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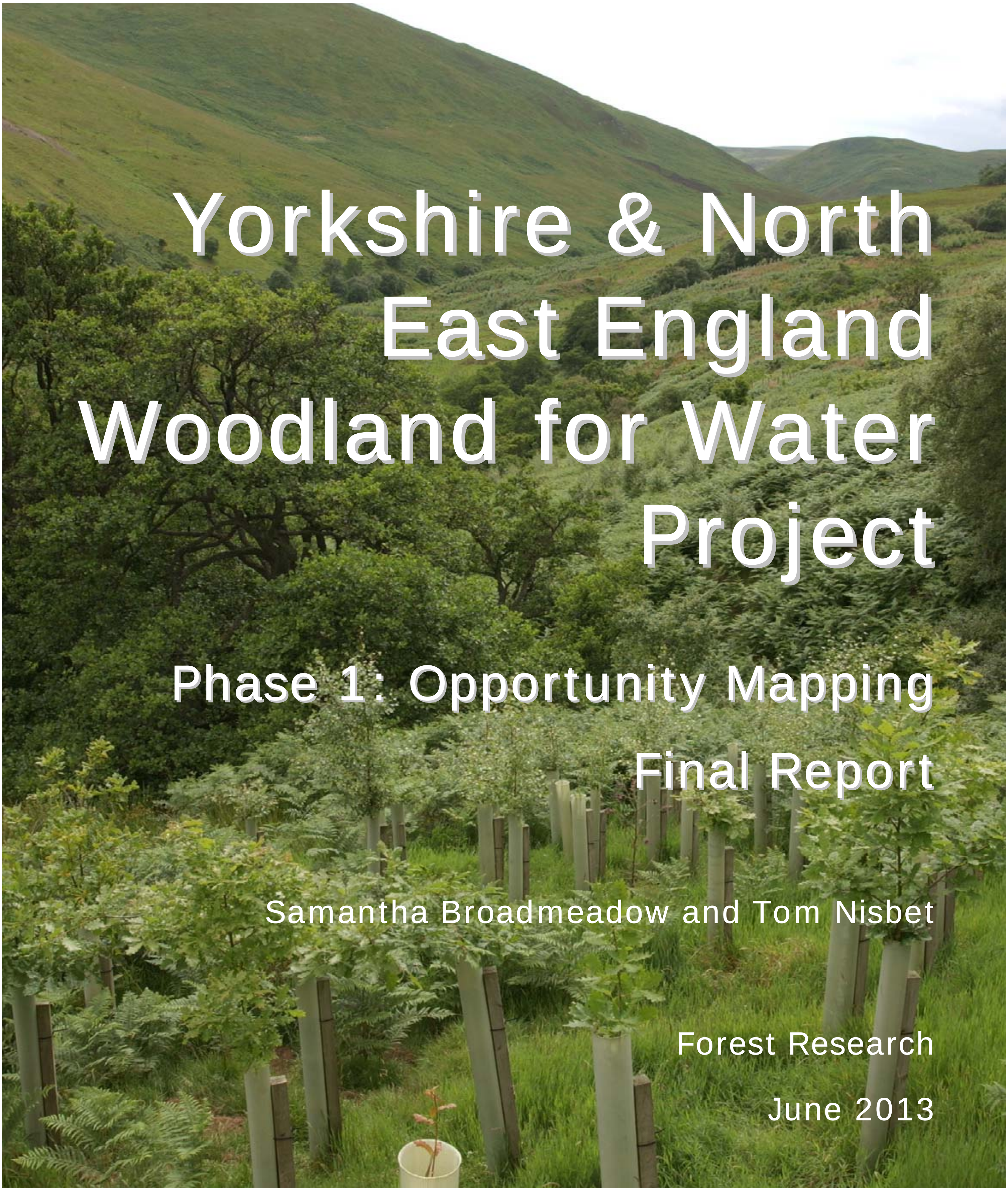

Yorkshire & North East England Woodland for Water Project

Phase 1: Opportunity Mapping

Final Report

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Forest Research

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Environment Agency

The Research Agency of the Forestry Commission

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Executive Summary

The Yorkshire and North East England Region faces a number of major water issues, with 77,000 properties at high risk of flooding and 73% of river water bodies currently failing to meet Good Ecological Status under by the Water Framework Directive (WFD). A recent review of relevant research provides strong evidence of the ability of woodland creation to mitigate these pressures by reducing and delaying flood waters, limiting pollutant loadings and retaining diffuse pollutants. The main aim of this study was to identify priority rural areas in the region for woodland creation and the improved management of existing woodlands to help reduce downstream flood risk and restore damaged waters. The project boundary was extended to include a small part of the adjacent Anglian Region to complete coverage of the Humber River Basin, although this area is excluded from the calculated statistics presented in the report.

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 suitable 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 flood risk management (FRM) and meet WFD targets, in addition to generating many other benefits for society. Woodland creation, however, is not without risks and care will be required in planting the right tree in the right place to avoid woodland acting as a pressure on the water environment.

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:

- 3,466 km^2 (15.3% of region) of priority areas for woodland planting to reduce downstream flood risk, comprising 2,336 km^2 of wider woodland, 505 km^2 of riparian woodland and 625 km^2 of floodplain woodland (Map 18b)
- 3,144 km^2 (13.9% of region) of priority areas for woodland creation to reduce one or more diffuse pollutants (phosphate, nitrate, pesticides and sediment) from agricultural sources (Map 27a)
- 506 km^2 (2.2% of region) of priority land where woodland planting could tackle both flood risk and one or more diffuse agricultural pollution pressures; 62% (313 km^2) of this land is free from all identified sensitivities to woodland planting (Map 28)
- 73.6 ha of priority land where woodland planting could reduce both flood risk and all four identified diffuse agricultural pollution pressures; all of this land is free from sensitivities
- 333 (>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 87 within areas vulnerable to acidification; 18,164 ha of riparian land where conifer woodland remains within 20 m of the river network; and 815 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.

Opportunities for woodland creation to reduce flood risk are greatest within the Yorkshire area, comprising the uplands of the Yorkshire Dales, Southern Pennine Fringe and North York Moors, and the lowlands of the Vales of Mowbray, York and Pickering. Notable locations in the North East include the upper Wear draining the North Pennines and the headwaters and floodplains of the Rivers Coquet and Till draining the Cheviot Hills.

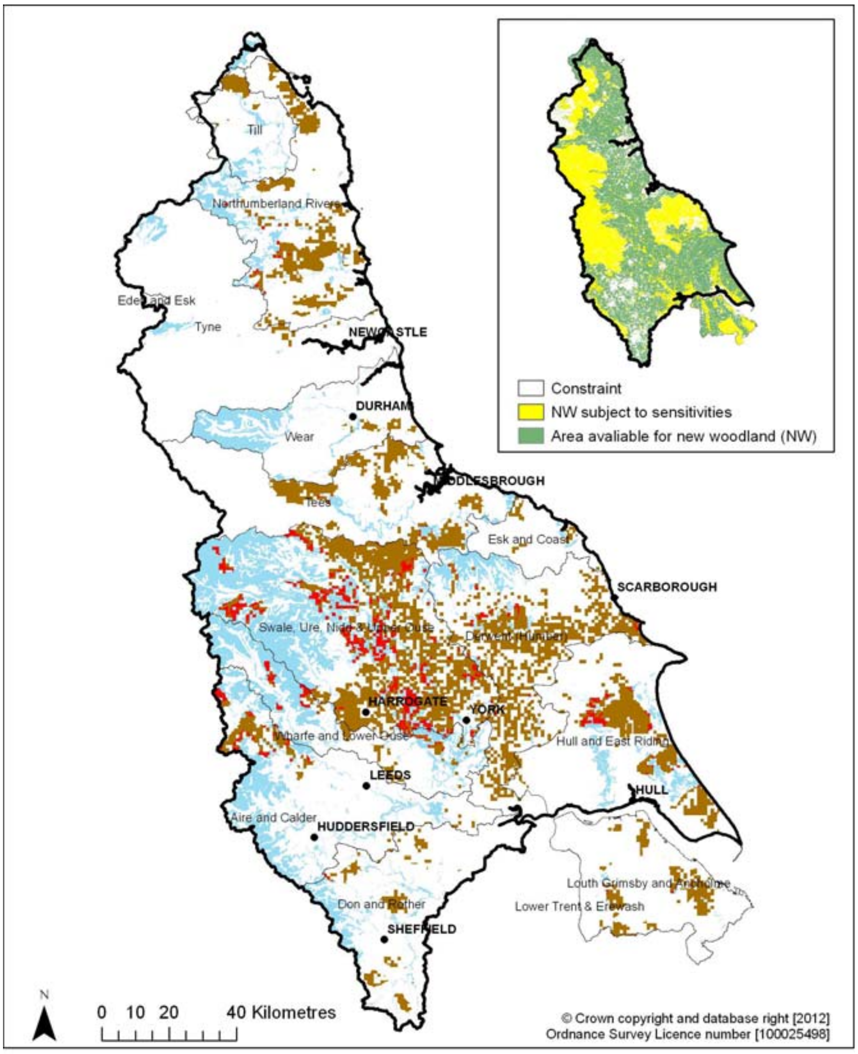
Opportunities to reduce diffuse pollution are also greatest in the Yorkshire area, although in contrast to FRM, are dominated by the lowlands, reflecting the distribution of arable crops and improved grassland. Target areas for reducing one or more diffuse pollutants include the Vales of Mowbray, York and Pickering, and Holderness. Opportunities in the North East mainly lie in the middle and lower Tees catchment and in a number of Northumberland Rivers, including the Wansbeck, Coquet and Till catchments. The greatest scope for multiple water benefits arise in the Vales of Mowbray, York and Pickering, parts of the Yorkshire Dales and Dales Fringe, and in Holderness.

There is a large degree of overlap between the identified priority land for woodland creation and existing regional initiatives designed to promote land use change or improve land management to mitigate flooding and diffuse pollution. This includes Catchment Flood Management Plans and Catchment Sensitive Farming Priority and Strategic Partnership 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 woodland functions not specifically addressed in this study, such as slope stabilisation and erosion control, or other woodland values, such as the provision of recreation and health benefits. This approach should help realise optimum benefits from any planting scheme tailored to local circumstances.

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. 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, small scale planting targeted to riparian buffers and along pollutant pathways could make a significant difference, while having a limited impact on agricultural incomes. There is scope for better integration of available incentives to secure greater land use change, as well as encouraging water companies to help fund woodland creation for water.

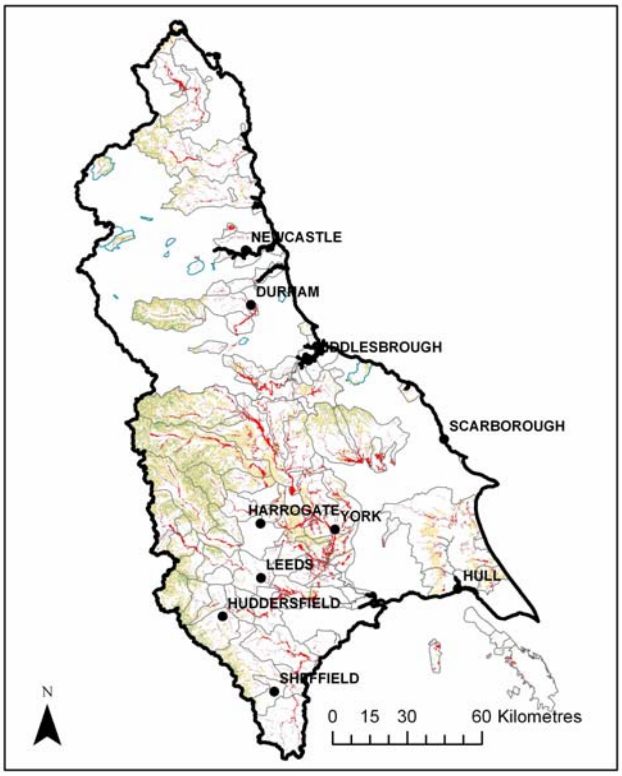
Finally, it is recommended that consideration should be given to establishing one or more sub-catchment studies within the region to demonstrate and help communicate the value and benefits of woodland creation for water. The opportunity maps can be used to guide the location of such a study by targeting an identified priority area where there is significant scope for land use change. The report provides guidance on the design principles for woodland creation to maximise benefits for FRM and WFD.



Map 28 Distribution of priority areas for woodland creation to reduce downstream flood risk in relation to those for reducing one or more diffuse pollutants to surface waters or groundwater

Priority areas for woodland planting

- to reduce downstream flood risk
- to reduce diffuse pollution pressures
- both downstream flood risk and diffuse pollution pressure



Map 18b: Priority areas for woodland creation to reduce downstream flood risk

- floodplain woodland
- riparian woodland
- woodland in wider catchment
- CFMP: policy units 4, 5 or 6
- Rapid Responce Catchment within CFMP PU1, 2 & 3

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- Phosphorus
- Sediment
- Nitrate
- Pesticides

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1. Background

The Water Framework Directive (WFD) poses a major 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 77,000 properties at high risk in the Yorkshire and North East Region. The 13 Catchment Flood Management Plans (CFMP) covering the Region's main rivers set out the approach to managing flood risk over the next 100 years, including policies around beneficial land management change and a greater working with natural processes.

A recent report jointly funded by Forestry Commission England and the Environment Agency reviewed the latest evidence concerning the positive and negative impacts of woodland on surface and groundwaters (Nisbet *et al.*, 2011a). The Environment Agency's Summary Report of this work concludes that:

- There is strong evidence to support woodland creation in appropriate locations to achieve water management and water quality objectives.
- Woodland contribution to tackling diffuse pollution includes both a barrier and interception function, helping to trap and retain nutrients and sediment in polluted runoff.
- A good case can be made for the mitigation of downstream flooding by riparian and floodplain woodland.

Defra's guide to mitigation methods (Newell *et al.*, 2011) identifies conversion of land from agriculture (arable or grassland) to permanent woodland as potentially effective in reducing rural diffuse pollution, especially for nitrogen, particulate phosphorus and sediment.

An Environment Agency report prioritising its scientific research on land use and FRM recommends working locally with others to deliver woodland planting schemes (within floodplains, along riparian strips and in the wider catchment) for FRM benefits, while continuing further research into improving the effectiveness of these interventions (EA, 2009a).

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. 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.

The specific spatial datasets and maps produced through this study will help maximise the value gained from new woodland by identifying where planting is most likely to reduce flood risk, rural diffuse pollution or both of these together. The maps may also be used with other information sources to select new woodland sites where these water benefits are co-located with opportunities for further environmental and societal benefits that woodland can provide, such as slope stabilisation, erosion control, carbon sequestration, habitat enhancement or recreational use. They will form the basis for incentivising the land use change process through future delivery phases of the Yorkshire and North East Woodlands for Water project.

The report describes the methodology used to generate opportunity maps for woodland creation to deliver water services in the 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 agricultural diffuse pollution pressures affecting river water bodies (RWBs) 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 are provided that identify priority areas for woodland creation to benefit water. The report concludes with a number of recommendations on next steps and guidance on the design principles for woodland creation to maximise benefits for FRM and WFD.

2. Objectives

To provide GIS spatial datasets and maps which identify priority rural 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 Yorkshire and North East Woodlands for Water project is defined by the EA regional boundary, with a small extension into the adjacent Anglian Region to complete coverage of the Humber River Basin (Map 1). The region covers 22,680 km^2 extending from the tip of Derbyshire in the south to the Scottish border in the north. Landform is dominated by the Pennines, forming the western edge and a series of predominantly east flowing river systems, including the Humber, Tees and Tyne (Map 2).

Geology varies considerably across the region from the carboniferous limestone and millstone grit of the Pennines, through the coal measures of Durham and Derbyshire, the magnesium limestone fringe and Permian and Triassic sandstones and mudstones of the Vales of Mowbray and York, the oolitic limestone of the North York Moors, to the chalk of the Yorkshire Wolds and Holderness (Map 3). Soils reflect the topography, ranging from peaty and stagnohumic gley soils on the hilltops, brown earth and podzols on the hillslopes, to stagnogley and alluvial gleys in the lowlands (Map 4).

Land use is mainly agricultural, with arable cropping dominating in the lowlands and grassland, shrub and heath in the uplands (Map 5). Urban is the next major land use at 9.1% (Map 6), reflecting the regions long history of industrialisation and settlement. It is now home to 7.7 million people, mainly located within the densely populated cities of Leeds, Sheffield, York, Hull, Middlesbrough and Newcastle. Existing woodland is less than the national average, at only 9.3% (Map 7). This is relatively evenly distributed, with sizeable forests limited to Dalby and Cropton Forests in the North York Moors and Kielder, Wark, Harwood and Kidland Forests in Northumberland. There are many important habitat and wildlife areas, including 35 Special Areas of Conservation, 15 Special Protection Areas, 26 National Nature Reserves and 599 Sites of Special Scientific Interest, of which over 100 include water bodies or water dependant priority habitats. A total of 75 of the 947 RWB catchments in the region are protected under the EU Habitats and Species Directive. There are four National Parks and five Areas of Outstanding Natural Beauty.

The region suffers from both tidal and fluvial flooding, although the latter causes most problems (Map 8). Surface water flooding in both urban and rural communities is locally significant but groundwater and snow melt induced flooding are rare. Overall in the Yorkshire and North East region, there are 285,000 properties at risk of tidal and fluvial flooding (7% of all properties, both residential and commercial), of which 77,000 are located within the high risk zone (EA, 2013). Within the region, the Yorkshire area has around 266,000 properties at risk (64,000 at high risk), compared to 19,000 properties in the North East area (13,000 at high risk). These figures are expected to rise significantly in the next 50 to 100 years as a result of climate change.

The water environment is under considerable pressure within the region, reflecting its intensive use by agricultural and urban activities. Of the 881 WFD RWB catchments, 642 (73%) are currently failing to meet the target Good Ecological Status (GES), and for 189 (21%) of these diffuse pollution from agriculture and rural land management has been identified as a reason for failure. Groundwater resources are also at risk, with 78% of the region underlain by groundwater with less than good water quality and another 6% 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 Yorkshire and the Humber (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 more recently in the Midlands Woodland for Water Project (Broadmeadow & Nisbet, 2013). The methodology has been further developed for this study, which updates the original work in Yorkshire and the Humber and extends this to North East England. A recent development has been the inclusion of the EA's Reason for Failure datasets, which has allowed more precise targeting of water bodies failing GES due to diffuse pollution from agriculture and rural land management.

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

4.2.1. Constraints

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 Sustainable Urban Drainage Systems within urban areas or in appropriate locations on Scheduled Ancient Monuments or World Heritage sites. Their inclusion as constraints 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 comprise the following (see Appendix 2 for details of data sources):

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

All areas identified in this list were removed from further consideration in the study as unsuitable for significant woodland planting (Map 9). A fixed, protective, 30 m buffer was added around Scheduled Ancient Monuments 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.

4.2.2. Sensitivities

There are additional factors that influence the scale, type and design of any woodland planting. These are termed sensitivities and 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 Statutory Main Rivers
- Area benefiting from flood defences
- EA floodplain washlands
- Ministry of Defence land
- RAMSAR sites
- Special Areas of Conservation (SAC)
- Special Protection Areas (SPA)
- Sites of Special Scientific Interest (SSSI)
- National Nature Reserves
- Common Land
- RSPB Reserves
- Historic Parks & Gardens
- Battlefields
- National Parks
- Areas of Outstanding Natural Beauty

- Land above the natural tree line
- Undesignated Biodiversity Action Plan (BAP) Habitats (including peatlands)

The above features were combined to form a single GIS layer, showing where woodland creation would be possible providing the scheme was appropriately designed in accordance with the UK Forestry Standard (FC, 2011a) 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. A selection of others is explained below, particularly those that required some processing, such as the floodplain buffers and the riparian zone along Statutory Main Rivers.

It was thought appropriate to include a buffer around urban areas within or adjacent to the floodplain and roads crossing it (railways were excluded on the basis that they were expected to be embanked and therefore less at risk). This reflected 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 (Nisbet *et al.*, 2011a). Consequently, a 500 m wide buffer was delineated around urban areas and a 300 m buffer along both sides of any roads that crossed the floodplain (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 Statutory 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 limit the nature of planting within this zone and the scope for water benefits. It was therefore decided to mark the full width of the riparian zone along Statutory Main Rivers, defined as a 30 m wide zone on either side of the EA's Detailed River Network (measured from the centre of the river), as a sensitive area for planting (Map 10).

Land benefiting from 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 planting behind defences 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 available volume for 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).

Peatland soils were included under undesignated BAP habitats 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 areas suitable 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 offers 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. Flood Zone 2 was selected as the boundary of the floodplain for woodland opportunities. 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 areas affected by the constraints defined in Section 4.2.1. 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 main river systems such as the Ouse. However, where the floodplain widened again in middle and upper reaches beyond 1 km in width, these wider areas were retained as they could become locally important for FRM (they also rarely extended beyond 2 km wide). The end result was a map showing areas within EA Flood Zone 2 that were 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 than 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).

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 13b). This width was selected as the zone most likely to interact with and provide woody debris to the river channel. All areas affected by constraints to riparian planting were removed.

4.3.3. Soils and flood generation

Riparian planting and woodland in the wider catchment is most likely to be 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 hydrological properties of soils and the susceptibility of soils to structural degradation from agricultural use were assessed.

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)'

HOST: The HOST system was developed to classify soils according to their hydrological behaviour (Map 14). 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. A slope factor is not specifically included within HOST as it did not significantly improve model performance. However, since soil formation and soil hydrological properties reflect the influence of slope, it is indirectly incorporated within the response models.

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 15a).

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.

HOST Class	Soil Series	Original SPR %	Amended SPR %	Area (km^2)	% of region	Physical Soil Description
0	Urban/water	-	-	556	2.3	Unclassified
1	341, 342a, 343fhi, 511cdef, 521, 571nor, 581d	2.0	14	1,284	5.3	Free draining over chalk
2	343abc, 511a, 544	2.0	14	704	2.9	Free draining over limestone

HOST Class	Soil Series	Original SPR %	Amended SPR %	Area (km^2)	% of region	Physical Soil Description
3	551a, 571f	14.5	27	37	0.2	Free draining over soft sandstone
4	541fgq, 631a	2.0	15	1,484	6.1	Free draining over consolidated rocks
5	361, 511i, 541Dru, 551d, 631f	14.5	27	1,093	4.5	Free draining over sands or gravel
6	541xy, 571q	33.8	44	552	2.3	Unconsolidated, free draining over colluvium and loamy drift
7	512bc, 543, 552a, 641c	44.3	44	364	1.5	Free draining over sands or gravel
8	512f, 532ab, 561abc	44.3	44	454	1.9	Unconsolidated, free draining over colluvium and loamy drift
9	22, 811bcd, 812c, 813bcdfg, 814c, 831bc, 851c	25.3	25	1,183	4.9	Unconsolidated, gleying <40 cm from surface
10	1011a, 811a, 812a, 821ab, 861b	25.3	25	688	2.8	Unconsolidated, gleying <40 cm from surface
11	1022a, 1024a	2.0	2	42	0.2	Drained peat
13	512a	2.0	15	51	0.2	Impermeable layer within 100 cm
15	311cd, 541o, 651abc, 652, 654a	48.4	48	972	4.0	Peat over permeable substrate
18	572glmos, 841a	47.2	59	662	2.7	Slowly permeable, gleying within 40 - 100 cm
19	611a	60	60	151	0.6	Impermeable (hard) substrate within 100 cm; gleying within 40 - 100 cm
20	421a	60	60	108	0.4	Impermeable (soft), gleying within 40 - 100 cm
21	431, 542	47.2	60	465	1.9	Slowly permeable, gleying within 40-100 cm
22	313a	60.0	60	63	0.3	Impermeable (hard), gleying within 40-100 cm
23	411b	60	60	5	0	Impermeable (soft), gleying within 40-100 cm
24	711cmnprsu, 712afhi, 713adefg	39.7	49	9,276	38.0	Slowly permeable, gleying <40cm from surface
25	711f, 712bc	49.6	60	216	0.9	Impermeable (soft), gleying <40cm from surface
26	721bc	58.7	59	2,364	9.7	Peat over slowly permeable substrate
27	311e	60	60	7	0	Peat over rock
29	1011b	60.0	60	1,598	6.6	Raw Peat

Table 1. The hydrological properties of the soils of the region

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 15b). 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 surface runoff (Table 2; Map 15c).

Propensity of soils to generate rapid runoff	HOST original SPR value (%)	Sensitivity to structural degradation by land management based on revised SPR
Low	<25 <25	Low sensitivity Moderate sensitive
Medium	>25 >25 <25	Low sensitivity Moderate sensitive High sensitivity
High	>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

4.3.4. Identifying preferred areas for woodland creation to reduce flood risk

The following land was defined as preferred areas for woodland planting to reduce flood risk: land comprising soils with a high propensity to generate rapid surface runoff (termed 'wider woodland'); riparian land abutting land with a high propensity for generating rapid surface runoff; and all suitable floodplain land identified in 4.3.1. A local example illustrating the application of this method is displayed in Map 16, while Map 17 shows the resulting distribution of preferred areas for planting floodplain, riparian and wider woodland across the region.

4.3.5. Prioritising areas for woodland creation to reduce flood risk

The 13 CFMPs covering the main rivers in Yorkshire and the North East classify land according to the preferred policy for FRM (Map 18a). There are a total of six policy options: 1. Areas of little or no flood risk where the EA will continue to monitor and advise; 2. Areas of low to moderate flood risk where there is scope to generally reduce existing FRM actions; 3. Areas of low to moderate risk where the existing flood risk is generally managed effectively; 4. Areas of low, moderate or high flood risk where the flood risk is being managed effectively but where further action is required to keep pace with climate change; 5. Areas of moderate to high flood risk where further action is needed to reduce flood risk; and 6. Areas of low to moderate flood risk where there is scope for working with others to store water of manage runoff to reduce flood risk or provide environmental benefits.

Woodland creation is likely to benefit FRM most either where the greatest number of properties and assets are at risk of flooding or where smaller numbers of properties remain undefended. Priority was therefore given to preferred areas for woodland creation to reduce flood risk that lay within policy units 4, 5 and 6 (Map 18b), although local opportunities for planting to aid FRM are likely to exist within policy units 1, 2 and 3.

The devastating flood of August 2004 in Boscastle highlighted the deadly potential of flash flooding in steep-sided valleys. Following that event a national survey was undertaken to identify Rapid Response Catchments (RRCs) and a national register was drawn up (EA, 2013:). The priority for action is to raise awareness in those communities at risk and to prepare and put plans in place to minimise the consequences of rapid flooding focusing on catchments at high or very high risk. There are 101 RRCs (54 at high or very high risk) in Yorkshire and the North East and they are sometimes not well represented with the CFMP process as the catchments are generally very small and react differently from the larger catchments into which they drain. It is recognised that well planned woodland has the potential to deliver significant benefits in RRCs and therefore these should also be considered as priority areas for planting.

The detailed determination and digitisation of RRC boundaries is currently in progress. Most RRC communities in the region lie within CFMP Policy Units 4, 5 and 6 but 12 fall outside (Map 18a). For this report the catchments above the 12 locations have been digitised approximately and the identified preferred areas for woodland creation within these added to Map 18b, along with the priority areas within CFMP Policy Units 4, 5 and 6. When the catchment boundaries can be identified more precisely these maps and datasets should be revised.

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 (Nisbet *et al.*, 2011a). This is more likely to be a problem with planting in the lower reaches of catchments closer to assets at risk (Broadmeadow *et al.*, 2013) and would need to be checked (possibly involving modelling) during the assessment of individual woodland planting applications.

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 water bodies (RWB) and to particular areas identified to provide long-term protection of drinking water sources. Individual water bodies 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 642 of the 881 RWBs in the region (based on 2009 data) fail to achieve Good Ecological Status (GES), while 18 of the 30 groundwater bodies (GWB) have less than good chemical status; one other GWB currently has good water quality but is subject to a deteriorating trend in water chemistry.

Priority locations for woodland creation are considered to be land within failing water bodies where the reason for failure had been identified as diffuse pollution from agriculture and rural land management. This was based on an assessment of catchment pressures and site investigations by EA staff, and totalled 189 RWBs. Attention was confined to those diffuse pollutants that could be potentially reduced by woodland planting, namely phosphorus (P), 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 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, and (ii) the EA's land use change (LUC) model (EA, 2012) developed by Chris Burgess to quantify the risk of diffuse nitrate and pesticide pollution from agriculture.

The application of these models is described below:

4.4.1. 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 P 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 from all agricultural diffuse sources via all runoff pathways to waters on a 1 km grid. The distribution of predicted annual total P and sediment losses to watercourses in kg/ha/yr across the region is illustrated in Maps 19a & 21a. Values were then regrouped into low, medium and high pollutant load classes for the purpose of identifying priority areas for woodland creation (Maps 19b & 21b). Thresholds of 0.5 kg/ha/yr and 1.0 kg/ha/yr were selected as class boundary thresholds for P informed by WFD phosphate concentration standards. Equivalent values for sediment were derived from the literature and set at 250 kg/ha/yr and 500 kg/ha/yr for low-medium and medium-high class boundaries, respectively.

4.4.2. The EA LUC Model: Nitrate and pesticide diffuse pollutant pressure characterisation in catchments

This model was developed to help identify where land use change may be a preferred option for tackling a range of 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 (based on connectivity) 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 loads/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. 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. For these reasons, its use here was limited to generating relative pressure scores for nitrate and pesticide diffuse pollutants derived from agricultural sources on a 1 km grid scale.

This involved interpolating the point field data for the two pollutants using an inverse distance weighting (IDW) to form a 1 km grid raster. 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 and delivery scores. A 1 km grid raster of baseline pollutant supply from semi-natural vegetation and a corresponding land cover mask based on a 1 km grid generalised land cover dataset were therefore created. The output from the latter was then used to replace the values in the original IDW interpolated surface to create a pollutant pressure score corrected for land use (Maps 23a and 25a). Scores for nitrate and pesticides were divided into three equal bands representing low, medium and high pollutant pressure classes (Maps 23b and 25b).

4.4.3. Identification of areas failing WFD due to diffuse pollution pressures

4.4.3.1 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. RWBs failing GES due to phosphate were selected, along with those failing for a biological element where phosphate was identified as a pressure. In the case of macrophytes and phytobenthos a phosphate pressure was inferred where the pressure was not specifically identified. This dataset was restricted to RWBs where “Agriculture and Rural Land Management” has been identified as a reason for failure. Map 20a shows the distribution of these failing RWBs across the region in relation to WFD management catchments and how the predicted pollutant pressure varies within them. Areas of medium and high pollutant pressure were identified as priority areas for woodland creation to address diffuse P pollution from agriculture (Map 20b).

4.4.3.2 SEDIMENT

Environmental standards remain undefined for sediment and this element is not included in the WFD assessment of GES for surface water bodies. Instead RWBs failing for a biological element were selected where sediment was identified as a pressure, or in the case of fish, also where the pressure was not specifically identified. This dataset was restricted to RWBs where “Agriculture and Rural Land Management” has been identified as a reason for failure. Map 22a shows the distribution of these failing RWBs across the region and how the predicted pollutant pressure varies within them. Areas of medium and high sediment pollutant pressure were identified as priority areas for woodland creation to address diffuse sediment pollution from agriculture (Map 22b).

4.4.3.3 NITRATE

There is currently no WFD environmental quality standard for nitrate in surface waters and thus it does not directly contribute to the assessment of RWB status. However, it remains a serious issue for drinking water supplies and can affect the ecological status of coastal waters. Much of England is classified as a Nitrate Vulnerable Zone (NVZ) and nitrate is regularly monitored by the EA and the data used to identify surface and groundwaters at risk from diffuse nitrate pollution. The extensive nature of NVZs reduces the scope for achieving a sufficient level of woodland creation to make a difference and therefore attention focused on selecting key vulnerable areas. These comprised surface and groundwater areas identified to help provide long-term protection of water supplies from nitrate pollution, and NVZ Eutrophic Areas where nitrate losses threaten GES of transitional or coastal water bodies. Map 24a shows their location in relation to WFD management catchments and how the relative pollutant pressure varies within them.

Areas with a high pressure score were identified as a priority for woodland creation to reduce diffuse nitrate pollution from agriculture (Map 24b).

4.4.3.4 PESTICIDES

Generally, pesticide concentrations found in surface waters from 'normal agricultural use' are insufficient to affect ecological status but they remain an important concern for the protection of drinking water supplies. Stringent standards are set for drinking waters and pesticide levels are regularly monitored to assess compliance. Contamination of drinking waters by metaldehyde is a particular problem in some parts of the region. Vulnerable areas were therefore defined as areas identified to provide long-term protection of drinking waters from this pesticide, as well as from herbicides, together with groundwater areas for general pesticides. Map 26a shows their location and how the relative pollutant pressure varies within them. Areas with a high pressure score were identified as a priority for woodland creation to reduce diffuse pesticide pollution from agriculture (Map 26b).

4.4.3.5 MULTIPLE POLLUTANTS

The distribution of the priority areas identified for woodland creation to help reduce each of the four individual pollutants (phosphate, sediment, nitrate and pesticides) derived from agricultural sources is compared in Map 27a. Opportunities for land use change to tackle multiple diffuse pollution pressures are displayed in Map 27b. Sensitivities are also shown.

4.4.3.6 COMBINED PRESSURES

Map 28 shows the distribution of the priority areas for woodland creation for FRM in relation to those for reducing one or more diffuse pollutant pressures to surface waters or groundwater. The degree of overlap between the two is also displayed separately in Map 29, along with identified sensitivities to woodland planting.

4.5. Identification of suitable areas for woodland creation to reduce flood risk and diffuse pollution within existing regional land management initiatives

There are a number of existing land management based initiatives and projects 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 shown in Map 30 and include EA CFMP policy units 4, 5 and 6, identifying where there is a need for further action to reduce flood risk, and the location of Rapid Response Catchments (RRC).

Also shown are EA/Natural England Catchment Sensitive Farming Delivery Initiative priority and strategic partnership catchments designed to tackle diffuse pollution, and Defra Nature Improvement Areas.

A number of catchments were selected within these initiatives to display opportunities for woodland creation to contribute to FRM and/or mitigate diffuse pollution at a more detailed scale.

4.5.1. River Coquet catchment within the North East Northumberland Catchment Flood Management Plan

The River Coquet drains the Cheviot Hills through the towns of Rothbury and Warkworth to the North Sea at Amble. This predominantly upland and rural catchment responds quickly to rainfall, placing a number of local communities at risk of fluvial flooding. A total of 260 properties are at risk from a one percent flood, which is predicted to rise to 269 in the future due to climate change (EA, 2009b). Flood risk is currently managed through raised defences, channel maintenance, a pumping station at Rothbury and a flood warning service. Because the risk of flooding is high and set to increase in the future, the catchment has been assigned policy unit 5 status. This requires further action and investment to reduce the risk of flooding and the hazard posed to dispersed settlements and to the town of Rothbury.

The CFMP describes a number of actions, including working closely with local landowners and partners to promote sustainable land management practices in order to reduce the amount and rate of runoff, as well as erosion. Another action is to investigate the benefit of afforestation, particularly in the upland parts of the catchment. There is one RRC comprising the Coplish Burn. This is classed as medium risk but flooding represents a very extreme hazard to 30 properties in Rothbury. The location of priority areas for woodland creation to reduce flood risk are displayed in Map 31 against an OS backdrop.

Diffuse pollution is also an issue, with the majority of the River Coquet lying within the Tweed, Aln, Coquet and Coastal Streams CSFDI Priority catchment. Map 32 shows where there are opportunities for woodland creation to tackle this pressure, while the degree of overlap between the priority areas to reduce flood risk and diffuse pollution is displayed in Map 33.

4.5.2. The Ouse, Nidd and Swale Catchment Sensitive Farming Delivery Initiative (CSFDI) Priority Catchment

This priority catchment comprises most of the low lying land in the Vales of Mowbray and York, drained by the lower reaches of the River Nidd, Swale and upper Ouse. Arable cropping and improved grassland predominate on the fertile soils, with only 5.6% of the area covered by woodland. As a result, diffuse pollution is a major issue responsible for most RWBs failing GES. Maps 34a and 34b show the distribution of priority areas for woodland creation to reduce individual and multiple agricultural sources of diffuse pollutants to waters.

The priority catchment occupies a large part of the Yorkshire Ouse CFMP and most of the land is susceptible to flooding. A number of towns and villages are at risk, including Boroughbridge, Northallerton, Catterick and Thirsk, as well as the larger population centres of York and Selby downstream. Large areas form strategic washlands that play a vital role in regulating flood flows and reducing flood risk. The land is divided into a number of policy units, most of which falls within units 5 and 6. The CFMP identifies a range of actions to reduce flood risk, including working with local landowners to change the way land is managed to slow the rate that floods are generated, such as planting gill and floodplain woodland. The location of priority areas for woodland planting to reduce flood risk are displayed in Map 35. Map 36 shows the degree of overlap between the priority areas to reduce flood risk and diffuse pollution.

4.5.3. The Semerwater and Upper Lune Strategic Partnership Catchment

The Semerwater and Upper Lune Strategic Partnership Catchment lies within the Yorkshire Dales National Park. It combines two previous CSFDI projects that were established to try to address diffuse pollution from farmland. The Semerwater catchment is a relatively small, upland, predominantly grassland catchment, which drains to the River Ure below the village of Bainbridge. Actions to improve water quality include planting riparian woodland to protect river banks and reduce the entry of diffuse pollutants.

The Semerwater lies close to the western edge of the Ouse CFMP. A combination of the steep topography of the surrounding hills and high rainfall generates rapid runoff that contributes to flooding further down the main river system. For this reason, the Semerwater and surrounding land is assigned to policy unit 6. A key action in the CFMP is to change land management to slow the rate of flood generation by reducing runoff and soil erosion, and increasing channel roughness.

Map 37a shows the location in the catchment of priority areas for woodland creation to reduce diffuse pollution and/or flood risk, while Map 37b displays the same but in greater spatial detail around the settlement of Stalling Busk.

4.6. Existing woodland - identification of areas where design and management changes 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 UK Forestry Standard Forests and Water Guidelines (F&WG; FC, 2011b) describe a range of measures to address these issues.

The following maps were developed to aid targeting of the measures:

Map 38 – river water bodies at risk of 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 water bodies that are failing or at risk of failing GES due to acidification. The methodology for addressing new planting and restocking is currently the subject of a consultation exercise 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 water bodies 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 7). The inset on Map 38 shows the distribution of sub-catchments with >20% forest cover (in 20% cover bands), while the main map displays the location of those lying within failing and at-risk RWBs; 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.

Maps 39 & 40 – river water bodies 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 help control the potential impact on peak flows and phosphate runoff within vulnerable areas. Vulnerable areas for phosphate comprise RWBs failing GES due to diffuse P pollution (Map 39), while those for FRM are defined as CFMP policy units 4, 5 and 6 (Map 40). The maps show the location of sub-catchments with >20% woodland cover in relation to these 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 41 – watercourses with existing conifer forest within 20 m of bankside. The F&WGs recommend 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 38).

Map 42 – water bodies potentially at risk from the higher water use by trees. The higher water use by trees could be an issue 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 (Nisbet, 2005). This map identifies sub-catchments with >20% woodland cover within GWBs that are failing WFD objectives due to poor quantitative status and RWBs subject to low flow pressure and failing to achieve hydrological complience. The impact on water resources is likely to be greatest for large-scale conifer cover.

4.7. Management of riparian vegetation for climate change adaptation - EA Keeping Rivers Cool Project

The EA has developed two mapping tools to help identify river reaches lacking riparian shade and therefore where salmonid fish and other sensitive freshwater life may be increasingly at risk from thermal stress due to climate warming. Both use LiDAR data, one to determine the distribution of riparian trees by mapping the presence and absence of riparian vegetation over 2.5m height, and the second to measure and map the degree of riparian shade along watercourses. These maps can be used to help direct woodland planting to where there is a greatest need for shade, although some ground truthing is required to aid local decision making.

Riparian tree presence and shade maps were initially limited to the Keeping Rivers Cool pilot catchments but recently, as an extension of the project, they have been produced for all areas in Yorkshire and the North East where there is LiDAR coverage. Map 43 provides an example map displaying the distribution of relative shade on a 25 m grid across a section of the floodplain of the River Swale.

Riparian shade maps will be produced and available for all WFD management catchments in England by January 2014 (maps for about 40 catchments are already available). External partners will be able to view the keeping rivers cool vegetation and riparian shade data online through the Rivers Trust catchment mapping portal, as well as ordering the data from the Environment Agency's Geomatics team (contact Rachel.lenane@environment-agency.gov.uk).

The data can be used at a sub-catchment or site level to identify stream reaches currently lacking riparian shade but the detail is lost when displayed/mapped at a larger scale. However, it is possible to average the data over larger areas to highlight where the need for shade provision is greatest. This has been done for RWBs failing GES for fish within the Yorkshire and NE region and Map 44 shows the distribution of those with an average relative riparian shade value of <20%. These results should be treated as indicative in view of the gaps in LiDAR coverage and the data processing involved.

5. Results

Calculated values for the extent and distribution of priority areas for woodland creation to tackle downstream flooding and selected diffuse pollutant pressures are presented below to highlight key opportunities for woodland planting to benefit water in the Yorkshire & North East Region (the part of the Anglian Region within the project boundary was excluded when deriving these numbers).

5.1. Constraints to woodland creation

A total of 4,757 km^2 or 21% of the region is excluded from woodland planting due to the listed constraints (Table 3). Urban infrastructure and the road and rail network represent dominant constraints, responsible for 56% of the total area excluded; the largest urban area being Leeds, followed by the major towns and cities of Sheffield, Newcastle, Middlesbrough, Hull and York. The other major constraint is existing woodland (NFI dataset), occupying nearly 2,111 km^2 or 9.3% of the region.

In terms of the fluvial floodplain, a total of 356 km^2 or 21% 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 111 km^2 or 6.6% is covered by woodland, which is mainly broadleaved.

Woodland constraint	**Area (km^2)**	**% of region or *fluvial floodplain***
Urban infrastructure	2,065 km^2 *Floodplain buffer – 489 km^2*	9.1% *30.4% of floodplain*
Road and rail network	1,064 km^2 *Rural road floodplain buffer – 275 km^2*	4.7% *17.1% of floodplain*
Sites of Antiquity [SAM, WHS]	177 km^2	0.8%
MOD and civil airports	19 km^2	0.1%
Open Water	72 km^2	0.3%
Existing Woodland	2,111 km^2	9.3%
Total area of all constraints for which spatial data is available *Across the fluvial floodplain*	4,757 km^2 *356 km^2*	21% *21.1% of floodplain*

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

5.2. Sensitivities to woodland creation

Around 8,945 km^2 or 39% of the region is identified as potentially sensitive to woodland creation, which may restrict the scale and character of any planting (Table 4). The dominant sensitivities are culturally important landscapes, national and international conservation designations, and undesignated BAP habitats. Some 29% of the region lies within Areas of Outstanding National Beauty and National Parks. 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.

Woodland sensitivity	Area (km^2)	% of region or *fluvial floodplain*
International conservation designations [RAMSAR, SPA, SAC]	2,319 km^2	10.2%
National conservation designations [SSSI, NNR, RSPB reserves]	2,631 km^2	11.6%
Protected and culturally important landscapes [AONB, National Parks, Common land, Battlefield and Historic Parks & Gardens]	6,831 km^2	30.1%
Grade 1 agricultural land	96 km^2	0.4%
Land above the natural treeline	1,275 km^2	5.6%
EA washlands	60 km^2	0.3%
Peatlands [blanket & lowland raised bogs]	1,271 km^2	5.6%
Riparian buffer along Main Rivers	225 km^2	1.0%
Urban and road floodplain buffer	764 km^2	*47.6%*
Undesignated BAP Habitats	3,496 km^2	15.4%
Total area of all sensitivities for which spatial data is available *Across the fluvial floodplain*	8,945 km^2 *909 km^2*	39.4% *53%*

Table 4. Sensitivities to woodland planting in the region (note that some of the features overlap with the constraints)

The buffer zone applied to urban areas and roads represents a major and dominant sensitivity within the floodplain, covering 764 km^2 or 48% of Flood Zone 2. This indicates that most planting proposals within the floodplain may 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 and riparian woodland is the potential restriction on planting close to Main Rivers, with a total area of 225 km^2 of land lying within the riparian buffer sensitivity.

5.3. Opportunities for woodland creation to reduce downstream flood risk

A total of 3,466 km^2 or 15.3% of the region is identified as a priority area for woodland creation to reduce downstream flood risk (Map 18b). This comprises 625 km^2 of priority floodplain, 505 km^2 riparian and 2,331 km^2 wider woodland. The majority lies within the Yorkshire Area and in particular, within the uplands of the Yorkshire Dales, Southern Pennine Fringe and North York Moors, and the lowlands of the Vales of Mowbray, York and Pickering. Most falls within the Ouse CFMP, although there are significant priority areas in the Aire, Calder, Don, Derwent and Hull CFMPs. These mainly comprise policy units 5 and 6. Within the North East, priority areas for planting are concentrated in the North Pennines and Cheviots. Notable catchments include the upper Wear (within the Wear CFMP) and the headwaters and floodplains of the River Coquet (North East Northumberland CFMP) and River Till (Till CFMP). As in Yorkshire, the land is dominated by policy units 5 and 6.

A large proportion (58%) of the priority land in the region is influenced by sensitivities, with the opportunities for riparian and wider woodland planting mainly affected by ANOBs and National Parks, while those for floodplain woodland overlap extensively with urban and road buffer zones.

5.4. Opportunities for woodland creation to reduce diffuse pollution

Maps 27a & b show that there are extensive opportunities across the region for woodland creation to reduce agricultural diffuse pollution pressures on the water environment. A total of 3,144 km^2 or 13.9% comprises priority land for planting to reduce one or more diffuse pollutants. As with FRM, opportunities are greatest within the Yorkshire Area, where most of the 1,596 km^2 of land (7.0% of region) for reducing pesticides is located. This is concentrated on the arable land within the Vales of Mowbray, Pickering and York, as well as in the northern part of the Humberhead Levels. Priority land for addressing diffuse phosphorus pollution is the next most extensive (1,220 km^2; 5.4% of region), with sizeable pockets scattered across lower lying parts of the region. These comprise a mix of arable and improved grassland and are mainly located within the Swale, Ure, Nidd & Upper Ouse, lower Tees, lower Till, southern half of the Northumberland Rivers and eastern part of the Hull & East Riding WFD management catchments. Opportunities to address diffuse sediment pollution are more restricted, totalling 1,011 km^2 of land (4.5% of region). This ranges from small scattered pockets to larger hotspots, with the latter centred in the northern part of the Holderness, the middle section of the River Tees and River Coquet catchments, and along the length of the River Wansbeck catchment. Priority areas for nitrate total only 237 km^2 (1.0% of region) and are largely confined to an indicative area identified to provide long-term protection for drinking water in Holderness (River Hull) and the relatively small NVZ Eutrophic Areas in Northumberland (Lindesfarne/Budle Bay) and Holderness (Hornsea Mere). Another hotspot lies to the south of the Humber in the northern part of the Anglian Region, focused on the drinking water protected area on the edge of the Lincolnshire Wolds. Sensitivities affect less than 20% of the priority land for reducing diffuse pollution.

Opportunities to tackle multiple diffuse pollutants are mainly confined to the Yorkshire area. Priority land to reduce two or more pollutants are scattered across the area, with notable concentrations located in the River Hull catchment in Holderness, the northern edge of the Ouse draining the Vale of Mowbray, the northwestern edge of the Vale of Pickering, the southern part of the Vale of York, and in the Upper valley of the River Aire. There are a total of 2,629 km^2 of priority land for planting to reduce one diffuse pollutant, 569 km^2 for two, 76 km^2 for three and 17 km^2 for four. The main opportunity to reduce four pollutants is centred on an indicative area identified to provide long-term protection for drinking water in Holderness.

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

Map 29 shows that there are relatively extensive areas where woodland creation could benefit both FRM and the WFD, totalling 506 km^2 or 2.2% of the region. Around 62% (313 km^2) is free from sensitivities to woodland planting. Most is concentrated in the Yorkshire Area, particularly within the Vales of Mowbray and York and along the Yorkshire Dales Fringe. Other notable locations include the Vale of Pickering, Holderness, and parts of the Yorkshire Dales draining to the Rivers Swale, Ure, Wharfe and Aire. Opportunities for woodland planting to help reduce both flood risk and at least one diffuse pollutant within the North East area are largely confined to small areas within the Rivers Coquet and Wansbeck catchments in Northumberland and in the River Leven catchment draining the Cleveland Hills. There are only 74 ha where woodland creation could benefit both FRM and help to reduce all four diffuse pollutants, most of which is located within the indicative drinking water protected area in Holderness.

5.6. Consideration of opportunities in relation to existing regional land management initiatives

Map 30 shows that there is a large degree of overlap between the identified priority land for woodland creation and existing regional initiatives designed to promote land use change or improve land management to mitigate flooding and diffuse pollution. There are extensive opportunities for woodland creation to help reduce flood risk within CFMP policy units 5 and 6, although most of this is affected by sensitivities. Opportunities are greatest within the Ouse and parts of the Aire, Calder, Don, Derwent and Hull CFMPs in the Yorkshire Area, and in the Wear, North East Northumberland and Till CFMPs in the North East. This includes sizeable areas of land draining to many of the 101 Rapid Response Catchments (RRC) in the region, including the 54 assessed as being at very high or high risk.

In terms of diffuse pollution, much of the Ouse, Nidd & Swale and Derwent CSFDI priority catchments comprises priority land for woodland to reduce at least one diffuse pollutant. Other major opportunities exist within the East Riding, North East Northumberland and Till CSFDI priority catchments, together with the Lincolnshire Coast CSFDI priority catchment in the Anglian Region. Most of the Semerwater catchment within the Semerwater and Upper Lune Strategic Partnership Catchment (SPC) comprises priority land for woodland planting, while opportunities within the River Nidd SPC are limited to the lower part of the catchment.

There is significant overlap between CFMP policy units 4, 5 and 6 and CSFDI priority catchments in Northumberland and central and east Yorkshire. Opportunities for woodland creation to address both objectives mainly lie in Yorkshire, centred on the

Ouse, Nidd and Swale CSFDI priority catchment. Other notable locations arise within the Derwent and Hull & East Riding CSFDI priority catchments, and within the Semerwater and Upper Lune SPC. There are very limited opportunities in Northumberland, which are largely restricted to the River Coquet catchment in the Tweed, Aln, Coquet and coastal streams CSFDI priority catchment.

Very little priority land for woodland creation to reduce flood risk and/or diffuse pollution occurs within the existing Nature Improvement Areas.

5.6.1. River Coquet Catchment in the NEN Catchment Flood Management Plan

Map 31 shows extensive opportunities for woodland creation in both the uplands and along the length of the floodplain to reduce flood risk. The priority area for planting covers a total of 145 km^2 or 23.2% of the catchment. Most of the upland part is affected by sensitivities, particularly by the Northumberland National Park and Ministry of Defence land, which will influence the scale, type and design of any planting. Opportunities to reduce diffuse pollution are largely limited to pesticides, with a total of 58 km^2 of priority land identified for this diffuse pollutant (Map 32). This mainly affects areas of improved grassland and arable land along the valley bottom and the lower lying, southeast part of the catchment. A total of 7.3 km^2 (1.2% of catchment) of priority land is potentially available to reduce both flood risk and diffuse pollution, most of which lies within the floodplain of the River Coquet (Map 33).

5.6.2. The Ouse, Nidd and Swale Catchment Sensitive Farming Delivery Initiative (CSFDI)

Map 34a shows that opportunities exist for woodland creation to reduce diffuse pollution across almost half (853 km^2; 49%) of the Ouse, Nidd and Swale CSFDI priority catchment. Opportunities are greatest for reducing pesticide pollution, which extend throughout the catchment. There are also sizeable areas of priority land to reduce diffuse phosphate and sediment pollution, mainly located in the Vale of Mowbray to the north of the catchment and in the southeast along the Yorkshire Dales Fringe. These represent the main areas for tackling multiple diffuse pollutants (Map 34b). The scope for reducing all three diffuse pollutants is largely confined to central and northern parts of the Vale of Mowbray.

Opportunities for woodland creation to reduce flood risk total 442 km^2 (26%) and mainly extend along the Yorkshire Dales Fringe and the floodplain of the River Ouse (Map 35). Pockets of priority land also occur to the east, along the edge of the North York Moors and Howardian Hills. These areas offer significant scope for planting to benefit both FRM and WFD, covering a total area of 238 km^2 (14%; Map 36). Most of this land is unaffected by sensitivities.

5.6.3. The Semerwater and Upper Lune Strategic Partnership Catchment

Virtually the whole (88%) of the Semerwater catchment comprises priority land for woodland creation to reduce flood risk and/or diffuse pollution (Map 37a). Almost two thirds (65%; 31 km^2) is a priority for flood risk, forming most of the upper slopes and hilltops. Another 56% (27 km^2) presents opportunities for reducing diffuse phosphate pollution, with a predominance on the lower slopes and valley bottom. A total of 16 km^2 (33% of the catchment) of priority land on the catchment mid-slopes could benefit both FRM and WFD. All of the catchment lies within the Yorkshire Dales National Park and therefore any planting would have to reflect landscape and open habitat sensitivities.

Map 37b focuses on a small area around the hamlet of Stalling Busk in the centre of the catchment to draw attention to scaling and data resolution issues. Much of the data used comprises shapefiles with no effective resolution but needs processing for data analyses and ease of handling. The creation of different data rasters can vary in resolution and in this project ranged from 6 m to 100 m. This results in a segmented or gridded appearance in the mapped data representing the borders of the different attributes/features. Another issue is the resolution of the soil and modelled diffuse pollution sources, which is currently only available at a 1 km grid scale. These issues result in hard data ‘edges’ that do not reflect natural and man-made boundaries on the ground, such as field borders and river courses. Consequently, when considering individual planting proposals targeting the identified priority land, particular care is required where these lie close to boundary areas. For example, in the case of the central 1 km square around Stalling Busk that does not form a priority for reducing diffuse pollution, it is possible or even likely that fields crossing or close to the grid border could actually qualify as a priority. Similarly, the opposite applies to edge fields in the adjacent priority grid squares. Mapped edges should therefore be treated as ‘indicative/soft’ and planting decisions informed by consideration of local topography, vegetation and soils.

5.6.4. Existing Land Management Projects in the Region

The Yorkshire and North East England Region is the location of a number of land management projects designed to demonstrate and evaluate the role of woodland and related measures in reducing flood risk and/or diffuse pollution (Map 30). Some of these are of national importance, such as the Defra funded ‘Slowing the Flow at Pickering’ project in North Yorkshire (http://www.forestry.gov.uk/fr/slowingtheflow). Its aim is to demonstrate how the integrated application of a range of best land management practices can help reduce flood risk at the catchment scale, as well as provide wider multiple benefits for local communities. A range of woodland measures are being trialed, including riparian woodland planting and the construction of large woody debris dams and ‘timber minibunds’. Other projects with an important regional or local profile include ‘The Source’ project in the River Calder (http://www.treesponsibility.com/projects/the-source). This involves planting trees on ten sites to minimise water runoff and reduce soil and riverbank erosion. It includes the use of 'leaky dams' and willow bundle fascines to help reduce sediment pollution and downstream flood risk. Future extensions to these projects and the siting of new ones will be able to draw on the opportunity maps from the current work to help guide the best placement of woodland measures.

Other projects have focused on developing models to inform particular land management issues such as reducing soil erosion and slope failure. For example, Durham and Lancaster Universities have developed the SCIMAP model to produce risk maps or erodability and sediment delivery to watercourses (http://www.scimap.org.uk/scimap-overview/). The model is available online for non-commercial use and the EA is able to run this to generate pdf maps of catchments for co-delivery partners on request. Woodland planting has a clear role to play in helping to stabilise slopes and reduce sediment delivery to watercourses.

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

5.7.1. River water bodies at risk of failing GES due to acidification

Map 38 shows that there are 61 RWBs in the region failing or at risk of failing GES due to acidification. All lie within upland areas, mainly in the Border Moors and Forests, Yorkshire Dales, Southern Pennines and North York Moors. Also shown is where the existing level of forest cover exceeds 20% of any sub-catchment (>100 ha in area) within these RWBs. Those sub-catchments with >20% broadleaved or mixed woodland cover will typically be managed under a low impact silviculture regime and are 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 28 RWBs that have 114 sub-catchments with extensive conifer cover. Most of these lie within Kielder and Kidland Forests in Northumberland, with others in the Dark Peak and North York Moors. The forest plans of the 18 conifer forest blocks that lie within the 28 failing and at risk RWBs require checking to ensure that felling does not pose a significant acidification pressure on local waters.

5.7.2. River water bodies with sub-catchments with >20% woodland cover

Maps 39 & 40 show the location of RWBs with >20% woodland cover within component sub-catchments, where the scale of felling could potentially pose a risk to FRM or diffuse phosphorus pollution. These are reasonably widely distributed across the region and in the 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 211 sub-catchments have more than 20% conifer cover in areas vulnerable to flooding, most of which lie within the Derwent and North East Northumberland CFMPs. Another 103 sub-catchments exceeding 20% conifer cover are located within RWBs vulnerable to diffuse phosphorus pollution, with these forming sizeable groups within the Northumberland Rivers and Tyne WFD management catchments. The plans for these woodlands need to be checked and amended where the felling threshold is exceeded.

5.7.3. Watercourses with existing conifer forest within 20 m of bankside

Map 41 displays 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 18,164 ha, with particular concentrations within the Border Moors and Forests, Tyne and Wear Lowlands and North York Moors. Individual woodland plans relating to these should be reviewed and opportunities taken to restore sites to native riparian 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.

5.7.4. Water bodies potentially at risk from the higher water use by trees

Relatively extensive areas within the region are under pressure from impoundment and/or overabstraction, including both groundwater and surface water resources. Map 42 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. There are 204 sub-catchments with >20% broadleaved or mixed woodland cover scattered across the region, with another 106 with >20% conifer cover. The higher water use of the latter will exert the greatest impact, especially within the Durham Limestone Plateau and the extensively forested North York Moors. Further large scale planting of conifers or short rotation forest crops within these areas could pose a significant risk to future water resources.

5.8. Management of riparian vegetation for climate change adaptation - EA Keeping Rivers Cool Project

The example map of relative shade along a section of the River Swale near Leeming in the Vale of Mowbray shows that most of the length of this embanked watercourse lacks riparian shade (Map 43). This is common to many rivers with flood defences and reflects limits on tree planting close to Main Rivers to maintain access for maintenance work, prevent damage to embankments from windblown trees, and to avoid restricting flood conveyance. The maps can be used to highlight where shading is most lacking and to promote discussion about possible tree planting for providing shade and shelter for fish where local circumstances allow.

Map 44 shows that 104 failing RWBs (16% of all failing RWBs) are lacking in riparian shade, which could be partly responsible for the less than good fish status. These RWBs are distributed across the region but with particular concentrations along the River Ouse floodplain and within the Humberhead Levels and Holderness. Riparian woodland planting within these water bodies to provide greater shade and shelter could aid ecological recovery of waters, as well as reduce diffuse chemical pollutants and downstream flood risk.

6. Conclusions

The Yorkshire and North East England Region faces a number of major water issues, with 77,000 properties at high risk of flooding and 73% of river water bodies currently failing to meet Good Ecological Status under by the Water Framework Directive (WFD). A recent review of relevant research provides strong evidence of the ability of woodland creation to mitigate these pressures by reducing and delaying flood waters, limiting pollutant loadings and retaining diffuse pollutants. The main aim of this study was to identify priority rural areas in the region for woodland creation and the improved management of existing woodlands to help reduce downstream flood risk and restore damaged waters. The project boundary was extended to include a small part of the adjacent Anglian Region to complete coverage of the Humber River Basin, although this area is excluded from the calculated statistics presented in the report.

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 suitable 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 flood risk management (FRM) and meet WFD targets, in addition to generating many other benefits for society. Woodland creation, however, is not without risks and care will be required in planting the right tree in the right place to avoid woodland acting as a pressure on the water environment.

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:

- 3,466 km^2 (15.3% of region) of priority areas for woodland planting to reduce downstream flood risk, comprising 2,336 km^2 of wider woodland, 505 km^2 of riparian woodland and 625 km^2 of floodplain woodland (Map 18b)
- 3,144 km^2 (13.9% of region) of priority areas for woodland creation to reduce one or more diffuse pollutants (phosphate, nitrate, pesticides and sediment) from agricultural sources (Map 27a)
- 506 km^2 (2.2% of region) of priority land where woodland planting could tackle both flood risk and one or more diffuse agricultural pollution pressures; 62% (313 km^2) of this land is free from all identified sensitivities to woodland planting (Map 28)

- 74 ha of priority land where woodland planting could reduce both flood risk and all four identified diffuse agricultural pollution pressures; all of this land is free from sensitivities
- 333 (>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 87 within areas vulnerable to acidification; 18,164 ha of riparian land where conifer woodland remains within 20 m of the river network; and 815 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.

Opportunities for woodland creation to reduce flood risk are greatest within the Yorkshire Area, comprising the uplands of the Yorkshire Dales, Southern Pennine Fringe and North York Moors, and the lowlands of the Vales of Mowbray, York and Pickering. Notable locations in the North East include the upper Wear draining the North Pennines and the headwaters and floodplains of the Rivers Coquet and Till draining the Cheviot Hills.

Opportunities to reduce diffuse pollution are also greatest in the Yorkshire Area, although in contrast to FRM, are dominated by the lowlands, reflecting the distribution of arable crops and improved grassland. Target areas for reducing one or more diffuse pollutants include the Vales of Mowbray, York and Pickering, and Holderness. Opportunities in the North East mainly lie in the middle and lower Tees catchment and in a number of Northumberland Rivers, including the Wansbeck, Coquet and Till catchments. The greatest scope for multiple water benefits arise in the Vales of Mowbray, York and Pickering, parts of the Yorkshire Dales and Dales Fringe, and in Holderness.

There is a large degree of overlap between the identified priority land for woodland creation and existing regional initiatives designed to promote land use change or improve land management to mitigate flooding and diffuse pollution. This includes Catchment Flood Management Plans and Catchment Sensitive Farming Priority and Strategic Partnership 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 woodland functions not specifically addressed in this study, such as slope stabilisation and erosion control, or other woodland values, such as the provision of recreation and health benefits. This approach should help realise optimum benefits from any planting scheme tailored to local circumstances.

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. 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, small scale planting targeted to riparian buffers and along pollutant pathways could make a significant difference, while having a limited impact on agricultural incomes. There is scope for better integration of 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 consideration should be given to establishing one or more sub-catchment studies within the region to demonstrate and help communicate the value and benefits of woodland creation for water. The opportunity maps can be used to guide the location of such a study by targeting an identified priority area where there is significant scope for land use change. The report provides guidance on the design principles for woodland creation to maximise benefits for FRM and WFD.

7. Recommendations

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 a need to improve the current 1 km resolution of modelled sources of diffuse pollutants and continue efforts to generate robust predictions at the field scale.

3 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 woodland at the earliest opportunity

4 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.

5 The maps should be used to facilitate the establishment of one or more sub-catchment studies to demonstrate and communicate the benefits of woodland creation for water. This would ideally target a priority area with significant scope for land use

change and through monitoring/research help to grow a local evidence base to promote the benefits of using woodland as part of a more integrated catchment-based approach to future water management.

8. Acknowledgements

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10. Maps

To reduce the size of this file and maximize the resolution of the map images the have been removed from this version of the report. The map images are available as pdf files; Maps 1_18_Section 1.pdf; Maps_19_20_Section 2.pdf; Maps_31_44_Section 3.pdf.

11. Additional reports, spatial data and metadata used - not directly referred to in the text of the report

ADAS PSYCHIC [Phosphorus and Sediment Yield Characterisation in catchments] Model: 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, EA 2012

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

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

River Basin Management Plans: http://cdn.environment-agency.gov.uk/gene0910bsqr-e-e.pdf

Internal Drainage Board Water Level Management Plans (WLMP)

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)

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:

Appendix 1: Derived GIS data sets

The following spatial datasets will be supplied in an ESRI ArcGIS10 Personal Geodatabase called OM_YandNE_2013. The data were created by Forest Research (Forestry Commission) under contract to the Environment Agency for this project and are the Intellectual Property of the Environment Agency. Most of the supplied data are illustrated in the maps accompanying the report.

1. **PNW**: Potential New Woodland - area suitable for woodland creation in the Yorkshire and North East region. This is land free from any known constraint to woodland planting and is illustrated in Map 12; the combined area shown in green and yellow.

2. **CON_YNE**: Constraints Y&NE region – constraints to woodland planting in the Yorkshire & North East region. The data is illustrated in Map 12 as the white area labelled '*Area excluded from woodland creation*'.

3. **SEN_YNE**: Sensitivities Y&NE region – sensitivities to woodland planting in the Yorkshire & North East region. The data is illustrated in Map 12 as the yellow area labelled '*Area suitable for new woodland creation subject to sensitivities*'.

4. **PNFW**: Potential New Floodplain Woodland. The area shown in green in Map 13a labelled '*Area suitable for floodplain woodland creation*'. This is land within the EA fluvial flood zone 2 that is free from constraints to woodland planting.

5. **PNRW**: Potential New Riparian Woodland. The area shown in green in Map 13b labelled '*Area suitable for riparian woodland planting*'. This is land within 30m of the EA Detailed river network that is free from constraints to woodland planting.

6. **SPRR**: Soil Propensity to generate Rapid Runoff. Reclassification of soil data to identity areas where woodland creation can improve soil structure and reduce rapid runoff. The classification combines the natural hydrological properties of the soil with its vulnerability to structural degradation by agricultural practices. The data is illustrated in Map 15c. In the attribute table the column 'Soil.priority' contains the final classification (Low, Medium or High) as labelled in the Map legend.

7. **PfAF**: Preferred Area – Flooding. Area suitable for woodland creation on (a) soils with a high propensity to generate rapid surface runoff, i.e. land within the area defined as High in SPRR dataset (point 6) and (b) in the floodplain. The data is illustrated in Maps 16 & 17. In the attribute table the column 'grid_code' contains the information required to define woodland type as labelled thus:

   Value 0: *woodland in the wider catchment* - shown in beige

   Value 1: *riparian woodland* – green

   Value 10: *floodplain woodland* – red

   Value 11: riparian woodland in the floodplain also shown in red

8. **PAF**: Priority Area - Flooding: Area suitable for woodland creation on (a) soils with a high propensity to generate rapid surface runoff, i.e. land within the area defined as a High in SPRR dataset (point 6) and (b) in the floodplain. Priority area

defined as land within the EA Catchment Flood Management Plan policy units 4, 5 or 6 and catchments of any Rapid Response Catchments falling outside these units. The data is illustrated in Map 18b. In the attribute table the column 'grid_code' contains the information required to define woodland type as described for the PfAF dataset.

9. **PADP**: Priority Area - Diffuse Pollution. Priority area for woodland creation to reduce diffuse pollutants from agricultural sources. Priority areas are identified using modelled pollution source data in areas of known vulnerability to diffuse agricultural pollution (as illustrated in Maps 20a, 22a, 24a and 26a). The data is illustrated in Maps 27a and 27b. The data includes columns in the attribute table to identify the diffuse pollutant thus:

    SEDIMENT - Value 1 – yes: Value 0 – no. Priority area to reduce diffuse agricultural sediment pressure in vulnerable river water bodies. Area shown in brown in Map 27a.

    PHOSPHORUS - Value 1 – yes: Value 0 – no. Priority area to reduce diffuse agricultural phosphorus pressure in failing river water bodies. Area shown in blue in Map 27a.

    NITRATE - Value 1 – yes: Value 0 – no. Priority area to reduce diffuse agricultural nitrate pressure in vulnerable areas. Area shown in purple in Map 27a.

    PESTICIDE - Value 1 – yes: Value 0 – no. Priority area to reduce diffuse agricultural pesticide pressure in vulnerable areas. Area shown in green in Map 27a.

    NUM_DP – Value = number of diffuse pollutant pressures potentially mitigated by woodland creation as illustrated in Map 27b

10. **PNW_PAC**: Potential New Woodland - Priority Areas Combined. Opportunities for woodland planting in areas identified as a priority for both flood risk management and diffuse pollution. The data is illustrated in Maps 28 & 29 as the area shown in red.

11. **PSY_PHOS**: PSYCHIC_Phosphorus. Relative loads of total phosphorus predicted by the ADAS model PSYCHIC (Collins and Zhang, 2012) to reach watercourses from all agricultural diffuse sources via all pathways. The data is illustrated in Map 19b. The model predicts total pollution loss from land to water across a 1km grid and values in column 'Total_river' are pollution losses to watercourses in kg/ha/y. Values of >0.5 kg/ha/y have been targeted for woodland creation. The column Rel_3class includes a classification of relative pollution pressure thus:

    High >1.0 kg/ha/y

    Medium 0.5 – 1.0 kg/ha/y

    Low <0.5kg/h/y

12. **PSY_SED**: PSYCHIC_Sediment. Relative loads of total sediment predicted by the ADAS model PSYCHIC (Collins and Zhang, 2012) to reach watercourses from all

agricultural diffuse sources via all pathways. The model predicts pollution losses to watercourses on a 1km grid. The data is illustrated in Map 21b. The values in column 'Total_river' are pollution losses to watercourses in kg/ha/y. Values of >250 kg/ha/y have been targeted for woodland creation. The column Rel_3class includes a classification of relative pollution pressure thus:

High >500 kg/ha/y

Medium 250 – 500 kg/ha/y

Low <250 kg/h/y

13. **LUC_NIT**: Land Use Change_Nitrogen. Relative nitrate pollution pressure from diffuse agricultural sources predicted by the Land Use Change Model (EA, 2012). The model predicts relative pollution pressure scores for each field in the country represented by a central point. The score value is unitless and the point data was interpolated to a 1km grid. The top tertile (>1.268) has been targeted for woodland creation. The data is illustrated in Map 23b.

14. **LUC_PEST**: Land Use Change_Pesticide. Relative pesticide pollution pressure from diffuse agricultural sources predicted by the Land Use Change Model (EA, 2012). The model predicts relative pollution pressure scores for each field in the country represented by a central point. The score value is unitless and the point data was interpolated to a 1km grid. The top tertile (>2.403) has been targeted for woodland creation. The data is illustrated in Map 25b.

15. **Conifer_20m**: Riparian Conifers within 20 m of a watercourse as illustrated in Map 41. Defined as conifer stands in the National Forest Inventory within a 20 m buffer created around the EA detailed river network.

16. **Watersheds_50m**: The existing woodland cover within tributary sub-catchments of >100 ha in area. The watersheds were created using the OS Land-Form PANORAMA 50m DTM. The watersheds were combined with the National Forest Inventory to determine woodland cover and existing conifer forest cover. The watersheds are intended to be indicative only as they were created by Forest Research for the current project using the hydrological tools in ArcMap and the OS Land-Form PANORAMA 50m DTM (interpolated from the contours on the OS Landranger Maps). The following information is provided in the attribute table:

Column	Description
FC_PC	Existing woodland cover as a percentage
CON_PC	Existing conifer forest cover as a percentage
PH	Known risk from acidification YES/NO
PHOS	Known vulnerability to phosphorus enrichment YES/NO
FLOOD	Known downstream flood risk YES/NO
AB	Known abstraction pressure YES/NO

17. **EA_RWB_FDP_PH**: <u>EA RWB existing forest – acidification risk.</u> EA WFD river water bodies failing or at risk of failing Good Ecological Status (GES) due to acidification and with tributary sub-catchments with >20% existing woodland cover. These are shown in grey in Map 38.

18. **FC_FB_FDP_PH**: <u>Forest Blocks – acidification risk.</u> Forestry Commission Forest Blocks within EA WFD river water bodies failing GES due to acidification, with tributary sub-catchments with >20% existing woodland cover.

19. **EA_RWB_F_ALF**: <u>EA RWB existing forest – water availability pressure.</u> EA WFD river water bodies subject to low flow pressure, with tributary sub-catchments with >20% existing woodland cover. These are shown in grey in Map 42.

20. **FC_FB_F_ALF**: <u>Forest Blocks – water availability pressure.</u> Forestry Commission Forest Blocks within Groundwater bodies with poor quantitative status and river water bodies subject to low flow pressure, in which there are tributary sub-catchments with >20% existing woodland cover.

Appendix 2: 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, Water bodies, Classification, Typology and Reasons for Failure data]
- WFD River Water body Classification and Status Review (AfA082)
- WFD Groundwater body 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

Licensed spatial datasets used in the project:

- Ordnance Survey – Meridian 2: 50k digital mapping of urban centres, road network, railways and water bodies
- 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)

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 areas identified to provide long-term protection of drinking water sources; • 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: • provide continuous canopy cover along the length of the	***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	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 water bodies

REASONS FOR WATER BODY 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.
Macro-invertebrates	Sensitive to organic enrichment, pollution by toxic chemicals, acidification and over abstraction	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 WATER BODY 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.