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Reducing surface flow during floods in the Upper Eden by scrub planting on Mallerstang West Common, Cumbria

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JBA consulting

WOODLAND TRUST

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Front cover: Fell Gill Sike, Mallerstang, Cumbria

WARNING

The results of any modelling are dependent on the assumptions and constraints applied. The following assumptions and constraints are applied to modelling the effects of proposed landscape interventions in the Upper Eden on surface flow (overland flow on soils and the channel flow component caused by overland flow) using the 2D JFLOW model:

1/ Only the process of *infiltration-excess overland flow on slopes* and the resultant impact of this *hydrological component on streamflow during floods* is modelled. The role of groundwater flow within the underlying solid geology and the return of groundwater to soil or channels is not simulated.

2/ Observations of streamflow are not available for planted headwater micro-basins, so the model parameters for the 'baseline' conditions have not been adjusted to capture the dynamics of observed streamflow records. A gauging structure is planned for the recently planted Shoregill micro-basin (also called 'Fall Gill Sike').

3/ Model parameterisation of the effects of 'scrub tree planting' and associated changes to ground cover has been set to conditions expected after 20 years of tree growth. These involve changes to surface infiltration capacity by a factor of five and also surface roughness increase of 10 percent (the latter set according to values used with the Environment Agency Working with Natural Processes, WwNP, research programme). Local experimental data on the magnitude of change in hydrological properties resulting from NFM-related interventions are not yet available for Mallerstang West Common planting area, but these are planned within new Defra-funded and NERC-funded projects.

Mallerstang West Common (part of the Wild Boar Ltd Estate) is located on the western side of the River Eden headwater, draining Little Fell and Aisgill Moor, both below Wild Board Fell (Figure 1). Model predictions are for a location immediately downstream on the main stem of the River Eden at Pendragon Castle near Outhgill hamlet, and for below Kirkby Stephen town (Figure 1).

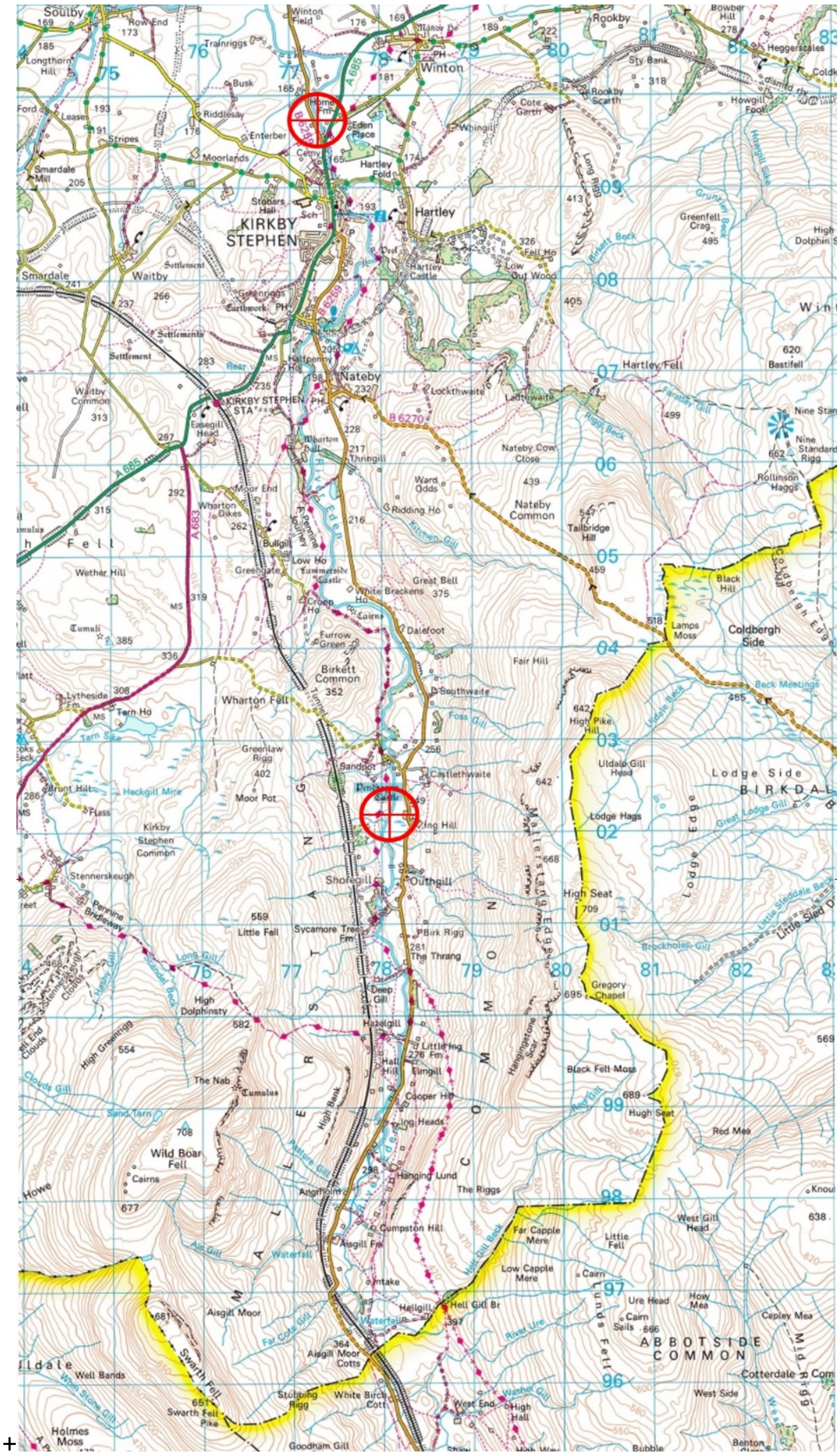


Figure 1. Model predictions are for the main stem of the River Eden at Pendragon Castle (lower red target symbol) and at the Environment Agency gauging station further downstream (upper red target symbol) © Crown copyright and database rights 2018 Ordnance Survey (Digimap Licence to Lancaster University).

The location of the planting areas with respect of the streams within Upper Eden is shown in Figure 2.

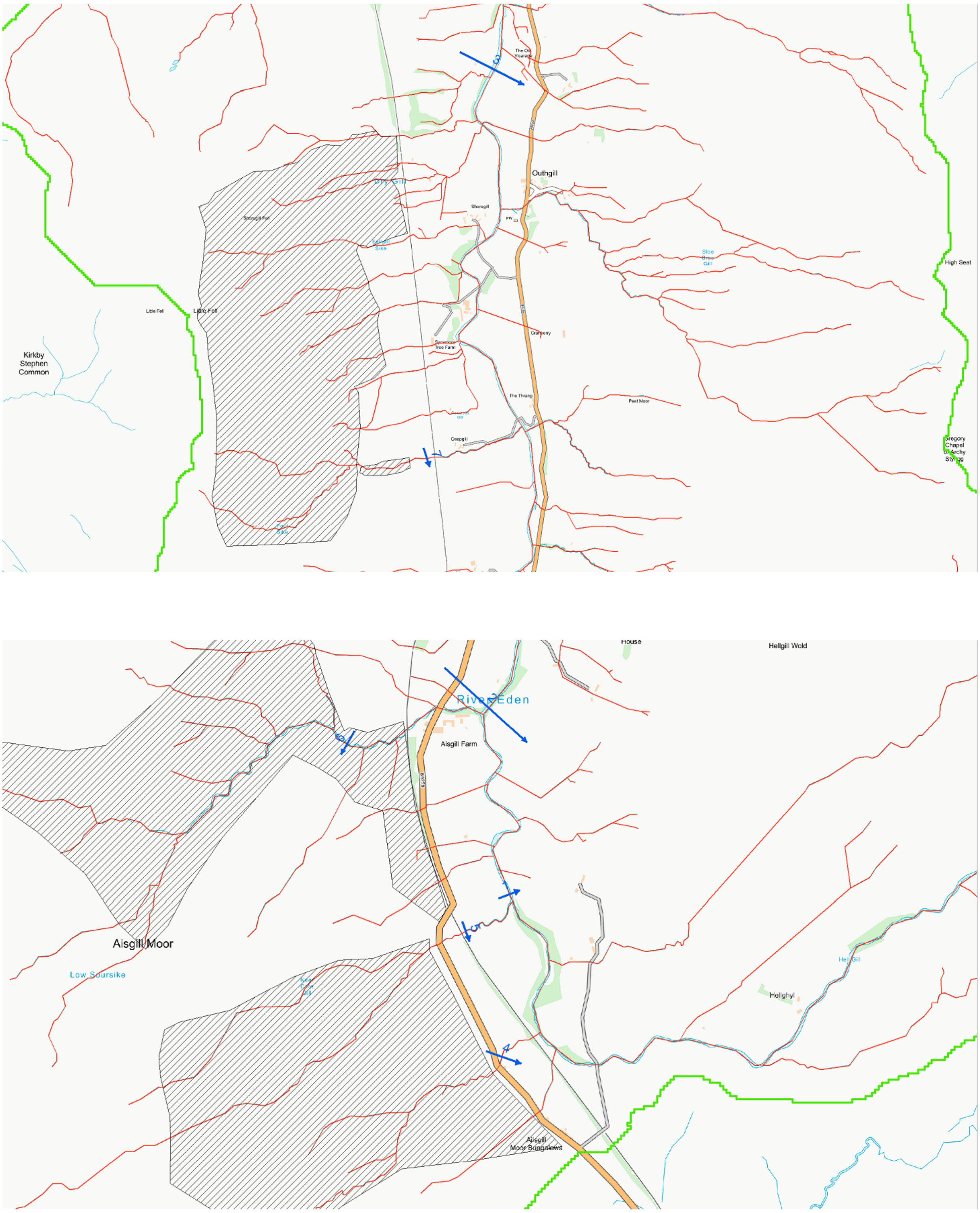


Figure 2. Location of the planting areas with respect of the streams (upper map: planting on Little Fell; lower map: planting on Aisgill Moor) on Mallerstang West Common. The upper map shows ‘blue arrow 3’ that is the location of the simulated flood hydrograph on main stem of the River Eden at Pendragon Castle (also shown with the ‘lower red target symbol’ in Figure 1).

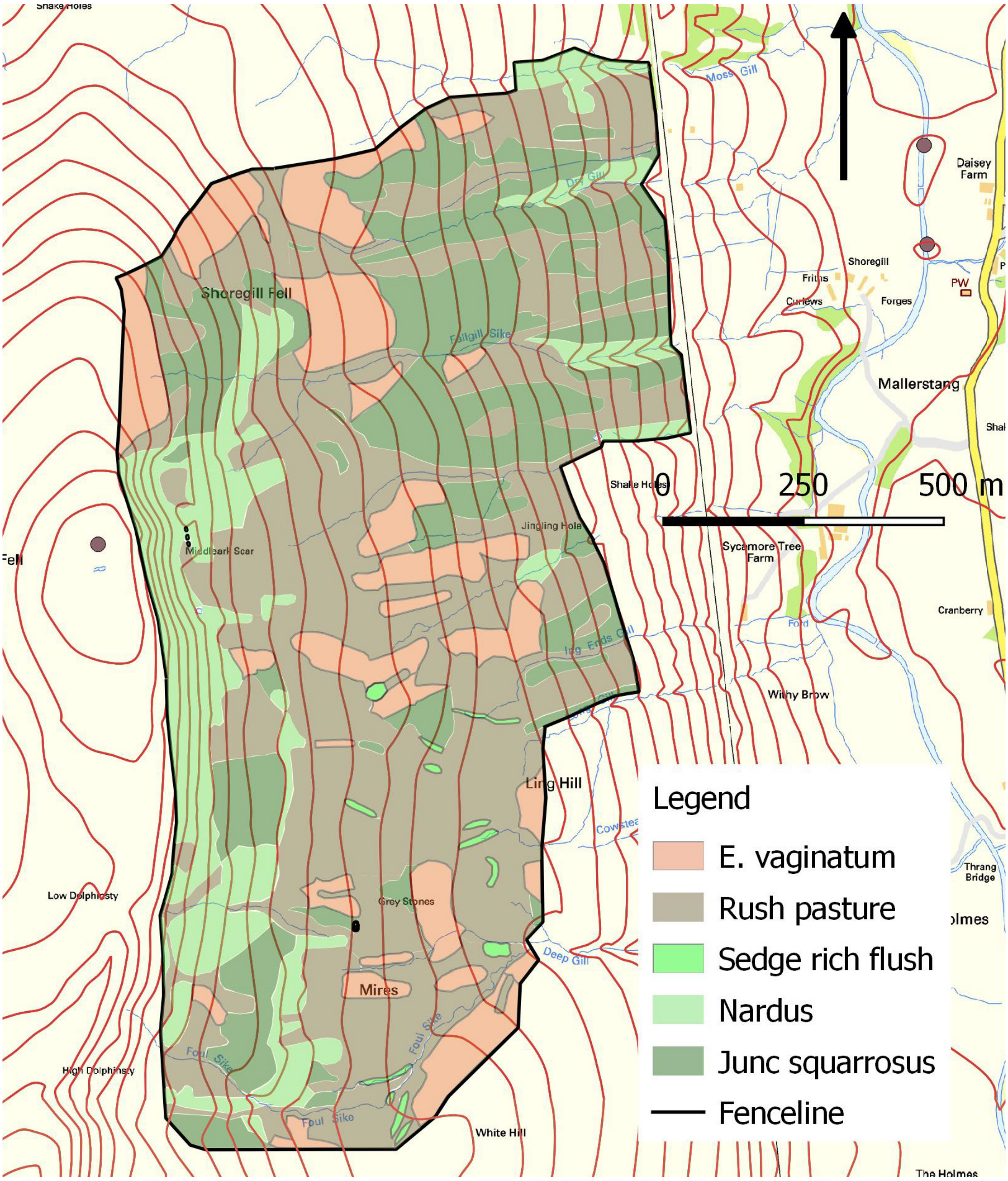


Figure 3. Detailed vegetation survey of the 1.38 km^2 'Little Fell planting area' (including Shoregill Fell) on Mallerstang West Common. The vegetation prior to planting comprised of *Eriophorum vaginatum* blanket bog (15%), Rush pasture (M6 and M23) (48%), Sedge rich flushes (<1%), *Nardus stricta* grassland (14%), and *Juncus squarrosus* grassland (22%). Image provided by the Woodland Trust.

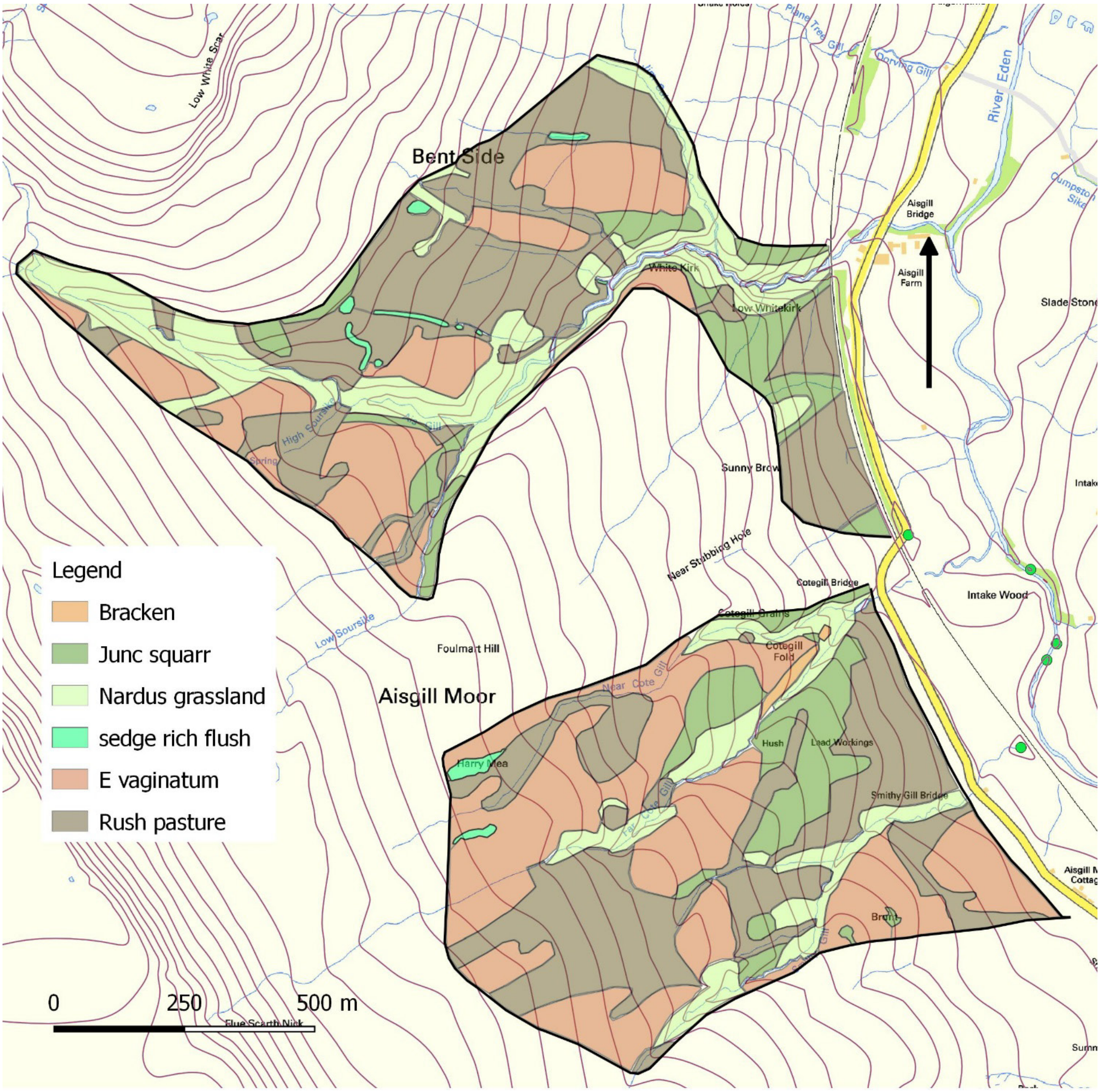


Figure 4. Detailed vegetation survey of the 1.23 km^2 ‘Aisgill Moor planting areas’ on Mallerstang West Common. The vegetation prior to planting comprised of *Eriophorum vaginatum* blanket bog (24%), Rush pasture (M6 and M23) (41%), Sedge rich flushes (1%), *Nardus stricta* grassland (23%), and *Juncus squarrosus* grassland (11%). Image provided by the Woodland Trust.

The potential value of the 'scrub planting' for reducing flood flows on the land surface (so called 'infiltration-excess overland flow') and once this component of the flood hydrology enters channels (so called 'channel flow' or 'stream discharge') is assessed within this study. The catchment area modelled is 69 km^2 (at Environment Agency river gauging station downstream of Kirkby Stephen: see upper red target on Figure 1).

The majority of this basin is underlain by sedimentary geology of the Carboniferous period, though Triassic and Permian sedimentary rocks are present around Kirkby Stephen. Except in the downstream location, the valley floor is primarily underlain by rocks of the Yordale Group (Limestone with subordinate Sandstone and Argillaceous rocks), with Mudstone, Siltstone and Sandstone rocks of the Millstone Grit Group beneath the fell tops.

Specifically, beneath the 'Little Fell planting area' (upper map in Figure 2, and Figure 3), Tan Hill Grit (Sandstone) lies beneath the summit of Little Fell (559 m). From the summit 1 km towards the eastern edge of the planting area, the solid geology changes from Tan Hill Grit (Sandstone) to the Millstone Grit Group, Upper Howgate Grit (Sandstone), Millstone Grit Group, Lower Howgate Grit (Sandstone), Stainmore Formation (Mudstone, Siltstone and Sandstone), Crow Limestone, Fathom Grit (Sandstone), Stainmore Formation, Little Limestone, and lastly Great Limestone. Further south beneath the two 'Aisgill Moor planting areas' (lower map in Figure 2 and Figure 4), the sequence in the solid geology goes from Crow Limestone, Fathom Grit (Sandstone), Stainmore Formation, Little Limestone, Stainmore Formation, Great Limestone, Alston Formation (Limestone, Sandstone, Siltstone and Mudstone), Four Fathom Limestone Member, and Alston Formation at the road (and to main stem of the River Eden).

In the north-eastern corner of the 'Little Fell planting area' (around the stream 'Dry Gill') the solid geology is overlain by glacial till diamicton. Hummocky diamicton is also present around the south-eastern tributary of Fall Gill Sike (also called Shoregill), but otherwise the planting area is free from unconsolidated geological materials. Further up the valley, the majority of the more northerly of two 'Aisgill Moor planting areas' (Figure 4) is covered by glacial till diamicton, though absent as the incised Aisgill valley nears the B6259 road. In the more southerly of the two 'Aisgill Moor planting areas' (Figure 4) glacial till diamicton is confined to between the lower reaches of Far Cote Gill and Smithy Gill. The fell tops above the 'Aisgill Moor planting areas' have substantial peat development. The areas of till diamicton are particularly important as they give rise to gley soils (Hankin et al., 2018) with their greater likelihood of the infiltration-excess overland flow (Chappell and Ternan, 1992) that is modelled in this study.

The modelling approach used

This study is solely a 'desk-based' modelling study for decision support. A more complete study would involve field experiments including stream gauging and direct measurements tree planting (including stock exclusion in planting areas) effects on wet-canopy evaporation, soil drying by transpiration, overland flow, ground-surface roughness and soil infiltration capacity. Such a 'field-based' study was not requested by the Woodland Trust for project EAA7570 (which is essentially a 'screening study'), but such field measurements are planned for future research. The model chosen for this study was JFLOW, an overland flow model that solves 2D Saint-Venant Equations for shallow water-flow on hillslopes and in channels (Lamb et al., 2009; Crossley et al., 2010). This model has been applied across England to provide guidance on locations to consider for tree planting and other interventions to mitigate floods using natural processes (Hankin et al., 2018).

A single design rainstorm was used for the simulations and had a return period of 1-in-10 years, or an event that has a 1/10 = 0.10 or 10 % chance of being present in any one year. The Open Access topographic map with complete coverage of the Upper Eden catchment has a coarse resolution of 50m x 50m (Note: 2m x 2m Open Access data is not available for the whole basin) and this is used for the JFLOW simulations in this initial screening study.

Hankin et al. (2018) have demonstrated the value of using 1:50,000 data on the presence or absence of till diamicton for predicting the location of gley soils in northern Britain (in preference to the use of the 1:625,000 Soil Association map). For areas of till diamicton in the Upper Eden, lower rates of infiltration were simulated in the 'baseline simulation' using a BFIHOST value of 0.700, while in areas without till diamicton higher rates of infiltration (for same 'baseline simulation') were modelled using a BFIHOST values of 0.900. It must be noted that this fast running model simulates only 'infiltration-excess overland flow' and the resultant routing of the resultant channel flow component. The role of subsurface flow in the soil, till or solid geology on the generation of 'saturation overland flow' (with soil-water returning to the surface before reaching the stream) and streamflow is beyond the scope of this initial study. Furthermore, within the JFLOW modelling framework, the proportion of rainfall falling <u>*directly on*</u> areas set as either high or low infiltration (depending on presence of till diamicton) is removed from the simulated surface flows, but the additional loss of water from overland flows <u>*from upslope into*</u> areas set as either high or low infiltration (so called 'runon') cannot be simulated within the typical setup of JFLOW.

Parameterisation of key hydrological functions of scrub planting

Within the model, the areas of 'scrub planting' of native trees were set to reduce overland flow on slopes by a combination of enhanced wet-canopy evaporation and infiltration of rainfall reaching the ground. On gleyed soil (predicted from the 1:50,000 till diamicton map), the baseline percentage overland flow on slopes of 30 percent was reduced to 6 percent for the 20 year scenario (i.e., reduced by 5 fold following Hankin et al., 2018). Where the aquifers were overlain by permeable soils, the baseline percentage overland flow on slopes of 10 percent was reduced to 2 percent (i.e., same 5 fold change). The velocity of infiltration-excess overland flow within the planted areas was reduced by increasing the Manning's Roughness Coefficient by 10 percent following Hankin et al. (2018). Enhanced infiltration in planting area from 'runon' could not be simulated by the JFLOW model.

Modelling results

The key result from the JFLOW modelling of the Upper Eden is the effect of the scrub planting following 20 years of tree growth on the 1-in-10 year *flood hydrograph produced by infiltration-excess overland flow* on the main stem of the River Eden, just downstream of the planting areas and just beyond Kirkby Stephen town.

Figure 5 shows the baseline 1-in-10 year flood hydrograph (overland flow component) for River Eden at Pendragon Castle (just downstream of the planting area) with that for the River Eden downstream of Kirkby Stephen, some 10 km downstream. The catchment draining to Pendragon contributes 72.2 percent of the overland flow volume to the whole catchment, despite being only half way between the Eden source (Hell Gill) and Kirkby Stephen, because considerably more design rainfall is received in the upstream part of the catchment. The peak flow at Pendragon is an even larger proportion at 83.3 percent of that for downstream of Kirkby Stephen because of the combination of greater rainfall in the upper headwaters and a greater proportion of steeper catchment. The delay between the simulated flood peak arriving at Pendragon to just beyond Kirkby Stephen is 3 hours and 35 minutes, largely as a result of the time taken to route flood water along the main stem of the Eden (Figure 5).

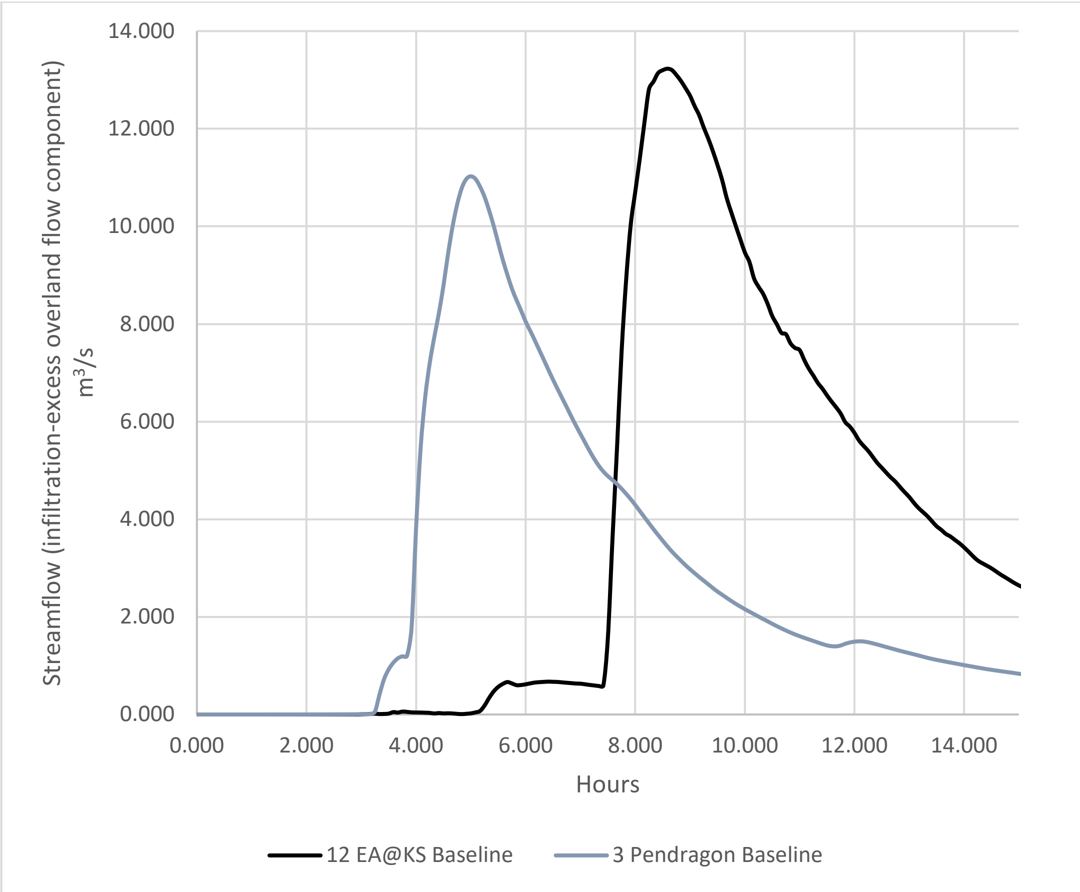


Figure 5. The simulated baseline 1-in-10 year flood hydrograph (overland flow component) for River Eden at Pendragon Castle (blue line) and just downstream of Kirkby Stephen (black line).

Figure 6 shows the 1-in-10 year flood hydrograph for River Eden at Pendragon Castle (just downstream of the planting area) without the effects of scrub planting with a red line. The addition of the small scrub planting areas within the JFLOW modelling produces the orange line in Figure 3. The JFLOW simulation of scrub planting on Mallerstang West Common reduce the overland flow component of the flood hydrograph to **only 89.6 percent of the pre-intervention simulated flood peak**.

The delay between the pre-intervention simulated flood peak and the peak following the intervention remains the same.

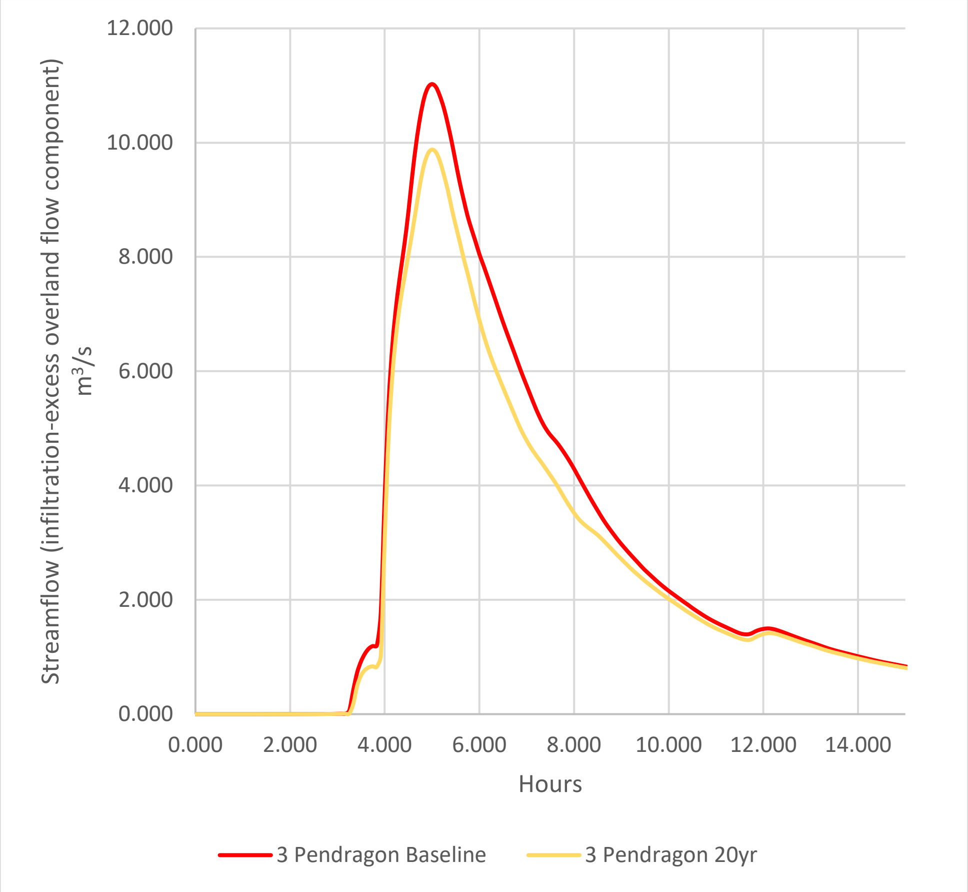


Figure 6. The 'infiltration-excess overland flow' component of flood hydrograph for the Eden main stem at Pendragon Castle following a 1-in-10 year design rainstorm is shown with a red line ('baseline'). The JFLOW-simulated effect of the scrub planting after 20 years of growth is shown with the orange line.

Figure 7 shows with a red line the 1-in-10 year flood hydrograph for River Eden at the Environment Agency river gauging station immediately downstream of Kirkby Stephen (gauging 69 km^2) without the effects of scrub planting. The addition of the small scrub planting areas (totalling 2.61 km^2 or 3.8 percent of whole basin) within the JFLOW modelling produces the orange line in Figure 7. The JFLOW simulation of scrub planting on Mallerstang West Common shows a reduction in the overland flow component of the flood hydrograph to **92.2 percent of the pre-intervention simulated flood peak (7.8 percent reduction)**. The effect is smaller than at Pendragon, due to the greater proportion of the catchment not occupied by the planting area.

The disproportionate effect on downstream flood response of planting a 2.61 km^2 area of Mallerstang West Common is due to the fact that scrub planting is within the extreme headwater 'micro-basins'. These micro-basins deliver their overland flow more quickly during the storm (see Figure 8), preferentially contributing to the rising stage and peak of the overland flow component of the flood hydrograph.

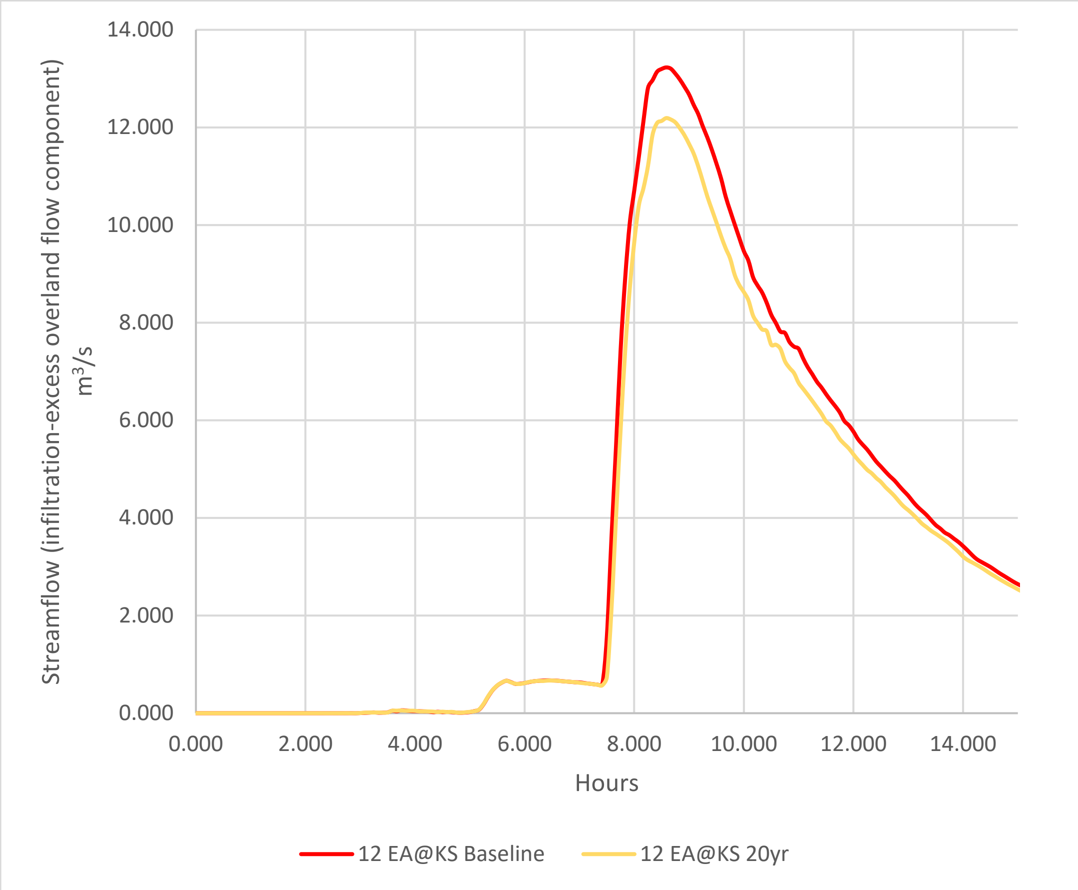
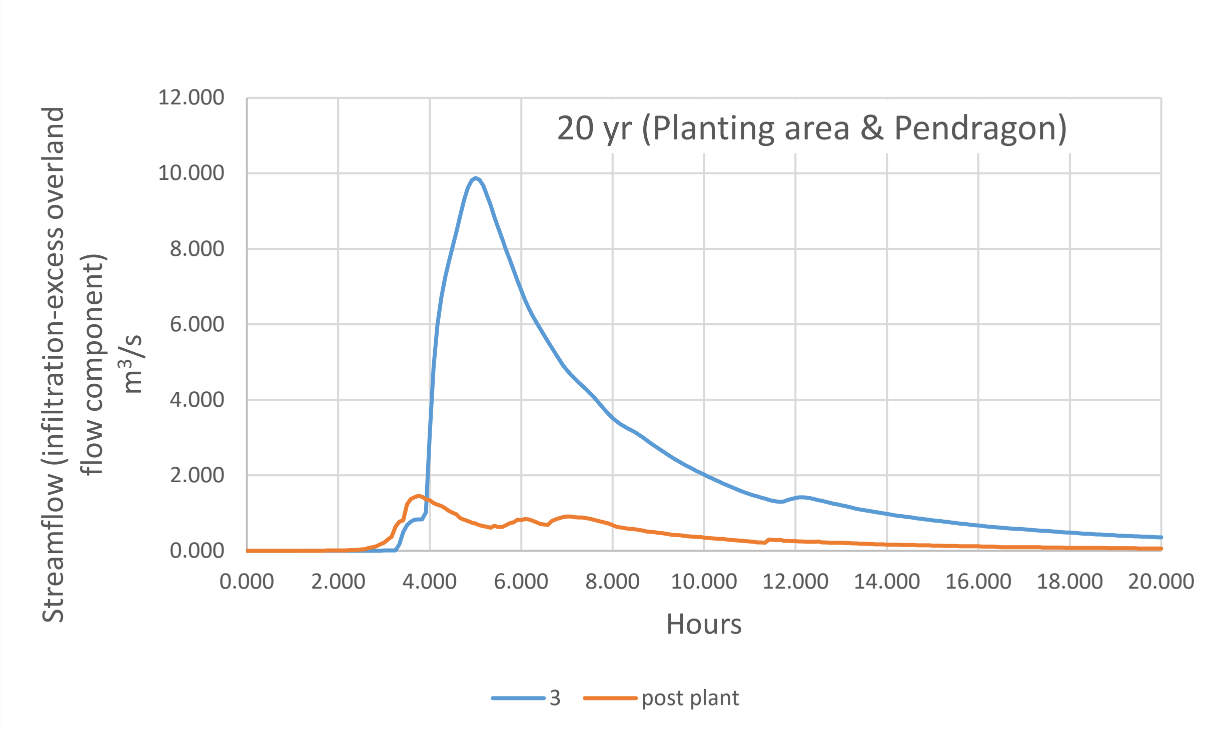


Figure 7. The 'infiltration-excess overland flow' component of flood hydrograph for the Eden main stem at the Environment Agency gauging station immediately downstream of Kirkby Stephen town following a 1-in-10 year design rainstorm is shown with a red line ('baseline'). The JFLOW-simulated effect of the scrub planting after 20 years of growth is shown with the orange line.

Summary of principal modelling findings

The study is based solely on modelling the effects of scrub planting on Mallerstang West Common for mitigating (infiltration-excess) overland flow produced by a design 1-in-10 year rainstorm. Local streamflow observations or direct measurements of the effects of tree planting on hydrological processes were not available to strengthen this initial phase of modelling. Further, the modelling tool used only simulates the effects of (infiltration-excess) overland flow and this component of flow in stream channels, the role of subsurface flow in the soil, till or solid geology ('aquifer') on streamflow is beyond the scope of this initial study.



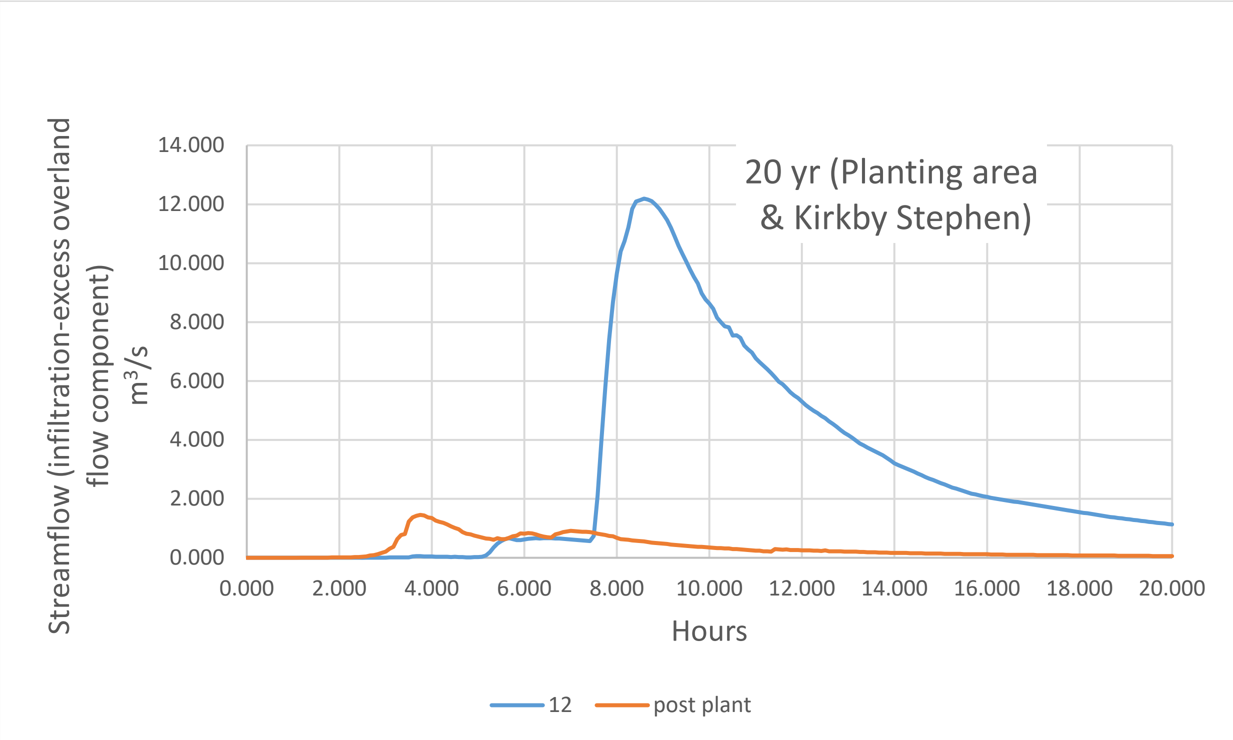


Figure 8. The total 'infiltration-excess overland flow' component of flood hydrograph for the three planting areas 20 years after growth is shown with a red line, and for the Eden main stem at Pendragon Castle (blue line '3' in upper figure) and the Environment Agency gauging station (blue line '12' in lower figure) following a 1-in-10 year design rainstorm. The routing of water down the channel network is seen with the delay between the peak in the headwater micro-basins ('post plant' red line) and the peak simulated down at Kirkby Stephen (blue line '12').

With this modelling approach, the **scrub planting in three blocks covering 2.61 km^2 of Mallerstang West Common were seen to reduce the peak in the overland flow component of streamflow at Kirkby Stephen to 92.1 percent of that without the planting (i.e., a 7.9 percent reduction)**. The simulated effects are disproportionality large because the planting is within those parts of the Upper Eden catchment that contribute most of their overland flow to the rising and peak stages of the responses observed downstream.

This desk study demonstrates that scrub planting by the Woodland Trust on Mallerstang West Common has the potential for significant 'Natural Flood Management (NFM) benefits for communities further downstream in the Eden Valley once the trees are fully established (e.g., 20 years post planting).

Given the *potential* demonstrated in this purely *desk-based study*, field observations within the micro-catchments containing the tree planting areas are needed to better quantify the shifts in hydrological processes and associated shifts in soil and canopy properties permitting use in physics-based modelling incorporating important subsurface processes. Such observed data should then be incorporated within a modelling framework that explicitly demonstrates the uncertainty in model parameters derived from the field measurements (i.e., sampling errors, instrument artefacts and so called 'effective parameterisation'), together with uncertainty in the representation of the hydrological processes in the selected catchment model.

References cited

Chandler, K.R., and Chappell, N.A. 2008. Influence of individual oak (*Quercus robur*) trees on saturated hydraulic conductivity. Forest Ecology and Management. 256, 1222-1229.

Chappell, N.A., and Ternan, J.L. 1992. Flow-path dimensionality and hydrological modelling. Hydrological Processes, 6, 327-345.

Crossley, A., Lamb, R. and Waller, S. 2010. Fast solution of the shallow water equations using GPU technology, in: Proceedings of the British Hydrological Society Third International Symposium, Newcastle, UK, 13-19 July 2010, 2010.

Hankin, B., Chappell, N.A., Page, T.J.C., Kipling, K., Whitling, M. and Burgess-Gamble, L. 2018. Mapping the potential for Working with Natural Processes – technical report. SC150005/R6, 77pp

Lamb, R., Crossley, A. and Waller, S. 2009. A fast 2D floodplain inundation model. Proceedings of the Institution of Civil Engineers - Water Management. 162: 363-370.