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Valuing flood-regulation services for inclusion in the UK ecosystem accounts

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Executive summary

The value of natural capital is not currently measured or included in the UK's National Accounts. In 2011, the Natural Environment White Paper committed the Government to working with the Office for National Statistics (ONS) to measure the value of natural capital. Since then, ONS, in partnership with the Department for Environment, Food and Rural Affairs (Defra), has been developing innovative ecosystem accounts in working towards incorporating natural capital into UK Environmental Accounts by 2020.

A key element missing from Initial Assets and Service Accounts for "Freshwater Ecosystems" and for "Woodland" that have been produced previously are estimates of the value of flood-regulation services. In both cases, data issues were seen as insurmountable without further research and collation. Flood risk management is an important policy issue and providing ecosystem accounts associated with flood-regulation services could aid effective targeting of policies.

Ecosystems (e.g. woodland or wetland) can contribute to reducing and delaying fluvial-flood flows in a range of ways down a catchment, broadly through:

- Increasing soil infiltration rates, reducing run-off, and preventing soil erosion (and subsequent siltation of water courses downstream), particularly in upper catchments.
- Contributing to the creation of debris dams in small streams that desynchronise peak flows.
- Increasing hydraulic roughness spanning the full width of floodplains, most notably where floodplains narrow and flood flows would otherwise accelerate, thereby reducing potential damage downstream.
- Providing areas on the floodplain for flood storage.

It should be noted that these same mechanisms can in some instances also compound flood flows

ONS commissioned Ricardo Energy & Environment to undertake this study between March and October 2016 to:

- Scope and produce a methodology to value floodplains and produce initial floodplain ecosystem accounts that could be incorporated into the UK ecosystem accounts.

An initial scoping review identified that developing a value for floodplains remains intractable for reasons described in the Initial Freshwater Ecosystem Assets and Service Accounts. So instead, the study sought to:

- Review simple, pragmatic, transparent approaches that could be taken to valuing flood-regulation services for inclusion in the UK's ecosystem accounts.
- Agree an approach to develop and apply.

A rapid review of the literature and discussions with a number of key experts revealed a lack of quantitative research relevant to a UK context linking variations in the extent of land covers and land uses to differential reductions in peak flows at a catchment scale. The only research found to provide data in a relevant form related to woodland, despite the method paper for the initial Woodland Ecosystem Assets and Service Accounts noting that *"there are no physical data available for the flood protection service from woodland".* The research quantified the impact of changes in woodland cover in an upper catchment on changes in peak flows, so it was ultimately agreed with ONS that the study's objective should be to:

- Develop and apply methods for valuing flood-regulation services provided by woodland in upper water catchments for inclusion in the UK woodland accounts.

Notably, ONS stipulated that as the accounts were experimental, *"something 'roughly right' was more important than undue precision".*

The research on which the methods for this study were based related changes in woodland cover on grazed pasture in the upper reaches of Pontbren, a small 6-12km^2 catchment in Wales, to changes in mean peak flows. During consultations with key stakeholders, reservations were expressed about basing a national valuation of flood-regulation services on a study of just one catchment. However, no other studies were put forward that provided suitable data. Having consulted with the authors of the Pontbren studies, we interpreted their results to provide data points for mean percentage change in peak flow associated with 0% to 100% woodland cover in the upper catchment. The report presents two methods that used these data.

Method 1 comprised three steps, which calculated:

1. The contribution of woodland to flood regulation per catchment.
2. Flood-defence expenditure per catchment.
3. The notional value of woodland for flood regulation based on the replacement-cost method.

It was based on existing fluvial-flood expenditure that was already notionally reduced by the presence of woodland and, therefore, did not calculate the full replacement cost.

Method 2 built upon Method 1 but was based on the notional annual reduction in fluvial-flood expenditure that would otherwise be required to maintain the same level of fluvial-flood defence if woodland was absent from upper catchments, i.e. the full replacement cost.

Estimates of asset values for Great Britain arising from use of central figures from the Pontbren studies in Method 2 (£2,052.4 million to £2,180.3 million) are higher than those from Method 1 (£1,833.4 million to £1,952.5 million). It was not possible to implement Method 1 or 2 for Northern Ireland, as relevant datasets were not made freely available to the study by Northern Ireland's Department of Finance, and asset values were not, therefore, calculated for the UK.

The estimates presented here take no account of flood-regulation services delivered by other land covers and land uses other than woodland. In relation to woodland, the method does not take into account the value of flood-regulation services provided by woodland on floodplains, most notably where floodplains narrow and flood flows would otherwise accelerate, thereby reducing potential damage downstream. Nevertheless, existing floodplain woodland is relatively rare, so may not substantially increase the estimates here for the contribution of woodland as a whole. However, the values should be regarded as 'baseline', as they do not take into account likely changes in the extent of woodland cover or the extent of flood risk zones arising from climate change, and in that sense are likely to be highly conservative. Adoption of a replacement-cost approach is also likely to have led to lower estimates than one based on avoided damages, although the latter could be contentious and its validity for ecosystem accounts would require further consideration if in future it is feasible to implement.

ONS desired a simple and transparent method in order to aid understanding and enable emulation by companies and charities that wish to implement their own natural environment accounts. However, the simplicity of the approach here, its sole focus on use of data from the Pontbren studies, and a lack of data on fluvial-flood expenditure at a catchment scale leads to a wide range of uncertainties, which are highlighted in the report. Data and research gaps, caveats and assumptions, and possible future improvements to the method and future research needs are systematically identified in relation to each stage of the method.

Asset values for flood-regulation services have not previously been presented in the UK's ecosystem accounts. Those presented here are a first attempt to do so and provide a foundation on which to build. The report concludes by recommending that the asset values for GB determined from Method 2 should be included in the UK's woodland accounts. Recommendations are also provided in relation to: possible improvements to the method; enhanced data collection; and future research priorities.

Acknowledgements
We would like to thank the following people who contributed to consultations or commented on the draft final report: Emily Connors, Brendan Freeman (Office of National Statistics); Julian Harlow, Rocky Harris, Colin Smith (Department for Environment, Food and Rural Affairs); Steve Arnold, Lydia Burgess-Gamble, Peter Dobson, Duncan Huggett, Chris Knight, Bruce Munro, Sue Reed, Mark Ross, Harry Walton (Environment Agency); Vince Carter, Richard Haw, Pat Snowdon (Forestry Commission); Tom Nisbet (Forest Research); Prof. Colin Thorne (Nottingham University); Prof. Neil McIntyre (Queensland University, Australia); Ruth Ellis (Scottish Environment Protection Agency); and David Thomas (Welsh Government). Thanks also to Ruth Ellis (Scottish Environment Protection

Agency), David Thomas (Welsh Government) and Richard Schaible (Department of Agriculture and Rural Development, Northern Ireland) for their assistance in providing input data.

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1 Introduction

1.1 Background

The value of natural capital is not currently measured or included in the UK National Accounts. In 2011, the Natural Environment White Paper[1] committed the Government to working with the Office for National Statistics (ONS) to measure the value of natural capital. Since then, ONS, in partnership with the Department for Environment, Food and Rural Affairs (Defra), has been developing innovative ecosystem accounts in working towards incorporating natural capital into UK Environmental Accounts by 2020.

The System of Environmental-Economic Accounting[2] (SEEA) describes ecosystem accounts as *"…a coherent and integrated approach to the assessment of the environment through the measurement of ecosystems, and measurement of the flows of services from ecosystems into economic and other human activity* [which]*…encompasses:*

- *Measurement of the contribution of ecosystems to standard measures of economic activity, such as* [Gross Domestic Product] *GDP and national income, and*
- *Measurement of the role that ecosystems play in providing a range of other benefits to human well-being that are commonly unpriced and not considered in national level economic reporting and analysis".*

Initial Freshwater Ecosystem Assets and Service Accounts[3], which have been produced by ONS, provide an estimated value for inland wetlands and open waters of £40 billion, which relates to fish extraction, water abstraction, peat extraction, outdoor recreation, and educational visits. However, a key element missing from the estimates is the value of flood-regulation services. The reason given is that *"In the UK, floodplains are often not identified as separate habitats but instead are included under several different categories. For example, some areas of natural grassland lie on floodplains. Therefore, it poses a challenge to identify what percentage of that category consists of floodplain. For this reason, it is very difficult to obtain reliable data for floodplains and to avoid double counting with other habitats, such as grasslands, this paper has not included floodplains in freshwater ecosystem accounts"*[3]. Similarly, the method paper for the initial Woodland Ecosystem Assets and Service Accounts notes that *"Flood protection… is considered important in relation to woodland… however, currently, there are no physical data available for the flood protection service from woodland. Further research is required to explore the possibility of measuring flood protection arising from woodland"*[4]. Hence, no value for flood-regulation services is currently included in the UK Environmental Accounts[5]. Flood risk management is an important policy issue and providing ecosystem accounts associated with flood-regulation services could aid effective targeting of policies.

An ongoing project "SC150005 - Working with Natural Processes (WWNP) - evidence base & catchment/coastal laboratories", commissioned by the Environment Agency, *"aims to develop a high quality WWNP evidence base to help flood and coastal erosion risk management (FCERM) authorities understand, justify, develop and implement FCERM schemes, which include WWNP to reduce flood risk".* The WWNP project started in February 2016 and ends in August 2017.

1.2 Flood-regulation services

Ecosystems (e.g. woodland or wetland) can contribute to reducing and delaying fluvial-flood flows in a range of ways down a catchment, broadly through:

- Increasing soil infiltration rates, reducing run-off, and preventing soil erosion (and subsequent siltation of water courses downstream), particularly in upper catchments.
- Contributing to the creation of debris dams in small streams that desynchronise peak flows.

[1] H.M. Government. 2011. The Natural Choice: securing the value of nature. London: TSO.
[2] Available at http://unstats.un.org/unsd/envaccounting/seea.asp
[3] Khan, J. and Din, F. 2015. UK Natural Capital – Freshwater Ecosystem Assets and Services Accounts. Office for National Statistics.
[4] Khan, J.; Greene P. and Hoo, K.W. 2013. Measuring UK Woodland Ecosystem Assets and Ecosystem Services. Office for National Statistics.
[5] Available at https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/ukenvironmentalaccounts/2016

- Increasing hydraulic roughness spanning the full width of floodplains, most notably where floodplains narrow and flood flows would otherwise accelerate, thereby reducing potential damage downstream.
- Providing areas on the floodplain for flood storage.

It should be noted that these same mechanisms can in some instances also compound fluvial-flood flows. For example:

- Delaying flood flows in one sub-catchment may lead to them being synchronised with those from another sub-catchment.
- Debris dams or increased hydraulic roughness on floodplains, as well as debris-washout blocking culverts or bridges, may lead to flood flows backing up and increasing potential damage upstream.
- Increased hydraulic roughness that does not span the full width of the floodplain may increase the speed of flood flows.

Management of ecosystems may also result in their beneficial impact on fluvial-flood flows being reduced or, in relation to clear-felling of woodland, temporarily or permanently lost.

One source of evidence for the relative benefits of mechanisms for flood regulation in a UK context is a project in the Pickering Beck catchment in Northern England. Between 2010 and 2012, a range of natural flood management measures (including tree planting, woody dams and moorland drain blocking) were implemented, followed by the construction of a large flood storage area in 2014/15. Detailed analysis of a subsequent flood event on Boxing Day 2015, in comparison to previous peak flows, estimated that around half of the reduction in flooding was due to the upstream land-management measures and half due to the flood-storage area[6]. Although this research helps to provide an overview of the balance of different flood-regulation services, associated data does not lend itself to developing national ecosystem accounts.

1.3 Objectives

ONS commissioned Ricardo Energy & Environment to undertake this study between March and October 2016 to:

- Scope and produce a methodology to value floodplains and produce initial floodplain ecosystem accounts that could be incorporated into the UK ecosystem accounts.

An initial scoping review identified that developing a value for floodplains remains intractable for the reasons described in the Initial Freshwater Ecosystem Assets and Service Accounts (see Section 1.1). So instead, the study sought to:

- Review simple, pragmatic, transparent approaches that could be taken to valuing flood-regulation services for inclusion in the UK's ecosystem accounts.
- Agree an approach to develop and apply.

It was identified that the UK National Ecosystem Assessment[7] (UK NEA) estimated the total value of flood control and storm buffering provided by UK inland waters as £366 million per annum. The UK NEA's method[8] used an international meta-regression model[9] based on replacement costs, and subsequent value transfer. However, the method's use of the model was not transparent, so did not meet this study's success criteria (see below).

A rapid review of the literature and discussions with a number of key experts sought to identify those elements of the ecosystem that deliver a substantial share of flood-regulation services for which a

[6] Slowing the Flow Partnership (2016) Slowing the Flow Partnership Briefing: Boxing Day 2015 Flood Event

[7] UK National Ecosystem Assessment. 2011. The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge.

[8] Morris, J. and Camino, M. 2010. Economic Assessment of Freshwater, Wetland and Floodplain (FWF) Ecosystem Services. UK NEA Economics Analysis Report.

[9] Brander, L.M.; Ghermandi, A.; Kuik, O.; Markandya, A.; Nunes, P.A.L.D.; Schaafsma and M., Wagtendonk, A. 2008. Scaling up ecosystem services values: methodology, applicability and a case study. Final Report, European Environment Agency, May 2008.

value could be estimated for inclusion in the UK's ecosystem accounts. Estimation of the value of flood storage was not progressed for the same reasons as identified in the Initial Freshwater Ecosystem Assets and Service Accounts, i.e., due to lack of data and to avoid double counting. More generally, our investigations revealed a lack of quantitative research relevant to a UK context linking variations in the extent of land covers and land uses to differential reductions in peak flows at a catchment scale. The only research found to provide data in a relevant form related to woodland, despite the method paper for the initial Woodland Ecosystem Assets and Service Accounts noting that *"there are no physical data available for the flood protection service from woodland".* The research quantified the impact of changes in woodland cover in an upper catchment on changes in peak flows[10,11], so it was ultimately agreed with ONS that the study's objective should be to:

- Develop and apply methods for valuing flood-regulation services provided by woodland in upper water catchments for inclusion in the UK woodland accounts.

1.4 Success criteria

It was agreed with ONS that the selected method should:

- Be simple and transparent in order to aid understanding and enable emulation by companies and charities that wish to implement their own natural environment accounts.
- Provide a value that was easily understood and of practical use for policy makers.
- Be based on accessible data.
- Successfully avoid double counting.
- Seek to consider how the impact of climate change could affect the results.
- Allow for spatial disaggregation, where practical, i.e. where the methodology and available data allowed.
- Bear in mind the SEEA framework and Defra and ONS' principles for ecosystems accounting[12].

ONS also stipulated that as the accounts were experimental, *"something 'roughly right' was more important than undue precision".*

[10] McIntyre, N. et al. (2012) The potential for reducing flood risk through changes to rural land management: outcomes from the Flood Risk Management Research Consortium. BHS Eleventh National Symposium, Hydrology for a changing world, Dundee 2012. British Hydrological Society
[11] McIntyre, N. and Thorne, C. (2013) Land use management effects on flood flows and sediment – guidance on prediction. CIRIA Report C719. CIRIA, London.
[12] Defra & ONS. 2014. Principles of ecosystems accounting. Available at https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/methodologies/naturalcapital

2 Method

2.1 Basis of the method

The research on which the method was based related changes in woodland cover on grazed pasture in the upper reaches of Pontbren[13,14], a small 6-12km^2 catchment in Wales, to changes in mean peak flows. It was based on empirical measurements and modelling of a single extreme flood event. More data were available from overseas studies but their relevance to the UK was questionable and other studies in the UK were wholly model-based, e.g. in relation to the Hodder catchment in Northwest England. Studies at Pontbren provided figures for reduction in peak flows associated with an increase or reduction of 7% woodland cover and full afforestation arising from a 93% increase in woodland cover (i.e. based on 7% existing woodland cover). A previous study of the catchment identified that soil infiltration rates under young native woodland were up to 60 times higher compared to adjacent heavily grazed pasture, with 90% of the improvement occurring within two years of stock removal and tree planting[15]. This suggests that existing woodland may deliver a major share of flood-regulation services associated with land cover and land use in upper catchments.

The results of studies at Pontbren were broadly supported by field data from other manipulation experiments[16]. Nevertheless, substantial uncertainties arose about the impact of woodland cover in upper catchments at larger scales and in relation to larger flood events because evidence (mainly modelled)[12,17,18,19,20] showed that woodland has a declining impact on peak flows with increasing:

- Scale of catchments due to the limited extent of woodland, a wide range of factors influencing flooding within large catchments, and potential for woodland to desynchronise or synchronise peak flows in different sub-catchments, which mean that woodland has greatest potential to reduce peak flows within smaller catchments (<100 km^2).
- Size of flood event, although woodland can still influence events with a probability of occurring once every 100 years or greater.

2.2 Stakeholder consultation

Key stakeholders (Table 1) were consulted on development of the method and a workshop was held at ONS offices to agree a way forward. Reservations were expressed about basing a national valuation of flood-regulation services on a study of just one catchment. However, no other studies were put forward that provided suitable data linking variations in the extent of land covers and land uses to differential reductions in peak flows at a catchment scale.

A method was presented for using the Pontbren data to value flood-regulation services delivered by woodland in upper catchments for inclusion in the UK's ecosystem accounts. Two options were considered by the workshop for estimating the notional value of woodland for flood regulation:

1. Calculating the replacement cost of flood-defence (i.e. how much it would cost to replace the ecosystem service).

[13] McIntyre, N. et al. (2012) The potential for reducing flood risk through changes to rural land management: outcomes from the Flood Risk Management Research Consortium. BHS Eleventh National Symposium, Hydrology for a changing world, Dundee 2012. British Hydrological Society

[14] McIntyre, N. and Thorne, C. (2013) Land use management effects on flood flows and sediment – guidance on prediction. CIRIA Report C719. CIRIA, London.

[15] Carroll, Z.L.; Bird, S.B.; Emmett, B.A.; Reynolds, B. and Sinclair, F.L. 2004. Investigating the impact of tree shelterbelts on agricultural soils. In: Smithers, R.J. (ed.) Landscape ecology of trees and forests. Proceedings of the twelfth annual IALE(UK) conference, held at the Royal Agricultural College, Cirencester, 21–24 June 2004. IALE(UK). 374pp.

[16] Jackson B.M.; Wheater, H.S.; McIntyre N.R.; Chell J.; Francis O.J.; Frogbrook Z.; Marshall, M.; Reynolds B. and Solloway I. 2008. The impact of upland land management on flooding: insights from a multiscale experimental and modelling programme. *Journal of Flood Risk Management*, 1: 71-80.

[17] Calder, I. and Aylward, B. 2006. Forest and floods: Moving to an evidence-based approach to watershed and integrated flood management. *Water International*, 87-99.

[18] Nisbet, T.R. and Thomas, H. 2008. Restoring floodplain woodland for flood alleviation. Final report for the Department of Environment, Food and Rural Affairs (Defra), Project SLD2316. Defra, London.

[19] Odoni, N.A. and Lane, S.N. 2010. Assessment of the impact of upstream land management measures on flood flows in Pickering using OVERFLOW. Contract report to Forest Research for the Slowing the Flow at Pickering Project. Durham University, Durham.

[20] Nisbet, T.R.; Roe, P.; Marrington, S.; Thomas, H.; Broadmeadow, S. and Valatin, G. 2015. Slowing the flow at Pickering. Final Report on Phase II for the Department of environment, food and rural affairs (Defra), Project RMP5455. Defra, London. Available at: http://www.forestry.gov.uk/fr/slowingtheflow

2. Calculating avoided-damage costs (i.e. how much damage is avoided as a result of the ecosystem service).

Table 1: Stakeholders consulted during development of the method

Name	Organisation
Julian Harlow	Defra
Rocky Harris	Defra
Colin Smith	Defra
Steve Arnold	Environment Agency
Lydia Burgess-Gamble	Environment Agency
Peter Dobson	Environment Agency
Duncan Huggett	Environment Agency
Chris Knight	Environment Agency
Bruce Munro	Environment Agency
Sue Reed	Environment Agency
Mark Ross	Environment Agency
Harry Walton	Environment Agency
Richard Haw	Forestry Commission
Pat Snowdon	Forestry Commission
Tom Nisbet	Forest Research
Ruth Ellis	Scottish Environment Protection Agency
David Thomas	Welsh Government

It is worthy of note that SEEA[2] states that *"Typically, the relationship between ecosystem assets and ecosystem services for regulating services has a spatial aspect…the service flood protection…occurs only if there are people living nearby or there is infrastructure in the zone at risk from flooding".* However, in a UK context this statement would seem to be addressed by both replacement-cost and avoided-damage cost approaches. SEEA highlights that welfare analysis is generally adopted for environmental valuation of regulating services but is not appropriate for accounting, apart from the replacement-cost approach. Both replacement costs and avoided costs are considered appropriate for ecosystem accounting by the Convention on Biological Diversity[21]. Nevertheless, Day[22] suggests replacement costs should be avoided in ecosystem accounting because they lack theoretical coherence with other preference-based valuations.

During the workshop, the replacement-cost approach was agreed as the preferred approach and was, in any case, ultimately, the only viable option due to a lack of suitable data, as damage costs were only available for Scotland (i.e. SEPA Flood Risk Annual Average Damages Grids). Data on expenditure on flood-defence schemes and its expected impact on reducing peak flows is not collated by the national agencies by catchment. The cost:benefit of flood-defence schemes is assessed on a case-by-case basis in relation to (potential) avoided damages but not at a catchment scale. Hence, the two final methods implemented involved calculating the notional cost of replacing the flood regulation provided by existing woodland cover and relied on data relating to annual national expenditure on fluvial-flood defence.

Method 1 based calculations on expenditure that had notionally already been reduced by the presence of existing woodland. Method 2 provided an alternative step, which calculated the additional

[21] Weber, J.-L. 2014. Ecosystem Natural Capital Accounts: A Quick Start Package. Montreal. Technical Series No. 77. Secretariat of the Convention on Biological Diversity. 248 pp.
[22] Day, B. 2014. An overview of valuation techniques for ecosystem accounting, Available at: http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjXq7KS1L_PAhUjOsAKHV5pC90QFggcMAA&url=http%3A%2F%2Fwww.ons.gov.uk%2Fons%2Fabout-ons%2Fget-involved%2Fevents%2Fevents%2Fvaluation-for-natural-capital-accounting-seminar%2Fissue-paper-1-1.pdf&usg=AFQjCNHtr223HPyhLkh-qr45C76nmiFrxg&bvm=bv.134495766,d.d24

expenditure that would be required to maintain the same level of fluvial-flood defence if existing woodland was absent (i.e. the full replacement cost).

2.3 Method 1

Method 1 for estimating the value of flood-regulation services for inclusion in the UK ecosystem accounts is outlined in the flow chart (Figure 1). It comprised three steps, which calculated:

1. The contribution of woodland to flood regulation per catchment (see Section 2.3.1).
2. Flood-defence expenditure per catchment (see Section 2.3.2).
3. The notional value of woodland for flood regulation based on the replacement-cost method (see Section 2.3.3).

A tabulated summary of information relevant to each stage of the method is provided at Appendix 1 in relation to:

- Data secured.
- Gaps in research/data.
- Caveats and assumptions.
- Improvements/future research.

Further details of data secured and the method implemented for each stage are provided in Sections 2.3.1 to 2.3.3.

Figure 1: Method 1 for estimating the value of fluvial flood-regulation services for inclusion in the UK ecosystem accounts

1. Contribution of woodland to fluvial flood regulation per catchment

1.1 Cookie-cutting a map of catchment boundaries in a GIS by land that has a 1 in 100 or greater (i.e. >1%) annual probability of flooding for England and Wales, or a 1 in 200 or greater (i.e. >0.5%) annual probability of flooding for Scotland. All remaining land was assumed to comprise upper catchments.

1.2 Overlaying the National Forest Inventory (NFI) to determine % woodland cover in each upper catchment.

1.3 Establishing relationships between % woodland cover in upper catchments and % reduction in peak flows from the Pontbren studies (through establishing relationships associated with available data points).

1.4 Using the relationship between % woodland cover in upper catchments and % reduction in peak flows from the Pontbren studies to determine the notional contribution of woodland to flood regulation in terms of % reduction in peak flows for each catchment.

2. Fluvial flood-defence expenditure per catchment

2.1 Identifying number of people at risk of fluvial flooding in each catchment by overlay in GIS of a 1km x 1km resolution population dataset with the areas at risk of flooding used in 1.1 above. Ensuring that the number of people at risk from coastal flooding was not inadvertently included in calculations through consideration of polygon attribution data.

2.2 Apportioning national expenditure on fluvial-flood defence to each catchment pro rata based on the number of people at risk of flooding.

3. Notional value of woodland for fluvial flood regulation based on replacement cost method

3.1 Calculating % reduction in expenditure on fluvial flood defence for each catchment based on % woodland cover in each upper catchment by assuming a 1:1 relationship between % reduction in peak flows and % reduction in expenditure on fluvial-flood defence.

3.2 Summating resultant values and considering implications of the SEEA framework and Defra and ONS' principles for this calculation in order to come up with a total figure for the UK ecosystem accounts (spatially disaggregated by country). The estimated figure represents the flow value of flood regulation services provided by woodland cover. An asset value based on a Net Present Value (NPV) calculation was based on a 50-year time-horizon using a 3.5% discount rate, as recommended by ONS.

2.3.1 Contribution of woodland to fluvial flood regulation per catchment

2.3.1.1 Data secured

Data secured for this analysis comprised:

- Data from the Pontbren studies providing figures for mean percentage change in peak flows associated with an increase or reduction of 7% woodland cover and an increase of 93% woodland cover, which were based on 7% existing woodland cover and changes from/to grazed pasture.[23]
- Digitised Water Framework Directive Catchment boundaries for England and Wales provided by the Environment Agency (EA) and Natural Resources Wales (NRW) respectively.
- Digitised main river and coastal catchment boundaries for Scotland provided by the Scottish Environment Protection Agency (SEPA).
- The digitised Flood Map for Planning (Rivers and Sea) Flood Zone 3 for England and Flood Zone 3 for Wales supplied by EA and NRW respectively. Flood Zone 3 comprises land having a 1 in 100-year or greater (i.e. >1%) annual probability of flooding.
- Digitised boundaries of land having a 1 in 200 year or greater (i.e. >0.5%) annual probability of flooding, included in the Flood Hazard and Flood Risk dataset for Scotland provided by SEPA (as the 1 in 200-year flood envelope is used by SEPA for flood risk management in Scotland rather than the 1 in 100-year flood envelope used by EA and NRW in England and Wales).
- The Forestry Commission's National Forest Inventory (Woodland GB 2015) and Northern Ireland's Woodland Basemap in order to identify woodland cover.
- NB Digitised boundaries of catchments and flood risk areas for Northern Ireland were not made available for this study, hence, this analysis could not proceed in its regard (see Section 2.6).

2.3.1.2 Method implemented

A number of steps were implemented in order to identify the contribution of woodland to flood regulation per catchment (see Appendix 1). Although some sources of digitised data differed (i.e. catchment boundaries and flood zones), the same method was used for England, Scotland and Wales. Firstly, the boundaries of upper catchments were identified by performing a union query between the flood risk layers and catchment areas and removing the overlapping areas (i.e. "cookie-cutting"), i.e. this assumed that all land outside Flood Zone 3 in England and Wales and outside the 1 in 200-year flood envelope in Scotland could be defined as the upper catchment. Secondly, the resulting upper catchment layer was intersected with the National Forest Inventory layer in order to identify the percentage woodland cover in each upper catchment.

Research demonstrates woodland types have differential impacts on infiltration rates and run-off. However, the Pontbren data did not allow such consideration, so, percentage woodland cover was determined irrespective of woodland type. All those areas categorised in the inventory as "Woodland" were taken into account and included the following Interpreted Forest Types (IFTs): Broadleaved; Conifer; Felled; Ground Prepared for New Planting; Mixed - predominantly Broadleaved; Mixed - predominantly Conifer; Young Trees; Coppice; Coppice with Standards; Shrub Land; Uncertain; Cloud or Shadow; Low Density; Assumed woodland; Failed; Windthrow/Windblow. The inclusion of a number of these IFTs might be questionable (e.g. Felled; Ground Prepared for New Planting; Young trees; Failed). However, as 90% of the improvement in soil infiltration rates has been shown to occur within two years of tree planting[24] and as the National Forest Inventory is only updated on a five year cycle, it was assumed that likely growth or regrowth of trees justified their inclusion.

After establishing the percentage woodland cover in each upper catchment, we estimated the contribution of woodland to reducing peak flows in each catchment using the data from the Pontbren

[23] McIntyre, N. and Thorne, C. (2013) Land use management effects on flood flows and sediment – guidance on prediction. CIRIA Report C719. CIRIA, London.

[24] Carroll, Z.L.; Bird, S.B.; Emmett, B.A.; Reynolds, B. and Sinclair, F.L. 2004. Investigating the impact of tree shelterbelts on agricultural soils. In: Smithers, R.J. (ed.) Landscape ecology of trees and forests. Proceedings of the twelfth annual IALE(UK) conference, held at the Royal Agricultural College, Cirencester, 21–24 June 2004. IALE(UK). 374pp.

studies presented in Table 2, which were based on 7% existing woodland cover and changes from/to grazed pasture.

Table 2: Summary of changes in peak flow for three land-use change scenarios in the Pontbren catchment modelled for an extreme rain storm event. 95% confidence intervals (CI) are in brackets[22]

Land use change	Area affected (%)	Mean change in peak flow (%)
Remove tree cover	7	+5 (3 to 7)
Increase tree cover	7	-5 (-2 to -11)
Full afforestation	93	-36 (-10 to -54)

Having consulted with the authors of the Pontbren studies[25], we interpreted the data in Table 2 cumulatively in relation to a baseline of 0% existing woodland cover to provide data points for mean percentage change in peak flow associated with 0% to 100% woodland cover in the upper catchment, as detailed in Table 3.

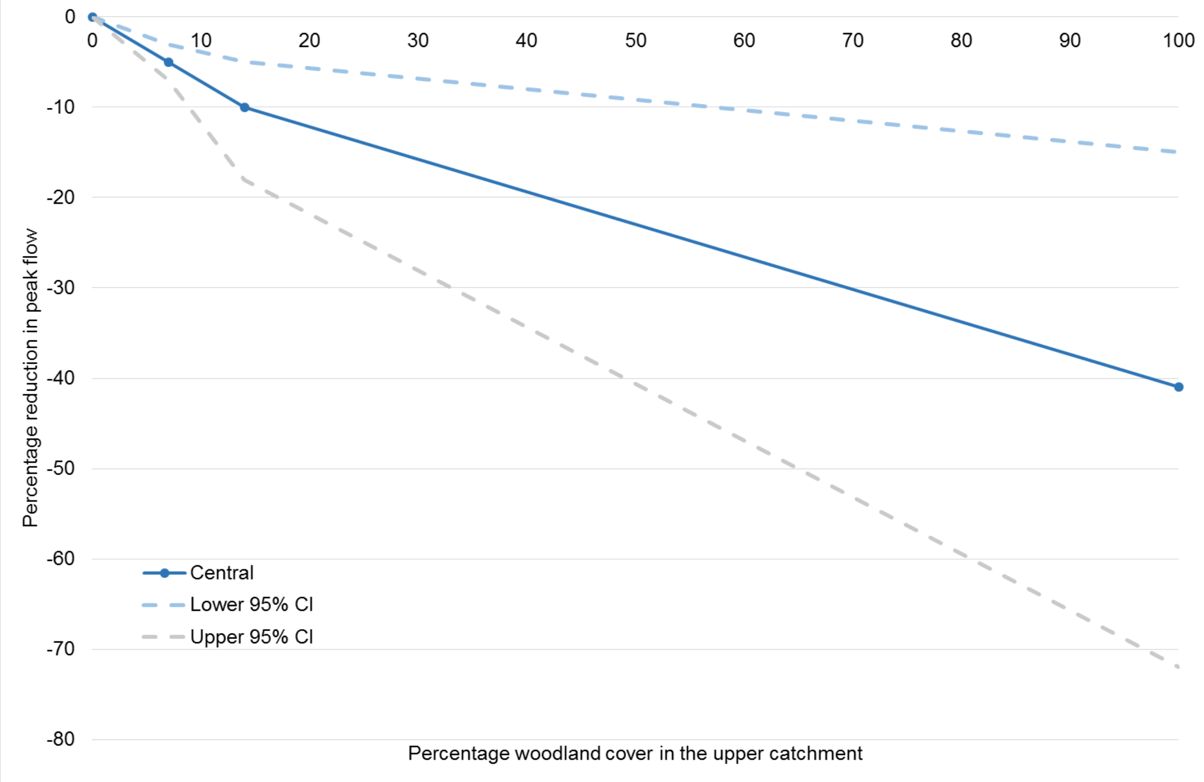
Table 3: Impact of woodland cover on peak flows in relation to a baseline of 0% existing woodland cover

% woodland cover	Mean reduction in peak flow (%)		
	Lower 95% CI	Central	Upper 95% CI
0	0	0	0
7	-5	-3	-7
14	-10	-5	-18
100	-41	-15	-72

For the purposes of this study, given the limited number of data points and the need for prudency, a piecewise linear relationship was assumed between percentage woodland cover in the upper catchment and percentage reduction in peak flow with a breakpoint at 14% woodland cover (Figure 2).

[25] McIntyre, N. and Thorne, C. pers. comm.

Figure 2: Our approach for estimating the relationship between woodland cover and reduction in peak flow



The estimated relationship[26] between percentage woodland cover in the upper catchment and percentage reduction in peak flow for areas with less than or equal to 14% woodland cover was calculated for the central data and lower and upper 95% CI using the following equation:

(1) $$\textit{Reduction in peak flow} = \textit{coefficient } 1 * \textit{woodland cover}$$

For areas with woodland cover greater than 14%, the relationship was calculated using an equation that included a constant because the segments of the lines used for the purposes of this study do not intersect the X-axis:

(2) $$\textit{Reduction in peak flow} = \textit{coefficient } 2 * \textit{woodland cover} - \textit{constant}$$

The coefficients and constants used in relation to each of the lines are provided in Table 4.

[26] Rate of change is calculated using the standard form: $\frac{(y2-y1)}{(x2-x1)}$

Table 4: Coefficients and constants used to calculate the estimated relationship between percentage woodland cover in the upper catchment and percentage reduction in peak flow

	Mean change in peak flow (%)		
	Lower 95% CI	Central	Upper 95% CI
Coefficient 1	-0.36	-0.71	-1.29
Coefficient 2	-0.12	-0.36	-0.63
Constant	-0.03	-0.05	-0.21

2.3.2 Fluvial flood-defence expenditure per catchment

2.3.2.1 Data secured

Additional data secured for this analysis comprised:

- Human population density at 1x1 km resolution based on ONS 2011 Census data.
- Expenditure on flood defence for
    - **England** (supplied by EA), which gave annual combined totals for fluvial and coastal flood defence (2005/2006 to 2015/2015), broken down into totals for capital expenditure and revenue expenditure funded by Government and funded by charges/levies/other income. As the data did not differentiate between fluvial and coastal expenditure, the proportion relevant to fluvial-flood defence was estimated as 55% in accordance with EA's new investment programme (Table 3).[27]

Table 5: Expenditure on flood defence for England

Year	Total expenditure (£ million)	Estimated fluvial-flood defence expenditure (£ million)
2005	946	520.30
2006	936	514.80
2007	963	529.65
2008	1095	602.25
2009	1170	643.50
2010	1170	643.50
2011	1113	612.15
2012	1091	600.05
2013	1143	628.65
2014	1265	695.75
2015 (budget)	1184	651.20

    - **Wales** (supplied by Welsh Government), which gave the estimated expenditure for fluvial-flood defence for the financial year 2010/2011 to 2014/2015. The data comprised a lump sum expenditure (£64.4 million) for this period covering expenditure from both the Welsh Government (£46 million) and local authorities (£18.3 million). However, the data only covered capital expenditure (i.e. revenue expenditure was not provided).
    - **Scotland** (supplied by Scottish Government via SEPA), gave the total estimated annual expenditure for fluvial-flood defence funded by Scottish Government for each of the financial years 2011/2012 to 2015/2016[28] plus an additional 20% funded by local authorities, totalling £52.5 million annually. Like Wales, the data only covered capital expenditure excluding revenue expenditure to maintain the services. In

[27] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/381747/6361_EA_SR_FCRM_Infographic_PF_Nov14_v8_lr.jpg

[28] No detailed breakdown across the years given.

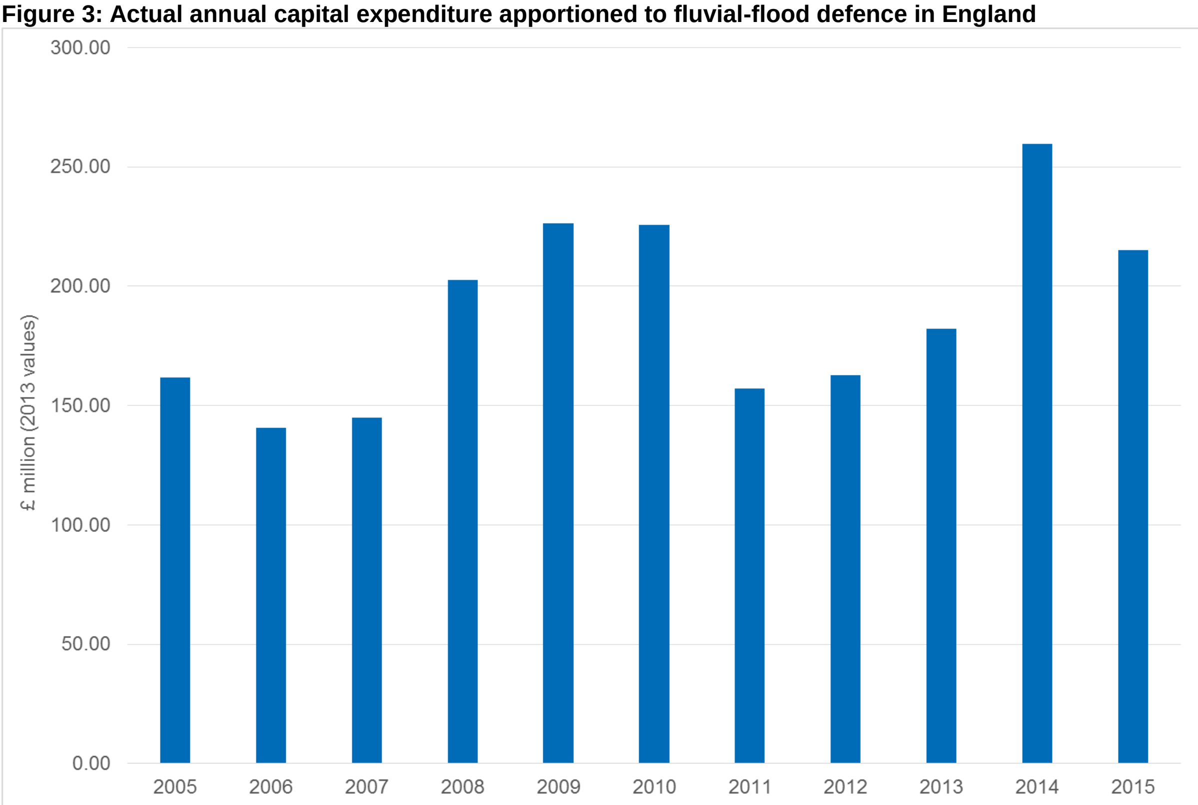
addition, the expenditure was not exclusively but predominantly related to fluvial-flood defence.

- **Northern Ireland** data regarding annual expenditure on fluvial-flood defence was not made available to this study, so again, the analysis could not proceed in its regard (see Section 2.6).

For accounting purposes, all expenditure data was adjusted for inflation and expressed as 2013 prices following Defra and ONS' principles for ecosystems accounting.

Both capital and revenue expenditure were used in the analysis. One approach to handling capital expenditure would have been to annualise expenditure over the lifetime of the asset. This was not done because annual capital expenditure provided was relatively constant (see Figure 3).

Figure 3: Actual annual capital expenditure apportioned to fluvial-flood defence in England



In order to harmonise data for England, Scotland and Wales:

- England's values for capital and revenue expenditure were deflated using GDP deflators for all years.
- Scotland's single value for total capital expenditure 2011-2015 was treated as a constant expenditure in nominal terms across the period, as that was the form in which the data was provided. An estimate of total expenditure (capital and revenue) was calculated using the average proportion of capital expenditure to overall expenditure in England across all years. This total expenditure value for Scotland was deflated using the GDP deflators.
- Wales' total capital expenditure across the period 2010/2011 to 2014/2015 was allocated to each year using a weighted average based on the inflation index over the period to provide annual capital expenditure. An estimate of total expenditure (capital and revenue) was calculated using the average proportion of capital expenditure to overall expenditure in England across all years. This total expenditure value for Wales was deflated using the GDP deflators.

2.3.2.2 Method implemented

It was assumed that expenditure on fluvial-flood defence was proportional to the number of people at risk of flooding. This allowed flood-defence expenditure to be apportioned to each catchment pro rata based on the number of people at risk of fluvial flooding. In reality, expenditure is also likely to be affected by a wide range of other factors, including catchment characteristics and the value of assets at risk.

Two stages of GIS analysis were implemented. Although sources of digitised data differed (i.e. catchment boundaries and flood zones), the same method was used for England, Scotland and Wales. Firstly, the areas at risk of flooding used in Section 2.3.1.2 in each catchment were identified by overlaying the separate flood risk layers with the catchment boundary data. The resultant layer was then overlaid with the 2011 census population dataset to calculate the number of people at risk from fluvial flooding. Polygon attribution data were used to ensure that only the number of people at risk from fluvial flooding was calculated (i.e. not people at risk of coastal flooding). In the absence of any data on catchment-level expenditure, national annual flood-defence expenditure was then apportioned to each catchment based on its percentage share of the total population of that country at risk from fluvial flooding.

2.3.3 Notional value of woodland for fluvial flood regulation based on replacement-cost method

2.3.3.1 Data secured

The previous stages of the method produced the following data:

- The percentage woodland cover in each upper catchment and the respective reduction in peak flow (Table 6 provides averages figures).
- The annual expenditure on fluvial-flood defence in each catchment based on the human population at risk of flooding.

Table 6: Average percentage woodland cover per upper catchment and respective average percentage reduction in peak flow per catchment for each country

Country	Average % woodland cover	Average % reduction in peak flow
England	11.14	-7.43
Scotland	14.78	-8.47
Wales	12.81	-8.03

2.3.3.2 Method implemented

The notional value of woodland for flood regulation was then calculated for each catchment by assuming a 1:1 relationship between reduction in peak flow and reduction in expenditure. In reality, this relationship is likely to be highly complex dependent on a wide range of variables relating to the nature and location of catchments, people and infrastructure. However, a simple 1:1 relationship was used for transparency in the absence of any data on the actual relationship between reduction in peak flow and reduction in expenditure for each catchment. For example in the Broadland Rivers catchment, the percentage of woodland area was 7.06% implying a 5.02% reduction in the peak flow (using Equation 1), which was equated to a 5.02% reduction in annual fluvial-flood expenditure. The reductions in expenditure for all catchments were then summated to give a notional value of woodland for flood regulation for each respective country. A sensitivity analysis was also undertaken that assumed 1:0.5 and 1:1.5 relationships between reduction in peak flow and reduction in expenditure.

2.4 Method 2: an additional step or alternative approach

Method 1 calculated the notional value of woodland for flood regulation based on a replacement-cost method, i.e. the costs of replacing the flood-regulation service delivered by existing woodland in upper catchments. It based calculations on expenditure that had notionally already been reduced by the presence of the woodland rather than calculating the additional expenditure that would be required to maintain the same level of fluvial-flood defence if the woodland was absent. Ideally, the method should have been based on the modelled larger size, shape and number of areas at risk of flooding if the woodland was absent, which would have encompassed a larger human population. The resultant increase in population at risk of flooding in each catchment could then have been used to calculate the notional increase in fluvial-flood expenditure. However, there is inadequate quantitative research to undertake such modelling of the changes in the shape and size of flood risk areas, so in Method 2 a simpler approach was taken to calculating the additional expenditure that would be required to maintain the same level of fluvial-flood defence if the woodland was absent and was replaced by grazed pasture.

For each catchment, the increase in the number of people at risk from flooding in the absence of the woodland was calculated[29] by regarding the existing figure calculated in Section 2.3.2.2 as being the result of the percentage reduction in peak flow delivered by woodland in the upper catchment calculated in Section 2.3.1.2. Hence, this assumed a 1:1 relationship between the percentage increase in peak flow and the percentage increase in area at risk of flooding if the woodland was absent. In reality, this relationship is likely to be highly complex dependent on a wide range of variables relating to the nature and location of catchments but, as in Section 2.3.3.2, a simple 1:1 relationship was used for transparency, given that modelling of the changes in the shape, size and number of flood risk areas was not possible. It also assumed that human population was evenly distributed within the catchment. The total percentage increase in human population at risk of flooding for all catchments within each country was then calculated and multiplied by the existing total annual expenditure on fluvial-flood defence within each country. The result of this calculation was the value of the contribution of existing woodland in the upper catchment to fluvial-flood regulation for each country. Sensitivity analyses were also undertaken that assumed 1:0.5 and 1:1.5 relationships between reduction in peak flow and increase in area at risk of flooding.

2.5 Calculation of asset values

Asset values were calculated, for the contribution of existing woodland in the upper catchment to fluvial-flood regulation in each country, for each year in which the estimated annual reduction in fluvial-flood expenditure could be determined using Method 1 (Sections 2.3.3) and, alternatively, using Method 2 (Section 2.3.4). Results for GB were only calculated for those years where data were available for all three constituent countries (i.e. 2011-2014).

The following assumptions were applied:

- All expenditure data was already adjusted for inflation and expressed as 2013 prices (see Section 2.3.2.1), in accordance with Defra and ONS' principles for ecosystem accounts.
- The asset values were calculated as the sum of the Net Present Value (NPV) over a lifetime of 50 years, in accordance with Defra and ONS' principles for ecosystem accounts.
- The discount rate for the first 30 years was 3.5% and for the following 20 years was 3%, in accordance with H.M Treasury's Green Book[30].
- Flow values were increased in line with population growth over the asset's lifetime[31].

Future estimated annual reduction in fluvial-flood expenditure delivered by existing woodland cover in upper catchments was not adjusted for projected impacts of climate change (e.g. any resultant increase in the size of areas at risk of fluvial flooding) or any other such factor.

2.6 Northern Ireland

The Forest Service supplied the Northern Ireland Woodland Basemap for determining woodland cover in upper catchments. However, neither digitised boundaries of catchments and flood risk areas nor data on annual expenditure on fluvial-flood defence were made freely available for this study by Northern Ireland's Department of Finance. Hence, it was not possible to implement Method 1 or 2 for Northern Ireland at this time.

[29] Specifically, we calculate $Population\ without\ woodlands = current\ population/(1 - \%\ reduction\ in\ peakflow)$

[30] H.M. Treasury. 2013, The Green Book: appraisal and evaluation in central government. London: TSO.

[31] ONS UK Population Projections: 2014-based principal projection for the UK. Available at https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections

3 Results

Full results of each and every stage of Method 1 and Method 2 are available from ONS, as a workbook.

3.1 Method 1: annual reduction in fluvial-flood expenditure

Table 7 presents the notional annual reduction in fluvial-flood expenditure delivered by existing woodland cover in upper catchments based on expenditure notionally already reduced by the presence of woodland (see Section 2.4). These results use the central figures for the relationship between percentage woodland cover in the upper catchment and percentage reduction in peak flow and assume a 1:1 relationship between reduction in peak flow and reduction in expenditure.

The results of using the lower and upper 95% CI are presented in Appendix 2, Table A2.1. The sensitivity analyses that assumed 1:0.5 and 1:1.5 relationships between reduction in peak flow and reduction in expenditure led to values that were 50% and 150% respectively of the values presented here and in Table A2.1.

Table 7: Annual reduction in fluvial-flood expenditure (£ million) – Method 1

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
England	41.1	39.4	39.6	43.9	46.2	45.4	42.6	40.9	42.1	46.0	42.8
Scotland							19.5	19.1	18.8	18.6	18.5
Wales						5.1	5.1	5.1	5.1	5.1	
GB							67.2	65.1	66.0	69.6	

3.2 Method 1: asset values

Table 8 presents the asset values of existing woodland cover in upper catchments for each country in relation to the notional annual reduction in fluvial-flood expenditure immediately above.

The results of using the lower and upper 95% CI are presented in Appendix 2, Table A2.2. The sensitivity analyses that assumed 1:0.5 and 1:1.5 relationships between reduction in peak flow and reduction in expenditure again led to values that were 50% and 150% respectively of the values presented here and in Table A2.2.

Table 8: Asset values (£ million) – Method 1

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
England	1173.5	1125.8	1128.3	1245.9	1311.2	1284.4	1201.5	1151.9	1185.9	1290.0	1198.8
Scotland	0.0	0.0	0.0	0.0	0.0	0.0	551.2	539.1	529.8	520.7	517.0
Wales	0.0	0.0	0.0	0.0	0.0	143.0	142.6	142.4	142.2	141.9	0.0
GB	0.0	0.0	0.0	0.0	0.0	0.0	1895.3	1833.4	1857.9	1952.5	0.0

3.3 Method 2: annual reduction in fluvial-flood expenditure

Table 9 presents the notional annual reduction in fluvial-flood expenditure that would otherwise be required to maintain the same level of fluvial-flood defence if woodland was absent from upper catchments, i.e. the full replacement cost (see Section 2.4).

The results of using the lower and upper 95% CI are presented in Appendix 2, Table A2.3. The sensitivity analyses that assumed 1:0.5 and 1:1.5 relationships between reduction in peak flow and increase in area at risk of flooding led to values that were 47-48% and 157-161% respectively of the values presented here and in Table A2.3.

Table 9: Annual reduction in fluvial-flood expenditure (£ million) – Method 2

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
England	44.7	42.9	43.1	47.7	50.3	49.4	46.3	44.5	45.8	50.0	46.6
Scotland	0.0	0.0	0.0	0.0	0.0	0.0	23.0	22.5	22.2	21.8	21.7
Wales	0.0	0.0	0.0	0.0	0.0	5.9	5.9	5.9	5.9	5.9	0.0
GB	0.0	0.0	0.0	0.0	0.0	0.0	75.2	72.9	73.9	77.7	0.0

3.4 Method 2: asset values

Table 10 presents the asset values of existing woodland cover in upper catchments for each country in relation to the notional annual reduction in fluvial-flood expenditure immediately above.

The results of using the lower and upper 95% CI are presented in Appendix 2, Table A2.4. The sensitivity analyses that assumed 1:0.5 and 1:1.5 relationships between reduction in peak flow and increase in area at risk of flooding again led to values that were 47-48% and 157-161% respectively of the values presented here and in Table A2.4.

Table 10: Asset values (£ million) – Method 2

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
England	1276.3	1224.5	1227.2	1355.0	1426.0	1396.9	1306.7	1252.8	1289.8	1403.0	1303.8
Scotland	0.0	0.0	0.0	0.0	0.0	0.0	648.6	634.4	623.4	612.7	608.4
Wales	0.0	0.0	0.0	0.0	0.0	165.9	165.4	165.2	165.0	164.6	0.0
GB	0.0	0.0	0.0	0.0	0.0	0.0	2120.8	2052.4	2078.3	2180.3	0.0

4 Discussion

This report has presented and implemented two methods to estimate the value of flood-regulation services provided by existing woodland in upper catchments for inclusion in the UK's ecosystem accounts. As our investigations identified a lack of quantitative research relevant to a UK context that linked differences in the extent of different land covers and land uses to differential reductions in peak flows at a catchment scale, both methods rely upon the results of research related to changes in woodland cover in relation to grazed pasture in the upper reaches of Pontbren[32], a small 6-12km^2 catchment in Wales. More data were available from overseas studies but their relevance to the UK was questionable and other studies in the UK were wholly model-based, e.g. in relation to the Hodder catchment in Northwest England

Method 1 was presented and discussed at the stakeholder workshop held at ONS offices. However, it was subsequently noted that it was based on existing fluvial-flood expenditure that was already notionally reduced by the presence of woodland and, therefore, did not calculate the full replacement cost. Hence, an additional step or alternative approach was developed as Method 2, which was based on the notional annual reduction in fluvial-flood expenditure that would otherwise be required to maintain the same level of fluvial-flood defence if woodland was absent from upper catchments and grazed pasture occurred instead, i.e. the full replacement cost. Estimates of asset values for Great Britain arising from use of central figures from the Pontbren studies in Method 2 (£2,052.4 million to £2,180.3 million) are higher than those from Method 1 (£1,833.4 million to £1,952.5 million). It was not possible to implement Method 1 or 2 for Northern Ireland, as relevant datasets were not made freely available to the study by Northern Ireland's Department of Finance, and asset values were not, therefore calculated for the UK.

A previous study of the Pontbren catchment identified that soil infiltration rates under young native woodland were up to 60 times higher compared to adjacent heavily grazed pasture, with 90% of the improvement occurring within two years of stock removal and tree planting[33]. This suggests that existing woodland may deliver a major share of flood-regulation services associated with land cover and land use in upper catchments. However, the two methods presented and implemented in our report did not take into account the value of flood-regulation services provided by woodland on floodplains, most notably where floodplains narrow and flood flows would otherwise accelerate, thereby reducing potential damage downstream. Nevertheless, existing floodplain woodland is relatively rare so, in relation to the contribution of woodland as a whole, may not substantially increase the asset values presented here. However, it is important to note that the values should be regarded as 'baseline', as they do not take into account likely changes in the extent of woodland cover or the extent of flood risk zones arising from climate change, and in that sense are likely to be highly conservative. Adoption of a replacement-cost approach is also likely to have led to lower estimates than one based on avoided damages, as expenditure on fluvial-flood defence may be only a fraction of the value of assets at risk from flooding (e.g. properties). However, for that same reason, an avoided-damage costs approach could be contentious and its validity in the context of ecosystem accounts would require further consideration and debate if in future it becomes feasible to implement.

While ONS desired a simple and transparent method in order to aid understanding and enable emulation by companies and charities that wish to implement their own natural environment accounts, the simplicity of the approach here and its sole focus on the role of existing woodland in upper catchments in relation to fluvial-flood defence was primarily a product of the lack of:

- Quantitative research relevant to a UK context that links differences in the extent of different land covers and land uses to differential reductions in peak flows at a catchment scale.

[32] McIntyre, N. and Thorne, C. (2013) Land use management effects on flood flows and sediment – guidance on prediction. CIRIA Report C719. CIRIA, London.

[33] Carroll, Z.L.; Bird, S.B.; Emmett, B.A.; Reynolds, B. and Sinclair, F.L. 2004. Investigating the impact of tree shelterbelts on agricultural soils. In: Smithers, R.J. (ed.) Landscape ecology of trees and forests. Proceedings of the twelfth annual IALE(UK) conference, held at the Royal Agricultural College, Cirencester, 21–24 June 2004. IALE(UK). 374pp.

- Data on fluvial-flood expenditure or avoided-damage costs at a catchment scale (although the latter could be calculated in Scotland from the SEPA Flood Risk Annual Average Damages Grids).

4.1 Comparison of values

The values calculated by this study have been compared to existing valuation studies related to flooding and woodland ecosystem services in Table 11. The values are within an order of magnitude of existing valuations of flood-regulation services delivered by woodland and of most valuations of other woodland-ecosystem services. The annual reduction in fluvial-flood defence expenditure that our study estimates can be attributed to woodland cover in upper catchments is also a significant but not disproportionate amount. Any conclusion reached from such comparisons can only largely be guided by intuition, particularly as the values are based on widely differing methodologies. Relying on existing values to provide a sense check risks a form of interpretation bias, as the focus of any comparison should be on the methodologies adopted not the resultant values.

Table 11: Comparison across existing valuations

Studies	Flow value	Flow value from our study
Europe Economics (2015) The Economic Benefits of Woodland.[34]	Value of reduction in flood damage provided by woodland £3.50 - £5.00 per ha	Values for flood-regulation services provided by woodland in upper catchments for Methods 1 and 2 and across years range from £22.00 to £26.60 per ha (2013 values)
eftec (2015), Developing UK Natural Capital Accounts: Woodland Accounts[35]	Values (2012 values): Biomass - £9m to £165m Carbon - £341m to £372m Recreation - £1,669m	Values for Methods 1 and 2 and across years range from £65.1m to £77.7m (2013 values)
Total fluvial-flood expenditure (various sources)	Total calculated expenditure (i.e. capital and revenue) on fluvial-flood defence is £840.6m to £910.5m per annum for years where data on capital expenditure for all countries was made available for our study.	Values expressed as a percentage of actual total expenditure on fluvial-flood defence and across years range from 7.7% to 8.7%

4.2 Sensitivity analyses

Use of figures from the lower and upper 95% confidence intervals associated with the Pontbren studies led to asset values ranging from £890.8 million to £4,424.7 million for Method 1 and from £949.4 million to £6,437.1 million for Method 2.

The results of the sensitivity analyses undertaken for comparison with the simple 1:1 relationships, used for the sake of transparency in the absence of any data, demonstrate:

- A straightforward linear relationship between variation in the ratio (percentage reduction in peak flow in relation to percentage reduction in expenditure) and the results for Method 1.
- A weakly non-linear relationship between variation in the ratio (percentage increase in peak flow in relation to percentage increase in area at risk of flooding if the woodland was absent) and the results for Method 2.

[34] Europe Economics (2015), The Economic Benefits of Woodlands, Woodland Trust.
[35] eftec (2015), Developing UK Natural Capital Accounts: Woodland Accounts. Report for Defra.

4.3 Uncertainties

Data and research gaps, caveats and assumptions, and possible future improvements to the method and future research needs are systematically identified in relation to each stage of the method in Appendix 1. The most notable uncertainties associated with each stage of the method are:

For calculations of the contribution of woodland to flood regulation per catchment:

- The Pontbren study was based on empirical measurements and modelling of a single extreme flood event. The event was not actually observed at Pontbren, so the predicted changes in peak flow are to a degree speculative.
- The Pontbren data is location-specific and differences in a wide range of variables (e.g. soil type, geology, water and land management, and scale between catchments) are likely to lead to substantial variation in relationships between woodland cover in different upper catchments and its impact on peak flows.
- Evidence (mainly modelled) shows that woodland has a declining impact on peak flows with increasing:
    - Scale of catchments due to the limited extent of woodland, wide range of factors influencing flooding within large catchments, and potential for woodland to desynchronise or synchronise peak flows in different sub-catchments, which mean that woodland has greatest potential to reduce peak flows within smaller catchments (<100 km^2).
    - Size of flood event, although woodland can still influence events with a probability of occurring once every 100 years or greater.
- Research demonstrates different woodland types have differential impacts on infiltration rates and run-off. However, the Pontbren data does not allow such consideration, hence, only percentage woodland cover was included in the calculations irrespective of woodland type.
- The inclusion of a number of Interpreted Forest Types might be questionable (e.g. Felled; Ground Prepared for New Planting; Young trees; Failed). However, as 90% of the improvement in soil infiltration rates has been shown to occur within two years of tree planting and as the National Forest Inventory is only updated on a five year cycle, it was assumed that likely growth or regrowth of trees justified their inclusion.

For calculations of flood-defence expenditure per catchment:

- Expenditure on fluvial-flood defence was assumed to be proportional to the number of people at risk of flooding, however, expenditure is also likely to be affected by a wide range of other factors, including catchment characteristics and the value of assets at risk.
- Expenditure is focused on protecting larger communities where cost-benefit is greatest. Protecting smaller communities would be more expensive, which would require much greater expenditure. Hence, the estimated value of flood regulation services delivered by woodland in upper catchments may be an underestimate as calculated, if there is a desire to sustain the same level of fluvial-flood defence for all communities.

For calculation of the notional value of woodland for flood regulation based on Method 1:

- A 1:1 relationship is assumed between reduction in percentage peak flows and percentage reduction in expenditure on fluvial-flood defence, however, as immediately above, expenditure is also likely to be affected by a wide range of other factors, including catchment characteristics and the value of assets at risk.
- The figures anticipate no change over the next 50 years in relation to the extent of woodland cover, the extent of flood risk zones arising from climate change, and fluvial-flood defence expenditure and its impact on reducing peak flows.

For calculations associated with Method 2, in addition to all the uncertainties identified in relation to the stages of Method 1 above:

- A 1:1 relationship is assumed between the percentage increase in peak flow and percentage increase in area at risk of flooding if the woodland was absent. In reality, this relationship is likely to be highly complex dependent on a wide range of variables relating to the nature and location of catchments.

- It is assumed that human population is evenly distributed within each catchment when it is likely to be clustered.
- It may or may not be the case that if existing woodland cover did not exist there would be public demand for expenditure on fluvial-flood defence equivalent to the flood-regulation services provided by that woodland cover.

5 Recommendations

5.1 Results of our study

1 Asset values for flood-regulation services have not previously been presented in the UK's ecosystem accounts. Those presented here are a first attempt to do so and provide a foundation on which to build.

2 The asset values for GB determined from Method 2 and presented in Table 10 (that used the central Pontbren figures and 1:1 relationships) should be included in the UK's woodland accounts, as they are based on the notional annual reduction in fluvial-flood expenditure that would otherwise be required to maintain the same level of fluvial-flood defence if woodland was absent from upper catchments, i.e. the full replacement cost.

3 The asset values should be regarded as a 'baseline' and in that sense are likely to be highly conservative, as they do not take into account likely changes in the extent of woodland cover or the extent of flood risk zones arising from climate change.

4 Considerable care should be taken in presentation of the UK's aggregate woodland accounts. Different methodologies have been used to calculate values for the various ecosystem services, so their meanings are very different from one another. Aggregating values risks losing this sense of nuance and suggests a fungibility of ecosystem-service valuations, which does not reflect reality.

5.2 Possible improvements to method

5 Existing Northern Ireland data on digitised boundaries of catchments and flood risk areas, and on annual expenditure on fluvial-flood defence should be secured from Northern Ireland's Department of Finance, so that a UK value can be calculated using Method 2 to update the UK's woodland accounts.

6 Further consideration should be given to the relative merits of including each of the Interpreted Forest Types categorised as "Woodland" within the Forestry Commission's National Forest Inventory when determining the percentage woodland cover in each upper catchment.

7 Data should be investigated for England, Northern Ireland and Wales that would allow fluvial flood-defence expenditure to be apportioned to each catchment pro rata based on the value of assets (as exemplified by SEPA Flood Risk Annual Average Damages Grids), rather than number of people, at risk of fluvial flooding.

8 There should be a further search for the availability of projections for the next 50 years of the extent of woodland cover, the extent of flood risk zones arising from climate change, and the spatial distribution of population growth that could be used to determine and apply changes at a catchment level. Likely increases in the extent of woodland cover and flood risk zones could significantly increase asset values.

9 As an interim measure in the absence of suitable projections, sensitivity analyses should be undertaken incorporating estimations of change in figures over the next 50 years in relation to woodland cover and the extent of flood risk zones. Likely increases in the extent of woodland cover and flood risk zones could significantly increase asset values.

5.3 Enhanced data collection

10 The agencies in England, Northern Ireland and Wales should seek to collate data nationally on fluvial-flood expenditure and avoided-damage costs (as exemplified by SEPA Flood Risk Annual

Average Damages Grids) at a catchment scale. This would not only aid enhancement of the methods presented here and allow application of any new quantitative research to further development of the UK's ecosystem accounts but could also enable cost-benefit analyses of fluvial-flood defence schemes to take greater account of the role of ecosystems.

11 If data was available on expenditure on fluvial-flood defence (or potential avoided-damage costs) linked to an anticipated reduction in a flood metric (e.g. percentage reduction in peak flow), ideally at a catchment level then it would be possible to get a better fix on the value of woodland in terms of its replacement cost (avoided damage cost). For example, if £100m reduces peak flows by 10% and 10% woodland cover reduces peak flows by 15% then the value flood-regulation services provided by the woodland would be £150 million.

5.4 Future research priorities

12 A Systematic Review or Rapid Evidence Assessment is required to identify if there is other quantitative research relevant to a UK context that links differences in the extent of different land covers and land uses to differential changes in peak flows at a catchment scale in such a way that it could be used to further develop the UK's ecosystem accounts. These needs may be fulfilled by an ongoing project "SC150005 - Working with Natural Processes (WWNP) - evidence base & catchment/coastal laboratories" commissioned by the Environment Agency, which *"aims to develop a high quality Working with Natural Processes evidence base to help flood and coastal erosion risk management (FCERM) authorities understand, justify, develop and implement FCERM schemes which include WWNP to reduce flood risk".* The project started in February 2016 and ends in August 2017.

13 There is an urgent need for further quantitative research (including modelling) relevant to a UK context that links variation in the extent of land covers and land uses to differential changes in peak flows at a catchment scale. Most notably, this research should address the impact of changes in:

- Percentage woodland cover by woodland type (e.g. at least conifer and broadleaved) in upper catchments to improve this study's calculation of the value of flood-regulation provided by woodland.
- Percentage cover by habitat in upper catchments to enable calculation of the value of flood-regulation services and its disaggregation by habitat.
- Percentage cover by habitat on floodplains to enable calculation of the value of flood-regulation services and its disaggregation by habitat.

Appendices

Appendix 1: Key issues in relation to each stage of the method

Appendix 2: Sensitivity analyses

Appendix 1: Key issues in relation to each stage of the method

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
Method 1				
1. Contribution of woodland to flood regulation per catchment				
1.1	Digitised Water Framework Directive Catchment boundaries for England and Wales provided by the Environment Agency (EA) and Natural Resources Wales (NRW) respectively. Digitised main river and coastal catchments for Scotland provided by the Scottish Environment Protection Agency (SEPA). Digitised Flood Map for Planning (Rivers and Sea) Flood Zone 3 for England and Flood Zone 3 for Wales supplied by EA and NRW respectively. Flood Zone 3 comprises land having a 1 in 100-year or greater (i.e. >1%) annual probability of flooding. Digitised boundaries of land comprises land having a 1 in 200-year or greater (i.e. >0.5%) annual probability of flooding, included in the Flood Hazard and Flood Risk dataset for Scotland	Existing digitised boundaries of catchments and flood risk areas for Northern Ireland were not made freely available for this study by Northern Ireland's Department of Finance, hence, this analysis could not proceed in its regard.	All land outside Flood Zone 3 in England and Wales and outside the 1 in 200-year flood envelope in Scotland were defined as the upper catchment.	Undertaking the same analysis for Northern Ireland.

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
	provided by SEPA (as the 1 in 200-year flood envelope is used by SEPA for flood risk management in Scotland rather than the 1 in 100 year flood envelope used by EA and NRW in England and Wales).			
1.2	The Forestry Commission's National Forest Inventory – NFI (Woodland GB 2015) and Northern Ireland's Woodland Basemap in order to identify woodland cover.	Research demonstrates different woodland types have differential impacts on infiltration rates and run-off. However, the Pontbren data does not allow such consideration, so percentage woodland cover was determined irrespective of woodland type.	All those areas categorised in the NFI as "Woodland" were taken into account and included the following Interpreted Forest Types (IFTs): Broadleaved; Conifer; Felled; Ground Prepared for New Planting; Mixed - predominantly Broadleaved; Mixed - predominantly Conifer; Young Trees; Coppice; Coppice with Standards; Shrub Land; Uncertain; Cloud or Shadow; Low Density; Assumed woodland; Failed; Windthrow/Windblow. The inclusion of a number of these IFTs might be questionable (e.g. Felled; Ground Prepared for New Planting; Young trees; Failed). However, as 90% of the improvement in soil infiltration rates has been shown to occur within two years of tree planting	Further consideration given to the relative merits of including each IFT.

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
			and as the National Forest Inventory is only updated on a five year cycle, it was assumed that likely growth or regrowth of trees justified their inclusion.	
1.3	Data from the Pontbren studies providing figures for mean percentage change in peak flows associated with an increase or reduction of 7% woodland cover and an increase of 93% woodland cover, which were based on 7% existing woodland cover and changes from/to grazed pasture.[36]	Investigations revealed a lack of quantitative research relevant to a UK context that linked differences in the extent of different land covers and land uses to differential reductions in peak flows at a catchment scale. The only research found to do so related to changes in woodland cover on grazed pasture in the upper reaches of Pontbren[37,38]	The Pontbren study was based on empirical measurements and modelling of a single extreme flood event. The event was not actually observed at Pontbren, so the predicted changes in peak flow are to a degree speculative. Having consulted with the authors of the Pontbren studies[39], we interpreted the data cumulatively in relation to a baseline of 0% existing woodland cover to provide data points for mean percentage change in peak flow associated with 0% to 100% woodland cover in the upper catchment. Given the limited number of data points and the need for prudency, a piecewise linear relationship was assumed	A Systematic Review or Rapid Evidence Assessment to identify if there is other quantitative research relevant to a UK context that links differences in the extent of different land covers and land uses to differential changes in peak flows at a catchment scale in such a way that it could be used to further develop the UK's ecosystem accounts. Quantitative research (including modelling) for a representative sample of catchments across the UK on the impact on peak flows of changes in: • Percentage woodland cover by woodland type (e.g. at least conifer and broadleaved) in upper

[36] McIntyre, N. and Thorne, C. (2013) Land use management effects on flood flows and sediment – guidance on prediction. CIRIA Report C719. CIRIA, London.
[37] McIntyre, N. et al. (2012) The potential for reducing flood risk through changes to rural land management: outcomes from the Flood Risk Management Research Consortium. BHS Eleventh National Symposium, Hydrology for a changing world, Dundee 2012. British Hydrological Society
[38] McIntyre, N. and Thorne, C. (2013) Land use management effects on flood flows and sediment – guidance on prediction. CIRIA Report C719. CIRIA, London.
[39] McIntyre, N. and Thorne, C. pers. comm.

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
			between percentage woodland cover in the upper catchment and percentage reduction in peak flow with a breakpoint at 14% woodland cover.	catchments. • Percentage cover by habitat in upper catchments to enable calculation of the value of flood-regulation services and its disaggregation by habitat. • Percentage cover by habitat on floodplains to enable calculation of the value of flood-regulation services and its disaggregation by habitat.
1.4	% woodland cover in each upper catchment established in Stage 1.2. The relationship between % woodland cover in upper catchments and % reduction in peak flows established in Stage 1.3.	There is a lack of quantitative research relevant to a UK context that links differences in the extent of different land covers and land uses to differential reductions in peak flows at a catchment scale. The only research found to do so related to changes in woodland cover on grazed pasture in the upper reaches of Pontbren[40].	Pontbren is a small 6-12km catchment in Wales. The Pontbren data is location-specific and differences in a wide range of variables (e.g. soil type, geology, water and land management, and scale between catchments) are likely to lead to substantial variation in relationships between woodland cover in different upper catchments and its impact on peak flows. The results of studies at Pontbren are broadly supported	As Stage 1.3.

[40] McIntyre, N. and Thorne, C. (2013) Land use management effects on flood flows and sediment – guidance on prediction. CIRIA Report C719. CIRIA, London.

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
			by field data from other manipulation experiments[41]. Nevertheless, substantial uncertainties arise about the impact of woodland cover in upper catchments at larger scales and in relation to larger flood events because evidence (mainly modelled) [12,42,43,44,45] shows that woodland has a declining impact on peak flows with increasing: • Scale of catchments due to the limited extent of woodland, wide range of factors influencing flooding within large catchments, and potential for woodland to desynchronise or synchronise peak flows in different sub-catchments, which mean that woodland has greatest potential to reduce peak flows within smaller catchments (<100	

[41] Jackson B.M.; Wheater, H.S.; McIntyre N.R.; Chell J.; Francis O.J.; Frogbrook Z.; Marshall, M.; Reynolds B. and Solloway I. 2008. The impact of upland land management on flooding: insights from a multiscale experimental and modelling programme. *Journal of Flood Risk Management*, 1: 71-80.

[42] Calder, I. and Aylward, B. 2006. Forest and floods: Moving to an evidence-based approach to watershed and integrated flood management. *Water International*, 87-99.

[43] Nisbet, T.R. and Thomas, H. 2008. Restoring floodplain woodland for flood alleviation. Final report for the Department of Environment, Food and Rural Affairs (Defra), Project SLD2316. Defra, London.

[44] Odoni, N.A. and Lane, S.N. 2010. Assessment of the impact of upstream land management measures on flood flows in Pickering using OVERFLOW. Contract report to Forest Research for the Slowing the Flow at Pickering Project. Durham University, Durham.

[45] Nisbet, T.R.; Roe, P.; Marrington, S.; Thomas, H.; Broadmeadow, S. and Valatin, G. 2015. Slowing the flow at Pickering. Final Report on Phase II for the Department of environment, food and rural affairs (Defra), Project RMP5455. Defra, London. Available at: http://www.forestry.gov.uk/fr/slowingtheflow

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
			km^2). • Size of flood event, although woodland can still influence events with a probability of occurring once every 100 years or greater. The NFI data is for 2015 and our method does not project change in woodland cover, implying that the reduction in peak flow in each upper catchment is constant over time.	
Method 1 **2. Flood-defence expenditure per catchment**				
2.1	Human population density at 1x1 km resolution based on ONS 2011 Census data. The digitised Flood Map for Planning (Rivers and Sea) Flood Zone 3 for England and Flood Zone 3 for Wales supplied by EA and NRW respectively. The digitised boundaries of land comprises land having a 1 in 200-year or greater (i.e. >0.5%) annual probability of flooding, included in the Flood Hazard and Flood Risk dataset for Scotland provided by SEPA.		Cookie-cutting the 1x1km population dataset by the boundaries of areas at risk of flooding assumes that human population density does not vary within each 1x1km square.	

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
2.2	**England** data (supplied by EA), on annual combined total expenditure on fluvial and coastal flood defence (2005/2006 to 2015/2015), broken down into totals for capital expenditure and revenue expenditure funded by Government and by charges/levies/other income. **Wales** data (supplied by Welsh Government) on the estimated expenditure on fluvial-flood defence for the financial year 2010/2011 to 2014/2015. The data comprised a lump sum expenditure (£64.4 million) for this period covering expenditure from both the Welsh Government (£46 million) and local authorities (£18.3 million). However, the data only covered capital expenditure (i.e. revenue expenditure was not provided). **Scotland** data (supplied by Scottish Government via SEPA) on the total estimated annual expenditure on fluvial-flood defence funded by Scottish Government for each of the	Value of assets (as exemplified by SEPA Flood Risk Annual Average Damages Grids) in Flood Zone 3 (England and Wales) or having a 1 in 200-year or greater (i.e. >0.5%) annual probability of flooding (Scotland) by catchment. Annual capital and revenue expenditure on fluvial-flood defence collated by catchment. Annual fluvial-flood damage costs collated by catchment.	England data did not differentiate between fluvial and coastal expenditure, so the proportion relevant to fluvial-flood defence was estimated as 55% in accordance with EA's new investment programme. All expenditure data was adjusted for inflation and expressed as 2013 prices following Defra and ONS' principles for ecosystems accounting. Annual capital expenditure was assumed to be relatively constant, so was not annualised over the lifetime of the asset. Harmonisation of expenditure data on fluvial-flood defence meant: • England's values for capital and revenue expenditure were deflated using GDP deflators for all years. • Scotland's single value for total capital expenditure 2011-2015 was treated as a constant expenditure in nominal terms across the	Apportioning fluvial flood-defence expenditure to each catchment pro rata based on the value of assets, rather than number of people, at risk of fluvial flooding. Expenditure on fluvial-flood defence collated by catchment would avoid having to make the assumptions in the neighbouring column.

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
	financial years 2011/2012 to 2015/2016[46] plus an additional 20% funded by local authorities, totalling £52.5 million annually. Like Wales, the data only covered capital expenditure excluding revenue expenditure to maintain the services. In addition, the expenditure was not exclusively but predominantly related to fluvial-flood defence. **Northern Ireland** data regarding annual expenditure on fluvial-flood defence was not made available to this study, so again, the analysis could not proceed in its regard.		period, as that was the form in which the data was provided. An estimate of total expenditure (capital and revenue) was calculated using the average proportion of capital expenditure to overall expenditure in England across all years. This total expenditure value for Scotland was deflated using the GDP deflators. • Wales' total capital expenditure across the period 2010/2011 to 2014/2015 was allocated to each year using a weighted average based on the inflation index over the period to provide annual capital expenditure. An estimate of total expenditure (capital and revenue) was calculated using the average proportion of capital expenditure to overall expenditure in England across all years. This total expenditure value for Wales was deflated using the GDP	

[46] No detailed breakdown across the years given.

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
			deflators. It was assumed that expenditure on fluvial-flood defence was proportional to the number of people at risk of flooding. This allowed fluvial flood-defence expenditure to be apportioned to each catchment pro rata based on the number of people at risk of fluvial flooding. In reality, expenditure is also likely to be affected by a wide range of other factors, including catchment characteristics and the value of assets at risk.	
Method 1 **3. Notional value of woodland for flood regulation based on replacement cost method**				
3.1	Expenditure data on fluvial-flood defence, as detailed and harmonised at Stage 2.2 above. Data on % woodland cover in each upper catchment, as determined at Stage 1.2 above. Data on the notional contribution of woodland to fluvial-flood regulation in terms of % reduction in peak flows for each catchment, as determined at Stage 1.4.	Flood-defence schemes are assessed on a case-by-case basis in relation to assets at risk not at a catchment level. Hence, data is not collated at a catchment level and there is no relevant research linking expenditure on fluvial-flood defence with flood metrics (e.g. % reduction in peak flows) or linking avoided-damage costs with flood metrics.	A 1:1 relationship was assumed between reduction in percentage peak flows and percentage reduction in expenditure on fluvial-flood defence, however, as immediately above, expenditure is also likely to be affected by a wide range of other factors, including catchment characteristics and the value of assets at risk. It was assumed that if the existing woodland cover did not	If data was available on expenditure on fluvial flood defence (or potential avoided-damage costs) linked to an anticipated reduction in a flood metric (e.g. % reduction in peak flow), ideally at a (sub)catchment level then it would be possible to get a better fix on the value of woodland in terms of its replacement cost (avoided damage cost). For example, if £100m reduces peak flows by 10% and 10% woodland cover

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
			exist there would be public demand for expenditure on flood defence equivalent to the flood-regulation services provided by that woodland cover. Calculations were based on expenditure that had notionally already been reduced by the presence of the woodland rather than calculating the additional expenditure that would be required to maintain the same level of fluvial-flood defence if the woodland was absent.	reduces peak flows by 15% then the value flood-regulation services provided by the woodland would be £150 million.
3.2	UK Population Projections: 2014-based principal projection for the UK (available at https://www.ons.gov.uk/)	No projections were available to determine changes at a catchment level over the next 50 years in: • The extent of woodland cover. • The extent of flood risk zones arising from climate change. • The spatial distribution of population growth. • Fluvial flood defence expenditure (or potential avoided-damage costs) and its impact on flood metrics (e.g. % reduction in peak	The asset values assume that there will be no change over the next 50 years in relation to the gaps in data highlighted in the neighbouring column. A 1:1 relationship was assumed between population growth and flow values over the asset’s lifetime, which thereby assumed that future population growth would be the same across all catchments.	Further investigate availability of and, where necessary, develop projections, as detailed in the gaps in research/data in order that the method could be subsequently improved. As an interim measure in the absence of suitable projections, undertake sensitivity analyses incorporating estimations of change in figures over the next 50 years in relation to the gaps in research/data highlighted in the relevant column in this row. Likely increases in the extent of woodland cover and flood risk zones could significantly

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
		flows).		increase asset values.
Method 2: an additional step or alternative approach				
		Value of assets (as exemplified by SEPA Flood Risk Annual Average Damages Grids) in Flood Zone 3 (England and Wales) or having a 1 in 200-year or greater (i.e. >0.5%) annual probability of flooding (Scotland) by catchment. Annual capital and revenue expenditure on fluvial-flood defence collated by catchment. Annual fluvial-flood damage costs collated by catchment.	For each catchment, the increase in the number of people at risk from flooding in the absence of the woodland was calculated[47] by regarding the existing figure calculated in Stage 2.1 as being the result of the percentage reduction in peak flow delivered by woodland in the upper catchment calculated in Stage 3.1. Hence, this assumed a 1:1 relationship between the percentage increase in peak flow and the percentage increase in area at risk of flooding if the woodland was absent. In reality, this relationship is likely to be highly complex dependent on a wide range of variables relating to the nature and location of catchments. It was assumed that human population is evenly distributed within each catchment when it is likely to be clustered. It may or may not be the case	Modelling the larger size, shape and number of areas at risk of flooding if existing woodland was absent, which itself would rely on further quantitative research identified at Stage 1.3. This would then mean the resultant increase in population at risk of flooding (or value of assets at risk or expenditure on fluvial-flood defence collated by catchment, see Stage 2.2 improvements/future research) in each catchment could then be used to calculate the notional increase in fluvial-flood expenditure (also see Method 2 below).

[47] Specifically, we calculate $Population\ without\ woodlands = current\ population/(1 - \%\ reduction\ in\ peakflow)$

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
			that if existing woodland cover did not exist there would be public demand for expenditure on fluvial-flood defence equivalent to the flood-regulation services provided by that woodland cover.	
Calculation of asset values				
	Estimated annual reduction in fluvial-flood expenditure determined from Method 1 and, alternatively, using Method 2.	Results for GB were only calculated for those years where data were available for all three constituent countries (i.e. 2011-2014).	The estimated current value of the percentage reduction in peak flows provided by the percentage woodland cover in upper catchments is assumed to be a reasonable proxy of its future value provided that an appropriate discount rate of 3.5% is applied. Capital costs were attributed to a single year, the year in which the expenditure was made. The asset values were calculated as the sum of the Net Present Value (NPV) over a lifetime of 50 years, in accordance with Defra and ONS' principles for ecosystem accounts. The discount rate for the first 30 years was 3.5% and for the following 20 years was 3%, in accordance with H.M Treasury's	

Stage (see Figure 1)	Data secured	Gaps in research/data	Caveats and assumptions	Improvements/future research
			Green Book[48].	

[48] H.M. Treasury. 2013, The Green Book: appraisal and evaluation in central government. London: TSO.

Appendix 2: Sensitivity analyses

Table A2.1: Annual reduction in fluvial-flood expenditure (£ million) – Method 1

	Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
England	Central	41.1	39.4	39.6	43.9	46.2	45.4	42.6	40.9	42.1	46.0	42.8
	Low CI	20.3	19.5	19.5	21.6	22.8	22.4	21.0	20.2	20.8	22.7	21.1
	Upper CI	87.6	84.1	84.5	93.5	98.5	96.8	90.8	87.2	89.8	98.0	91.3
Scotland	Central	0.0	0.0	0.0	0.0	0.0	0.0	19.5	19.1	18.8	18.6	18.5
	Low CI	0.0	0.0	0.0	0.0	0.0	0.0	9.3	9.1	8.9	8.8	8.8
	Upper CI	0.0	0.0	0.0	0.0	0.0	0.0	49.2	48.1	47.4	46.7	46.5
Wales	Central	0.0	0.0	0.0	0.0	0.0	5.1	5.1	5.1	5.1	5.1	0.0
	Low CI	0.0	0.0	0.0	0.0	0.0	2.4	2.4	2.4	2.4	2.4	0.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	13.0	13.0	13.0	13.0	13.0	0.0
GB	Central	0.0	0.0	0.0	0.0	0.0	0.0	67.2	65.1	66.0	69.6	0.0
	Low CI	0.0	0.0	0.0	0.0	0.0	0.0	32.7	31.6	32.1	33.8	0.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	0.0	153.0	148.3	150.2	157.7	0.0

Table A2.2: Asset values (£ million) – Method 1

	Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
England	Central	1173.5	1125.8	1128.3	1245.9	1311.2	1284.4	1201.5	1151.9	1185.9	1290.0	1198.8
	Low CI	578.7	555.2	556.4	614.3	646.5	633.3	592.5	568.0	584.8	636.1	591.1
	Upper CI	2501.4	2399.7	2405.0	2655.6	2794.7	2737.7	2561.0	2455.3	2527.8	2749.6	2555.2
Scotland	Central	0.0	0.0	0.0	0.0	0.0	0.0	551.2	539.1	529.8	520.7	517.0
	Low CI	0.0	0.0	0.0	0.0	0.0	0.0	261.1	255.4	251.0	246.7	244.9
	Upper CI	0.0	0.0	0.0	0.0	0.0	0.0	1386.6	1356.2	1332.7	1309.8	1300.5
Wales	Central	0.0	0.0	0.0	0.0	0.0	143.0	142.6	142.4	142.2	141.9	0.0
	Low CI	0.0	0.0	0.0	0.0	0.0	67.7	67.5	67.4	67.3	67.1	0.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	368.3	367.2	366.7	366.3	365.3	0.0
GB	Central	0.0	0.0	0.0	0.0	0.0	0.0	1895.3	1833.4	1857.9	1952.5	0.0

	Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	Low CI	0.0	0.0	0.0	0.0	0.0	0.0	921.1	890.8	903.1	949.9	0.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	0.0	4314.7	4178.1	4226.8	4424.7	0.0

Table A2.3: Annual reduction in fluvial-flood expenditure (£ million) – Method 2

	Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
England	Central	44.7	42.9	43.1	47.7	50.3	49.4	46.3	44.5	45.8	50.0	46.6
	Low CI	21.1	20.2	20.3	22.5	23.7	23.3	21.9	21.0	21.6	23.6	22.0
	Upper CI	112.1	107.7	108.1	119.7	126.2	123.9	116.3	111.6	115.0	125.5	116.9
Scotland	Central	0.0	0.0	0.0	0.0	0.0	0.0	23.0	22.5	22.2	21.8	21.7
	Low CI	0.0	0.0	0.0	0.0	0.0	0.0	10.3	10.1	9.9	9.8	9.8
	Upper CI	0.0	0.0	0.0	0.0	0.0	0.0	86.4	84.6	83.2	82.0	81.7
Wales	Central	0.0	0.0	0.0	0.0	0.0	5.9	5.9	5.9	5.9	5.9	0.0
	Low CI	0.0	0.0	0.0	0.0	0.0	2.6	2.6	2.6	2.6	2.6	0.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	21.9	21.9	21.9	21.9	21.9	0.0
GB	Central	0.0	0.0	0.0	0.0	0.0	0.0	75.2	72.9	73.9	77.7	0.0
	Low CI	0.0	0.0	0.0	0.0	0.0	0.0	34.8	33.7	34.2	36.0	0.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	0.0	224.5	218.1	220.2	229.4	0.0

Table A2.4: Asset values (£ million) – Method 2

	Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
England	Central	1276.3	1224.5	1227.2	1355.0	1426.0	1396.9	1306.7	1252.8	1289.8	1403.0	1303.8
	Low CI	602.0	577.5	578.8	639.1	672.6	658.8	616.3	590.9	608.3	661.7	614.9
	Upper CI	3203.1	3072.9	3079.7	3400.6	3578.8	3505.7	3279.4	3144.1	3237.0	3520.9	3272.1
Scotland	Central	0.0	0.0	0.0	0.0	0.0	0.0	648.6	634.4	623.4	612.7	608.4
	Low CI	0.0	0.0	0.0	0.0	0.0	0.0	291.1	284.7	279.8	275.0	273.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	0.0	2436.5	2383.1	2341.8	2301.6	2285.3
Wales	Central	0.0	0.0	0.0	0.0	0.0	165.9	165.4	165.2	165.0	164.6	0.0
	Low CI	0.0	0.0	0.0	0.0	0.0	74.1	73.9	73.8	73.7	73.5	0.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	619.5	617.6	616.8	616.1	614.5	0.0

	Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
GB	Central	0.0	0.0	0.0	0.0	0.0	0.0	2120.8	2052.4	2078.3	2180.3	0.0
	Low CI	0.0	0.0	0.0	0.0	0.0	0.0	981.3	949.4	961.8	1010.2	0.0
	Upper CI	0.0	0.0	0.0	0.0	0.0	0.0	6333.6	6144.0	6194.9	6437.1	0.0

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