Forest Research

Valuing flood regulation services of existing forest cover to inform natural capital accounts

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Forest Research

November 2018

The Research Agency of the
Forestry Commission

Summary

This study uses the Joint UK Land Environment Simulator (JULES) model and expert judgement from floodplain modelling to estimate the additional volume of flood water potentially lost by woodland water use or retained by hydraulic roughness of floodplain woodland for existing GB woodland, compared to an alternative grass cover. The assessment was limited to 'Flood Risk Catchments (FRC)' defined as areas draining to downstream communities impacted by flooding. Calculated volumes are expressed in m^3/ha and considered to be equivalent to effective flood water storage that would have to be provided if the woodland cover was absent and replaced by managed grassland. The value of this woodland flood water storage was estimated based on the average cost per m^3 for providing the same volume by constructing and operating a flood storage reservoir. A central estimate of £12.7/m^3 at 2018 prices was obtained from seven reservoir storage schemes (of equivalent volume) and used to estimate the replacement cost of flood storage provided by existing woodland by country and for the public and private woodland estate (based on discounted costs applying the Treasury Green Book discount rates to costs incurred in future years). These replacement costs were annualised assuming a 100 year life span for the constructed reservoir storage and gave a central estimate of £0.42/m^3/yr.

Since the woodland water use effect varies during the year, especially in terms of below-ground water storage, separate values were calculated for summer and winter floods. For summer-type floods, the flood regulation service provided by existing GB woodland within FRC was estimated at £2.76 billion (£1,121/ha), compared to a much higher value of £10.26 billion (£4,162/ha) for winter-type floods. The equivalent annual average value was £6.51 billion (£2,642/ha). Expressing the flood regulation service as an annualised central estimate gave values of £92.7 million/yr for summer-type floods, £344.2 million/yr for winter-type floods and £218.5 million/yr as an annual average. These numbers are heavily caveated by a range of limitations of the approach, particularly by questions about the parameterisation of the JULES model. It is thought likely that the assessment underestimates the contribution of woodland to flood risk management, especially for conifer woodland. Nevertheless, the method is considered to improve on previous estimates and to provide conservative lower bound values for the flood regulation service provided by existing GB woodland. A number of recommendations are made to address highlighted weaknesses in the methodology.

1. Introduction

The objective of the project was to estimate the value of the flood regulation service provided by existing forest cover on a country basis to inform national capital accounts. It focuses on upstream catchments draining to communities at risk of downstream flooding and builds on our theoretical understanding of the different ways that trees can affect flood runoff. A mix of modelling and expert judgement was used to develop a range of values for the flood regulation service provided by the public and private woodland estates within England, Scotland and Wales.

2. Background

Forests have long been associated with an ability to reduce flood flows, although the issue is complex and continues to be explored. While there is strong process understanding of how trees and their management can affect the generation and conveyance of flood waters, there remains a lack of measurements to fully quantify effects at the catchment scale, particularly on large floods and within large river basins. This means that we continue to largely rely on modelling studies to estimate impacts.

Valuing the contribution that forest cover makes to downstream flood alleviation is very difficult given the multiple factors and associated uncertainties involved. Work is ongoing to provide estimates for specific sites and catchments but these are few in number and leave the much greater challenge of upscaling results to a region or country level. In principle, process data and models are available to support a larger scale assessment, but the challenge is constraining this potentially huge task within available resources and a sensible time scale.

This project adopts a relatively simple and limited approach for valuing the flood regulation service provided by existing forest cover in Great Britain (GB). The method is heavily caveated but improves on previous estimates (e.g. Ricardo, 2016). Forest cover is based on the Forestry Commission GB National Forest Inventory, which maps the extent of all woodland >0.5 ha, primarily using aerial photographs. Small woodlands, trees and hedges are therefore excluded and no consideration is given to forest age. Managed grassland is selected as the counterfactual land cover.

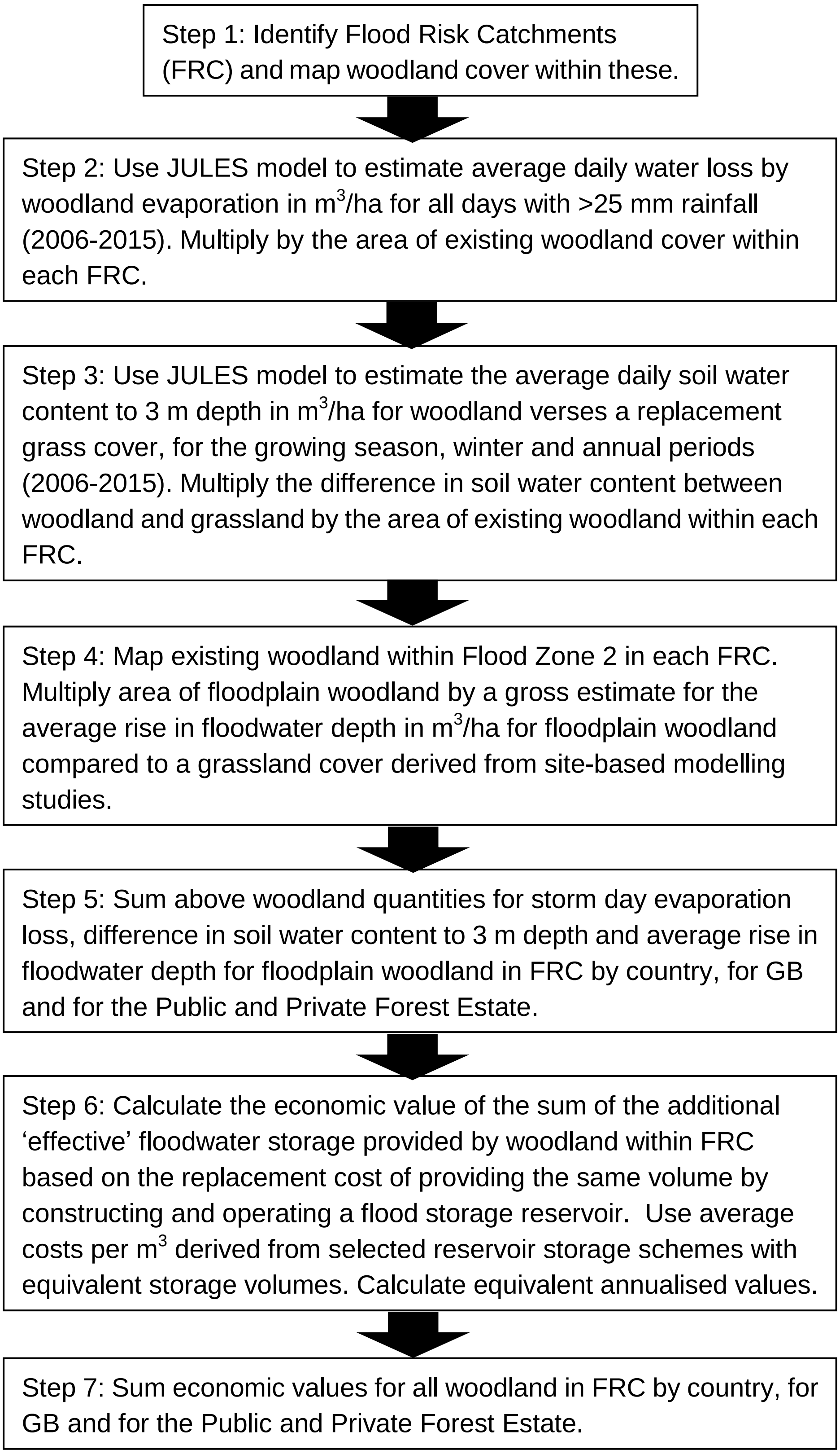
3. Approach

A flow chart showing the main steps involved in the methodology is displayed in Figure 1. A detailed description of the approach is provided below.

3.1 Identifying Flood Risk Catchments

The adopted approach recognises that flood risk varies across GB and some areas have few or no impacts. Consequently, efforts focused on catchments draining to known communities at risk from flooding (denoted as Flood Risk Catchments (FRC)). Forest cover is assumed to provide a flood risk benefit to all downstream affected communities and therefore the most downstream community at risk is used to define the outlet for

Figure 1 Flow chart displaying main steps in the methodology



Step 1: Identify Flood Risk Catchments (FRC) and map woodland cover within these.

Step 2: Use JULES model to estimate average daily water loss by woodland evaporation in m^3/ha for all days with >25 mm rainfall (2006-2015). Multiply by the area of existing woodland cover within each FRC.

Step 3: Use JULES model to estimate the average daily soil water content to 3 m depth in m^3/ha for woodland verses a replacement grass cover, for the growing season, winter and annual periods (2006-2015). Multiply the difference in soil water content between woodland and grassland by the area of existing woodland within each FRC.

Step 4: Map existing woodland within Flood Zone 2 in each FRC. Multiply area of floodplain woodland by a gross estimate for the average rise in floodwater depth in m^3/ha for floodplain woodland compared to a grassland cover derived from site-based modelling studies.

Step 5: Sum above woodland quantities for storm day evaporation loss, difference in soil water content to 3 m depth and average rise in floodwater depth for floodplain woodland in FRC by country, for GB and for the Public and Private Forest Estate.

Step 6: Calculate the economic value of the sum of the additional 'effective' floodwater storage provided by woodland within FRC based on the replacement cost of providing the same volume by constructing and operating a flood storage reservoir. Use average costs per m^3 derived from selected reservoir storage schemes with equivalent storage volumes. Calculate equivalent annualised values.

Step 7: Sum economic values for all woodland in FRC by country, for GB and for the Public and Private Forest Estate.

determining the upstream catchment. This means that in very large catchments such as the River Thames, calculations are based on all woodland above the lowest town or city, in this case London, since in principle the upstream flood storage generated will have some value by reducing the flood volume reaching the city, albeit by a small margin. The study concentrated on communities at risk from fluvial flooding due to the added difficulty of defining contributing areas for groundwater and surface water flooding (coastal flooding was also excluded).

For Scotland, the Scottish Environment Protection Agency coordinates efforts to tackle flooding through fourteen local Flood Risk Management Strategies. These identify areas of high risk for targeting investment, called Potentially Vulnerable Areas (PVA). FRC were defined as areas draining to one or more downstream PVA. There are currently 241 PVA in Scotland located in 170 catchments, totalling 45,503 km^2 in area. These contain 8,874 km^2 of woodland, comprising 1,408 km^2 of broadleaves and 4,474 km^2 of conifer. Another 2,993 km^2 is classed as ‘assumed woodland and young trees’.

A different strategy has been adopted by English and Welsh agencies and similar spatial data for potential vulnerable areas is not available. In 2011 Local Authorities in England and Wales prepared preliminary flood risk assessments, which identified locations with a significant risk of flooding. Cluster areas of high risk were defined by Defra and the Welsh Government as those with populations of >30,000 people in England and >5,000 people in Wales. Consequently, only large urban centres in England and South Wales were included in the final maps.

Use of cluster areas was thought to seriously underestimate the actual population at risk of flooding across England and Wales and therefore an alternative approach was sought. This drew on the Environment Agency’s Indicative Flood Map, which identifies areas at risk of fluvial flooding, and combined with the National Receptor Dataset (NRD), showing the location of properties, to identify assets at risk. A total of 1,012 FRC were identified with an area of 145,640 km^2, containing 12,759 km^2 of woodland cover (Figure 2). This comprised 8,005 km^2 of broadleaved woodland, 3,085 km^2 of conifer and 1,670 km^2 of assumed woodland and young trees.

In total, 82.6% of the GB land area fell within a FRC.

3.2 Quantifying the contribution of existing woodland to flood risk management

Four ways are recognised by which woodland can reduce flood flows: by the potentially high water use by trees; the high infiltration rates of woodland soils; the high hydraulic roughness exerted by trees, shrubs and large woody debris; and the ability of trees to protect the soil from erosion and interrupt the delivery of sediment via run-off to watercourses. Our ability to estimate the relative contribution of these varies between the individual processes, mainly reflecting the way that they act. Effects on the timing of run-off and river flows are very difficult to estimate due to the high dependency on catchment characteristics (particularly physiographic features, channel morphology and location of affected communities) and are not considered here. Instead, we focused on assessing how woodlands contribute to flood storage in terms of volume of water lost by water use or stored below or above ground. It proved too difficult to assess the contribution of the greater soil infiltration rates and reduced sediment delivery associated with woodland cover compared to other land uses and so these processes were excluded from the evaluation.

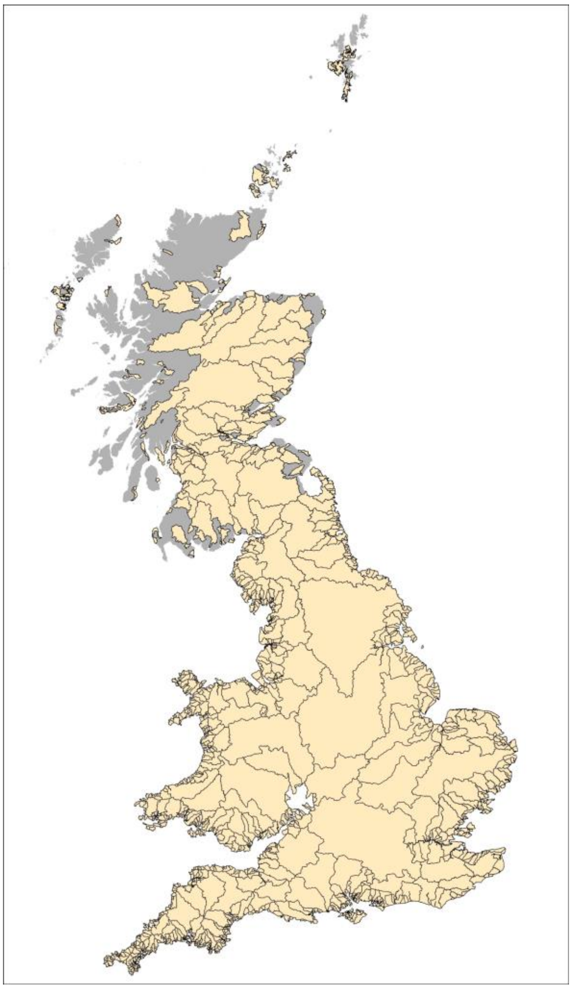


Figure 2 The distribution of FRC across GB delineated as individual areas of land bounded by black lines. FRC naturally become smaller closer to the coast. Areas lying outside FRC are shaded grey.

3.2.1 Volume of water lost by forest water use

The contribution of the higher water use of trees compared to shorter vegetation was estimated by woodland type (conifer and broadleaves) and converted to cubic metre (m^3) equivalent flood water storage per hectare. This comprised two components: the direct evaporation of water due to canopy interception during an actual flood event; and the additional potential available water storage within woodland soils created by the higher woodland water use over consecutive days leading up to a flood event.

The Joint UK Land Environment Simulator (JULES) model was used to estimate both of these components of water use compared to a baseline grass cover, which was selected as the dominant alternative land cover for existing woodland. JULES is a process based model that couples land surface processes to Met Office global circulation models (Best et al, 2011). It simulates fluxes of carbon, water, energy and momentum between the land surface and atmosphere to facilitate weather forecasting and climate change prediction. Different versions of the JULES model have been developed for investigating the impact of climate change on land carbon sinks, methane emissions from wetlands, atmospheric aerosols and tropospheric ozone.

For this study, Dr Alberto Martinez-de la Torre of CEH ran the latest version of the JULES model to compare the effect of woodland cover on water fluxes at a 1 km grid scale across GB. Ten years of observed met data (2006-2015) were used to generate daily average values for canopy interception, transpiration and soil water content for three land cover scenarios; complete GB coverage of grass, broadleaf woodland and conifers. The JULES model produced 2d gridded .csv files, which were used to create a 1 km grid raster of model output parameters which were then analysed spatially using ArcGIS.

3.2.1.1 Canopy interception

For canopy interception, we were mainly interested in evaporation losses on very wet days that were more likely to be associated with generating flood events. Consequently, the modelled data were processed to extract values for individual days with >25 mm rainfall, which was considered to be the minimum storm size likely to generate a flood event. Annual mean values for the interception loss for all days with >25 mm rainfall for each of the ten years was reported for each grid square. The 10 year annual mean values for each land cover scenario across GB are given in Table 1.

	Mean (mm)	**St.dev.**
Grass	0.603	+/- 0.106
Broadleaf	1.358	+/- 0.203
Conifer	1.414	+/- 0.221

Table 1 Modelled ten year annual mean daily interception loss for days with >25 mm rainfall across GB for each land cover scenario

The modelled values for broadleaf woodland were in line with plot studies but those for grass were higher and for conifer much lower than expected. Grass interception is usually taken as being close to zero due to the low canopy height (especially where grazed or cropped) and low aerodynamic roughness. However, we learned that the JULES model assumed a taller 3 m high cover for grass, explaining the predicted interception loss.

The very close agreement between the modelled broadleaved and conifer interception values was much more surprising, with process modelling indicating that conifers can potentially intercept as much as 7-8 mm of water per day on very wet days (Calder, 2003). On closer inspection, the reason for the smaller than expected difference appeared to be due to broadleaves being assigned a much higher Leaf Area Index (LAI) than conifers (9 vs 5), which is not in line with published data. Figure 3 illustrates the spatial variation in broadleaved interception loss across GB and as expected, shows losses to be generally greatest in the wetter and windier climate of the western coastal fringes.

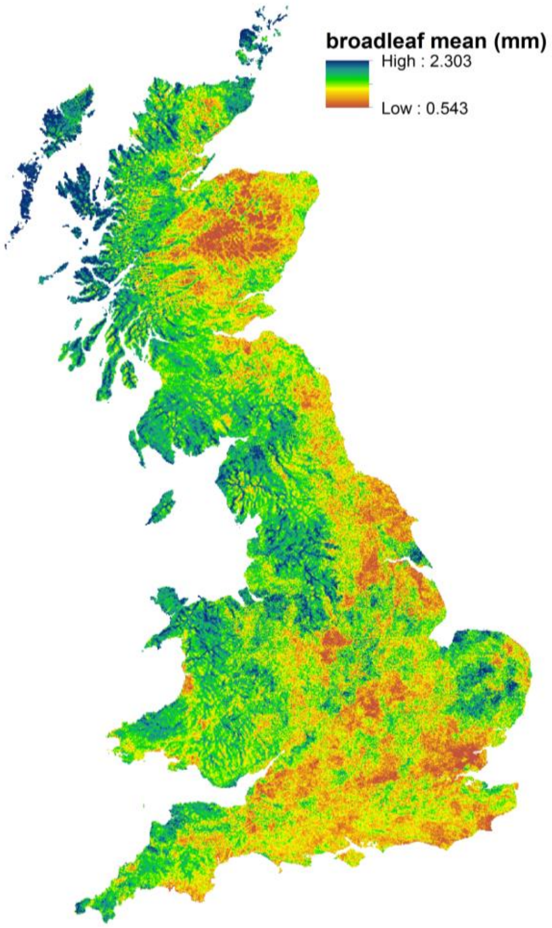


Figure 3 Spatial variation in mean daily interception loss (2005-2016) across GB for broadleaved woodland on days with >25 mm rainfall

Since there was no time to explore the differences and discuss changes to the established model with CEH and re-run this, we decided to discount the conifer data and treat all woodland as being broadleaved. It was also decided to treat grass interception losses as zero to accord with a more realistic baseline scenario of short grass.

The spatial analyst tools in ArcGIS were used to multiply the modelled ten year mean daily interception loss for days with >25mm rainfall for broadleaved cover for each 1 km (100 ha) grid square with the percentage total existing woodland cover (conifer and broadleaved) present to estimate the actual woodland interception loss per grid cell. Interception values were then summed across the grid squares within each individual FRC, including fractions of grid squares. The results (in mm and converted to m^3/ha based on 1 mm = 10 m^3/ha) for all FRC are summarised for each country and for cross-border FRC in Table 2.

	Wales	**Wales/ England**	**England**	**Scotland/ England**	**Scotland**	**GB Total**
Area (ha) of woodland in all FRC based on NFI (2016)						
ha	238,831	119,476	1,214,079	36,287	856,860	**2,465,533**
% of total woodland in region/ country	98.4%	100%	97.3%	100%	61.1%	**80.9%**
Equivalent flood storage (m^3) based on woodland canopy interception loss (for days with >25 mm rainfall) for all woodland within FRC (expressed in first and second rows as average values per ha of woodland in m^3 and mm, respectively)						
m^3/ha	11	12	11	8	9	**11**
mm	1.1	1.2	1.1	0.8	0.9	**1.1**
Total m^3	2,659,816	1,406,544	13,799,262	276,518	7,815,731	**25,957,871**

Table 2 Estimated flood water storage due to interception loss on days with >25 mm rainfall for woodland cover in FRC

3.2.1.2 Soil Water Storage

The accumulated woodland interception loss over consecutive wet days results in soils being generally drier under woodland compared to grass. This means that there is greater potential for woodland soils to store more flood water below ground before saturation results in rapid runoff and flood generation. The daily soil water contents calculated to 3 m depth for 2006-2015 by the JULES model were used to compare differences between broadleaf, conifer and grass covers (Figure 4).

Since conifers generally have a much greater water use than broadleaves, it is surprising that the modelled conifer soil water profile turned out to be the wettest of the three land covers, while that for broadleaved woodland was closer to what might have been expected for conifers based on our understanding of forest hydrology. These results can be explained by the models treatment of conifer vs broadleaved water use, including the selection of Leaf Area Index (see above) and leaf nitrogen concentration values (the latter are considered to be too low for conifers, which would exert a depressing effect on photosynthetic uptake and thereby on conifer transpiration rates and water use).

Of particular significance is the prediction that the difference in soil water content between grass and broadleaves is greatest during the winter compared to summer periods. This reflects the slower rate of rewetting in the autumn and carry over of drier conditions to the following spring, when grass water use begins earlier in the year and at a faster rate compared to woodland. These predictions are in line with the results of the TADPOLE study in Clipstone Forest in the East Midlands (Calder et al., 2003), although closer to the observations for Corsican pine than oak. At Clipstone, the soil water content under pine did not appear to return to the state of 'Field Capacity' in most winters, resulting in the carryover of a soil moisture deficit between years.

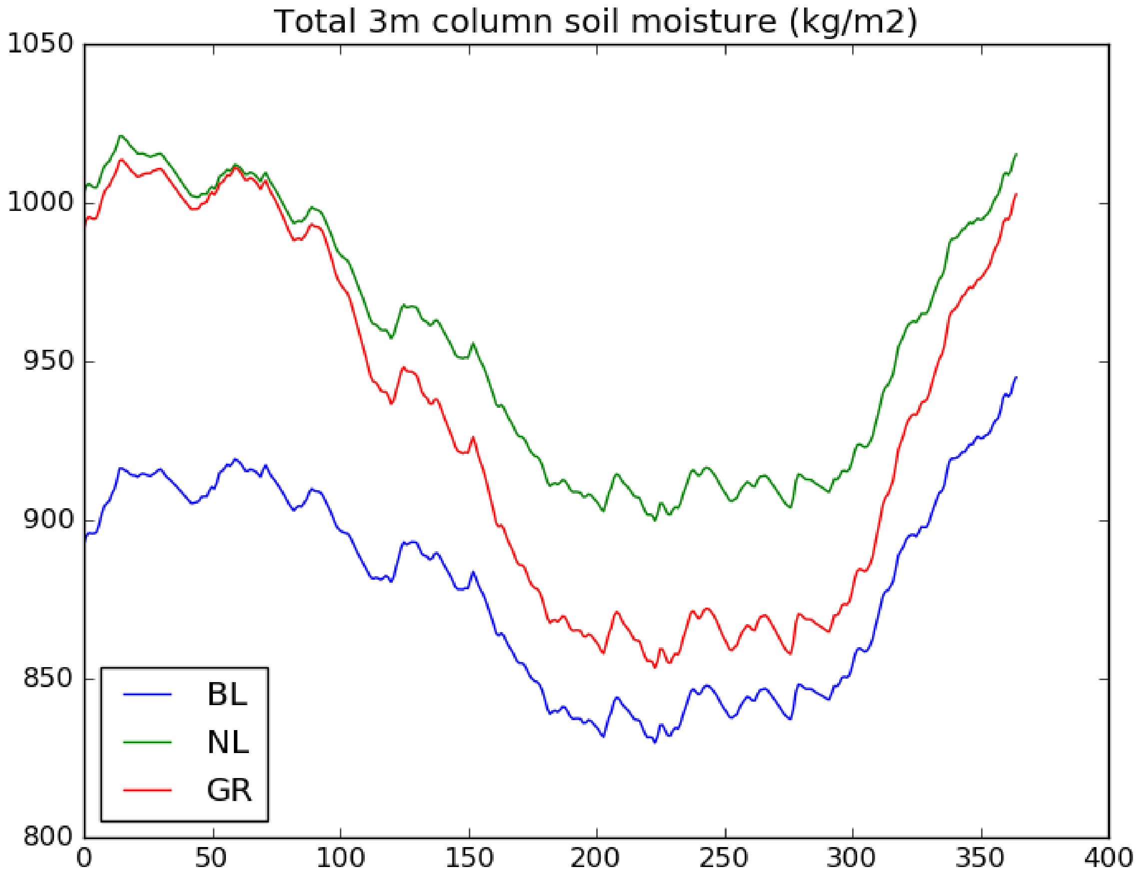


Figure 4 Seasonal difference and changes in daily GB mean soil water content (values on Y axis are total soil profile water content in kg/m^2 or mm) to 3 m depth under broadleaved woodland (BL), conifer (NL) and grass (GR); X axis displays Julian day for 2015

The JULES model predictions have important implications for flood risk management, indicating that while the greatest volume of potential belowground flood water storage is available in summer and early autumn, the relative difference in available storage between grass and woodland is much greater in late autumn to early spring, which is the period when most floods occur.

Since the JULES model results for conifer woodland depart from established understanding of woodland water use, once again it was decided to discount the conifer data and treat all woodland as broadleaved. It was not possible in the timescale to remove the influence of the unnaturally high interception loss for the modelled grass soil water content (as was done for the calculation of storm-day interception loss) and therefore these data were used as the basis of calculating the difference between grass and a woodland cover. Consequently, it is to be expected that the predicted greater available flood water storage values for woodland soils will be underestimated.

The spatial analyst tools in ArcGIS were used to multiply the average difference in soil water content between grass and woodland cover for the growing season (April to September) and winter (October to March) periods for each 1 km grid square with the area of existing woodland cover to estimate the value per grid cell. These values were then summed for each FRC and summarised by country and cross-border FRC in Table 3. Figure 5 illustrates the spatial variation in the difference in soil water content between grass and broadleaved woodland across GB and as expected, shows differences to be generally greatest in the drier and warmer climate of the east, southeast and the Midlands of England and Wales. Negative values occur for the growing season in a number of areas, particularly in Wales and SW England, implying that woodland soils are wetter than grass due to a lower summer water use.

	Wales	**Wales/ England**	**England**	**Scotland/ England**	**Scotland**	**GB Total**
Area (ha) of woodland in all FRC based on NFI (2016)						
ha	238,831	119,476	1,214,079	36,287	856,860	**2,465,533**
Equivalent additional average belowground flood water storage volume (m^3) for all woodland within FRC for the growing season compared to short grass (expressed as average values per ha of woodland in m^3 and mm in first and second rows)						
m^3/ha	7.81	46.04	57.1	55.25	38.37	**45.24**
mm	0.78	4.60	5.71	5.52	3.84	**4.52**
Total m^3	1,864,381	5,501,068	69,301,741	2,004,772	32,880,783	**111,552,746**
Equivalent additional average belowground flood water storage volume for all woodland within FRC during the winter season compared to short grass						
m^3/ha	210.45	350.11	374.19	114.05	178.79	**285.43**
mm	21.04	35.01	37.42	11.41	17.88	**28.54**
Total m^3	50,261,246	41,830,010	454,300,194	4,138,675	153,195,452	**703,725,577**

Table 3 Estimated additional below ground flood water storage due to woodland water use compared to grass based on existing woodland cover within FRC

3.2.2 Volume of water stored above ground due to forest hydraulic roughness

While all woodland generates hydraulic roughness due to the friction or drag created by the physical presence of trees and shrubs, ground flora, surface roots and deadwood (plus by associated micro-topography such as mounds and hollows), this only acts during periods of overland flow. Instances of overland flow are most common within the floodplain where waters exceed the capacity of watercourse channels and overtop river banks. Consequently, efforts to calculate the potential contribution of woodland hydraulic roughness to store more flood water focused on the area of floodplain woodland. The latter was defined as all existing woodland within Flood Zone 2, defined by the Environment Agency as land having >0.1% probability of fluvial flooding in any year, ignoring flood defences. The extent of woodland within Flood Zone 2 in each FRC was determined using ArcGIS.

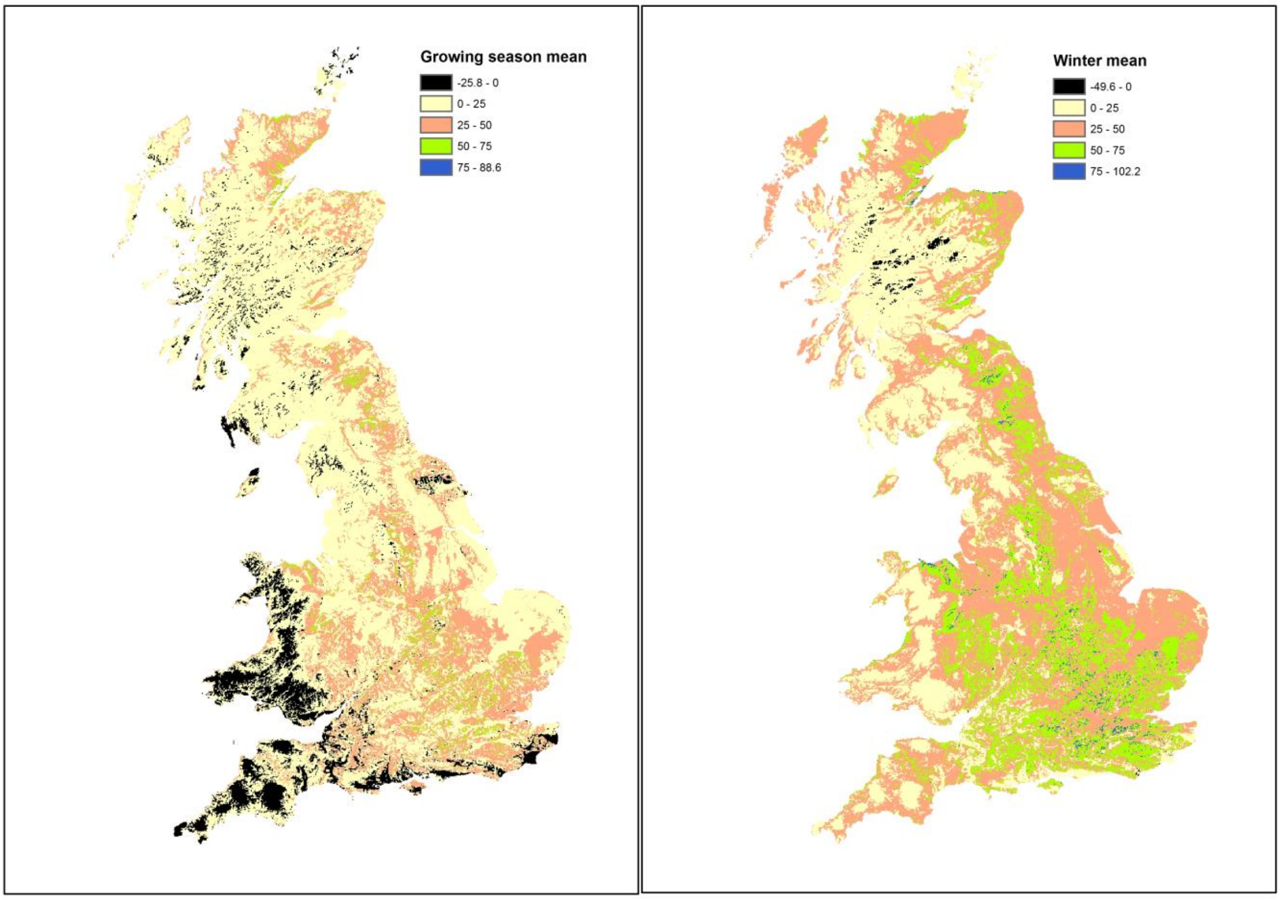


Figure 5 Spatial distribution of difference in soil water content (mm) to 3 m depth between grass and broadleaved woodland during a) growing season (April-September) and b) winter (October-March) periods (mean 2005-2016)

Estimation of the additional aboveground flood storage generated by the hydraulic roughness of floodplain woodland was based on the results of previous modelling studies. The effect of floodplain woodland on flood depth is very complex being site and event specific, with water depth varying both temporally and spatially across the width and length of the floodplain. Studies show that the friction or drag created by woodland raises flood water levels within and upstream of the woodland, with the extent of the backwater effect dictated by channel/floodplain gradient and nature of the 'choke' on flows.

An assessment of the hydraulic impact of woodland creation in the River Cary floodplain in Somerset (Thomas and Nisbet, 2006) predicted an increased flood depth compared to high grass of up to 270 mm for a large 100 year flood. This compared with a maximum rise of 190 mm for a floodplain woodland in the River Laver catchment at Ripon in North Yorkshire (Nisbet and Thomas, 2008), and a much larger increase of up to 1 m depth for an extremely dense cover of short rotation coppice on the floodplain of the River Dyfi in mid Wales. The average rise in water depth within and upstream of the simulated native floodplain woodland footprint for a 100 year flood event was used from the first two of these studies, which gave a value of 52 mm or 520 m^3/ha. This value was multiplied by the extent of floodplain woodland within Flood Zone 2 to estimate the potential additional flood water storage generated by woodland hydraulic roughness within each FRC. The results are presented by country in Table 4.

	Wales	**Wales/ England**	**England**	**Scotland/ England**	**Scotland**	**GB Total**
Area (ha) of floodplain woodland in all FRC based on NFI (2016)						
ha	21,507	5,430	102,111	627	25,675	**155,351**
Additional aboveground flood water storage (m^3) potentially created by floodplain woodland within FRC (expressed as average values per ha of floodplain woodland in first row)						
m^3/ha	520	520	520	520	520	**520**
Total m^3	11,183,615	2,823,776	53,097,968	326,040	13,350,917	**80,782,317**

Table 4 Estimated flood water storage generated by the hydraulic roughness of existing floodplain woodland in FRC

3.2.3 Scoping the volume of flood water stored above ground due to large woody dams within riparian woodland

Riparian woodland also generates hydraulic roughness and thereby increased flood storage, particularly through the effects of large woody dams (LWD) raising water levels within channels and pushing more water out of bank. Studies have measured volumes of water stored by individual dams to range from <1 m^3 to >100 m^3, depending on dam size, location and design/condition (Nisbet et al., 2015).

A history of river managers and land owners regularly removing large items of dead wood from watercourses for a variety of reasons, including concerns over washout of material leading to the blockage of downstream structures, has resulted in GB watercourses being greatly denuded in woody material and LWD. While efforts are underway in some locations to re-build LWD in streams or to facilitate their development, such activities remain highly localised. Consequently, the general absence of LWD in GB streams and uncertainty over the potential number/spacing of these precluded an assessment of their contribution to catchment flood storage. Instead a catchment-based approach was adopted to estimate the potential flood storage that could be provided in forest streams if LWD dams were allowed to form naturally or were constructed at appropriate locations and spacing. This drew on an existing case study that was part of the Strathard project in the Trossachs area of Scotland, involving the catchment of the Duchray Water, a tributary of the River Forth.

Airborne discrete-return LiDAR data were used to determine suitable locations for LWD formation in the catchment. A digital terrain model (DTM) was created from the LiDAR data by selecting the minimum elevation in the first return dataset within each 20 cm pixel (Suárez *et al.,* 2012). This provided high resolution elevation data for hydrological modelling, with Arc Hydro tools used to create a drainage network and channel slope for 37 individual sub-catchments (Figure 6). Stream reaches greater than 10 m long with channels between 1 - 5 m wide and slopes of <2° were identified as the most promising locations for LWD formation/construction. These mainly lay within twelve sub-catchments and the total length of suitable stream reaches and the number of potential LWD in each of these is tabulated in Table 5. Based on an average storage volume of 10 m^3 for 102 LWD measured at Pickering, this would give a total potential flood storage volume of 4,480 m^3 in the forested part of the catchment (36.3 km^2 forest area within ~70 km^2 catchment). This equates to only 1.2 m^3 per hectare of forest in this relatively steep catchment but nevertheless represents a potentially significant additional volume of flood water stored upstream.

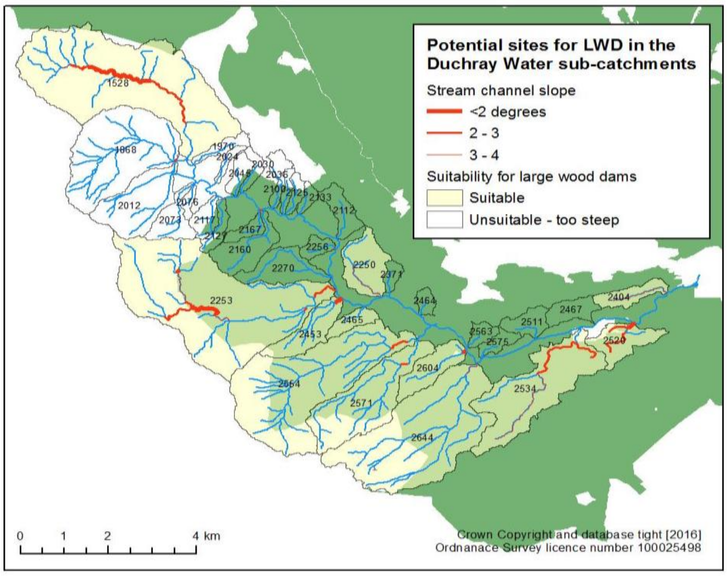


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Figure 6 Lidar derived stream sub-catchments with suitable channel slope, width and reach length for constructing LWD

Catchment	**Length (m) of stream channel suitable for LWD**	**Number of potential dams**	**Potential storage volume (m^3) based on 10 m^3/dam**
1528	4,140	61	**610**
2250	1,181	31	**310**
2253	5,157	60	**600**
2404	1,401	58	**580**
2453	213	4	**40**
2465	715	23	**230**
2520	1,645	64	**640**
2534	5,206	112	**1,120**
2554	2,117	21	**210**
2571	177	3	**30**
2604	101	5	**50**
2644	496	6	**60**
Total	22,540	448	**4,480**

Table 5 Extent of opportunities for LWD plus potential flood storage volumes in suitable sub-catchments of the Duchray Water

3.3 Estimating the economic contribution of existing woodland to flood risk management

The last step was to estimate the economic contribution of existing woodland to flood risk management. In principle, estimates of the value of associated reductions in flood risk could be based on a number of different approaches, including revealed preference methods to estimate the property price premiums for properties with reduced flood risks, and stated preference methods used to derive households' and businesses' willingness to pay to avoid flood damages. However, due to the lack of estimates from previous valuation studies (as well as resource constraints that precluded carrying out a primary valuation study here) a simple cost-based approach was adopted.

The approach does not estimate damage and other costs avoided as has been done elsewhere in catchment scale studies such as for the Slowing the Flow at Pickering project (e.g. Nisbet et al, 2015), which computed a central estimate of the annual value of additional flood storage in terms of avoided damage to property of £1.20/m^3/yr (within a range of £0.19/m^3/yr to £1.23/m^3/yr). Estimating avoided damage costs would have required catchment-scale modelling of the flood storage impacts on the properties at risk of flooding, with such analysis beyond the resources available for this study.

Instead, the economic contribution was estimated using an indicative replacement cost approach, based on the cost of the alternative of constructing a reservoir to provide an equivalent amount of flood storage if the woodland was not present. The calculation drew on published figures for a number of constructed flood storage schemes reviewed by JBA Consulting for the Environment Agency (Keating et al., 2015). A total of 16 construction projects were reviewed giving capital costs expressed in £/m^3 stored (adjusted for inflation to 2010). As expected, there was a reasonably strong negative relationship between cost/m^3 and reservoir size, with large schemes (>1m m^3) costing <£2/m^3 and the smallest one (312 m^3) £417/m^3.

It was decided to narrow the range of costs by taking into account the average size of the flood storage volume provided by existing woodland within FRC. Based on the calculated mean storage volume of 184.5k m^3 for the growing season and 689.9k m^3 for the winter period, only those reservoir construction projects that ranged in size from 100k m^3 to 1m m^3 were selected. This left six schemes to which was added the more recent flood storage reservoir constructed as part of the Slowing the Flow at Pickering project. The resulting seven schemes gave capital costs ranging from £1.9/m^3 to £23.2/m^3 and a mean of £8.5/m^3 based on 2010 prices.

A number of additional costs were then added to reflect initial procurement, enabling works, general maintenance, monitoring and inspection associated with reservoir safety. Estimates were based on Keating et al. (2015) and assumed:

- an average £1.0/m^3 (range of £0.5 to £1.50/m^3) for land purchase or rental/agreements
- an average of 15% (range of 10% to 24%) of the scheme capital cost for enabling works (planning, permissions and design)
- an average 3% (range of 1% to 5%) of the scheme capital cost for general maintenance over a 100 year life time
- and an average discounted cost of £60.1k per scheme (range £49.9k to £68.4k at 2010 prices) for statutory inspections and the required Flood Plan (made up of £2k/inspection (range of £1.5k to £2.5k/inspection) for a minimum eleven inspections over 100 years by an inspecting engineer, £750/yr (range of £500 to £1k/yr) for annual inspections by a supervising engineer and £2.6k plus £940/yr for preparation of the Flood Plan plus annual updates).

Costs were converted to £/m^3 and are summarised in Table 6. Adopting the lowest £/m^3 estimate for the seven schemes for the 'low estimate', the mean £/m^3 for the 'central estimate' and the highest £/m^3 estimate for the seven schemes for the 'high estimate' and reflating to 2018 prices, generated revised total cost estimates ranging from £3.02/m^3 to £35.59/m^3 and a central estimate of £12.66/m^3. Lastly, the annual mean equivalent costs were estimated based on an assumed 100 year life span for constructed reservoir storage to give a range of £0.10/m^3/yr to £1.19/m^3/yr and a central estimate of £0.42/m^3/yr at 2018 prices. These values were up-scaled using the calculated flood storage volumes generated by existing woodland across GB.

Flood storage scheme	**Capital cost for construction**	**Land purchase or rental**	**Enabling cost**	**General maintenance**	**Statutory inspections and Plan**	**Total cost £/m^3**
Pickering	15.5	1.0	2.3	0.14	0.50	**19.5**
Harberton	2.9	1.0	0.44	0.03	0.40	**4.8**
Weedon	1.9	1.0	0.29	0.02	0.07	**3.3**
Bruton	5.5	1.0	0.83	0.05	0.12	**7.5**
Cobbins	7.9	1.0	1.2	0.07	0.08	**10.2**
Kersal	23.2	1.0	3.5	0.21	0.09	**28.0**
Unnamed	2.7	1.0	0.41	0.02	0.60	**4.7**

Table 6. Costs for selected flood storage reservoirs over a 100 year life span expressed as £/m^3 water stored (central estimates at 2010 prices)

4. Results

The flood storage volumes (m^3) generated by the water use and hydraulic roughness calculations (excluding the contribution of riparian woodland and LWD) are summed for each FRC and then totalled for all FRC within individual countries and then for GB in Table 7. Values are also broken down by the public and private woodland estate (Table 8). These are then multiplied by the range of published costs/m^3 for providing an equivalent volume of flood storage by constructing flood storage reservoirs. Central estimates of the replacement cost for the flood regulation service provided by existing woodland by country and the public vs private woodland estate are presented in Table 9. These values reflect the replacement costs for providing equivalent volume of flood water storage over 100 years and are converted to annualised values in Table 10, reflecting the mean annual discounted cost of providing equivalent flood water storage.

Of the assessed woodland processes of forest water use (canopy interception and soil water storage) and floodplain hydraulic roughness, the average interception loss for days with >25 mm rainfall is the smallest at 1.05 mm and therefore makes a relatively minor contribution to the overall potential flood storage volume provided by existing GB woodland (~2-5%; Table 7). The accumulated interception loss during the year resulting in drier soils/greater available soil water storage beneath woodland exerts the largest influence, providing an average of 4.5 mm additional belowground flood water storage for flood events between April and September and 28.5 mm from October to March (amounting to 74-77% of the total additional woodland flood water storage). This is less than the potential 52 mm aboveground flood water stored by the hydraulic roughness created by floodplain woodland, however the latter effect is highly constrained by the relatively small spatial footprint of floodplain woodland within FRC (averaging 3.3 mm per ha for all woodland).

ALL WOODLAND	**Wales**	**Wales/ England**	**England**	**Scotland / England**	**Scotland**	**GB Total**
Woodland area (ha)	238,831	119,476	1,214,079	36,287	856,860	**2,465,533**
Floodplain woodland area (ha)	21,507	5,430	102,111	627	25,675	**155,351**
Canopy interception (days >25 mm rainfall)						
m^3/ha	11.1	11.8	11.4	7.6	9.1	**10.5**
mm	1.11	1.18	1.14	0.76	0.91	**1.05**
Total m^3	2,659,816	1,406,544	13,799,262	276,518	7,815,731	**25,957,871**
Additional woodland soil water storage capacity – growing season						
m^3/ha	7.8	46.0	57.1	55.2	38.4	**45.2**
mm	0.78	4.60	5.71	5.52	3.84	**4.52**
Total m^3	1,864,381	5,501,068	69,301,741	2,004,772	32,880,783	**111,552,746**
Additional woodland soil water storage capacity – winter						
m^3/ha	210.4	350.1	374.2	114.1	178.8	**285.4**
mm	21.04	35.01	37.42	11.41	17.88	**28.54**
Total m^3	50,261,246	41,830,010	454,300,194	4,138,675	153,195,452	**703,725,577**
Additional woodland soil water storage capacity – annual average						
m^3/ha	109.1	198.1	215.7	84.7	108.6	**165.3**
mm	10.91	19.81	21.57	8.47	10.86	**16.53**
Total m^3	26,062,814	23,665,539	261,800,968	3,071,724	93,038,118	**407,639,162**
Floodplain woodland storage						
m^3/ha	520	520	520	520	520	**520**
mm	52	52	52	52	52	**52**
Total m^3	11,183,615	2,823,776	53,097,968	326,040	13,350,917	**80,782,317**

Table 7 Estimated flood water storage due to woodland water use (split by canopy interception and soil water capacity for growing season and winter periods plus annual average) and floodplain woodland hydraulic roughness for GB woodland, split by country (including cross-border FRC)

PUBLIC FOREST	**Wales**	**Wales/ England**	**England**	**Scotland/ England**	**Scotland**	**GB Total**
Woodland (ha)	94,665	26,950	203,322	10,962	275,377	**611,277**
Floodplain woodland (ha)	6,933	298	6,925	90	2,884	**17,130**
Canopy interception (days >25 mm rainfall)						
m^3/ha	14.6	14.3	13.8	15.4	13.1	**14.1**
Total m^3	1,385,434	386,085	2,798,744	168,436	3,619,287	**8,357,986**
Woodland soil storage capacity – growing season						
m^3/ha	-1.4	127.2	152.9	152.2	114.9	**110.7**
Total m^3	-134,490	3,427,868	31,078,056	1,668,627	31,643,468	**67,683,529**
Woodland soil storage capacity – winter						
m^3/ha	200.4	337.2	354.9	278.6	224.3	**269.9**
Total m^3	18,971,118	9,086,422	72,159,911	3,054,500	61,762,295	**165,001,782**
Woodland soil storage capacity – annual average						
m^3/ha	99.5	232.2	253.9	215.4	169.6	**190.3**
Total m^3	9,418,314	6,257,145	51,618,984	2,361,564	46,702,882	**116,342,656**
Floodplain woodland storage						
Total m^3	3,604,931	155,119	3,600,904	46,828	1,499,890	**8,907,672**

PRIVATE FOREST	**Wales**	**Wales/ England**	**England**	**Scotland/ England**	**Scotland**	**GB Total**
Woodland(ha)	144,165	92,525	1,010,757	25,325	581,483	**1,854,256**
Floodplain woodland (ha)	14,574	5,132	95,187	537	22,790	**138,220**
Canopy interception (days >25 mm rainfall)						
m^3/ha	8.8	11.0	10.9	4.3	7.2	**9.4**
Total m^3	1,274,382	1,020,459	11,000,518	108,082	4,196,444	**17,599,885**
Woodland soil storage capacity – growing season						
m^3/ha	13.9	22.4	37.8	13.3	2.1	**23.7**
Total m^3	1,998,871	2,073,200	38,223,685	336,145	1,237,315	**43,869,216**
Woodland soil storage capacity – winter						
m^3/ha	217.0	353.9	378.1	43.2	157.2	**290.5**
Total m^3	31,290,127	32,743,588	382,140,283	1,116,640	91,433,157	**538,723,795**
Woodland soil storage capacity – annual average						
m^3/ha	115.5	188.2	207.9	28.2	79.9	**157.1**
Total m^3	16,644,499	17,408,394	210,181,984	726,393	46,335,236	**291,296,506**
Floodplain woodland storage						
Total m^3	7,578,683	2,668,658	49,497,064	279,212	11,851,027	**71,874,644**

Table 8 Estimated flood water storage due to woodland water use and floodplain woodland hydraulic roughness for GB woodland, split by country and the public and private estate

ALL FOREST	**Wales**	**Wales/Eng**	**England**	**Scotland/Eng**	**Scotland**	**GB**
Canopy interception	£33.7m	£17.8m	£174.7m	£3.5m	£99.0m	**£328.7m**
Soil storage – growing season	£23.6m	£69.7m	£877.5m	£25.4m	£416.4m	**£1,413m**
Soil storage – winter	£636.4m	£529.7m	£5,753m	£52.4m	£1,940m	**£8,911m**
Soil storage – annual	£330.0m	£299.7m	£3,315m	£38.9m	£1,178m	**£5,162m**
Floodplain storage	£141.6m	£35.8m	£672.4m	£4.1m	£169.1m	**£1,023m**
Total storage	£505.3m	£352.2m	£4,162m	£46.5m	£1,446m	**£6,513m**

PUBLIC FOREST	**Wales**	**Wal/Eng**	**England**	**Scot/Eng**	**Scotland**	**GB**
Canopy interception	£17.5m	£4.9m	£35.4m	£2.1m	£45.8m	**£105.8m**
Soil storage – growing season	-£1.7m	£43.4m	£393.5m	£21.1m	£400.7m	**£857.0m**
Soil storage – winter	£240.2m	£115.1m	£913.7m	£38.7m	£782.1m	**£2,089m**
Soil storage – annual	£119.3m	£79.2m	£653.6m	£29.9m	£591.4	**£1,473m**
Floodplain storage	£45.6m	£2.0m	£45.6m	£0.6m	£19.0m	**£112.8m**
Total storage	£182.5m	£86.1m	£734.7m	£32.6m	£656.2m	**£1,692m**

PRIVATE FOREST	**Wales**	**Wal/Eng**	**England**	**Scot/Eng**	**Scotland**	**GB**
Canopy interception	£16.1m	£12.9m	£139.3m	£1.4m	£53.1m	**£222.9m**
Soil storage – growing season	£25.3m	£26.3m	£484.0m	£4.3m	£15.7m	**£555.5m**
Soil storage – winter	£396.2m	£414.6m	£4,839m	£14.1m	£1,158m	**£6,822m**
Soil storage – annual	£210.8m	£220.4m	£2,661m	£9.2m	£586.7m	**£3,689m**
Floodplain storage	£96.0m	£33.8m	£626.8m	£3.5m	£150.1m	**£910.1m**
Total storage	£322.9m	£267.1m	£3,428m	£14.1m	£789.9m	**£4,822m**

Table 9 Estimated values for the flood regulation service provided by existing woodland by country and the public and private forest estate (central estimates at 2018 prices); Total storage = canopy interception + annual soil storage + floodplain storage.

ALL WOODLAND	Wales	Wal/Eng	England	Scotl/Engl	Scotland	GB
Canopy interception (days >25 mm rain)	£1.1m	£0.6m	£5.9m	£0.1m	£3.3m	**£11.0m**
Soil storage – growing season	£0.8m	£2.3m	£29.4m	£0.9m	£14.0m	**£47.4m**
Soil storage – winter	£21.3m	£17.8m	£193.0m	£1.8m	£65.1m	**£298.9m**
Soil storage – annual	£11.1m	£10.1m	£111.2m	£1.3m	£39.5m	**£173.1m**
Floodplain storage	£4.8m	£1.2m	£22.6m	£0.1m	£5.7m	**£34.3m**
Total storage	£16.9m	£11.8m	£139.6m	£1.6m	£48.5m	**£218.5m**

PUBLIC FOREST	Wales	Wal/Eng	England	Scotl/Engl	Scotland	GB
Canopy interception (days >25 mm rain)	£0.6m	£0.2m	£1.2m	£0.1m	£1.5m	**£3.5m**
Soil storage – growing season	-£0.1m	£1.5m	£13.2m	£0.7m	£13.4m	**£28.7m**
Soil storage – winter	£8.1m	£3.9m	£30.6m	£1.3m	£26.2m	**£70.1m**
Soil storage – annual	£4.0m	£2.7m	£21.9m	£1.0m	£19.8m	**£49.4m**
Floodplain storage	£1.5m	£0.1m	£1.5m	£0.0m	£0.6m	**£3.8m**
Total storage	£6.1m	£2.9m	£24.6m	£1.1m	£22.0m	**£56.7m**

PRIVATE FOREST	Wales	Wal/Eng	England	Scotl/Engl	Scotland	GB
Canopy interception (days >25 mm rainfall)	£0.5m	£0.4m	£4.7m	£0.0m	£1.8m	**£7.5m**
Soil storage – growing season	£0.8m	£0.9m	£16.2m	£0.1m	£0.5m	**£18.6m**
Soil storage – winter	£13.3m	£13.9m	£162.3m	£0.5m	£38.8m	**£228.8m**
Soil storage – annual	£7.1m	£7.4m	£89.3m	£0.3m	£19.7m	**£123.7m**
Floodplain storage	£3.2m	£1.1m	£21.0m	£0.1m	£5.0m	**£30.5m**
Total storage	£10.8m	£9.0m	£115.0m	£0.5m	£26.5m	**£161.7m**

Table 10 Estimated annualised values for the flood regulation service provided by existing woodland by country and the public and private forest estate (central estimates at 2018 prices) ; Total storage = canopy interception + annual soil storage + floodplain storage.

A simple aggregation of all three components of woodland flood water storage gives a total average volume for existing GB woodland of 8.8 mm/ha for the growing season and 32.9 mm/ha during the rest of the year. These amounts could be expected to exert a significant influence on flood generation by amounting to a 9-18% reduction in runoff for summer-type floods (generated by shorter periods of heavy rainfall of the order of 50-100 mm) and a 16-33% reduction for more prolonged winter-type floods (generated by 100-200 mm rainfall), based on 100% woodland catchment cover.

Differences in potential flood storage volumes between countries mainly reflect the different levels of woodland cover present in FRC and are in the order of England>Scotland>Wales for each storage component. The same generally applies to the public vs private woodland estate, with storage volumes for the latter exceeding the former by x3 to x4, reflecting the x3 greater woodland extent (Table 8). Relatively small negative storage volumes for the growing season occur for the public estate in Wales due to the modelled lower water use/wetter soil conditions compared to long grass.

Estimating the replacement cost of flood water storage by GB woodland based on the costs of planning, constructing, maintaining and inspecting reservoir storage (range of £3.0/m^3 to £35.6/m^3 and mean of £12.7/m^3) generates large numbers for the potential woodland contribution to flood risk management (Table 9). For summer-type floods, the combination of flood storage by interception loss, additional soil water storage and hydraulic roughness of floodplain woodland, gives a central estimate of £2.76 billion (a £billion = £1,000 million) and range of £0.66 billion to £7.77 billion for all GB woodland. This compares to a much larger storage volume and value for winter-type flood events, totalling £10.26 billion and ranging from £2.45 billion to £28.84 billion. The breakdown by country and public vs private forest estate reflects differences in woodland area, although with some variation in scaling factor due to climate and other factors (such as variation in amounts of floodplain woodland).

Converting the numbers to annualised values assuming a 100 year life span gives a central estimate of £92.7 million/yr and a range of £22.1 million to £260.6 million/yr for summer-type floods. The equivalent value for winter-type floods is £344.2 million/yr, ranging from £82.2 million to £967.5 million/yr.

Averaging the values per hectare of woodland generates mean estimates for GB floodplain woodland of £6.6k/ha (£1.6k/ha - £18.5k/ha) for flood storage created by hydraulic roughness; £133/ha (£32/ha - £375k/ha) for storm-day interception loss for all woodland; and £573/ha (£137/ha - £1,610/ha) for belowground soil water storage during the growing season, and £3.6k/ha (£863/ha - £10.2k/ha) for belowground soil water storage in the winter season at 2018 prices. Equivalent annualised values per hectare of woodland based on central estimates are £221/ha/yr for the contribution of hydraulic roughness by GB floodplain woodland, £4.5/ha/yr for storm-day interception loss for all woodland, and £19.2/ha/yr for belowground soil water storage during the growing season and £121.2/ha/yr for belowground soil water storage in the winter season.

Aggregating the above estimates to produce a total woodland contribution is not straightforward as the occurrence of floods is not evenly distributed throughout the year and for winter floods, are more likely to follow periods of prolonged rainfall resulting in less than average belowground water storage (with the opposite applying to flash summer floods). Nevertheless, it is helpful to derive annual average estimates for the flood regulation service of GB woodland for the 10-year study period, combining annual average below ground soil water storage with the contribution from average storm-day interception loss and hydraulic roughness from floodplain woodland. This gave a central estimate of £6.5billion (or £2,642/ha) based on the replacement cost of providing flood water storage at 2018 prices and £218.5million (£88.6/ha/yr) for the equivalent annualised value.

5. Areas for Development

It is important to note a number of weaknesses in the approach that would benefit from further work. These include:

- The definition of flood risk communities is not consistent between Scotland and England & Wales.

- The contribution of small woodlands, trees and hedges is excluded, while no account is taken of forest age (i.e. all forest cover is treated as established woodland). The former will underestimate the overall woodland flood regulation service but the latter will overestimate it, since recently felled and young forests will have a smaller water use compared to an established forest canopy.

- The selection of managed grassland rather than a neutral surface as the counterfactual land cover. This was influenced by the existing version of the JULES model which was set up for a grass cover, albeit a 3-m high cover (see below). Since grassland will provide a degree of flood regulation it may have been better and more in line with other accounting models to set the counterfactual to zero or to bare soil or even concrete. The present approach will therefore underestimate the woodland flood regulation service.

- The spatial resolution of soils data in the JULES model is not ideal as it relies on the open source, free to use FAO Harmonized World Soil Database. This means that UK soils were ascribed to four main soil types.

- The parameterization of conifer woodland in the JULES model does not agree with process understanding and generates questionable output. For this reason, the conifer scenario was considered not fit for purpose and all woodland treated as broadleaved. This is expected to significantly underestimate the conifer interception effect, which has been modelled as peaking at 6-8 mm on days with >25 mm rainfall, compared to the adopted JULES model prediction for GB broadleaved woodland interception of 1.05 mm on such days.

- There are also issues with the model's treatment of grass as having a relatively tall canopy (3 m high), which enhances grass interception loss, while some of the parameter values for broadleaved woodland need checking and revision (e.g. those for Leaf Area Index and leaf nitrogen content).

- The unreasonably high interception loss for the baseline (tall) grass cover could not be discounted from the modelled soil water contents and so will underestimate grass soil wetness and thus the difference with broadleaved woodland. However, there is a potential element of double accounting in the forest interception assessment since the storm-day interception loss could contribute to the available below-ground flood water storage, which has not been allowed for in the separate calculations.

- It was not feasible to assess the soil infiltration benefit of existing woodland or the contribution from reduced sediment delivery to watercourses.

- The October to March additional belowground flood water storage under woodland, which dominates the calculated values, is only partly renewable within individual winter periods. Once filled during a very wet period and first flood event of the autumn or winter, it will be slow to regenerate, especially under broadleaved woodland with its relatively low interception loss compared to conifer.

- The replacement costs are based on a limited number (seven) of reservoir storage schemes and some elements of the costs involved draw on general estimates rather than actual values, which are often difficult to obtain.

- The calculated flood storage volumes are not directly related to a specific level of flood protection or flood risk for vulnerable communities within FRC. There is a possibility that the number of FRC is underestimated due to the existing forest flood regulation service providing sufficient protection, although this is unlikely in view of the nature of flood risk.

- In the absence of evidence for each FRC confirming both that building a reservoir is the least cost alternative and that the flood protection benefits equal or exceed the construction plus associated costs, the replacement cost approach adopted to estimate the economic contribution of existing woodlands for flood risk mitigation remains tentative and exploratory. In most cases there is insufficient evidence available at present to determine whether the net present value of annualised benefits of the level of flood protection provided by existing woodlands would exceed the initial costs of building a reservoir. It might be expected that the benefits would exceed the costs in some, with costs exceeding the benefits in others. Were both effects taken into account, the net effect on the aggregate estimates of the economic contribution of existing woodlands to flood risk mitigation is difficult to determine.

Undertaking a benefit-cost test on a selected proportion of FRC would help to demonstrate whether the simple use of replacement costs is justified.

- The estimated replacement cost values for the flood regulation service draw on data from different time periods. In particular, the interception loss and soil water storage estimates use Met data for the ten-year period 2006-2015, while the forest cover data are based on the 2016 National Forest Inventory (NFI). In principle, some of these numbers could be updated on an annual basis (e.g. Met data, although would require re-running models) but with a lag of one to two years for release of Met data due to quality control, while the NFI data are only reviewed on a five-yearly basis. Since all countries support woodland creation the capital value of the flood regulation service can be expected to progressively rise over time, albeit by a relatively small degree in the short-medium term in relation to the extent of the existing woodland cover. The largest annual change is likely to be in terms of the contribution of below ground flood water storage as soil water content and the forest water use effect respond to the variation in seasonal rainfall and evaporation between years. This would generate significant 'noise' in an annual valuation record and thus updates would be better suited to a five or ten-year moving average aligned to NFI repeat surveys. The number of FRC is unlikely to change significantly over time since much of the country is already included. Flood damages can be expected to rise with population and economic growth, as well as with climate change, but the replacement cost methodology is unable to take this into account. As existing forests will continue to provide flood water retention benefits beyond the 100 year expected life span of storage reservoir, the replacement values estimated could be considered to be under-estimates of the associated natural capital value.

6. Summary

This study uses the Joint UK Land Environment Simulator (JULES) model and expert judgement from floodplain modelling to estimate the additional volume of flood water potentially lost by woodland water use or retained by hydraulic roughness of floodplain woodland for existing GB woodland, compared to an alternative grass cover. The assessment was limited to 'Flood Risk Catchments (FRC)' defined as areas draining to downstream communities impacted by flooding. Calculated volumes are expressed in m^3/ha and considered to be equivalent to effective flood water storage that would have to be provided if the woodland cover was absent and replaced by managed grassland. The value of this woodland flood water storage was estimated based on the average cost per m^3 for providing the same volume by constructing and operating a flood storage reservoir. A central estimate of £12.7/m^3 at 2018 prices was obtained from seven reservoir storage schemes (of equivalent volume) and used to estimate the replacement cost of flood storage provided by existing woodland by country and for the public and private woodland estate (based on discounted costs applying the Treasury Green Book discount rates to costs incurred in future years). These replacement costs were annualised assuming a 100 year life span for the constructed reservoir storage and gave a central estimate of £0.42/m^3/yr.

Since the woodland water use effect varies during the year, especially in terms of below-ground water storage, separate values were calculated for summer and winter floods. For summer-type floods, the flood regulation service provided by existing GB woodland within FRC was estimated at £2.76 billion (£1,121/ha), compared to a much higher value of £10.26 billion (£4,162/ha) for winter-type floods. The equivalent annual average value was £6.51 billion (£2,642/ha). Expressing the flood regulation service as an annualised central estimate gave values of £92.7 million/yr for summer-type floods, £344.2 million/yr for winter-type floods and £218.5 million/yr as an annual average. These numbers are heavily caveated by a range of limitations of the approach, particularly by questions about the parameterisation of the JULES model. It is thought likely that the assessment underestimates the contribution of woodland to flood risk management, especially for conifer woodland. Nevertheless, the method is considered to improve on previous estimates and to provide conservative lower bound values for the flood regulation service provided by existing GB woodland. A number of recommendations are made to address highlighted weaknesses in the methodology.

7. Recommendations

The following recommendations are made for improving the approach for valuing the flood regulation service provided by existing woodland:

- Meet with CEH to discuss issues over the parameterisation of woodland and grass within the JULES model and assist with revising numbers to better reflect process understanding.
- If changes are made, encourage CEH to re-run the JULES model and then amend flood storage numbers and calculated values accordingly.
- Seek more details on component costs of the selected flood storage reservoir schemes plus find additional schemes to extend the cost basis.
- Incorporate the contribution of small woodlands in each FRC to the valuation of the food regulation service and discount the reduced effect of recently felled and young forest.
- Attempt to extrapolate the estimated flood storage potentially provided by LWD in the Duchray Water case study to all existing woodland across GB.

- Explore ways of trying to incorporate soil infiltration and sediment delivery benefits of woodland into the valuation approach.
- Consider scope for extending valuation to include Northern Ireland.
- Undertake a benefit-cost test on a selected number of FRC to demonstrate whether the simple use of replacement costs is justified.

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9. Acknowledgements

We thank the Forestry Commission and Defra for funding this study. We also thank the Centre of Ecology and Hydrology and in particular Eleanor Blyth and Alberto Martinez-de la Torre for running the JULES model and help with processing the data.