Forest Research

Opportunity mapping for woodland creation to meet the objectives of the Water Framework Directive

Final report to the Environment Agency and FC England, May 2009

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ADAS

The Research Agency of the Forestry Commission

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Forestry Commission

Table of contents

List of Tables

1. Aims and Objectives

- To develop a robust and flexible methodology to identify where woodland creation should be targeted in the landscape to help meet the objectives of the Water Framework Directive.

- To facilitate better integration of woodland creation into wider land management practices (especially agriculture) to benefit the freshwater environment.

2. Background

The objective of the European Water Framework Directive is to achieve sustainable management of rivers, lakes, groundwaters, estuaries and coastal waters across all EU Member States. Key targets are to (1) achieve good chemical and ecological status in all surface waters, groundwaters and groundwater dependent wetlands, (2) prevent the deterioration of water quality and water resources, (3) promote the sustainable use of water and (4) help reduce the effects of floods and drought.

In England, the Environment Agency (EA) is the Competent Authority for implementation and regulation of the WFD. However, Forestry Commission (FC) England has regulatory and grant giving responsibilities which can help meet the WFD requirements by targeting resources to where they can be most effective (e.g. via Woodland Creation Grants, Felling licences, forest policy, Environmental Assessments, management and forest design planning).

To date, forestry has maintained a low profile through the WFD process on the basis that, if properly implemented, the Forest & Water Guidelines (FC, 2003) represent an effective programme of measures that adequately address all threats to water status. Forestry has been identified as a ‘pressure’ in a minority of Significant Water Management Issue (SWMI) reports as potentially contributing to diffuse water pollution (sediment, nutrient enrichment and pesticides in runoff), acidification and physical modification of rivers and coastlines. The Literature Review in Part 1 concluded that there was good quantitative evidence and practical experience that these risks could be effectively controlled by good forest design and management practice. The Forests & Water Guidelines, developed in partnership with the EA and other regulators, form the cornerstone of best practice management for protecting and enhancing the freshwater environment within forests. The Forests & Soil Conservation Guidelines (1998) also form an important part of environmental best practice for the sector.
The positive role that woodland creation and good management can play in meeting the objectives of the WFD is undervalued in the current SWMI reports and River Basin Management Plans (RBMP), except for the Northwest England region. This is largely

because agriculture is seen as the main rural pressure, with changes in agricultural practice rather than land use change sought as the primary solution. However, FC England recognises that targeted woodland creation is a potentially very effective measure for tackling agricultural pressures. The provision of water and other ecosystem services through land use change are highlighted in the Delivery Plan for 'The Strategy for England's Trees, Woods and Forest' (FC, 2008):

- Woodland as low input but productive land cover for catchment management of diffuse pollution (e.g. buffer strips to reduce nutrient and sediment runoff).
- Riparian woodland can restore natural physical processes leading to improved stream habitat condition.
- Wet woodland recognised as a priority habitat.
- Floodplain woodland contributing to flood alleviation.

3. Opportunity Mapping

The literature review found strong qualitative and some quantitative evidence to support the role of woodland creation and management in protecting the freshwater environment. This potential has yet to be realised, with current levels of woodland creation too small and unfocused to make a significant contribution at a landscape scale. Better targeting of measures through grant aid to the private sector and via the public forest estate is required.

A key need is for greater engagement with Environment Agency and Natural England staff at both the local (e.g. Catchment Sensitive Farming officers) and regional scale (during strategic planning consultations). Multi-agency partnerships are required to identify and agree priority areas where woodland creation or management could contribute most in terms of improving water status (e.g. tackling diffuse pollution and enhancing hydromorphology) and alleviating downstream flooding. These opportunities need to be integrated into River Basin Management Plans and Catchment Flood Management Plans, and given a higher profile in industry best practice guidance. Work is also required to re-evaluate available financial incentives for woodland planting so that these better reflect the full range of water and other ecosystem services.

This part of the report describes the development of a mapping methodology to identify areas were woodland creation would be most beneficial for water management. The method works across a range of scales from assessing opportunities for planting at a strategic regional or river basin level down to the practical field scale.

The essential attributes of the methodology are:

- It utilises existing and widely available data sets to characterise the opportunities and constraints to woodland planting.
- The procedure is easy to follow and adapted by local staff to meet the particular needs and circumstances of their region.
- An individual component of the method can be updated to incorporate revised model outputs, as new information becomes available.

4. Methodology

4.1. Strategic model structure

The strategic approach relies on easily obtainable data with the best possible resolution and accuracy to characterise water pressures and issues, and identify opportunities where woodland creation could help tackle these. The main steps are set out below:

1. Identify water bodies currently failing to meet 'good' ecological or chemical status based on data published by the EA in the River Basin Management Plans (RBMP). Also, identify areas at risk of flooding in the EA's Catchment Flood Management Plans (CFMP).	RBMP – Annex A current state of waters: ecological status or potential for rivers and lakes, and chemical status of groundwater bodies. Select catchments of water bodies of moderate, poor or bad status or potential. Select catchments where habitation or infrastructure is at risk of flooding.
2. Identify the probable cause(s) of a water body failing to meet the required status, using risk maps and pressures identified in the RBMP. Identify catchment factors contributing to flood risk in CFMP.	RBMP – Annex B tables of proposed objectives and Annex G pressures and risks to waters: Select water bodies at risk from pressures that could be alleviated by woodland creation/management, such as diffuse pollution from agricultural and urban sources and/or poor riparian or channel structure. CFMP – Select areas identified as Flood Zone 6.
3. Depending on risk factor, identify potential pollutant sources and pathways within the catchment using best available data.	• Remote sensing methods such as the interpretation of aerial photography, LiDAR or satellite imagery. • Application of published models for assessing nutrient and sediment losses from soils and loading to watercourses. • Soil risk mapping based on soil association, topography and land use data. • Available field data from catchment surveys such as fluvial audits and river habitat surveys.

4. Assess connectivity to watercourses or groundwater	EA Detailed river network – land within 50 m of watercourses EA Indicative flood map EA Groundwater map
5. Identify constraints to woodland creation	Including urban infrastructure; incompatible land uses; scheduled and protected sites; and economic assets or structures at risk from the backing-up of floodwaters upstream of floodplain woodland or by blockage by large woody debris.
6. Identify priority areas for woodland creation	Assess where woodland creation could provide the greatest water and wider ecosystem services. For example, an area of new woodland (riparian or floodplain) that helps to mitigate downstream flooding, control thermal stress and create new wet woodland habitat, in addition to protecting watercourses from diffuse pollution from the adjacent land.

4.2. Application of the model

The following section provides details on the strategic modelling methodology, which is followed by a detailed case study involving the Bassenthwaite Lake catchment on the River Derwent in the Northwest Region.

4.2.1 Identify water bodies currently failing to meet ‘good’ ecological or chemical status.

The EA assesses the condition of water bodies across England and Wales in terms of water chemistry, ecology and flow. The information is being used to characterise and classify the status of all water bodies and is available in Annex A [Current state of waters] of the regional RBMP.

The spatial data used in the preparation of the WFD RBMP is entitled ‘Consultation Data for our WFD Co-delivers’ and is available from the regional EA River Basin Management team or the National Data and Information Manager [Alex Coley]. The supporting non-spatial information [WFD_Classifications_v1] contains the overall ecological and separate biological and chemical classifications for each water body. The objective of the WFD is for all water bodies to achieve good ecological status by 2015; catchments of water bodies of moderate, poor or bad ecological status should therefore be targeted for mitigation measures.

4.2.2 Identify probably cause of water body failing to meet the required status.

The EA has undertaken a range of qualitative and/or quantitative risk assessments of the probable pressures causing a water body to fail to meet good ecological or chemical status. The information is provided in the Objectives Tables (one table for each surface water body) in Annex B of the RBMP and the supporting information [WFD_Risk_v1] which is supplied with the spatial data sets.

Attribute Name	**Description**
RSKDFF	Diffuse source pollution
PEST	Diffuse source pesticides
SHEEP	Diffuse source sheep dip
SEDI	Diffuse source sediments
P_AG	Diffuse source phosphorous pollution from agriculture
NH3	Ammonia from point and diffuse sources
BOD	Increased BOD from point and diffuse sources
RSKCSNUTS	Diffuse and point sources from nutrients
NO3	Diffuse and point sources nitrogen
P	Diffuse and point sources phosphorous
RSKPMOR	Physical and morphological pressures

Table 1 Specific risks to water bodies where woodland creation has the potential to improve water status.

Work is ongoing and data are not available for the full set of elements listed in the WFD status classification for all water bodies. For some elements, the classification status recorded is the result of modelling or expert judgement. Annex G of the RBMP provides information of the pressures and risks for each water body. Woodland creation may be effective in alleviating a number of pressures, particularly those relating to diffuse pollution and hydromorphology (Table 1). Action should therefore be targeted to the catchments of water bodies at high or moderate risk of failing to meet good status due to these pressures.

4.2.3 Depending on risk factor, identify potential pollutant sources and pathways within the catchment using best available data.

4.2.3.1 Remote sensing techniques:

Interpretation of aerial photographs and CASI hyperspectral data

Recent high-resolution digital aerial photography is available for most of the country and it is possible to commission new surveys from commercial companies if the existing data are of insufficient resolution or outdated. Such images have been used to assess the extent and location of active soil erosion, as in the case study described below. A polygon can be drawn around each patch of bare ground and the percentage of exposed soil or rock estimated (Figure 2). This approach can be used to identify precise locations where erosion pressures are most intense and prioritise grant aid towards stabilising and restoring these areas through woodland creation (Nisbet et. al., 2004).

Figure 2 Identification of potential sediment sources from aerial photography in the catchment of Bassenthwaite Lake in northwest England.

It is also possible to use compact airborne spectrographic imager (CASI) hyperspectral data to automate the acquisition of relevant vegetation and soil properties, including soil type, texture, soil moisture and organic matter content (Liu *et al.,* 2005). These techniques have been applied in the UK by Scottish Natural Heritage, to asses the condition of terrestrial SSSIs (Yallop *et al*., 2004) and Natural England, to monitor the revegetation of eroded peat soils (McMorrow *et al*., 2006).

Countryside Survey Land Cover Map 2000 (LCM2000) classification of land use and associated risk

LCM2000 is a spatial data set representing the thematic classification of spectral data recorded by satellite images into 26 land cover classes. From these it is possible to identify areas of land use with inherently high erosion risk (DEFRA, 2005a – listed in Table 2) and quantify the extent within a given water body.

LCM2000 Sub-classes	Land Use	DEFRA erosion risk
Arable cereals, arable horticulture	Late sown winter cereals, potatoes, sugar beet, field vegetables, outdoor pigs, grass re-seeds, forage maize, out wintering stock, grazing forage crops in autumn or winter	Highly susceptible
	Early sown winter cereals, oilseed rape, spring sown cereals, spring sown linseed, short rotation coppice/Miscanthus	Moderately susceptible
Non-rotational horticulture, improved grassland, other grass, broadleaf woodland	Long grass leys, permanent grassland, woodland	Less susceptible
Others	Not mentioned	

Table 2 LCM2000 land use classes and their susceptibility to erosion.

This spatial data set will soon be superseded by the Land Cover Map 2007, which classifies land cover using the same aggregate classes but on a field-by field scale using OS MasterMap cartography (should be available from CEH by September 2009).

LIDAR (Light Detection and Ranging technology)

LIDAR is an airborne remote sensing technique that uses light in a similar way that sonar uses sound. It can produce very high-resolution and accurate images of the ground surface that have a number of proven environmental applications, such as erosion risk assessment, flood risk mapping and vegetation monitoring. One example is its application in the Peak District National Park as a tool to identify and quantify the development of peat gullies in the Dark Peak SSSI (Haycock *et al.,* 2004).

There are several commercial companies offering commissioned LIDAR surveys, although data may be obtained directly from the Environment Agency's Geomatics Group. They hold aerial survey data for England and Wales collected since 1991 comprising aerial photography, CASI and more recent airborne LIDAR data; coverage is particularly good for flood prone areas: see http://www.geomatics-group.co.uk/GeoCMS/Products.aspx. Further information on the technical and applied aspects of LIDAR can be found at: http://www.forestresearch.gov.uk/fr/infd-6fkhfe

Satellite Imagery

New methods are being developed to utilise increasingly available satellite acquired imagery to create high-resolution data for model input parameters for entire river basins. Whilst field work remains an important component, not least for validation purposes, these techniques offer many advantages in terms of coverage and cost. Algorithms have been developed to automate and so speed-up the analysis of hyper-spectral images. In due course, it will be possible to readily provide data on fractional soil and vegetation cover within the landscape, as well as more detailed data on vegetation type, growth and surface roughness (Davenport *et al.*, 2003).

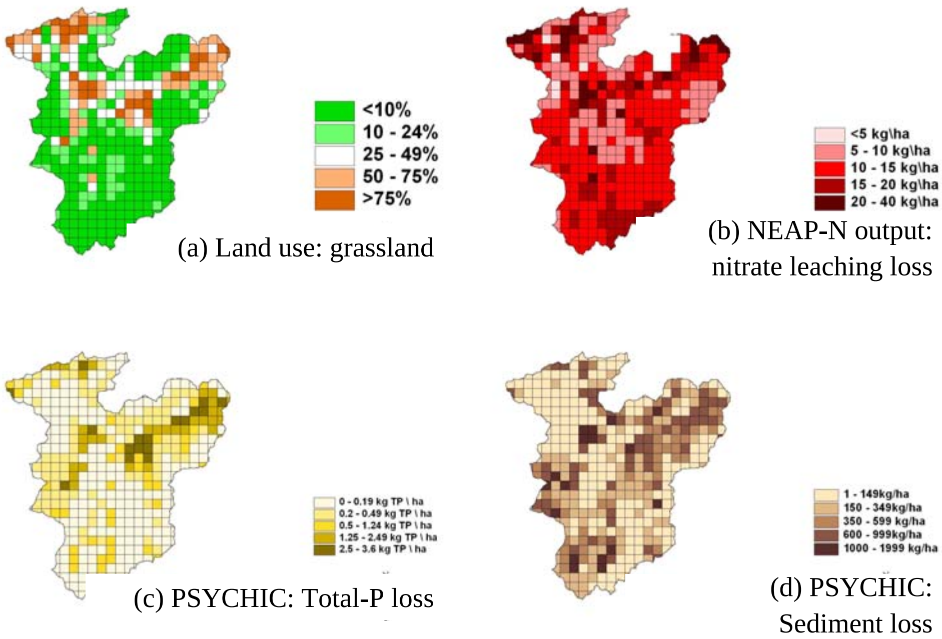
4.2.3.2 Catchment scale models

Often there are insufficient funds or time to conduct detailed field-based surveys or assessments and it is necessary to use models. Staff from ADAS have developed a spatial model to predict the mean annual sediment delivery to rivers from eroding channel banks using a national bank erosion index based on river flow regime and soil series (Collins and Anthony, 2008).

A number of decision support systems (DSS) have also been developed in the UK to support agricultural land use planning and management in relation to pollution abatement. These spatial GIS models are used by policy, regulatory and conservation bodies to identify priority river basins at risk from diffuse pollution (Silgram et. al., 2001 and Silgram et. al., 2008). The common conceptual framework underlying these models is to identify and quantify pollutant sources, mobilisation and delivery pathways to watercourses.

MAGPIE, a national data base of agricultural and environmental data for each 1 km^2 cell in the UK (Lord and Anthony, 2000), has been designed to evaluate nitrate losses at national and catchment scales. Another is PSYCHIC (Davison *et a*l., 2008), which is a research prototype model developed for the management of phosphorus and sediment inputs. Both these models were developed by ADAS and are widely used by the EA. The models rely on data for crops, fertiliser inputs and livestock numbers taken from the annual agricultural census. The census data is modified in relation to land cover derived from remote sensing and interpolated to a 1 km grid. It is then possible to combine this with data on climate, soils and altitude (Figure 3). The resulting DSSs have been validated and found to match measured nutrients and sediment loads well (Stromqvist *et al.,* 2008). As the input data is based on the agricultural census, which includes actual fertilizer inputs and livestock, the model outputs represent estimated pressure rather than assumed risk. The PSYCHIC model is currently being revised to introduce greater process representation and produce daily output of phosphorus and sediment loss to rivers.

Figure 3 Illustration of MAGPIE and PSYCHIC model outputs for the River Derwent,



Cumbria: (a) land cover assessment; (b) modelled nitrate leaching losses using NEAP-N; (c) modelled Total-P mobilisation and losses from PSYCHIC; and (d) modelled sediment mobilisation and losses from PSYCHIC.

The output from these models cab be used in three ways:

1. To identify specific hotspots and waterbodies under greatest pressure from diffuse pollution (Figure 3c).
2. To identify where woodland creation would be most effective at interrupting pollutant pathways in the landscape and thereby reduce delivery to watercourses (Figure 3b).
3. To provide a preliminary assessment of probably mitigation effectiveness by changing model input parameters to simulate the effect of land use change.

4.2.3.3 Soil risk mapping based on soil association, topography and land use

Soil risk mapping identifies soils that are vulnerable to erosion and to delivering diffuse sediment and nutrient pollutants to watercourses. It also provides a way of locating soils that are liable to generate rapid surface runoff and therefore contribute to both flood generation and diffuse pollution. These soils can then be targeted for woodland planting to deliver multiple benefits, including water protection.

The resistance of soils to erosion is largely determined by soil texture. Soils with high sand or silt content are most vulnerable, while those with high clay and organic matter tend to have more stable soil crumbs and better aggregation. Once soil particles have become detached, erosion is dependent on wind or surface runoff to transport sediment off site. Erosion is enhanced where soil infiltration has been reduced, particularly on degraded sandy or silty soils subject to repeated cultivation or poaching by livestock.

The simplest mapping approach is to identify steeply sloping land as the most vulnerable to rapid runoff and soil damage. Slope gradient can readily be derived from a Digital Elevation Model (e.g. OS10k land-form PROFILE DTM) and is used in Defra's soil erosion guidelines to define four slope classes in terms of sensitivity to erosion (Table 3).

Class	Sensitivity to erosion	Slope
4	High	steep >7°
3	Moderate	moderate slopes: 3 – 7°
2	Lower	gentle slopes: 2 - 3°
1	Low	level ground, slope <2°

Table 3 Class boundaries for slope erosion risk: defined as 3° for the critical angle at which rill erosion begins and 7° as the upper limit of land considered suitable for arable farming (DEFRA, 2005a)

More complex approaches involve an assessment of a range of site factors. For example, national maps are available for England and Wales that classify soil vulnerability to erosion and sediment delivery to watercourses based on an assessment of soil type, topography and connectivity to watercourses (McHugh *et al*., 2002). The classification uses empirical data from field studies on the erodibility of upland, lowland grassland and arable soils, which was used to calculate the probability of erosion of a given magnitude occurring for different soil-slope combinations. These values were then combined with an index which defined the degree of connectivity between hillslopes and watercourses, to derive maps illustrating the risk of sediment delivery for different return periods.
The work is somewhat dated being based on LCMGB1990 spatial land cover data from 1990, although the analysis of topographical connectivity to watercourses and land-use classification into arable, lowland grassland and upland remains robust. Spatial data [1 km^2 raster] is available for England and Wales for erosion potential,

connectivity and sediment delivery. Although the spatial scale is coarse, the map can help to identify priority areas for more detailed inspection at the field level.

Alternative approaches focus on soil data and have classified soil associations in terms of soil sensitivity to damage and erodibility (Evans, 1990); these can be used to map soil vulnerability at a finer scale. This includes local classifications based on established relationships between soil associations and observed erosion (Nisbet *et al.,* 2004). Others utilise the hydrology of soil types (HOST) system (Boorman *et al.,* 1995), which was developed as a conceptual representation of the hydrological processes in the soil zone. All soil series in the UK have been grouped into one of 29 hydrological response models or 'HOST classes'. Calibrated values of Standard Percentage Runoff (SPR) have been derived for each HOST class. 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 and be highly vulnerable to water borne erosion.

The HOST classification deals primarily with water movement but since the basis of the classification is the physical structure and configuration of the soil profile, it can also be used to underpin other physical and hydrogeochemical models. For example, Harrod (1998) used HOST to classify the vulnerability of lowland grassland soils to poaching by livestock (Table 4). Poaching leads to surface compaction and waterlogging, which increase the risk of rapid surface runoff.

HOST poach class	HOST classes	Vulnerability
1	1 – 5	Slight
2	6 – 8, 11, 6 – 20, 22	Moderate
3	10, 14, 21, 23	High
4	9, 13, 24, 25	Very high
5	12, 15, 26 – 29	Extreme

Table 4 Vulnerability of soils to poaching as predicted by HOST class (Harrod, 1998).

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*., 2004a and b). The revised SPR values for the soils in the region are listed in Table 5. Soils considered to be most sensitive to structural degradation leading to increased surface runoff are brown earths (NATMAP vector codes 541, 542, 543, 571, 572, 581, 582) and brown sands (NAT MAP vector codes 551, 553, 554). Other soil series were considered to be either moderately sensitive or not sensitive to increasing runoff generation.

HOST Class	Physical Soil Description	Original SPR %	Revised SPR %	Sensitivity to rural land use
1	Free draining over chalk	2	14	Moderate
2	Free draining over limestone	2	14	Moderate
3	Free draining over soft sandstone	14.5	27	Moderate
4	Free draining over consolidated rocks	2	15	Moderate
5	Free draining over sands or gravel	14.5	27	Moderate
6	Free draining over colluvium and loamy drift	34	44	Moderate
7	Free draining over sands or gravel	44	44	Low
8	Free draining over colluvium and loamy drift	44	44	Low
9 & 10	Unconsolidated, gleying <40 cm from surface	25	25	Low
11	Drained peat	2	2	Low
12	Undrained Peat	60	60	Low
13	Impermeable layer within 100 cm	2	15	Moderate
14	Impermeable layer within 40 cm	25	40	Moderate
15	Peat over permeable substrate	48	48	Low
16	Slowly permeable, gleying within 100 cm depth	29	47	Moderate
17	Impermeable rocks, gleying within 100 cm depth	29	47	Moderate
18	Slowly permeable, gleying within 40-100 cm	47	59	Moderate
19	Impermeable rocks, gleying within 40-100 cm	60	60	Low
20	Impermeable clay, gleying within 40-100 cm	60	60	Low
21	Slowly permeable, gleying within 40-100 cm	47	60	Moderate
22	Impermeable rocks, gleying within 40-100 cm	60	60	Low
23	Impermeable clay gleying within 40-100 cm	60	60	Low
24	Slowly permeable, gleying <40 cm from surface	40	49	Moderate
25	Impermeable clay, gleying <40 cm from surface	50	60	Moderate
26	Peat over slowly permeable substrate	59	59	Low
27	Peat over impermeable substrate	60	60	Low
28 & 29	Raw Peats	60	60	Low

Table 5 Hydrology of soil types (HOST) classification with typical standard percentage runoff values for intact soils and those subject to degradation by agricultural land use.

Some workers have combined a number of these data sets to identify soils that would benefit most from woodland planting in terms of diffuse pollution control and flood risk management. For example, Broadmeadow and Nisbet (2009) used data sets on SPR value, soil vulnerability to structural degradation/runoff enhancement and sediment delivery to prioritise sites for woodland planting within the Yorkshire and the Humber Region. Table 6 illustrates a similar scheme, which focuses on the propensity of the soil to degrade structurally by poaching or arable cropping leading to increased runoff and risk of delivering sediment and associated pollutants to watercourses.

Risk of soil	Poach	Sensitivity to structural degradation	Sediment delivery to

erosion	class	by rural land management	watercourses (m^3/ha/y)
Low risk	<3	Low	<0.1
	=3	Low	<0.1
	<3	Moderate	<0.1
	>3	Low	<0.1
	=3	Moderate	<0.1
	<3	High	<0.1
Medium risk	>3	Moderate	<0.1
	=3	High	<0.1
	<3	Low	>0.1
	=3	Low	>0.1
	<3	Moderate	>0.1
	>3	High	<0.1
High risk	>3	Low	>0.1
	=3	Moderate	>0.1
	<3	High	>0.1
	>3	Moderate	>0.1
	=3	High	>0.1
	>3	High	>0.1

Table 6 Classification of soils in terms of propensity to degrade structurally by poaching or arable cropping leading to increased runoff and risk of delivering sediment and associated pollutants to watercourses.

4.2.3.4 Field based catchment surveys

Fluvial audit

Most diffuse pollution models focus on predicting sediment mobilisation from catchment surfaces by sheet and rill erosion and overlook within-river sources. Soil released from eroding riverbanks can make a significant contribution to sediment and nutrient loads within watercourses and merits attention in at-risk water bodies. Knowing the source and fate of suspended sediment is important when designing sediment control strategies since measures are best targeted to where benefits are likely to be greatest.

For relatively small areas, it may be cost effective to conduct a field based fluvial audit to identify the extent and causes of actively eroding riverbanks (Orr, 2004). Alternatively, it is possible to identify specific sediment sources using source tracing and fingerprinting techniques (Walling, 1999), such as to discriminate between pasture, arable, woodland and stream bank sources. A study by Walling *et al*., (2008) showed that the relative contribution from pasture and cultivated fields differed between catchments depending on soils and land use patterns; contributions of fine sediment from woodland areas were typically <1%. Cultivated areas were the dominant source of sediment within the River Wye and Avon catchments, with pasture forming a significant source where livestock grazing caused poaching. Eroding riverbanks were an additional significant source of sediment to the River Wye, contributing between 21-43% of the total suspended sediment. In contrast, in the River Avon, which is underlain primarily by chalk, the contribution from bank and subsurface sources was typically less than 20% (Walling *et al*., 2008). Mitigation options in the River Wye catchment are therefore directed towards the stabilisation and protection of channel margins through riparian fencing and woodland planting.

Field scale erosion risk assessments

In order to receive their area-based, Single Farm Payments farmers are required to keep land in good agricultural and environmental condition. All farmers need to carry out a soil protection review, which assesses the risk of erosion on their fields and considers possible countermeasures. A simple scheme was published by DEFRA (2005) to encourage farmers to prepare soil management plans for their land, involving the identification of high-risk erosion sites and implementation of best practice measures in return for financial support. The method involves the farmer or his agent ranking each field in terms of risk of erosion based on an assessment of soil texture, slope and land-use.

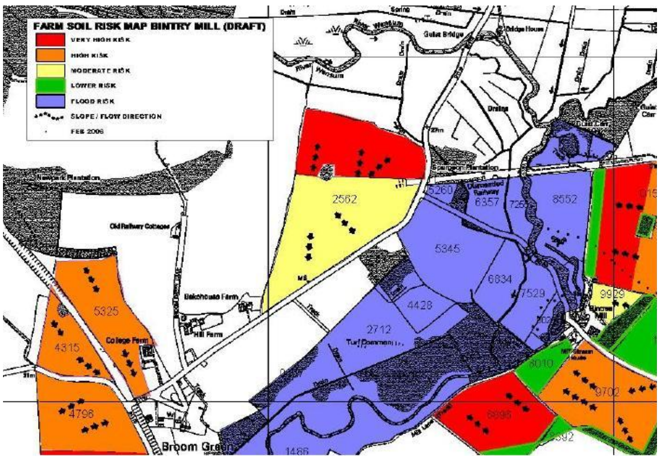


Figure 1 Example of a farm soil-risk map from Bintree in Norfolk (River Wensum catchment) developed under the England Catchment Sensitive Farming Delivery Initiative

This scheme has been heavily promoted in Catchment Sensitive Farming Initiative (CSFI) catchments and locally adapted to reflect observed erosion and knowledge of sediment delivery to watercourses. These maps can be particularly useful for identifying where woodland would be best placed to protect sources and intercept pollutant pathways. Where data are lacking and especially for high priority waterbodies, it may be appropriate to conduct a local soil survey to assess the risk of erosion (DEFRA, 2005b, Boardman *et al.,* 2009). However, soil surveys are expensive and only likely to be justified in special cases.

The high cost of field based measurements has resulted in the development of a range of modelling tools to predict diffuse pollution over larger spatial scales. Several models are currently used by the EA for assessing the risk of diffuse pollution from nutrient and sediment losses. However, the accuracy of the model output is very variable depending on the spatial resolution of available crop-specific information such as ground cover, fertiliser inputs and livestock density. Input data are frequently derived from agricultural census, although these sources can be sensitive and not always easily accessible. Data derived from remote sensing have the advantage of being contemporaneous and both spatially and temporally precise.

4.2.4 Connectivity to rivers - proximity to watercourses and flood zone

Riparian and floodplain zones form a buffer area between potential polluting activities on the adjacent land and watercourses. Woodland planting within these zones can help to reduce pollutant delivery to watercourses by intercepting surface flow. In addition, woodland can protect stream banks from erosion, reduce thermal stress, enhance freshwater habitats, reduce downstream flooding and help create woodland habitat networks.

4.2.4.1 Riparian zone

The riparian zone is the land immediately adjoining the aquatic zone and influenced by it. No data sets are available that map this zone and a common approach is to delineate a buffer of specified width along either side of the watercourse. To be effective, a riparian woodland buffer should be a minimum of 15 to 30 m wide depending on the topography of the site (Broadmeadow and Nisbet, 2004).

The EA Detailed River Network (DRN) spatial data set encompasses all watercourses. It can be used to create a riparian buffer of desired width, typically 30 m wide on either bank. Riparian woodland buffers 7 – 30 m wide have been reported to be effective at removing nutrients, while greater widths (15 – 65 m) are required to control sediment delivery, depending on soil and slope. This data set can be combined with information on slope gradient, soil vulnerability to erosion and sediment delivery from the adjacent land to highlight where riparian woodland planting would be most beneficial.

4.2.4.2 Floodplain zone

The EA indicative flood maps delineate areas of land vulnerable to flooding along main rivers for different return periods. These are classed into one of six generic policy units within Catchment Flood Management Plans (CFMPs). In most areas the policy is to take action to reduce or sustain current flood risk by flood defence but in others the priority is to store or mange floodwaters for downstream flood alleviation (Policy 6). Floodplain woodland should be considered as a land use option for this zone as a means of enhancing flood retention and delaying flood flows, as well as improving water quality through sediment and nutrient retention. Woodland planting would be less effective in managed washlands but could still confer other benefits such as for biodiversity.

The restoration of floodplain woodland and associated re-wetting of floodplain soils is not without risks and could facilitate the remobilisation of stored nutrients or other pollutants in contaminated soils. Soil enrichment and contamination may be an issue in water bodies with a long history of high fertiliser inputs or industrial activity. The CFMP should be consulted to determine the nature of these risks.

4.2.5 Identify constraints to woodland creation

Once potential pollutant sources and runoff pathways have been identified the next step is to remove those areas affected by constraints to woodland planting. The most common constraints are listed in the Appendix, along with the relevant government or non-government agencies who are responsible for creating and updating the spatial data sets; they should be consulted as part of any opportunity mapping project.

4.2.6 Identify priority areas for woodland creation

The end result of combining the previous steps is a map showing priority areas within catchments where targeted woodland creation offers the greatest water benefits. In due course it should be possible to combine these maps with those ranking sites for other benefits such as improving connectivity of existing woodland habitat networks (Catchpole, 2006, Broadmeadow and Nisbet, 2009) or provision of recreational opportunities (Penny, 2005), to highlight areas where land use change could deliver the largest 'bundle' of ecosystem services.

5. Case study: The Bassenthwaite Lake Catchment

The purpose of the case study is to demonstrate how a range of available data sets (as described above) can be used to identify opportunities within problem catchments for targeting woodland planting to deliver water services, especially diffuse pollution control and downstream flood alleviation. The catchment of Lake Bassenthwaite was selected as a prime example of how integrated land use planning and management is being developed to improve water status.

5.1 Catchment overview

Bassenthwaite Lake, within the Lake District National Park in northwest England, is a candidate Special Area of Conservation, a National Nature Reserve and a Grade 1 SSSI. This makes it very vulnerable to disturbance and highly sensitive to pollution. A key issue is poor water quality due to a high level of erosion in the catchment caused by a range of pressures, including overgrazing by livestock and excessive trampling by walkers. Erosion has led to large amounts of sediment being washed into the rivers and lake causing them to 'silt up', choking fish spawning beds and damaging wildlife habitats.

The Bassenthwaite Lake catchment covers an area of 354 km^2 in the upper catchment of the River Derwent. The geology is hard and volcanic, with the headwaters rising in the central high fells and then falling steeply, often through a series of waterfalls, until they reach the more gentle slopes of the middle catchment, upstream of Keswick. The soils of the high ground are peat or peaty and generally wet all year due to high rainfall. Soils in the valley bottoms mainly comprise permeable loams that are highly suitable for agricultural activities such as rearing dairy stock and some arable cropping.

River flow responds rapidly to rainfall (often very local in distribution) and leads to local flooding. To reduce the future flood risk in Keswick and the villages of the Upper Derwent, the CFMP (EA, 2008a) objective for the area is to 'naturalise' as much of the Bassenthwaite Lake catchment area as possible. The principal aim is to reconnect the floodplain and watercourses through the creation of wetland habitats (including wet woodland), thereby increasing flood storage and reducing flood flows. Another aim is to reduce the sediment load entering the river system to alleviate downstream siltation and increase flood conveyance.

Diffuse pollution is a major problem in the catchment and has led to it being selected as one of the priority catchments under the England Catchment Sensitive Farming Delivery Initiative. Environmental Stewardship grants are being used to bring about changes in land use and improve land management to help restore water quality.

The catchment is also the subject of the 'Bassenthwaite Lake Restoration Programme' (BLRP), which is a multi-agency initiative to restore the ecological status of the lake by reducing diffuse phosphorus and sediment pollution. In 2004 Forest Research and Lancaster University teamed up with the BLRP to develop a framework for targeting woodland creation in the catchment to help control soil erosion and reduce sediment delivery (Nisbet *et al*., 2004). This involved the creation of a number of spatial data sets (BassGIS) to identify the main sediment sources and pathways, including the use of recent digital aerial photographs and the results of a field-based fluvial audit (Orr *et al*., 2004). The resulting 'opportunity map' is being used by the FC to attract and help secure applications from land owners for woodland planting in preferred locations. This includes offering a locational grant premium for the water-related forest benefits.

5.2 Catchment assessment

5.2.1 Identify water bodies currently failing to meet good chemical or ecological status based on data published by the Environment Agency in the River Basin Management Plans.

The Bassenthwaite Lake system drains the upper catchment of the River Derwent and comprises 4 lake and 13 river water bodies (Map 1). Three of the river water bodies have yet to have their ecological status assessed, while another two have been designated as Heavily Modified and therefore classified according to their ecological potential rather than status. Information is available for biology and water chemistry, although the fish element has been removed from the classification for the time being, pending improvements to both the classification tool and survey data (due to concerns over mis-classification). The published maps (Map 1, Table 7a & 7b) show the amended ecological status or potential for the water bodies in the catchment. At present, the ecological status is only considered to be good in two lakes, Thirlmere and Blea Tarn, and two river water bodies, Dash Beck and Naddle Beck.

5.2.2 Identify probable cause of water body failing to meet required status based on risk maps and pressures identified in the RBMP.

The environmental pressures acting on the water bodies currently failing to meet good status within the Bassenthwaite Lake catchment are listed in Table 8. The widespread threat of diffuse pollution from rural sources is illustrated in Map 2, with the entire river system considered to be 'at risk' from sedimentation. Acidification, sheep dip, diffuse phosphorus and physical modification are the other main pressures. Woodland creation offers a number of opportunities to reduce sedimentation, diffuse phosphorus and physical modification pressures, although the focus would need to be on broadleaved rather than conifer woodland in view of the acidification issue.

Name	Map I.D.	Category	Annex A: National Ecological Status	Annex A: Amended Ecological Status
Wythop Beck	70500	River	Poor	Poor
Dash Beck	70530	River	Poor	Good
River Derwent	70330	River	Bad	Moderate
Stonethwaite Beck	70340	River	Poor	Moderate
River Derwent	70410	River	Not yet assessed	Not yet assessed
Naddle Beck	70420	River	Good	Good
St John's Beck	70430	River	Moderate	Moderate Potential
Newlands Beck	70440	River	Poor	Poor
Trout Beck	70450	River	Bad	Moderate
Glenderamackin (Greta)	70460	River	Bad	Moderate
Glenderaterra Beck	70470	River	Bad	Not yet assessed
Glenderamackin (Greta)	70490	River	Bad	Not yet assessed
River Derwent	73560	River	Bad	Moderate

Table 7a Ecological Status classification of river water bodies in the catchment of Bassenthwaite Lake.

Name	MapID	Category	Annex A: National Ecological Status	Annex A: Amended Ecological Status
Bassenthwaite lake	28847	Lake	Moderate	
Thirlmere	29021	Lake	Good	
Derwent water	28965	Lake	Moderate	
Blea Tarn	29097	Lake	Good	

Table 7b Ecological Status classification of lake water bodies in the catchment of Bassenthwaite Lake

Annex B of the RBMP also contains information on the planning process and the proposed measures to improve water quality. There are actions for nearly all sectors (agriculture, rural, angling, conservation, local and central government, Environment Agency and industry) to reduce the pressures from excess nutrients, sediment delivery and/or physical modification of riverbanks. Woodland creation is a potentially effective measure and is encouraged through targeted Forestry Commission grant aid and related activities. Better application of the Forests & Water Guidelines and planting of woodland along river corridors to act as a buffer and improve habitat connectivity are specifically recommended for all water bodies in the northwest.

Smaller scale, woodland planting is also encouraged through additional support provided by Environmental Stewardship Schemes and the England Catchment Sensitive Farming Delivery Initiative.

Name	MapID	Category	Annex B: elements currently less than good*	Annex G Pressures and risks**
Wythop Beck	70500	River	Fish	*Sediment*, Sheep dip
Dash Beck	70530	River	Fish, Flow	*Sediment*, Sheep dip, *Acidification*
River Derwent	70330	River	Fish, pH	*Sediment*, Acidification
Stonethwaite Beck	70340	River	Fish, pH	*Sediment*, Acidification
River Derwent	70410	River	Fish	*Sediment*, *Acidification*, Physical modification
Naddle Beck	70420	River		*Sediment*
St John's Beck	70430	River	Fish, hydro-morphology	*Sediment*, Sheep dip, Physical modification
Newlands Beck	70440	River	Fish, zinc, copper	*Sediment*, Sheep dip, Acidification
Trout Beck	70450	River	Fish, phytobenthos	*Sediment*,
Glenderamackin (Greta)	70460	River	Fish, phytobenthos, zinc, copper	*Sediment*, Sheep dip, *Diffuse P*
Glenderatera Beck	70470	River	Fish, Flow	*Sediment*,
Glenderamackin (Greta)	70490	River	Fish	Sediment, Acidification, *Diffuse P*
River Derwent	73560	River	Fish, zinc, copper	*Sediment*, Acidification
Bassenthwaite lake	28847	Lake	Phytoplankton, Dissolved Oxygen	
Thirlmere	29021	Lake		
Derwent water	28965	Lake	Dissolved Oxygen	
Blea Tarn	29097	Lake		

Table 8 Specific pressures affecting the ecological status of the water bodies within the catchment of Bassenthwaite Lake.

*Fish criteria indicates that water bodies have a poor ecological status based on the national classification scheme, but this does not account for the naturally low fish productivity in these waters.

**Italics indicate water bodies considered to be probably at risk

5.2.3 Depending on risk factor, identify potential sources and pathways within the catchment using best available data.

In a recent study, Hatfield and Mayer (2008) applied a magnetic fingerprinting technique to characterise and trace the deposited sediment within the deep basin of the Bassenthwaite Lake. They were able to discriminate between different sources of sediment and quantify the loads delivered from the tributary sub-catchments. Their results indicate that Newlands Beck, which provides around 10% of the lake's hydraulic load, is the main contributor of sediment to the lake. The lower delivery from the main River Derwent sub-catchment, which contributes ~ 80% of the hydraulic load, is thought to be due to sediment deposition and retention either on the floodplain or in shallower areas of the lake.

The PSYCHIC model has been applied to the catchment several times (Anthony *et al*., 2005, Collins *et al*., 2007 and Anthony *et al*., 2008) to estimate the sources and losses of phosphorus and sediment from the predominant grassland (managed plus rough) land cover (<3% of catchment is under arable land use).

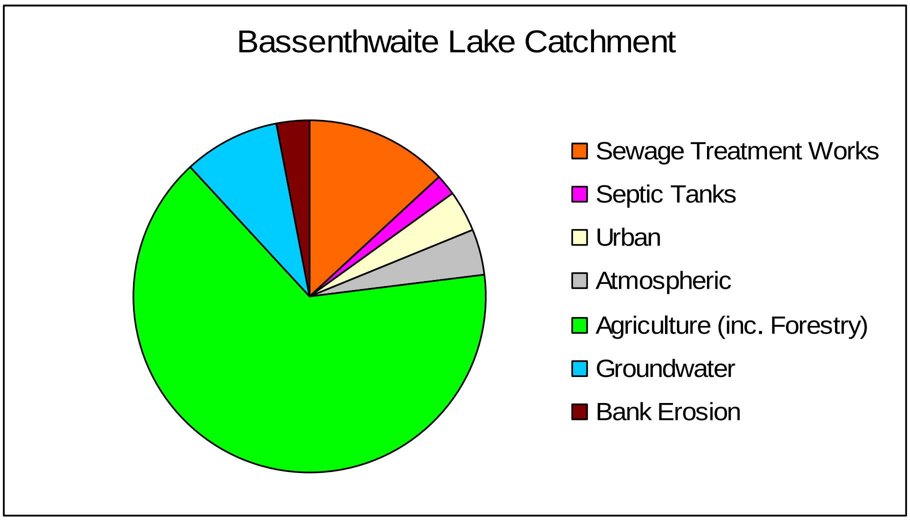


Figure 4 PSYCHIC output: source apportionment of Total P in the Bassenthwaite Lake catchment (% of total annual load) (Anthony *et al*., 2005).

Anthony *et al*., (2008) reported the source apportionment (% of total annual load) of total phosphorus (TP) from all diffuse and point sources in the Bassenthwaite Lake catchment (Figure 4). The main source of TP across the area is agriculture, predominantly from animal manure on the grazed grassland. Spatial distribution of TP losses show a concentration in the floodplain areas (Figure 3c), where there is the greatest density of dairy and beef cattle, human settlement and roads.
The PSYCHIC model outputs have been validated against measured lake water chemistry data (Anthony *et al*., 2008), with the model predicting a mean lake

concentration of 24 µg [TP] L^{-1} compared to a measured value of 21 µg TP L^{-1}. The modelled sediment losses concur with P sources but include additional “hot spot” high values on steep slopes. The model illustrates how efficiently the field drains transport P to the watercourses (Figure 5b), with delivery strongly reflecting source strength. Nitrogen leaching losses are directly related to livestock density, particularly with cattle numbers in the northern low ground and sheep on the southern fells.

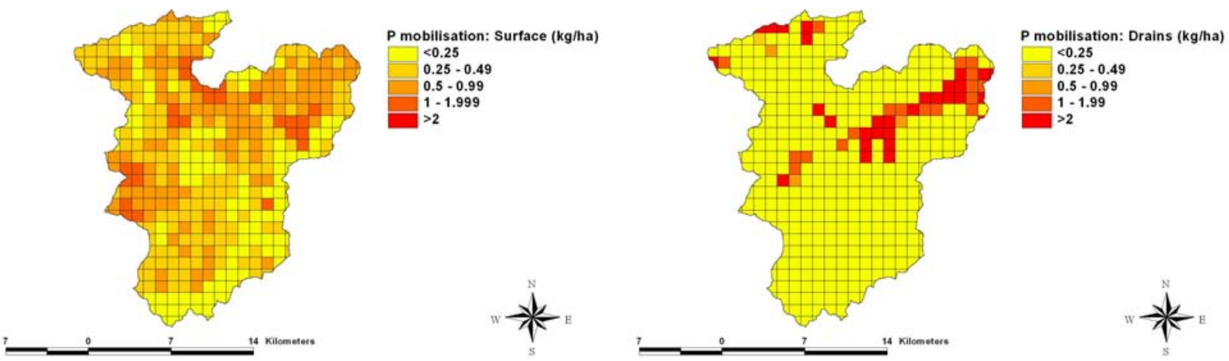


Figure 5 PSYCHIC model outputs: Total-Phosphorus mobilisation in the River Derwent catchment: (a) surface runoff and (b) field drains (Collins *et al*., 2007).

Based on the soil associations of the 1:250,000 National Soil Map, soil risk maps have been prepared for the catchment using both national (Map 3) and local (Map 4) classifications. Map 3 shows the Defra/EA classification of soils for their vulnerability to runoff enhancement due to structural degradation caused by arable cropping or livestock (Defra, 2004; JBA, 2007). The more fertile, floodplain soils are identified as being the most at risk of contributing increased rapid runoff due to inappropriate agricultural practices. In comparison, Map 4 illustrates a locally derived classification of soils in terms of vulnerability to soil erosion, based on an established relationship between soil association and observed bare ground (Nisbet *et al*., 2004). Some 66% of the bare ground is concentrated within two soil associations, with the most vulnerable soils being the peaty rankers on the hill-tops.

Woodland planting offers an effective measure for protecting vulnerable soils or reducing delivery of mobilised pollutants to watercourses by intercepting polluted runoff.

5.2.4 Connectivity to rivers - proximity to watercourses and flood zone

Across the catchment, some 10,945 ha of land are either within 50 m of a watercourse or lie within the EA flood zone (Map 5). A fluvial audit of the catchment identified 20.7 km of river channel exhibiting evidence of significant erosion on one or both banks (Nisbet *et al*., 2004). Map 6 shows the stream/river network dividing the river lengths (by soil association) into low, medium and high classes of vulnerability to erosion. A total of 61 km and 138 km are considered to be at high and medium risk of damage, respectively. Most of the main river channels have been subject to engineering works in the past and are currently affected by soil poaching. Riparian woodland could assist sediment control by protecting these sites from erosion.

A combination of high rainfall, impermeable geology and waterlogged soils means that the Bassenthwaite Lake catchment suffers from recurrent flooding. The main towns at risk are Keswick within the study catchment and Cockermouth further downstream, but there are also many smaller settlements subject to local flooding. The catchment lies within the Upper Derwent policy unit of the River Derwent CFMP and the recommended approach is: *'to take actions to store water or manage runoff in locations that provide overall flood risk reduction or environmental benefits, locally or elsewhere within the catchment'*. Woodland creation offers a number of opportunities in this regard, especially involving the planting of floodplain woodland to help retain and slow down flood flows.

5.2.5 Identify constraints to woodland creation

It is essential to consider whether land use change to woodland would be appropriate for the identified sites by assessing the full range of potential constraints. The main constraints to woodland planting are shown in Map 7 and listed in Table 9. Together they cover an area of 23,030 ha or 64.8% of the catchment.

5.2.6 Identify priority areas for woodland creation

Map 6 shows the end result of combining all of the spatial data sets on pollution sources and pathways with woodland constraints to identify opportunities for woodland planting to deliver the greatest water benefits. Areas of highest priority for woodland creation mainly comprise sites within the riparian/flood zone at high risk of riverbank erosion or structural degradation by agriculture, or soils in the wider catchment classed as being highly vulnerable to soil erosion.

Constraint	Notes
Scheduled conservation sites:	28 SSSIs – 12, 883 ha (including 3 cSACs - 10,683 ha, and one NNR - 560 ha)

Unscheduled conservation sites: Priority [BAP] Habitats Cumbria Wildlife Trust Cumbria Local Wildlife Sites (County Wildlife Site) RSPB reserves	 17,494 ha are identified by NE as being one of the priority (UK BAP) habitats. Two sites - spatial data not acquired for case study Spatial data available from county ecologist but not acquired for case study None in catchment
EA flood infrastructure:	There are no designated flood storage areas (wash lands) within the catchment but 40 ha of floodplain is protected by raised flood defences
Historic and cultural landscapes: Country Parks Historic Houses	There are no World Heritage Sites, Listed Buildings, Historic Parks and Gardens or Battle fields within the catchment 1 – Whinlatter Forest Park 1 – Mire House
Urban areas	192 ha
Roads	448 ha
Rail	None
Landfill Sites	Information not acquired for case study
MOD land	None
Prime agricultural land	No Grade 1 ALC
Sites of Antiquity:	29 Scheduled Ancient Monuments - 175 ha
Camping and caravan sites	22 mapped sites
Golf courses	1 mapped site
Airports	None
Land over 450m AOD	10,459 ha
Moorland	20,659 ha, including 13,687 ha subject to commoners' rights
Common land	13,711 ha, of which 13 sites (only 23.8 ha) are not moorland
Open water	1,561 ha
Existing woodland	4,181 ha

Table 8 Constraints to woodland planting in the catchment of Bassenthwaite Lake.

Most of the observed bare ground (Map 4) occurs on land that is subject to a nature conservation constraint and therefore potentially excluded from woodland planting. However, there are a number of opportunties for planting immediately downslope of these areas (many already classed as high priority), which would have the added benefit of helping to intercept and thereby prevent the delivery of sediment to watercourses. There may also be a possibility of limited riparian woodland planting along the upland valleys/ghylls within conservation designated areas.

5.3 Field scale assessment

An example 'Farm Estate' has been created to illustrate how the catchment mapping can be translated to the field scale in terms of identifying precise locations where tree planting could be targeted for water quality improvement. This fictional farm, illustrated in Map 9, is situated in the upper catchment of the River Derwent where first and second order streams draining the steeper hill slopes join the main river. The river water and downstream lake water bodies are currently failing to meet good ecological status and have been identified as being at risk from diffuse pollution from rural sources, principally diffuse source sediment and phosphorus. The area also lies within Policy Unit 6 of the CFMP and therefore is highlighted for land use and management actions to increase flood storage and delay rapid runoff in order to reduce flood risk in and around Keswick.

The northern boundary of the farm is the riverbank and the lower fields are situated on the floodplain (160 m AOD). A road forms the southern boundary and the highest point on the farm is 220 m AOD, although the fells above the farm reach heights over 500 m AOD. Soils mainly belong to the Brickfield 2 series, a seasonally waterlogged, slowly permeable, surface-water gley. The whole farm has been classed as having high or medium priority soils for woodland creation in terms of the risk of soil structural degradation leading to rapid surface run-off and delivery of sediment and nutrient pollutants to watercourses, and river bank erosion (Map 10). There are no constraints to woodland planting although the farmer is reluctant to lose any productive land and needs to retain access to watercourses for drinking water for livestock.

The soils are naturally imperfectly drained and there is likely to be piped underdrainage. A straight ditch has been cut across the south west corner of the farm to intercept drainage from the southern fells. Despite the drain, the land on the western edge remains very wet and marshy. The other watercourses on the farm are semi-natural in character. The farm grazes livestock and the only crop is grass for silage. Around 40% of the farm is unimproved rough pasture comprising semi natural moorland vegetation, while the other 60% has been improved through drainage and the use of fertilisers. Many fields are relatively steep with slopes in excess of 10 degrees. The heavy, wet soils are at a high risk of poaching and compaction by livestock, enhancing rapid surface runoff and pollutant delivery to watercourses. The central stream has incised a deep, steep sided channel in places.

Map 11 illustrates the current diffuse pollution issues. There is unrestricted access by livestock to watercourses, which has resulted in severe poaching at several sites along both the main river and the banks of the central stream. In periods of heavy rainfall, muddy runoff from the steading around the farm buildings runs down the track and flows into the central stream at the ford. Many of the fields also generate overland flow during storm events resulting in dirty water directly entering streams.

An assessment of the farm reveals a number of opportunities for woodland creation to help reduce diffuse pollution, enhance stream morphology and slow down flood flows. A total of six sites for targeting woodland planting are shown in Map 12 and comprise the following:

1. Planting new floodplain woodland on the south bank of the main river to delay flood flows, intercept diffuse pollutants, especially sediments and attached phosphate, and protect the river bank. The woodland has been extended upslope beyond the indicative floodplain in order to (a) enhance the interception of pollutants in runoff from the adjacent fields, (b) include the existing wetland within the new wet woodland habitat and (c) reduce costs by linking with the existing fence line. The planting design would need to be sensitive to the existing wetland vegetation and biodiversity value of the site, with the aim being to maintain open areas surrounded by a light woodland canopy to maintain wet meadow/marsh species.

2. Planting new riparian woodland within a fenced buffer strip along the steeper west bank of the central stream. This would act to intercept pollutants draining the adjacent fields, slow down flood flows and protect stream banks. The width of the woodland buffer would vary between 10 - 30 m to reflect the shape and slope of the land, enclosing and protecting the more vulnerable, steeper sections.

3. Plant a new block of riparian/farm woodland on the southern edge of the farm along the east bank of the central stream. This would mainly be designed to intercept run-off from the adjacent steep slope and to receive discharge from a main road drain, helping to improve local water quality.

4. Plant a new farm/riparian woodland within the existing field boundary enclosing a small, steep sided gully on the eastern edge of the farm. Benefits would be as per site 2.

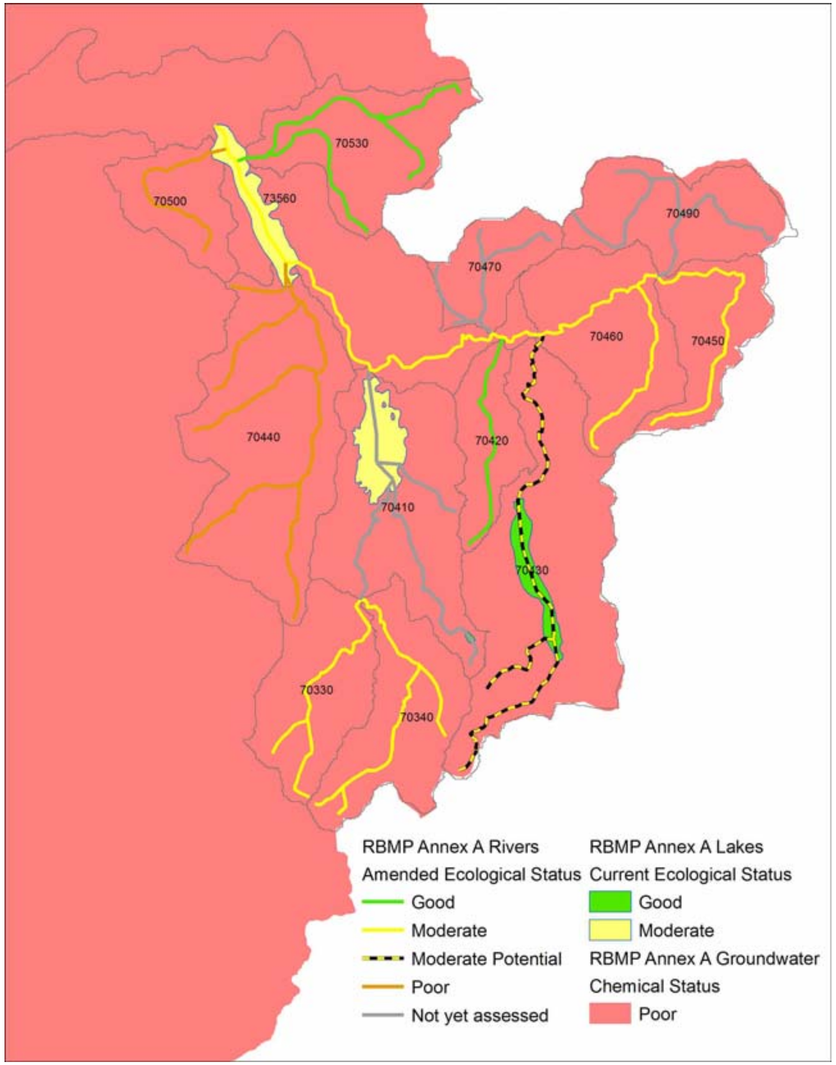
5. Plant a new woodland block within a constructed farm swale/infiltration zone designed to receive water draining from the steading; the woodland would promote infiltration and pollutant retention.

6. Plant a new strip of woodland alongside the main drain and road on the southern boundary of the farm. This would help to alleviate soil poaching (by preventing livestock access, including from crossing the drain) and disturbance along this seepage zone, which receives shallow groundwater from the fells plus road drainage. Ideally, the drain would be blocked to create an area of wet woodland that would help to improve water quality and retard flood flows.

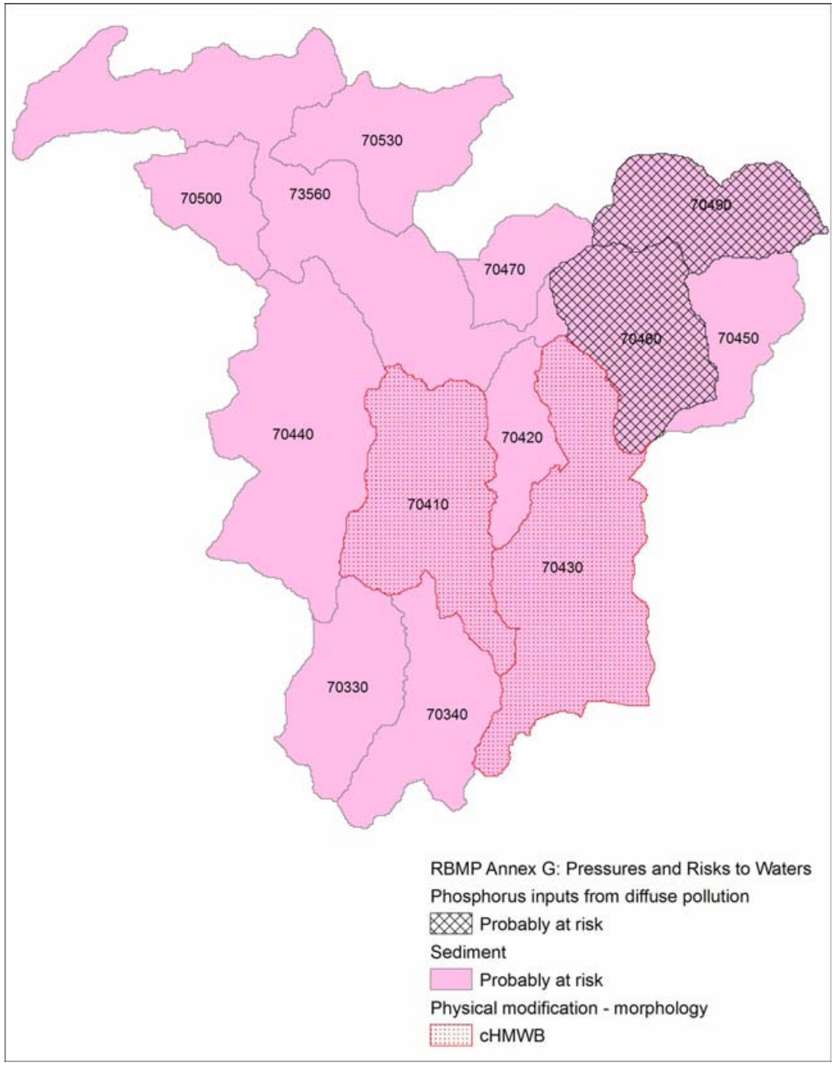
6. Conclusions

The report considers how woodland creation could be better targeted to locations within catchments where it would contribute most to maximising water and other benefits, while minimising risks. It uses a case study approach with a focus on spatial mapping to identify pollutant and runoff sources and pathways. The catchment of Bassenthwaite Lake in northwest England provides a prime example of how integrated land use planning and management can be developed to improve water status. A method is described that works across a range of scales from assessing opportunities for planting at a strategic regional or river basin level down to the practical field scale. It relies on easily obtainable data with the best possible resolution and accuracy to characterise water pressures and issues, and identify opportunities where woodland creation could help tackle these. An example 'Farm Estate' is created to illustrate how the catchment mapping can be translated to the field scale in terms of identifying precise locations where tree planting could be targeted for water quality improvement. 'Opportunity mapping' is helping to restore Bassenthwaite Lake by successfully directing woodland planting onto preferred sites for protecting sediment sources and intercepting sediment pathways. The assessment of the example farm reveals a number of opportunities for woodland creation to help reduce diffuse pollution, enhance stream morphology and slow down flood flows.

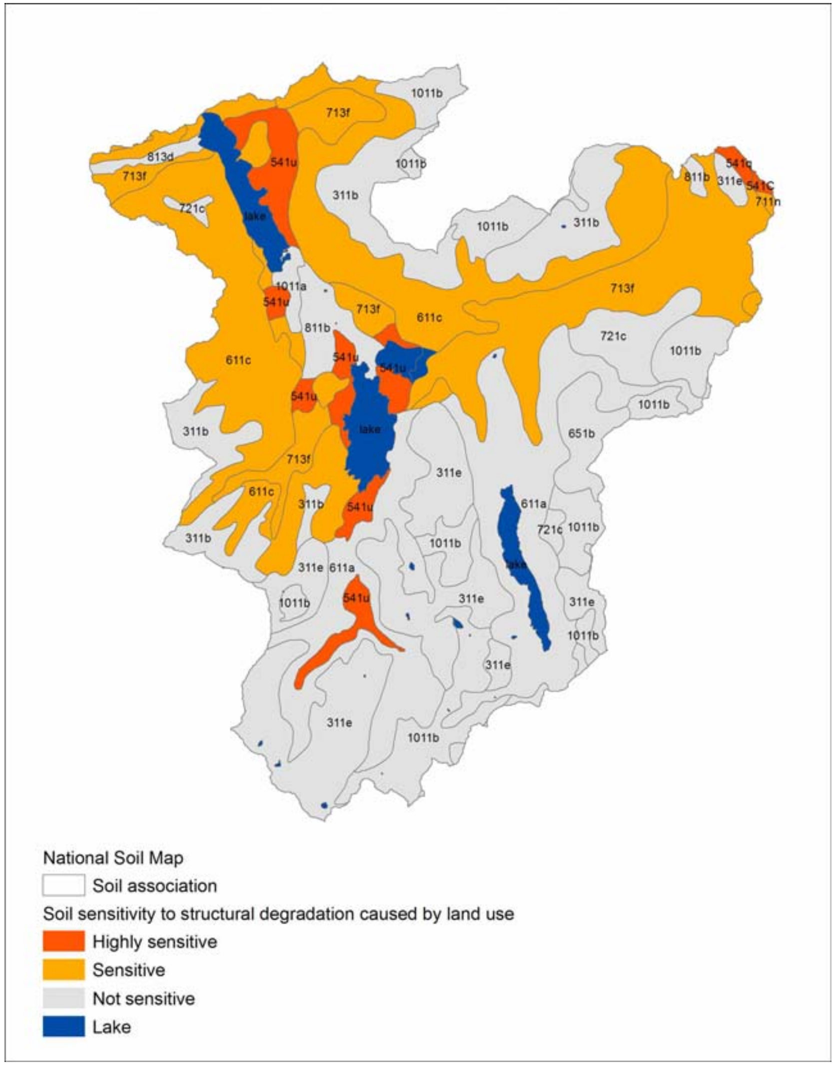
Map 1 Current ecological status of waters bodies in catchment of Bassenthwaite Lake



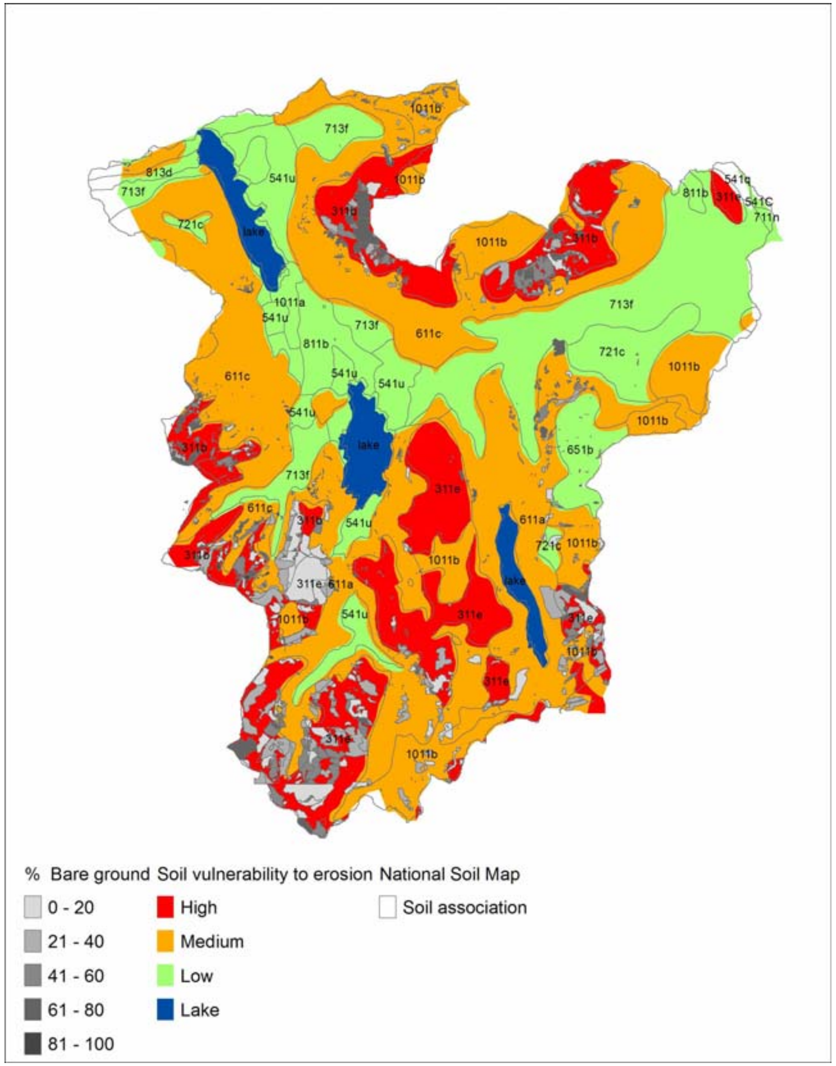
Map 2 Pressures and risks to the water environment in the catchment of Bassenthwaite Lake



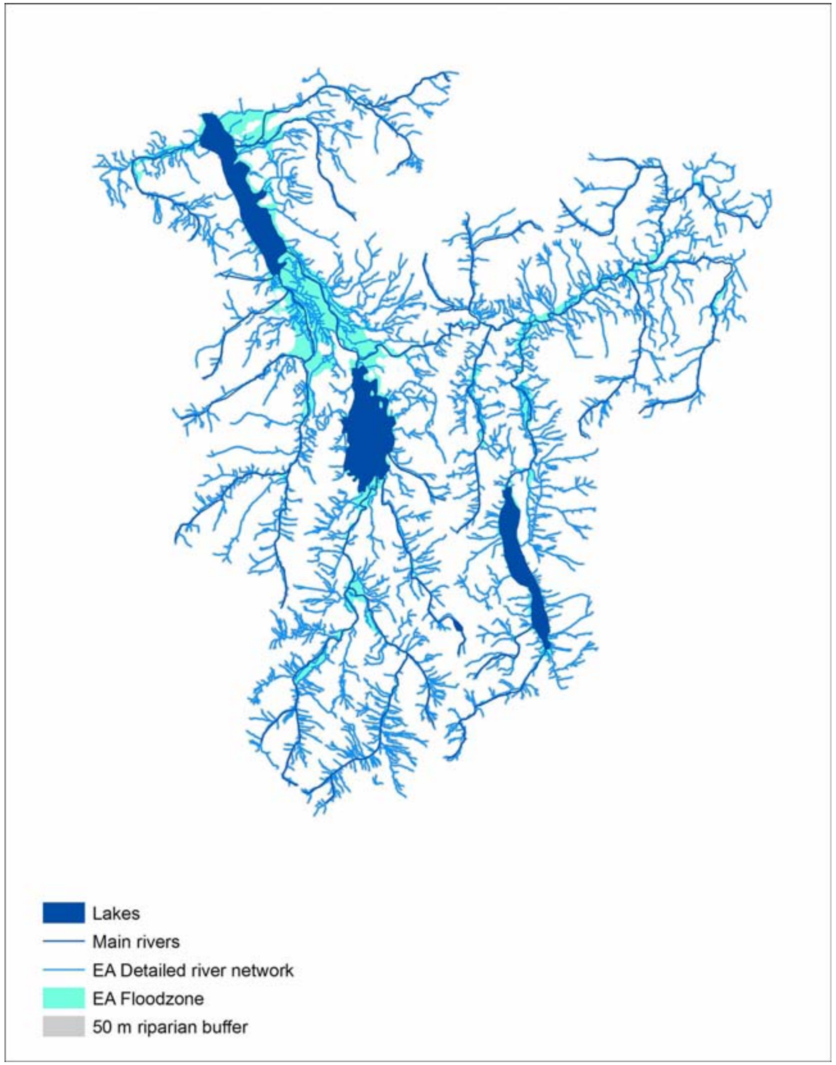
Map 3 Sensitivity of soils to runoff enhancement due to structural degradation by agriculture.



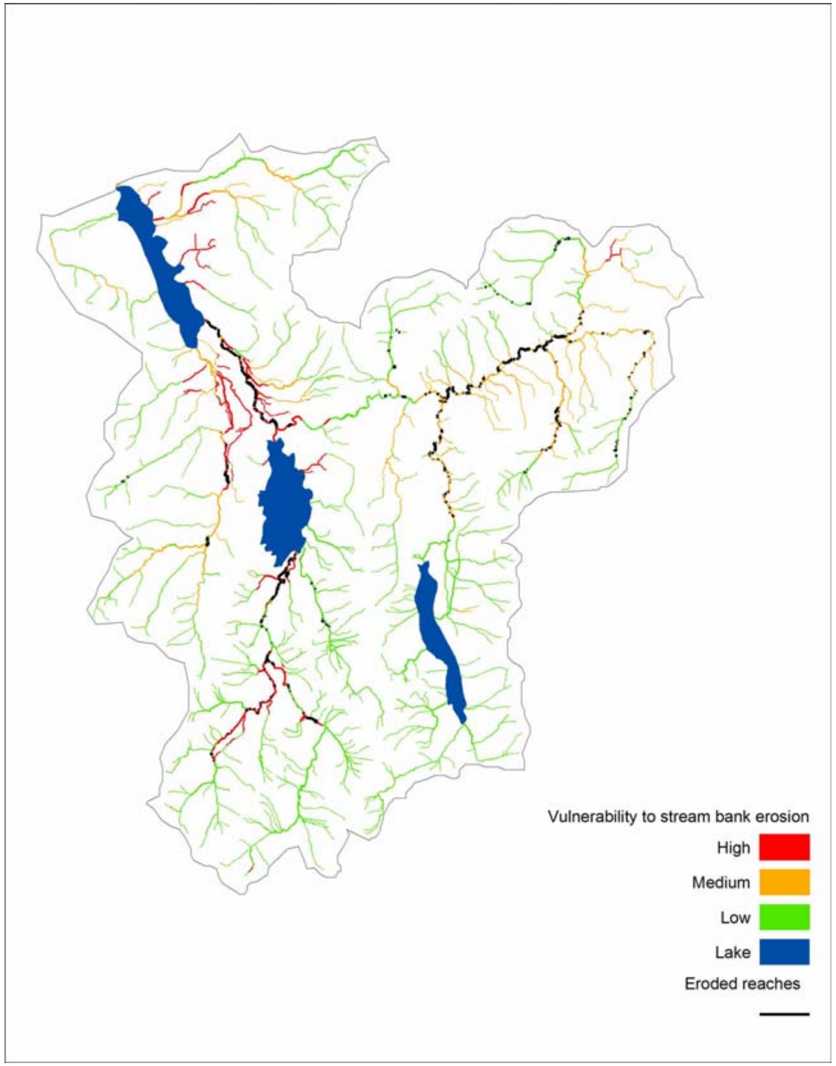
Map 4 Vulnerability of soils to erosion and the extent of observed bare ground.



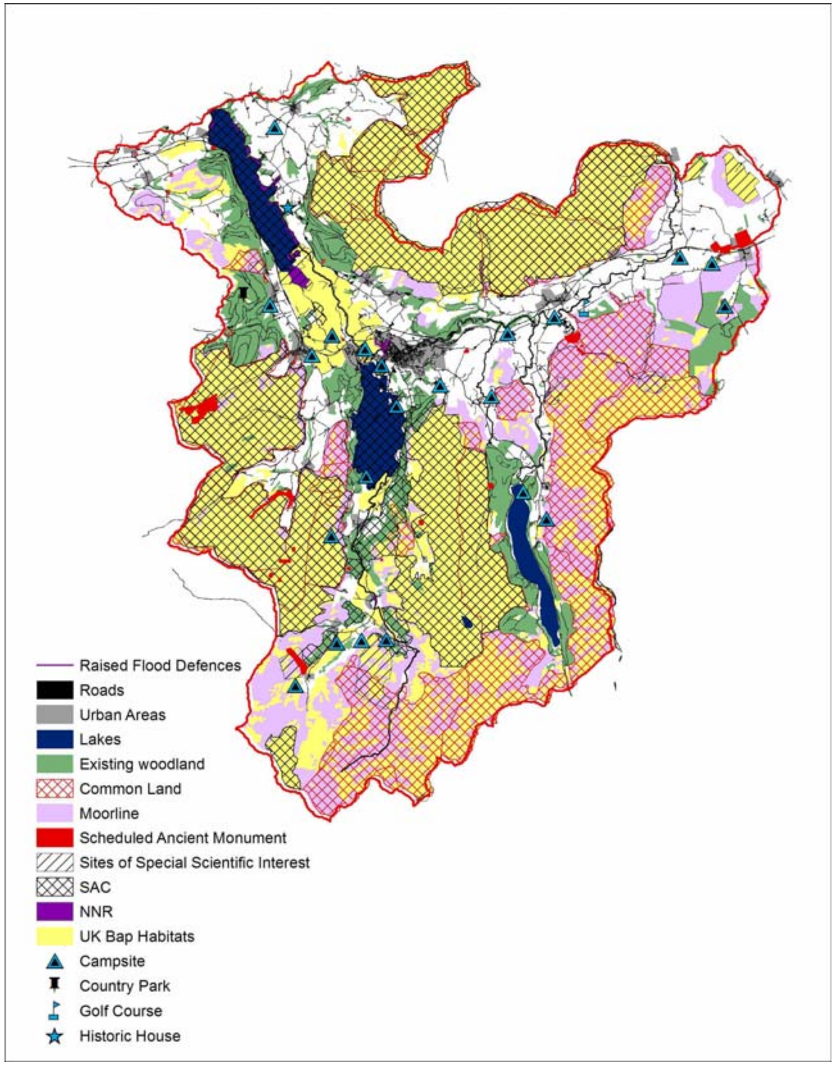
Map 5 The Riparian/Flood zone - land within 50 m of a watercourse or at risk from flooding.



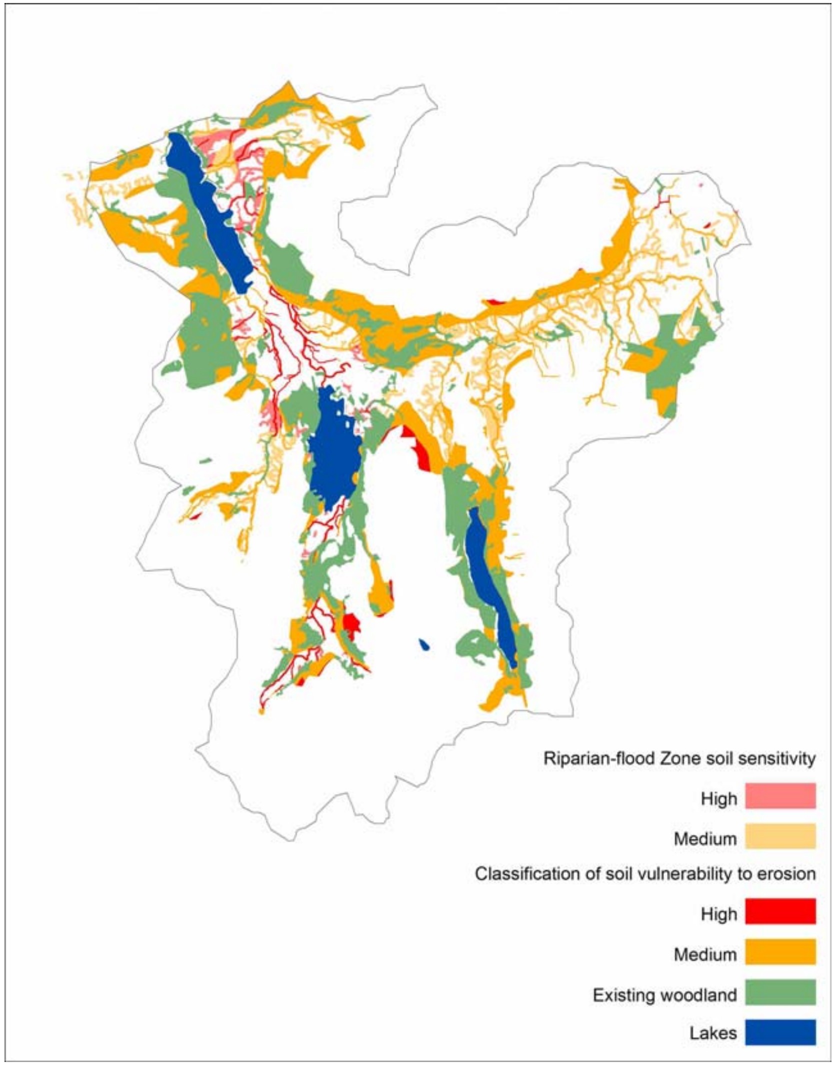
Map 6 Classification of riparian zone according to high, medium and low vulnerability to bank erosion and observed stream/river reaches exhibiting significant channel and/or bank erosion



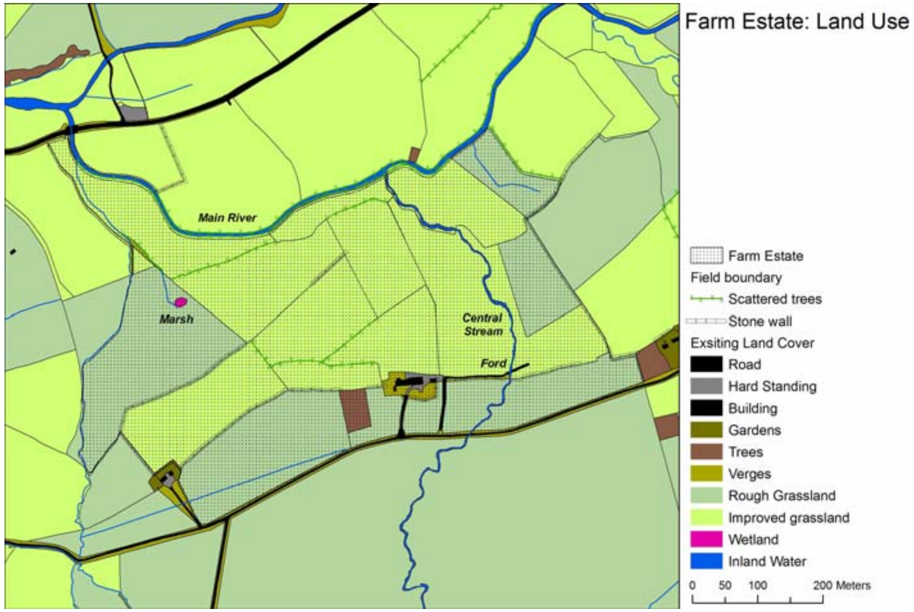
Map 7 Constraints to woodland planting in the catchment of Bassenthwaite Lake.



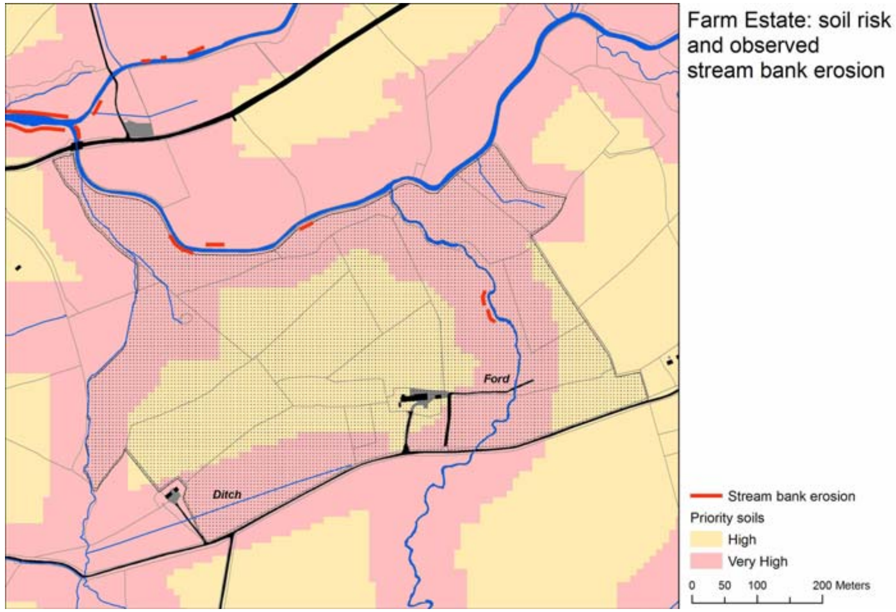
Map 8 Opportunities for woodland planting to reduce sediment delivery and delay flood flows.



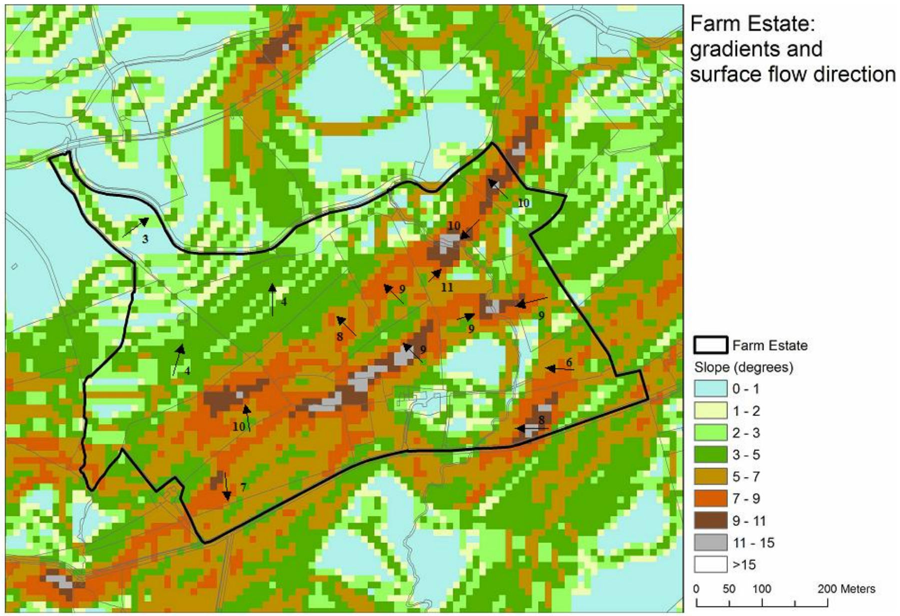
Map 9



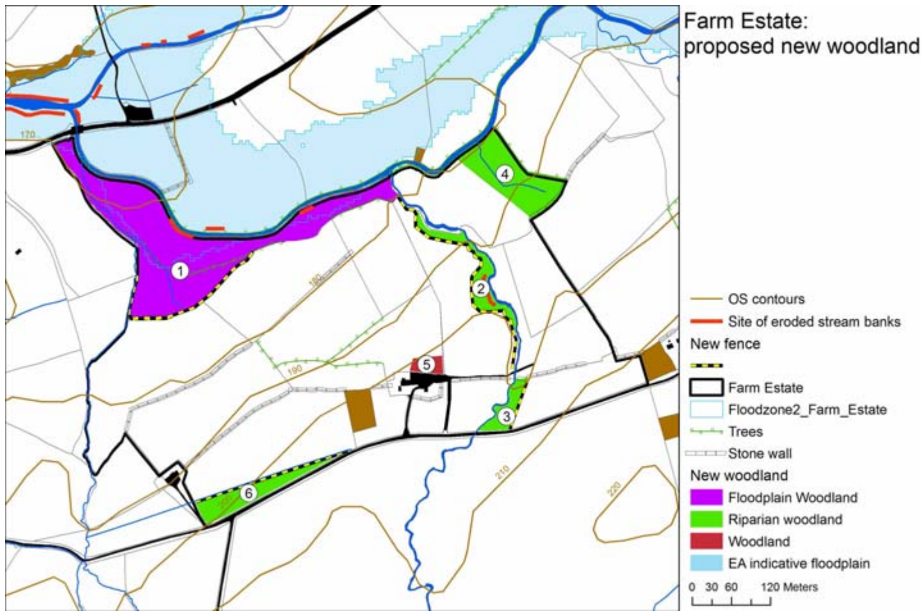
Map 10



Map 11



Map 12



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Appendix 1: Constraints to woodland planting and additional spatial data requirements

CONSTRAINT		
AGENCY	FEATURE	Notes
Scheduled conservation sites		
Natural England: Spatial data available on FCSDR or direct from http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	SSSIs: these include international sites such as SAC, SPA and Ramsar sites. National Nature Reserves	Character and habitat details for each site are available on line: http://www.english-nature.org.uk/special/sssi/search.cfm. All sites have a detailed management plan and there is limited scope for additional woodland creation.
Unscheduled conservation sites		
Local Authorities – county ecologist	Local Nature Reserves, And County Wildlife Sites.	Brief information on the nature of the habitat at each site is available on line at http://www.lnr.naturalengland.org.uk/special/lnr/lnr_search.asp
Country Wildlife trusts RSPB [FCSDR]	Wildlife Trust Sites. RSPB reserves and Important Bird Areas Moorland	All sites have a detailed management plan and there is limited scope for additional woodland creation.
Flood infrastructure		
Environment Agency	Flood storage areas (washlands) Land adjacent to existing raised flood defences	Woodland is not generally considered suitable on these sites and thus represent a potential constraint.
FCSDR	Main Rivers	Riparian Woodland is not acceptable on the banks of main rivers
Sites of Antiquity and Historic and Cultural landscapes:		
English Heritage via the National Monument Record (NMR) spatial data web site: http://services.english-	Scheduled Ancient Monuments and World Heritage Sites	In accordance with the Forest & Archaeology Guidelines (FC, 1995), World Heritage sites and SAMs should be buffered by 30 m and excluded as an absolute constraint for new woodland.

heritage.org.uk/NMRDataDownload/	Registered Battlefields Registered Historic Parks and Gardens; Listed Buildings	Each site was buffered by 30 m in accordance with the F & A Guidelines and excluded from the area of potential new woodland. The extent of the land included in the P & G register is extensive and many landscapes include elements with trees and woodland. They should therefore be considered as a potential, rather than absolute constraint. Areas of potential new woodland that intersect a registered site should be flagged as requiring further consideration. Excluded as an absolute constraint.
Cultural landscapes:		
Natural England [FCSDR]	Country Parks Common Land	Excluded as an absolute constraint.
Urban Infrastructure		
Ordinance Survey –	Urban areas	All urban areas should be excluded, including a 500 m buffer for potential floodplain woodland sites situated adjacent to or downstream of settlements.
OS 50k polyline [FCSDR]	Roads	Features have to be buffered to create polygons approximate to their actual size in the landscape: • A Roads + 50 m buffer • B Roads + 20 m buffer • Minor roads + 5 m buffer. The buffered roads should be amalgamated using the UNION tool and dissolved to create a single feature road network. Apply a 300 m buffer to the road network. As with the urban area, exclude floodplain fragments within a 300 m buffer adjacent to or downstream of a road.

OS 50k polyline [FCSDR]	Rail	Features should be buffered by 20 m to create a polygon approximate to their actual size in the landscape. It is assumed that rail tracks are raised above the floodplain on embankments and thus do not require to be buffered. However this would need to be verified on an individual site by site basis.
Existing Land Uses not compatible with woodland creation		
OS profile DTM data	Land over 450 m AOD	Above the natural tree line and therefore not suitable, except for riparian woodland in sheltered gullies, although this may shift in the future with climate change
Environment Agency regional offices	Landfill sites	Point source data is available. Buffer each site by 500 m to create polygons approximate to their actual size in the landscape. All active and old landfill sites are considered to be absolute constraints to woodland creation.
FCSDR [FR]	Existing Woodland	NIWT- used to identify existing high canopy woodland using IFTs: conifer (including felled and ground prepared for planting), mixed, coppice and broadleaf.
OS [FCSDR] FCSDR [DEFRA – Grade 1 ALC]	MOD land, Prime agricultural land	Both MOD land and Grade 1 ALC are absolute constraints to woodland planting
OS Strategi [FCSDR] - Indicative only intended to be used at >30k	Airports Golf courses Race courses Zoos Camp and caravan sites	Features were identified using the OS 30k Stategi airport data set. Aerial photographs were then used to select the appropriate polygons from OS Master Map to create a shapefile for the boundary of each feature. These features were then excluded. Additionally, each airport was buffered to form a bird strike exclusion zone of 13 km radius

ADDITIONAL SPATIAL DATA SETS REQUIRED	
Environment Agency data is available on licence and its use is subject to intellectual property restrictions	Water Framework Directive spatial data: WFD River Basin Districts; WFD Management Catchments; WFD River Waterbody Catchments; WFD River Waterbodies; WFD Groundwaterbodies; WFD Lake waterbodies; WFD Artificial Waterbodies: canals; WFD Artificial Waterbodies: Surface Water Transfer Channels; SSSI ditches; WFD Detailed River Network Non Spatial supporting information: Summary information (Characterisation Typology); Risk Assessment; Classifications; Predicted Outcomes; Measures; Protected Areas Indicative Flood Zone Map
Spatial data sets created from published model outputs may be obtainable from the authors of the reports/ papers, usually EA or ADAS staff	MAGPIE PSYCHIC Sediment Delivery to Watercourses from Land McHugh et al., (2002).
Natural England spatial data is available at: http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	Habitat Networks Priority (BAP) habitat sites
OS Profile - Digital elevation model available from FC_IS	Slope Contours Drainage network – can be created to identify seasonally wet channels and surface runoff pathways
Countryside Survey: Land Cover Map 2007	Spatial data for the 2007 survey will be available from September 2009 from the Countryside Survey website: http://www.countrysidesurvey.org.uk/land-cover-map-2007 Data from previous surveys is available by contacting CEH direct.

DEFRA these spatial data can be viewed using the magic website: www.magic.gov.uk	England Catchment Sensitive Farming Delivery Initiative Priority Catchments Countryside Stewardship and Environmental Stewardship agreements
British Geological Society [FCSDR]	Geology
National Soil Resources Institute [FCSDR]	National soil map HOST soil classification Standard percentage runoff POACH risk classification
DEFRA [FCSDR]	National Parks AONB Environmentally Sensitive Areas

FCSDR: obtained from the Forestry Commissions' spatial data repository, original data source indicated.