend.

4. Methods

4.1 Approach to GIS mapping

Opportunities for woodland planting to contribute to flood mitigation and a reduction in diffuse pollution were identified using a GIS mapping assessment of the region. This was based on the approach originally developed for FRM in the River Parrett Catchment in Somerset (Nisbet & Broadmeadow, 2003) and subsequently applied to the Yorkshire and The Humber Region (Broadmeadow & Nisbet, 2010a) and the River Derwent catchment in Cumbria (Broadmeadow & Nisbet, 2010b). The benefits of woodland for reducing diffuse water pollution were incorporated into the method applied to the Lake District National Park (Broadmeadow & Nisbet, 2010c) and further developed for this study.

The current project draws heavily on spatial datasets prepared by the EA under their FRM and WFD programmes, including the recent work ‘Targeting land use change options to meet water quality objectives in English priority areas’ (Environment Agency, 2012). It also uses datasets generated by ADAS’s PSYCHIC model (Davison *et al.,* 2008).

4.2 Identification of constraints and sensitivities to woodland creation

The first step in determining the extent and scale of woodland creation opportunities was to identify constraints to woodland planting. These are locations where the creation of sizeable areas of woodland is either not possible or very unlikely due to existing land use, land ownership or the presence of vulnerable assets. They should not all be seen as absolute barriers to planting as some will provide local opportunities, such as part of SUDS within urban areas or in appropriate locations on Scheduled Ancient Monuments or World Heritage sites. Their inclusion reflects their highly sensitive nature and restricted scope for woodland planting to play a significant part of any flood mitigation or water quality improvement scheme. The list of constraints comprised the following:

- Urban areas, including villages, towns and cities
- Roads
- Railway infrastructure
- Scheduled Ancient Monuments
- World Heritage Sites
- Airports and military air fields
- National Grid gas pipelines
- National Grid overhead cables
- Open water & Canals
- Existing woodland

The combined dataset was used to remove areas that would be unsuitable for significant woodland planting (Map 9). Scheduled Ancient Monuments were protected by adding a fixed 30 m buffer, as recommended by the FC's Forest and Archaeological Guidelines. Wider buffer zones may be required to preserve the setting of a particular scheduled monument, which would be determined during specific site assessments.

There are additional factors that will influence the scale, type and design of any planting. These are termed sensitivities and would require careful consideration on an individual site basis in consultation with relevant agencies. This would be undertaken as part of the normal assessment and approval process for woodland planting applications. Sensitivities include the most valuable agricultural land, sites close to flood defence and urban infrastructure, and areas scheduled or recognised for their nature conservation, historic or cultural importance. The full list is as follows (see Appendix 1 for details of the data sources):

- Grade 1 agricultural land
- Floodplain buffer around urban centres and along roads
- Riparian zone of designated Main Rivers
- Land behind raised flood defences

- EA floodplain washlands
- Ministry of Defence land
- RAMSAR sites
- SAC
- SPA
- SSSI
- National Nature Reserves
- Common Land
- RSPB Reserves
- Historic Parks & Gardens
- Battlefields
- National Parks
- Areas of Outstanding Natural Beauty
- Deep peat
- Land above the natural tree line
- Undesignated BAP Habitats

The above features were combined to form a single GIS layer, showing where woodland creation would be possible providing the scheme was appropriately designed to protect and enhance the value of the existing habitat, landscape or assets on the site (Map 10). Most of the sensitivities are self-explanatory and well defined by formal designated boundaries. The selection of others is explained below, particularly those that required some processing, such as the floodplain buffers and the riparian zone along Main Rivers.

It was thought appropriate to include a buffer around urban areas and roads (railways were excluded on the basis that they were expected to be embanked and therefore less at risk) within or adjacent to the floodplain in view of the potential sensitivity of these assets to the backing-up of floodwaters upstream of any planted floodplain woodland or the blockage of downstream culverts or bridges by the washout of woody debris. The buffer acts as a flag to check for these issues when a planting application is made, which may require reach-scale modelling of flood levels and an assessment of the vulnerability of local pinch points to blockage. Uniform fixed width buffers were created, principally guided by the results of previous modelling work which showed the backwater effect to be largely confined to a distance of 300-400 m upstream. Consequently, a 500 m wide buffer was delineated around urban areas and a 300 m buffer along both sides of roads (Map 11). It is important to note that an allowance has not been made for the protection of isolated buildings and farmsteads and these would need to be assessed on an individual site by site basis when an application is made.

The delineation of a riparian buffer along Main Rivers was dictated by the possible need to maintain access for flood protection purposes and to protect floodbanks from tree rooting and windblow. Consent may be required from the EA for the planting of trees within a given distance (generally within 7-16 m) of these watercourses, depending on local Byelaws. This could greatly limit the nature of planting within this zone and the scope for water benefits, such as slowing flood flows, protecting banksides, providing shade and retaining diffuse pollutants. It was therefore decided to mark the full width of the riparian zone along Main Rivers, defined as a 30 m wide zone on either bank of the EA's Detailed River Network, as a sensitive area for planting.

Land behind raised flood defences was also included as a sensitivity to reflect the reduced scope for woodland planting to provide certain water benefits, such as mitigating downstream flooding (due to having little effect on flood conveyance). These areas would not normally be considered a priority for planting for FRM unless there were plans to remove or breach the flood defences to increase flood storage and promote interactions with any planted woodland.

Similarly, washlands were considered to be a sensitivity because planting here would provide no FRM benefit and could actually reduce the actual volume of flood storage (although the impact is likely to be small). If planting was proposed for water quality or biodiversity gains, an important issue would be the timing, frequency and depth of flooding. Some tree species are more sensitive than others to inundation and care would be required in the design and management of these woodlands to secure establishment and sustain growth. Recent guidance on this issue is provided in FOWARA (2006).

Deep peat soils were included to reflect potential issues over the impact of planting on soil carbon stocks, depending on the nature of planting and woodland management.

Finally, the constraints and sensitivities were brought together in Map 12 to show the distribution of land potentially available for woodland planting in the region.

4.3 Identification of suitable areas for woodland creation to reduce downstream flood risk

Woodland can help alleviate flooding in three main ways: through the potentially high water use of trees increasing available soil water storage and reducing the generation and volume of flood water; by the typically high infiltration rates of woodland soils reducing direct surface runoff and delaying the passage of water to streams; and by the greater hydraulic roughness created by woodland vegetation acting to increase above ground flood water storage and delay the downstream passage of flood flows (Nisbet et al., 2011a). These mechanisms are to varying degrees location dependent and considered to be greatest where there is most contact between water and woodland, such as along runoff pathways and on floodplains. Consequently, the focus of mapping is to identify preferred locations where woodland planting is likely to be most effective.

4.3.1 Floodplain

Planting within floodplains is thought to offer the greatest potential for downstream flood mitigation and therefore the first step was to define the extent of the floodplain where woodland could interact with flood flows. The EA's indicative floodplain maps were selected for this purpose. Map 8 delineates both fluvial and tidal flood zones, with the fluvial floodplain defined for flood events with a 1% (Flood Zone 3) and a 0.1% (Flood Zone 2) probability of occurring in any year. The Flood Zone 2 was selected as the boundary of the floodplain to better represent the potential area at risk from inundation if new woodland was effective at raising upstream flood levels due to a backwater effect (see below). The tidal and combined tidal and fluvial zones were excluded since they were downstream of most sites that would benefit from a woodland induced flood lag effect. However, there may be scope for woodland within these zones to hold back and retard tidal surges for the protection of upstream sites, although this is not considered further in the report.

The next step was to remove all of the areas affected by the constraints defined in Section 5.2. Account was then taken of the practicality of achieving a sufficient/sizeable area of woodland planting in the floodplain to have an impact on flood flows. This involved removing all sections of the floodplain over 1 km wide in the lower reaches of the River Trent and River Severn (areas wider than 1 km were retained within middle and upper reaches). The end result was a map showing areas within EA Flood Zone 2 that were potentially suitable for planting floodplain woodland for flood mitigation (Map 13).

The efficacy of floodplain woodland in retarding flood flows and mitigating downstream flooding is dependent on the size of the woodland in relation to the scale of the floodplain (Thomas and Nisbet, 2006). Obviously, woodland spanning the entire floodplain will generate a greater impact compared to an isolated, small block of woodland on one side or on the margin of the floodplain. However, modelling shows that it is not necessary to plant a continuous stretch of woodland either across the full width or an extended length of the floodplain to achieve a significant delay in flood flows; a series of smaller blocks spread out along or across the floodplain may be just as effective at flood attenuation, depending on location and overall extent (Nisbet and Thomas, 2008). Map 14 shows the distribution of small (2-50 ha) and large (>50 ha) areas of land in the region with potential for planting floodplain woodland.

4.3.2 Riparian zone

The close proximity between woodland and water in the riparian zone also makes this a very effective location for woodland planting to aid FRM, as well as to deliver other significant water benefits. A key attribute is the formation of large woody debris (LWD) dams from fallen trees and the input and collection of dead wood. These dams impede water flow and promote out of bank flows, increasing flood storage and delaying flood flows. Additionally, riparian woodland can buffer/reduce sediment delivery from the adjacent land and protect riverbanks, reducing downstream siltation and helping to maintain the flood storage capacity of river channels.

The riparian zone and therefore the potential to plant riparian woodland was defined as a 30 m wide area along both banks of the EA's Detailed River Network (Map 15). This width was selected as the zone most likely to interact with and provide woody debris to the river channel. The preference was to exclude sections of the river channel that were too wide (e.g. >5 m) to establish stable debris dams but unfortunately no data were available on river channel width.

4.3.3 Adjacent land

Woodland in the wider catchment can be most effective at reducing flood flows when targeted to soils that are prone to generating rapid runoff or the pathways along which water flows to streams. Such areas include naturally wet soils subject to seasonal waterlogging or surface ponding, and sensitive soils at risk of surface compaction and sealing. Following the removal of the listed constraints, the identification of priority locations for planting was based on an assessment of the hydrological properties of soils and the susceptibility of soils to structural degradation from agricultural use.

This drew on the following datasets:

- The Hydrology Of Soil Types (HOST) (Boorman *et al*., 1995)
- Standard Percentage Runoff (SPR) based on the HOST classification
- Revised SPR values derived from the study 'Impact of land use and management on flooding (Packman *et al*., 2004)'

These are described below:

HOST: The HOST system was developed to classify soils according to their hydrological behaviour (Map 16). HOST is a conceptual representation of the hydrological processes in the soil zone. All soil types (soil series) in the UK have been grouped into one of 29 hydrological response models or 'HOST classes'. Allocation to a HOST class is by a hierarchical classification. Soils are first allocated to one of three physical settings:

- a soil on a permeable substrate in which there is a deep aquifer or groundwater (i.e. at >2 m depth)
- a soil on permeable substrate in which there is normally a shallow water table (i.e. at <2 m depth)
- a soil (or soil and substrate) which contains an impermeable or semi-permeable layer <1 m from the surface.

Each physical setting is sub-divided into response models, which describe flow mechanisms and identify groups of soils that are expected to respond in the same way to rainfall. Finally there are sub-divisions of some of these models according to the rate of response and water storage within the soil profile.

SPR: Calibrated values of SPR for each HOST class were derived from multiple regressions between the proportion of each response model within a number of UK river catchments and the SPR values derived from river gauging data. The SPR represents the percentage of rainfall that contributes to quick response runoff. HOST classes with a SPR

>25% represent seasonally waterlogged and flashy soils that are likely to make a significant contribution to the generation of flood flows (Map 17).

Revised SPR values: A joint DEFRA/EA funded research programme reviewed the impacts of rural land use and management on flood generation. One output was a refinement of the Flood Estimation Handbook (FEH) rainfall-runoff model to account for the effects of soil degradation due to intensive agricultural practices. This involved reclassifying the SPR values for each HOST class by assigning an appropriate analogue HOST class to represent the degraded soil (Packman *et al*., 2004). The revised SPR values for the soils in the region are listed in Table 1. Soils considered to be most vulnerable to structural degradation-induced changes in SPR were brown earths (NATMAP vector codes 541, 542, 543, 571, 572, 581, 582) and brown sands (NATMAP vector codes 551, 553, 554) (Map 18).

A combination of SPR and sensitivity of soils to structural degradation datasets were used to classify soils in terms of their propensity to generate rapid runoff and thus to prioritise areas for woodland planting in the wider catchment to aid flood management (Table 2; Map 19).

4.3.4 Prioritising floodplain and riparian zone for woodland creation

Priority was given to planting within the floodplain (Flood Zone 2) and riparian zone abutting land classed as having a high propensity for generating rapid surface runoff (Map 20). These areas are favoured in view of their proximity to sources of flood generation and the expected greater potential for planting across the full width of the floodplain.

4.3.5 Combined map

Map 21 brings together the high priority areas for planting floodplain, riparian and wider woodland within the region to reduce downstream flood risk. The area of potential new floodplain woodland is also displayed in view of its relative importance for downstream flood mitigation.

It is important to note that in some locations planting could have the opposite outcome of increasing flood risk where the delaying effect of woodland synchronises, rather than desynchronises downstream flood peaks. This factor would need to be checked during the assessment of individual woodland planting applications.

HOST Class	Soil Series	Original SPR %	Amended SPR %	Area (km^2)	% of region	Physical Soil Description
0	Urban/water	-	-	186,323	8	Unclassified
1	571r	2.0	14	278	<1	Free draining over chalk
2	343abcd, 511a, 544, 571A	2.0	14	56,334	3	Free draining over limestone
3	541be, 511ab, 571df, 631be	14.5	27	142,391	7	Free draining over soft sandstone
4	313c, 541cdfilnpq	2.0	15	173,377	8	Free draining over consolidated rocks
5	511hi, 541ruwD, 551dg, 571A, 631f	14.5	27	142,537	7	Free draining over sands or gravel
6	541xyz, 571lpq	33.8	44	55,622	3	Unconsolidated, free draining over colluvium and loamy drift
7	542, 641c	44.3	44	24,235	1	Free draining over sands or gravel
8	532ab, 561abcd, 573a	44.3	44	49,378	2	Unconsolidated, free draining over colluvium and loamy drift
9	22, 811ce, 812c, 813bcde, 814ac, 831c, 851c	25.3	25	93,180	4	Unconsolidated, gleying <40 cm from surface
10	1011a, 372, 811a, 813a, 821b, 832, 861b, 872b	25.3	25	46,000	2	Unconsolidated, gleying <40 cm from surface
11	1022ab, 1024ab	2.0	2	10,040	<1	Drained peat
13	512a	2.0	15	3	<1	Impermeable layer within 100 cm
15	311c, 541o, 651a, 654b, 721a	48.4	48	14,929	1	Peat over permeable substrate
17	541aj, 611c	29.2	47	11,323	1	Impermeable – hard, no gleying within 100 cm
18	571b, 572abcgilmqt, 582c	47.2	59	247,969	12	Slowly permeable, gleying within 40 - 100 cm
19	611a			5,152	<1	
20	572h	60	60	9,322	<1	Impermeable (soft), gleying within 40 - 100 cm
21	92b, 411d, 421b, 431, 541h, 572def	47.2	60	204,966	10	Slowly permeable, gleying within 40-100 cm
22	313b	60.0	60	532	<1	Impermeable (hard), gleying within 40-100 cm
23	411abc	60	60	86,601	4	Impermeable (soft), gleying within 40-100 cm
24	711adcdklmnoqrt, 712afgi, 713acdefg, 714bc	39.7	49	479,264	22	Slowly permeable, gleying < 40cm from surface
25	711dg, 712b	49.6	60	86,684	4	Impermeable (soft), gleying < 40cm from surface
26	721bcde	58.7	59	11,776	1	Peat over slowly permeable substrate
29	311a, 1011b, 1013b	60.0	60	8,672	<1	Raw Peat

Table 1 The hydrological properties of the soils of the region

Priority for wider woodland planting	HOST original SPR value (%)	Sensitivity to structural degradation by land management based on revised SPR
Low priority	<25 <25	Low sensitivity Moderate sensitive
Medium priority	>25 >25 <25	Low sensitivity Moderate sensitive High sensitivity
High priority	>25 >50 >50 >50	High sensitivity Low sensitivity Moderate sensitive High sensitivity

Table 2 Classification of soils by their propensity to generate rapid surface runoff

4.4 Identification of suitable areas for woodland creation to reduce diffuse pollution

The mapping of woodland opportunities to address diffuse pollution in the region was based on EA WFD datasets and modelled assessments of pollution loads to watercourses from agricultural sources. Priority was given to land draining to failing river waterbodies RWBs) and groundwaterbodies (GWBs). Individual waterbody catchments are attributed with a unique identifier (EA_WB_ID), which allows the spatial data to be linked directly to other WFD data sources such as classification and typology, risks and pressures, designations, current status and proposed objectives. Some 612 of the 724 RWBs in the region currently (2011) fail to achieve GES, while 22 of the 60 GWBs have less than good water chemical status. Another 3 GWBs with good water quality are subject to a deteriorating trend in water chemistry.

Priority locations for woodland creation were considered to be land within failing waterbodies where the reason for failure had been identified as diffuse pollution, either through direct measurement or an assessment of risk. Attention was confined to those diffuse pollutants that could be potentially reduced by woodland planting, namely phosphate, nitrate, sediment and pesticides (Nisbet et al., 2011a). The identification of individual areas drew on the best available information on agricultural pollution sources and delivery pathways. Two assessment tools were used in the analysis: (i) the EA's land use change (LUC) model (EA, 2012) developed by Chris Burgess to quantify the risk of diffuse pollution from agriculture and (ii) the PSYCHIC model (Davison *et al.,* 2008) developed by ADAS to quantify the spatial distribution of sediment and phosphorus (both particulate and dissolved forms) losses to watercourses.

The application of these models is described below:

4.4.1 The EA LUC Model: Targeting land use change options to meet water quality objectives in English priority areas.

This model was developed to help identify where land use change may be a preferred option for tackling diffuse pollution pressures on the water environment. It assesses the relative risk of agricultural land contributing multiple diffuse pollutants (nutrients, sediment, pesticides and faecal indicator organisms) to waters. A GIS spatial assessment tool is used to determine the relative pressure for individual pollutants from every field in England, based on the equation:

$$P = Sc + Mc + Dc$$

where P represents the pressure, S the relative threat of the field acting as a pollution source dependant on land cover class (arable, permanent pasture, rough grazing or other), M the relative likelihood of pollutant mobilisation, D the risk of the pollutant reaching the watercourse and c a pressure specific constant. The scores per factor are normalised to a value between zero and one and then added together, ensuring equal weighting between factors. The approach allows individual fields to be ranked in terms of their relative contribution to each pollutant pressure but does not provide real values of pollutant losses.

The model represents a proof of concept and remains to be thoroughly tested. It is a relatively minimalistic, conceptual risk model that has simplified key factors and soil processes to enable a detailed spatial application to the field level across all of England. The model does not replace more quantitative process models and was essentially a one-off exercise to inform high-level discussion on the merits of targeting different land use change options for addressing diffuse pollution. In view of the differences in approach, it was decided to compare the pressure scores for sediment and phosphate with the respective pollutant loadings predicted by PSYCHIC (see below). To facilitate the comparison, it was first necessary to translate the field based pressure scores generated by the land use change model to the 1 km scale of the PSYCHIC model predictions.

Map 22a illustrates the modelled output for phosphorus (P), each data point representing the centre of an individual field; the histogram below the map illustrates how the pollutant source score for each of the four land cover classes has been modified by the relative mobilisation and delivery factors for each field. The point data were interpolated using an inverse distance weighting (IDW) to form a 1 km grid raster (Map 22b). Unfortunately, the EA LUC model only accounts for agricultural fields so that areas of semi-natural vegetation, woodland and urban centres are holes in the dataset. They are thus misrepresented by the interpolation process as having a pollutant source score equivalent to the agricultural fields around their perimeter, instead of one more akin to the combined value of the mobilisation (Map 23a) and delivery (Map 23b) scores. A 1 km grid raster of baseline pollutant supply from semi-natural vegetation (Map 23c) and a corresponding land cover mask based on a 1 km grid generalised land cover dataset

(Maps 24a-c) were therefore created. The output from the latter was then used to replace the values in the original IDW interpolated surface to create a P pressure score corrected for land use (Map 22c). The data values have no units but illustrate locations in the region with the greatest relative pressure from diffuse agricultural P. This process was repeated for all of the diffuse pollutants. Maps 25a & b and 26a & b illustrate the relative pressure from diffuse agricultural P and sediment pollution using the range of pollutant scores and these grouped into low, medium and high pressure classes. Maps 27a & b and 28a & b show the same for nitrate and pesticides.

4.4.2 PSYCHIC: Phosphorus and sediment yield characterisation in catchments.

PSYCHIC is a process-based model that is sensitive to land management practices which influence the mobilisation and delivery of sediment and P to waters. The model takes account of climate, landscape and land management factors (including crop type, livestock numbers and subsurface drainage), and utilises current knowledge of sediment and P export processes. A full description of the PSYCHIC model structure and its parameters is given by Davison et al. (2008). For this study we used an application of the PSYCHIC model based on the 2010 agricultural census data for England. This represents the best available estimate of current sediment and phosphorus losses to watercourses and updates the previous model application in 2002, which was used for the original river basin characterisation and risk assessment for preparing the first River Basin Management Plans.

The PSYCHIC model provides mean monthly losses of sediment and P to waters on a 1 km grid. The distribution of annual total sediment and P losses in kg/ha/yr across the region is illustrated in Maps 29a & b. Values were then regrouped into low, medium and high classes for the purpose of identifying priority areas for woodland creation (Maps 30 a & b). Thresholds of 0.5 kg/ha/yr and 1.0 kg/ha/yr were selected as class boundary thresholds for P based on the WFD phosphate concentration standards. Equivalent values for sediment were set at 250 kg/ha/yr and 500 kg/ha/yr for low-medium and medium-high class boundaries, respectively. A sediment delivery rate of 500 kg/ha/yr is used by the EA to define RWBs at risk from diffuse sediment pollution.

4.4.3 Comparison of EA LUC and PSYCHIC model outputs

A comparison of the spatial distribution of the relative pollution pressures for P and sediment reveals significant discrepancies between the two models, especially for sediment (Maps 31 & 32). The maps display the range of modelled values for each dataset in five classes of equal size (i.e. each class/colour represents 20% of the region). PSYCHIC values are less evenly distributed, with a distinct zone of highest pollutant pressures in the Teme and Wye catchments; in contrast the LUC model shows a more widespread scatter of local pollutant hotspots. The discrepancy is most marked in the Belvoir Vales of the Lower Trent and Erewash catchment, where the low pollutant loads predicted by PSYCHIC are in sharp contrast to the high scores generated by the LUC model.

Much more work is needed comparing the two datasets and explaining the differences. While the LUC model has the clear advantage of allowing multiple pollutant pressures to be mapped at the field scale, in view of the unexplained and significant discrepancies it was decided to rely on the more empirically based and intrinsically sensitive PSYCHIC model for mapping sediment and P pollutant pressures. However, the LUC model was retained for identifying both nitrate and pesticide pollutant pressures, although for consistency the interpolated 1 km dataset was used instead of the individual field scale data.

4.4.4 Identification of areas failing WFD due to diffuse pollution pressures

NITRATE

There is currently no environmental quality standard for nitrate in surface waters and thus it does not directly contribute to the assessment of river waterbody status. However, it remains a serious issue for drinking water supplies with much of England classified as a Nitrate Vulnerable Zone (NVZ). Consequently, nitrate is regularly monitored by the EA in both surface and groundwaters and the data used to identify RWBs at risk from diffuse nitrate pollution and GWBs failing good water quality. Map 33a shows the distribution of GWBs either failing the general quality assessment (GQA) or subject to a deteriorating trend in water quality, RWBs failing GES, and areas lying within surface water or groundwater NVZs. In the absence of more specific data on individual waterbodies failing due to diffuse nitrate, the identified GWBs and failing RWBs were selected as the areas at greatest risk (grey zone in Map 33b). The component 1 km grid squares predicted by the LUC model to exert the greatest nitrate pollution pressure defined the high priority area for woodland creation to address diffuse agricultural nitrate pollution.

PESTICIDES

Generally, pesticide concentrations found in surface waters from ‘normal agricultural use’ are insufficient to affect ecological status but they remain a very important concern for the protection of drinking water supplies. Robust standards are set for drinking waters and pesticide levels are monitored as part of the GQA for GWBs. As with nitrate, in the absence of more specific data to gauge which GWBs were failing due to pesticide use in agriculture, the area at greatest risk was defined as land draining to GWBs either failing the general quality assessment (GQA) or subject to a deteriorating trend in water quality (Map 34a). Similarly, those 1 km grid squares predicted to have the highest pressure scores were identified as the high priority area for woodland creation to address diffuse pesticide pollution (Map 34b).

PHOSPHORUS

Phosphate is a physico-chemical quality element that is directly measured in surface waters and contributes to the WFD assessment of ecological status by comparing with environmental quality standards set for catchment typology (EA, 2009). RWBs failing GES due to phosphate were selected as the main vulnerable area. In addition, those RWBs separately failing GES due to the condition of the diatom community were also included based on their sensitivity to phosphate pollution. Map 35a shows the distribution of these failing RWBs across the region and Map 35b the component 1 km grid squares predicted by PSYCHIC to have the highest phosphate losses to watercourses (>1 kg/ha/yr). The latter were defined as high priority areas for woodland creation to address diffuse P pollution from agriculture.

SEDIMENT

Environmental standards remain undefined for sediment and this element is not included in the WFD assessment of GES for surface waterbodies. Instead the EA's catchment characterisation datasets were used to define the vulnerable area, which was considered to be those RWBs classed as being at moderate or high risk from diffuse sediment pollution (Map 36a). The 1 km grid squares predicted by PSYCHIC to have the highest sediment losses (>500 kg/ha/yr) were selected as the high priority areas for woodland creation to address diffuse sediment pollution from agriculture (Map 36b).

GROUNDWATER RESOURCE PROTECTION

Groundwater Source Protection Zones (GWSPZs) have been established by the EA to highlight the vulnerability of local water supplies and to help manage activities that could have a detrimental impact. Woodland creation could be particularly beneficial for reducing nitrate and pesticide pollutant pressures within these zones, especially the most vulnerable Inner Protection Zones. Map 37 illustrates the distribution of 1 km grid squares with the highest predicted nitrate and pesticide pressure scores in relation to Inner and Outer GWSPZs and GWBs either failing the general quality assessment (GQA) or subject to a deteriorating trend in water quality. Those sources known to be failing or at risk of failing good water quality due to diffuse agricultural pollution could be targeted for planting. The same approach could be applied to Drinking Water Protection Zones and Surface Water Safeguard Zones but these data were not available at the time.

MULTIPLE POLLUTANTS

The high priority areas identified for woodland creation to help reduce each of the four individual pollutants (phosphate, sediment, nitrate and pesticides) are combined in Map 38 to show opportunities for land use change to tackle multiple (up to four) diffuse pollutants. Sensitivities are also shown.

COMBINED PRESSURES

Map 39 shows the distribution of the high priority areas for woodland creation for FRM in relation to those for reducing one or more diffuse pollutant pressures to groundwater or surface waters. The degree of overlap between the two is displayed in Map 40, along with mapped sensitivities.

4.5 Identification of areas where changes to the design and management of existing woodland could benefit FRM and WFD

Forestry and conifer plantations in particular can exert a number of pressures on the water environment. Some of these need to be addressed through changes to forest design and management at the catchment scale, including the potential for clearfelling and restocking to increase surface water acidification, and the risk of clearfelling contributing to higher peak flows and promoting nutrient release. Others require action at the local scale, such as the need to improve bankside morphology and riparian habitat by clearing back conifer crops from streamsides. The FC's Forests and Water Guidelines (F&WG; FC, 2011) describe a range of measures to address these issues. The following maps were developed to aid targeting of the measures:

Map 41 – river waterbodies failing GES due to acidification. The F&WGs place restrictions on the extent of new planting, restocking and felling of both conifer and broadleaved woodland within surface waterbodies that are failing or at risk of failing GES due to acidification. Work is ongoing to revise the methodology for addressing new planting and restocking but the method for felling is largely agreed. This requires that no more than 20% of the catchment of individual permanent watercourses (deminimus of 100 ha) within failing waterbodies is to be felled within any three-year period. To facilitate this assessment a 50 m Digital Terrain Model (DTM) was used to define boundaries for the catchments of all component permanent watercourses (>100 ha in area) and the extent of forest cover within these determined from the National Forest Inventory (NFI). Map 41 shows the distribution of failing RWBs with >20% woodland cover in tributary catchments; those with >20% conifer cover are more likely to pose an issue due to shorter rotations and larger scale of felling. These locations merit closer attention to determine whether the planned timing of felling (based on forest plans) is likely to breach the threshold rate and thus require amending.

Map 42 – river waterbodies with sub-catchments with >20% woodland cover. The F&WGs also recommend the application of a 20% threshold on the extent of clearfelling in any three-year period to control the potential impact on peak flows and phosphate runoff within vulnerable areas. This map shows the location of sub-catchments with >20% woodland cover in relation to potential vulnerable areas, derived using the 50 m DTM and NFI, as described above. Once again, the likelihood of clearfelling breaching the 20% threshold will be greatest for conifers.

Map 43 – watercourses with existing conifer forest within 20 m of bankside. The F&WGs recommended that conifers should be cleared from streamsides to create a riparian native woodland buffer zone when access allows. This work is likely to be programmed within existing forest plans but the map provides a check showing the remaining areas that require attention. Early clearance is recommended within RWBs vulnerable to acidification to promote ecological recovery.

Map 44 – waterbodies potentially at risk from the higher water use by trees. The F&WGs recommend avoiding large scale conifer planting in areas where the water supply is being, or is planned to be, fully exploited or in catchments which fail to sustain adequate environmental flows. This map identifies the areas at greatest risk in terms of GWBs that are failing WFD objectives due to poor quantitative status plus RWBs failing GES due to inadequate flows. Also shown is the extent and distribution of sub-catchments with >20% woodland cover, where the impact of existing forestry is likely to be greatest (greatest for conifer).

5. Results

Calculated values for the extent and distribution of priority areas for woodland creation to tackle downstream flooding and selected diffuse pollutant pressures across a wide range of water strategy and project areas are provided in Appendix 2. A selection of these values are included in this Section to highlight key opportunities for woodland planting to benefit water in the Midlands Region.

5.1 Constraints and sensitivities to woodland creation

A total of 6,373 km^2 or 30% of the region is excluded from woodland planting due to the constraints listed in Section 5.2. In addition to the constraints, a further 4,774 km^2 or 22% of the region is subject to sensitivities that may restrict the scale and character of any woodland creation. Details of the individual constraints and sensitivities are listed in Table 3.

Urban infrastructure and the road and rail network represent the dominant constraints, responsible for 69% of the total area excluded; the largest urban area being Birmingham, followed by the major towns and cities of Stoke-on-Trent, Derby, Nottingham, Leicester, and Coventry. The other main constraint is existing woodland (NFI dataset), occupying nearly 2,000 km^2 or 9% of the region.

Around 33% of the region is identified as potentially sensitive to woodland creation, the dominant features being culturally important landscapes, national and international conservation designations, and undesignated BAP habitats. Some 15% of the region lies within Areas of Outstanding National Beauty and the Peak District National Park. These support woodland creation but influence the scale, type and design of any planting. For example, the 'Landscape Strategy and Action Plan for the Peak District National Park' identifies a need for woodland creation to enhance priority woodland habitats and strengthen the existing landscape character.

Potential constraint or sensitivity	Area (km^2)	% of region or fluvial floodplain
Urban infrastructure	**2,576 km^2** ***Floodplain buffer – 791 km^2***	**12%** ***56% of floodplain***
Road and rail network	**2,934 km^2** ***Rural road floodplain buffer – 476 km^2***	**14%** ***34% of floodplain***
Sites of Antiquity [SAM, WHS]	**124 km^2**	**0.6%**
MOD land and civil airports	**86 km^2**	**0.4%**
Open Water	**62 km^2**	**0.3%**
Existing Woodland	**1,965 km^2**	**9%**
International conservation designations [RAMSAR, SPA, SAC]	488 km^2	2%
National conservation designations [SSSI, NNR, RSPB reserves]	666 km^2	3%
Protected and culturally important landscapes [AONB, National Parks, Common land, Battlefield and Historic Parks & Gardens]	3,163 km^2	15%
Grade 1 agricultural land	259 km^2	1%
Land above the natural treeline	108 km^2	0.5%
EA washlands	13 km^2	0.06%
Deep Peat	358 km^2	1.6%
Riparian buffer along Main Rivers	235 km^2	1%
Undesignated BAP Habitats	974 km^2	5%
Total area of all constraints for which spatial data is available *Across the fluvial floodplain*	6,373 km^2 *622 km^2*	30% *44% of floodplain*
Total area of all sensitivities for which spatial data is available	7,058 km^2	33%

Table 3 Constraints (in bold) and sensitivities to woodland planting in the region (note that some of the features overlap)

In terms of the fluvial floodplain, a total of 622 km^2 or 44% of Flood Zone 2 (area at risk from a 1 in 1000 year flood event) is excluded from woodland planting due to constraints, primarily urban and transport infrastructure (Table 3). Only 134 km^2 or 9.5% is covered by woodland, which is mainly broadleaved. The buffer zone applied to urban areas and roads represents a major and dominant sensitivity, covering 1,219 km^2

or 86% of Flood Zone 2. This indicates that most planting proposals within the floodplain are likely to require detailed consideration of the impact of the backing-up of flood waters on local buildings and transport, which is likely to influence the scale and nature of planting. Another significant factor affecting the scope for new floodplain woodland is the potential restriction on planting close to Main Rivers, with a total area of 235 km^2 of land lying within the riparian buffer sensitivity.

5.2 Opportunities for woodland creation to reduce downstream flood risk

A total of 5,189 km^2 or 24% of the region is identified as a priority area for woodland creation to reduce downstream flood risk (Map 21). This land mainly comprises the heavy clay soils in the Belvoir and Severn & Avon Vale and the wet surface water gleys of Shropshire, Staffordshire and Leicestershire (Maps 2 & 4). Most is intensively farmed and covered by a mosaic of arable fields and improved grassland (Map 5). About a quarter or 1,304 km^2 is affected by sensitivities. Around 2,604 km^2 falls within the River Trent catchment, of which 318 km^2 comprises priority riparian woodland, 88 km^2 priority floodplain woodland and 2,198 km^2 priority wider woodland. This compares to 2,516 km^2 in the River Severn catchment and 295 km^2, 123 km^2 and 2,098 km^2 of priority riparian, floodplain and wider woodland, respectively.

Map 45 shows the distribution of priority land in relation to CFMPs. The region is covered by four CFMPs: River Trent, River Severn, Severn Tidal Tributaries and the Wye and Usk. These identify the preferred approach to FRM within individual sub areas or policy units in each river catchment. Extensive opportunities exist for planting priority woodland within three of the six policy units: areas of low to moderate flood risk under effective management (Policy 3); areas of low to high risk under threat from climate change (Policy 4); and areas of low to moderate risk with potential for improved management through increased water storage or better runoff management (Policy 6). There appears to be limited scope for planting in areas identified at moderate to high flood risk requiring additional investment in flood protection (Policy 5).

A breakdown of the extent of priority land and the type of woodland within the different policy units is provided in Table 4. Opportunities within the River Trent CFMP are greatest in three Policy 6 units (Rural Leicester – 855 km^2; Peaks & Moorlands - 550 km^2 and Mid Staffs & Lower Tame - 371 km^2). These include a total area of 63 km^2 of priority floodplain woodland, 234 km^2 riparian woodland and 1,478 km^2 wider woodland. Opportunities within the River Seven CFMP are greatest within the Policy 6 unit of the Upper Avon (436 km^2), with 19 km^2 of priority floodplain woodland, 45 km^2 riparian woodland and 371 km^2 wider woodland.

Woodland actions have already been implemented or are planned in a number of policy units to promote sustainable flood risk management (Map 46). The majority fall within Policy 3 areas, where there is greater scope to create green corridors along watercourses and naturalise river processes. Extensive areas of priority land lie within a cluster of four Policy 3 units in the middle Avon catchment, comprising a total of 1,475 ha of priority floodplain woodland and 4,967 ha of priority riparian woodland. Woodland actions have also been identified within the Policy 6 unit of the Upper Avon, where there is plenty of scope to plant on priority land (see above). The ambition in these areas is to encourage land owners to consider changes in land use and/or management that will slow flood flows and restore natural flood attenuation processes.

EA Catchment Flood Management Plan – Policy unit	Preferred FRM Policy[1]	Area (ha)	Area of potential new floodplain woodland (ha)	Extent of opportunities for woodland creation		
				PNFW –	PNRW –	PNWW –
River Trent Catchment Flood Management Plan						
Axholme and N W Lincolnshire	4	75,230	354	86	1,689	11,622
Sherwood[2]	3	117,623	4,868	267	1,820	14,790
Peaks and Moorlands	**6**	**185,887**	**4,462**	**1,303**	**9,722**	**44,003**
Shelford to Gainsborough	4	73,191	9,335	934	2,174	18,290
Burton, Derby and Nottingham	5	63,891	8,977	176	647	5,512
Mid Staffs and Lower Tame	**6**	**149,044**	**15,072**	**1,747**	**4,398**	**30,942**
West Staffs	4	93,488	3,751	804	2,439	18,009
Rural Leicestershire	**6**	**163,150**	**8,546**	**3,284**	**9,308**	**72,870**
Upper Soar and Upper Anker	4	54,552	4,130	712	1,575	12,090
Birmingham and Black Country	5	56,911	926	114	298	2,175
River Severn Catchment Flood Management Plan						
Severn and Vyrnwy Uplands	**6**	**4,046**	**0**	**0**	**301**	**1,610**
Severn Vyrnwy Confluence	**6**	**12,522**	**701**	**118**	**533**	**3,238**
Severn Vale	3	21,206	259	154	889	4,424
North Shropshire Tributaries	2	106,776	5,961	1,538	3,086	25,923
South Shropshire Tributaries	2	37,418	915	424	2,521	13,971
Middle Severn Corridor	4	77,464	4,886	352	858	7,338
Telford and Black Country	5	61,536	1,109	253	728	6,458
Coventry Cluster	5	34,630	1,546	163	586	5,532
Kidderminster and Bromsgrove	5	33,101	936	204	424	3,206
Lower Severn Corridor	2	33,420	3,783	840	1,278	8,566

EA Catchment Flood Management Plan – Policy unit	Preferred FRM Policy[1]	Area (ha)	Area of potential new floodplain woodland (ha)	Extent of opportunities for woodland creation		
				PNFW –	PNRW –	PNWW –
Leadon	2	32,640	1,752	371	580	3,020
Upper Avon	**6**	**62,722**	**2,770**	**1,937**	**4,546**	**37,100**
Middle Avon	3	11,424	1,712	180	288	3,128
River Arrow and River Alne	3	23,354	1,048	603	1,111	9,066
Redditch	3	17,233	379	189	849	5,673
Rugby	3	8,353	555	354	444	2,883
Teme	3	146,736	6,392	370	2,303	12,612
Tewkesbury	5	2,990	510	257	156	916
Severn Tidal Tributaries & Wye and Usk Catchment Flood Management Plans						
Cheltenham and NE Gloucester	5	17,571	1,101	557	934	4,686
Avon Tributaries	3	121,535	7,265	3,873	7,163	56,395
Lower Wye	**6**	**151,630**	**10,086**	**565**	**899**	**4,861**

Table 4 Extent and distribution of priority land for woodland planting for Flood Risk Management within the key Catchment Flood Management Plan (CFMP) Policy units.

PNFW_priority new floodplain woodland

PNRW_priority new riparian woodland

PNWW_priority new wider woodland

[1]CFMP Policy units in bold are Policy 6, where the focus is on storing flood water or managing runoff to reduce flood risk.

[2]CFMP Policy units shaded green have existing flood management initiatives which include an element of woodland creation and/or management (including the use of LWD).

5.3 Opportunities for woodland creation to reduce diffuse pollution

Maps 37 and 38 show that there are extensive opportunities across the region for woodland creation to reduce diffuse pollution pressures on the water environment. A total of 4,670 km^2 or 22% comprises high priority land for planting to reduce one or more diffuse pollutants. Opportunities to tackle multiple pollutants and failing groundwaters are concentrated in the north and west of the region, especially within the Idle & Tone WFD management catchment in the Trent, and the Herefordshire Wye, Worcestershire Middle Severn, Shropshire Middle Severn and Severn Uplands catchments in the Severn. High priority land occupies around 3,064 km^2 or 14% of failing groundwaters, including 283 ha and 3,320 ha within component Inner and Outer GWSPZs, respectively.

Table 5 gives a breakdown of the extent of high priority land within individual WFD management catchments. The catchments with the largest areas of priority land comprise the Lower Trent & Erewash (719 km^2) in the River Trent system and the Wye

(611 km^2) and Warwickshire Avon (571 km^2) in the Severn. However, in terms of percentage areas, the greatest opportunities for larger scale planting (priority area >30% of catchment) lie within the Witham (43%) and Lower Trent & Erewash (31%) catchments in the Trent, and Middle Dee (57%), Wye (33%) and Shropshire Middle Severn (32%) in the Severn. For groundwater protection, the opportunities are greatest both in terms of area and percentage cover within the Idle & Tome (158 km^2, 12%) and Shropshire Middle Severn (100 km^2, 9%) catchments.

EA WFD management catchment	Area (ha)	Area (ha) classed as high priority for woodland planting	
		to reduce one or more diffuse pollutants	to protect groundwater resource[1]
Derbyshire Derwent - EA Pilot	120,423	19,945 [17%]	464 [0.4%]
Dove – WCI	101,671	14,615 [14%]	1,191 [1.2%]
Idle & Torne - WCI	132,600	38,449 [29%]	15,799 [11.9%]
Lower Trent & Erewash - WCI	231,800	71,892 [31%]	5,725 [2.5%]
Middle Dee	2,758	1,582 [57%]	0
Severn Uplands - WCI	138,626	19,154 [14%]	2,084 [1.5%]
Severn Vale - WCI	145,696	12,481 [9%]	280 [0.2%]
Shropshire Middle Severn - WCI	110,772	35,040 [32%]	10,009 [9.0%]
Soar	138,625	34,067 [25%]	76 [0.1%]
Staffordshire Trent Valley - WCI	134,447	24,237 [18%]	2,616 [1.9%]
Tame Anker and Mease – DEFRA Pilot	179,440	30,893 [17%]	3,876 [2.2%]
Teme - DEFRA Pilot	152,923	20,671 [14%]	0
Upper Dee	4,232	1,236 [29%]	0
Warwickshire Avon - EA Pilot	287,322	57,112 [20%]	1,642 [0.6%]
Witham	1,569	674 [43%]	0
Worcestershire Middle Severn - WCI	151,114	23,858 [16%]	9,811 [6.5%]
Wye - WCI & Keeping Rivers Cool Pilot	184,812	61,078 [33%]	1,150 [0.6%]

Table 5 Extent and distribution of high priority land for planting to reduce one or more diffuse pollution pressures within the EA WFD management catchments. WCI: Wider Catchment Initiative.

[1]The land identified for the protection of the groundwater resource is a subset of the area quoted in the column to left and refers only to diffuse nitrate and/or pesticide pollution

Details of the extent of high priority areas for woodland creation to reduce multiple diffuse pollution pressures within CSFDI Priority Catchments are given in Table 6. Opportunities for addressing 2, 3 or 4 pollutants all tend to be greatest within the River Wye (Herefordshire), Lugg and Teme catchments, while there is also a significant priority area that could help reduce three diffuse pollutants in the Worfe catchment. The majority of these areas are clear of sensitivities (see Appendix 2), increasing the potential for significant planting if landowners could be persuaded to integrate more woodland into their farm units.

CSF Initiative Priority Catchments	Area (ha) classed as high priority for woodland creation to reduce one or more diffuse pollution pressures			
	Number of diffuse pollution pressures			
	1	2	3	4
Peak District Dales	5,833	1,280		
River Eye	4,764	95		
River Leadon	3,721	1,517	315	
River Lugg	13,103	12,881	5,102	965
River Mease	4,150	1,833	152	0
River Perry	1,618	2,163	347	91
River Roden	5,142	3,625	332	93
River Teme	19,617	1,112	31	0
River Tern	5,293	6,733	4,604	501
River Worfe	1,132	2,290	4,634	0
River Wye	15,137	10,120	2,708	2,530
West Midlands Meres and Mosses	1,815	1,113	595	81

Table 6 Extent and distribution of high priority areas for woodland creation to reduce multiple diffuse pollution pressures within CSFDI Priority Catchments.

5.4 Consideration of opportunities in relation to existing regional strategies, projects and plans

There is a wide range of existing land use and land management based strategies, projects and plans within the region that are relevant to woodland creation and its role in helping to reduce flood risk and improve water quality. The boundaries of these are displayed in Map 46 and include FC priority areas for planting to improve biodiversity, FRM and/or WFD; EA/NE CSFDI priority catchments to reduce diffuse pollution; EA and Defra pilot/demonstration catchments to test the effectiveness of farm measures to reduce diffuse pollution and/or flood risk; Defra Nature Improvement Areas; and a number of local projects and initiatives aimed at improving the water environment. Some areas are overlapping but together cover most of the region, with the main exceptions being parts of the lower (Lower Trent & Erewash) and middle (Soar and lower Dove) catchment of the River Trent, and a relatively small area in the lower part of Severn Vale.

The identified priority areas for woodland creation to benefit water are considered in relation to a number of the existing initiatives below; linkage to CSFDI Priority Catchments and CFMPs already been covered above in Sections 6.2 and 6.3.

5.4.1 FC Regional Forestry Strategies

There are two FC Regional Forestry Strategies covering the Midlands Region; East and West Midlands. These were formulated to show how the region could help deliver the Government's strategy for England's Trees, Woods and Forests (2007), including an expansion of woodland cover for multiple benefits. The strategies led to the development of regional targets and mapping to identify opportunities for woodland creation.

The West Midlands Strategy was guided by the West Midlands Woodland Opportunity Mapping (WMWOM) exercise, which characterised the region in terms of priority areas for planting to deliver landscape, biodiversity, cultural heritage and access benefits. For biodiversity, specific targets were set for the restoration (4,750 ha) and expansion (5,479 ha) of UK Biodiversity Action Plan (BAP) woodland habitats by 2015 (Table 7).

Priority BAP Habitat Type	**Target**		
	Protection	**Restoration**	**Re-creation**
Upland oakwood	Maintain all	450 ha by 2010	350 ha by 2010
Upland mixed ashwood	Maintain all	250 ha by 2015	35 ha by 2015
Wet woodland	Maintain all	25 ha by 2015	370 ha by 2015
Lowland oak and mixed deciduous woodland	Maintain all	1,700 ha by 2020	1,700 ha by 2020

From http://www.wmbp.org/strategy_and_targets

Table 7 Targets for the protection, restoration and re-creation of woodland BAP habitats in the West Midlands

The WMWOM priority areas were compared with those for water derived from the present project to establish potential synergies and highlight sensitive areas to avoid (Figure 1). There is significant overlap between the two priority areas, with much of the priority land for water classed as 'Preferred' or 'Neutral' for biodiversity'. This includes northern parts of the Warwickshire Avon catchment and the southwest of the Staffordshire and Trent Valley catchment. Conflict is more likely to arise in the relatively small areas of overlap with land classed as 'Sensitive for Cultural Heritage', 'Preferred for Landscape', or 'Sensitive for Biodiversity'.

The East Midlands Strategy is less supported by mapping data. A separate Biodiversity Strategy includes a number of objectives and actions aimed at enhancing the character and quality of the region's environment (Tables 8 & 9). This adopts a landscape scale approach to woodland planning, although there are no spatially explicit targets for the restoration or expansion of woodland priority habitats.

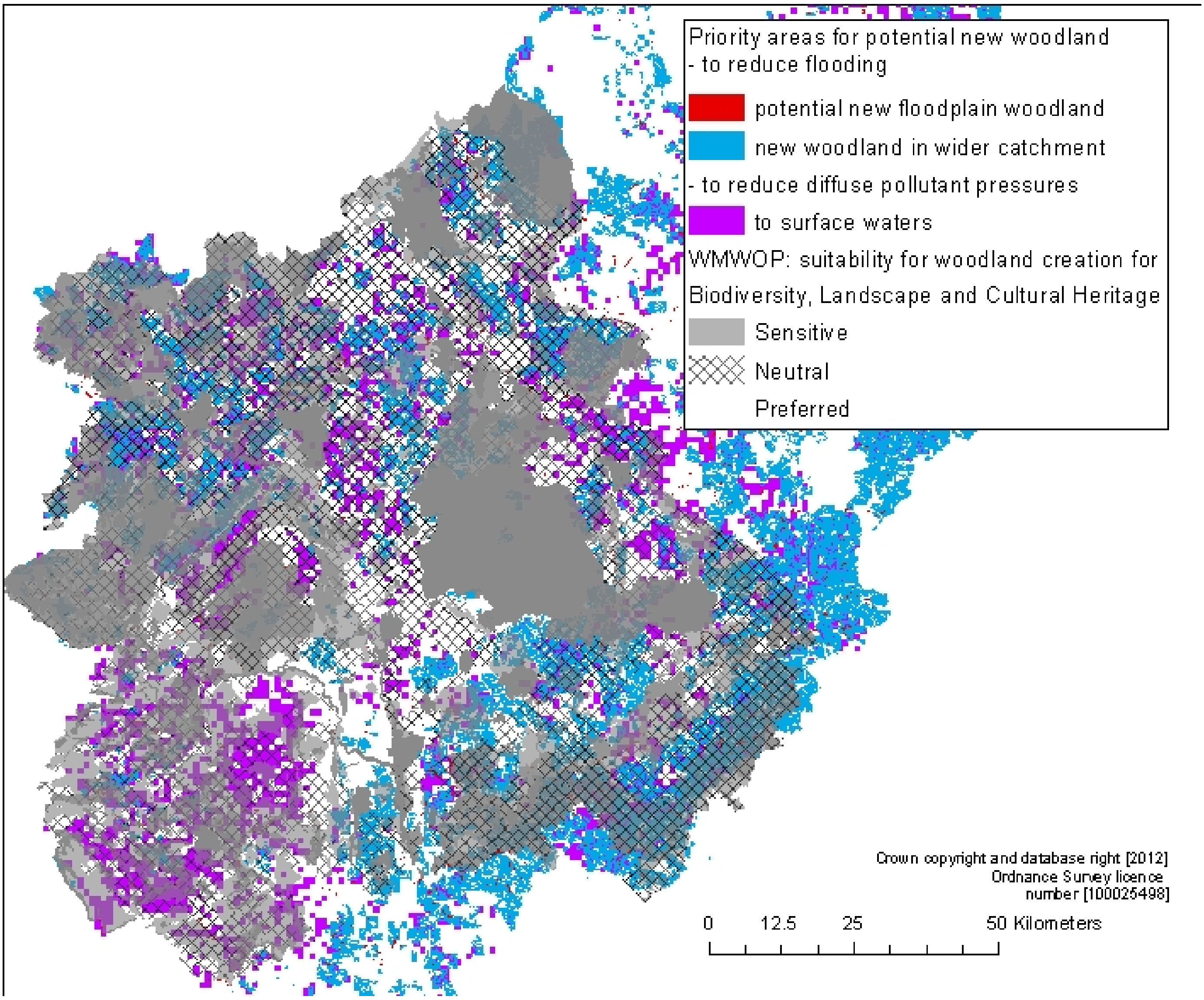

Figure 1 Opportunities for woodland creation to meet FRM and WFD objectives in the preferred areas for woodland creation identified in the West Midlands Woodland Opportunities Map in the Regional Forestry Framework

The forest strategies have led to a number of local project initiatives to promote woodland creation. Two of these are located in Nottinghamshire: the Sherwood Forest Project, which aims to restore the traditional landscapes and habitats of the ancient hunting forest; and the Greenwood Community Forest Project, aimed at creating an extensive woodland network of environmental regeneration sites and community green spaces, including through reclamation of disused colliery sites.

Action required to meet objective	Outcome desired	Target	Timescale
Support initiatives to conserve and expand East Midlands' priority woodland habitats and species populations. Encourage the restructuring of woodland plantations where the restoration of other national priority habitats is sustainable at a landscape scale.	Halt and reverse the decline in the priority woodland habitats; and the species populations, as identified by the England Woodland Biodiversity Group's priority target species list		2020
Promote the role of new woodland and associated habitats on the floodplain as part of CFMPs and the regeneration of strategic river corridors.	Recognition of the benefits of woodland in enhancing river catchments	Creation of new floodplain woodland and associated habitats	Ongoing

Table 8 Regional targets for BAP woodland habitats in the East Midlands Biodiversity Strategy

Priority BAP Habitat Type	Management, Restoration & Creation	Woodland Creation		Prioritised Natural Areas*
	by 2015 (ha)	by 2015 (ha)	2016 – 2020 (ha)	
Broadleaved woodland inc. all priority woodland habitats	100% ASNW, 60% Other	5400	3000	All
Lime woods	1200	100	50	Lincolnshire Wolds
Wet Woodland	2500	440	1132	Fens, Lincolnshire Coast & Marshes, Trent Valley & West Anglian Plain
Upland mixed ash woods	2000	75	100	White Peak
Upland oak woodland	1500	400	600	Dark Peak & SW Peak

From www.embiodiversity.org.uk/.../documents/revised-regional-habitat-targets-sept-2006.pdf

Table 9 Targets for the protection, restoration and re-creation of woodland BAP habitats in the East Midlands (ASNW: Ancient Semi-Natural Woodland)

There are two older (2005-6) FC 'JIGSAW' projects, the Lincolnshire Lime Woods and the Leicestershire Leighfield Forest. They were designed to link-up and buffer remaining fragments of ancient woodland sites, and promote their collective management as a resource for rural enterprise, public access and environmental education. Other initiatives are aimed at converting non-native conifer plantations back to ancient woodland, such as the 7,000 ha Ancient Woodlands Project in Northamptonshire.

All of the above project areas overlap to varying degrees with the identified priority land for woodland creation for water, providing opportunities to maximise multiple benefits.

5.4.2 The National Forest

The National Forest extends over a 200 square mile area in Leicestershire and Derbyshire, with a target to increase woodland cover from 6% to 30%. Figure 2 shows that there is plenty of scope for guiding planting to deliver water benefits, including for both FRM and WFD.

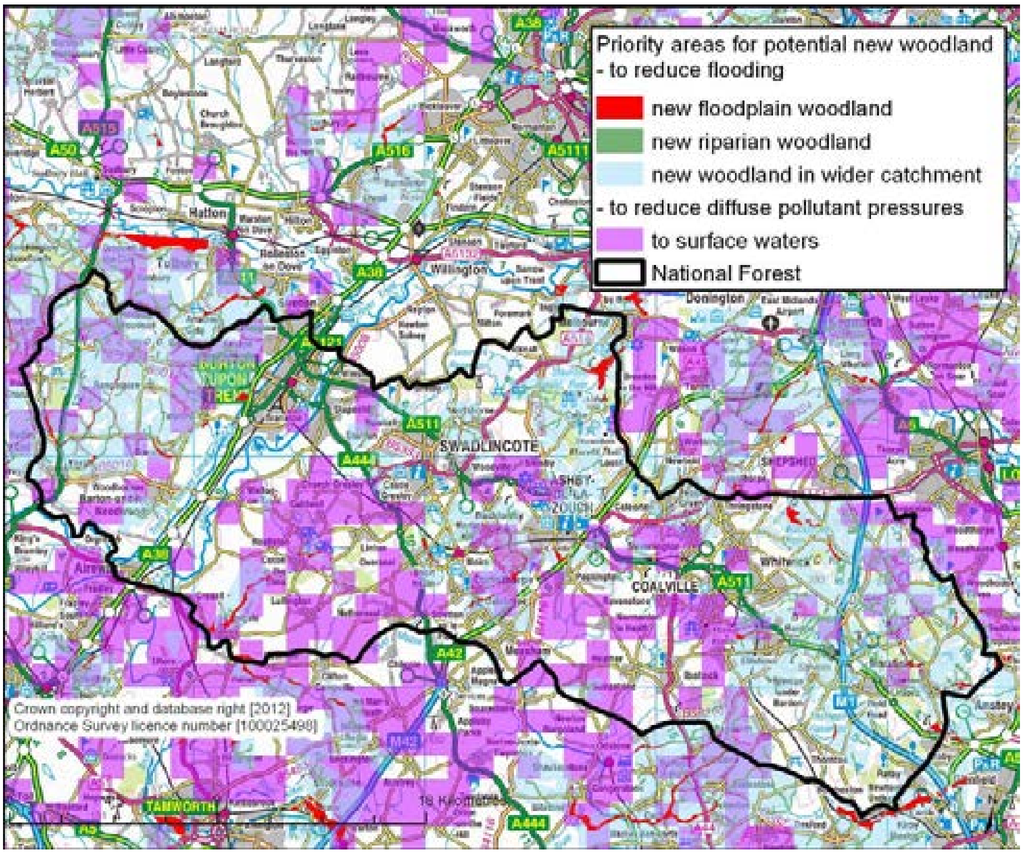

Figure 2 Opportunities for woodland creation to meet FRM and WFD objectives within the National Forest

There are opportunities to plant 101 km^2 of priority wider woodland, 963 ha riparian woodland and 137 ha of floodplain woodland to reduce flood risk, as well as 1,145 ha and 267 ha of land to tackle two and three diffuse pollutants, respectively, all of which is free of sensitivities (Appendix 2).

5.4.3 The Derwent Land Management, Clough woodlands and Dark Peak NIA projects

The Derwent Land Management Project (DLMP) seeks to deliver FRM and WFD benefits from land management changes in the Derwent valley, including the creation of riparian buffer strips and the construction of LWD dams. Figure 3 shows that there is significant scope for woodland creation to contribute to these objectives, with 181 km^2 of priority wider woodland, 43 km^2 of riparian woodland and 535 ha of floodplain woodland (Appendix 2).

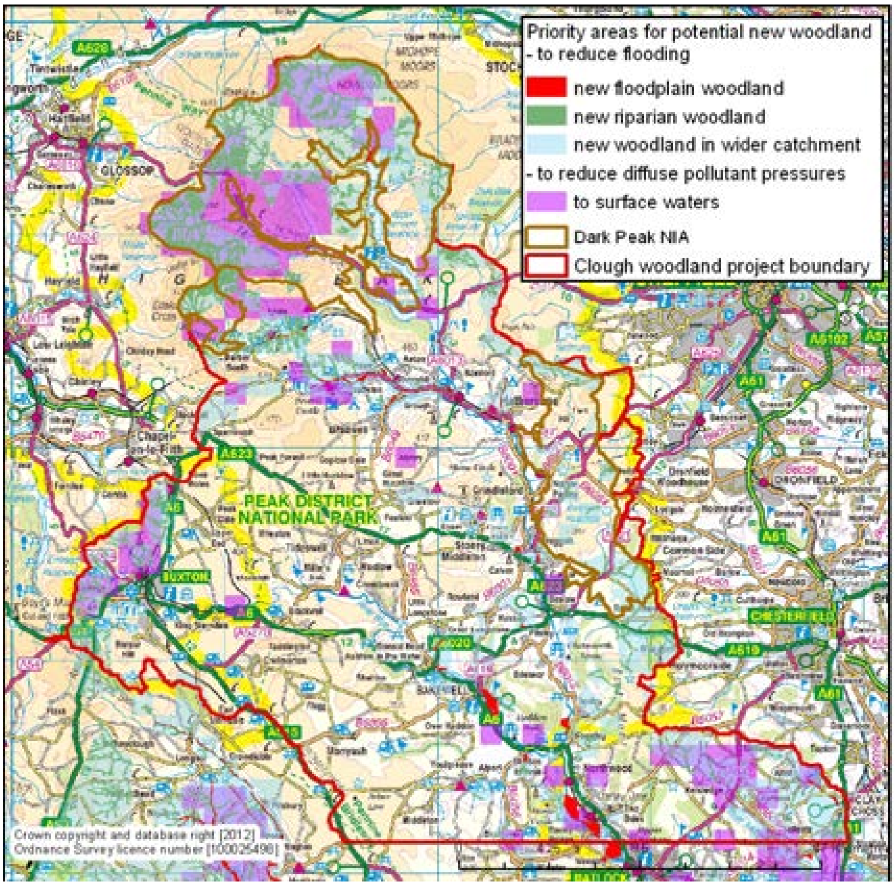

Figure 3 Opportunities for woodland creation to meet FRM and WFD objectives in the Upper Derwent Land Management Project area, Clough woodlands project area and Dark Peak Nature Improvement Area

There are also extensive areas of high priority land to reduce diffuse pollution (177 km^2 of land that could help tackle one or more diffuse pollutants and 355 ha involving 4 diffuse pollutants) and a total of 88 km^2 that would deliver both FRM and WFD benefits. Much of the priority land is affected by sensitivities, including extended stretches of Main River. These do not necessarily preclude woodland creation and some actively support appropriate planting to enhance priority habitats and landscape character, such as within the Peak District National Park. The EA hope to install monitoring equipment to quantify the effect of new woodland on flood flows; hydrological consultants are presently investigating potential sites at Burbage, to the east of Buxton and Baslow.

The DLMP area also includes the Clough Woodlands Project and the Dark Peak Nature Improvement Area, both of which contain significant priority land where woodland could deliver FRM and/or WFD benefits (Figure 3). The Clough woodland project aims to scope the potential to establish 800 ha of new native woodland on the steep slopes of the High Peak by 2013. The Dark Peak NIA is focused on sustainable moorland management, including enhancing and protecting core areas of blanket bog habitat. The restoration of 2,100 ha of heathland and 200 ha of new native woodland will form buffers along the bog edge and act as ecological corridors between the existing wildlife sites of the moors and surrounding farmland to create a dynamic, landscape scale habitat mosaic.

5.4.4 DerwentWISE and Ecclesbourne catchment projects

DerwentWISE is a landscape and heritage restoration project in the lower Derwent valley, funded by the Heritage Lottery Fund. It is led by Derbyshire Wildlife Trust, which, if the phase 2 bid is successful, will receive £2.1million to deliver the project. Key elements of the landscape restoration include management of existing woodlands, meadow restoration and potentially woodland creation. Derbyshire Wildlife Trust are also delivering 'The Big Tree Plant' initiative in which community groups are encouraged to collect and propagate seeds from local veteran trees and replant these. Project partners have made land available for planting the saplings: the Haddon Estate, the National Trust at Hardwick and Kedleston, the RSPB on its reserve at Dovestone, and Severn Trent Water at Carsington Water.

Unfortunately, opportunities for woodland creation to benefit water are limited in the project area, mainly due to the extent of the World Heritage Site. However, while this has been viewed as a constraint there are likely to be opportunities for small-scale woodland planting to help restore the landscape character of the site particulary outside the core area. There is much greater scope in the adjacent Ecclesbourne catchment, where 2,019 ha of high priority land are potentially available for planting to both reduce flood risk and diffuse pollution pressures (Figure 4). The Ecclesbourne is the location for an EA WFD pilot catchment restoration project designed to understand how water quality improvements can be delivered through a collaborative approach. This involves working with land owners and farmers to implement a range of land management measures to control diffuse pollution.

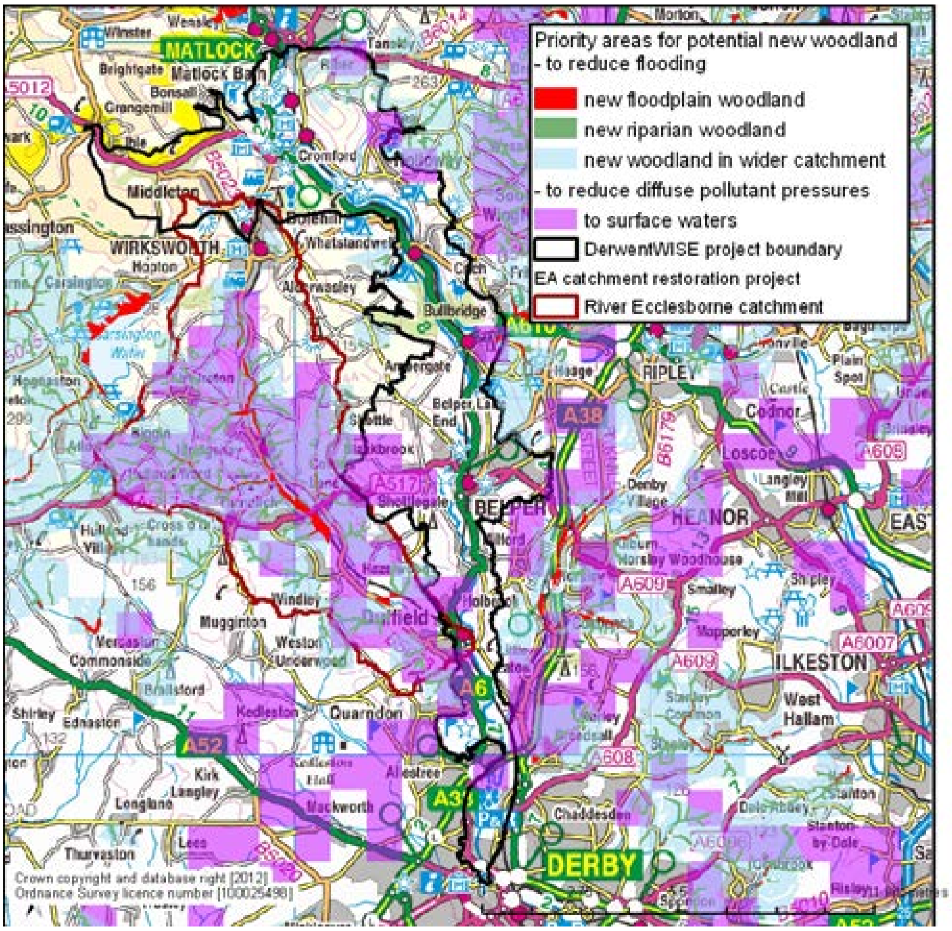

Figure 4 Opportunities for woodland creation to meet FRM and WFD objectives in the DerwentWISE project area and the River Ecclesbourne restoration catchment

5.4.5 Upper Fleet partnership catchment

The Upper Fleet is the location of another EA catchment restoration project to address diffuse pollution. There is considerable potential for woodland creation to assist by expanding woodland cover from its existing very low base (3%). Almost half of the catchment (1,065 ha) is identified as high priority land to reduce diffuse nitrate pollution, the majority of which is unaffected by sensitivities (Figure 5). There are also opportunities to plant up to 640 ha of priority wider woodland and 77 ha of priority riparian woodland to help reduce downstream flood risk.

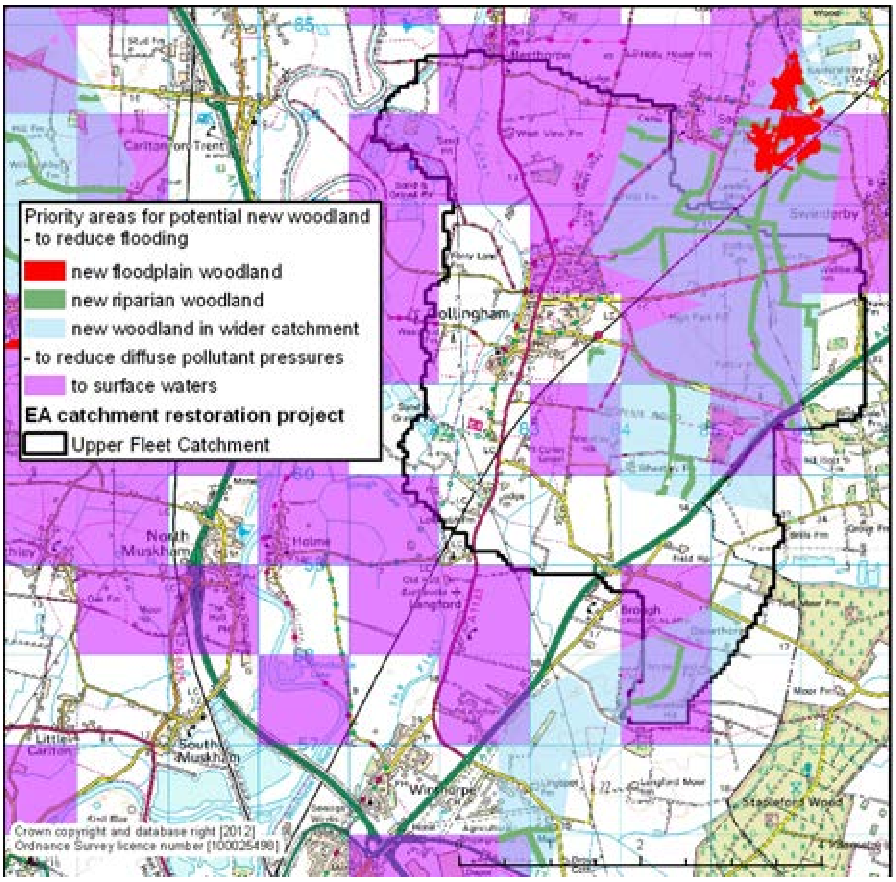

Figure 5 Opportunities for woodland creation to meet FRM and WFD objectives in the Upper Fleet partnership catchment

5.4.6 River Trent partnership restoration projects

There are three catchment restoration projects located to the south of Derby: the River Trent, River Mease and Stafford Brook Restoration Schemes. Opportunities for woodland creation to benefit water vary greatly between these, ranging from only a few hectares of priority land for either FRM or WFD in Stafford Brook to 43 km^2 of priority wider woodland and 62 km^2 of high priority land to reduce at least one diffuse pollutant in the River Mease catchment (Figure 6). Most of this land is unaffected by catchment sensitivities to woodland planting.

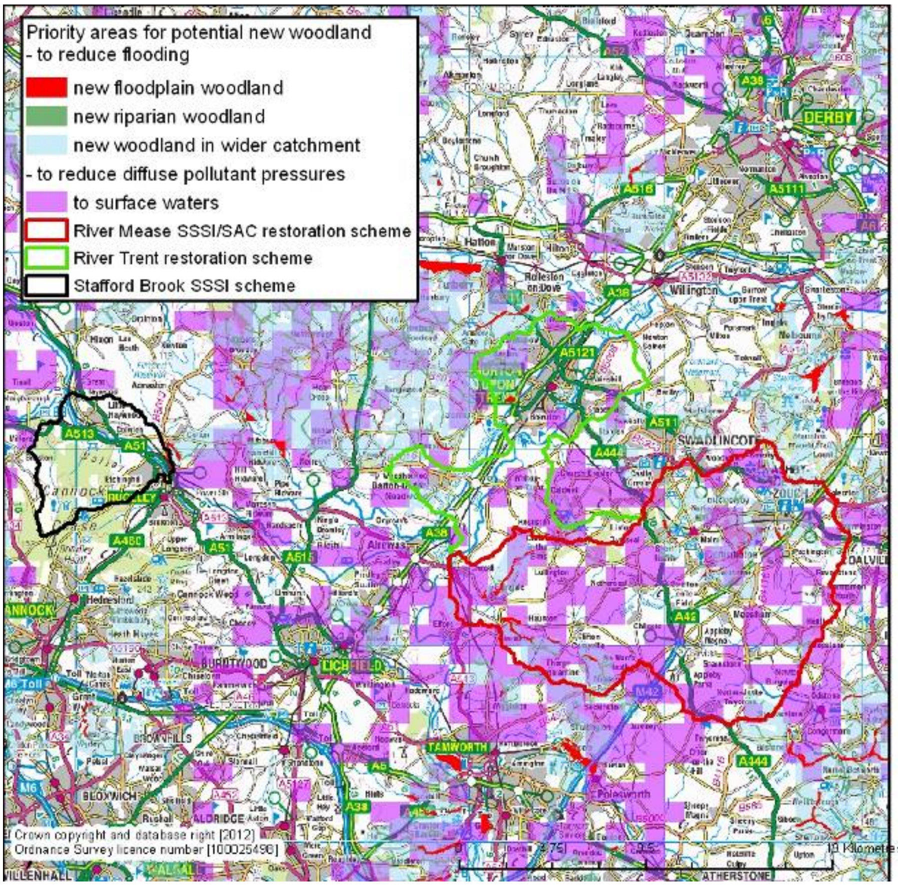

Figure 6 Opportunities for woodland creation to meet FRM and WFD objectives in the River Trent partnership catchments

5.4.7 Humberhead Levels Nature Improvement Area

The Humberhead Levels NIA aims to restore wetlands within this agricultural dominated landscape by re-wetting unproductive drain-sides, headlands and field corners. Figure 7 shows that there is ample (9,921 ha) potential for the creation of wet woodland to improve water quality (to reduce between one and three diffuse pollutants) across the area, subject to achieving a balance with other wetland habitats. Using woodland to slow the flow is unlikely to provide any flood risk benefit in this low-lying location but could aid rewetting of wetlands.

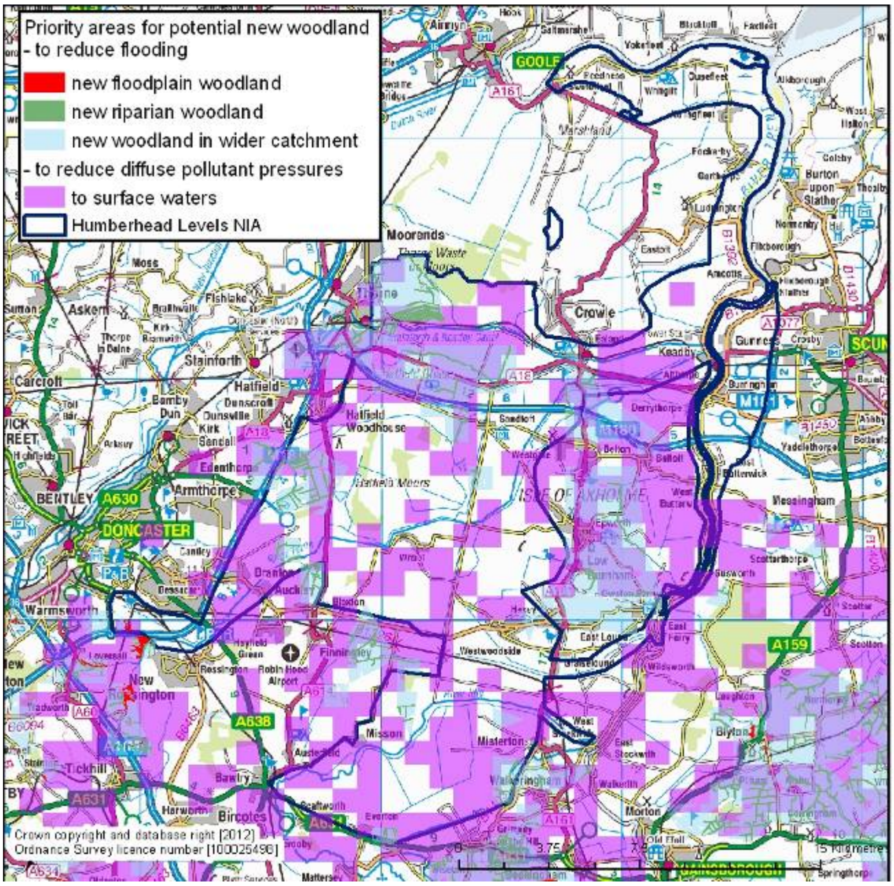

Figure 7 Opportunities for woodland creation to meet FRM and WFD objectives in the Humberhead Levels NIA

5.4.8 Meres and Mosses Nature Improvement Area

The principal aim of the Meres and Mosses NIA project is the protection and restoration of the largest cluster of lowland ponds, bogs and glacial lakes in England. Although woodland is not a priority wetland habitat in this area there is significant scope for wet woodland creation, with 14 km^2 of the identified 55 km^2 of priority land for reducing one or more diffuse pollutants unaffected by sensitivities (Figure 8). There are also major opportunities for planting priority wider, riparian and floodplain woodland to reduce downstream flood risk.

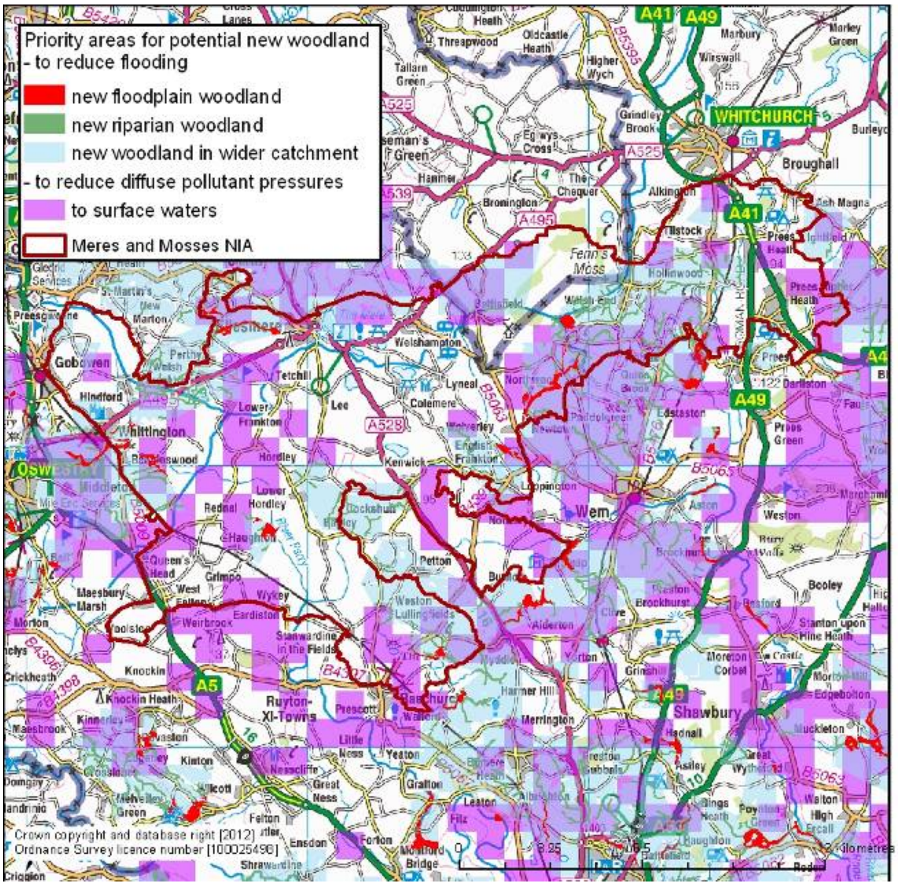

Figure 8 Opportunities for woodland creation to meet FRM and WFD in the Meres and Mosses of the Marches NIA

5.4.9 EA Keeping Rivers Cool Project, River Wye Pilot Catchment

The River Wye is one of a number of EA Pilot catchments for trialling the use of LiDAR data to identify river reaches lacking riparian shade and thus where salmonid fish and other sensitive freshwater life are potentially at risk from climate warming. Figure 9 shows that there is an extensive lack of riparian shade within the part of the River Wye system draining the Midlands Region, with most RWBs assessed as having <20% riparian woodland cover. There is potential to plant up to 620 ha of riparian woodland to increase shade and deliver both FRM and WFD benefits across some 20 RWBs.

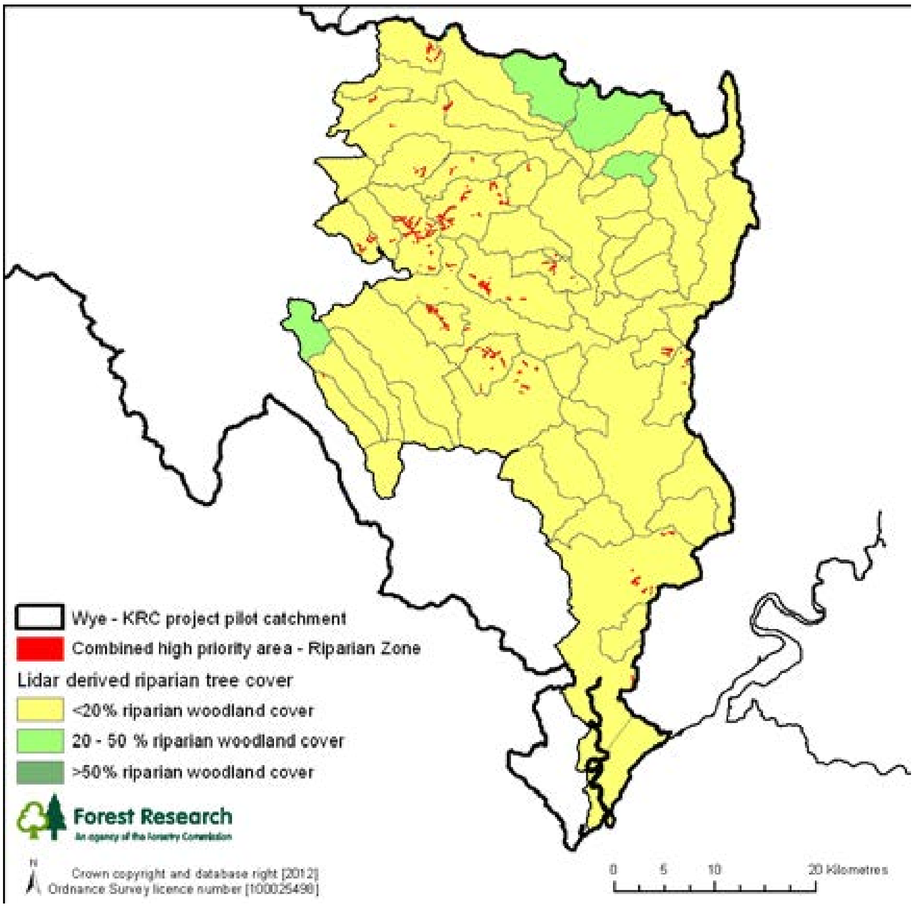

Figure 9 Opportunities for riparian woodland planting to contribute to FRM and WFD in the River Wye Pilot catchment of the Keeping Rivers Cool Project

5.5 Priority areas for woodland creation to provide both FRM and WFD benefits

Map 40 shows that there are relatively extensive areas of land within the region where woodland creation could benefit both FRM and the WFD. The greatest scope for multiple water benefits arise in the northern parts of the River Severn catchment and in a relatively narrow band along the eastern boundary of the region, stretching from the Warwickshire Avon to the Lower River Trent. There are a total of 1919 km^2 of priority land (9% of region) where planting could benefit FRM and at least one diffuse pollutant pressure, and 737 ha both FRM and all four diffuse pollutants (Appendix 2).

5.6 Opportunities for the re-design and management of existing woodland to benefit FRM and WFD

5.6.1 River waterbodies failing GES due to acidification

Map 41 shows that there are only a few (11) RWBs in the region failing GES due to measured pH, although many remain to be assessed. Also shown is where the existing level of forest cover exceeds 20% of any sub-catchment (>100 ha in area) within both the failing and not assessed RWBs. Most of the sub-catchments with >20% woodland cover comprise broadleaved or mixed woodland, which will typically be managed under a low impact silviculture regime and thus very unlikely to breach the 20% threshold for felling in any three-year period. The greatest risk of breaching this threshold will be in the 11 RWBs (one known to be failing) that have sub-catchments with extensive conifer cover. The forest plans of the two forest blocks that lie within the failing RWB requires checking to ensure that felling does not pose a significant acidification pressure on local waters. Checks may also be needed in the remaining ten forest blocks within sub-catchments in not assessed RWBs or in any others that are subsequently found to be failing or at risk of failing GES due to acidification.

5.6.2 River waterbodies with sub-catchments with >20% woodland cover

Map 42 shows the distribution of RWBs across the region with >20% woodland cover within sub-catchments, where the scale of felling could potentially pose a risk to FRM or WFD. As was found for acidification, the vast majority of cases involve broadleaved or mixed woodland, which present a low risk of felling exceeding the 20% threshold in any three-year period. A total of 116 RWBs with 112 sub-catchments have more than 20% conifer cover, the majority of which lies within a potentially vulnerable area. The plans for these woodlands need to be checked and amended where the felling threshold is exceeded.

5.6.3 Watercourses with existing conifer forest within 20 m of bankside

Map 43 illustrates the distribution and extent of conifer stands within 20 m of the river network. There are a large number of small sites spread across the region, amounting to a total area of 2,795 ha. Individual woodland plans relating to these should be reviewed and opportunities taken to restore sites to native riparian broadleaved woodland at the earliest opportunity. Priority should be given to sites where conifer forest has been planted up to the waters edge, especially within RWBs vulnerable to acidification. Consideration should be given to retaining a few conifer trees (where these are likely to be stable) to provide some shade and shelter until the riparian zone re-vegetates.

5.6.4 Waterbodies potentially at risk from the higher water use by trees

Relatively extensive areas within the region are under pressure from overabstraction, including both groundwater and surface water resources. Map 44 shows where these overlap with surface water sub-catchments containing >20% woodland cover as an indicator of those most affected by the potentially higher water use by trees (Nisbet, 2005). Conifer forest will exert the greatest impact and further large scale planting of conifers or short rotation forest crops within the identified ~100 sub-catchments could pose a significant risk to future water resources.

6. Conclusions

The Midlands Region faces a number of major water issues, with over 100,000 properties at significant risk of flooding and 85% of river waterbodies currently failing to meet the target Good Ecological Status required by the Water Framework Directive. A number of recent publications provide strong evidence of the ability of woodland creation to help tackle these pressures by reducing and delaying flood waters, limiting pollutant loadings and retaining diffuse pollutants. Ongoing studies designed to improve our understanding of the effects of woodland on flood flows have been reviewed and the findings found to further strengthen the supporting evidence base. A significant caveat, however, is the need for care in site selection to ensure that planting does not increase flood risk by synchronising, rather than desynchronising downstream flood flows.

The main aim of this study was to identify priority areas for woodland creation and the improved management of existing woodlands to reduce downstream flood risk and achieve the objectives of the Water Framework Directive. A wide range of spatial datasets were accessed from partners, particularly the Environment Agency, and used to generate a large number of maps and supporting GIS shapefiles showing priority areas potentially available for planting. The results provide a strong basis for developing and refining regional objectives, initiatives and projects to deliver new woodlands where they can best contribute to FRM and meet WFD targets, in addition to generating many other benefits for society.

There are extensive opportunities across the region for woodland creation or the improved management of existing woodlands to mitigate downstream flood risk and improve water quality, including:

- 5,189 km^2 (24% of region) of priority sites for woodland planting to reduce downstream flood risk, comprising 4,349 km^2 of wider woodland, 623 km^2 of riparian woodland and 217 km^2 of floodplain woodland

- 4,670 km^2 (22% of region) of high priority land in failing or vulnerable waterbody catchments subject to one or more diffuse agricultural pollution pressures (phosphate, nitrate, pesticides and sediment)

- 1,919 km^2 (9% of region) of priority land where woodland planting could tackle both flood risk and one or more diffuse agricultural pollution pressures; 18% (341 km^2) of this land is free from all sensitivities

- 737 ha of priority land where woodland planting could reduce both flood risk and all four identified diffuse agricultural pollution pressures; 81% (599 ha) of this land is free from all sensitivities

- 112 (100 ha) sub-catchments with >20% conifer forest cover where the scale of felling could potentially increase local flood risk or reduce water quality, including seven within areas vulnerable to acidification; 2,795 ha of riparian land where conifer woodland remains within 20 m of the river network; and ~100 sub-catchments with >20% forest cover where further conifer planting could potentially pose a risk to future water resources due to the higher water use of trees.

These opportunities are reasonably widely distributed across the region, although there are notable 'hotspots'. The greatest scope for multiple water benefits arise in the northern parts of the River Severn catchment and in a relatively narrow band along the eastern boundary of the region, stretching from the Warwickshire Avon to the Lower River Trent. There is a large degree of overlap between the identified priority land for woodland creation and the many existing regional strategies, plans and projects designed to promote land use change or improve land management to mitigate flooding and diffuse pollution, including Catchment Flood Management Plans and England Catchment Sensitive Farming Delivery Initiative Priority Catchments. A significant proportion of the priority land is subject to sensitivities that may restrict the scale and character of any woodland creation.

It is recommended that partners and other regional stakeholders use these maps and spatial data to target locations where woodland planting can provide the greatest benefits to water at the catchment scale. This includes using the identified opportunities to better integrate woodland into existing and new catchment initiatives to improve the chances of success and help secure longer-term performance. There is also significant scope to overlay the maps with those of other woodland values such as the provision of recreation and health benefits, so that opportunities to further widen the range of potential benefits from planting can be realised.

Woodland planting is limited by economic and other considerations. In particular, landowners and farmers are likely to be resistant to land use change unless it is economically attractive. The study notes that while recent progress has been made in raising the value of woodland grants to promote better targeting of woodland creation for water, more will need to be done to achieve the required level of planting to make a difference at the catchment scale. This is especially the case for tackling agricultural diffuse pollution pressures, which tend to be greatest on arable land. While land values and crop prices will greatly constrain woodland creation on such land, it is thought that small scale planting targeted to riparian buffers and along pollutant pathways could make a significant difference, while having a limited impact of agricultural incomes. There is scope for better integrating available incentives to secure greater land use change, as well as encouraging water companies to help fund woodland creation for water.

Finally, it is recommended that one or more pilot studies are established within the region to demonstrate and help communicate the value and benefits of woodland creation for water. Ideally, any such study should be incorporated within one of the existing pilot catchment sites that have been set up to examine the effectiveness of agricultural best practice measures, but failing this a new site should be sought guided by the opportunity maps. The report provides guidance on the monitoring and evaluation of woodland benefits to provide a more robust local evidence base.

7. Recommendations (including summary of delivery mechanisms)

The following recommendations would help to secure the identified opportunities for woodland creation and the improved management of existing woodland to deliver FRM and WFD benefits:

1. Regional stakeholders use the maps and supporting datasets to help target future woodland creation within priority areas to make a difference at the catchment scale. One or more regional dissemination events should be held to promote the findings of this work and to discuss how to pool available resources to achieve implementation.
2. The maps should continue to be refined as new monitoring and modelled data become available. In particular, there is much scope for improved targeting of

woodland creation to reduce agricultural diffuse pollutant pressures by incorporating reason for failure datasets following the completion of on-going EA investigations.

3. There should be a detailed comparison of the EA LUC and PSYCHIC model predictions and an evaluation of differences. The findings should be used to refine and further develop the LUC model to aid the mapping of diffuse pollutant pressures at the field scale.
4. The FC should use the maps showing sub-catchments with >20% cover to check that felling plans will not breach thresholds set for the protection of water quality and to minimise the risk of increasing flood flows. Woodland plans should also be reviewed where conifer stands remain within 20 m of the river network and opportunities taken to restore sites to native riparian broadleaved woodland at the earliest opportunity
5. Further work is needed to raise the value of and improve the synergy between available incentives to secure land management change in desired locations. This includes working with water companies to explore scope for investing in woodland creation to protect water supplies.
6. The maps should be used to facilitate the establishment of one or more demonstration woodlands to monitor and quantify the benefits of woodland creation for water. This would provide a local evidence base and help communicate the need for and success of using woodland as part of a more integrated catchment-based approach to future water management.

Existing delivery mechanisms to support woodland creation are summarised below:

(a) English Woodland Grant Scheme managed by Forestry Commission England:
East Midlands: http://www.forestry.gov.uk/forestry/infd-7bbfhp
West Midlands: http://www.forestry.gov.uk/forestry/INFD-83ECJT

An amalgamation of six grant schemes for the creation and stewardship of woodlands that generate public benefits; Woodland Planning Grant; Woodland Assessment Grant; Woodland Regeneration Grant; Woodland Management Grant; Woodland Improvement Grant and Woodland Creation Grant. Also includes annual Farm Woodland Payments for woodland creation, covering the first 10 or 15 years after planting on farmland. An ‘Additional Contribution’ is available towards the costs of establishing new woodland in a defined area (Map 46) where planting is expected to deliver FRM or WFD benefits. Proposals need to meet certain design standards, including on species choice linked to category of grant. Additional standards apply to the Additional Contribution, which are described in Appendix 3. There is no minimum size for new woodland to qualify for grant support but planting areas will normally be >0.25 ha and no narrower than an average of 30 m, with an absolute minimum width of 15 m at any point. See http://www.forestry.gov.uk/pdf/eng-oh-policy-march2010.pdf/$FILE/eng-oh-policy-march2010.pdf for more details. The current grant scheme only runs to December 2013, when the present Rural Development Programme comes to an end. Details of the next programme remain the subject of discussion, as does the nature of any replacement woodland grant schemes.

(b) Natural England's Environmental Stewardship Scheme administered under two headline categories: Entry Level Stewardship (ELS) and Higher Level Stewardship (HLS).
East Midlands: http://www.naturalengland.org.uk/Images/eastmidlands_tcm6-6469.pdf
West Midlands: http://www.naturalengland.org.uk/Images/westmidlands_tcm6-6478.pdf

This provides funding to farmers and other land managers to deliver effective environmental management on their land. Farmers in the Midlands Region can apply for HLS support for woodland creation to reduce soil erosion and runoff from agricultural land. In the East Midlands, qualifying sites include the River Eye and the land draining it and its tributaries east of Melton Mowbray; Newbeck drained by Brocklesby; catchments of the Great Eau and Hobhole; River Mease between Haunton and Measham; Lower Mercaston catchment; and the Western half of the River Doe Lea. In the West Midlands, the focus is on Herefordshire and South Shropshire (particularly around Marton Pool); the rivers Tern, Roden and Leadon, and the upper Severn in North Shropshire.

(c) The Woodland Trust
Landowners not in receipt of government grants can apply to the Woodland Trust for financial support to aid woodland creation under their 'More Woods' scheme. This is aimed at encouraging the establishment of small copses of native tree species along river banks and in field corners, which should facilitate the targeting of woodland planting within riparian buffer areas and along pollutant pathways to maximise water benefits. Full details of eligibility are available at http://www.woodlandtrust.org.uk/en/planting-woodland/funding-and-planting-grants/woodland-trust-grants/Pages/eligibility-and-criteria.aspx

(d) Water Companies
Water companies have an opportunity to invest in land management solutions and build on South West Water's experience in the West Country and United Utilities' SCAMP project in Northwest England. In particular, there is scope for companies to submit proposals to OFWAT under the next water price review to incorporate a greater woodland element into catchment management schemes to help deliver more effective and sustainable, environmental based solutions to water problems, including adapting to the threats presented by climate change.

8. Update of Woodland for Water Report

8.1 Review of relevant research and case studies on the benefits of woodland creation for reducing flood risk and WFD pressures

This section provides an update to the Woodland for Water: Woodland Measures for Meeting WFD Objectives Report (Nisbet et al., 2011a). It focuses on on-going and new case studies addressing the benefits of woodland creation for reducing flood risk since the authors are aware of little new work on evaluating the use of woodland to reduce WFD pressures. A total of eight studies are described below, followed by a summary.

8.1.1 Slowing the Flow at Pickering

Slowing the Flow at Pickering is one of three Defra sponsored multiple objective projects to demonstrate the role that land use change and land management could play in reducing flood risk (Nisbet et al., 2011b). It is located at Pickering in North Yorkshire and initially ran from 2009-2011, but has since been granted a four-year extension to March 2015. The project is led by Forest Research (FR) in partnership with the Forestry Commission (FC), Environment Agency (EA), Natural England (NE), North York Moors National Park Authority, Durham University and various local organisations. It involves trialling a number of land management interventions aimed at slowing flood flows within the Pickering Beck and adjacent River Seven catchments. Woodland-based interventions include the planting of riparian woodland and the construction of large woody debris (LWD) dams and timber 'minibunds'. Initial targets were set for the creation of 50 ha of riparian woodland, 30 ha floodplain woodland, 5 ha of farm woodland and construction of 150 LWD dams split between both catchments (restricted to river channels <5 m wide to improve the stability of dams and reduce the risk of wash-out).

The project benefited from the availability of opportunity mapping data and models from a number of previous regional flood risk management projects, which helped to guide site selection. In particular, a new coupled hydrological-hydraulic model 'OVERFLOW' developed by Durham University was used to identify locations where the intervention measures would be best targeted to optimise flood reduction (Odoni et al., 2010). The model uses a flow accumulation and routing algorithm to calculate how rain falling on the catchment flows through the landscape, with flows converted to inferred flow depths based on a 'Manning map' and thence flow velocities. It is calibrated using flow hydrographs for known events. The impact of planting riparian woodland and constructing LWD dams is represented by changing the Manning's n values for appropriate reaches.

A particular strength of the model is its ability to separate sites where planting would have a beneficial effect (flood reducing) from those where it would be neutral or could be damaging (flood increasing) by assessing whether slowing the flow synchronised or desynchronised tributary responses. Figure 10 shows that as expected, most of the positive sites were clustered in the upper half of the catchment, where there is greater potential to decouple runoff delivery between the upper and the lower catchment. Correspondingly, the negative sites were in the bottom third, generally in reaches much closer to the town, while neutral reaches were relatively evenly distributed across the catchment.

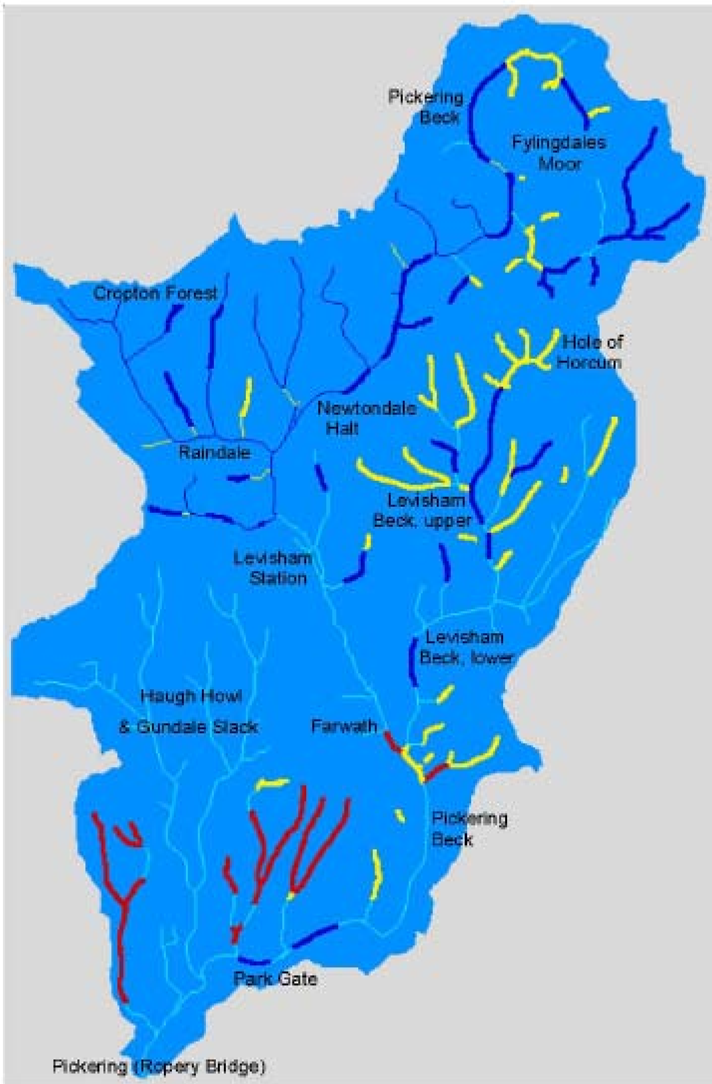

Figure 10 Map of the catchment of Pickering Beck showing where the planting of riparian woodland and construction of LWD dams is predicted by OVERFLOW to reduce peak flood discharge (reaches marked in dark blue), have a neutral effect (yellow) or increase peak flows (red) at Pickering (from Odoni & Lane, 2010).

In addition to aiding site selection, the model was used to predict the combined effect that the planting of riparian woodland and the construction of LWD dams in the Pickering

Beck catchment would have had on two previous flood events (~1-in-25 year event in November 2000 and 1-in-100 year event in June 2007). A number of scenarios were tested, ranging from planting woodland and installing LWD dams along all available positive and neutral reaches of riparian land to restricting these to a sub-set of sites. The main scenario was 'Case 7', which considered the impact of achieving the project target of planting 50 ha or riparian woodland and installing 100 LWD dams along the most positive sites. These measures were represented in the model by increasing Manning's n from 0.06 to 0.20 for riparian woodland and from 0.035 to 0.18 for river channel sections with LWD dams. The modelling did not incorporate the effects of the other planned woodland measures in the catchment or related 'flood reduction' woodland mechanisms such as the potential higher water use of trees and greater soil infiltration and water storage of woodland soils. Figure 11 shows the contribution of the woodland measures to the November 2000 event and the key results were:

- Planting along main Beck sites had a greater positive effect in terms of reducing downstream flood risk than planting along tributaries.

- The effectiveness of planting was greater for the larger (2007) flood event than the smaller one (2000) studied.

- Peak flow reductions for 50 ha planting plus 100 LWD dams ranged from 2.2 cumecs for the 2007 event to 0.8 cumecs for the main peak in the 2000 event. The figures translated into reductions in flood volume of 53,000 m^3 and 15,000 m^3, respectively. While these represented only 4% of the peak flood discharge for the 2000 event and 7% for the larger 2007 flood, they made a greater contribution (15% and 21%, respectively) to managing the 'Excess flood volume' (the volume of water above the critical discharge of 15 cumecs for major flooding in Pickering).

The modelling indicates that a large number of smaller woodland interventions can lead to significant reductions in peak flows, albeit not enough on their own to protect properties from flooding during major floods. However, such interventions could make an important contribution to a whole-catchment approach to managing flood risk, where the integration of a range of different measures could help to protect communities from significant flooding events.

One novel technique being trialled in the adjacent catchment of the River Seven is to evaluate the effectiveness of timber minibunds for increasing flood storage. Two minibunds have been constructed across the floodplain to provide a greater storage volume than is possible by using individual LWD dams, but not too great to breach the 10,000 m^3 threshold that may define a large raised reservoir under the Floods Act (2010) (requiring a higher and more costly design standard). The minibunds were formed from a 1.0-2.0 m high 'wall' of horizontally stacked tree logs braced against standing trees or log pile supports. Initial estimates suggest that they are relatively cheap to install and could hold up to 6,000 m^3 of flood water. Key unknowns include how long the structures will last for and how 'leaky' they will be.

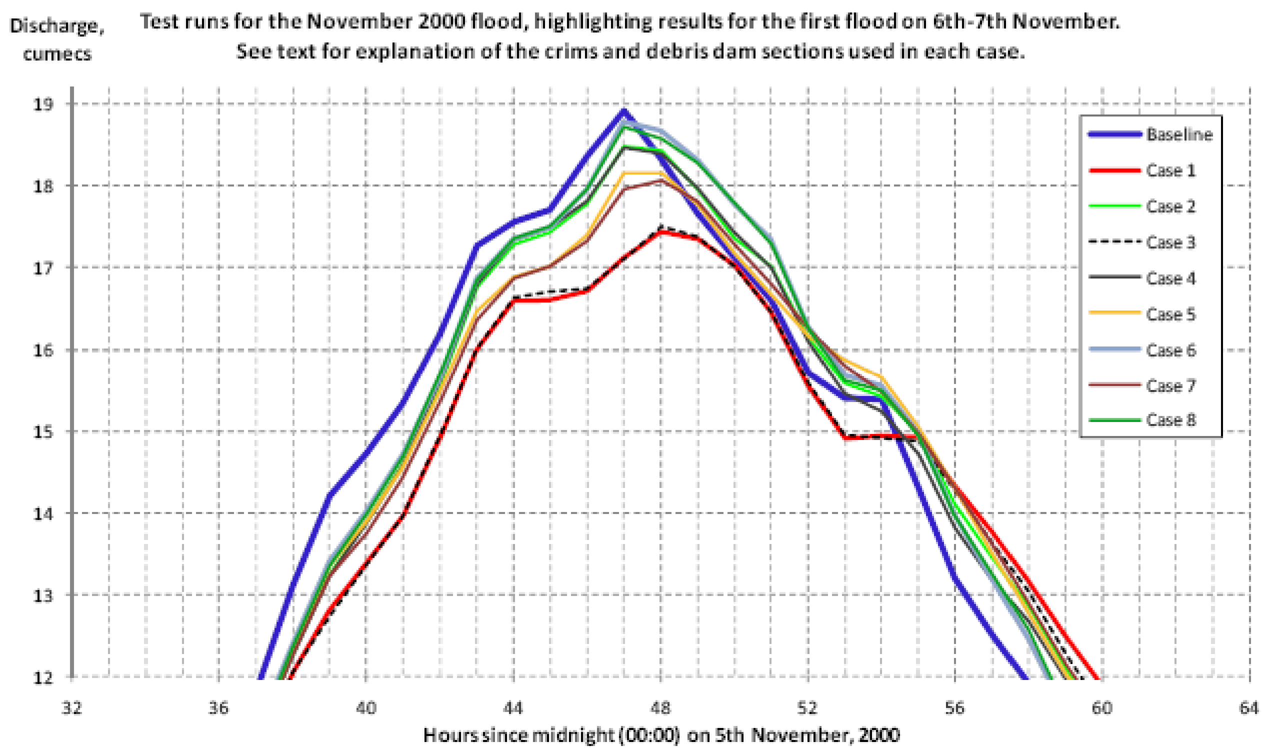

Figure 11 Predicted impact using OVERFLOW of different combinations of riparian woodland planting and construction of LWD dams on the simulated 6-7 November 2000 flood; each curve is the mean of 200 calibrated runs (from Odoni & Lane, 2010)

Monitoring is in place to assess the effects of the riparian woodland planting, multiple LWD dams and timber minibunds on flood flows. This relies on a network of 10 water level recorders that has been installed upstream and downstream of the implemented measures. Unfortunately, pressure on time to instrument reaches during the first phase of the project severely constrained the collection of baseline data. Assessments will therefore rely on upstream-downstream comparisons, except in the case of the planted riparian woodland where the lag in the trees becoming established will effectively extend the baseline period. Longer-term flow data are also available from the EA's main river gauging stations in both catchments, which will allow an assessment of the integrated effect of all upstream measures.

Monitoring includes the downloading, quality control and analysis of water level data, as well as annual assessments of the condition of LWD dams and the performance of the timber minibunds. The first analysis of the results is planned for 2014/15. The impact of the minibunds and LWD dams should be established in the medium term (5-10 years), depending on future flood frequency. In contrast, the effects of the new riparian woodland will take much longer to fully establish (50+ years).

Phase 1 of the Slowing the Flow at Pickering project also included a preliminary economic evaluation of the ecosystem services provided by the land management interventions (Nisbet et al., 2011b). This followed the draft EA guide 'Ecosystem services assessments: How to do them in practice' and involved an initial qualitative assessment of the 'likelihood of impact' of the planned interventions across the full set of ecosystem services (using the UN Millennium Ecosystem Assessment (2005) classification of provisioning, regulatory, cultural and supporting services). An additional service was added to the list of cultural services in the form of 'education and knowledge'.

The measures were considered to provide potential significant positive effects for six services (flood regulation, erosion regulation, recreation & tourism, social relations, education & knowledge, and habitat provision), with none yielding any potential significant negative effects. This was followed by an economic valuation of the significant positive impacts provided by the woodland creation (floodplain, riparian and farm woodland) measures plus LWD dams. Climate regulation was added to the list of significant positive effects and a reduction in food provision from the loss in agricultural production was included as a potential negative impact. The objective was not to estimate definitive values but to provide conservative estimates to serve as the foundation for a more robust future valuation of ecosystem services. Although the woodland is likely to be established in perpetuity, a 100-year time horizon was selected for the purposes of the assessment.

Minima, maxima and means for the indicative central estimates for each of the impacts are summarised in Table 10 below. The estimates suggest that habitat creation and climate regulation are by far the largest benefits, with flood regulation a more distant third, while the loss of agricultural production could be a significant disbenefit.

	Minimum (£/yr)	**Maximum (£/yr)**	**Mean (£/yr)**
Habitat creation	£0	£138,514	£121,524
Flood regulation	£4,200	£6,000	£5,964
Climate regulation	-£18,241	£317,943	£107,035
Erosion Regulation	£0	£221	£205
Education and knowledge	£10	£60	£14
Community development	£549	£549	£549
Agricultural production	-£32,056	-£3,771	-£31,604
Total	**-£42,653**	**£431,180**	**£203,687**

Table 10 Indicative annual ecosystem service values based on central estimates for the woodland creation and LWD dam measures

The benefit calculations are gross values and do not allow for the costs of the forestry measures implemented or for the timing of both these and the benefits to accrue (i.e. their distribution over the 100 year period considered). These aspects were accounted by converting each 100 year flow of annual values into a present value by discounting based upon the Treasury Green Book protocol (HM Treasury, 2011; Table 11). Aggregating gave net present (2011) values (NPV) ranging from around £0.8m to £9.6m, with a central estimate of £4.3m.

The preliminary evaluation indicates that from a societal perspective the public benefits from the forestry measures would outweigh the costs. However, it is important to note that it is unlikely to be cost effective to implement the forestry measures solely for flood regulation, highlighting the need to factor in other ecosystem benefits. It is also notable that the benefits of the measures to private landowners are unlikely to outweigh their costs. For example, the study found that based upon Treasury Green Book discount rates, the 2011 values of expected woodland grant payments (ranging from £4,515/ha to £6,780/ha) would only partly cover the forestry costs (£4,200 to £8,200/ha) and that of lost agricultural production (£3,600/ha to £13,100/ha). Woodland grant payments were increased in 2012 to reflect flood and WFD benefits but the ecosystem service assessment remains to be reworked.

	Low (£k)	**Central (£k)**	**High (£k)**
Habitat creation	£1,630	£2,773	£4,459
Flood regulation	£88	£175	£292
Climate regulation	£923	£2,800	£5,464
Erosion Regulation	£0	£5	£10
Education and knowledge	£0	£1	£6
Community development	£0	£16	£62
Agricultural production	-£1,113	-£911	-£306
Forestry Costs	-£710	-£539	-£369
Net Present Value	**£819**	**£4,321**	**£9,618**

Table 11 Indicative ecosystem service present values (£k at 2011 prices) for the woodland creation and LWD dam measures

The other two Defra sponsored multiple objective demonstration flood management projects are the National Trust's 'Source to Sea' Holnicote project in North Somerset and the Moors for the Future 'Making Space for Water' project in the Upper Derwent in Derbyshire. The Moors for the Future project has no plans to implement any woodland-based measures but the Holnicote project is encouraging the development of LWD dams within local rivers and hopes to extend woodland planting in the catchment. A network of instrumented sites is in place to evaluate the impact of implemented measures on flood flows.

8.1.2 Great Triley Wood

Great Triley Wood is the location for a study by FR of the interaction between native floodplain woodland and flood flows. The wood is located two kilometres north of

Abergavenny in South Wales and is owned and managed by the Woodland Trust. It comprises some 6 ha of mainly mature, semi-natural, broadleaved, wet woodland, with alder, willow and hazel dominating the wettest areas, and oak and birch on the higher ground. The woodland straddles the full floodplain and occupies a 500 m length reach, including one main tributary, of the River Fenni.

The study was initiated in 2004 to test the hypothesis that LWD dams in riparian woodland streams increase flood storage and make a significant contribution to attenuating downstream flood flows. A second objective was to assess the stability and performance of constructed debris dams to determine whether this is an effective option for speeding up the process of their formation within degraded watercourses. Work has involved characterising flood flows through the woodland using a network of water level recorders supplemented by occasional water velocity measurements, and assessing the impact of installing multiple LWD dams within selected reaches. Regular surveys and photographs of the LWD dams are taken to record the rate of dam development and their response to flood events. A 1-D hydraulic model of the River Y Fenni floodplain has been set up for the wooded reach and upstream and downstream sections using the Infoworks RS and HEC-RAS river modelling software packages. These have been used to predict the impact of the installed LWD dams across a range of flood flows (dams represented by creating a channel blockage at appropriate cross section locations to represent physical presence of the dams).

The results of modelling the impact of installing five LWD dams in the main river channel and another four dams within the tributary stream on a 1-in-100 year flood event were recently published by Thomas and Nisbet (2012). The main finding was that the in-channel hydraulic roughness created by the LWD dams acted to slow down water flows by up to 2.1 m/s, raising water levels upstream by up to 1.5 m over a distance of 165 m. Although the dams appeared to have little effect on the height of the flood peak, its passage was delayed by an average of 2-3 minutes per dam. Of particular note was the ability of LWD dams to raise water levels above bank height, promoting out-of-bank flows and further increasing flood storage.

The results support the use of LWD dams in streams and small rivers (e.g. <5 m wide; see section 3.1.1) as a viable soft engineering technique for downstream flood mitigation. To be effective at a larger scale, however, would require an extensive series of dams across the upper and middle reaches of a catchment. The results also confirm that the artificial construction of debris dams is an effective way of restoring degraded and incised reaches. Some dam failures were recorded but released debris was largely retained by downstream dams. These appear to have developed into stable structures although remain to be tested by a major flood event.

Monitoring is continuing at the site to record the evolution of the LWD dams and their interaction with future flood events. It is planned to eventually remove all of the dams to assess the response of flows and to test model predictions. EA Wales have carried out a fish survey of the instrumented reaches and it is hoped that they will repeat this after the removal of the dams to evaluate their importance to fish populations.

8.1.3 River Parrett

The River Parrett in Somerset is the location for a long-term study by FR of the impact of planting floodplain woodland on flood flows. Work began in 2002 with a mapping exercise to identify opportunities in the catchment for using woodland creation to mitigate downstream flooding. This led to the planting in 2005 of five sites with small areas (2-5 ha) of native floodplain woodland (by EA and the Farming & Wildlife Advisory Group as part of an EU project). One of the sites in the upper reaches of the River Parrett catchment at Bower Hinton Farm, near South Petherton, was selected in 2007 for long-term monitoring. Although the location was not ideal due to the limited area (4.9 ha) of planting and the fact that it is restricted to one side of the floodplain, it was decided to instrument the site to generate some data on the interaction between the growing woodland and flood flows. Funding from Defra and the EA facilitated the installation of four water level recorders in the river channel above, within and below the site, together with an instrument on the floodplain to monitor out-of-bank water depths and flow velocity. Regular vegetation surveys are undertaken to assess the development of vegetation roughness.

The River2D model has been set up for the site and used to predict the impact of the establishment of the planted woodland on flood flows (the woodland was represented by increasing the roughness parameter ks to give the equivalent change in Manning's n, from 0.035 to 0.15). The model predicted significant local effects in terms of reduction in flow velocity and increased flood levels within and upstream of the woodland, but the area involved is too small to affect downstream flood risk. Continued monitoring will allow model predictions to be tested, although only a few flood events have been captured to date.

The monitoring at Bower Hinton Farm was supplemented in 2011 by installing instrumentation at a second of the originally planted floodplain sites, located at Wigborough Farm, a short distance upstream of Bower Hinton. This site was selected to facilitate a PhD study (2011-13) by Cardiff University to improve the modelling of sub- and trans-critical flow conditions and interactions with floodplain vegetation in middle and upper catchment reaches (see below).

8.1.4 Eddleston

The Eddleston Water Project is a partnership project between Dundee University, Scottish Environment Protection Agency (SEPA), Scottish Government, Scottish Borders Council, National Farming Union Scotland, Tweed Forum, British Geological Survey, FC and Scottish Natural Heritage. Its main aim is to investigate if changes to land use management and the restoration of natural habitats can help improve river ecology in the Eddleston Water (a tributary of the River Tweed) and reduce the risk of downstream flooding to the communities of Eddleston and Peebles in the Scottish Borders. Work began in 2009 with a scoping study, survey and modelling work, which led to the development of a restoration strategy. The strategy involves a number of woodland measures, including the planting of riparian woodland and the construction of LWD dams. A total of 37 ha of riparian land is being planted or secured for planting along a number of tributary streams, with further areas planned.

A comprehensive surface water monitoring network was installed within the study area in 2011 by Dundee University and FR to capture the effects of the different measures on flood flows. This involves 14 water level recorders, 7 rain gauges and one automatic weather station, supported by two existing SEPA river gauging stations. The focus of the assessment of riparian woodland involves the Longcote Burn, where a total area of 7.5 ha is in the process of being planted. Water level recorders have been installed at downstream, middle and upstream locations to monitor the impact of the growth of the riparian woodland on stream flows. Ecological monitoring is planned to assess changes to fish and benthic macroinvertebrate populations.

An initial modelling study used a coupled 1D/2D model (MIKE 11/21) to predict the impact of different management interventions on flood flows (2, 10 and 200 year design floods). Two integrated scenarios were modelled, one comprising channel remeandering, riparian woodland planting and reduced agricultural pressures (removal of flood banks), and a second, reduced agricultural pressures and hedgerow placement. Riparian woodland was represented in the model by increasing Manning's n from 0.035 to 0.08. The study concluded that while each scenario provided local flood attenuation benefits (as well as significant ecological benefits), the effects did not transmit downstream to the higher flood risk areas in the town of Peebles, primarily due to scale factors (Moir *et al.*, 2011).

8.1.5 River Derwent

A modelling study of the River Derwent catchment in Cumbria was undertaken in 2011/12 by Atkins in partnership with the EA, NE, FR and Cumbria Woodlands to explore where woodland creation would provide the greatest benefit and least risk to flood management (Atkins, 2012). Previous mapping work had identified opportunities in the catchment for floodplain, riparian and wider woodland planting to reduce downstream flooding (Broadmeadow and Nisbet, 2010b) but it was recognised that the resulting attenuation effect may not always be beneficial due to the potential to synchronise, rather than desynchronise flood flow contributions from tributary catchments. The main purpose of the study was therefore to undertake a sensitivity analysis to investigate the impact of delaying flood flows to different degrees across the main sub-catchments for a range of return periods. Adjustments for the effects of woodland were based on expert judgement as there is a lack of quantitative data on the impact of planting on model parameter values.

Existing ISIS models for the River Derwent were checked, reviewed and extended to include upstream reaches, with inflows calculated using the ReFH (Revitalised Flood

Hydrograph) method. Following an initial calibration phase, the models were used to explore the effect on downstream flood levels of increasing Tp (time to peak) by 20%, floodplain Manning's n by between 50 to 100% (from 0.06 to 0.09/0.12) and the maximum water storage capacity (Cmax) of catchment soils by 20%, for a range of storm durations (5 to 15 hours) and flood return periods (2 to 100 year). The main findings were:

- Increasing Tp reduced peak water levels along most watercourses, with the greatest benefit in the River Greta catchment, reducing peak stage in Keswick by a maximum of 180 mm for a 100 year event; the degree of reduction increasing with the size of flood event.
- Increasing Manning's n by 100% resulted in higher peak water levels in a number of river catchments, including by up to 380 mm in the River Cocker. However, water levels were reduced in Keswick.
- Increasing Tp by 20% and Manning's n by 50% produced an average reduction of 50 mm in water levels in Keswick for a 100 year, 10 hour design event. However, increasing both parameters in all tributaries had a negative effect on peak stage at several downstream locations.
- Increasing both Tp and Cmax had a positive effect for all flood events.

The report concludes that there is potential for woodland planting in the Greta and St John's Beck catchments to benefit flood risk management in the town of Keswick. While planting has the potential to have a negative influence on flooding in some locations, it is noted that this can be mitigated through careful site selection.

8.1.6 Energy Crops and Floodplain Flows

A modelling study was undertaken by JBA Consulting for the EA to evaluate the impact of the planting of energy crops on river and floodplain flows (Rose and Rosolova, 2010). A linked 1D-2D hydraulic model using ISIS-TuFLOW software was applied to two case study sites on the River Severn near Tewkesbury in the West Midlands and on the River Isle near Ilminster in South West England. The model assessed the effect of changing land cover across the floodplain from winter wheat to either short rotation willow coppice (SRC) or Miscanthus. Different planting scenarios were simulated, including randomly located, different sized blocks (1 ha vs 3 ha), variable spaced and oriented rides (5 m or 10 m spacing and aligned parallel or perpendicular to the flow), planting on one or both sides of the floodplain, and up to 30% vs 100% coverage of the floodplain. Changes in vegetation were represented by increasing Manning's n from 0.06 to 0.2 for Miscanthus and between 0.1 (0.5 m) and 0.34 (2 m) for SRC, depending on flood depth (values given in brackets). The main findings were:

- The effects of both energy crops on flood flows were broadly similar, although Miscanthus was found to have a greater effect on shallow (<1 m) flood flows due to differences in low height vegetation roughness.

- The very dense nature of the mature SRC plantation acted like a 'green leaky dam', holding back flood waters both within and immediately upstream of the crop (generally <300 m upstream) and slowing water velocity across the floodplain. In most cases this resulted in a corresponding, but smaller, decrease in flood levels immediately downstream.
- Complete plantation coverage of the floodplain produced the greatest effect on flood flows, while distributed and dispersed planting totalling <30% of the floodplain produced only very localised effects.
- Distributed blocks or a central plantation block did not change the maximum flood extent significantly.

The results were used to develop supplementary internal guidance for the EA on 'Flood Risk Management: Woodland, tree planting and flood risk', which includes advice on the selection of appropriate Manning's n roughness coefficients for use when modelling the impact of energy forest crops on flood flows.

8.1.7 Methods to Screen and Quantify Natural Flood Management Effects

Halcrow were funded by SEPA and FC Scotland in 2011 to advance development of a methodology for assessing the contribution that Natural Flood Management (NFM) could make to managing flood risk. The report (Halcrow, 2012) built on earlier work by Jacobs (2011) and reviewed their proposed method for assessing NFM. It notes that due to licencing issues, technical difficulties and other deficiencies, this method was not adopted by SEPA. The report includes an extended literature review and proposes a new method to identify opportunities and appraise the contribution of NFM techniques to flood management in Scotland.

The review considers the literature (both monitoring and modelling studies) relating to the impact of NFM on flood flows, including upland afforestation and the planting of riparian and floodplain woodland. It concludes:

Upland afforestation: While there is a consensus in the literature (derived from both catchment monitoring and modelling studies) that the afforestation of small catchments can reduce flood flows (up to 10% attenuation for high order events and 25% for low order floods), the complexity of the variables involved (e.g. climate, geology/soils, forest type and design, species and management regime) means that it is difficult to apply a simple rule relating changes in percentage forest area to a percentage reduction in flow.

Riparian woodland: The general consensus is that riparian woodland and associated LWD dams act to slow in-channel flows and that the decrease in flow velocity can be represented by an increase in Manning's n. Its effect is greatest in the upper and middle reaches of catchments, where reductions of up to 10% in flood peaks have been reported in modelling studies, subject to scale and local factors.

Floodplain woodland: There is a weight of academic agreement that the increased hydraulic roughness created by planting floodplain woodland can benefit flood risk management. Reductions in flood peaks of up to 10-15% have been reported but solely based on modelling studies.

The proposed new method for appraising NFM techniques includes three phases: a national screening process to identify NFM opportunities within vulnerable areas (map based); an assessment of preferred NFM options based on a consideration of catchment characteristics and constraints; and the use of a new model to estimate the flood risk management benefits of selected measures. The new model would be a single event spatially distributed model, with elements based on the ReFH (Revitalised Flood Hydrograph) method. It would include physically based flow routing via a time to outlet grid and allow the effects of land degradation and land use change (including hydrological (water use and soil water storage/pathways) and hydraulic (increased channel and floodplain roughness) effects of woodland creation) to be incorporated. The model would be GIS based and meet the recommendations of O'Connell et al. (2004). However, new software is required to facilitate its development, followed by a period of rigorous calibration and validation to demonstrate fitness for purpose.

8.1.8 PhD Studies at Cardiff University

Two PhD studies based in the Hydro-environmental Research Centre of the School of Engineering in Cardiff University have investigated the detailed interactions between floodplain woodland and flood flows. The first by Xavier (2010) studied the hydraulic impact of floodplain woodland and involved:

- Developing a simple to use modelling tool to address better the specific effects of woodlands on flood hydraulics, including the role of woodland type and design. Different ways of representing vegetation roughness were explored, including Manning's n, the Darcy-Weisbach friction factor ‘f’ and the bulk drag coefficient ‘C_d’.
- Using hydrological & topographical data from field study sites to further test and refine the modelling tool.
- Using results from experiments at the CEHIPAR large flume facility in Madrid to analyse the drag force behaviour of full-sized, submerged, young floodplain trees. This showed that the drag force reduced with increasing velocity until reaching an asymptotic value. The presence of leaves and flowers can significantly contribute towards the overall drag of a tree, while the dry mass and volume of trees were found to be positively correlated to the linear drag-area coefficient (Wilson et al., 2010).
- Undertaking controlled experimental studies in the new NERC flume in the Hydraulics Laboratory at Cardiff University to investigate the governing flow processes and determine parameters for use in a refined 1-D/2-D linked model

‘DIVAST’ (a depth-integrated finite difference numerical model). This included full scale drag force-velocity tests for three broadleaved tree species.

This PhD has helped improve our understanding of the dynamic nature of the variation in the roughness characteristics of woodland vegetation (e.g. in relation to tree species, spacing, flood depth and flow velocity) and how to better capture this in hydraulic models. A reach scale model using DIVAST of the River Laver in North Yorkshire was built to explore local interactions between woodland design and flood flows, but due to instabilities encountered, the model was not running by the end of the research study.

The second PhD ‘Realising the Potential of Floodplain Woodland in Flood Risk Reduction for Sub- and Trans-critical Flow Conditions in Middle to Upper Catchments’ is ongoing and builds on the results of the first. This includes:

- Further analysis of results from previous experiments at the CEHIPAR large flume facility. Two empirical models proposed to predict drag force response based on tree physical properties: a two-stage linear model and a Vogel exponent model. Analyses have shown that wet mass and volume are the most influential parameters. This work has been submitted for publication in the Journal of Hydraulic Research (Whittaker et al., 2012) “Drag force behaviour of submerged floodplain woodland trees”, Journal of Hydraulic Research, *in press*).
- Investigating the turbulence and hydrodynamics of flows through emergent cylinders and vegetation, and incorporating findings into a 3D model.
- Refining DIVAST model and testing at floodplain woodland field sites in Somerset (Wigborough and Bower Hinton).

8.1.9 Summary

The above studies are adding to the evidence base in support of using woodland creation to help reduce downstream flooding, as well as to provide other benefits. They also confirm that care is required in site selection to ensure that planting does not have the opposite effect by synchronising, rather than desynchronising downstream flood flows. The study by Atkins (2012) shows how the ReFH model can be readily used to identify where this could be an issue.

Quantification of the contribution of woodland to flood mitigation continues to rely on modelling studies, with direct measurements limited to shorter-term, hillslope process, in-stream LWD dam placement and local catchment or reach-scale studies. Modelling of riparian and floodplain woodland interactions is dominated by the use of 1D/2D hydraulic models and the manipulation of the Manning’s n roughness parameter. Studies by Cardiff University are improving our knowledge of the hydrodynamics of flooded woodland and hold out the possibility of developing improved numerical models that can take account of the effects on local drag forces.

While research models are available that can incorporate both the hydrological and hydraulic effects of woodland, these are data intensive and computationally expensive. There is a proposal in Scotland to develop a simpler, more user-friendly tool for quantifying the impact of NFM measures on flood risk but even if approved, remains several years off.

8.1.10 Woodland creation for reducing WFD pressures

Little progress has been made to date in addressing the evidence gaps identified by Nisbet *et al.,* (2011a) concerning the use of woodland to reduce WFD pressures (these are described in Section 3.3). One difficulty is the extended timescale required to establish effects, while another is finding suitable sites with willing land owners. It was hoped that a test of woodland measures could have been integrated into one of the established Priority or Demonstration test catchments but this has not been possible to date. There is interest in trying to establish a case study of the effectiveness of targeted woodland creation for reducing diffuse pollution pressures within the River Tay catchment in Scotland, which will be subject to further discussions in 2013.

8.2 Modelling the impacts of woodland on flood flows

8.2.1 Introduction

A meeting was held with EA FRM staff (Rhys McCarthy & Rob Stroud) in Tewkesbury on 20 March 2012 to discuss how best to incorporate woodland effects into catchment hydrological and hydraulic models. Catherine Wilson and Pete Whittaker from Cardiff University School of Engineering also attended. RM described the EA's approach to modelling and noted that they have no experience in using catchment hydrology models to assess the impact of woodland planting on flood generation. The focus of their work is on applying hydraulic models at the reach scale within urban dominated floodplains, for the purpose of managing flood risk and the impact of development. Four different 1D/2D hydraulic models are in use by the EA and their consultants but these have rarely been used to assess woodland effects. Where woodland is a factor, this is addressed by adjusting the Manning's 'n' value to account for increased hydraulic roughness; appropriate values are selected from the literature. To date, there has been little call for floodplain modelling in rural areas as these usually lack LIDAR coverage.

The following section describes the main differences between one-dimensional (1D) and two-dimensional (2D) hydraulic models and the common use of Manning's 'n' to represent the impacts of floodplain woodland. Ongoing developments in new hydraulic models and better ways of handling the effects of woodland vegetation are also covered.

8.2.2 Choice of models

Models of river flooding are primarily based on hydraulics, representing water flow both within the channel and on the floodplain. Most hydraulic models require the parameterisation of separate roughness factors for each of these pathways. A hydrograph or constant discharge is usually taken as the input and routed downstream through the modelled reach. The hydrograph may be derived through direct flow measurement or generated by catchment rainfall-runoff models.

Traditional 1D models have been used to investigate river flood inundation by performing a series of 1D hydraulic calculations for steady or unsteady flow conditions for a range of channels. These use a 1D resistance formula, which is usually calibrated by adjusting the roughness coefficient until the model output reproduces the observed hydraulic behaviour of the reach as accurately as possible. However, the calibration procedure lumps together several resistance effects such as skin friction and form roughness, turbulence, and multidimensional flows into a single term.

Many problems in floodplain hydraulics require the prediction of flows over complicated topography and in these cases the inadequacies of 1D models are highlighted. For example, 1D models have difficulty in simulating the effect of water spreading out onto the floodplain from a breach in the riverbank, as there are a myriad of possible flow directions that the water could take.

2D hydraulic models were first developed and applied to flows in estuaries and are currently at the forefront of research into river flood modelling. They represent a significant advancement on 1D models in being able to predict certain aspects of out-of-bank flows. The fundamental physics of all 2D models is more or less common. They solve the basic mass conservation equation and two (horizontal) components of momentum conservation. The main model outputs are two (horizontal) water velocity components and a vertical water depth for each point or node. Water velocity is assumed to be uniform with depth, while water pressure is assumed to be hydrostatic. Each node, being a point in space (i.e. with east and north co-ordinates) is associated with a topographical height and a friction factor. Water flows from one node or cell to the next based on the difference in water level and velocity.

The principal effect of floodplain vegetation is to increase surface roughness. Modelling techniques in the past have treated vegetation in open channels and on floodplains as an additional flow resistance to be added to the bed roughness. The presence of submerged or non-submerged vegetation along riverbanks and/or across floodplains is often found to be the largest source of resistance.

A roughness coefficient is used to represent the energy lost from flowing water due to hydraulic roughness. One of the most commonly applied uniform-flow formulae for open-channel computations is the Manning’s formula, owing to its simplicity and to the satisfactory results that have been achieved in practical applications.

The selection of an appropriate value for the Manning’s roughness coefficient (n) is crucial to the accuracy of the computed hydraulic parameters. The value of Manning’s n is highly variable and depends on several factors including: surface roughness;

vegetation; channel irregularities; channel alignment; scour and deposition; obstructions; size and shape of the channel; stage and discharge; seasonal changes; water temperature; and suspended material and bedload. Table 12 gives typical Manning's n values drawn from the published literature for a range of channel and floodplain characteristics.

Floodplains	Min	Normal	Max
a. Pasture no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, few downed trees, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above but with flow into branches	0.100	0.150	0.200
5. Dense willows, summer, straight	0.110	0.150	0.300

Table 12 Typical Manning's n values for floodplains, after Chow (1959)

8.2.3 Scope for improvements

The use of Manning's n remains a crude method to represent vegetation, especially the dynamic, heterogeneous nature of floodplain woodland. Attempts have been made to improve the methodology for determining Manning's n for shrubs and woody vegetation, including by relating to measurements of horizontal plant density, stem diameter, and the height and width of the leaf mass of a typical plant. Investigations have shown that the plant stiffness modulus may be predicted with good accuracy by using stem diameter and plant height in a non-linear relationship. New relationships have therefore been developed for the calculation of Manning's n values for both submerged and partially submerged vegetation. Those for flow through vegetated channels still require a trial and error solution when both depth and velocity are unknown, but simplify the solution technique significantly.

An alternative approach is to use hydrodynamic drag force, which acts as a sink term in the momentum equations. Typically the drag force exerted by floodplain woodland has been modelled using rigid cylinders, for which the corresponding drag coefficients are well known. While this may be somewhat valid for isolated emergent vegetation such as reeds, or trees without low-hanging branches, research has shown that in practice this approach is not applicable. For instance, the sheltering effect of many plants or stems in relative close proximity will reduce the effective drag coefficient. Moreover, it has been demonstrated that vegetation cannot be assumed to be rigid under load and that this in turn also reduces the effective drag coefficient. The a priori determination of suitable drag coefficients using measurable parameters of the vegetation, such as the stem diameter and planting density is the focus of current research.

A summary of the different hydraulic modelling software programmes in use and how they incorporate woodland roughness is given in Table 13.

8.3 Methodology for monitoring and measuring the short and long-term benefits of woodland creation for the water environment and flood management

The review in Section 3.1 identified a lack of direct measurements quantifying the impacts of woodland creation on flood flows and on the effectiveness of targeted planting to reduce diffuse pollution. Key recommendations on research needs from the Woodland for Water Report (Nisbet *et al.*, 2011a) remain outstanding, namely:

- 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.
- 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.
- 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.

Model	Capabilities	Comments	Representation of woodland
HEC-RAS	Steady and unsteady one-dimensional (1D) flood flow simulation in river channels	Produced in the US by the Army Corps of Engineers. Widely used in the UK by consultants for EA projects	Primarily Manning's n
ISIS	Steady and unsteady 1D flood flow simulation in river networks	Suited to simulate open channels and floodplains. Commonly used by the EA and others	Primarily Manning's n
TELEMAC	Unsteady two-dimensional (2D) simulation of river floods	Research applications undertaken in UK by HR Wallingford and University of Bristol	Bed roughness parameters
TUFLOW	Powerful computational engine that provides 1D and 2D solutions of the free-surface flow equations to simulate flood and tidal wave propagation.	BMT Group / Halcrow in UK	Primarily Manning's n
River2D	2D depth averaged finite element hydrodynamic model	Used for river flood simulation and fish habitat studies	Roughness parameter "ks". Better reflects changes in the friction factor due to flow depth
DIVAST	2D depth averaged steady and unsteady simulation of flow and solute transport	University of Cardiff	Drag coefficient derived from laboratory flume experiments
DIVAST-TVD	2D depth averaged steady and unsteady simulation of sub- and super-critical flows		
TRIVAST	Unsteady 3D simulation of hydrodynamics		

Table 13 Brief summary of typical hydraulic modelling software used for river flood analysis

This section of the report considers a methodology for monitoring and measuring the short and long-term benefits of woodland creation for the water environment and flood management. It describes issues related to site selection, study design and measurements/instrumentation.

8.3.1 Site selection

In principle, the same site could be used to measure the impact of woodland creation on both flood flows and diffuse pollution, although this is likely to further constrain site selection. For flood management, a decision would need to be made on whether to focus on the effects of woodland planting in the wider catchment, within the riparian zone or on the floodplain. Measurements are available for the impact of planting woodland shelterbelts on soil infiltration rates and hillslope run-off pathways at Pont Bren in mid Wales (Caroll et al., 2004), while assessments of the effects of riparian woodland creation and/or the construction of large woody debris dams are ongoing at Pickering in North Yorkshire and in Great Triley Wood near Abergavenny in S Wales. Data gaps are greatest for floodplain woodland and although monitoring is in place to assess interactions with flood flows for new planting (in the upper River Parrett catchment in Somerset) and existing semi-natural floodplain woodland (at Great Triley Wood), both of these studies involve small woodlands (5-6 ha). There remains a need for direct measurements to evaluate the impact of a sizeable area (20-50 ha) of floodplain woodland on flood flows, ideally straddling both sides of the floodplain and involving sections managed for SRC and/or SRF.

A mid catchment location is considered best for a floodplain woodland study to avoid limitations posed by steeper channel gradients and narrow floodplains within upper reaches and wide floodplains and possible tidal influences in lower reaches. It would also be necessary to exclude sites where flows are constrained/controlled by man-made features or natural topography, and where assets are at risk from the backing-up of flood waters upstream of the planted woodland. Sites with deeply incised river channels are likely to require restoration work (e.g. the construction of large woody debris dams) to reconnect the river with its floodplain and promote interactions between flood flows and the planned woodland.

Site selection for an assessment of the benefits of woodland creation for the wider water environment would similarly be guided by the preferred aspect of study. Results are available from overseas studies of the impact of planting riparian woodland buffer areas and field edge shelterbelts on a range of diffuse water pollutants (Nisbet *et al.*, 2011a), but generally lacking on the effects of planting on infiltration basins or as part of Sustainable Drainage Systems (SuDS). However, the greatest gap concerns an evaluation of the integrated effect of a number of these targeted measures at reducing one or more diffuse pollutants at the sub-catchment or catchment scale. This would require the selection of appropriate sites within a water body known to be failing or at risk of failing good water status for the target pollutant(s) that could be potentially addressed by woodland planting (mainly sediment, nitrate, phosphate and pesticides derived from agricultural sources).

Land owner willingness to plant and manage new woodland in the desired locations would be a major factor influencing site selection. Public land would allow greater flexibility in study design and planning but need to consider wider constraints such as landscape and conservation designations. It is likely that additional funding would be required to incentivise and secure private land owner interest. Catchment Sensitive Farming Delivery Initiative (CSFDI) or related Priority and Demonstration catchments are potentially ideal locations, although care would be required to avoid confounding factors such as the adoption or trialling of existing farm good practice measures to reduce diffuse pollution or rapid runoff in experimental and control catchments.

8.3.2 Study design

The preferred study would be a before and after intervention plus control, paired catchment or upstream-downstream design (BACI). This would be particularly challenging for a floodplain woodland study in view of the difficulty of maintaining the control site in a relatively undisturbed state over the long-term. Any significant land use or management changes to the control could affect its flood response and thus make it difficult to disentangle any background changes in runoff response, e.g. due to climate change. A paired catchment design with independent control would be better than an upstream-downstream comparison but more difficult to manage.

It would be desirable to collect a number of years of baseline data prior to planting, although funding and time pressures are likely to constrain this unless a site can be found with an existing flow record. A minimum period of one year of measurements would be required to allow a basic between-site characterisation/comparison, but three or more years would be preferable. The longer the baseline period, the greater the chance of capturing an extreme event to form the basis of assessing future change post woodland planting.

The minimum length of post-planting study would be five years and often significantly longer than this. The time scale for woodland effects to become established will depend on the nature of the planting and associated intervention measures. Channel restoration works or the construction of LWD dams to improve connectivity between flood flows and floodplain may have an immediate effect, although likely to evolve over subsequent years as the dams build or break and restoration measures bed-in. Planting and associated works to aid tree establishment (e.g. cultivation, use of tree shelters or fencing) could be expected to have limited influence on flood response and it will not be until the trees are between 5 and 10 years old that they will start to offer significant resistance to flood flows. This resistance will depend on tree spacing and design, the extent of shrub planting, and type of woodland system, all of which could be factored into the study.

The most rapid impact would result from the planting of short rotation coppice (2-4 years) or short rotation forestry (8-20 years), although these systems would be subject to more frequent and regular harvesting interventions, which would negate or reduce vegetation resistance for one or more years following harvesting (compared to baseline; e.g. due to lack of ground vegetation or impact of machine trafficking). For more 'typical' native floodplain woodland, hydraulic resistance will continue to develop through time (80+ years) as the woodland becomes established, matures, contributes dead wood and potentially influences channel development and the formation of alluvial features. Monitoring would therefore need to extend into the very long-term to evaluate the full effects of the creation of a natural floodplain woodland.

The study design for assessing water quality benefits would depend on whether there was a desire to measure the effects of individual woodland measures (such as variously placed woodland buffers) or their combined impact. As with floodplain woodland, it would be necessary to constrain changes in land use and management in the control site to facilitate the before and after assessment. The impacts of woodland creation on water quality are likely to be quicker to establish, depending on the type of pollutant. Planting will lead to a cessation of agricultural nutrient and pesticide inputs, and soil disturbance regime, which could have a short-term response. Other effects that are reliant on pollutant interception, uptake and removal by trees could take 2-5 years to become established, while those dependent on providing a barrier effect, e.g. for pesticide spray drift, may need 10+ years.

8.3.3 Measurements & Instrumentation

An assessment of the impact of floodplain woodland on flood flows could involve a range of measurements. A basic need is to measure river channel flows on a semi-continuous basis (e.g. 15 min) so that changes in parameters such as time to peak, peak height, peak duration and frequency of different sized flood events can be determined. Ideally, this would involve the installation of control structures within study reaches. However, in view of their high cost and limitations for containing more extreme flows, the normal approach is simply to install water level recorders within suitable reaches. Self-contained pressure transducer type recorders with on-board data logging and power supply are simple, cost-effective and reliable.

Selected reaches should have stable channels and river banks, with a gentle gradient and smooth water surface. Water level recorders are best placed within a protective stilling well, which must be securely attached to the bank to withstand high flows but follow the bankside profile so as not to inhibit river flows. Sites need to be accessible for safely downloading data (e.g. at 6-8 weekly intervals) or linked to a telemetry system for remote data transfer.

It would also be advantageous to measure flood levels at one or more points on the floodplain to assess local variability in flood levels and relate to levels within river channels. This would be necessary where there was a desire to look at the effect of woodland design and management factors, and would be best done in combination with water velocity measurements, as described below.

Preferably, sites should have LIDAR coverage to characterise surface topography at a minimum resolution of 2 m, supplemented by a number of river channel cross sections. This will aid scaling of the water level results and facilitate modelling work. If LIDAR data are unavailable then as a minimum cross section surveys of the full floodplain width and river channel(s) should be carried out. The required spacing of cross sections would vary between sites, depending on reach length, channel morphology and complexity.

River channel sections with water level recorders should be rated across a range of events to allow level measurements to be converted to discharge values. This is best achieved by temporarily installing a velocity bed profiler to take continuous water level and velocity measurements until a reasonable rating is obtained. Instruments are best fixed onto a concrete plinth at ground level. Conversion to discharge will aid interpretation of the data from a flood risk management perspective. Velocity profilers can also be installed on the floodplain to assess local interaction between flood flows and woodland structure.

Once a floodplain woodland has been planted and begun to establish, a vegetation survey repeated every 5-10 years can be helpful to quantify the development of hydraulic roughness. It would also be appropriate to monitor changes to any constructed LWD dams or to channel and floodplain morphology in general. Such data will aid interpretation of future changes in flood flows and assist modelling studies.

Water quality measurements generally rely on regular, manual collection of water samples from each monitoring point. A monthly sampling regime is the norm for long-term studies but best supplemented by fortnightly or weekly sampling during periods of significant change, such as any ground preparation and harvesting work. Shorter-term campaigns of more intensive sampling using automated samplers at daily or sub-daily frequencies can help to characterise high flow conditions, when some pollutants (e.g. sediment) often reach a peak in concentration. Alternatively, continuous monitoring probes can be installed to record certain parameters such as water turbidity and temperature. Water samples need to be analysed by a qualified laboratory for each pollutant of concern.

For most pollutants, it is helpful to also measure water flows so that pollutant concentrations can be converted to loads. This would require the installation of water level recorders and possibly flow control structures, as described above. Monitoring elements of freshwater biology such as fish and benthic macroinvertebrates would assist interpretation of results in terms of the impact on ecological status.

On some sites, more detailed sampling and analysis of soil drainage waters would aid understanding of the effects of the woodland measures, including the role of woodland design and management factors. For example, soil waters can be sampled at incremental distances across a buffer area to look at the influence of buffer width or structure. Similarly, supplementary studies could assess the effect of varying tree species or woodland management system on pollutant retention. These measurements could be undertaken at various periods throughout the establishment and development of the planted woodland.

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Modelled phosphorus and sediment yield to watercourses spatial data derived using ADAS LAND USE DATABASE 2010 created under licence for the FC England by Prof Adrain Collins & Dr Yusueng Zhang, 2012.

EA Diffuse Pollution Risk Model
Spatial data for targeting land use change options to meet water quality objectives in English priority areas. Chris Burgess, Environment Agency 2012

Catchment Flood Management Plans (CFMP)
http://www.environment-agency.gov.uk/research/planning/114

Severn Tidal Tributaries December 2009
River Severn December 2009
Wye and Usk January 2010
River Trent December 2010

Catchment Abstraction Management Strategies (CAMS)
http://www.environment-agency.gov.uk/business/topics/water/119943.aspx

Derbyshire Derwent
Dove
Idle and Torne update March 2008
Lower Trent and Erewash
Severn Corridor update March 2007
Severn Uplands part 1, part 2 and update June 2006
Severn Vale
Shropshire and Middle Severn
Soar
Staffordshire and Trent Valley
Tame, Anker and Mease
Trent Corridor
Warwickshire Avon
Worcester Middle Severn

River Basin Management Plans
Severn: http://www.environment-agency.gov.uk/research/planning/124941.aspx
Humber: http://www.environment-agency.gov.uk/research/planning/124803.aspx
http://cdn.environment-agency.gov.uk/gene0910bsqr-e-e.pdf

Internal Drainage Board Water Level Management Plans (WLMP)
http://www.environment-agency.gov.uk/static/documents/Research/Midlands_12_13_published_programme.xls

Water Framework Directive Programme of Measures - RBMP web page
http://www.environment-agency.gov.uk/static/documents/Business/WFD_investigations_programme_Detail.xls

County Biodiversity Action Plans (BAP)
These cover all priority UK BAP habitats, including wet woodland. They typically record the current extent and condition of the key sites within each county and include action plans for their enhancement and targets for habitat expansion. Details of the published plans are available on the archived BARS1 website:
http://ukbars.defra.gov.uk/archive/plans

River Habitat Action Plans (HAP)
Including River Mease SSSI/SAC Restoration scheme, East Midlands Strategic River Corridors Initiative and West Midlands Biodiversity Enhancement Areas. An interactive map of in-stream river restoration projects in the region is available on the River Restoration Centre website: http://www.therrc.co.uk/uk_midlands.php

SSSIs
Details of most international and national designated sites are available in the SSSI citations from the Natural England website.
http://www.sssi.naturalengland.org.uk/Special/sssi/search.cfm

National Character Areas
Landscape character assessment of the features that define the landscape of each area. Reports describing individual areas, differences between these, how the landscape character has arisen and how it is changing are available on line:
http://www.naturalengland.org.uk/publications/nca/eastmidlands.aspx and
http://www.naturalengland.org.uk/publications/nca/westmidlands.aspx

Appendix 1a: Derived GIS data sets

The following spatial datasets are supplied in an ESRI ArcGIS10 Personal Geodatabase called **OM Midlands 2012:**

- **PNFW**: Potential New Floodplain Woodland
- **HPAF**: Priority areas for woodland creation to reduce flooding
- **HPADP**: High priority areas for woodland planting to reduce diffuse pollution
  1. HP_SED - high priority area to reduce diffuse agricultural sediment pressure in vulnerable river waterbodies
  2. HP_PHOS - high priority area to reduce diffuse agricultural phosphorus pressure in failing river waterbodies
  3. HP_NIT - high priority area to reduce diffuse agricultural nitrate pressure in vulnerable areas
  4. HP_PEST - high priority area to reduce diffuse agricultural pesticide pressure in vulnerable areas
  5. HP_GW_SPZ - high priority area to reduce diffuse agricultural nitrate and pesticide pollution to groundwater resources
  6. HP_NUM – number of diffuse pollutant pressures potentially mitigated by woodland creation
- **PNW_HPAF**: Priority new wider woodland to reduce downstream flood risk: PNWW
- **PNRW_HPAF**: Priority new riparian woodland to reduce downstream flood risk: PNRW
- **PNFW_HPAF**: Priority new floodplain woodland to reduce downstream flood risk: PNFW
- **PNW_HPAC**: Combined opportunities for woodland planting to address both FRM and WFD
- **EA_RWB_FDP_PH**: Environment Agency WFD river waterbodies failing GES due to acidification comprising tributary sub-catchments with >20% woodland cover
- **FC_FB_FDP_PH**: Forestry Commission forest blocks within river waterbodies failing GES due to acidification comprising tributary sub-catchments with >20% woodland cover
- **EA_RWB_FDP_HS**: Environment Agency WFD river waterbodies failing GES due to poor hydrological status comprising tributary sub-catchments with >20% woodland cover
- **FC_FB_FDP_HS**: Forestry Commission forest blocks within Groundwaterbodies with poor quantitative status or River waterbodies failing GES due to poor hydrological status; in which there are tributary sub-catchments with >20% woodland cover
- **CONIFER_20m**: Conifers within 20 m of a watercourse
- **CON_Midlands**: Constraints to woodland planting
- **SEN_Midlands**: Sensitivities to woodland planting
- **Watersheds_50m**: Tributary sub-catchments modelled using 50m DTM

Appendix 1b: GIS data sources

Environment Agency spatial datasets available for access and licensing from DataShare website:
http://www.geostore.com/environment-agency/

- Detailed River Network (AfA036)
- WFD spatial datasets [River Basins, Management Catchments, Waterbodies, Classification and Typology dataset]
- WFD River Water body Classification and Status Review (AfA082)
- WFD Groundwaterbody Classification and Status Review (AfA087)
- Nitrate Vulnerable Zones (NVZ) – Surface Waters (England) (AfA073)
- Source Protection Zones [Merged] (AfA029)
- Flood Map (AfA031)
- Statutory Main River
- Catchment Flood Management Plan policy units [with woodland actions]
- Existing flood defences which isolate river from adjacent floodplain
- Water storage areas – Washlands
- National LIDAR-derived mapping of riparian tree and shade cover
- Defra test demonstration catchments
- Existing habitat enhancement projects
- Spatial data for targeting land use change options to meet water quality objectives in English priority areas. Chris Burgess, Environment Agency 2012

Natural England spatial datasets available via the internet:
http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp

- Agricultural Land Classification
- Priority BAP habitats
- Catchment Sensitive Farming Initiative project boundaries
- Natural Character Areas
- Nature Improvement Areas
- Registered Common Land
- Land management Initiatives
- Digital Boundary data for designated sites
  - RAMSAR
  - SAC
  - SPA
  - NNR
  - SSSI
  - LNR
- Areas of Outstanding Natural Beauty
- National Parks

Forestry Commission data

- Existing Woodland: National Forest Inventory 2011

- Forest Blocks: Subcompartment database 2012
- FC England EWGS Additional contribution – woodlands for water 2012/13
- FC England EWGS Priority areas 2009/10
- FC England EWGS Additional contribution – priority areas 2012/13
- Climate Zones for Forestry

English Heritage spatial datasets available for download via the internet:
http://services.english-heritage.org.uk/NMRDataDownload/
- Scheduled Monuments
- Registered Parks & Gardens
- Registered Battlefields
- World Heritage Sites

National spatial datasets available for download from the **Defra MAGIC website**:
http://magic.defra.gov.uk/DataDoc/datadoc.asp
- RSPB Reserves
- National Grid
- National Forest
- Land Management Initiatives
    - DerwentWISE project boundary
    - Derwent Land Management project
    - Clough Woodland Project

Licensed spatial datasets used in the project:
- Ordnance Survey – Meridian 2: 50k digital mapping of urban centres, road network, railways and waterbodies
- OS Land-form PROFILE: Elevation DTM
- NSRI, Cranfield University – National Soil map: digital soil association data which were reclassed to derive Hydrology of Soil Types (HOST), Standard Percentage Runoff and vulnerability to structural degradation leading to accelerated runoff
- British Geological Survey - Geology
- Countryside Survey, CEH - Landcover2000
- MOD holdings
- ADAS PSYCHIC [Phosphorus and Sediment Yield Characterisation In Catchments] modelled phosphorus and sediment yield to watercourses (Collins & Zhang, 2012)
- Natural England - Peatlands in England: spatial data for deep peaty soils in England

Appendix 2: Tables giving breakdown of priority areas, constraints and sensitivities (ha & %) for woodland creation in main river and relevant priority catchments in the Midlands Region.

Midlands_final_report_statistics.xls

Appendix 2: Table 1a	Area	Existing woodland		Constraints (100 m grid)		Sensitivities (100 m grid)		Land free from CON & SEN
		Area	%	Area	%	Area	%	%
Midlands Region	**2,146,302**	**196,522**	**9**	**636,644**	**30**	**475,717**	**22**	**48**
EA WFD Surface Water Management Catchments – Integrated Catchment Management Pilot								
Derbyshire Derwent - EA Pilot	120,423	11,201	9	36,676	30	56,051	47	23
Dove - WCI	101,671	6,436	6	21,277	21	36,127	36	44
Idle & Torne - WCI	132,600	16,683	13	43,239	33	24,606	19	49
Lower Trent & Erewash - WCI	231,800	14,219	6	64,654	28	40,126	17	55
Middle Dee	2,758	226	8	553	20	313	11	69
Severn Uplands - WCI	138,626	4,599	3	15,031	11	16,709	12	77
Severn Vale - WCI	145,696	20,321	14	50,525	35	44,271	30	35
Shropshire Middle Severn - WCI	110,772	7,190	6	25,615	23	17,556	16	61
Soar	138,625	6,698	5	38,345	28	16,929	12	60
Staffordshire Trent Valley - WCI	134,447	12,030	9	47,306	35	18,678	14	51
Tame Anker and Mease - DEFRA Pilot	179,440	11,271	6	82,059	46	19,747	11	43
Teme - DEFRA Pilot	152,923	18,189	12	36,049	24	62,575	41	36
Upper Dee	4,232	254	6	996	24	737	17	59
Warwickshire Avon - EA Pilot	287,322	17,453	6	71,828	25	57,126	20	55
Witham	1,569	130	8	253	16	229	15	69
Worcestershire Middle Severn - WCI	151,114	19,071	13	55,396	37	19,042	13	51
Wye – WCI & Keeping rivers cool pilot	184,812	20,706	11	46,841	25	44,895	24	50

Appendix 2: Table 1b	Area	Existing woodland		Constraints (100 m grid)		Sensitivities (100 m grid)		Land free from CON & SEN
		Area	%	Area	%	Area	%	%
Catchment Flood Management Plan - policy units with agreed woodland actions								
Avon Tributaries	121,535	8,329	7	23,771	20	37,190	31	50
Cheltenham and NE Gloucester	17,537	1,309	7	7,361	42	5,043	29	29
Coventry Cluster	33,132	1,996	6	15,182	46	3,363	10	44
Forest of Dean and Cinderford Streams	12,751	6,740	53	8,759	69	605	5	27
Kidderminster and Bromsgrove	33,101	3,107	9	11,127	34	4,316	13	53
Leadon	32,483	3,658	11	8,387	26	7,024	22	53
Lower Severn Corridor	33,324	2,057	6	8,218	25	9,590	29	47
Middle Avon	11,424	468	4	3,183	28	2,560	22	50
Middle Severn Corridor	77,464	11,379	15	26,541	34	10,504	14	52
North Shropshire Tributaries	105,093	6,427	6	22,517	21	17,085	16	62
Redditch	16,779	1,659	10	6,309	38	1,410	8	54
River Arrow and River Alne	23,015	2,051	9	6,217	27	2,810	12	61
Rugby	8,353	234	3	3,063	37	1,108	13	50
Severn Vyrnwy Confluence	10,856	558	5	1,908	18	2,932	27	55
Sherwood	116,360	17,503	15	40,590	35	14,979	13	52
South Shropshire Tributaries	37,070	3,029	8	7,224	19	11,500	31	49
Telford and Black Country	60,961	6,201	10	25,752	42	5,872	10	48
Teme	144,547	17,787	12	34,239	24	61,368	42	34
Tewkesbury	2,990	61	2	1,019	34	1,090	36	29
Upper Avon	62,383	2,286	4	10,805	17	6,127	10	73
Nature Improvement Areas								
Birmingham and the Black Country	62,470	3,365	5	51,810	83	2,653	4	13
Dark Peak	13,754	741	5	1,565	11	12,154	88	0
Humberhead Levels	28,822	1,371	5	4,656	16	11,197	39	45
Meres and Mosses	21,458	863	4	3,926	18	5,525	26	56

Appendix 2: Table 1c	Area	Existing woodland		Constraints (100 m grid)		Sensitivities (100 m grid)		Land free from CON & SEN
		Area	%	Area	%	Area	%	%
Catchment Sensitive Farming Initiative Project Areas								
Peak District Dales	65,485	4,741	7	13,848	21	37,019	57	22
River Eye	18,273	561	3	2,559	14	1,938	11	75
River Leadon	33,077	3,724	11	8,564	26	6,865	21	53
River Lugg	83,855	8,019	10	18,289	22	13,955	17	62
River Mease	17,011	1,447	9	5,059	30	1,541	9	61
Priver Perry	17,074	798	5	3,377	20	3,437	20	60
River Roden	24,583	1,343	5	4,815	20	4,024	16	64
River Teme	155,041	18,213	12	36,043	23	62,587	40	36
River Tern	53,601	3,845	7	13,706	26	7,533	14	60
River Worfe	25,947	2,397	9	7,460	29	2,923	11	60
River Wye	106,727	12,010	11	27,129	25	30,387	28	46
West Midlands Meres and Mosses	13,106	1,051	8	2,896	22	2,352	18	60
EA Pilot & Restoration Catchment Project Areas								
River Ecclesborne catchment	5,950	388	7	1,572	26	667	11	62
River Trent restoration scheme	7,180	490	7	3,011	42	1,168	16	42
River Mease SSSI/SAC restoration scheme	17,154	1,464	9	5,059	29	1,605	9	39
Stafford Brook SSSI scheme	3,293	1,207	37	1,833	56	928	28	16
Upper Fleet catchment	2,342	75	3	458	20	374	16	64
Additional Projects								
Derwent Land Management Project	109,248	10,798	10	31,120	28	54,104	50	22
The National Forest	49,195	6,698	14	18,638	38	5,288	11	51
Clough Woodland project area	68,893	7,220	10	15,975	23	47,412	69	8
DerwentWISE project area	7,067	1,493	21	6,158	87	245	3	9

Appendix 2: Table 2a	Woodland opportunities to address both FRM & WFD		Potential New Floodplain Woodland	Priority land for FRM		Priority land for diffuse pollution reduction	
	Both	*Both - free from SEN*		Area	%	Area	%
Midlands Region	**191,945**	***34,052***	**118,329**	**518,915**	**24**	**466,984**	**22**
EA WFD Surface Water Management Catchments							
Derbyshire Derwent	9,487	*4,503*	3,701	24,291	20	19,945	17
Dove	8,774	*2,398*	6,683	34,518	34	14,615	14
Idle & Torne	8,612	*1,010*	4,726	15,264	12	38,449	29
Lower Trent & Erewash	33,002	*2,633*	19,583	58,249	25	71,892	31
Middle Dee	1,338	*176*	32	1,734	63	1,582	57
Severn Uplands	11,330	*2,573*	2,361	22,439	16	19,154	14
Severn Vale	4,065	*1,352*	7,267	28,819	20	12,481	9
Shropshire Middle Severn	15,216	*1,585*	6,003	29,868	27	35,040	32
Soar	23,525	*2,329*	8,410	64,741	47	34,067	25
Staffordshire Trent Valley	11,654	*1,134*	7,316	31,071	23	24,237	18
Tame Anker and Mease	10,032	*1,155*	10,039	31,225	17	30,893	17
Teme	3,542	*3,183*	6,877	14,477	9	20,671	14
Upper Dee	1,031	*215*	57	2,086	49	1,236	29
Warwickshire Avon	40,388	*7,582*	16,191	136,487	48	57,112	20
Witham	543	*89*	0	1,017	65	674	43
Worcestershire Middle Severn	5,422	*746*	5,561	15,671	10	23,858	16
Wye	3,984	*1,386*	13,522	6,957	4	61,078	33
Nature Improvement Areas							
Birmingham and the Black Country	292	*35*	874	1,826	3	571	1
Dark Peak	2,802	*2,793*	4	6,506	47	4,837	35
Humberhead Levels	1,918	*228*	105	3,298	11	9,921	34
Meres and Mosses	2,314	*341*	1,197	5,236	24	5,495	26

Appendix 2: Table 2b	Woodland opportunities to address both FRM & WFD		Potential New Floodplain Woodland	Priority land for FRM		Priority land for diffuse pollution reduction	
	Both	*Both - free from SEN*		Area	%	Area	%
Catchment Flood Management Plan – policy units with agreed woodland actions							
Avon Tributaries	20,574	*5,519*	*7,265*	63,473	52	5,614	5
Cheltenham and NE Gloucester	1,742	*682*	*1,101*	5,724	33	962	5
Coventry Cluster	787	*37*	*1,546*	5,361	16	1,868	6
Forest of Dean	11	*0*	*79*	70	1	125	1
Kidderminster and Bromsgrove	1,031	*63*	*936*	3,581	11	1,113	3
Leadon	863	*261*	*1,752*	3,746	12	1,600	5
Lower Severn	625	*185*	*3,783*	9,938	30	269	1
Middle Avon	328	*24*	*1,712*	3,394	30	232	2
Middle Severn	2,980	*340*	*4,886*	7,926	10	2,732	4
N. Shropshire Tributaries	14,809	*1,694*	*5,961*	28,030	27	6,786	6
Redditch	1,604	*140*	*379*	6,020	36	770	5
Rivers Arrow and Alne	2,056	*401*	*1,048*	9,732	42	1,123	5
Rugby	858	*149*	*555*	3,428	41	357	4
Severn Vyrnwy Confluence	1,011	*140*	*701*	3,323	31	413	4
Sherwood	8,994	*589*	*4,868*	15,339	13	8,605	7
South Shropshire Tributaries	8,467	*2,244*	*915*	15,706	42	2,870	8
Telford and Black Country	2,496	*225*	*1,109*	6,809	11	3,641	6
Teme	3,544	*3,172*	*6,392*	14,066	10	4,794	3
Tewkesbury	279	*157*	*510*	1,214	41	165	6
Upper Avon	12,922	*1,088*	*2,770*	41,058	66	2,692	4

Appendix 2: Table 2c	Woodland opportunities to address both FRM & WFD		Potential New Floodplain Woodland	Priority land for FRM		Priority land for diffuse pollution reduction	
	Both	*Both - free from SEN*		Area	%	Area	%
Catchment Sensitive Farming Initiative Project Areas							
Peak District Dales	5,085	*2,483*	1,212	21,103	32	7,114	11
River Eye	4,179	*3,651*	666	13,057	71	4,858	27
River Leadon	884	*630*	1,721	3,987	12	5,554	17
River Lugg	1,442	*1,113*	8,029	2,477	3	32,050	38
River Mease	1,218	*1,079*	715	2,428	14	6,134	36
Priver Perry	1,356	*1,121*	952	4,507	26	4,218	25
River Roden	4,177	*3,850*	1,395	7,263	30	9,192	37
River Teme	3,555	*377*	6,862	14,500	9	20,759	13
River Tern	7,626	*6,855*	3,140	13,509	25	17,130	32
River Worfe	1,273	*1,192*	459	3,136	12	8,056	31
River Wye	2,494	*1,441*	5,470	4,300	4	30,496	29
West Midlands Meres and Mosses	1,438	*1,228*	400	2,704	21	3,605	28
EA Pilot & Restoration Catchment Project Areas							
River Ecclesborne catchment	2,019	*326*	214	2,550	43	2,779	47
River Trent scheme	369	*39*	1,185	814	11	1,038	14
River Mease SSSI/SAC restoration scheme	1,253	*1,114*	766	2,442	14	6,186	36
Stafford Brook SSSI scheme	0	*0*	213	6	0	1	0
Upper Fleet catchment	534	*0*	30	717	31	1,065	45
Additional projects							
Derwent LM Project	8,833	*4,457*	1,925	22,977	21	17,701	16
The National Forest	3,221	*255*	2,579	12,842	26	8,984	18
Clough Woodland project	4,430	*3,871*	1,119	14,639	21	8,419	12
DerwentWISE project area	59	*6*	4	176	2	86	1

Appendix 2: Table 3a	PRIORITY AREAS FOR WOODLAND CREATION FOR FLOOD MITIGATION					
	Priority New Wider Woodland	*PNWW - free from sensitivities*	Priority New Riparian Woodland	*PNRW - free from sensitivities*	Priority New Floodplain Woodland	*PNFW - free from sensitivities*
Midlands Region	**434,908**	***350,891***	**62,323**	***39,463***	**21,703**	***7,486***
EA WFD Surface Water Management Catchments						
Derbyshire Derwent	19,278	*8,741*	4,472	*1,090*	541	*47*
Dove	28,202	*16,511*	5,379	*2,340*	937	*243*
Idle & Torne	13,532	*11,755*	1,513	*1,144*	219	*74*
Lower Trent & Erewash	49,092	*45,884*	6,651	*5,532*	2,506	*1,304*
Middle Dee	0	*0*	1,734	*1,510*	20	*6*
Severn Uplands	18,814	*14,310*	3,083	*1,970*	542	*178*
Severn Vale	22,978	*15,742*	3,873	*1,915*	1,968	*585*
Shropshire Middle Severn	25,349	*23,555*	2,923	*2,106*	1,596	*561*
Soar	56,106	*52,192*	6,629	*5,247*	2,006	*741*
Staffordshire Trent Valley	26,535	*24,380*	3,554	*2,740*	982	*267*
Tame Anker and Mease	26,034	*23,781*	3,586	*2,574*	1,605	*479*
Teme	11,989	*2,809*	2,129	*440*	359	*52*
Upper Dee	2,055	*1,690*	11	*4*	20	*1*
Warwickshire Avon	115,088	*93,777*	14,138	*9,143*	7,261	*2,518*
Witham	1,015	*805*	2	*2*	0	*0*
Worcestershire Middle Severn	13,523	*11,524*	1,641	*1,188*	507	*210*
Wye	5,318	*3,436*	1,005	*518*	634	*220*

Appendix 2: Table 3b	PRIORITY AREAS FOR WOODLAND CREATION FOR FLOOD MITIGATION					
	PNWW	*PNWW - free from sensitivities*	PNRW	*PNRW - free from sensitivities*	PNFW	*PNFW - free from sensitivities*
Catchment Flood Management Plan – policy units with agreed woodland actions						
Avon Tributaries	53,235	*36,608*	6,605	*3,513*	3,633	*1,233*
Cheltenham and NE Gloucester	4,349	*2,999*	848	*404*	527	*133*
Coventry Cluster	4,732	*4,544*	476	*409*	153	*85*
Forest of Dean and Cinderford Streams	47	*43*	15	*6*	8	*0*
Kidderminster and Bromsgrove	2,994	*2,750*	393	*303*	194	*93*
Leadon	2,834	*2,128*	555	*301*	357	*148*
Lower Severn	7,989	*6,024*	1,162	*636*	787	*299*
Middle Avon	2,963	*2,693*	266	*172*	165	*46*
Middle Severn	6,837	*6,112*	763	*564*	326	*104*
North Shropshire Tributaries	23,728	*21,960*	2,849	*2,058*	1,453	*500*
Redditch	5,088	*4,678*	761	*608*	171	*61*
Rivers Arrow & River Alne	8,220	*7,476*	970	*674*	542	*135*
Rugby	2,690	*2,394*	406	*236*	332	*96*
Severn Vyrnwy Confluence	2,791	*2,234*	427	*255*	105	*20*
Sherwood	13,507	*12,280*	1,592	*1,330*	240	*94*
South Shropshire Tributaries	13,055	*9,169*	2,262	*1,369*	389	*156*
Telford and Black Country	5,930	*5,379*	647	*492*	232	*98*
Teme	11,672	*2,489*	2,053	*387*	341	*42*
Tewkesbury	833	*603*	144	*33*	237	*26*
Upper Avon	34,998	*32,771*	4,212	*3,276*	1,848	*739*

Appendix 2: Table 3c	PRIORITY AREAS FOR WOODLAND CREATION FOR FLOOD MITIGATION					
	PNWW	*PNWW - free from sensitivities*	PNRW	*PNRW - free from sensitivities*	PNFW	*PNFW - free from sensitivities*
EA Pilot & Restoration Catchment Projects						
River Ecclesborne catchment	2,086	*1,879*	378	*283*	86	*14*
River Trent restoration scheme	728	*681*	61	*50*	25	*5*
River Mease SSSI/SAC Restoration scheme	2,126	*2,010*	198	*136*	118	*43*
Stafford Brook SSSI scheme	0	*0*	1	*0*	6	*0*
Upper Fleet catchment	640	*640*	77	*77*	0	*0*
Nature Improvement Areas						
Birmingham and the Black Country	1,559	*1,398*	233	*184*	34	*4*
Dark Peak	4,568	*24*	1,938	*10*	0	*0*
Humberhead Levels	2,818	*2,349*	473	*339*	7	*1*
Meres and Mosses	4,433	*3,961*	599	*401*	204	*63*
Additional Projects						
Derwent Land Management Project	18,100	*7,694*	4,342	*992*	535	*46*
The National Forest	11,265	*10,145*	1,233	*963*	344	*137*
Clough Woodland project area	11,173	*1,533*	3,208	*160*	258	*8*
DerwentWISE project area	162	*153*	13	*12*	1	*0*

Appendix 2: Table 4a	PRIORITY AREAS FOR WOODLAND CREATION TO CONTROL DIFFUSE POLLUTION									
	P	*P - free from sensitivities*	Sediment	*Sediment - free from sensitivities*	Nitrate	*Nitrate - free from sensitivities*	Pesticides	*Pesticides - free from sensitivities*	GW resource	*GW resource - free from sensitivities*
Midlands Region	**94,243**	***74,624***	**55,149**	***38,920***	**324,939**	***245,369***	**118,621**	***86,129***	**71,474**	***54,722***
EA WFD Surface Water Management Catchments										
D. Derwent	7,004	*5,551*	996	*778*	11,192	*5,132*	11,651	*5,097*	692	*464*
Dove	8,401	*7,059*	2,017	*512*	5,998	*4,548*	81	*77*	1,333	*1,191*
Idle & Torne	309	*307*	342	*245*	31,465	*22,129*	23,510	*17,908*	22,248	*15,799*
Lower Trent & Erewash	2,856	*2,537*	163	*163*	68,853	*55,954*	1,174	*922*	6,783	*5,725*
Middle Dee	1,580	*1,373*	117	*116*	0	*0*	0	*0*	0	*0*
Severn Uplands	9,516	*6,679*	392	*325*	9,142	*7,369*	8,810	*7,039*	2,449	*2,084*
Severn Vale	5,763	*3,813*	2,405	*2,178*	4,505	*3,206*	1,635	*305*	813	*280*
S. Middle Severn	10,075	*9,158*	1,682	*1,432*	24,687	*20,282*	14,737	*12,252*	12,410	*10,009*
Soar	6,225	*5,422*	181	*129*	29,883	*25,574*	253	*142*	81	*76*
Staffordshire Trent Valley	10,307	*9,297*	269	*910*	13,917	*11,895*	3,939	*3,160*	3,175	*2,616*
Tame Anker and Mease	2,131	*1,839*	4	*4*	27,648	*23,300*	2,905	*2,546*	4,549	*3,876*
Teme	6,180	*2,111*	14,763	*7,065*	830	*646*	62	*54*	0	*0*
Upper Dee	886	*800*	493	*252*	7	*7*	0	*0*	0	*0*
Warwickshire Avon	6,438	*5,495*	777	*225*	49,380	*38,875*	3,040	*2,533*	2,955	*1,642*
Witham	119	*60*	0	*0*	555	*518*	0	*0*	0	*0*
Worcestershire Middle Severn	4,006	*3,432*	251	*251*	15,563	*1,281*	12,750	*10,071*	12,068	*9,811*
Wye	12,447	*9,691*	30,297	*24,337*	31,314	*24,655*	34,074	*24,023*	1,918	*1,150*

Appendix 2: Table 4b	PRIORITY AREAS FOR WOODLAND CREATION TO CONTROL DIFFUSE POLLUTION									
	P	*P - free from SEN*	Sediment	*Sediment - free from SEN*	Nitrate	*Nitrate - free from SEN*	Pesticides	*Pesticides - free from SEN*	GW	GW – free from SEN
Catchment Sensitive Farming Initiative Projects Areas										
Peak District Dales	4,238	*2,819*	1,684	*223*	1,758	*993*	250	30	465	415
River Eye	0	*0*	95	*78*	4,858	*4,174*	0	0	0	0
River Leadon	1,592	*1,156*	2,087	*1,861*	2,597	*2,114*	789	307	638	279
River Lugg	3,835	*3,171*	15,471	*13,061*	19,355	*15,433*	18,486	13,853	884	505
River Mease	66	*42*	0	*0*	5,696	*4,996*	800	685	1,708	1,531
Priver Perry	617	*538*	489	*319*	3,427	*2,676*	776	674	2,039	1,632
River Roden	3,257	*2,980*	423	*377*	6,766	*5,184*	2,242	1,722	1,071	646
River Teme	6,134	*2,101*	14,877	*7,177*	855	*667*	66	57	0	0
River Tern	5,218	*4,815*	813	*766*	10,802	*9,272*	9,565	8,054	8,176	6,759
River Worfe	0	*0*	0	*0*	6,901	*6,042*	5,966	5,072	6,746	5,846
River Wye	8,691	*6,611*	16,204	*12,632*	12,030	*9,288*	15,664	10,237	1,034	645
W.M. Meres & Mosses	992	*813*	0	*0*	2,779	*2,322*	1,540	1,275	842	746
Nature Improvement Areas										
Birmingham & the Black Country	0	*0*	0	*0*	395	*37*	176	3	235	3
Dark Peak	0	*0*	0	*0*	4,102	*4,094*	4,163	4,155	0	0
Humberhead Levels	0	*0*	0	*0*	9,886	*4,308*	4,980	1,829	5,901	2,285
Meres & Mosses	1,902	*1,585*	191	*3*	3,738	*1,087*	152	45	1,141	390

Appendix 2: Table 4c	PRIORITY AREAS FOR WOODLAND CREATION TO CONTROL DIFFUSE POLLUTION									
	P	*P - free from sensitivities*	Sediment	*Sediment - free from sensitivities*	Nitrate	*Nitrate - free from sensitivities*	Pesticides	*Pesticides - free from SEN*	GW	GW – free from SEN
EA Pilot & Restoration Catchment projects										
River Ecclesborne catchment	2,393	1,972	926	708	1,018	765	956	734	237	161
River Trent restoration scheme	218	218	0	0	899	694	5	5	57	6
River Mease SSSI/SAC scheme	66	42	0	0	5,748	5,022	780	684	1,623	1,447
Stafford Brook SSSI scheme	0	0	0	0	0	0	0	0	0	0
Upper Fleet catchment	0	0	0	0	1,065	935	0	0	0	0
Additional Projects										
The National Forest	713	687	0	0	8,058	7,034	1,033	896	1,064	891
Clough Woodland project area	1,218	652	1	1	5,359	4,893	5,886	5,444	73	60
DerwentWISE project area	5	0	0	0	17	12	72	6	4	2
Derwent LM Project	7,004	5,551	996	778	8,957	3,401	10,196	4,054	477	292

Appendix 2: Table 5a	PRIORITY AREAS FOR WOODLAND CREATION TO CONTROL MULTIPLE DIFFUSE POLLUTANTS Number of diffuse pollution pressures							
	1	*1 - free from sensitivities*	2	*2 - free from sensitivities*	3	*3 - free from sensitivities*	4	*4 - free from sensitivities*
Midlands Region	**319,664**	***246,401***	**102,048**	***76,985***	**40,627**	***31,564***	**4,645**	***3,882***
EA WFD Surface Water Management Catchments								
Derbyshire Derwent	10,623	*6,200*	7,438	*3,014*	1,499	*1,165*	385	*325*
Dove	11,616	*8,677*	2,782	*2,060*	217	*196*	0	*0*
Idle & Torne	11,650	*8,209*	14,172	*10,915*	12,627	*8,783*	0	*0*
Lower Trent & Erewash	64,156	*52,132*	7,736	*6,585*	0	*0*	0	*0*
Middle Dee	1,467	*1,262*	115	*114*	0	*0*	0	*0*
Severn Uplands	10,591	*7,320*	5,971	*4,800*	2,592	*2,192*	0	*0*
Severn Vale	10,158	*6,563*	2,008	*1,298*	315	*208*	0	*0*
Shropshire Middle Severn	14,164	*12,013*	13,970	*11,491*	6,140	*5,157*	766	*665*
Soar	31,608	*27,093*	2,362	*2,032*	97	*62*	0	*0*
Staffordshire Trent Valley	18,013	*15,845*	5,080	*4,319*	1,144	*898*	0	*0*
Tame Anker and Mease	25,211	*21,220*	5,019	*4,304*	663	*579*	0	*0*
Teme	19,541	*8,129*	1,096	*824*	34	*33*	0	*0*
Upper Dee	1,086	*814*	150	*123*	0	*0*	0	*0*
Warwickshire Avon	51,986	*42,098*	4,776	*2,975*	350	*241*	0	*0*
Witham	674	*577*	0	*0*	0	*0*	0	*0*
Worcestershire Middle Severn	10,228	*8,375*	6,479	*5,212*	7,151	*5,857*	0	*0*
Wye	26,892	*19,874*	22,894	*16,920*	7,798	*6,193*	3,494	*2,891*

Appendix 2: Table 5b	**PRIORITY AREAS FOR WOODLAND CREATION TO CONTROL MULTIPLE DIFFUSE POLLUTANTS Number of diffuse pollution pressures**							
	1	*1 - free from sensitivities*	**2**	*2 - free from sensitivities*	**3**	*3 - free from sensitivities*	**4**	*4 - free from sensitivities*
Catchment Sensitive Farming Initiative Projects Areas								
Peak District Dales	5,833	*3,114*	1,280	*683*	0	*0*	0	*0*
River Eye	4,764	*4,096*	95	*78*	0	*0*	0	*0*
River Leadon	3,721	*3,033*	1,517	*1,030*	315	*208*	0	*0*
River Lugg	13,103	*10,952*	12,881	*9,671*	5,102	*4,147*	965	*823*
River Mease	4,150	*3,587*	1,833	*1,632*	152	*134*	0	*0*
Priver Perry	1,618	*1,188*	2,163	*1,667*	347	*319*	91	*90*
River Roden	5,142	*4,257*	3,625	*2,887*	332	*186*	93	*80*
River Teme	19,617	*8,237*	1,112	*838*	31	*30*	0	*0*
River Tern	5,293	*4,751*	6,733	*5,769*	4,604	*3,898*	501	*421*
River Worfe	1,132	*996*	2,290	*2,083*	4,634	*3,932*	0	*0*
River Wye	15,137	*10,239*	10,120	*7,363*	2,708	*2,058*	2,530	*2,068*
West Midlands Meres and Mosses	1,815	*1,508*	1,113	*892*	595	*523*	81	*74*
EA Pilot & Restoration Catchment Projects								
River Ecclesborne catchment	1,159	*999*	807	*633*	495	*348*	318	*258*
River Trent restoration scheme	887	*724*	151	*99*	0	*0*	0	*0*
River Mease SSSI/SAC restoration scheme	4,288	*3,699*	1,747	*1,547*	151	*134*	0	*0*
Stafford Brook SSSI scheme	0	*0*	0	*0*	1	*0*	0	*0*
Upper Fleet catchment	1,065	*935*	0	*0*	0	*0*	0	*0*

Appendix 2: Table 5c	**PRIORITY AREAS FOR WOODLAND CREATION TO CONTROL MULTIPLE DIFFUSE POLLUTANTS** **Number of diffuse pollution pressures**							
	1	*1 - free from sensitivities*	**2**	*2 - free from sensitivities*	**3**	*3 - free from sensitivities*	**4**	*4 - free from sensitivities*
Nature Improvement Areas								
Birmingham and the Black Country	336	*37*	235	*3*	0	*0*	0	*0*
Dark Peak	1,409	*1,407*	3,428	*3,421*	0	*0*	0	*0*
Humberhead Levels	3,927	*2,044*	1,141	*475*	4,853	*1,809*	0	*0*
Meres and Mosses	3,957	*969*	1,448	*394*	91	*29*	0	*0*
Additional projects								
Derwent Land Management Project	9,902	*5,570*	6,056	*2,002*	1,358	*1,067*	385	*325*
The National Forest	7,365	*6,476*	1,355	*1,145*	264	*247*	0	*0*
Clough Woodland project area	4,439	*3,706*	3,845	*3,671*	135	*0*	0	*0*
DerwentWISE project area	79	*15*	3	*1*	3	*1*	1	*0*

Appendix 3: Design principles for woodland to contribute to the objectives of FRM and WFD

Priority Locations for Woodland Creation within Target Catchments	Objectives and Design Principles	EWGS Woodland Category
Wider Catchment Woodland Planting will generally be located: • within groundwater and surface water Protection Zones; • on soils at high or moderate risk of erosion or leaching chemical pollutants; • on source areas of overland flow and along known runoff pathways (defined by local topography as areas where temporary surface water collects and flows); • on areas receiving runoff from hard standings, on infiltration basins and on sustainable rural and urban drainage systems; • down slope of erosion or chemical pollutant sources;	***Planting here can help reduce fertiliser and pesticide usage; protect sensitive soils from disturbance and erosion; increase infiltration and reduce water runoff; and intercept sediment and chemical pollutants in runoff, reducing the delivery of pollutants to watercourses.*** For maximum benefit, planting will generally: • target pollutant sources and retention zones • run parallel to the contour where designed to intercept pollutants draining from upslope areas • be at its densest along runoff pathways; • include an open ground edge located to enhance the trapping of fine sediment where overland flow is an issue;	***Native Woodland*** Stocking Density – 1600 sph, average 2.5m spacing, though closer spacing across runoff pathways Open Ground – maximum 40% of the grant aided area where fully justified, but preferably much less Shrub – maximum 25% of the grant aided area
Riparian Woodland Planting will generally be: • located adjacent to and within 30 m either side of watercourses, on average; • targeted towards stretches of watercourse draining adjacent land identified as at high or moderate risk of delivering sediments and nutrient pollutants or pesticide spray drift;	***Planting along watercourses can act as a buffer between rivers and the adjacent land, intercepting and removing nutrient pollutants and sediment in runoff; providing a barrier to pesticide spray drift; protecting river banks from disturbance and erosion; increasing hydraulic roughness and slowing flood flows; and providing shade to reduce thermal stress to fish and other aquatic life.*** For maximum benefit, planting will generally:	***Native Woodland*** Stocking Density – 1600 sph, average 2.5m spacing, though closer spacing in the floodplain and where overland flow discharges from the adjacent land Open Ground – maximum 40% of the grant aided area, though

Priority Locations for Woodland Creation within Target Catchments	Objectives and Design Principles	EWGS Woodland Category
• along reaches of watercourse vulnerable to bank erosion • along watercourses lacking shade and where fish are thought to be at risk from thermal stress	• provide continuous canopy cover along the length of the riparian woodland, but allowing for a mix of open ground and dappled shade alongside the watercourse itself; • include open ground along the outer edge of the new planting to enhance the trapping of fine sediment where overland flow from adjacent land is an issue • be at its widest and densest where overland flow discharges from the adjacent land, and extend to include areas of active erosion and unstable slopes where possible; • extend right up to the edge of the watercourse where bank erosion is an issue • where appropriate and practicable, include the construction of large woody debris dams within the watercourse to aid re-wetting of the riparian zone	preferably less, and located primarily along the outer edge of the new woodland and on key areas of open habitat such as wetland flushes Shrub – maximum 25% of the grant aided area
Floodplain Woodland Where possible, planting will generally be aligned perpendicular to the watercourse and occupy a significant part of the width of one or both sides of the floodplain. Planting should avoid areas: • where flood flows are controlled by existing restrictions such as bridges and culverts, particularly where these are vulnerable to blockage; • alongside stretches of main river with engineered flood defence banks; • where the backing-up of floodwaters could threaten local properties; and, • within 'washlands'.	***Planting here can increase hydraulic roughness which helps to slow flood flows and encourages the deposition of sediment and the retention of pollutants on the floodplain.*** For maximum benefit, planting will: • involve random spacing but, if in rows, the rows will be offset and aligned perpendicular to the flow of water in order to create maximum roughness; • be down to 1.0 m spacing across the lowest lying/wettest parts of the floodplain; • have open ground will be concentrated on the higher/drier parts of the site • involve shrubs being concentrated along the downstream edge of the planting to increase low level roughness and temporary flood storage	***Standard Woodland*** Stocking Density – 2250 sph, average 2.1m spacing, though closer (down to 1.0m) on the lower lying parts of the floodplain Open Ground - maximum of 20% of the grant aided area, but preferably less than this. Shrubs – maximum 10% of the grant aided area, but located along runoff pathways and along downstream edge of the planting

Appendix 4: Benefits and risks of woodland creation for failing waterbodies

REASONS FOR WATERBODY FAILING TO ACHIEVE GOOD ECOLOGICAL STATUS	SOURCE/PRESSURE INDICATED BY QUALITY ELEMENTS	POTENTIAL BENEFITS AND/OR RISKS ASSOCIATED WITH WOODLAND CREATION
Biological quality elements		
Fish	Sensitive to physico-quality elements, low flows and morphological alterations	Reduce pollutant loads; provide shade to mitigate thermal stress; increase productivity via inputs of woody debris and leaf litter; improve river bed, banks and riparian habitat; and potentially reduce river flows and water pH.
Macroinvertebrates	Sensitive to organic enrichment, pollution by toxic chemicals, acidification and overabstraction	Reduce pollutant loads, especially of sediment and pesticides; increase productivity via inputs of woody debris and leaf litter; improve river bed, banks and riparian habitat; and potentially reduce river flows and water pH.
Physico-chemical quality elements		
Phosphate	Polluted run-off and associated sediment delivery from agricultural sources	Conversion to woodland can reduce nutrient loadings to the soil, reduce leaching losses via higher water use and decreased runoff, and interrupt delivery pathways to watercourses.
Dissolved oxygen	Organic pollution from slurry, sewage and urban run-off	Conversion to woodland can reduce nutrient loadings to the river and water temperature, which will help maintain higher DO levels in water.
Pesticide concentrations exceed water quality standards, including ‘priority substances’ and/or ‘priority hazardous substances’	Diffuse pesticide sources, including in water run-off and spray drift from agricultural land	Conversion to woodland can reduce pesticide loadings to the soil, reduce leaching losses via higher water use and decreased runoff, and interrupt delivery pathways to watercourses, e.g. by acting as a physical barrier to reduce spray drift.
Sediment	Soil disturbance due to agricultural activity, including damage to river banks	Conversion to woodland can improve soil structure and thereby increase infiltration, reducing rapid surface run-off and the entrainment of soil particles; protect river banks from erosion; and interrupt delivery pathways to watercourses.

REASONS FOR WATERBODY FAILING TO ACHIEVE GOOD ECOLOGICAL STATUS	SOURCE/PRESSURE INDICATED BY QUALITY ELEMENTS	POTENTIAL BENEFITS AND/OR RISKS ASSOCIATED WITH WOODLAND CREATION
Dissolved inorganic nitrogen (nitrate) exceeding water quality standards in Groundwater	Diffuse nutrient runoff from excessive fertiliser use & animal husbandry	Conversion to woodland can reduce nutrient loadings to the soil, reduce leaching losses via runoff, and interrupt delivery pathways; woodland can increase the capture of nitrogen pollutants in the atmosphere.
pH	Acidification within acid-sensitive areas subject to high pollutant emissions and acid deposition	Woodland can exacerbate acidification due to pollutant scavenging by tree canopy. Current guidelines restrict scale of forest cover (<30%) within at-risk water bodies.
High water temperature	Thermal stress, particularly to salmonid fish, due to climate warming, heated effluent and lack of riparian shade	Riparian woodland shades water surface thereby reducing solar insolation and cooling water temperature.
Morphological conditions		
River continuity, variation in channel depth, width, structure and bed substrate; structure of the riparian zone.	Modifications/damage to stream banks and channel, including lack of riparian vegetation and canopy cover	A cover of native riparian woodland provides the best morphological condition.
Hydrological conditions		
Quantity and dynamics of flow and supply from groundwater sources	Over abstraction leads to inadequate ecological flows and prevents recharge of aquifers	Conversion to woodland can increase water use and reduce water resources, especially extensive areas of conifer forest or short rotation forestry.

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