Climate Change Adaptation in the Glasgow and Clyde Valley: Opportunity Mapping for Woodland Creation to Reduce Flood Risk

Report prepared for the GCV Green Network Partnership by Forest Research

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Project overseen by Steering Group comprising:

Forest Research is the Research Agency of the Forestry Commission and is the leading UK organisation engaged in forestry and tree related research. The Agency aims to support and enhance forestry and its role in sustainable development by providing innovative, high quality scientific research, technical support and consultancy services.

Executive Summary

The Glasgow and Clyde Valley is impacted by a number of water issues, with almost 42% of the catchment classed as Potentially Vulnerable Areas to flooding (covering 69 flood management units). There are also 170 river waterbodies currently failing to meet the required Good Ecological Status (GES). A recent review of relevant research provides strong evidence of the ability of woodland creation to mitigate these pressures by reducing and delaying flood waters, limiting pollutant loadings and retaining diffuse pollutants. The aim of the study, commissioned by the GCV Green Network Partnership, was to provide GIS spatial datasets and maps to identify opportunities for woodland creation to reduce flood risk and diffuse pollution in the Glasgow and Clyde Valley catchment.

A wide range of spatial datasets were accessed from partners and used to generate a set of maps and supporting GIS shapefiles showing priority areas for planting. The results provide a strong basis for developing and refining regional strategies, initiatives, plans and incentives to deliver new woodlands where they can best contribute to flood risk management (FRM) and Water Framework Directive (WFD) targets, in addition to generating many other benefits for society. Woodland creation, however, is not without risks and care will be required in planting the right tree in the right place to avoid woodland acting as a pressure on the water environment.

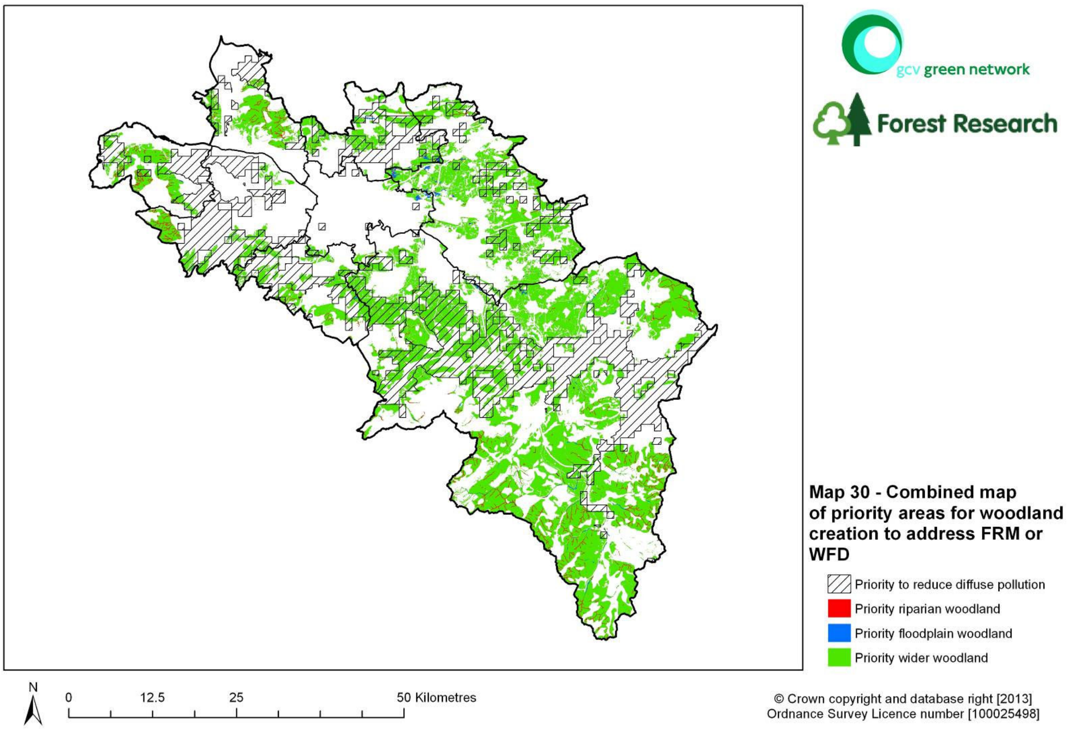
There are extensive opportunities within the catchment for woodland creation to mitigate downstream flood risk and improve water quality, including:

- 1,893 km^2 (56% of the GCV catchment) of priority land for woodland planting to reduce downstream flood risk. 717 km^2 of the total priority area may be subject to restrictions due to sensitivities. Within this total area, 1,198 km^2 is available for wider woodland, 36 km^2 for riparian woodland and 18 km^2 for floodplain woodland planting.

- 889 km^2 (20% of catchment) of priority land in failing river waterbody catchments subject to one or more diffuse agricultural pollution pressures (phosphate, nitrogen and sediment)

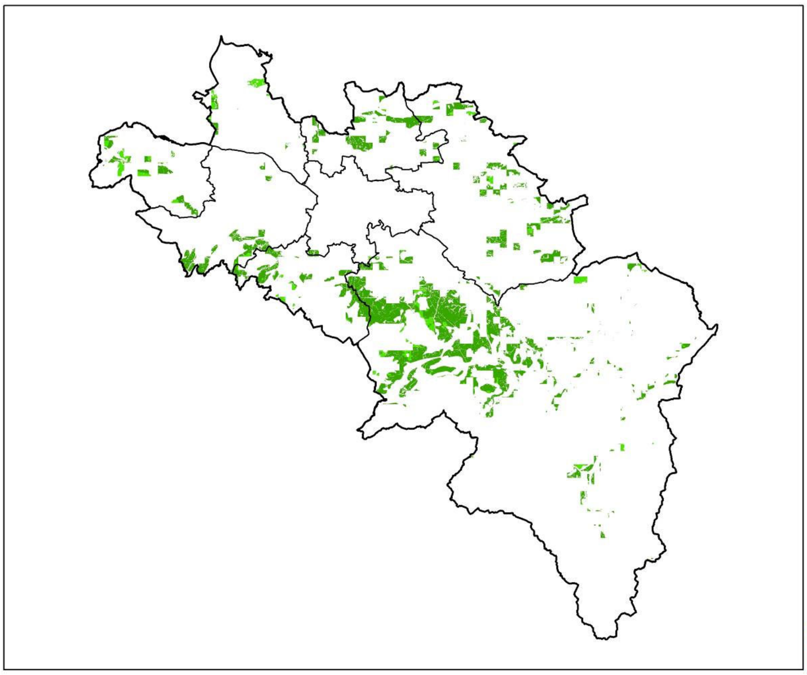
- 277 km^2 (8% of catchment) of priority land with opportunities for woodland planting to reduce both flood risk and one or more diffuse agricultural pollution pressures; 89% (246 km^2) of this land is free from all sensitivities

Opportunities for woodland creation to reduce flood risk are relatively evenly distributed across the catchment (excluding urban areas; Map 30), mainly comprising higher ground with improved or acid grassland and dwarf shrub heath.



Most of this targets soils with a high propensity to generate rapid runoff or extreme/high vulnerability to livestock poaching. Nearly all of the priority land drains to Potential Vulnerable Areas and therefore planting could directly contribute to protecting those communities at greatest risk from future flooding. As a catchment percentage, the Upper Clyde and Dumbarton coastal sub-catchments have the largest proportion of priority land for planting (45%) and the Glasgow Coastal the lowest (9%).

In contrast, opportunities for planting to reduce diffuse pollution are concentrated on the lower-lying, better agricultural land surrounding the Glasgow conurbation and extending up the Clyde Valley (Map 30). The greatest scope to tackle multiple diffuse pollutants lie within the River Leven and Loch Lomond, River Gryfe, Black Cart Water and western side of the upper River Clyde catchments. Opportunities for woodland creation to benefit both FRM and WFD are relatively thinly distributed around the Glasgow conurbation, with particular 'hot spots' in the northwestern corner of the upper River Clyde and southeastern edge of the White Cart Water catchments (Map 31).



Map 31 - Opportunities for woodland creation to address both FRM and WFD (one or more pollutants)

Priority areas subject to sensitivities

Priority areas unaffected by sensitivities

N 0 12.5 25 50 Kilometres

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

Achieving a sufficient level of planting to make a difference at the sub-catchment scale will require modifications to the Scottish Rural Development Programme to promote better targeting of woodland creation for water. This includes raising the value of woodland grants and supporting smaller planting schemes, the latter being especially important for tackling agricultural diffuse pollution pressures, which tend to be greatest on arable land. While land values and crop prices will greatly constrain the scope for woodland creation on such land, it is thought that small scale planting targeted to riparian buffers and along pollutant pathways could make a significant difference, while having a limited impact of agricultural incomes. There is a good case for better integrating available incentives to secure greater land use change, as well as exploring other funding options for woodland creation for water.

Finally, it is recommended that one or more case studies are established within the catchment to demonstrate and help communicate the value and benefits of woodland creation for water.

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1. Objective

To provide GIS spatial datasets and maps which identify opportunities for woodland creation to reduce flood risk and diffuse pollution in the Glasgow and Clyde Valley Catchment.

2. Background

The Flood Risk Management (Scotland) Act 2009 introduced a more sustainable approach to managing flood risk in Scotland, requiring greater consideration to be given to the role of natural flood management (NFM). According to Nutt (2012) woodland offers a number of NFM techniques that can help to mitigate downstream flooding, including upland afforestation, gully planting, riparian planting, floodplain planting and the artificial placement of large woody debris dams within streams. These act in various ways to reduce and/or delay the downstream passage of flood flows, including through increased water use, promoting rainfall infiltration into the soil, stabilising river banks and increasing channel and floodplain hydraulic roughness.

The beneficial role that woodland can play in reducing flood risk and improving water quality is highlighted by Nisbet *et al.* (2011a) in a review of the subject commissioned by the Environment Agency (EA) and Forestry Commission (FC). The Summary Report published by the EA on this work concluded that:

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

- A good case can be made for the mitigation of downstream flooding by riparian and floodplain woodland.

- The benefits of riparian and floodplain woodland for protecting river morphology and moderating stream temperatures are well proven.

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

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

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

Whilst significant progress has been made in recent years towards improving the condition of surface waters across Scotland, assessments indicate that about 40% of waterbodies continue to fail the environmental standards required to support good ecology, with diffuse pollution identified as one of the most important water management issues (SEPA, 2012a). The main diffuse pollutants affecting waters are phosphorus, nitrate, pesticides, sediment, ammonia and faecal microorganisms. Agriculture is the primary source and thought to be responsible for nearly half of Scotland's waterbodies failing due to diffuse pollution, a total of 495 waterbodies (SEPA, 2007). Commercial forestry can also act as a pressure on the water environment if poorly designed and managed, although this has largely been addressed by developments in good forestry practice (Forestry Commission, 2011).

The Metropolitan Glasgow Strategic Drainage Plan (MGSDP) has five key objectives, which include reducing flood risk, improving river water quality, enabling economic development, improving habitats and better integrating investment planning. Woodland creation offers potential to deliver most if not all of these objectives, as well as providing other ecosystem services such as carbon sequestration, recreation and landscape improvement.

Opportunities for woodland creation to benefit water are constrained by many factors, not least economics. It is therefore imperative that planting is targeted to the most effective locations where it can best benefit society. 'Opportunity mapping' has been developed to help identify these locations and promote more integrated catchment management. The method can be applied across a range of scales, from assessing opportunities for planting at a strategic regional or river basin level down to the practical farm/field scale.

This report describes how opportunity mapping was used to assess opportunities for woodland creation to reduce flood risk and diffuse pollution within the Glasgow and Clyde Valley catchment in Scotland. The approach comprised three strands: identifying constraints and sensitivities to woodland creation; assessing the scope for woodland planting to reduce flood risk; and identifying opportunities for woodland creation to address diffuse pollution pressures affecting surface waters. A series of maps and tabulated data are provided that identify priority areas for woodland creation to benefit water. A selection of key maps is incorporated into the report, while the full set of maps is available as a separate document. The report also provides a number of recommendations on next steps to try and deliver benefits on the ground.

3. Study Area

The Glasgow and Clyde Valley catchment (Map 1) covers an area of 3,388 km^2. It is drained by a total of 154 main rivers and 17 lochs, which feed into the River Clyde. The River Clyde rises in the Southern Uplands in the south-east, flows north-west through the Clyde Valley and eventually through Glasgow and into the Firth of Clyde (Map 2). There are several major sub-catchments around Glasgow, including the Gryfe, Kelvin, and White and Black Cart Waters.

The catchment is one of contrasting landscapes: the rolling uplands of the south, east and west, the lower lying grasslands of the lower Clyde Valley, and the open water and wetlands of the Loch Lomond and The Trossachs National Park. It also includes the large urban conurbation centered on the City of Glasgow, which is home to approximately 600,000 people.

Catchment geology (Map3) is dominated by sandstone and a large area of extrusive igneous lava to the west. Pockets of limestone cut across the middle of the catchment, while basic igneous extrusions occur throughout the area. Soil types reflect the variation in geology and topography, with the fertile brown forest and gley soils of the lowlands contrasting with the nutrient poor peaty podzols, peaty gleys and peats of the uplands (Map 4).

Land capability for agriculture is dictated by soils and geology. The uplands comprise rough grazing on the hill tops and improved grassland in valley bottoms, with mixed agriculture dominating the lowlands. There are a few pockets of Grade 3.1 arable land distributed around Glasgow (Maps 5 & 6). Existing woodland covers 16% of the catchment, made up of a number of large conifer plantations around the upland periphery and many small woodlands throughout the lowlands (Map 7). The uplands are attracting increasing attention for windfarms, with a number of major developments already in place. Most of the population is concentrated in the urban conurbation formed by Glasgow and adjoining towns in the north-west of the catchment (Map 8).

The recent National Flood Risk Assessment shows that flooding is a major issue in the catchment, with most of the land falling within the Clyde and Loch Lomond Local Plan District (SEPA 2011). Around 136 km^2 or 4% of the project area is at risk of flooding from a 1 in 1000 year event. A total of 18 Potentially Vulnerable Areas have been identified at risk from mainly surface water and river flooding, affecting 69 of the 222 individual flood management units in the catchment (Map 9).

Diffuse pollution is another important issue, especially in central parts of the catchment. It is responsible for 101 river and 14 loch waterbodies failing good water status (SEPA, 2012b).

The Glasgow and Clyde Valley contains a number of key wildlife and landscape designations, including 25 Special Areas of Conservation (SACs), 22 Special Protection Areas (SPAs) and a part of the Loch Lomond and The Trossachs National Park. There are 137 nationally important Sites of Special Scientific Interest (SSSIs).

4. Methods

4.1 Approach to GIS mapping

Opportunities for woodland planting to contribute to flood mitigation and a reduction in diffuse pollution within the Glasgow and Clyde Valley were identified using a GIS mapping assessment. This was based on the approach originally developed for flood risk management in the River Parrett Catchment in Somerset (Nisbet & Broadmeadow, 2003) and subsequently applied to other parts of England (Broadmeadow & Nisbet, 2010a & b). It has since been extended to incorporate the benefits of woodland for reducing diffuse water pollution (Broadmeadow & Nisbet, 2010c; Broadmeadow & Nisbet, 2011) and further developed in recent applications to the Environment Agency's Midlands (Broadmeadow *et al*., 2012) and Yorkshire and North East Regions (Broadmeadow *et al*., 2013a) in England, and to the Tay Priority catchment in Scotland (Broadmeadow *et al*. (2013b).

The current project draws heavily on spatial datasets prepared by SEPA under their FRM and WFD programmes. It also uses modelled datasets of pollution loss to water derived from the Diffuse Pollution Screening Tool developed for SEPA by ADAS, JHI and HR Wallingford (SNIFFER, 2006).

4.2 Identification of constraints and sensitivities to woodland creation

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

- Urban areas, including villages, towns and cities
- Roads

- Railway infrastructure
- Scheduled Ancient Monuments
- National Grid gas pipelines
- National Grid overhead cables
- Open water
- Existing woodland
- Deep peat (>50 cm depth)

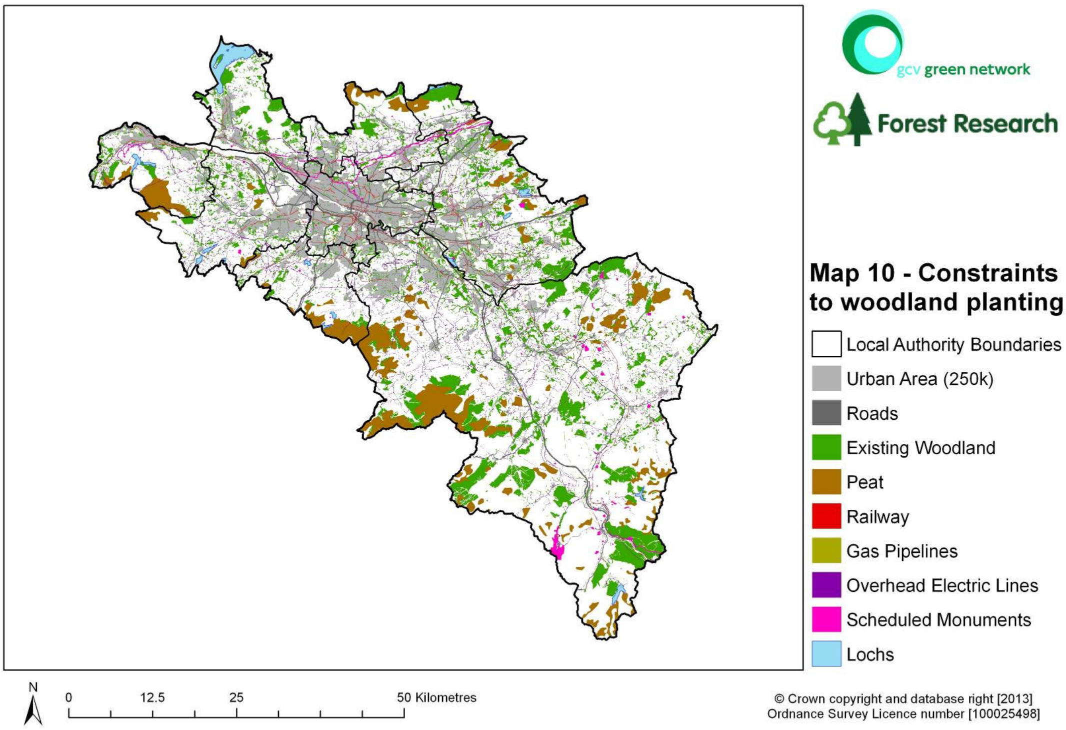
The combined dataset was used to remove areas that would be unsuitable for significant woodland planting (Map 10). Scheduled Ancient Monuments were protected by adding a fixed buffer (30 m), as recommended by the Forestry Commission's Forests and Historic Environment Guidelines (FC, 2011a). Wider buffer zones may be required to preserve the setting of a particular scheduled monument, which would be determined during specific site assessments. Deep peat soils were included as a constraint to reflect potential issues over the impact of planting on soil carbon stocks, depending on the nature of planting and woodland management.

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

- Floodplain buffer around urban centres and along roads
- Sites of proposed windfarms
- Ministry of Defence land
- RAMSAR sites
- SAC
- SPA
- SSSI
- National Nature Reserves
- RSPB Reserves
- Battlefields
- National Parks
- Agricultural Land Class 3.1
- Land above the natural tree line (>500 m AOD)
- Undesignated BAP Habitats (e.g. Wetlands, Upland Heath & Moor, and Blanket Bog)

The above features were combined to form a single GIS layer, showing where woodland creation would be possible providing the scheme was appropriately designed to protect and enhance the value of the existing habitat, landscape or assets on the site (Map 11). Most of the sensitivities are self-explanatory and well defined by formal designated boundaries.

The selection of others is explained below, particularly those that required some processing, such as the floodplain buffers.



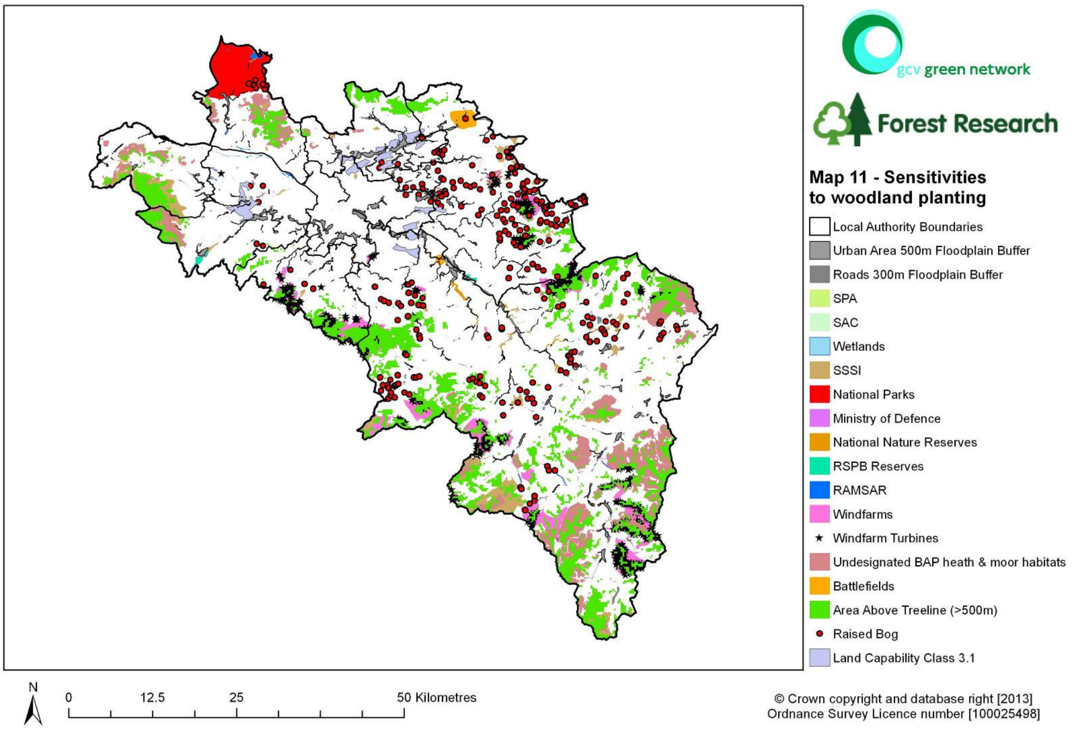
It was thought appropriate to include a buffer around urban areas and roads (railways were excluded on the basis that they were expected to be embanked and therefore less at risk) within or adjacent to the floodplain. This was in view of the potential sensitivity of these assets to the backing-up of floodwaters upstream of any planted floodplain woodland, or the blockage of downstream culverts or bridges by the washout of woody debris. The buffer acts as a flag to check for these issues when a planting application is made; this may require reach-scale modelling of flood levels and an assessment of the vulnerability of local pinch points to blockage.

Uniform fixed width buffers were created, principally guided by the results of previous modelling work which showed the backwater effect to be largely confined to a distance of 300-400 m upstream. Consequently, a 500 m wide buffer was delineated around urban areas and a 300 m buffer along both sides of roads. It is important to note that an allowance has not been made for the protection of isolated buildings and farmsteads, which would need to be assessed on an individual site by site basis when an application is made.

There are several sensitivities which were not included in the combined dataset because the available spatial data did not define the location of the feature with sufficient precision. This includes land protected by existing or proposed flood defences as these features were only available as a point dataset. Such land should be considered as a sensitivity to reflect the reduced scope for woodland planting to mitigating downstream flooding (due to having little effect on flood conveyance). These areas would not normally be considered a priority for planting for FRM unless there were plans to remove or breach the flood defences to increase flood storage and promote interactions with any planted woodland. This factor will need to be taken into account at the local level when considering individual applications for woodland creation. The same applies to the planting of trees close to rivers where there may be a need to preserve access to maintain flood embankments or protect these from tree rooting and windblow.

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

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



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

Woodland can help alleviate flooding in three main ways:

- through the potentially high water use of trees increasing available soil water storage and reducing the generation and volume of flood water
- by the typically high infiltration rates of woodland soils reducing direct surface runoff and delaying the passage of water to streams;
- by the greater hydraulic roughness created by woodland vegetation acting to increase above ground flood water storage and delay the downstream passage of flood flows (Nisbet *et al*., 2011a).

These mechanisms are to a varying degrees location dependent and considered to be greatest where there is most contact between water and woodland, such as along runoff pathways and on floodplains. Consequently, the focus of mapping is to identify preferred locations where woodland planting is likely to be most effective. The catchment was divided into three zones for this purpose: floodplain, riparian and wider catchment.

4.3.1 Floodplain

Planting within floodplains is thought to offer the greatest potential for downstream flood mitigation and therefore the first step was to define the extent of the floodplain where woodland could interact with flood flows. SEPA's indicative floodplain maps were selected for this purpose. Map 9 delineates the fluvial flood zones defined for flood events with a 1% (1:100) and a 0.1% (1:1000) probability of occurring in any year. The 1:1000 Flood Zone was selected as the boundary of the floodplain to better represent the potential area at risk from inundation if new woodland was effective at raising upstream flood levels due to a backwater effect.

The next step was to remove areas affected by the constraints defined in Section 4.2, resulting in a map showing areas within the Flood Zone that are potentially suitable for planting floodplain woodland for flood mitigation (Map 13). The efficacy of floodplain woodland in retarding flood flows and mitigating downstream flooding is dependant on the size of the woodland in relation to the scale of the floodplain (Thomas and Nisbet, 2006). Clearly, woodland spanning the entire floodplain will generate a greater impact compared to an isolated, small block of woodland on one side or on the margin of the floodplain. However, modelling shows that it is not necessary to plant a continuous stretch of woodland either across the full width or an extended length of the floodplain to achieve a significant delay in flood flows; a series of smaller blocks spread out across the floodplain may be just as effective at flood attenuation, depending on location and overall extent (Nisbet and Thomas, 2008). Map 14 shows the distribution of small (<2 ha), medium (2-50 ha) and large (>50 ha) parcels of land with potential for planting floodplain woodland.

4.3.2 Riparian zone

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

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

4.3.3 Adjacent land

Woodland in the wider catchment can be most effective at reducing flood flows when targeted to soils that are prone to generating rapid runoff or the pathways along which water flows to streams. Such areas include naturally wet soils subject to seasonal waterlogging or surface ponding, and sensitive soils at risk of surface compaction and sealing. Following the removal of the listed constraints, the hydrological properties of soils and the susceptibility of soils to structural degradation by livestock poaching were assessed.

This drew on the following datasets:

- The Hydrology Of Soil Types (HOST) (Boorman *et al*., 1995)
- Standard Percentage Runoff (SPR) based on the HOST classification
- Poach Class based on the HOST classification

These are described below:

HOST: The HOST system was developed to classify soils according to their hydrological behaviour (Map 16; Table 1). HOST is a conceptual representation of the hydrological processes in the soil zone. All soil types (Soil Series) in the UK have been grouped into one of 29 hydrological response models or 'HOST classes'. Allocation to a HOST class is by a hierarchical classification. Soils are first allocated to one of three physical settings:

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

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

HOST Class	Soil Series	SPR %	Poach Class	Area (km^2)	% of Region	Physical Soil Description
4	448	2	1	8	0.25	Humus iron podzols
5	89, 99, 163, 164, 168, 196, 197, 198, 267, 516, 576, 579	16.4	1	208	6.15	Brown forest soils
6	49, 296, 341, 374, 418, 432, 447, 468, 490	34.4	2	67	1.99	Brown forest soils; humus Iron podzols with gleys
7	1	42	2	90	2.64	Free draining alluvial soils
12	3	60	5	51	1.52	Peat
13	337	15.5	3	15	0.45	Brown forest soils
14	233	36.6	3	20	0.59	Peaty gleys
15	55, 117, 153, 154, 155, 158, 218, 226, 228, 229, 230, 231, 234, 268, 299, 301, 302, 343, 344, 345, 347, 376, 377, 434, 435, 436, 449, 450, 451, 476, 477, 478	49.4	5	641	18.93	Peat, peaty gleys and podzols
16	413	29.2	2	2	0.04	Brown forest soils
17	53, 147, 150, 156, 161, 206, 221, 225, 227, 236, 352, 353, 472, 475, 602	29.8	2	330	9.73	Brown forest soils, subalipne soils, humus iron podzols
18	41, 169, 274, 304, 414, 444, 465,	46.7	2	134	3.96	Brown forest soils, some with gleying
19	151, 158, 223,	60	2	56	1.66	Brown forest

	474					soils, rankers, humus iron podzols
22	224	48.9	2	0	0.01	Rankers
24	39, 40, 47, 51, 148, 149, 171, 209, 210, 265, 266, 331, 338, 359, 360, 374, 415, 433, 445, 446, 466, 467, 473	39.1	4	955	28.19	Noncalcareous gleys, brown forest soils with gleys
26	48, 50, 219, 269, 270, 469, 470	56.7	5	40	1.18	Peaty gleys, podzols
29	4, 220	59.6	5	205	6.06	Peat, Peaty gleys

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

SPR: Calibrated values of SPR for each HOST class were derived from multiple regressions between the proportion of each response model within a number of UK river catchments and the SPR values derived from river gauging data. The SPR represents the percentage of rainfall that contributes to quick response runoff. HOST classes with a SPR >25% represent seasonally waterlogged and flashy soils that are likely to make an increasing contribution to the generation of flood flows (Map 17).

Poach class: 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 hydrological models. Harrod (1998) used HOST to classify the vulnerability of lowland grassland soils to poaching by livestock and this system was applied to the Glasgow and Clyde Valley (Map 18). Poaching leads to surface compaction and waterlogging, increasing the risk of rapid surface runoff.

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

Propensity of soils to generate rapid runoff	HOST - SPR	Sensitivity to structural degradation: Poach Risk Class
Low	L <25% L <25%	L – Slight to Moderate M - High
Medium	M >25% M >25% L <25%	L – Slight to Moderate M - High H – Very High to Extreme
High	M >25% H >50% H >50% H >50%	H – Very high to Extreme L – Slight to Moderate M - High H – Very High to Extreme

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

4.3.4 Prioritising areas for woodland creation to reduce flood risk

The following land was defined as priority areas for woodland planting to reduce flood risk: land comprising soils with a high propensity to generate rapid surface runoff (termed 'priority wider woodland'); riparian land abutting land with a high propensity for generating rapid surface runoff ('priority riparian woodland'); and floodplain land with a high propensity for generating rapid surface runoff ('priority floodplain woodland'). These areas are favoured either in view of their proximity to sources of flood generation of their ability to reduce the conveyance of flood flows downstream. However, it is important to note that this prioritisation should not be seen as a barrier to woodland planting on other land and there could be significant local opportunities for woodland creation to reduce downstream flood risk within the identified potential land, especially within the floodplain.

Map 20 shows the distribution of the priority areas for planting floodplain, riparian and wider woodland within the catchment. These are related to the location of Potential Vulnerable Areas in Map 21, where the risk of flooding is greatest.

It is important to note that in some locations planting could have the opposite outcome of increasing flood risk where the delaying effect of woodland synchronises, rather than desynchronises downstream flood peaks (Nisbet *et al*., 2011a). This is more likely to be a problem with planting in the lower reaches of catchments closer to assets at risk (Broadmeadow *et al*., 2013) and would need to be checked (possibly involving modelling) during the assessment of individual woodland planting applications.

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

The mapping of woodland opportunities to address diffuse pollution in the catchment was based on modelled assessments of pollution loads to watercourses from agricultural sources. Attention was confined to three diffuse pollutants with available data that studies have shown could be potentially reduced by woodland planting; these are phosphate, nitrate and sediment (Nisbet *et al.*, 2011a). Spatial data for modelled losses of these pollutants from agricultural land to watercourses were used to determine the distribution of pollutant sources in the catchment. This relied on the Diffuse Pollution Screening Tool developed for SEPA by ADAS, JHI and HR Wallingford (SNIFFER, 2006). The tool utilises a range of simple models informed by more complex models such as PSYCHIC (Phosphorus and Sediment Yield Characterisation in Catchments) and NIRAMS (Nitrogen Risk Assessment Model for Scotland) to provide estimates of pollutant pressures and annual loads delivered to waters on a 1 km^2 grid scale across Scotland. Diffuse pollutant loads are generated for individual pollutants for a range of land uses. The mapping work described below used the estimated pollutant loads associated with agricultural land use.

4.4.1 Phosphorus

Map 22 illustrates the annual modelled loss of phosphorus in kg/ha/y across the catchment derived from agricultural land use via surface runoff, drain flow and seepage to groundwater. Values were then regrouped into low, medium and high classes for the purpose of identifying preferred areas for woodland creation (Map 23). Thresholds of 0.5 kg P/ha/y and 1.0 kg P/ha/y were selected as class boundaries by relating these to WFD phosphate concentration standards.

4.4.2 Sediment

The distribution of annual total sediment loss in kg/ha/yr is illustrated in Map 24 and grouped by low, medium and high classes in Map 25 for the purpose of identifying preferred areas for woodland creation. Thresholds of 250 kg/ha/yr and 500 kg/ha/yr were selected for low-medium and medium-high class boundaries, respectively. A sediment delivery rate of 500 kg/ha/y was used by the Environment Agency to define river waterbodies in England at risk from diffuse sediment pollution in their initial catchment characterisation.

4.4.3 Nitrate

Map 26 shows the modelled nitrate loss from agricultural land in surface runoff and drain flow plus seepage to groundwaters, while Map 27 regroups the data into low, medium and high classes using class boundary thresholds of 5 kg N/ha/y and 10 kg N/ha/y, respectively. The component 1 km grid squares exerting the highest nitrate pollution pressure (>10 kg/ha/y) defined the preferred area for woodland creation to address diffuse agricultural nitrate pollution.

4.4.4 Multiple diffuse pollutants

Map 28 shows the distribution of modelled high sources of one, two or three diffuse pollutants in relation to failing river and loch waterbodies. Unfortunately, information was not available on the reasons for failure and so all failing waterbodies were considered to be at risk. Priority locations for woodland creation were defined as available land (minus constraints) forming a high source of at least one diffuse pollutant lying within a failing waterbody (Map 29).

4.4.5 Combined pressures

Map 30 shows the distribution of the priority areas for woodland creation for FRM in relation to those for reducing one or more diffuse pollutant pressures to surface waters. Opportunities for planting to benefit both are displayed in Map 31, along with mapped sensitivities.

5. Results

Calculated values for the extent and distribution of priority areas for woodland creation to help tackle downstream flooding and selected diffuse pollutant pressures are presented below to highlight key opportunities for woodland planting to benefit water in the Glasgow and Clyde Valley catchment.

5.1 Constraints to woodland creation

A total of 1,342 km^2 or nearly 40% of the catchment is excluded from woodland planting due to the constraints listed in Section 4.2 (Table 3). Urban infrastructure and the associated road and rail network represent the dominant constraints, affecting 17.5% of the catchment. Existing woodland cover (16.6%; predominantly conifer) and deep peat (7.4%) are the other main constraints. The constraints are reasonably well distributed throughout the catchment, with the urban area dominating in the north-western half and existing woodland and deep peat in the south-west (Map 9).

In terms of the fluvial floodplain, a total of 42 km^2 or 31% of the Flood Zone (area at risk from a 1 in 1000 year flood event) is excluded from woodland planting due to constraints, primarily urban and transport infrastructure (Table 3). Around 11% is covered by woodland, which is mainly broadleaved.

Constraints	Area km^2	%
Peat	251	7.4%
Existing Woodland	563	16.6%
Lochs	30	0.9%
Road and rail network	155	4.6%
Urban infrastructure	438	12.9%
Gas pipeline & Wayleaves under overhead electrical cable	79	2.3%
Scheduled Monuments	26	0.8%
Total area of all constraints for which spatial data are available: Catchment Floodplain	 1,342 42	 39.6% 31% of FP

Table 3 Constraints to woodland planting in the catchment (note that several of the features overlap)

5.2 Sensitivities to woodland creation

Some 967 km^2 or almost 29% of the Glasgow and Clyde Valley catchment is identified as potentially sensitive to woodland creation, which may restrict the scale and character of any planting (Table 4). Much of this is centred on the uplands (Map 11). The largest individual sensitivity is land above the treeline (>500 m AOD), affecting 12% of the catchment. Around 10% of land is subject to a national or international conservation designation, while another 8% comprises undesignated BAP habitats. Only 1% of the area involves arable agricultural land (Grade 3.1), most of which is located around the environs of Glasgow.

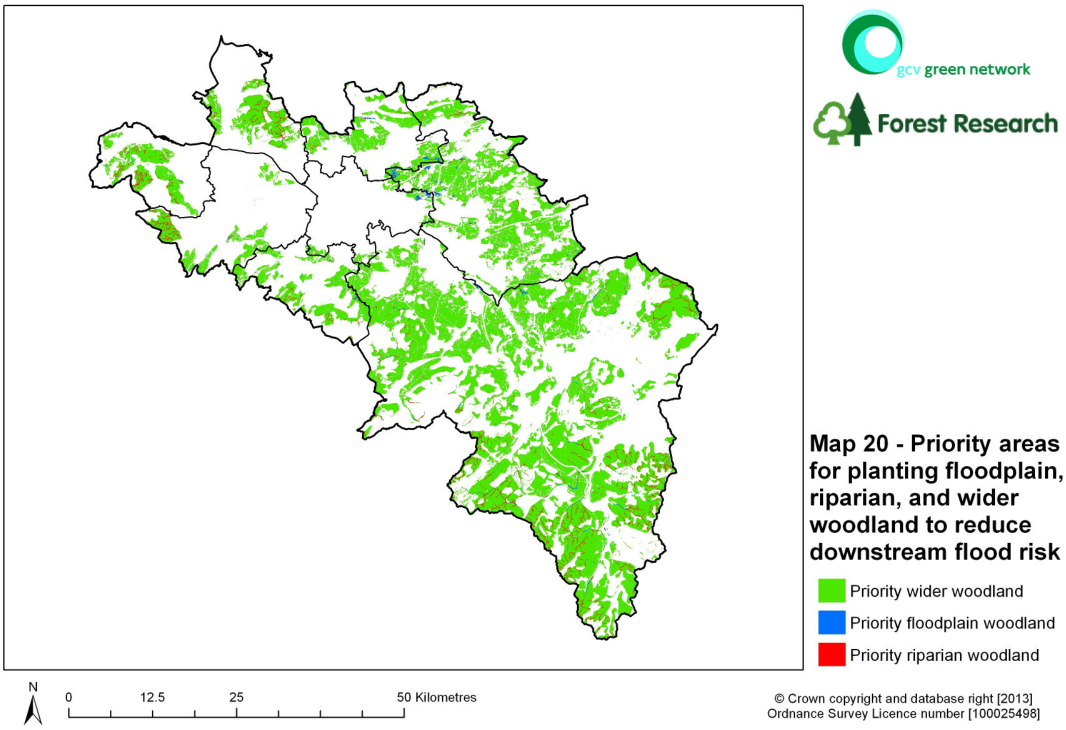
Nearly 85% of the floodplain is subject to sensitivities, the majority of which is due to the buffer zone applied to urban areas and roads. This indicates that most planting proposals within the floodplain may require detailed consideration of the impact of the backing-up of flood waters on local buildings and transport infrastructure, which is likely to influence the scale and nature of planting.

Sensitivities	Area km^2	%
International conservation designations: RAMSAR SPA SAC	Combined – 127 3 110 14	4% <1% 3.3% <1%
National conservation designations: SSSI NNR	 177 5	 5.2% <1%
Protected and culturally important landscapes: National Parks Battlefield	 57 10	 1.7% <1%
Grade 3.1 agricultural land	38	1.1%
Land above treeline	406	12%
Undesignated BAP Habitats: Wet heath and moor Dry Heath and moor Upland heath and moor Wetlands	 33 120 106 3	 1% 3.6% 3.1% <1%
Buffers for roads and urban areas in the floodplain.	121	3.6%
Area of all combined sensitivities for which spatial data are available: Catchment Floodplain	 967 115	 28.5% 84.8% of FP

Table 4 Sensitivities to woodland planting in the catchment (note that several of the features overlap)

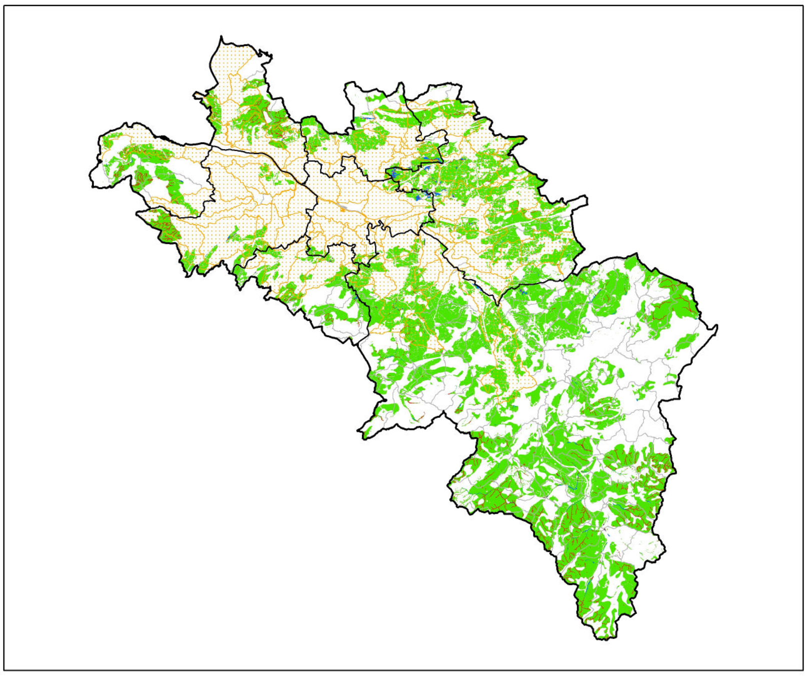
5.3 Opportunities for woodland creation to reduce downstream flood risk

A total of 1,893 km^2 or 56% of the Glasgow and Clyde Valley is identified as a priority area for woodland creation to reduce downstream flood risk (Map 20). This land is relatively evenly distributed across the catchment (excluding the urban areas), with the majority on higher ground comprising improved or acid grassland and dwarf shrub heath (Map 6).



Most of the priority land (63% or 1,198 km^2) involves wider woodland, targeting soils with a high propensity to generate rapid runoff or extreme/high vulnerability to livestock poaching (Maps 17-19). Around 36 km^2 comprises priority riparian woodland and 18 km^2 priority floodplain woodland, both of which reflect the distribution of watercourses draining priority wider woodland.

Map 21 compares the distribution of priority land with the Potentially Vulnerable Areas (PVA) identified by the National Flood Risk Assessment (SEPA, 2011a).



Map 21 - Comparison of priority areas for planting floodplain, riparian, and wider woodland in relation to Potential Vulnerable Areas to fluvial flooding

Priority wider woodland
Priority floodplain woodland
Priority riparian woodland
Potential Vulnerable Areas
Flood Management Units

N 0 12.5 25 50 Kilometres

Spatial data for the PVAs was not available for this project and instead the WFD RWB boundaries which equate to the PVAs were selected to define these. The catchment contains 69 areas at risk from flooding, which affect much of the urban area in the northern half of the Glasgow and Clyde Valley. Most of the priority land drains to the PVAs and therefore planting could directly contribute to protecting communities at greatest risk from future flooding.

A breakdown of priority land for planting within each of the main tributary sub-catchments in the Glasgow and Clyde Valley is provided in Table 5. Apart from the Upper Clyde, most of the sub-catchments are dominated by PVAs. The Upper Clyde and Dumbarton coastal sub-catchments have the largest proportion of priority land for planting (44% and 43% respectively) and the Glasgow Coastal the lowest (9%). The vast majority of the priority land comprises wider woodland, with both riparian and floodplain priority land each occupying <2% of the tributary catchments.

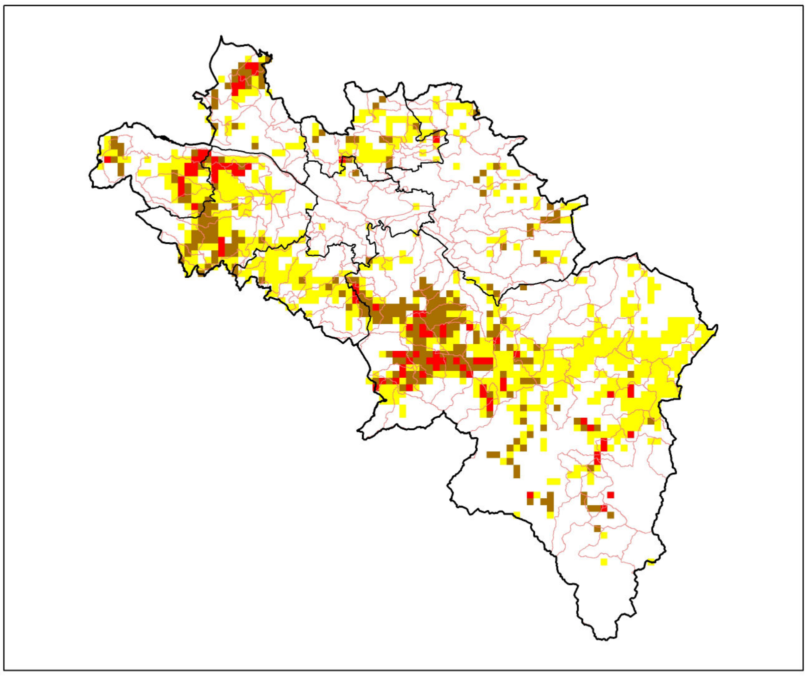
Catchment	Total Catchment Area (km^2)	Total Floodplain Area (km^2)	PWW (km^2)	% catchment	PRW (km^2)	% catchment	PFW (km^2)	% floodplain
Dumbarton Coastal	20.6	0.1	9.1	44.0	0.2	1.1	0.01	8.7
Inverclyde Coastal	76.3	2.5	22.5	29.6	1.6	2.1	0.2	6.9
River Leven	97.0	24.0	22.2	22.9	1.8	1.9	0.1	0.4
Black Cart Water	118.8	8.7	30.8	25.9	2.0	1.7	0.4	5.1
River Gryfe	127.0	5.8	21.9	17.3	1.3	1.0	0.3	4.8
Glasgow Coastal	218.9	7.0	19.3	8.8	1.1	0.5	0.1	0.9
White Cart Water	243.1	11.3	65.4	26.9	1.2	0.5	1.1	9.7
River Kelvin	337.9	24.2	118.4	35.0	2.2	0.6	5.2	21.3
River Clyde	1905.4	77.0	822.8	43.2	23.4	1.2	9.6	12.5
Boundary Catchments	225.4	5.7	65.5	29.1	1.4	0.6	0.6	10.2

Table 5 **Extent of priority areas for planting wider woodland (PWW), riparian woodland (PRW) and floodplain woodland (PFW) to reduce flood risk within the main tributary catchments in the Glasgow and Clyde Valley.**

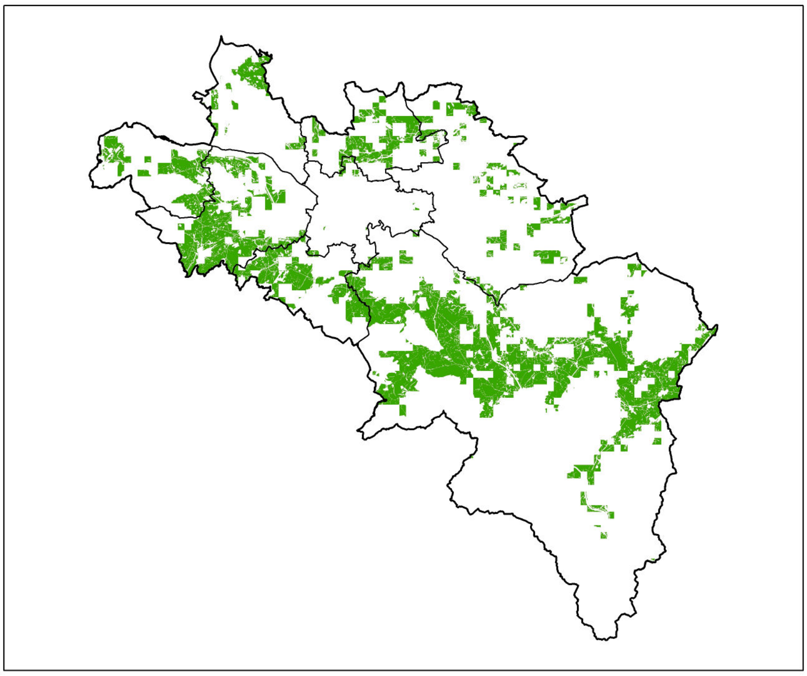
5.4 Opportunities for woodland creation to reduce diffuse pollution

A total of 880 km^2 or just over 20% of the Glasgow and Clyde Valley catchment comprises priority areas for woodland planting to reduce one or more diffuse pollutants (Table 6). Maps 22-27 show the distribution of predicted sources of diffuse pollution from phosphate, sediment and nitrate. Sources are similar for all three pollutants and tend to be greatest for the areas of improved grassland, arable and horticulture (on brown forest soils with and without gleying) that circle the Glasgow conurbation and extend up the Upper Clyde valley (Maps 4 & 6). Over 77% of the high pollutant sources are free from constraints and most (87%) is unaffected by sensitivities.

The identified priority areas present significant opportunities for woodland creation to reduce multiple diffuse pollutants, with a total of 183 km^2 (5.4% of catchment) of priority land able to address two diffuse pollutants and 54 km^2 (1.6% of catchment) all three (Table 6). These areas are mainly located within the River Leven and Loch Lomond, River Gryfe, Black Cart Water and western side of the upper River Clyde catchments (Maps 28 & 29).



Map 28 - Priority areas for woodland creation to reduce phosphorus, nitrate, and suspended sediment diffuse pollutants from agricultural sources



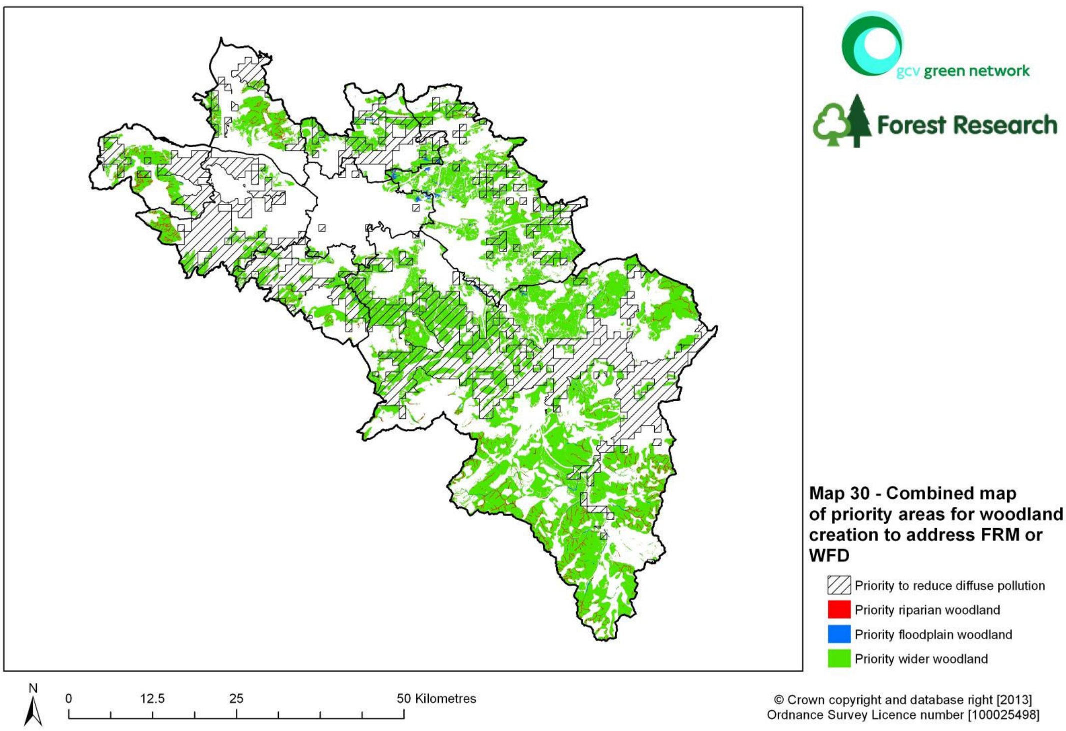
Map 29 - Priority areas for woodland creation to address multiple diffuse pollutants (phosphorus, nitrogen, and sediment)

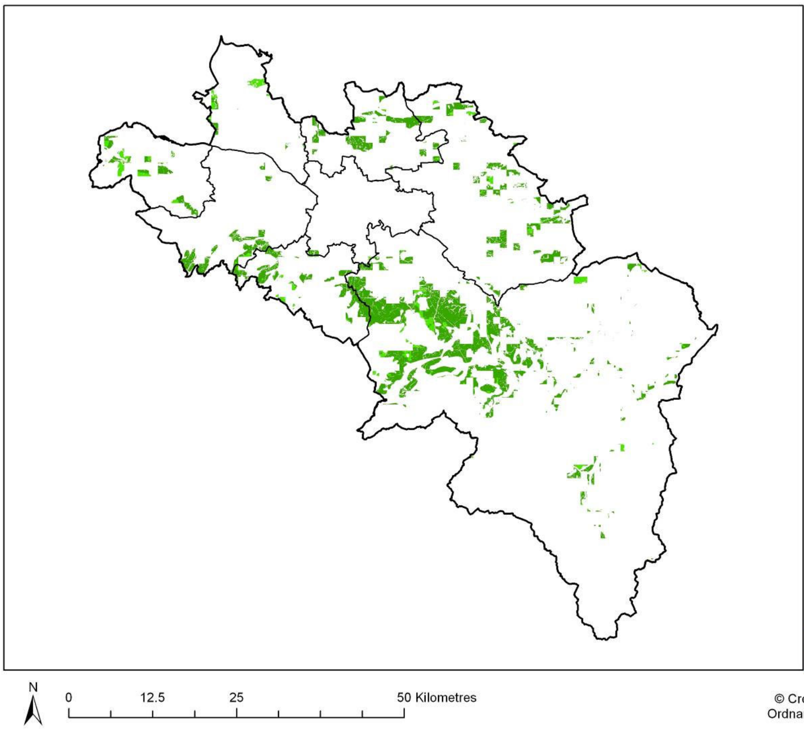
Number of diffuse pollutants	Total area of priority land for woodland creation (km^2) to reduce diffuse pollution (km^2), [% of Catchment]
1	443 [13.1%]
2	183 [5.4%]
3	54 [1.6%]
Total	681 [20.1%]

Table 6 Extent of priority land for planting to reduce one or more diffuse pollution pressures within the Glasgow and Clyde Valley catchment.

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

Map 30 compares the distribution of priority areas for planting to reduce flood risk with those for diffuse pollution, while Map 31 shows the area of overlap between the two. Opportunities for woodland creation to benefit both FRM and WFD are spread relatively thinly around the Glasgow conurbation, with the main concentration occurring in the northwestern corner of the upper River Clyde catchment and southeastern edge of the White Cart Water catchment. There are a total of 277 km^2 where planting could benefit FRM and all three diffuse pollutants. Sensitivities only affect 11% of the dual priority area for FRM and WFD.





Map 31 - Opportunities for woodland creation to address both FRM and WFD (one or more pollutants)

5.6 Consideration of opportunities in relation to existing projects and plans

There are a number of existing land management based studies within the Glasgow and Clyde Valley that are relevant to woodland creation and its role in helping to reduce flood risk. This includes the Upper Clyde Natural Flood Management Scoping study and the Gartloch and Gartcosh Hydrological study. The opportunity maps were applied to these to determine the scope for woodland creation to help meet study objectives, the results of which are described below.

5.6.1 Upper Clyde Natural Flood Management Scoping Study

This scoping study was undertaken in 2011 to assess the potential for using natural flood management (NFM) techniques in the Upper Clyde to reduce flood risk to downstream communities (AECOM, 2011b). A number of woodland options were considered, including restoring floodplain woodland, riparian planting and reintroducing large woody debris into watercourses. Sub-catchments were identified where these measures were thought to be suitable and an assessment made of their effectiveness based on hydrological modelling. Table 7 shows the list of selected options.

Option	Catchment	Description	Take Forward	Reason
2	Portrail Water	Gully woodland planting/introduction of large wooded debris for area between Nether Burn and Ever Burn.	No	Catchment too small – negligible impact
9	Duneaton Water	Floodplain/riparian planting for 3km reach upstream and downstream of Snar Water	Yes	
10	Medwin Water	Channel restoration plus floodplain planting of 4.26 km reach from South Medwin to Newholm Cottages.	Yes	Medwin peak almost coincident with Dalserf peak, so any reduction in Medwin peak likely to be effective at Dalserf.
11	Medwin Water	Floodplain planting for 1.25 km reach upstream of A721 on North Medwin	Yes	Medwin peak almost coincident with Dalserf peak so any reduction in Medwin peak likely to be effective at Dalserf. Relatively low cost & low maintenance
18	Douglas Water	Floodplain/riparian planting between town of Douglas and M74	Yes	Douglas Water contributes to rising limb of hydrograph at Dalserf (although need to be careful not to synchronise peaks)
20	Douglas Water	Large woody debris management on Glespin Burn and tributaries, which already flow through wooded areas.	No	Affects relatively small catchment area - effect downstream will be small
23	Nethan Water	Floodplain/riparian planting of 850 m reach between confluences of Pockmuir and Scots Burn	No	Catchment too small – negligible impact
25	River Clyde	Floodplain planting	No	High risk of debris causing blockages at bridges/culverts downstream

Table 7 List of woodland options identified for natural flood management in the Upper Clyde and outcomes of subsequent assessment

A number of options were carried forward for further analysis, some of which included opportunities for woodland planting (Options 9, 10, 11 & 18). Following site visits to assess suitability, only Option 9 progressed to the modelling stage. Two scenarios were investigated, involving the planting of 40 ha and 140 ha of floodplain woodland. These were predicted to reduce flood flows from 122 m^3s^{-1} to 118 m^3s^{-1} and 114 m^3s^{-1}, respectively, for a 1 in 200 year flood. This equates to a reduction of 2.7% and 5.9% in flood peak, respectively.

Map 32 shows the location of priority land for planting wider, riparian and floodplain woodland in the sub-catchment. There are 2,820 ha of priority land available for wider woodland, 180 ha for riparian woodland and 60 ha for floodplain woodland. The latter area falls short of the 140 ha modelled scenario but much of the priority land for riparian and wider woodland lies upstream and therefore planting here could help achieve a greater reduction in flood risk. There are no priority areas within the sub-catchment for planting to reduce diffuse pollution

5.6.2 Gartloch and Gartcosh Hydrological Study

This hydrological and hydraulic modelling study was carried out by AECOM (2011b) on behalf Glasgow City Council, North Lanarkshire Council, and the Glasgow and Clyde Valley Green Network Partnership for the purpose of presenting a Hydrological Study for the Gartloch and Gartcosh area to further inform the master planning process and assist with the sustainable development objectives of the Community Growth Areas (CGAs) in eastern Glasgow and at Gartcosh and Glenboig in North Lanarkshire.

The 24km^2 site is part of the long term vision for the Gartloch / Gartcosh area to create a wetland park of national significance provisionally named 'The Seven Lochs Wetland Park'. The challenge is to blend predicted community growth with the natural environment and fulfil the five underlying objectives of the Metropolitan Glasgow Strategic Drainage Plan (MGSDP) of:

1. Flood risk reduction
2. River water quality improvement
3. Enabling economic development
4. Habitat improvement
5. Integrated investment planning

The beneficial role that woodland can play in reducing flood risk and improving water quality has been highlighted earlier in this report and it is believed that woodland could play an important role in achieving the objectives of this project, therefore the Opportunity Mapping exercise has focused on this area to identify potential areas of new woodland planting to help reduce flood risk and improve water quality.

Map 33 shows the location of priority land for planting wider, riparian and floodplain woodland in the catchment to help reduce downstream flood risk. A total of 910 ha of priority land are available for wider woodland, 30 ha for riparian woodland and 170 ha for floodplain woodland. A small proportion of the priority wider woodland overlaps with priority land for reducing diffuse pollution, presenting opportunities for planting to benefit both FRM and WFD.

6. Conclusions

The Glasgow and Clyde Valley is impacted by a number of water issues, with almost 42% of the catchment classed as Potentially Vulnerable Areas to flooding (covering 69 flood management units). There are also 170 river waterbodies currently failing to meet the required Good Ecological Status (GES). A recent review of relevant research provides strong evidence of the ability of woodland creation to mitigate these pressures by reducing and delaying flood waters, limiting pollutant loadings and retaining diffuse pollutants. The aim of the study, commissioned by the GCV Green Network Partnership, was to provide GIS spatial datasets and maps to identify opportunities for woodland creation to reduce flood risk and diffuse pollution in the Glasgow and Clyde Valley catchment.

A wide range of spatial datasets were accessed from partners and used to generate a set of maps and supporting GIS shapefiles showing priority areas for planting. The results provide a strong basis for developing and refining regional strategies, initiatives and plans to deliver new woodlands where they can best contribute to flood risk management (FRM) and Water Framework Directive (WFD) targets, in addition to generating many other benefits for society. Woodland creation, however, is not without risks and care will be required in planting the right tree in the right place to avoid woodland acting as a pressure on the water environment.
There are extensive opportunities within the catchment for woodland creation to mitigate downstream flood risk and improve water quality, including:

- 1,893 km^2 (56% of the GCV catchment) of priority land for woodland planting to reduce downstream flood risk. 717 km^2 of the total priority area may be subject to restrictions due to sensitivities. Within this total area, 1,198 km^2 is available for wider woodland, 36 km^2 for riparian woodland and 18 km^2 for floodplain woodland planting.

- 889 km^2 (20% of catchment) of priority land in failing river waterbody catchments subject to one or more diffuse agricultural pollution pressures (phosphate, nitrogen and sediment)

- 277 km^2 (8% of catchment) of priority land with opportunities for woodland planting to reduce both flood risk and one or more diffuse agricultural pollution pressures; 89% (246 km^2) of this land is free from all sensitivities

Opportunities for woodland creation to reduce flood risk are relatively evenly distributed across the catchment (excluding urban areas), mainly comprising higher ground with improved or acid grassland and dwarf shrub heath. Most of this targets soils with a high propensity to generate rapid runoff or extreme/high vulnerability to livestock poaching. Nearly all of the priority land drains to Potential Vulnerable Areas and therefore planting could directly contribute to protecting those communities at greatest risk from future flooding. As a catchment percentage, the Upper Clyde and Dumbarton coastal sub-catchments have the largest proportion of priority land for planting (45%) and the Glasgow Coastal the lowest (9%).

In contrast, opportunities for planting to reduce diffuse pollution are concentrated on the lower-lying, better agricultural land surrounding the Glasgow conurbation and extending up the Clyde Valley. The greatest scope to tackle multiple diffuse pollutants lie within the River Leven and Loch Lomond, River Gryfe, Black Cart Water and western side of the upper River Clyde catchments. Opportunities for woodland creation to benefit both FRM and WFD are relatively thinly distributed around the Glasgow conurbation, with particular 'hot spots' in the northwestern corner of the upper River Clyde and southeastern edge of the White Cart Water catchments.

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

Achieving a sufficient level of planting to make a difference at the sub-catchment scale will require modifications to the Scottish Rural Development Programme to promote better targeting of woodland creation for water. This includes raising the value of woodland grants and supporting smaller planting schemes, the latter being especially important for tackling agricultural diffuse pollution pressures, which tend to be greatest on arable land. While land values and crop prices will greatly constrain the scope for woodland creation on such land, it is thought that small scale planting targeted to riparian buffers and along pollutant pathways could make a significant difference, while having a limited impact of agricultural incomes. There is a good case for better integrating available incentives to secure greater land use change, as well as exploring other funding options for woodland creation for water.

Finally, it is recommended that one or more case studies are established within the catchment to demonstrate and help communicate the value and benefits of woodland creation for water.

7. Recommendations

The following recommendations would help to secure the identified opportunities for woodland creation to deliver flood risk management and Water Framework Directive benefits:

1. Forestry Commission Scotland, SEPA and partner organisations use the maps and supporting datasets to help target future woodland creation within priority areas to make a difference at the sub-catchment scale. One or more regional dissemination events should be held to promote the findings of this work and to discuss how to pool available resources to achieve implementation.

2. The maps should continue to be refined as new monitoring data become available. In particular, there is significant scope for improved targeting of woodland creation to reduce agricultural diffuse pollutant pressures by incorporating information gained by SEPA from catchment surveys/walks.

3. There is a good case for updating the application of the diffuse pollution screening tool to capitalise on improvements in modelling (e.g. PSYCHIC). This would improve the accuracy of modelled data and aid the mapping of diffuse pollutant pressures at the field scale.

4. The vulnerability of affected properties and scope for upstream woodland creation to protect these should be examined for the Potential Vulnerable Areas. This should include an assessment of the potential for planting to increase flood risk by synchronising, rather than desynchronising downstream flood flows, and the vulnerability of any key 'pinch points' to blockage by woody debris. These assessments would help to refine the relatively large area of identified priority land for planting to reduce flood risk.

5. Further work is needed to raise the value of and improve the synergy between available incentives to secure land management change in desired locations. This includes working with partners to evaluate the full range of woodland ecosystem services and explore other sources of funding for investing in woodland creation.

6. The maps should be used to facilitate the establishment of one or more demonstration woodlands to monitor and quantify the benefits of woodland creation for water. This would provide a local evidence base and help communicate the need for and success of using woodland as part of a more integrated catchment-based approach to future water management.

8. Acknowledgements

We would like to thank Glasgow and Clyde Valley Green Network Partnership for funding this work and for providing a number of the spatial datasets used in the opportunity mapping. We would also like to acknowledge SEPA for providing several datasets, and ADAS, HR Wallingford and JHI for use of the modelled pollutant loading data from their Diffuse Pollution Screening Tool.

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