Forest Research

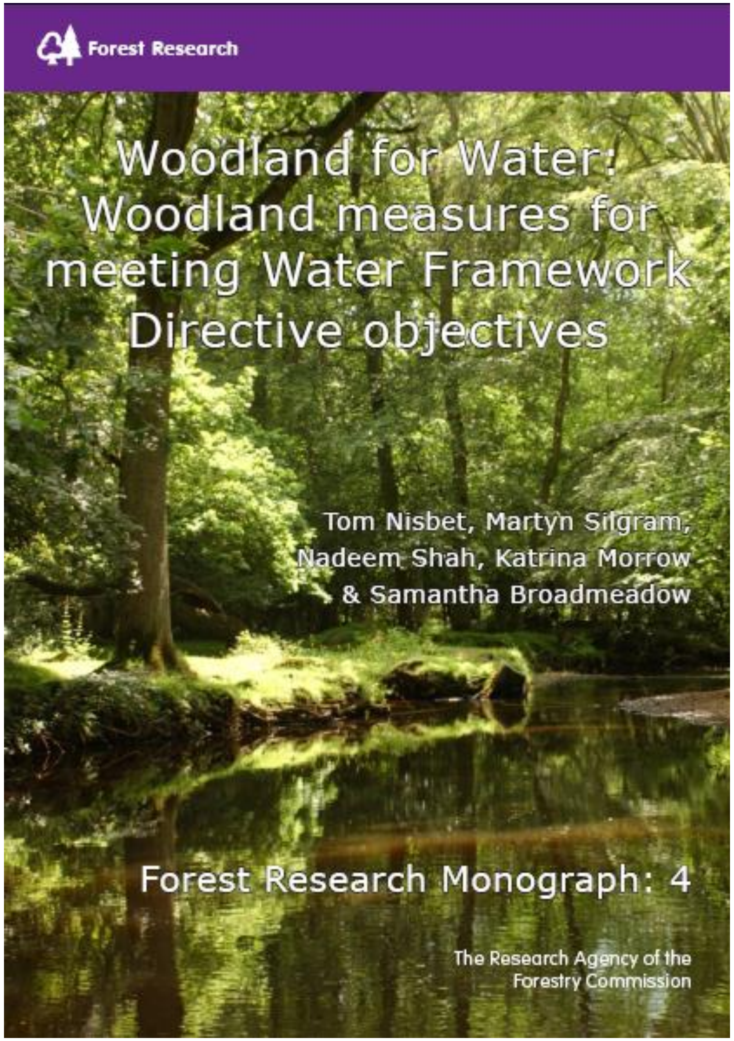
Water Services – Protecting Water Quality, Shade Provision and Flood Regulation

Dr T R Nisbet, Head of Physical Environment Research

A well known service: role of protection forests

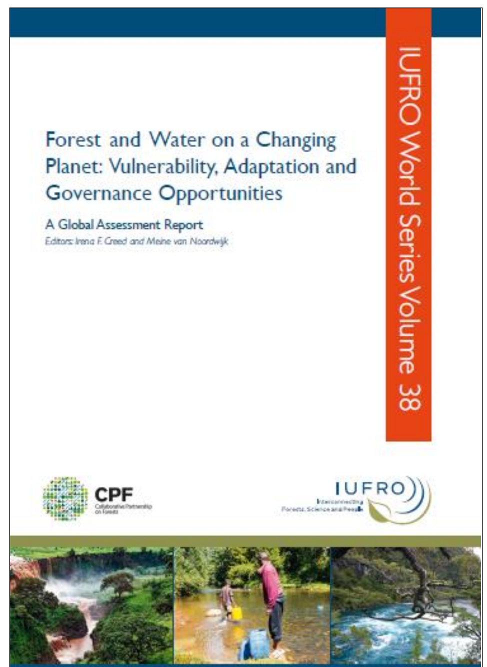
Case for Water Protection

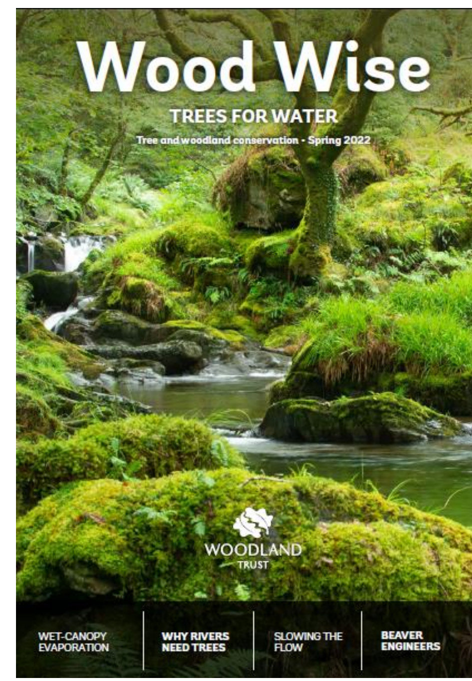
- Semi-permanent land cover, protecting soils and water from disturbance;
- Tight cycling of nutrients, yielding good water quality;
- Canopy provides physical shelter, moderating rainfall inputs and water temperature;
- Well structured soils increase rainfall infiltration and water storage, reducing rapid runoff;
- Riparian woodland improves river channel form and connectivity, increasing habitat diversity and slowing the flow;
- But water benefits are dependent on good forest design and management!



https://www.gov.uk/government/publications/woodland-for-water

"There is strong evidence to support forest planting in appropriate locations to achieve water management and water quality objectives"





Growing Demand for Water Services

- Water environment and ecological status remains severely impacted by diffuse pollution; woodland can reduce sediment delivery, nutrient inputs (nitrate and phosphate), pesticide runoff and FIO load;
- Freshwater environment under increasing thermal stress; woodland can provide effective cooling;
- Flood risk appears to be increasing and FRM more expensive; woodland can reduce flood peaks;
- Woodland creation provides a secure and sustainable measure to tackle these pressures;
- Effectiveness depends on location, scale, design and management.

Pollutant inputs are much lower to woodland compared to agriculture

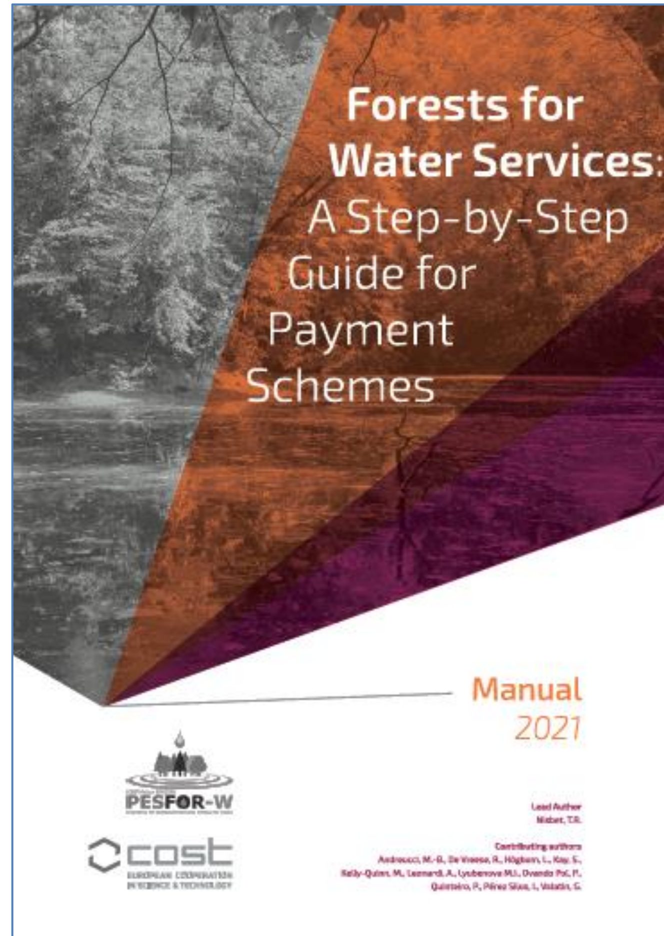
	Permanent Grassland	Rough Pasture	Wheat	Barley	Maize	Oil Seed Rape	Woodland
Nitrogen Input (kg/ha/yr)	94-135	10	131-167	120-132	46-62	155-189	20
Nitrate-N Export (kg/ha/yr)	0.86-10.58	0.02-0.05	1.54-19.72	1.54-19.72	1.52-19.72	3.29-17.4	0.02-0.1
Phosphate Input (kg/ha/yr)	6-16	0	13-35	18-41	27-43	15-37	0
Phosphate Export (kg/ha/yr)	0.012-0.169	0.008	0.038-0.458	0.038-0.458	0.038-0.458	0.15-1.834	0.008

Table 1
Nutrient loads and modelled export coefficients for different crops vs woodland in Great Britain. Nutrient loads taken from the British Survey of Fertiliser Practice for 2000-2011 (BSFP, 2013) and export coefficients based on the same data modelled for the UK National Ecosystem Assessment Follow-on Report (Bateman et al., 2014).

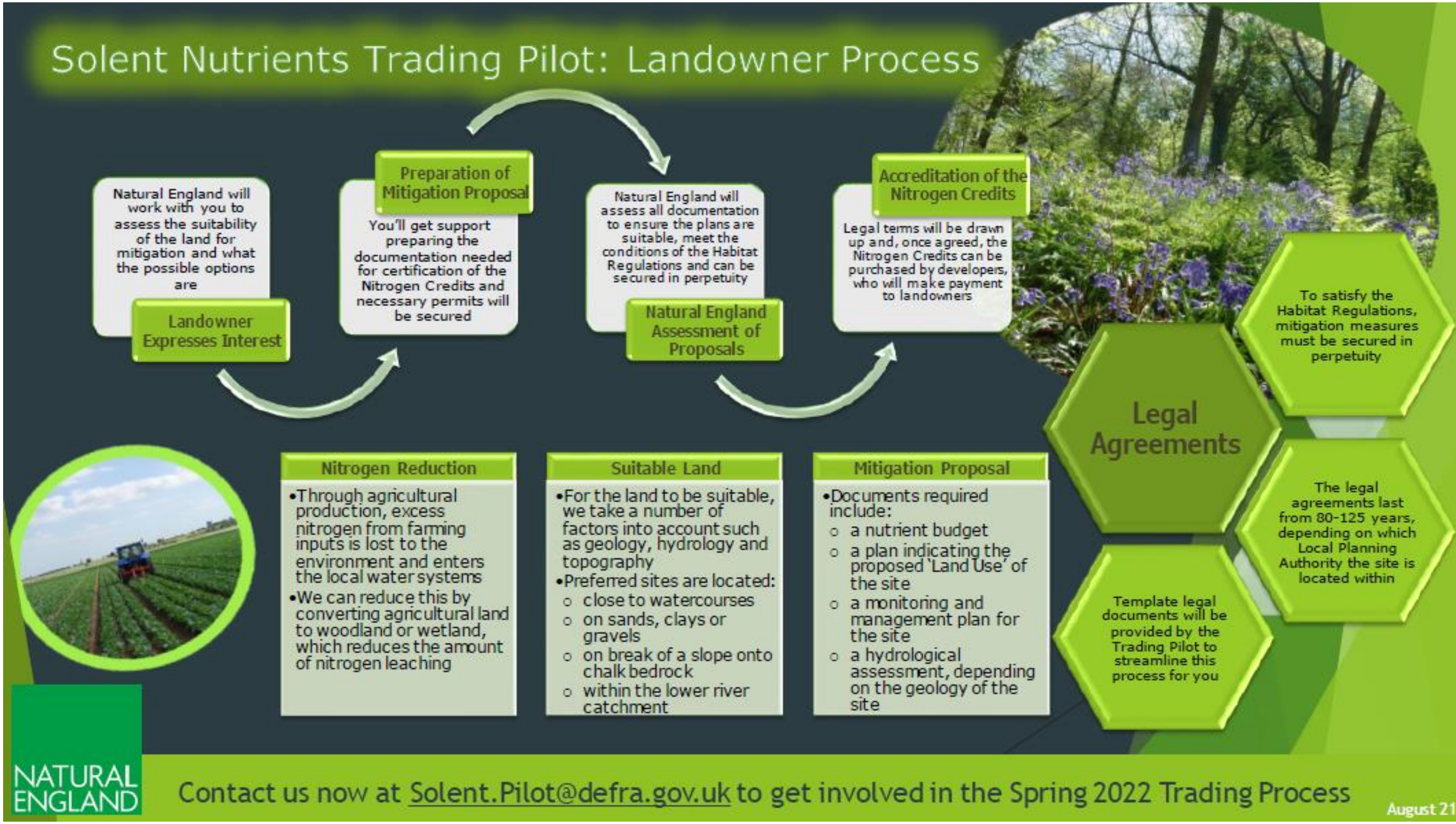
Effectiveness: Buffers

Woodland buffers are effective for removing pollutants draining adjacent land; buffer width is a key factor:

Buffer width	5 m	10 m	20 m
Nitrate-N	20%	30%	40%
Phosphate-P	10%	20%	30%
Suspended Sediment	80%	90+%	90+%

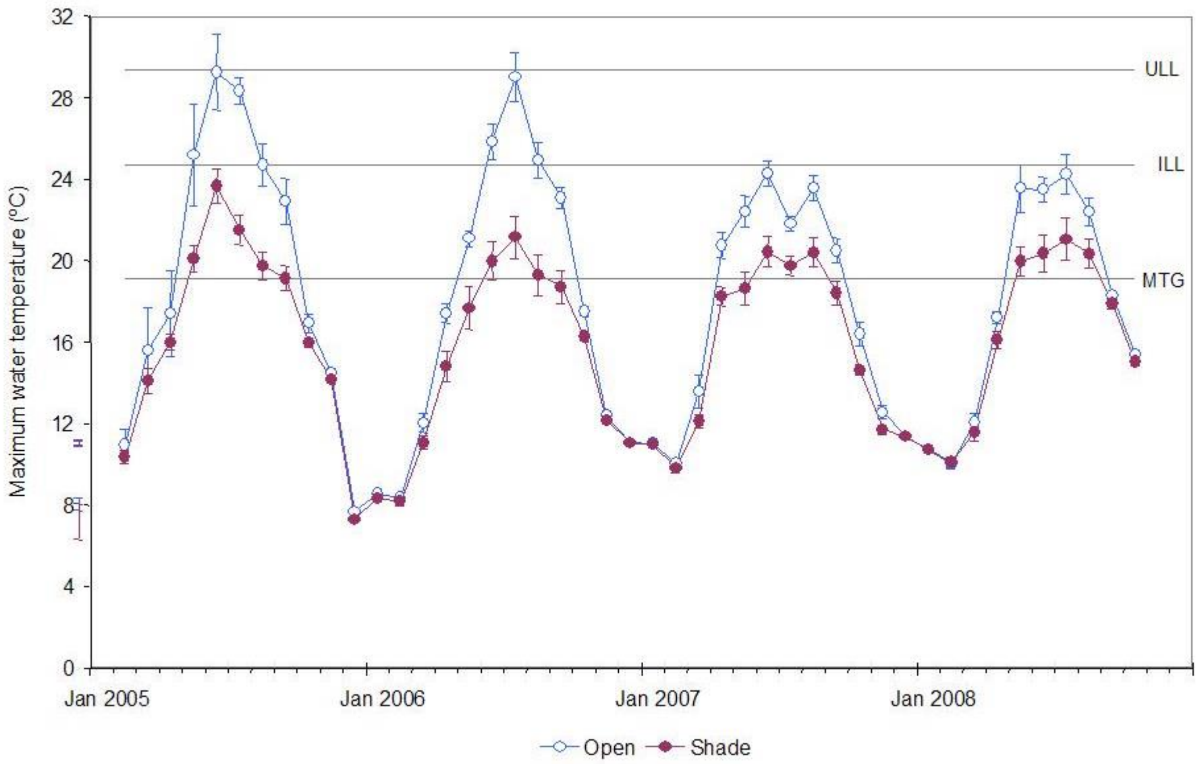


Nutrient Trading



Underpinned by Nutrient Reduction Standard for Interceptor Woodland projects (ARUP & EnTrade, 2022)

Effectiveness: Cooling



Daily peaks in water temp typically 5˚C cooler in shaded reaches (Broadmeadow et al., 2010); shaded channels typically 1.5˚C lower on average than open (KRC)

Depth (m)	Velocity (m/s) 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	48	96	144	192	240	288	336	384	288	480
0.2	102	204	306	408	510	612	714	816	288	1020
0.3	150	300	450	600	750	900	1050	1200	288	1500
0.4	192	384	576	768	960	1152	1344	1536	288	1920
0.5	240	480	720	960	1200	1440	1680	1920	288	2400
0.6	300	600	900	1200	1500	1800	2100	2400	288	3000
0.7	360	720	1080	1440	1800	2160	2520	2880	288	3600
0.8	390	780	1170	1560	1950	2340	2730	3120	288	3900
0.9	450	900	1350	1800	2250	2700	3150	3600	288	4500
1	498	996	1494	1992	2490	2988	3486	3984	288	4980

[Johnson and Wilby, 2015]

Shade-a-lator

Quantifying solar load avoided through riparian restoration

Riparian shade provided by streamside vegetation blocks the sun's rays from reaching the surface of the water, reducing the amount of thermal energy entering the river. In effect, this shade prevents the water from heating up. Anadromous fish, such as salmon and steelhead, are extremely sensitive to water temperature; therefore, healthy riparian buffers help ensure healthy fish habitat.

Shade-a-lator is a module of Heat Source, a stream assessment tool used by Oregon Department of Environmental Quality (ODEQ). It was developed in 1996 at Oregon State University in the Departments of Bioresource Engineering and Civil Engineering. ODEQ currently maintains the Heat Source methodology and software development.

Using pre-project data (see sidebar for model inputs), **Shade-a-lator** calculates the current load of solar radiation reaching the surface of a stream. Once vegetation is planted, **Shade-a-lator** predicts the new load of solar radiation reaching the stream based on the new vegetation's shading capacity at maturity. The difference between pre-project and post-project solar loading represents a project's uplift in terms of solar radiation avoided by streamside riparian vegetation. **Shade-a-lator** expresses this uplift in energy units of kilocalories per day. Once we have this calculation, we can determine which restoration sites will most benefit from riparian restoration.

Shade-a-lator has been in use and ongoing development for more than a decade. With The Freshwater Trust's projects, its refinement will continue.

Field staff maintain a freshly planted riparian site in the Rogue Basin of southern Oregon.

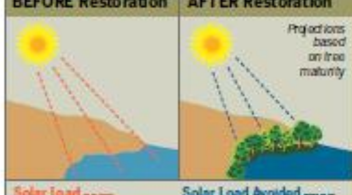
MODEL INPUTS

- Upstream & downstream boundaries of the stream reach
- Stream aspect (azimuth)
- Wetted width of the stream
- Bank slope
- Distribution of existing riparian trees & plants
- Modeling time period, including the time of year the model is run & the number of days the model is run
- Surrounding topography

HOW IT WORKS: Calculating Uplift for Solar Load Avoided

UPLIFT = Change in kilocalories per day (a measurement of energy)

BEFORE Restoration | AFTER Restoration



Solar Load Avoided	
Tool used →	Shade-a-lator
Units of measure →	kilocalories per day (kcals/day)
Before (pre-project)	10,000,000
After (post-project)	4,500,000
UPLIFT	5,500,000 kcals/day
Sample restoration actions	• Plant streamside vegetation

Water Temperature Transaction Tool (W3T)

Quantifying decreased water temperature through flow restoration

Increasing river flow can buffer water temperature and increase velocity through a stream reach. Higher velocity can limit the water's exposure to local solar impact, keeping the water from warming. Additional temperature benefits can be achieved if the increased flow is cooler than the water in the existing stream reach.

The **Water Temperature Transaction Tool (W3T)** uses river and landscape characteristics to estimate hourly solar radiation and overall heat loss or gain from a water body. **W3T** also incorporates temperature and flow inputs provided by tributaries and meteorological information. From these inputs, **W3T** calculates temperature changes in a river reach.

W3T is based on a steady flow approach requiring pre-project data (see sidebar for model inputs). **W3T** models water temperature based on energy transfer to and from the water across the air-water interface and bed-water interface. **W3T** also accounts for transport of heat energy in the downstream direction.

Water temperature reduction from increased flow can be determined by subtracting pre-project conditions from modeled conditions after flow has been restored. The difference in water temperature represents the temperature improvement (uplift) from restoring flow to that reach. Once the temperature impacts of flow are quantified, flow restoration can be used as a tool to directly address and account for water temperature as a limiting factor that affects the survival of threatened and endangered fish species.

National Fish and Wildlife Foundation contracted with Watercourse Engineering to develop the **W3T** model, with funding from USDA Natural Resources Conservation Service.

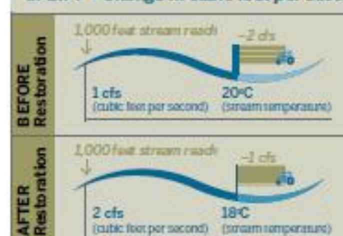
Field staff take a flow measurement to help determine the temperature benefit for restored flow.

MODEL INPUTS

- River length, width & depth
- Stream bed roughness
- Topographical & vegetation features: surrounding zones of vegetation that provide shade & inhibit solar radiation
- Inflow water temperatures
- Flow volumes
- Atmospheric heat exchange, air-water interface & bed-water interface
- Tributary inputs
- River velocity

HOW IT WORKS: Calculating Uplift for Decreased Water Temperature

UPLIFT = Change in cubic feet per second/degrees Celsius

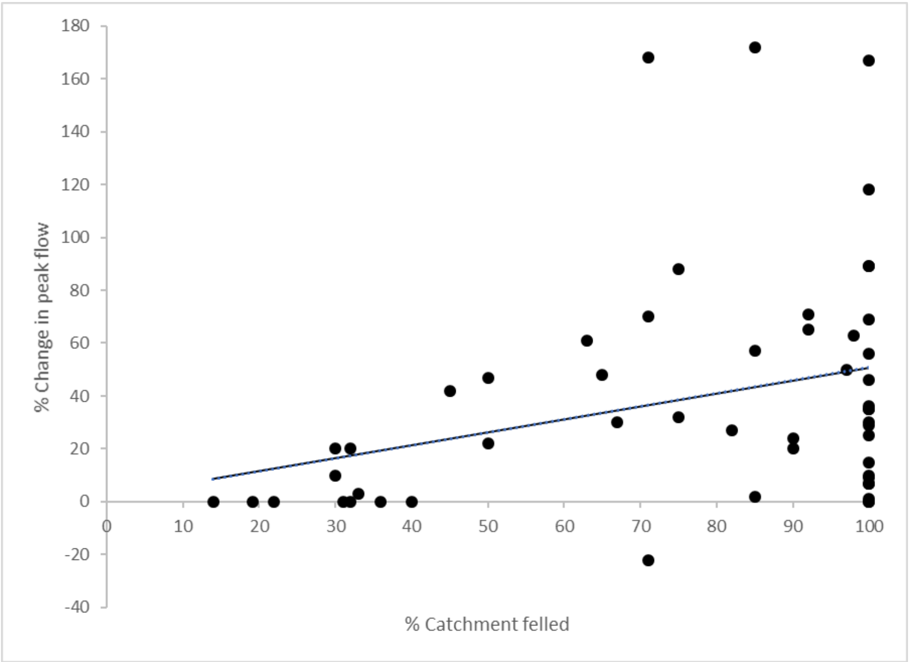


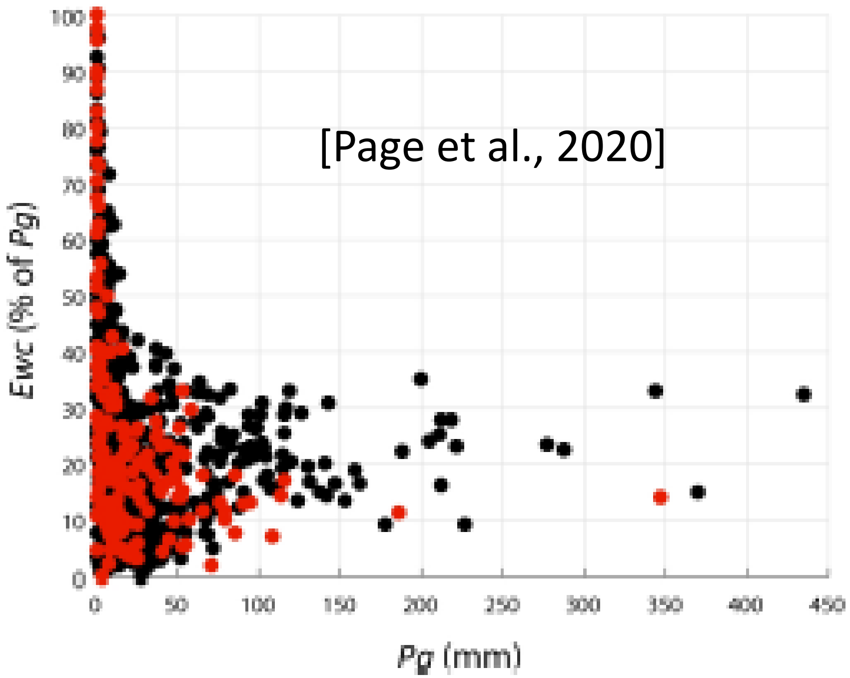
Water Temperature Decreased (Daily Max)		
Tool used →	Water Temperature Transaction Tool (W3T)	
Units of measure →	Cubic feet per second (cfs)	Degrees Celsius (°C)
Before (baseline)	1	20
After (post-project)	2	18
UPLIFT	1 cfs	2 °C
Sample restoration actions	• Introduce cooler water • Increase stream velocity • Deepen channel	

Effectiveness: Flood Reduction

Observed data show woodland creation can reduce flood peaks by 5% to 65%, while the effects of clearfelling range from -22% to +172%

[From Guillemette et al., 2005]



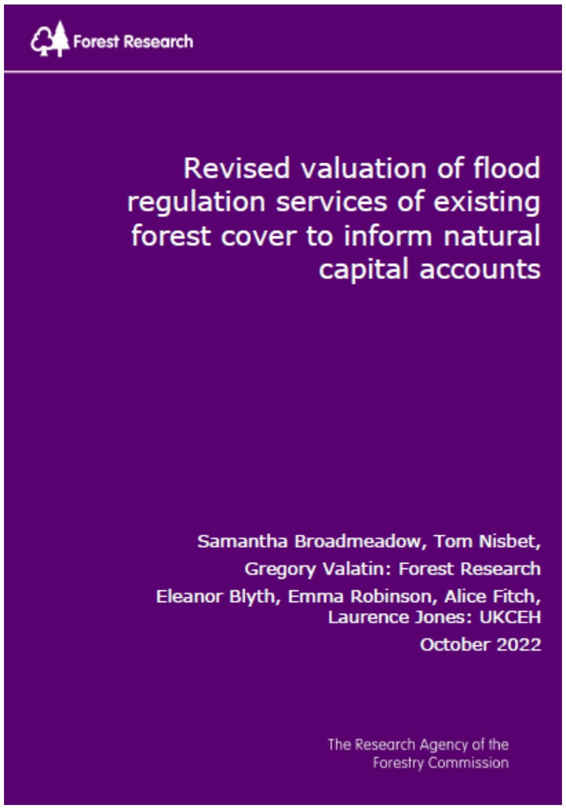


[Page et al., 2020]

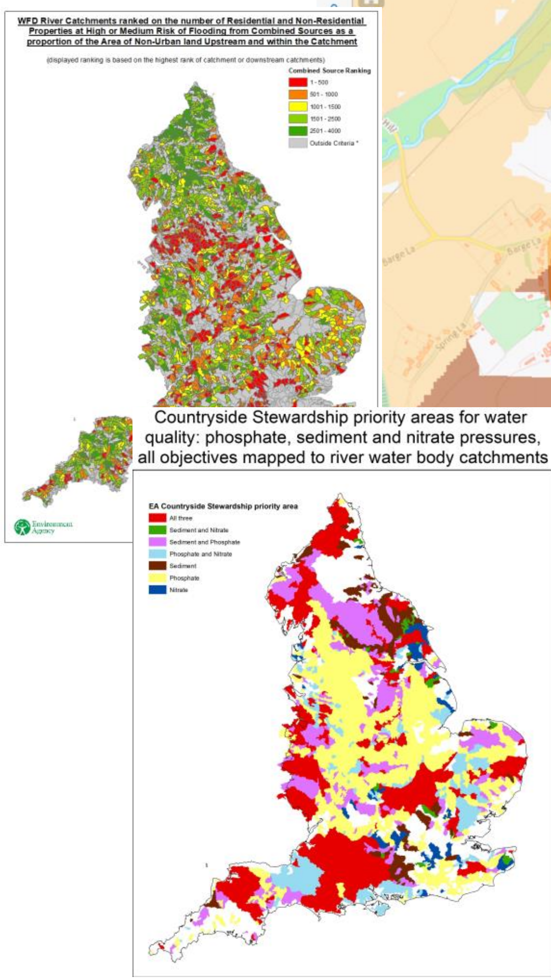
Modelling predicts forest planting can reduce flood peaks by -3 to +54%

[Ngai et al., 2017]

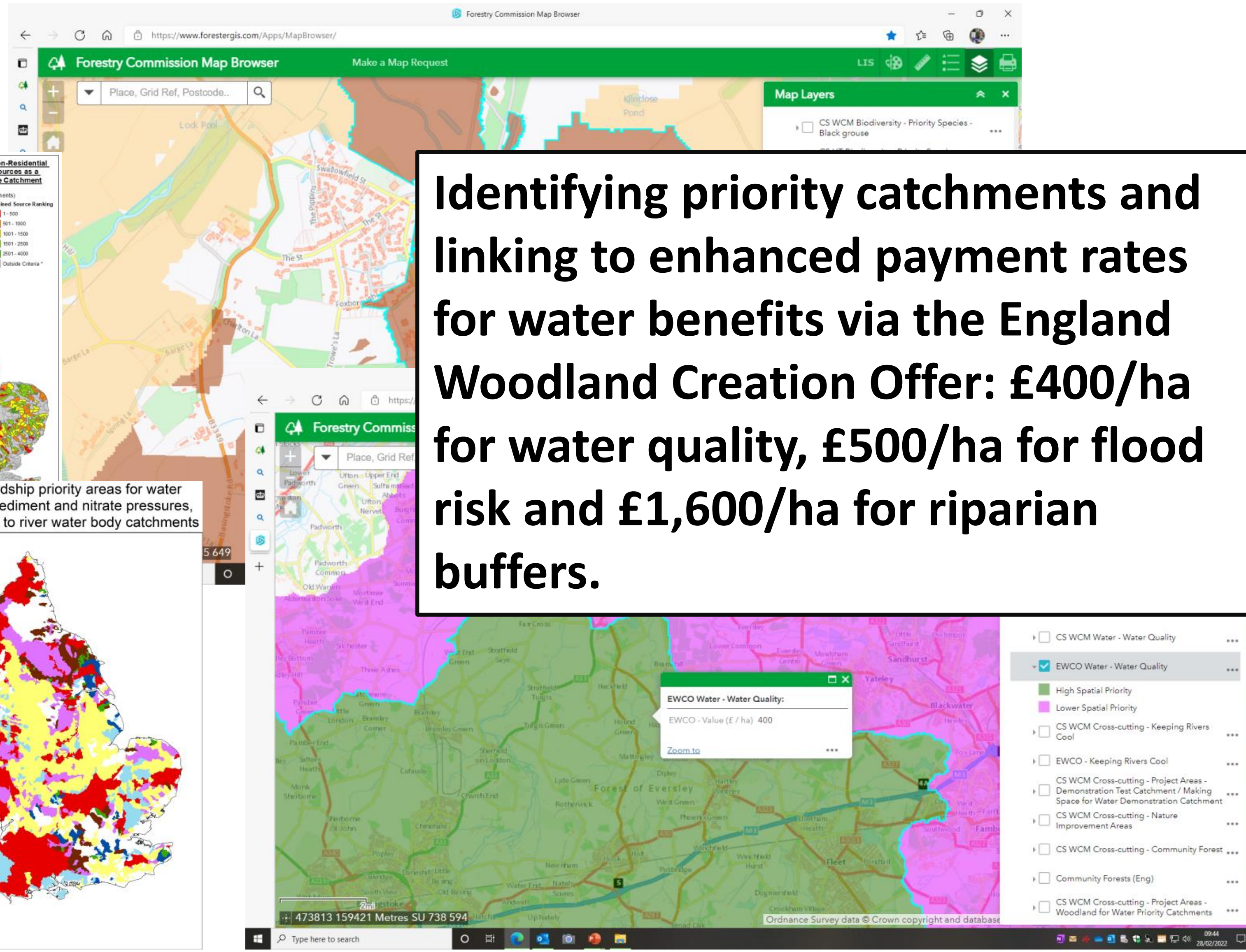
Three studies have generated annualised central estimates for the flood regulation benefit of woodland vs grass that range between £126-250/ha/yr.



National Spatial Prioritisation

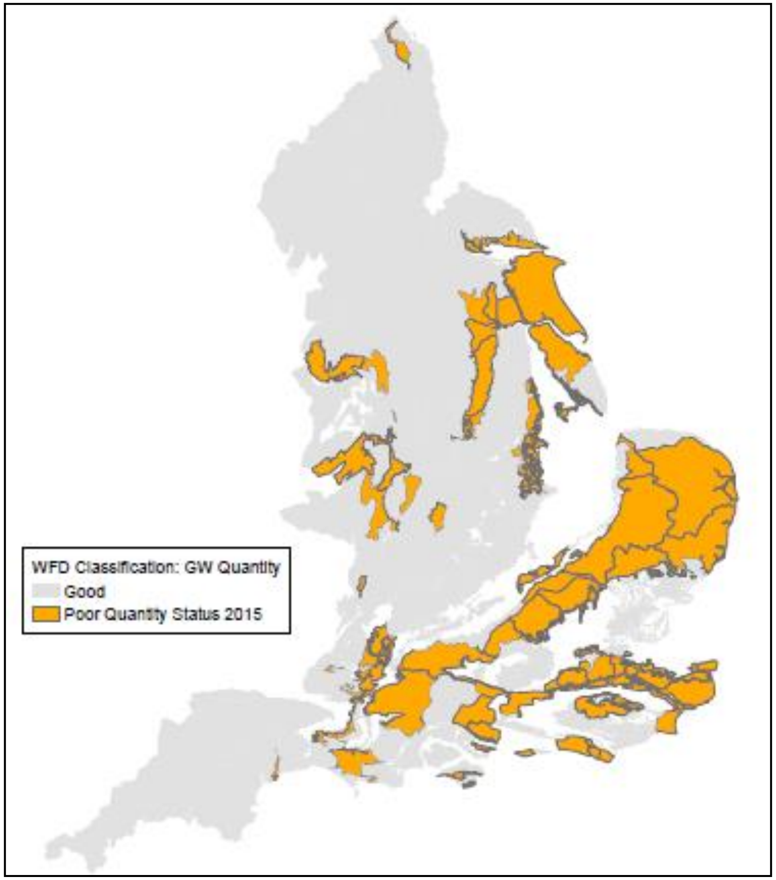


Countryside Stewardship priority areas for water quality: phosphate, sediment and nitrate pressures, all objectives mapped to river water body catchments



Identifying priority catchments and linking to enhanced payment rates for water benefits via the England Woodland Creation Offer: £400/ha for water quality, £500/ha for flood risk and £1,600/ha for riparian buffers.

Potential for forests to reduce water resources and environmental flows, which can be managed by appropriate design and management in vulnerable locations.



Scoping a Woodland Water Code

Forest Research

Towards a Woodland Water Code: Exploring Options

Ecosystem Markets

Tom Nisbet & Gregory Valatin: Forest Research
March 2022

The Research Agency of the Forestry Commission

- Develop as an add-on to the WCC;
- Focus on woodland creation – no credits for existing woodland (assume UKFS);
- Potential to incorporate water quality, flood risk and water cooling benefits but start with nutrient reduction;
- Target areas where water pressures are impacting most on the environment;
- Baseline is existing agricultural practice averaged over a crop rotation plus presumption of good farming practice;
- Adopting modelling to quantify baseline conditions and effects of land use change;
- Establish several case studies to test and trial application.

Conclusions

- The water environment remains severely impacted by diffuse pollution, rising water temperature is a growing concern for salmonid fisheries and the frequency of flooding is set to increase due to climate change and urban development;
- There is strong evidence underpinning forest water services, although environmental effectiveness depends on a wide range of factors, including forest design and management;
- A range of indicators and metrics can be used to value forest water benefits and to assess potential dis-benefits, while spatial mapping can help target action and deliver outcomes;
- Trading schemes and other financial support mechanisms are increasingly being developed to secure greater private investment in forest water services, including a planned Woodland for Water Code with scope to stack carbon and water benefits while ensuring additionality.