Opportunity Mapping for Woodland to Reduce Flooding in the River Derwent, Cumbria
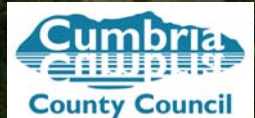
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Executive Summary

Forests and woodland have long been associated with an ability to slow down run-off and reduce downstream flooding. There are three ways trees can assist flood risk management; by reducing the volume of runoff, by promoting rainfall infiltration into the soil and slowing runoff to streams, and delaying the downstream passage of flood flows. This report considers opportunities for using woodland for flood mitigation within the catchment of the River Derwent in Cumbria, upstream of Cockermouth.

The ability of floodplain and riparian woodland to retard flood flows is believed to offer the greatest potential for flood management and therefore effort focused on identifying land suitable for creation these types of woodland. A range of spatial data sets were used to locate land vulnerable to flooding and unaffected by constraints to woodland planting. The approach was similar to previous work in the Yorkshire and Humber Region (Broadmeadow and Nisbet, 2009). The main output is a series of maps showing opportunities for planting riparian and floodplain woodland for flood mitigation in the River Derwent.

Opportunities for planting woodland in the wider catchment to assist both flood and water pollution management were also assessed. This drew heavily on the results and maps generated by a concurrent study of the vulnerability of soils to structural degradation, erosion and sediment delivery across the Lake District National Park (Broadmeadow and Nisbet, 2010).

It is hoped that the opportunity maps will be used by local stakeholders to promote the use of woodland in sustainable flood management and in so doing, help meet the following objectives:

- Delivery of reduced flood risk through effective and better integrated catchment flood management
- Delivery of flood alleviation for smaller communities where traditional methods of flood defence are not cost effective
- Contribute to the development of regional and national forestry strategies, including climate change adaptation
- Contribute to the England Catchment Sensitive Farming Delivery Initiative
- Contribute to a reduction in diffuse water pollution and an improvement in hydromorphology, thereby helping to meet EU WFD targets for water bodies to reach good water status by 2015
- Develop partnerships to establish floodplain, riparian and wider woodland creation demonstration projects within the region as a way of developing a local evidence base and communicating the expected success of this option for flood and water pollution management

- Contribute to the delivery of Vital Uplands and the UK Biodiversity Action Plan targets to expand the extent of priority woodland habitats and enhance the native woodland forest habitat network in the region.

1. Background

There is a long history of flooding in the Derwent catchment (EA 2009), with the most recent event being in November 2009 when the towns of Keswick, Cockermouth and Workington suffered a major flood. Rain gauges at Seathwaite farm recorded over 400 mm of rain falling in the catchment between 18-20 November. Research at Newcastle University suggests that the intensity of rainstorms has doubled over the last 40 years (Fowler and Ekström, 2009), while the Environment Agency predicts that the number of days of heavy rainfall each year is likely to increase by a factor of three to four due to climate change. The frequency and extent of flooding is therefore expected to increase in the future.

The November 2009 flood caused loss of life and much damage, with the insurance sector estimating that the final bill will exceed £100 million. Across the catchment hundreds of people were forced to leave their homes and in Cockermouth, Keswick and Workington over 1,200 properties were flooded. At its peak, the flood water in Cockermouth was about 2.5 m deep in the town centre and most of the shops, restaurants and pubs in the main street were seriously damaged. The flood destroyed six bridges and a police officer was killed when the main bridge at Workington collapsed beneath him. The loss of the bridges made local travel very difficult and delayed the restoration of basic services.

It is becoming increasingly clear that the problem of flooding can no longer be solved by building ever higher flood defences and instead the emphasis must be on restricting development in the floodplain and pursuing 'softer', more sustainable methods of flood control. The desire to see greater working with natural processes is set out in the Government's policy 'Making Space for Water' (EA, 2007b) and in the recent Flood and Water Management Act (2010). Recommendation 27 of Sir Michael Pitt's Review of the summer 2007 floods highlights the need for action and calls for: "Defra, the Environment Agency and Natural England should work with partners to establish a programme through Catchment Flood Management Plans and Shoreline Management Plans to achieve greater working with natural processes."

Forests and woodland management practices have long been associated with affecting both the quantity and timing of stream flows (McCulloch and Robinson, 1993). Forestry offers a number of options for flood alleviation, principal amongst which is the ability of floodplain woodland to slow down flood flows and enhance flood storage (Thomas and Nisbet, 2006). Creating new woodland to reduce flooding in urban areas has been identified as one of the four priorities for action in adapting to the impacts of

climate change in the North West Regional Forestry Framework. The guiding principal is to create a mosaic of semi-natural habitats including trees and woodland in the floodplain to alleviate flooding and erosion (NRFFP, 2005). Natural England's recent long-term vision for England's upland environment (Natural England, 2009) includes an increase of woodland cover to up to 25% targeted along streams and on former bracken-covered gully slopes.

Woodland can also attenuate flooding due to the greater water use by trees and by the ability of woodland soils to intercept and delay the passage of rain water to streams and rivers (Thomas and Nisbet, 2006). These benefits can be maximised by targeting woodland planting onto the most sensitive soils or in key locations for intercepting and 'soaking-up' surface run-off generated from the adjacent ground. Examples include establishing woodland buffers along lower field edges, on infiltration basins/swales, or within the riparian zones of streams and rivers. Care is required to balance the water use benefit for flood flows against a potential reduction in summer low flows, through appropriate species choice and site selection (Nisbet, 2005).

The use of woodland for flood management has the potential to yield a number of other important benefits, including improvements to water quality, fisheries, carbon sequestration, nature conservation, recreation, and landscape. Planting floodplain and riparian woodland would help to meet the UK Biodiversity Action Plan Target of creating 3,375 ha of wet woodland in England by 2010.

This study was designed to identify sites within the catchment of the River Derwent where the creation or expansion of woodland could be expected to reduce flood risk, while consistent with the established priorities for protected sites and designated landscapes. The work is GIS-based and followed the approach used by Broadmeadow and Nisbet (2009) in the Yorkshire and the Humber Region. The methodology and results are described below.

2. Objectives

There are two main objectives:

1. To create a suitability map identifying areas of the fluvial floodplain and stream riparian zone within the upper catchment of the River Derwent in Cumbria where there is potential to create or expand floodplain and riparian woodland to reduce downstream flood risk.

2. To identify areas within the wider catchment where woodland planting is free from constraints and could benefit flood management and water quality by improving soil structure and reducing erosion, sediment delivery and rapid surface runoff. This drew heavily of the results from the companion study 'Opportunity mapping for woodland

creation to reduce sediment and phosphate problems in the Lake District National Park' Broadmeadow and Nisbet (2010).

3. Study Area

The project area is illustrated in Map 1 and covers the upper catchment of the River Derwent, comprising both the River Cocker and the River Derwent above Cockermouth. The area extends over 541 km^2 of the Cumbrian High Fells (Map 2), which are dominated by hard volcanic rocks (Map 3). Soils range from peat and humic rankers on the high ground to stagnogleys in the lowlands (Map 4). They tend to become saturated quickly after heavy or prolonged rainfall, generating rapid surface runoff. The soils of the steep hill slopes are typically shallow and used primarily for extensive sheep grazing, with grazing pressure proportionately greater in the River Derwent compared to the River Cocker catchment (Map 5). In the valley bottoms and on low ground, soils are deeper and suitable for beef and dairy stock rearing. Use for arable crops is very limited (Map 6). Around 10.7% of the whole catchment is presently wooded (Map 7). Natural England are keen to expand the area of native woodland habitat in the English uplands as part of the Vital Uplands project. Currently <1% of the land above the moor line in the Bassenthwaite catchment is woodland and their aim is to expand the area of upland oak habitat within the SAC.

The River Derwent catchment is divided into four distinct sub areas within the Catchment Flood Management Plan (EA 2008). The area around the towns of Cockermouth and Keswick is identified as requiring further action to reduce flood risk through investment in maintaining and improving the flood defence infrastructure (Map 9). In contrast, the preferred policy for the rural upper catchments of the Upper Derwent and River Cocker is to manage flood risk by working with natural processes. The principal aim is to reconnect the streams to their floodplain through the creation of wetland habitats (including wet/floodplain woodland), thereby reducing flood flows and sediment loads.

4. Methods

4.1 Identification of areas suitable for restoring floodplain woodland to retain out-of-bank flows

Floodplain woodland is considered to provide the greatest potential for flood mitigation and therefore effort focused on identifying areas where its restoration would be both feasible and desirable.

4.1.1 The extent of the floodplain

The Environment Agency flood map identifies the extent of the floodplain. It is based on detailed topographical surveys combined with modelled river flows and water levels. The models are used to predict the spatial extent of flood inundation for flood events with a 1% and 0.1% probability of occurring in any one year (EA, 2006). Map 9 delineates the fluvial floodplain defined for the more extreme 0.1% flood events. This was selected to allow for the potential area at risk from local inundation if new woodland was effective at raising upstream flood levels due to a backwater effect.

4.1.2 Constraints to new woodland planting

The next step was to identify constraints to woodland planting where the creation of new woodland was not possible or unsuitable due to existing land-use, ownership or the presence of vulnerable assets. Map 10 illustrates the extent of the following constraints identified in the River Derwent catchment, while the areas involved are detailed in Table 1 (potential constraints such as Grade 1 agricultural land, rail infrastructure and land owned by the MOD were absent from the catchment):

- Urban areas
- Roads
- Land protected by existing flood defences
- Scheduled Ancient Monuments
- Existing woodland
- Lakes and tarns
- SSSIs largely dependent on maintaining open habitat.

Potential constraint	Area (ha)	% of catchment
Urban areas	800	1.5
Road network	489	<1
Existing woodland	5,811	10.7
Open water	1,742	3.2
Selected SSSIs reliant on maintaining open habitat[1]	1,910	3.5
Scheduled monuments and listed buildings	120	<1
Combined total area of all constraints for which spatial data is available	**9,363**	**17.3**

Table 1 Constraints to woodland planting in the catchment (note that the total area is less than sum of individual constraints due to overlap between some categories).

[1] Although there may be some potential for the creation of wet woodland stands in a mosaic of open fen and swamp habitat within these SSSIs, the likely restrictions on size and scale would limit the effect of new woodland on downstream flooding.

In a landscape as spectacular and sensitive as the Lake District there are additional factors that will influence the scale and design of new woodland and thus require careful consideration on an individual site by site basis (Map 11). These would be addressed in consultation with the relevant agencies during the normal assessment and approval process for woodland planting applications. The areas affected by a number of sensitivities are shown in Table 2 and include:

- Land above the natural tree line .Tree growth above this altitude will be stunted and new planting is likely to be restricted to sheltered valleys and in species suitability. The tree line will vary with aspect, topography, exposure and soil depth, in this project an elevation of 450m AOD has been used to illustrate the extent of very high ground although low growing scrub may extend to 600m in sheltered sites.
- Sites scheduled for their nature conservation or geological importance. Extensive woodland planting is unlikely to be acceptable across the upland open fells, however there is likely to be scope for the targeted planting of native woodland as part of a mosaic of upland habitats. Natural England are keen to encourage the creation of new native woodland habitat in former woodland sites such as gills and bracken beds.
- Sites registered for their historic or cultural landscapes
- Common land. New woodland planting requiring the erection of fences would need the consents of the Secretary of State.

Landscape sensitivity	Area (ha)	% of catchment	Notes
SACs	15,417	28.5	
Extensive upland SSSIs	376	<1	
Common land	16,240	30.0	
Land above the natural tree line (450 m).	12,925	23.9	
Total area of combined landscape sensitivities for which spatial data is available	**20,753**	**38.4**	**1,421 ha of this land is subject to the constraints listed in Table 4**

Table 2 Sensitive landscapes that may limit the scale, structure or species choice of new woodland planting (note that the total area is less than sum of individual constraints due to overlap between some categories).

The sources of the data sets used and the processing required in their preparation are detailed in Appendices 1 and 2. The combined data set created by the amalgamation of the individual constraints was used to remove the areas from the floodplain that were considered unsuitable for planting woodland. Sites supporting existing priority habitat listed under the UK Biodiversity Action Plan (UK BAP). Typically UK BAP targets aim to maintain, expand and restore priority habitats and improve connectivity between sites. Consideration would therefore be required of the likely impact of any new woodland planting on existing habitats. Current spatial data for the 65 UK BAP priority habitats was not available to the authors of this project. However when such data becomes available it should be included in the assessment and approval process for the woodland application.

It is also necessary to protect vulnerable assets such as buildings and roads within the floodplain that would potentially be placed at risk from the backing-up of floodwaters associated with the restoration of floodplain woodland. Ideally, individual assets should be buffered to take into account the difference in micro-elevation between them and the adjacent area of potential new woodland. However, it was not practicable to do this at the scale of the whole catchment. Therefore fixed buffers were created around the most vulnerable features. Although the extent of the backwater effect is dependent on the gradient of the floodplain, modelling studies have shown that it usually does not extend beyond a distance of 300-400 m upstream. A fixed buffer of 500 m length was therefore selected below urban areas and 300 m for roads. The latter narrower buffer was based on the assumption that roads were more likely to be built on embankments and therefore potentially protected, as well as being more resilient to short term flooding than homes.

OS_MasterMap topographic area data was used to select individual buildings within the settlements included in the OS_Strategi 250k urban area data set. Aerial photographs helped to determine if these buildings were inhabited or had a purely agricultural purpose such as stock sheds or stables. This was assumed when there was no visible road or track leading to the building. A total of 132 individual buildings in 14 settlements were identified as requiring protection from the potential backing-up of floodwaters upstream of planted woodland, below which a 500 m buffer was created. Buffer areas were not required upstream of buildings and roads since the backing-up effect only applies to woodland located below them.

The efficacy of floodplain woodland to attenuate flood waters and mitigate downstream flooding will be dependant on the absolute size of the woodland created and its scale in relation to the floodplain in which it is situated (Thomas and Nisbet, 2006). Woodland spanning the entire floodplain will present a significantly more effective barrier to flood flows than woodland situated on a single bank of the river or located on the margin of the floodplain. Although several small blocks of woodland in

close proximity within a catchment may be as effective as a single larger wood, the complexity of land tenure makes it unlikely that adjacent landowners would sign up to such a large restoration scheme involving composite sites in suitable locations. Thus an absolute minimum area of 0.1 ha was adopted and sites less than 2 ha only retained if they presented an opportunity to extend existing woodland.

The final data set comprising all of the areas within the EA flood zone that remained free from constraints (not including landscape sensitivities) and thus deemed potentially suitable for planting floodplain woodland for flood mitigation are displayed in Map 12.

4.2 Identification of suitable areas for planting riparian woodland

Established riparian woodland can ameliorate flooding through the action of woody debris dams, which impede water flow and promote out-of-bank flows, thereby delaying the flood peak (WDFW, 2004). Additionally, riparian woodland can act as a buffer to retain sediment washed from adjacent hill slopes, reducing siltation within watercourses and increasing the flood storage capacity of river channels. Tree rooting also acts to stabilise and strengthen river banks, decreasing bank erosion and sedimentation.

The riparian area was defined as a 30 m wide zone on either bank of the Environment Agency's Detailed River Network spatial data set. This width was selected as the zone most likely to interact with and provide woody debris to the river channel. The preference was to exclude lower sections of the river channel that were too wide (>5 m) to establish stable debris dams but unfortunately no data were available on river channel width. Instead, the downstream limit for riparian woodland to create 'effective' dams was defined by the upper extent of the river length classified as 'Main river'. This had the advantage of removing the need to consider the potential restriction on planting riparian woodland along such designated reaches due to possible adverse impacts on flood conveyance and the need to retain river access for maintenance work. The riparian areas subject to the constraints to planting new woodland were identified using the data sets described in the previous section (4.1.2).

To account for the additional benefit of riparian woodland in reducing sediment delivery to watercourses, the area identified as potentially suitable for planting was over laid with soil vulnerability to bank erosion (Map 13), vulnerability of wider catchment soils to erosion leading to sediment delivery (Map 14), and soil propensity to generate rapid runoff (Map 15). These data sets were prepared in the companion study 'Opportunity mapping for woodland creation to reduce diffuse sediment and phosphorus pollution in the lake District', full details of the data sources and methodology can be found in the report (Broadmeadow and Nisbet 2010). Priority

areas for riparian woodland creation were selected based on a combination of these factors (Table 3 and Map 16)

Soil association	Soil vulnerability to bank erosion leading to sediment delivery to watercourses (Fluvial audit)	Predicted soil vulnerability to erosion leading to sediment delivery to watercourses (PSYCHIC - Total sediment)	HOST SPR value
1011b	Low	Moderate	>50%
721c	Low	Moderate	>50%
611a	High	Moderate	>25%
541u	High	Low	<25%
311e	Not included in survey	High	>50%
311b	Low	High	>50%
713f	High	High	>25%
611c	Moderate	High	>25%

Table 3 High priority soils for new riparian woodland planting due to their vulnerability to bank erosion and propensity to deliver sediment to watercourses and generate rapid surface runoff.

4.3 Identification of areas in the wider catchment where woodland could aid flood control

The potentially high water use of woodland, particularly conifers may help reduce rainfall-runoff and the generation of flood flows. Research suggests that the effect is greatest in headwater catchments and for small floods (Nisbet and Thomas, 2006). Potentially, woodland planting in most locations in the catchment could contribute through a reduction in flood flows and therefore all areas that are free from the identified constraints could be considered beneficial.

An additional benefit of woodland is the ability to protect soils from disturbance and improve soil structure through the input of organic matter and the action of tree roots. Agricultural intensification in the uplands has damaged soils through compaction and poaching leading to increased surface runoff volumes and delivery of coarse sediment to rivers, which has raised riverbed levels and increased the risk of flooding. An analysis of where new woodland would be most effective at reducing surface runoff and/or sediment delivery to watercourses was made based on an assessment of the hydrological properties of the soil and modelled predictions of sediment loss. This involved the following data sets:

• The Hydrology Of Soil Types (HOST)

- Standard percentage runoff (SPR) based on the HOST classification
- PSYCHIC total sediment loss to watercourses

HOST: The Hydrology Of Soil Type system (Boorman et. al., 1995) was developed to classify soils according to their hydrological behaviour. 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). Each class identifies groups of soils that are expected to respond in the same way to rainfall. Map 17 illustrates the HOST classes of the soils in the Upper Derwent catchment

SPR: The SPR represents the percentage of rainfall that contributes to quick response runoff. Map 15 illustrates the extent of HOST classes with SPR values <25%, 25 – 50% and >50%. The latter soils are seasonally waterlogged and likely to make a marked contribution to flood flows.

PSYCHIC: This model predicts total loss of sediment to watercourses and has been used to classify soils in terms of their vulnerability to sediment delivery (Broadmeadow and Nisbet 2010). The extent of vulnerable soils is displayed in Map 18.

The data for SPR was combined with the predicted sediment delivery to watercourses to identify the soils where targeted woodland planting could have greatest potential to improve soil structure and reduce rapid surface runoff (Table 4 and Map 14).

Priority for new woodland planting	HOST SPR value	Predicted soil vulnerability to erosion leading to sediment delivery to watercourses (PSYCHIC - Total sediment)
Low priority	<25%	Low
	<25%	Med
Medium priority	<25%	High
	>25%	Low
	>25%	Med
High priority	>25%	High
	>50%	Low
	>50%	Med
	>50%	High

Table 4 Classification of soils by their propensity to generate rapid surface runoff and/or deliver sediment to watercourses.

5. Results

5.1 Opportunities for restoring floodplain woodland

Map 12 illustrates the extent and distribution of 70 locations in the floodplain potentially available for new woodland planting. In total, an area of 1,138 ha out of a total of 4,780 ha (23.8%) of fluvial floodplain has been identified, comprising 899 ha in the River Derwent catchment (23.3%) and 239 ha in River Cocker catchment (25.7%). Only 260 ha (5.4%) of the combined fluvial floodplain is presently under woodland cover.

Most of the length of the River Derwent is designated as an SAC affecting 16 sites totalling 693 ha, while a further 15 sites (62 ha) were located within the Common Land of the Lake District High Fells SAC. The largest single site (>350 ha) is situated on Rough Mire on the southern shore of Bassenthwaite Lake. The effectiveness of planting floodplain woodland here will be limited to a degree by Bassenthwaite Lake, including by the potential backing up of floodwaters. This aspect would have to be investigated by hydraulic modelling.

Most of the length of the River Cocker is also designated as an SAC affecting 9 sites totalling 163 ha, while a further 4 sites (11 ha) were located within the sensitive landscape of the High Fells.

In terms of providing flood protection for individual towns, a total area of 250 ha spread between 21 locations was identified for potential floodplain woodland upstream of Cockermouth, and a similar area over 17 locations upstream of Keswick. There is also significant scope for establishing a series of smaller floodplain woodlands across several tributaries, which could help to reduce flood risk in smaller towns and villages. Table 5 illustrates the scope for floodplain woodland creation to contribute to the wider catchment flood management plan.

Total area of potential floodplain woodland situated upstream of an urban centre	Towns and villages
> 50 ha	Cockermouth, Grange, Keswick
10 - 50 ha	Bassenthwaite, Dubwath, Little Town, Portinscale, Stonethwaite & Rosthwaite,
5 – 10 ha	Braithwaite, Lorton, Troutbeck
< 5 ha	Buttermere, Mungrisdale, Seathwaite, Sunderland, Wadcrag, Watendlath

Table 5 The total area of potential floodplain woodland upstream of individual urban centres located within the Environment Agency's Flood Zone

5.2 Opportunities for planting riparian woodland

A total area of 5,848 ha of land was identified as a high priority for potential new riparian woodland (PNRW) for flood mitigation and diffuse pollution control, which was distributed across both catchments (Map 16). This comprised 4,545 ha in the River Derwent catchment and 1,302 ha in the River Cocker catchment. Almost half the PNRW (2,134 ha) in the Derwent is located within a designated landscape, compared to only 290 ha in the Cocker. The detailed stream network used to create the riparian zone includes the small head water streams of the high ground, 1,132 ha of which lies above 450 m elevation in the combined catchments. Although not all of this land will be suitable for planting, there is likely to be significant scope for new native riparian woodland within the more sheltered valleys. In particular, to the south of the catchment, there is an opportunity to extend riparian woodland up the Borrowdale Fells into the headwaters above Seathwaite and Stonethwaite. Similarly, there is significant potential for woodland creation along Tom Rudd Beck and Wythop Beck to the east of Cockermouth, as well as in the upper catchment of the River Glenderamackin. The effectiveness of riparian woodland for flood attenuation is greatest where there is scope to create a series of woody debris dams to promote overbank flows and retard their passage downstream.

5.3 Opportunities for woodland planting in the wider catchment to aid flood control

Map 19 illustrates the priority areas for woodland planting in the wider catchment to reduce rapid surface runoff and sediment delivery to watercourses. Of the 44,709 ha of the catchment mapped as free from constraints, an extensive area of 35,136 ha (79%) is classified as a high priority for planting, reflecting the prolonged waterlogged nature of the catchment soils and their vulnerabiity to structural degradation and erosion.

A higher proportion (85%) of the available ground for planting in the River Cocker catchment is classed as high priority compared to the River Derwent (76%)(Table 6), which is also less affected by landscape sensitivities or high altitude. A very small proportion (<5%) of each catchment is classed as low priority for planting, most of which comprises lower ground.

Map 20 overlays the high priority areas for woodland planting within the wider catchment with that for the riparian zone, together with the potential sites for new floodplain woodland. As expected, the priority areas largely overlap and cover most of the higher ground, with the floodplain areas distributed relatively evenly along the main watercourses.

Priority for new woodland planting	Area (ha) and % of River Derwent catchment free from constraints to woodland planting	Area (ha) and % of River Cocker catchment free from constraints to woodland planting
High priority	24,415 [76%]	10,721 [85%]
Medium priority	627 [20%]	1,755 [14%]
Low priority	126 [4%]	114 [1%]
Area (ha) and % of High Priority Area that is in a sensitive landscape	13,670 [56%]	2,539 [24%]
Area (ha) and % of High Priority Area that is above 450 m	8,652 [35%]	2,422 [23%]

Table 6 Assessment of priority areas for woodland creation on the basis of the propensity of soils to generate rapid surface runoff and risk of sediment delivery to watercourses.

6. Conclusions

A range of data sets have been used to generate opportunity maps identifying potential areas within the catchments of the River Derwent and River Cocker where woodland could aid flood risk management. The restoration of floodplain woodland is considered to offer the greatest ability to reduce flood flows and significant opportunities exist within the catchments to realise this benefit. A total of 1,138 ha of the fluvial floodplain is potentially available for woodland planting spread across 70 separate sites. In terms of providing flood protection for individual towns, an area of 250 ha spread between 21 locations was identified for potential floodplain woodland upstream of Cockermouth, and a similar area over 17 locations upstream of Keswick. Most of these sites lie within areas designated for biodiversity. However, the River Derwent and Bassenthwaite Lake SAC has little woodland at present and there may be scope to increase the area of wet woodland habitat within a mosaic of open fen and swamp habitat. The sensitivities of the existing habitat in the designated sites will influence the scale, design and species choice of new woodland and thus require careful consideration on an individual site by site basis.

There are also extensive opportunities across the two catchments for using riparian woodland to help reduce flood flows. A total of 5,848 ha of land was identified as a high priority for planting, which would assist both flood mitigation and diffuse pollution

control. The land is distributed across both catchments, comprising 4,545 ha in the River Derwent and 1,302 ha in the River Cocker. Almost half of the land identified within the Derwent is within the designated landscape, compared to 20% in the Cocker. However there is scope to expand the area of woodland and scrub along the stream banks and gills.

Finally, much of the land (79%) in the wider catchments of the Derwent and Cocker is classified as a high priority for planting on the basis of soil propensity to generate rapid runoff and vulnerability to erosion and sediment delivery to watercourses. This land covers most of the high ground and is proportionally greater within the River Cocker catchment. The latter catchment is also less affected by landscape sensitivities and high altitude restrictions on tree planting.

Using woodland creation to reduce flood risk can also provide a range of additional benefits to the region: reduced diffuse pollution, better water quality, increased biodiversity, improved landscape, and economic opportunities from tourism and the timber sector (NWRFFP 2005).

It is recommended that regional stakeholders use these maps to help target future woodland creation to aid flood risk and diffuse pollution management. However, if the opportunities identified in this study are to be realised, there will also be a need to increase the value of and improve the synergy between available incentives to secure land use change. Woodland establishment and management is long-term in its nature and requires specific financial, practical and political support.

The establishment of demonstration woodlands is recommended, to illustrate how land management can create space for water and slow its progress to reduce the risk flash flooding. In steep valleys and upland areas this could involve the use of woody debris to create dams and the blocking of drainage ditches to hold up the water, reduce sediment loss and recreate wetland habitats. In the lowlands it may be possible to recreate wet woodland habitat through the reconnection of rivers to their natural floodplains. Such projects would provide a local evidence base and help communicate the need for and efficacy of a more integrated whole catchment based approach to flood management.

7. Acknowledgements

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Appendix 1 GIS data sources

Source	Name	Content	Date
ADAS	ADAS Grazing Livestock Units ADAS Land Cover ADAS PSYCHIC Diffuse Phosphorus and Total sediment reaching watercourses via all pathways	1 km modelled data of sediment and phosphorus mobilisation and delivery to watercourses.	2004
Ordnance Survey	OS Colour Raster OS Strategi Land-Form PROFILE Plus	OS map images Digital data for mapped features e.g. roads Digital terrain model at 1:10 000 scale, from which can be derived slope, land form, water flow direction, drainage networks, river catchments and topographic wetness index	
National Soils Resources Institute	NATMAP	National digital soil association data from which can be derived: Hydrology of Soil Types (HOST), Standard Percentage Runoff, Poach Class, Vulnerability to structural degradation leading to accelerated runoff	
Countryside Survey CEH	Land Cover 2000	Vegetation cover (20 broad habitat classes) based on the interpretation of aerial photographs	2002
English Heritage	National Monuments Record	Scheduled Monuments Registered Parks & Gardens Listed Buildings World Heritage Sites Registered Battlefields	2010 2010 2010 2009 2008
Environment Agency	National Flood Zone Map Flood defences Land benefiting from flood defences Detailed River Network		2008

	Main Rivers		
Forestry Commission	National Inventory of Woods and Trees	Existing woodland	2002
Orr et al 2004	BASS GIS	Observed bank erosion and bare ground (from aerial photographs) in the Bassenthwaite Lake Catchment	2004
British Geological Survey	Geology		
Natural England	National Character Area Map Site of Special Scientific Interest Special Areas of Conservation National Nature reserves Local Nature Reserves Environmentally Sensitive Area Scheme	Landscape character Site boundaries, name and details ESA scheme boundary and agreements	2005 2002
RSPB	Reserves and Important Bird Areas	The RSPB may object to expanded tree cover within their reserves	
Defra	Lake District National Park Agricultural Land Classification Registered Common Land	Boundary Boundary and name	

Appendix 2: Pre processing required to generate spatial data for the constraints to woodland creation

Sites of special scientific interest

There are 31 SSSIs in the catchment upstream of Cockermouth. The site citation (available on line at: http://www.english-nature.org.uk/special/sssi/search.cfm) was used to determine the character of the habitat and ascertain whether woodland creation was likely to acceptable. There were 27 sites considered to be a constraint to woodland planting because of their existing habitat. These included lakes, existing woodland, wetlands, meadows and geological sites. However, four sites have been treated as sensitive landscapes in which some woodland creation would be appropriate. There are the River Derwent and its tributaries and three additional sites of extensive upland habitat (Barf and Thornthwaite, Eycott Hill and Rothwaite fell).

Scheduled Monuments

The register of Scheduled Monuments including features of linear antiquity and World Heritage Sites were all buffered by 30 m, in accordance with the Forest and Archaeology Guidelines

Urban areas

Urban Area + 500 m buffer: All urban areas were excluded. In addition, floodplain within the 500 m buffer was excluded if adjacent or downstream of the settlements that intersected the floodplain.

Roads

Spatial data for the road network is available as OS 50k polyline features, which were buffered to create polygons approximate to the actual size of feature in the landscape:
A Roads + 50 m buffer
B Roads + 20 m buffer
Minor roads + 5 m buffer.
The buffered roads were amalgamated using the UNION tool and dissolved to create a single feature for the road network.
The road network + buffer: As with the urban areas, a 300 m wide buffer was created around the road network; areas of floodplain within 300m downstream of a road were excluded as potential new woodland.

Map 1 The project area: the upper River Derwent, Cumbria
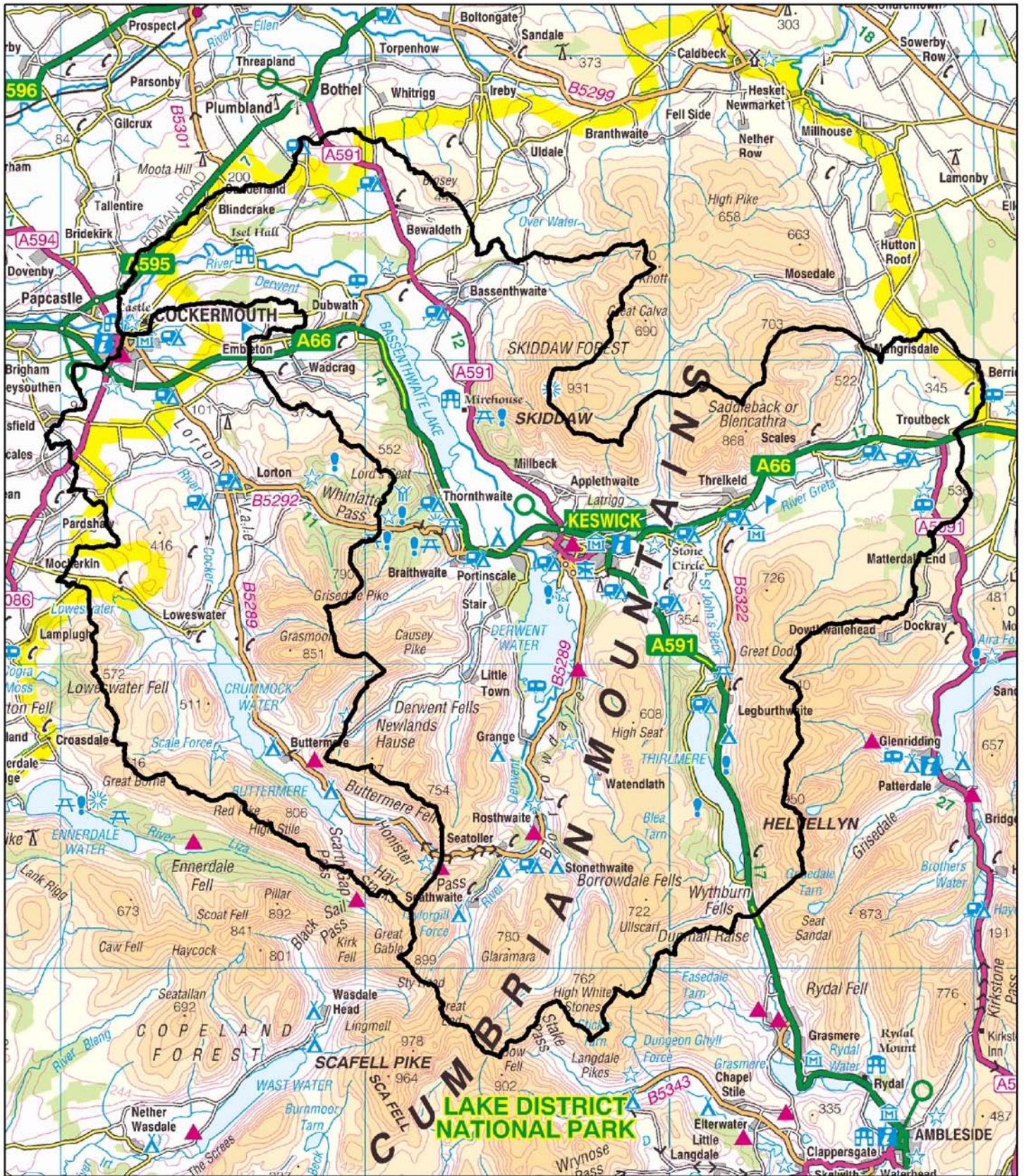
▭ River Derwent and Cocker catchment boundaries

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Ordnance Survey Licence number 100025498

Kilometers

0 1.5 3 6 9 12

Forest Research
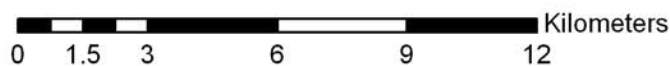
Map 2 Elevation and Landscape

Eden Valley

Coastal Plain

High Fells
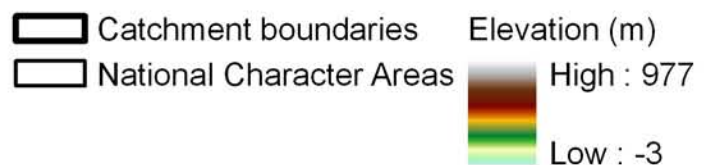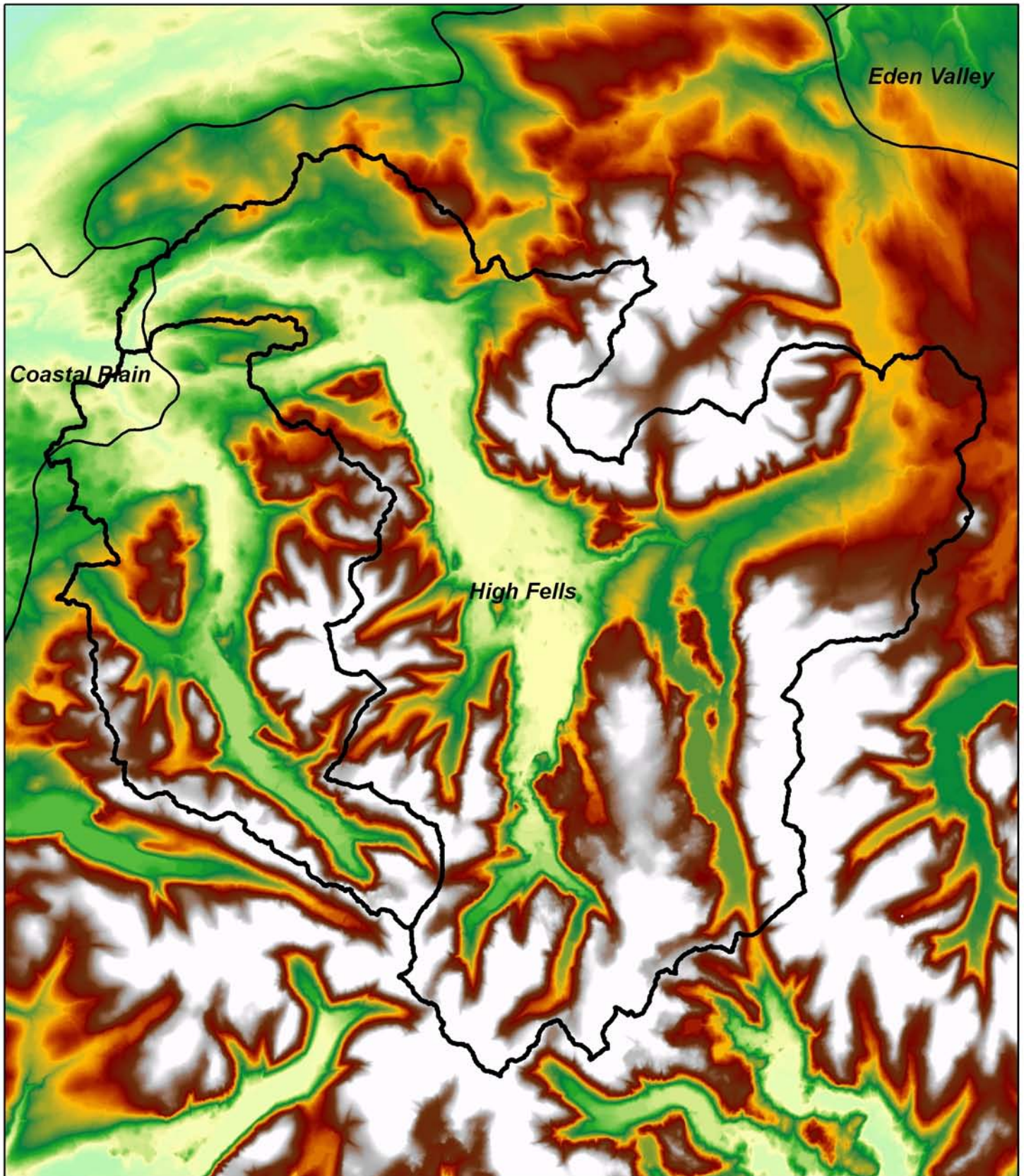
The character of England landscape, wildlife
and cultural features map. Natural England 2005.

Catchment boundaries
National Character Areas

Elevation (m)
High : 977
Low : -3

Kilometers
0   1.5   3   6   9   12

Forest Research

Map 3 Geology
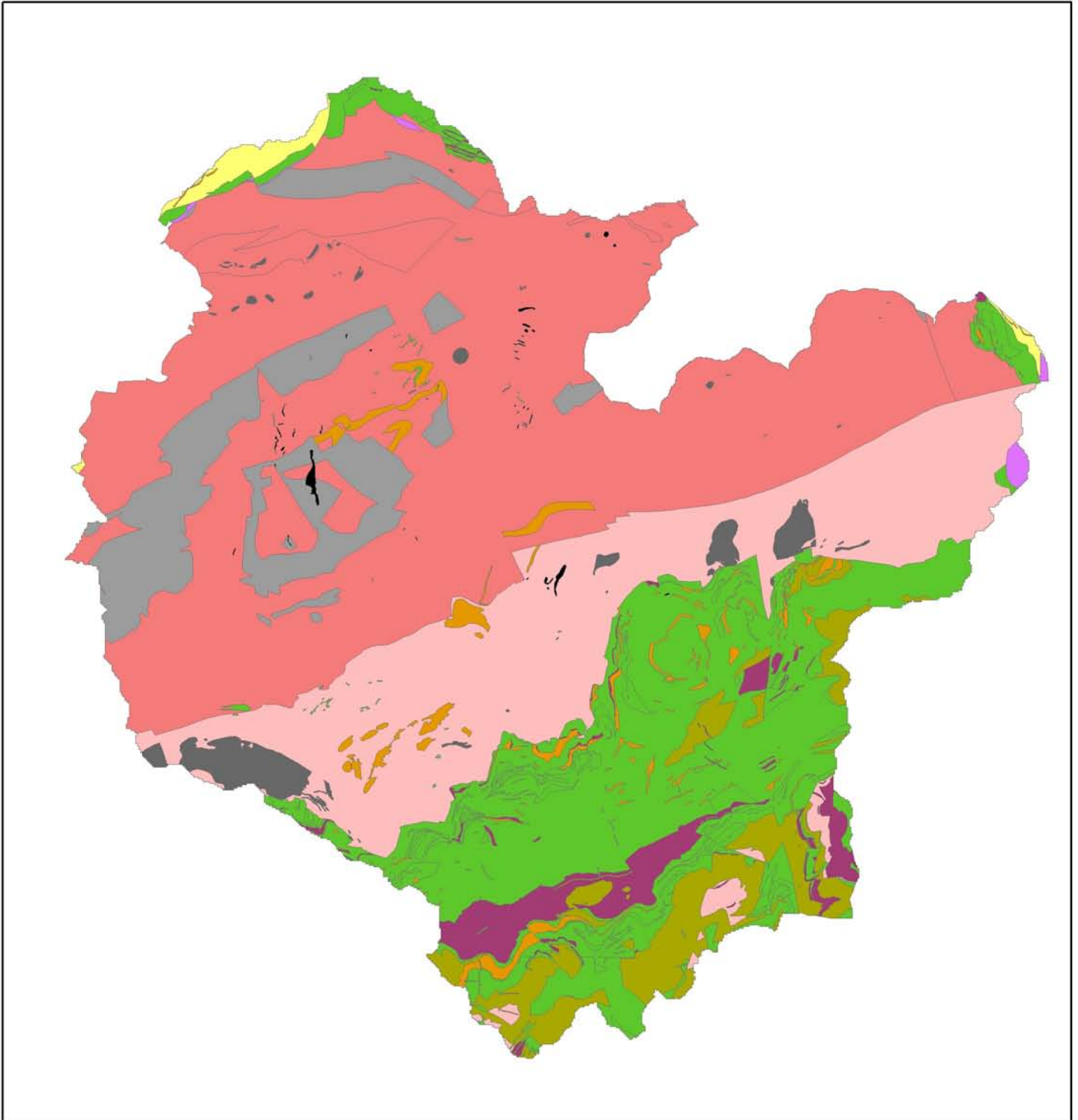
Rock description

⬜ Mudstone	🟩 Dolerite	🟧 Sandstones
🟥 Mixed sedimentary rocks	🟫 Greisen	🟦 Siltstones
🟩 Gabbro	⬜ Greywacke	⬜ Slate
🟪 Conglomerate	⬛ Lamprophyre group	🟪 Tuff
⬛ Granites	🟨 Limestone	🟩 Volcaniclastic rocks
	🟨 Rhyolite	

British Geological Survey DiGMap GB data at 1:50,000 scale

Kilometers

0   1.5   3   6   9   12

Forest Research

Map 4 Soils

Legend:

- Humic rankers
- Brown earths
- Brown alluvial soils
- Brown podzolic soils
- Ironpan stagnopodzols
- Ferric stagnopodzols
- Typical stagnogley soils
- Cambic stagnogley soils
- Cambic stagnohumic gley soils
- Typical alluvial gley soils
- Pelo-alluvial gley soils
- Peat
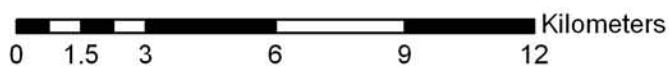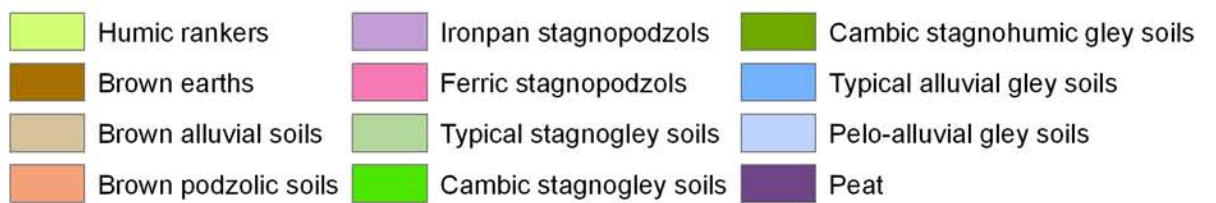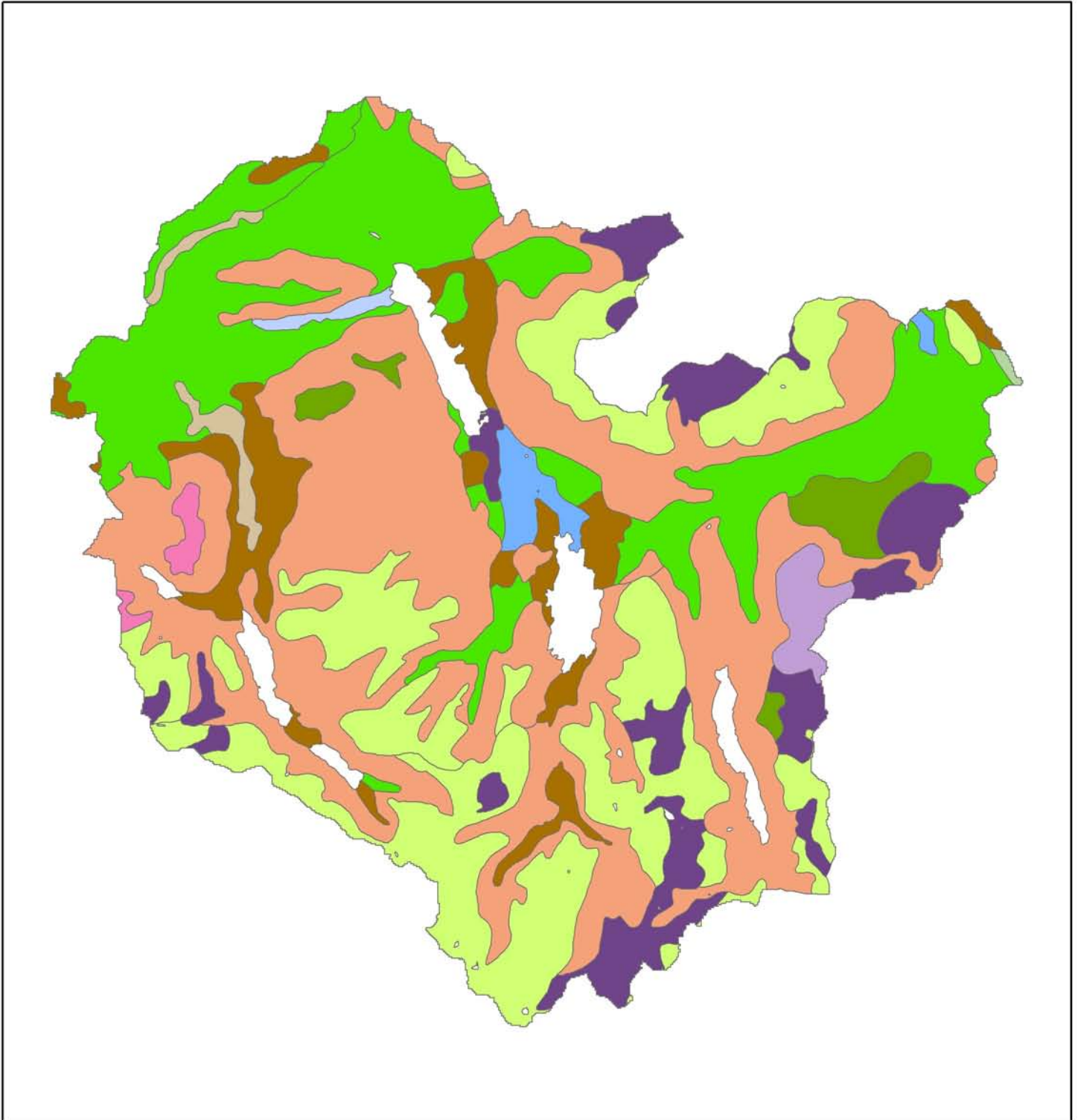
National soil map of England and Wales (NATMAP). LandIS:NSRI

Kilometers
0   1.5   3   6   9   12

Forest Research
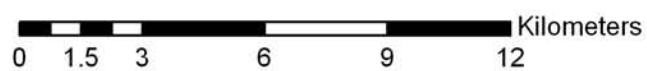
Map 5 Grazing pressure

ADAS Total livestock units

- <0.4 livestock units/ha
- 0.4 - 0.8
- 0.8 - 1.4
- 1.4 - 1.6
- 1.6 - 2.0
- >2.0
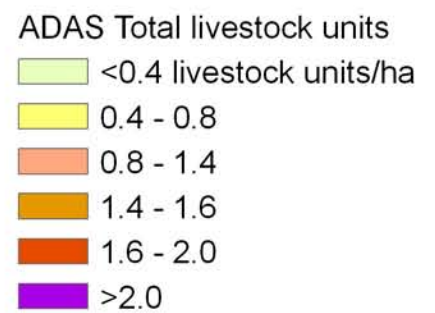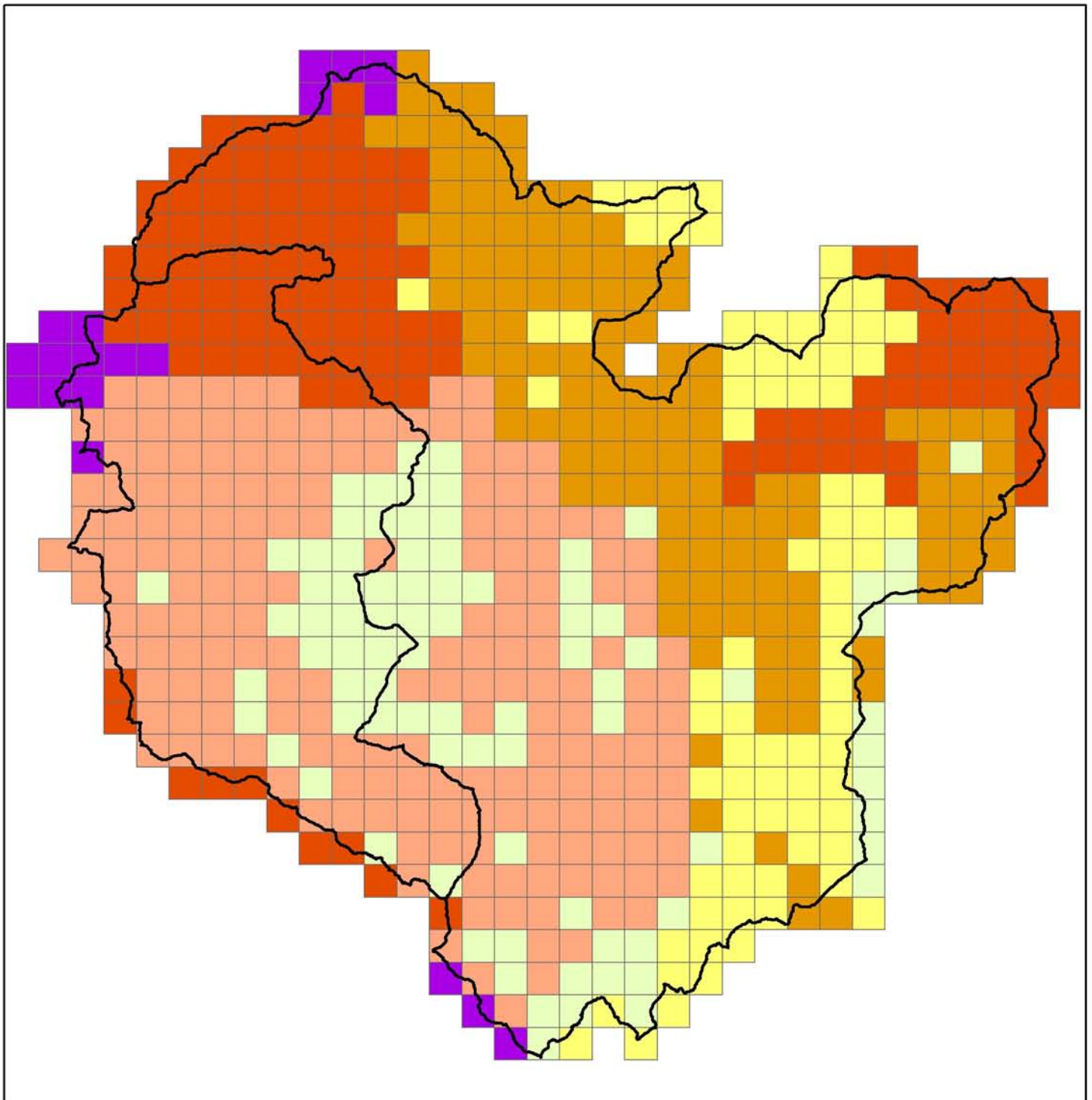
ADAS land use data base, livestock units per ha (rough grass and grass).
Phosphorus and sediment yield characterisation in catchments (PSYCHIC). ADAS (2008).

Kilometers

0   1.5   3   6   9   12

Forest Research

Map 6 Land use - Countryside Survey 2000

Countryside Survey, Land Cover Map 2000. CEH (2002)
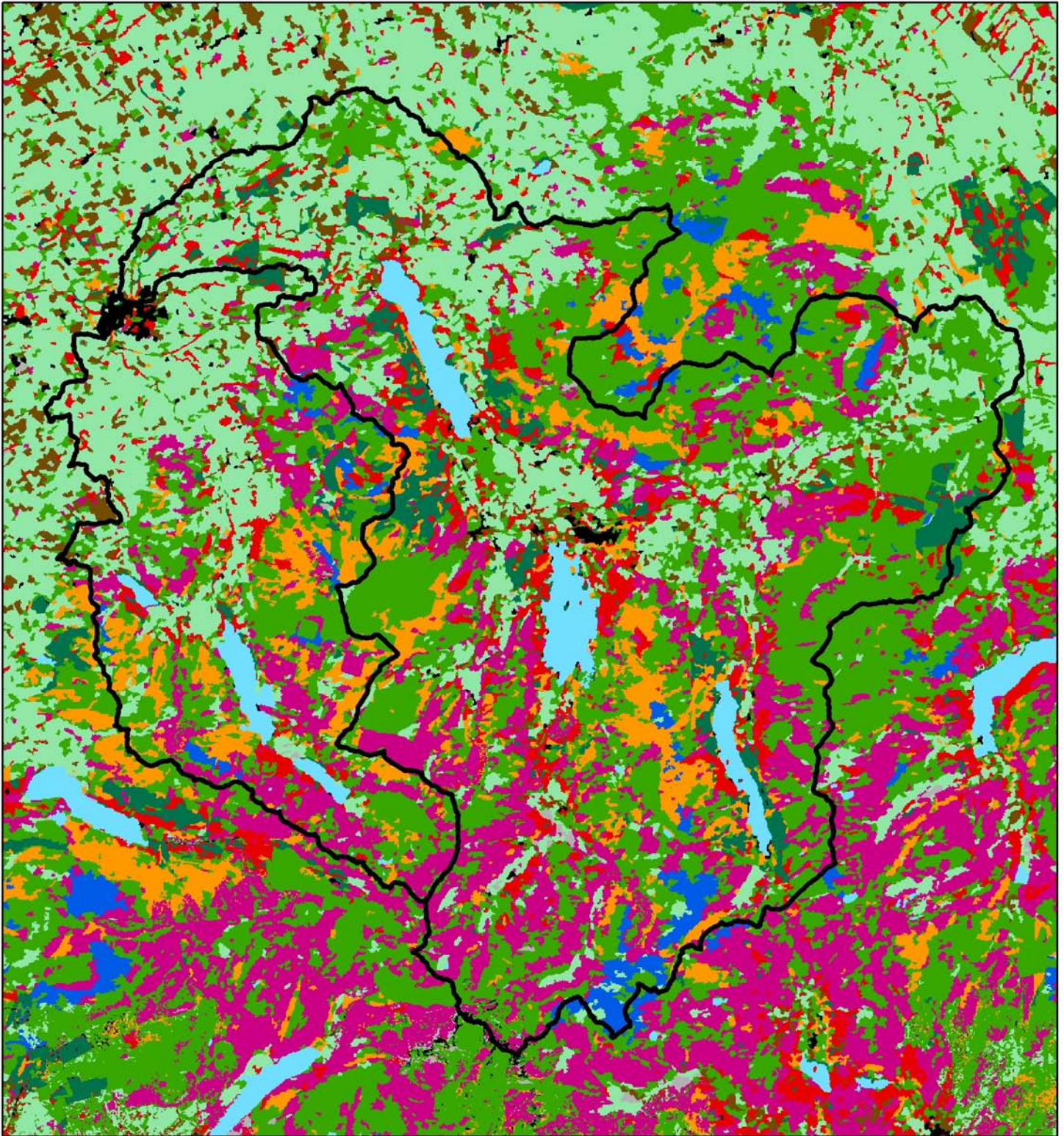
Land Cover Map 2000

- Broadleaved woodland
- Coniferous woodland
- Arable
- Improved grassland
- Unimproved grassland
- Bracken
- Shrub and heath
- Bog
- Water
- Bare ground
- Urban
- Coastal

Kilometers
0 1.5 3 6 9 12

Forest Research

Map 7 Existing woodland
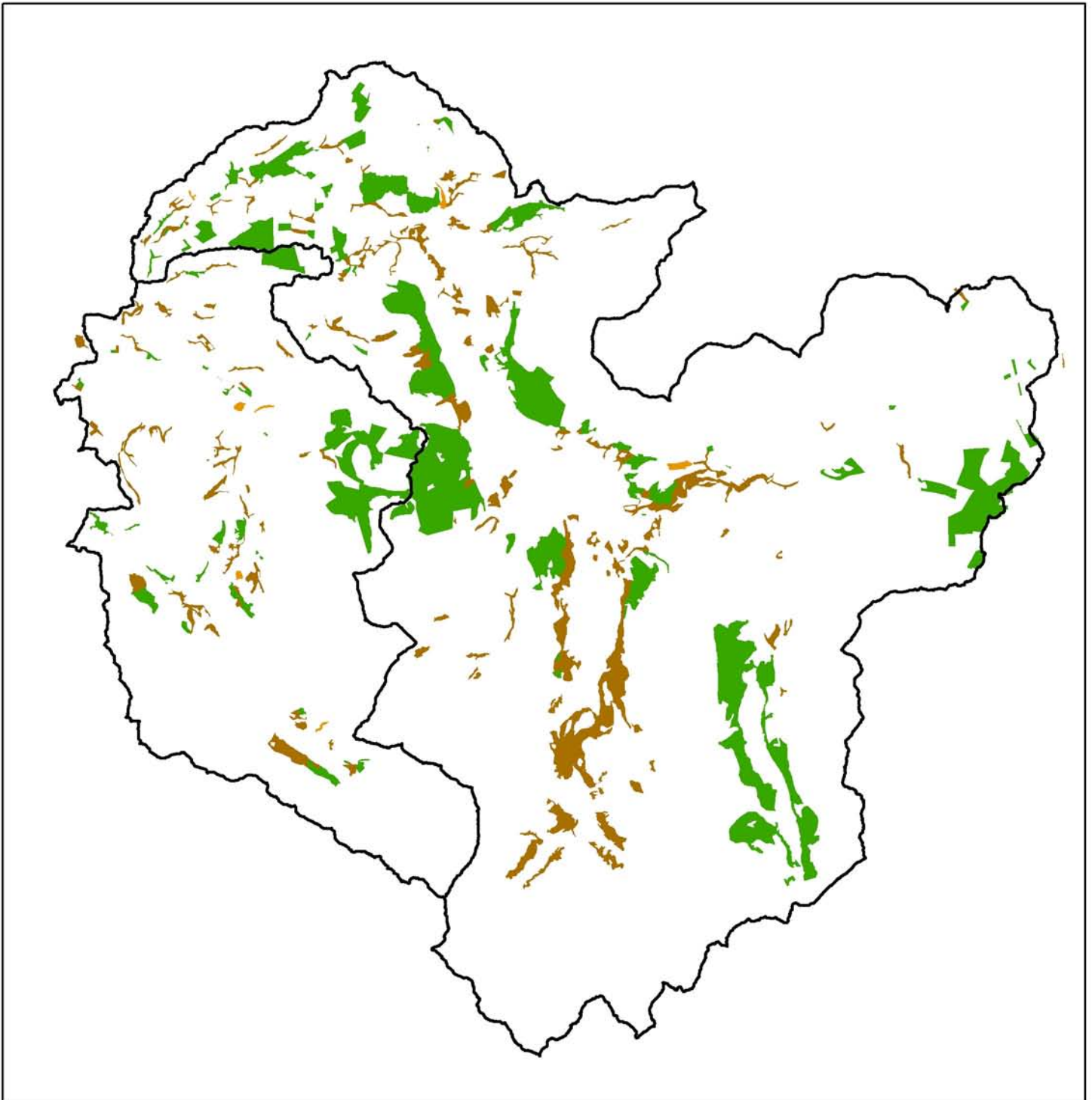
National Inventory of Woodland and Trees
- Broadleaved
- Coniferous
- Mixed

National Inventory of Woodland and Trees (NIWT). Forestry Commission (2002)

Kilometers
0   1.5   3   6   9   12

Forest Research

Map 8 Urban infrastructure and parish boundaries

Blindcrake
Sunderland
Bewaldeth
Bassenthwaite
COCKERMOUTH
Embleton
Wadcrag
Eaglesfield
Lorton
Mungrisdale
Scales
Troutbeck
Thornthwaite
Millbeck
Applethwaite
Threlkeld
BraithwaitePortinscale
KESWICK
Loweswater
Stair
Legburthwaite
Buttermere
Grange
Rosthwaite
Seatoller
Stonethwaite
Seathwaite
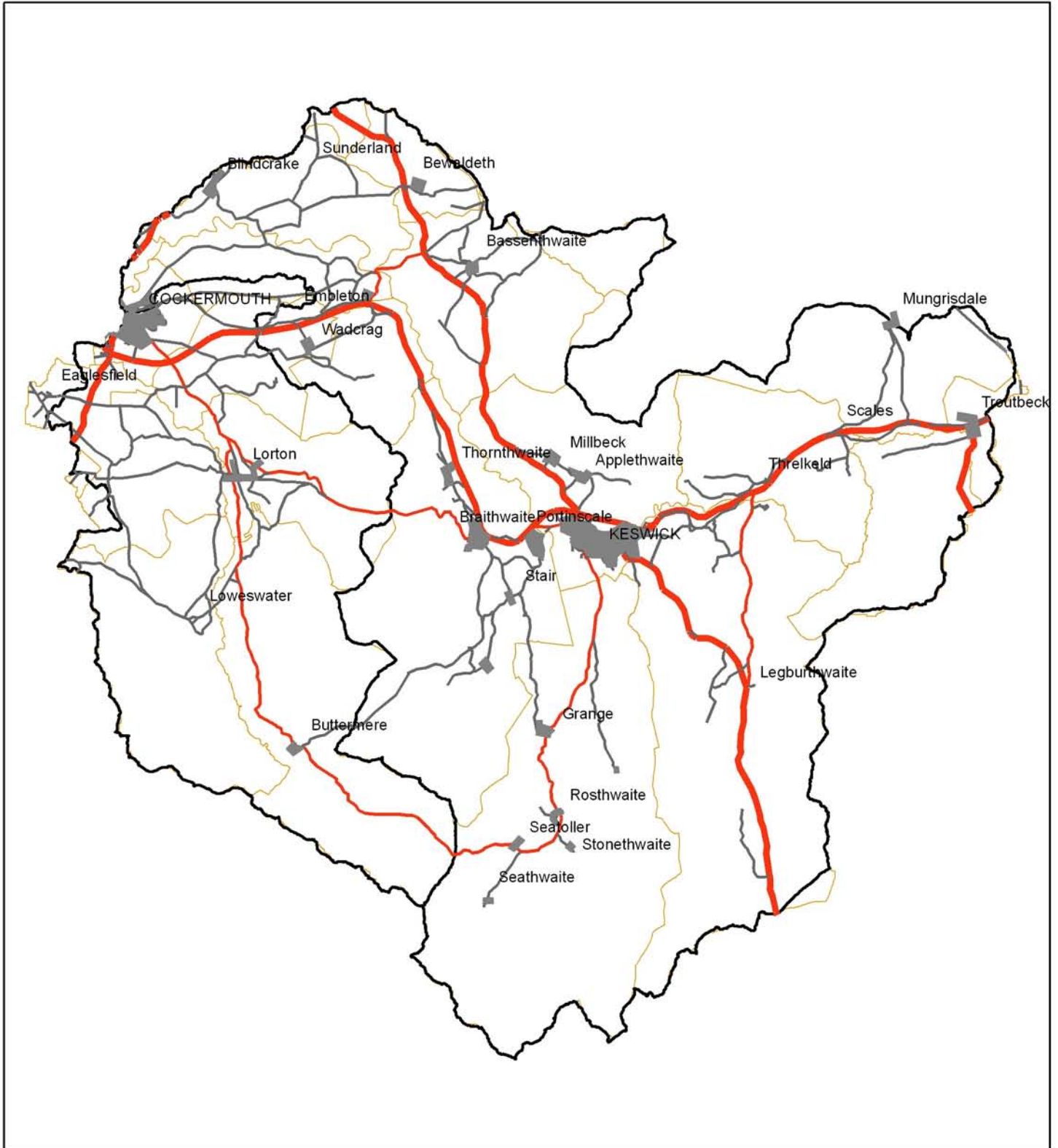
Urban areas
Minor roads
B roads
A roads
Parish boundary

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Ordance Survey Licence number [100025498].

Kilometers
0   1.5   3   6   9   12

Forest Research
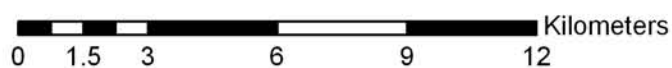
Map 9 Environment Agency Flood Zone, main rivers and detailed river network

Dubwath

Bassenthwaite

Cockermouth

Wadcrag

Mungrisdale

Troutbeck

Lorton

Keswick

Braithwaite

Portinscale

Stair

Grange

Watendlath

Buttermere

Rosthwaite

Seatoller

Stonethwaite

Seathwaite
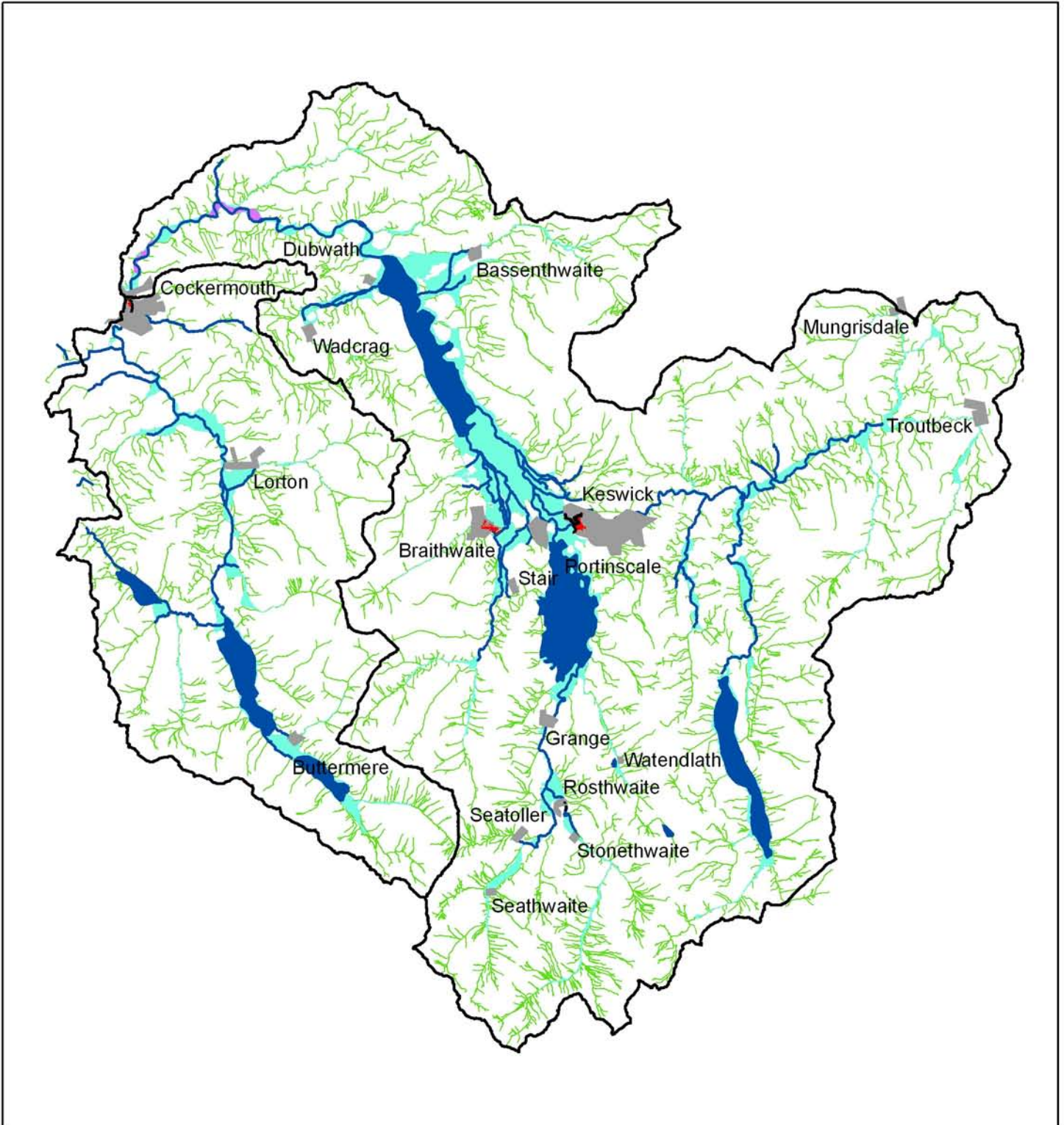
—— Flood defences	▨ Urban areas at risk from flooding
▮ Areas protected by flood defences	▮ Lakes
Flood zones	—— EA designated Main Rivers
▮ Fluvial	—— EA Detailed river network
▮ Fluvial / Tidal	

Kilometers

0   1.5   3   6   9   12

Forest Research

Map 10 Some constraints to woodland planting
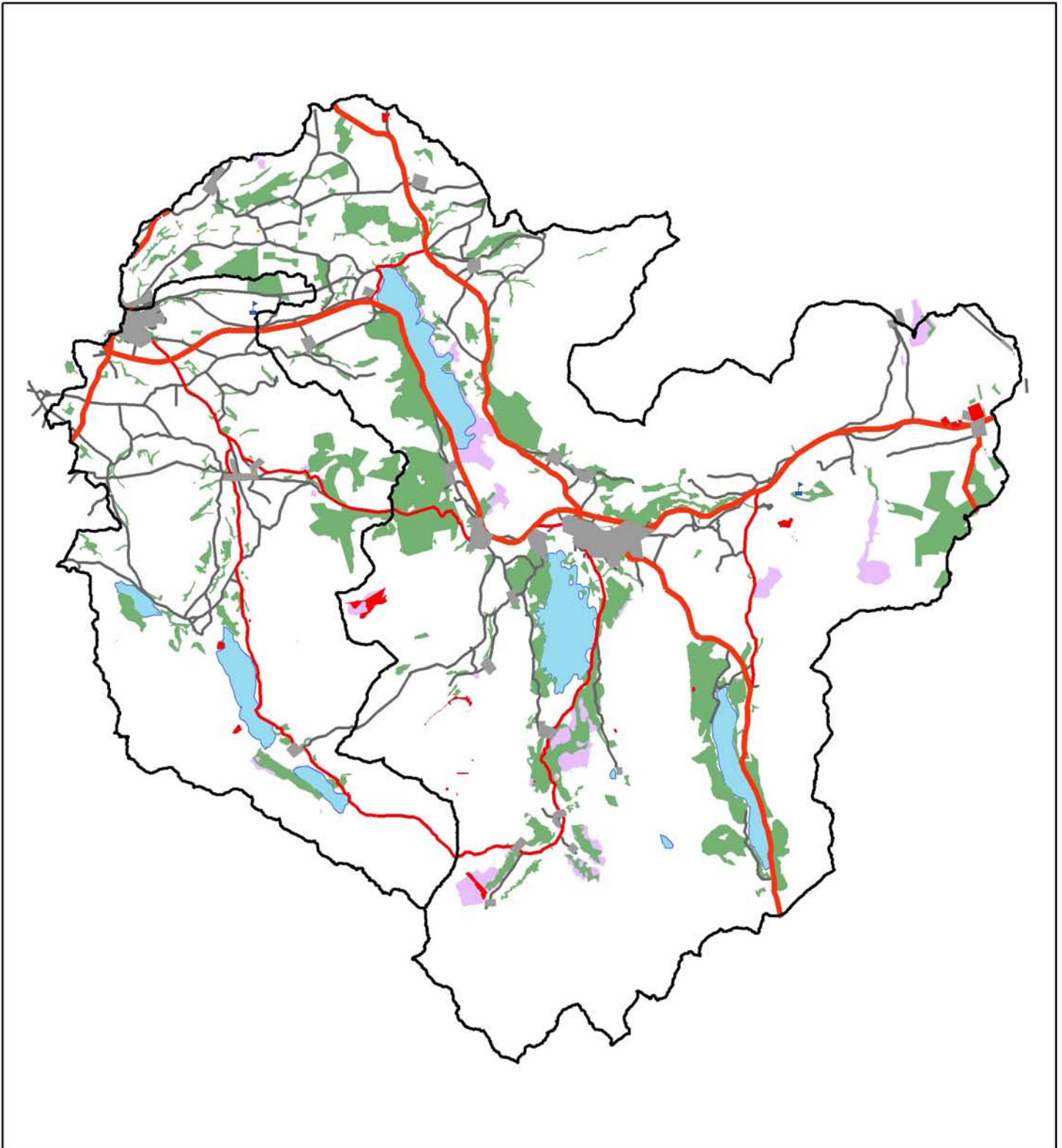
▨ Urban Areas		▨ Existing woodland	
━ A roads		▨ Lakes	
━ B roads		▨ Scheduled monuments	
━ Minor roads		▨ Registered parks and gardens	
		▨ selected SSSIs	
		⚑ Golf courses	

Kilometers

0   1.5   3   6   9   12

Forest Research

Map 11 Factors for consideration when planning woodland creation

Legend:
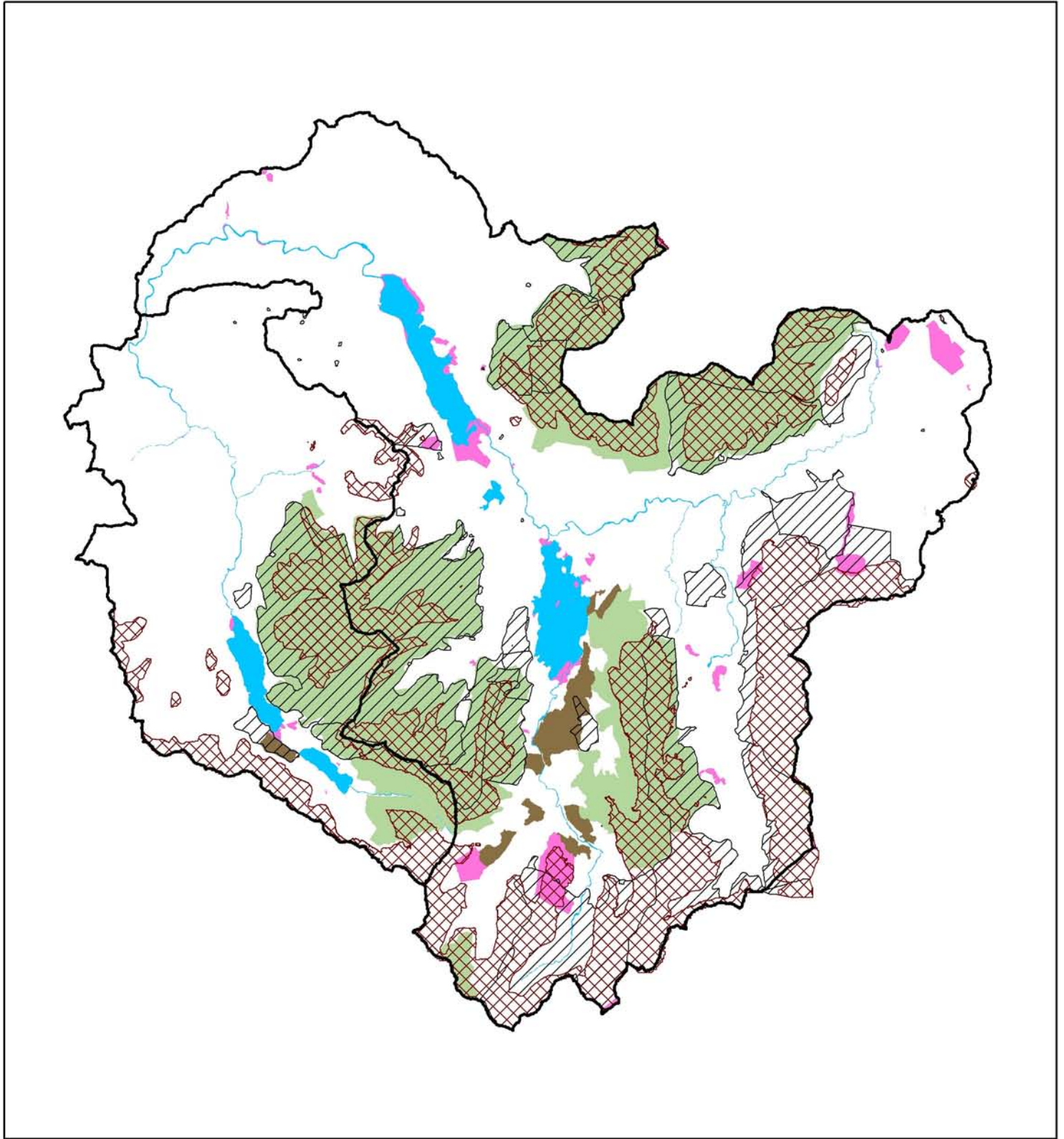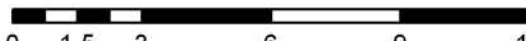
- ⧄ Land above 450 m
- ⧄ Common Land
- ▨ Borrowdale Woodland SAC
- ▨ Lake District High Fells SAC
- ▨ River Derwent & Bassenthwaite Lake SAC
- ▨ SSSIs

Kilometers
0   1.5   3   6   9   12

Forest Research

Map 12 Potential new floodplain woodland
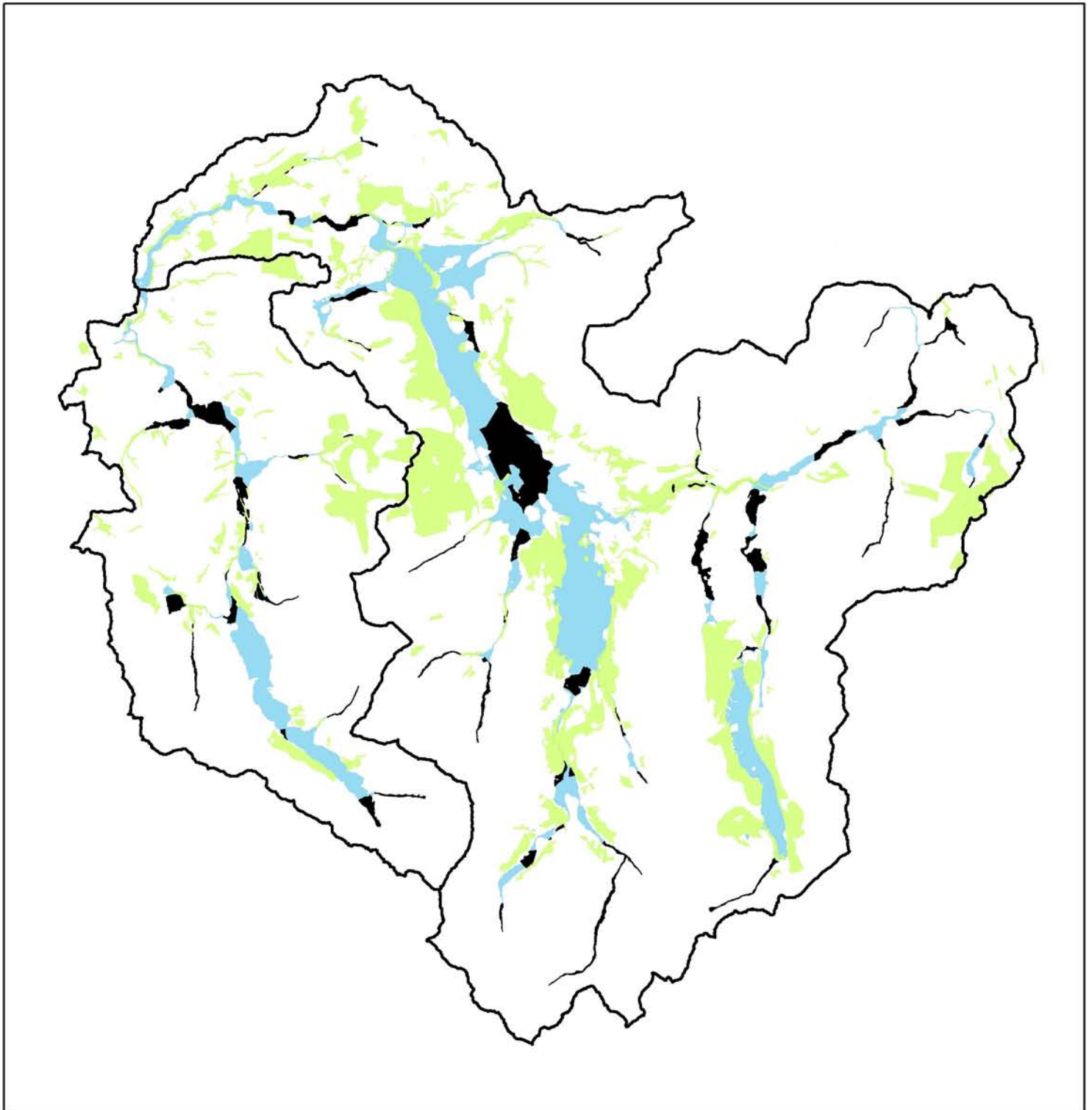
Potential new floodplain woodland

Existing woodland

Flood zone

Kilometers

0   1.5   3   6   9   12

Forest Research

Map 13 Vulnerability of riparian soils to stream bank erosion
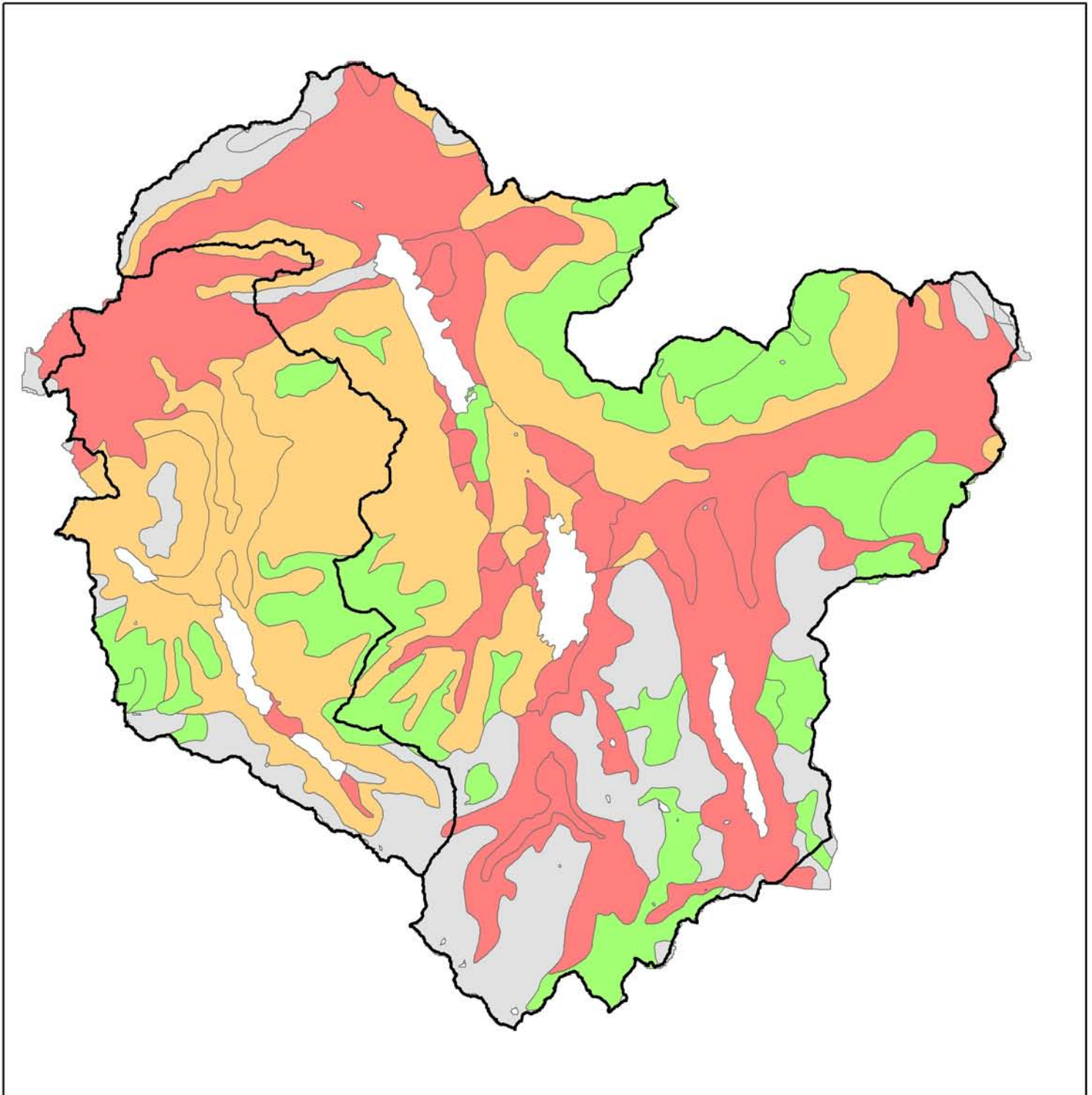
Classification of riparian soil vulnerability based on the distribution and extent of stream bank erosion observed in recent fluvial audits of the headwaters of Lake Bassenthwaite and Lake Windermere. Full details of the assement methodology are given in Broadmeadow and Nisbet (2010).

Vulnerability to bank erosion

- High
- Moderate
- Low
- Not Surveyed

Kilometers

0   1.5   3   6   9   12

Forest Research

Map 14 Vulnerability of soils to generate sediment
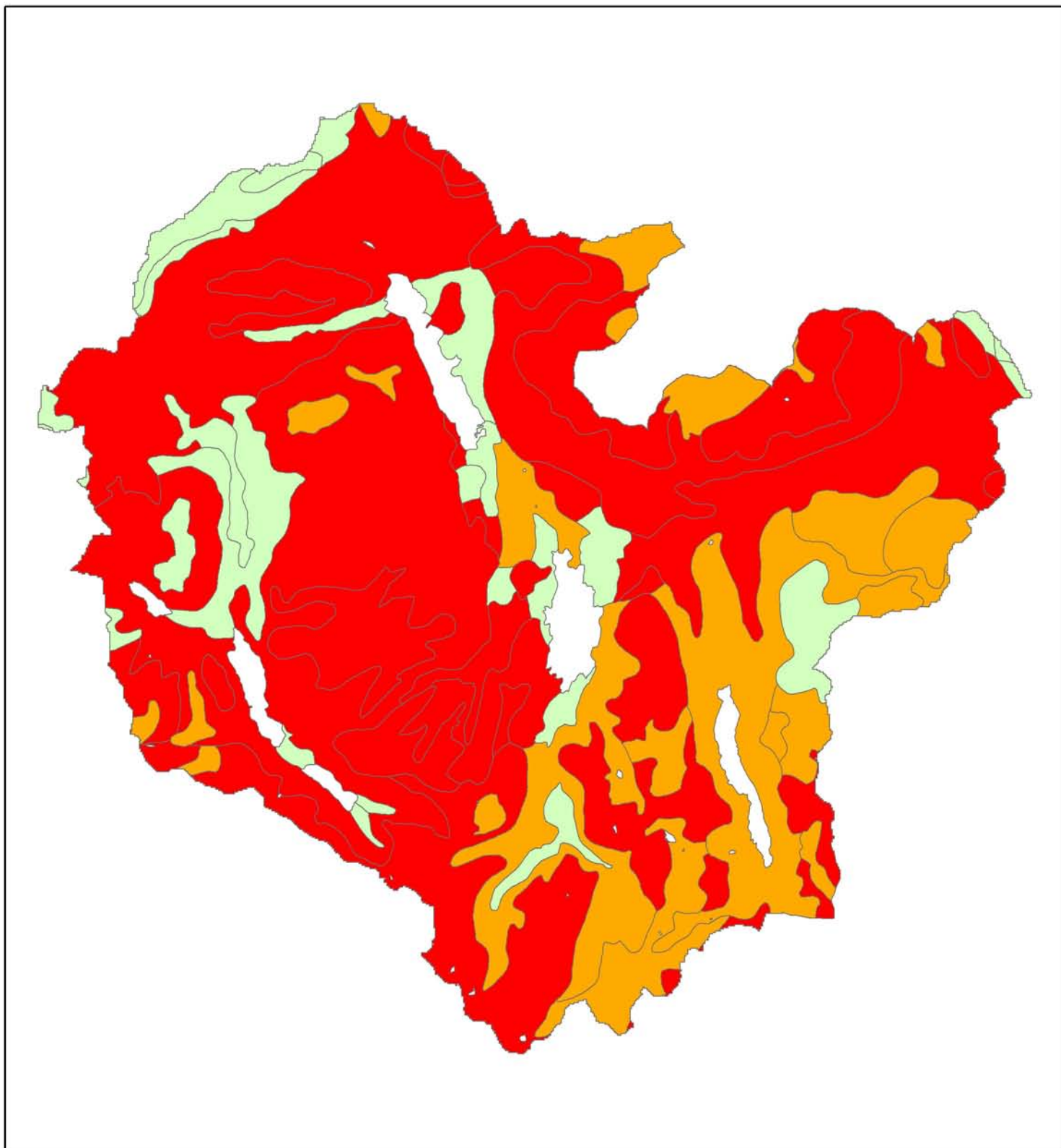
Soil vulnerability to erosion
- High
- Moderate
- Low

Based on ADAS (2008) Phosphorus and sediment yields characterisation in catchments (PSYCHIC). DEFRA & CEH.

Kilometers
0   1.5   3   6   9   12

Forest Research

Map 15 Propensity of soils to generate rapid surface runoff
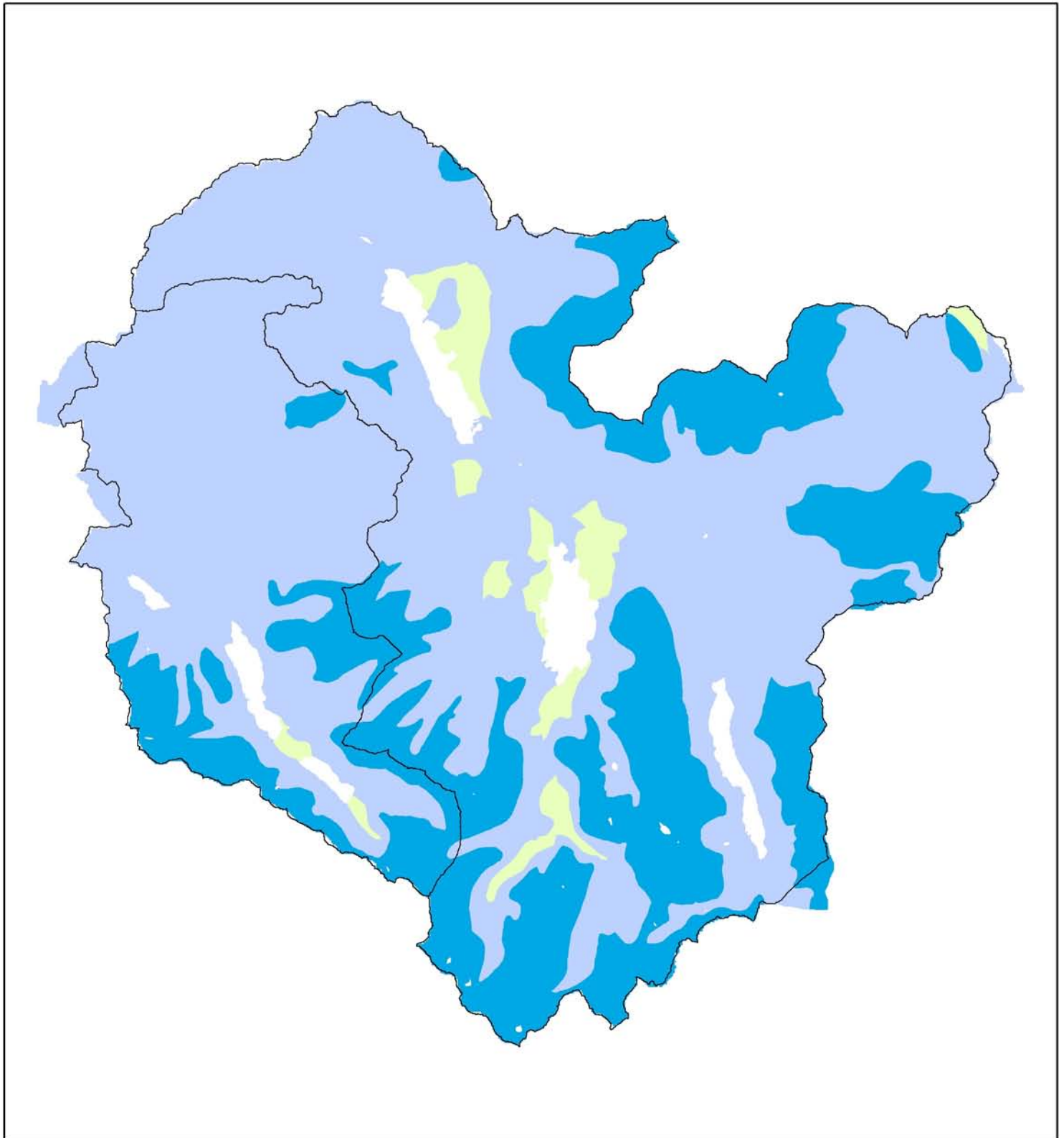
Standard percentage runoff values indicate the proportion of rainfall contributing to rapid increase in stream flow.
Hydrology of soil types: a hydrologically based classification of the soils of the United Kingdom.
Instutue of Hydrology Report No. 126. Boorman et al. (1995).

Standard percentage runoff

- <25% (free draining)
- 25 - 50% (seasonally waterlogged)
- >50% (flashy)

Kilometers

0   1.5   3   6   9   12

Forest Research

Map 16 High priority areas for new riparian woodland creation to reduce surface runoff and/or sediment delivery to watercourses
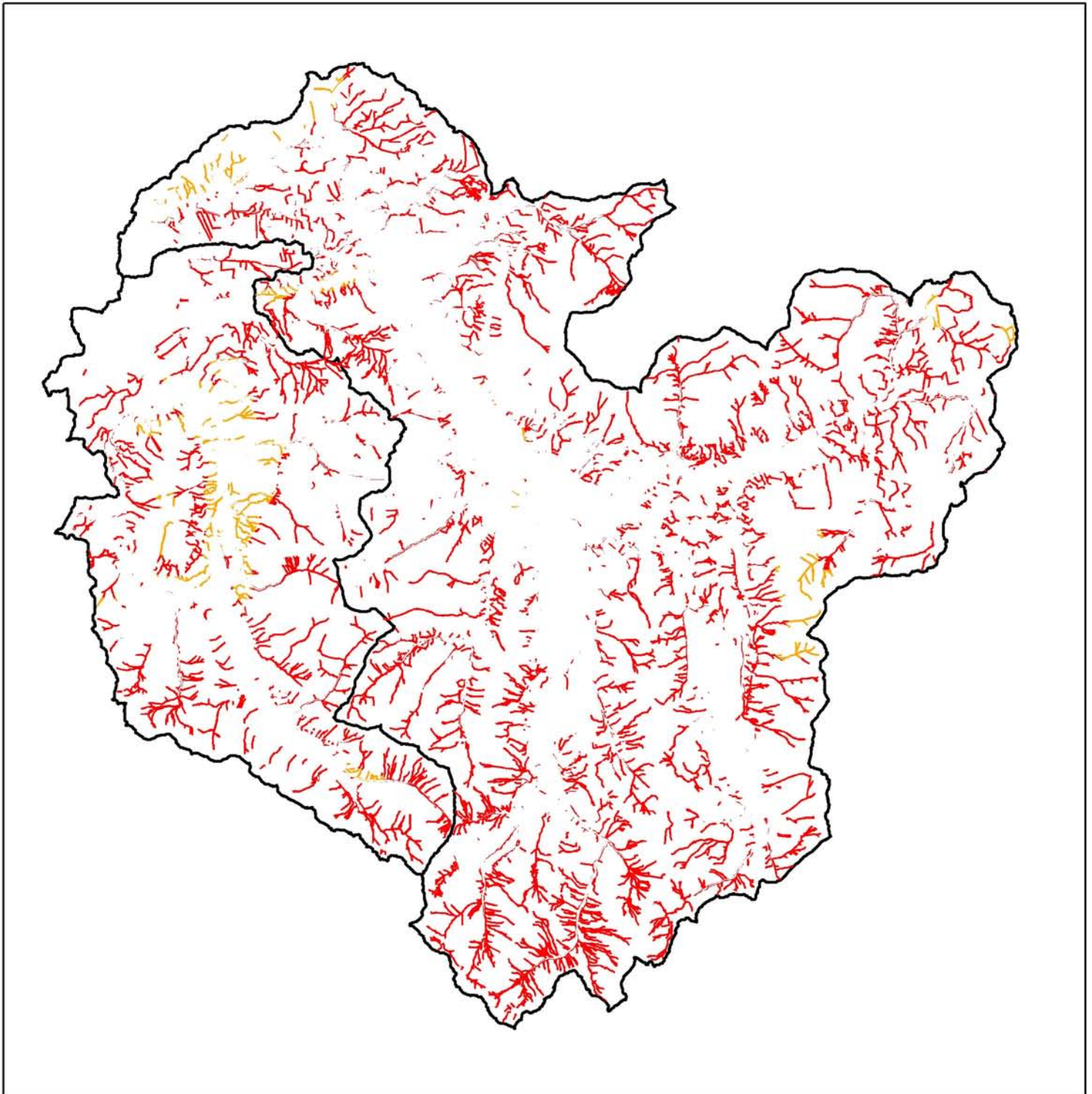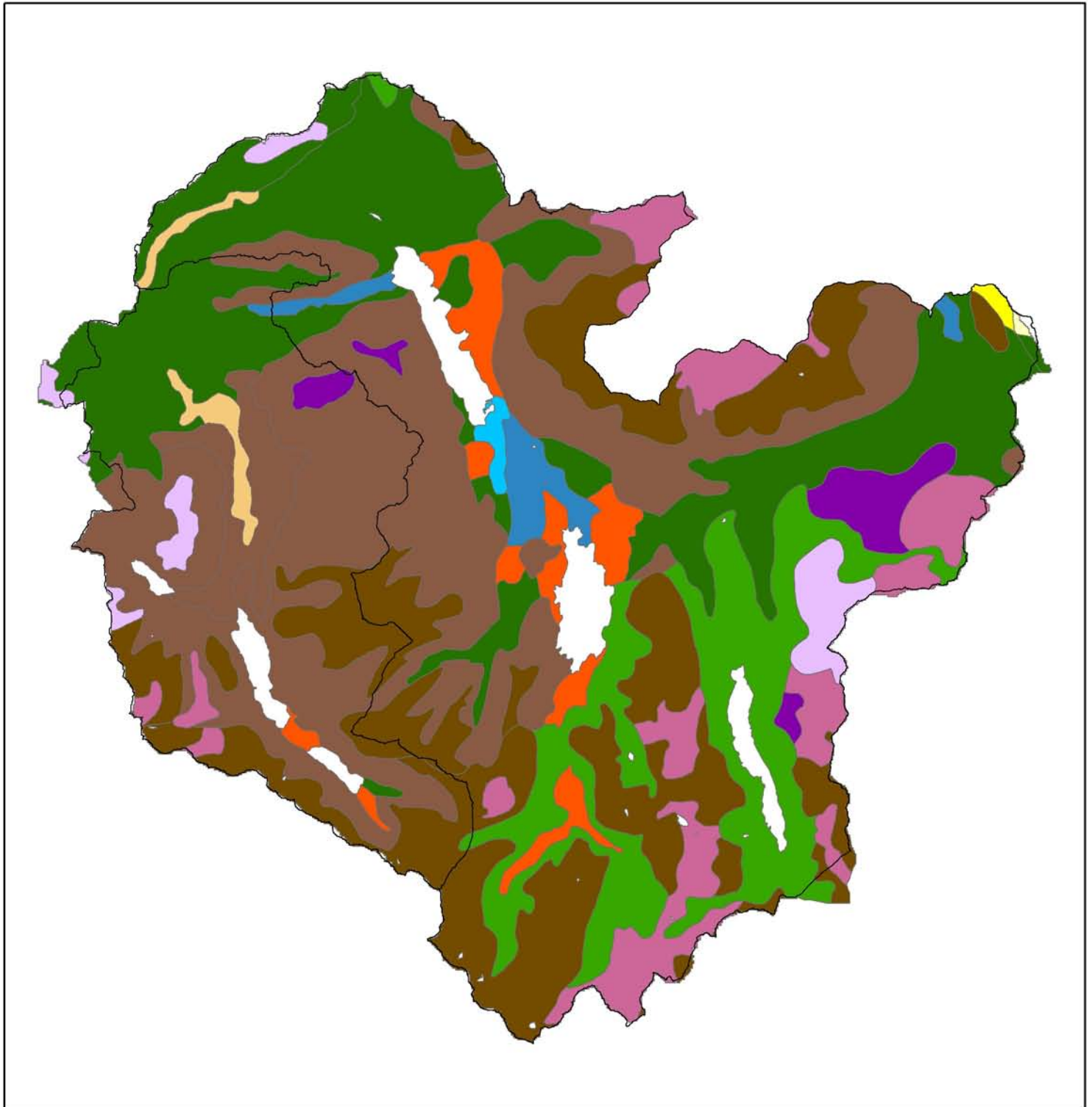

Potential new riparian woodland
- High priority soils
- Medium priority soils

Kilometers
0   1.5   3   6   9   12

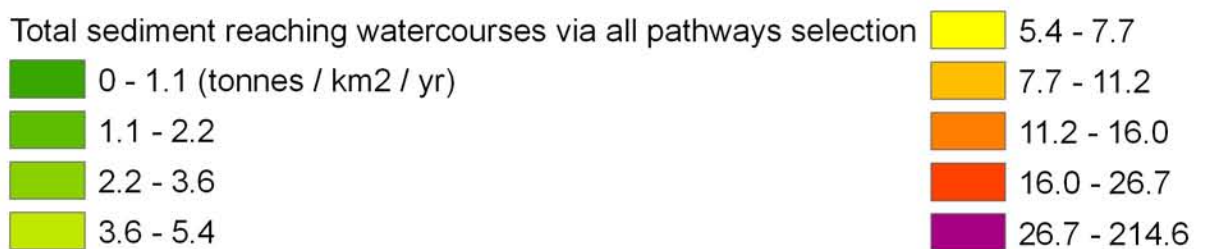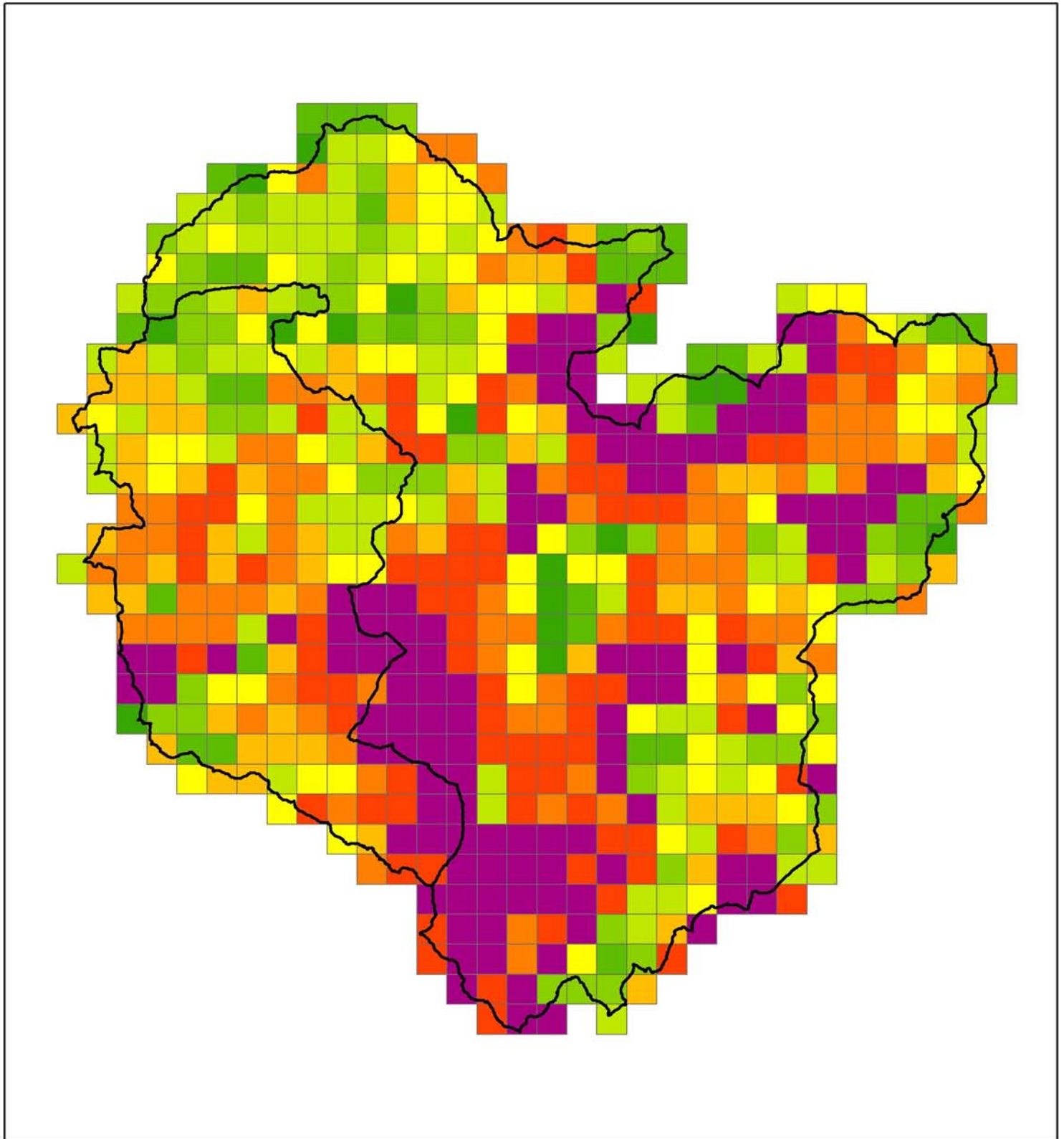Forest Research

Map 17 Hydrological properties of soil types (HOST)

Host Class 4 - 8 are generally free draining soils; Host Class 9 - 15 are soils which become seasonally waterlogged to a variable degree and Host Class 16 -29 are soils where surface runoff is common these are typically shallow and/or permanently saturated.
Hydrology of soil types: a hydrologically based classification of the soils of the United Kingdom.
Instutue of Hydrology Report No. 126. Boorman et al. (1995).

HOST Class

4	9		22
5	10		24
6	11		26
7	15		27
8	19		29
	17		

Kilometers

0   1.5   3   6   9   12

Forest Research

Map 18 Modelled sediment loss to watercourses

Total sediment reaching watercourses via all pathways selection

- 0 - 1.1 (tonnes / km2 / yr)
- 1.1 - 2.2
- 2.2 - 3.6
- 3.6 - 5.4
- 5.4 - 7.7
- 7.7 - 11.2
- 11.2 - 16.0
- 16.0 - 26.7
- 26.7 - 214.6

Created by - ADAS (2008) Phosphorus and sediment yields characterisation in catchments (PSYCHIC). DEFRA & CEH.

Kilometers
0   1.5   3   6   9   12

Forest Research
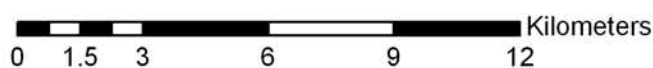
Map 19 Priority soils for woodland creation in the wider catchment to reduce surface runoff and/or sediment delivery to watercourses
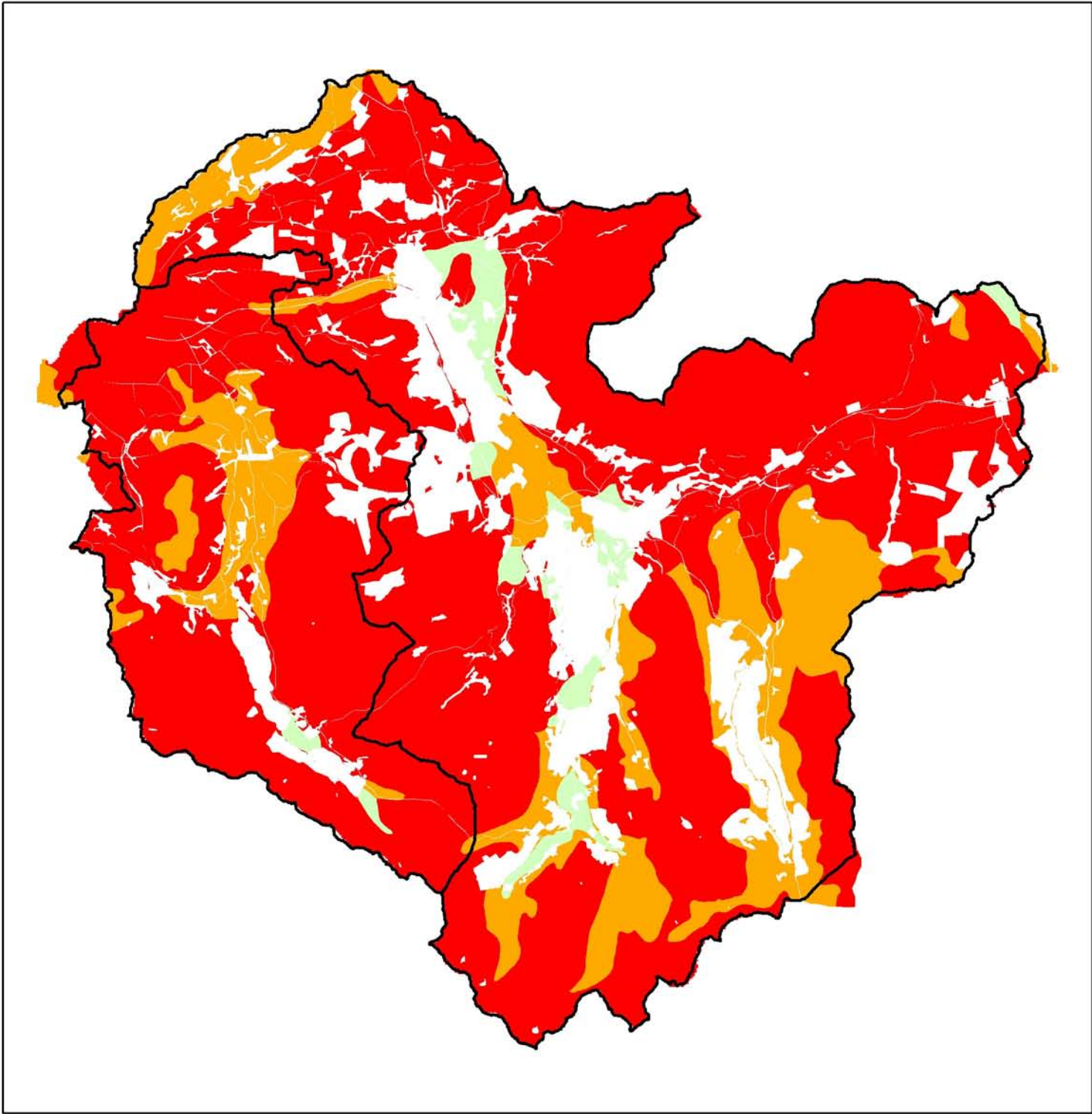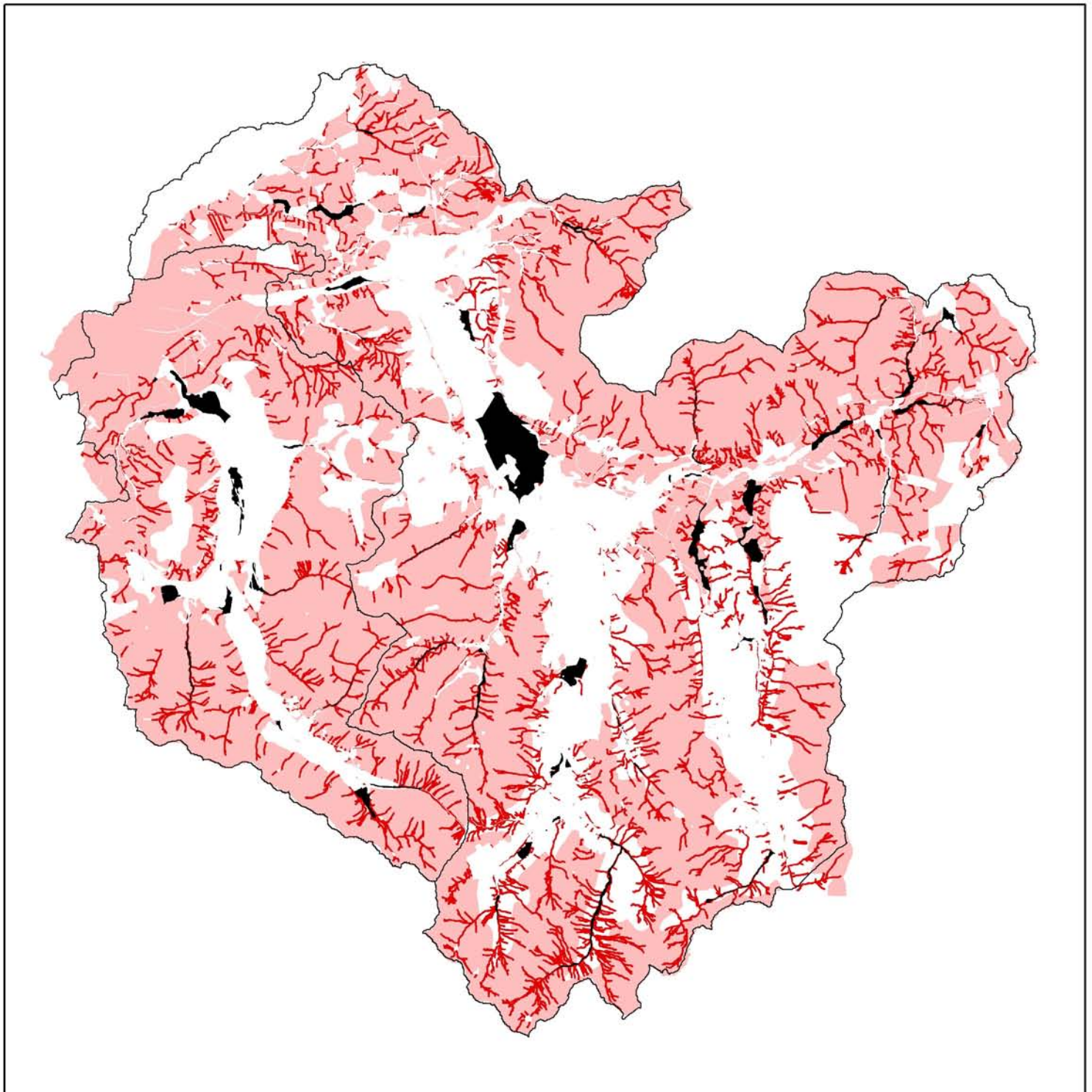

Potential new woodland in the wider catchment

- High priority
- Medium priority
- Low priority

Kilometers
0   1.5   3   6   9   12

Forest Research

Map 20 Combined map showing high priority areas for floodplain, riparian and wider woodland creation to reduce downstream flooding

Legend:
- Floodplain woodland
- Riparian woodland
- Woodland in the wider catchment

Kilometers
0   1.5   3   6   9   12

Forest Research