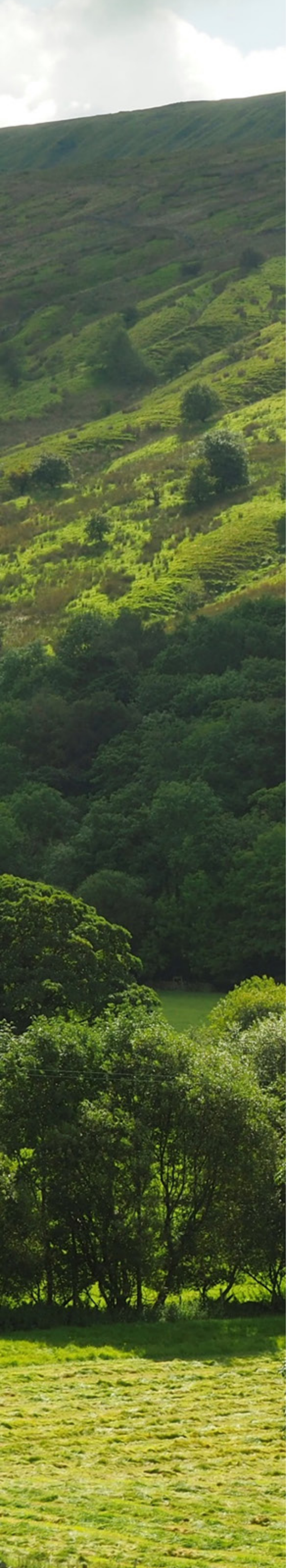

Lancaster Environment Centre
Lancaster University

Reducing surface flow during floods by proposed landscape interventions at Gaythorne Hall Farm in the headwater of Scale Beck, Cumbria

Flood storage upstream of drystone wall 3c following Storm Eva 23-24 December 2015 at Gaythorne Hall Farm
Photograph c/o Mr Stephen Lord (Gaythorne Hall Farm)

WOODLAND TRUST
JBA consulting

Reducing surface flow during floods by proposed landscape interventions at Gaythorne Hall Farm in the headwater of Scale Beck, Cumbria

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Funder

The Woodland Trust
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WARNING

The results of any modelling is dependent on the assumptions and constraints applied. The following assumptions and constraints are applied to modelling the effects of proposed landscape interventions in the headwater of Scale Beck on surface flow (overland flow on soils and channel 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 Scale Beck, so the model parameters for the simulations of conditions without farmer-defined interventions (i.e., 'baseline' conditions) have not been adjusted to capture the dynamics of observed streamflow records.

3/ Model parameterisation of the effects of 'leaky dams', pond modification for the benefit of 'Natural Flood Management' (NFM), and tree planting and associated changes to ground cover has been set according to values used with the Environment Agency Working with Natural Processes (WwNP) research programme (https://www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk). Local experimental data on the magnitude of change in hydrological properties resulting from NFM-related interventions are not available for the Scale Beck headwater basin.

Gaythorne Hall Farm (part of the Levens Estate) is located in the headwater basin of Scale Beck that rises on Bank Moor (Figure 1), joining Asby Beck to form Hoff Beck to then joining the main stem of the River Eden 3 km downstream of Appleby-in-Westmorland. Interventions are being considered on the farm as part of environmental improvements under the Natural England Countryside Stewardship (CS) scheme.

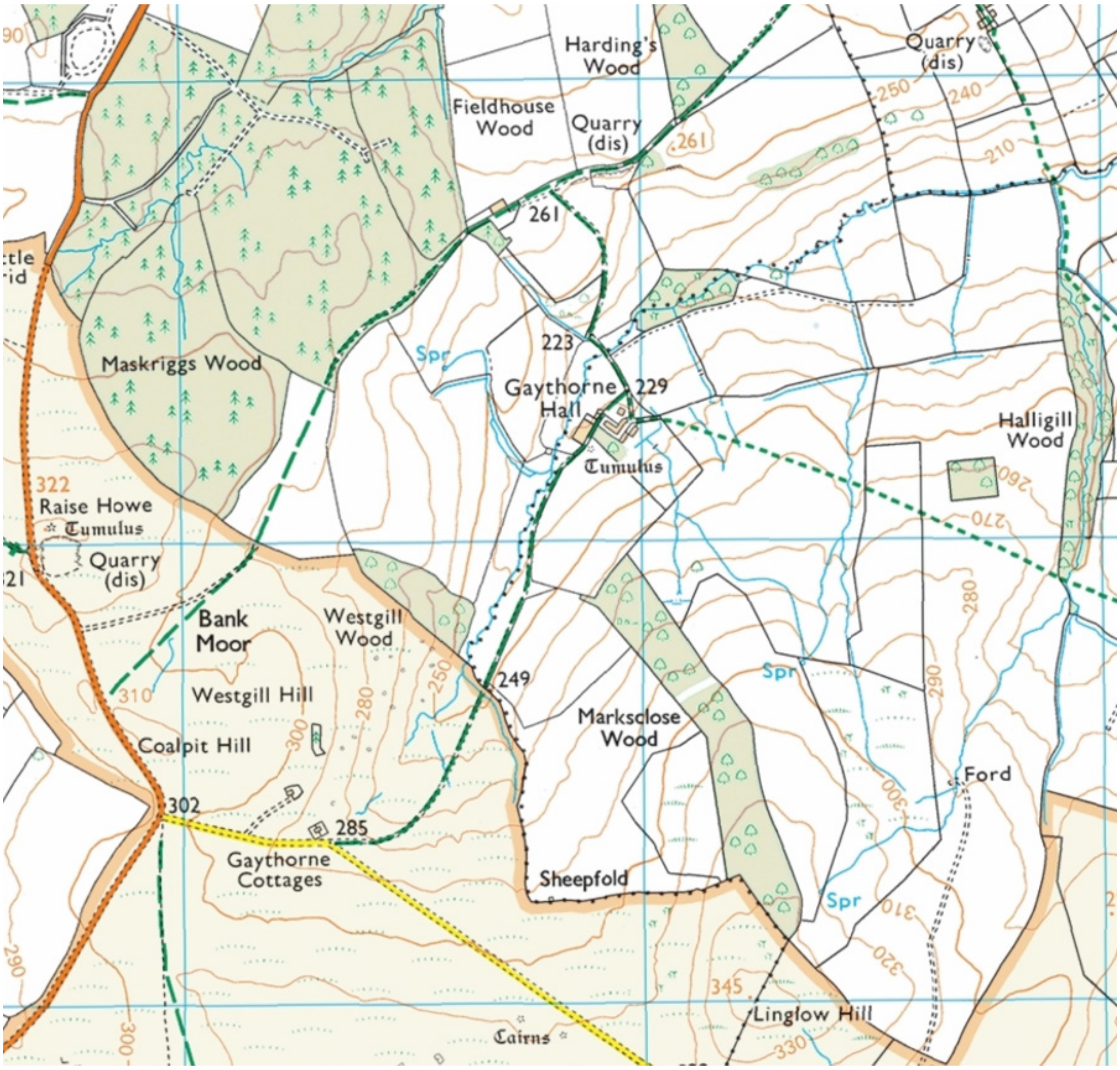

Figure 1. Location of Gaythorne Hall Farm at the centre of the headwater basin of Scale Beck. Model simulations predict streamflow at the location on Scale Beck just upstream of the confluence with Halligill stream where the public footpath north from Halligill Wood crosses Scale Beck. © Crown copyright 2016. All rights Reserved.

The potential value of the proposed interventions 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 almost 3 km^2; this figure being uncertain due to the underlying limestone (mostly Askam Limestone Member and Lower Little Limestone) and Alston sedimentary geology. More than half of the basin is covered by glacial till diamicton that gives gley soils with their greater likelihood of infiltration-excess overland flow (Hankin et al., 2018). The farm buildings of Gaythorne Hall are located in the centre of the 3 km^2 headwater basin of Scale Beck.

Countryside Stewardship interventions being considered within this study

The following interventions being considered by the Levens Estate for Gaythorne Hall Farm are:

Intervention 1. Strengthening the near channel areas of three drystone walls (and associated Scale Beck culverts) that cross the Scale Beck valley to provide structurally-stable flood storage (Figure 2).

Intervention 2. Reinstatement of two historic hedge lines parallel to the topographic contours, where one is 1 km in length, to capture and infiltrate the 'infiltration-excess overland flow' from upslope areas (Figure 2).

Intervention3. Addition of 5 very small 'leaky dams' on the Eastern micro-tributaries of the main stem of Scale Beck, to add temporary flood storage.

Intervention 4. Modification of a small series of wildlife ponds to deliver enhanced storage for flood mitigation, acting as a Runoff Attenuation Feature or RAF (Figure 2).

Intervention 5. Extension of 'scrub planting' of woodland in two small areas (dark green shading in Figure 2) to enhance in-storm losses of rainfall by wet-canopy evaporation (formerly called 'interception loss').

The modelling approach used

This study is solely a 'desk-based' modelling study for decision support. A more complete study would have involved field experiments on features in the basin functioning similarly to those of the proposed interventions. Such a 'field-based' study was not requested by the funder. The model chosen for this study was JFLOW, a 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 for the majority of Scale Beck headwater catchment has a resolution of 2m x 2m (http://environment.data.gov.uk/ds/survey/#/survey?Grid =NY61), and this is used for the JFLOW simulations. 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. For areas of till diamicton in the Scale Beck headwater, lower rates of infiltration were simulated using a BFIHOST value of 0.700, while in areas without till diamicton higher rates of infiltration were simulated using a BFIHOST value of 0.900. It must be noted that this fast running model simulates only 'infiltration-excess overland flow' and the resultant channel flow. The role of subsurface flow in the soil, till or solid geology on the generation of (i) 'saturation overland flow' (with soil-water returning to the surface before reaching the stream) and (ii) streamflow is beyond the scope of this study. Within the modelling framework, a proportion of rainfall falling on areas of high soil infiltration area may be removed from the surface flows, but water running over the surface into an area of high soil infiltration (so called 'runon') cannot be simulated within the current formulation of JFLOW.

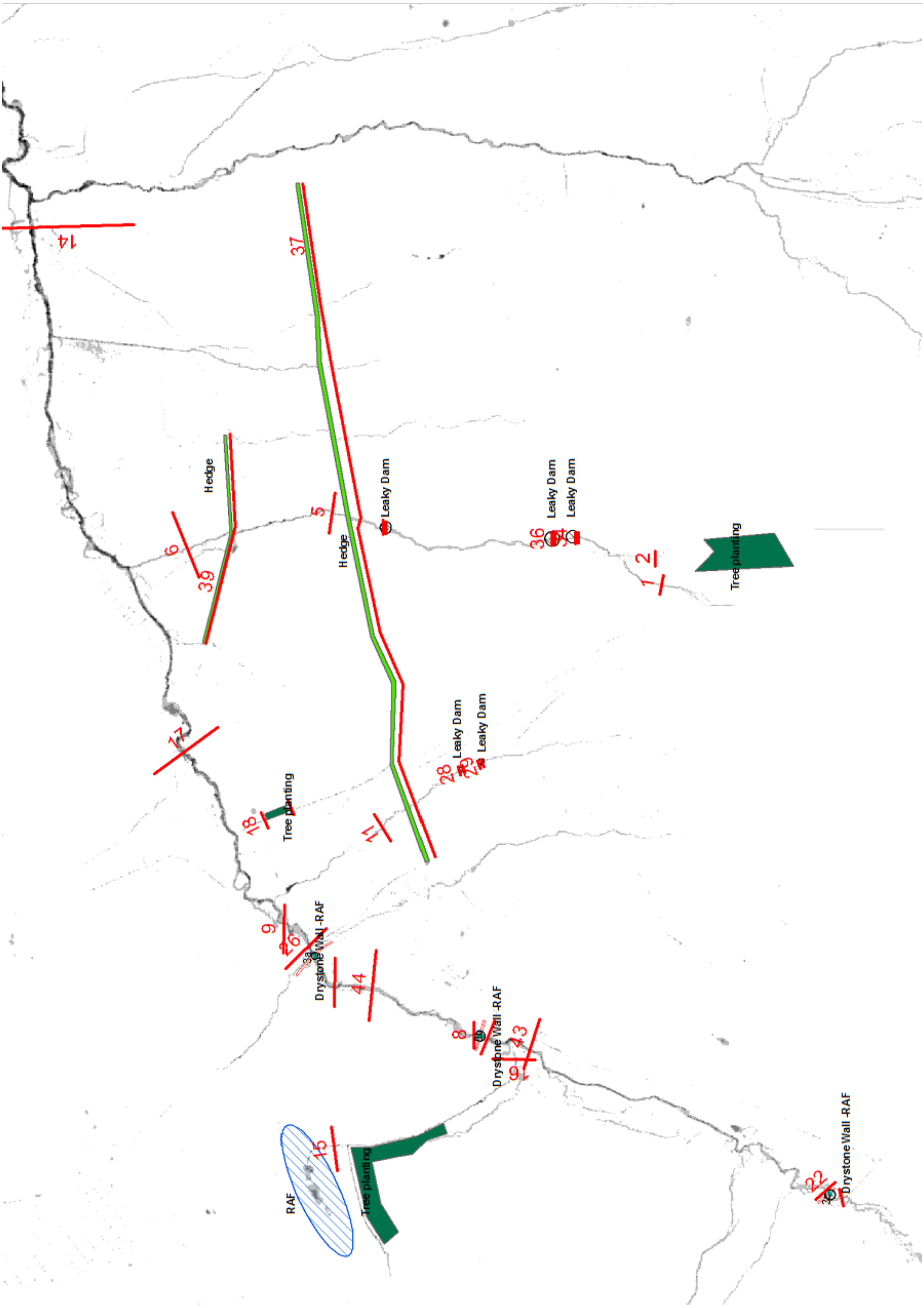

Figure 2. Location of interventions being considered by the Levens Estate for Gaythorne Hall Farm and assessed for their flood mitigation benefit by this desk-based modelling study. The numbered arrows show the cross-sections where flood hydrographs are calculated during the JFLOW modelling.

Within this study the removal of infiltration-excess overland flow from upslope areas as it reaches the proposed 1 km length of reinstated hedge on the resultant overland flow component of streamflow at the catchment outlet (Figure 1) is demonstrated by post-processing the JFLOW results (see later).

Parameterisation of the hydrological functions of the interventions

The way that each type of intervention functions within the JFLOW-based modelling approach for this study is as follows:

Intervention 1. Within the model, the culvert on the main stem of Scale Beck through each of the three drystone walls is set to permit 0.5 m^3/s of streamflow. Typical flows, including small flood events would pass through the culvert unaffected. In contrast, during large flood events, the size of the culvert would restrict the passage of water and cause temporary ponding upstream of the wall. The wall close to the culvert would need strengthening to prevent failure. The culverts acted to hold back streamflow following Storm Eva (23-24 December 2015), until the walls failed (see front cover).

Intervention 2. The new hedgerows (simulated width of 5 m) were set to reduce overland flow on slopes by a combination of enhanced wet-canopy evaporation and infiltration of direct rainfall reaching the ground. On gleyed soil, 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 and passing through hedgerow areas was reduced by increasing the Manning's Roughness Coefficient following Hankin et al. (2018). Enhanced infiltration of 'infiltration-excess overland flow' running into a hedgerow ('runon') could not be simulated by the JFLOW model. The simulated amount of combined infiltration-excess overland flow and channel flow entering the 1 km^2 length hedgerow (Figure 2) from upslope land was, however, calculated by JFLOW. Once the channel flow component was removed, the effect of removing all of this infiltration-excess overland flow by greatly enhanced hedgerow infiltration to the overland flow component of the whole of the Scale Beck headwater was, however, derived.

Intervention 3. For each of the 5 very small 'leaky dams' on the Eastern micro-tributaries (Figure 2), a maximum flow through each leaky dam was set to 0.5 m^3/s.

Intervention 4. To deliver enhanced flood storage at a small series of wildlife ponds (Figure 2), the ponds were modified to add an additional 0.1 m depth of flood-only storage.

Intervention 5. The extension of areas 'scrub planting' of woodland were set to reduce rainfall by a combination of enhanced wet-canopy evaporation and infiltration of rainfall reaching the ground, using the same reductions described for hedgerows. The velocity of infiltration-excess overland flow within and passing through these areas following 20 years of growth was reduced by increasing the Manning's Roughness Coefficient by 10 percent (as with intervention 2). Enhanced infiltration of infiltration-excess overland flow running into these new wooded areas ('runon') could not be simulated by the JFLOW model.

Modelling results

The most important result from the JFLOW modelling of the Scale Beck headwater is the combined effect of all proposed interventions on the 1-in-10 year flood hydrograph produced by infiltration-excess overland flow (at the most downstream boundary of the Gaythorne Farm estate). Figure 3 shows the 1-in-10 year flood hydrograph for Scale Beck without the proposed CS interventions with a red line. The addition of the CS interventions within the JFLOW modelling produces the grey-purple line in Figure 3. The JFLOW simulation of the CS interventions change the flood hydrograph from a single peak to a double peak, where the highest of the two peaks is now **only 87 percent of the pre-intervention simulated flood peak**. The two peaks are caused primarily by the effects of storage behind the redesigned drystone walls in the upper part of the catchment. Similarly, the reduction in the peak flow is also caused by temporary ponding upstream of the redesigned wall culverts (permitting no more than 0.5 m^3/s through the culvert).

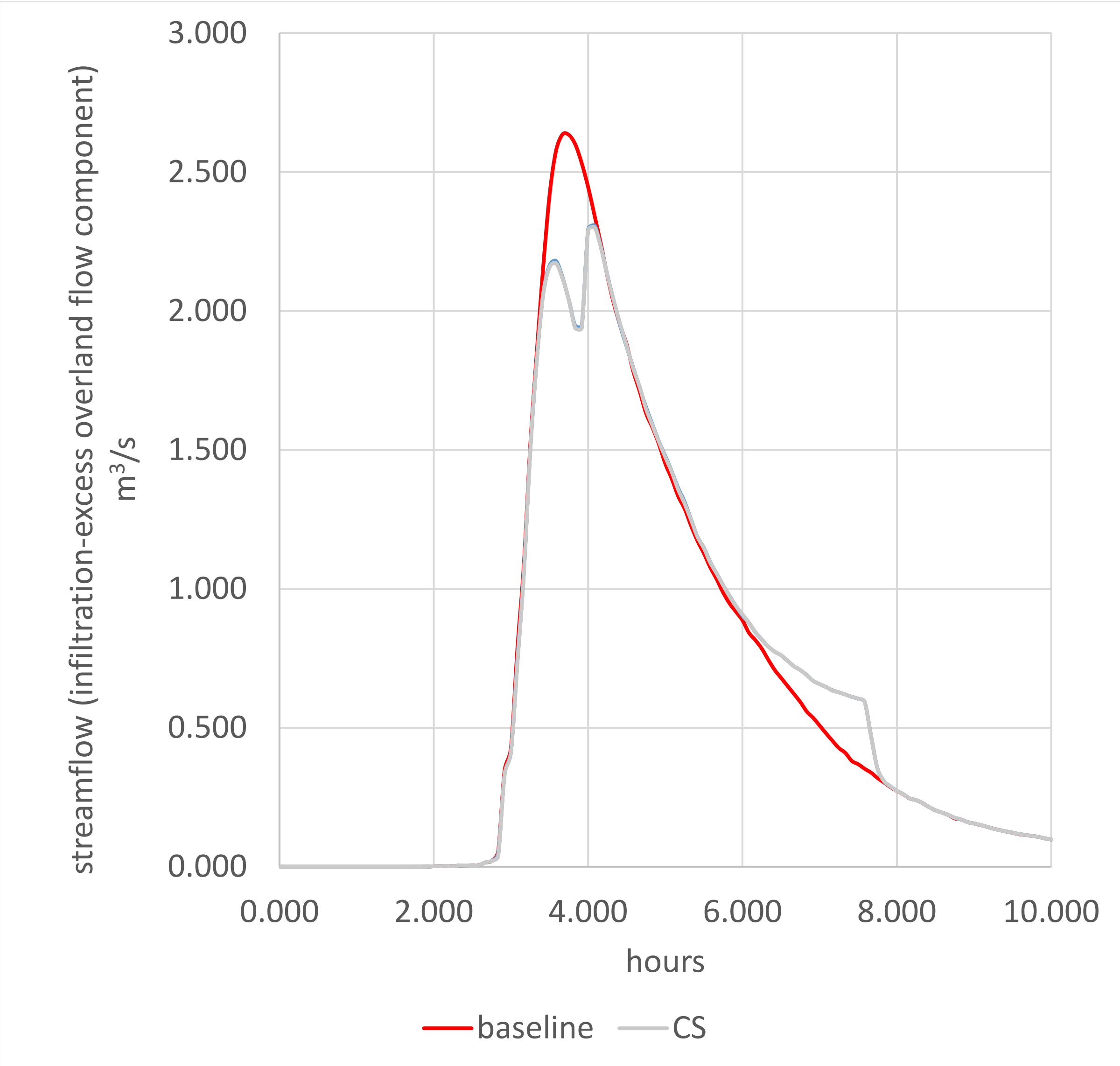

Figure 3. The 'infiltration-excess overland flow' component of flood hydrograph for the Scale Beck at 54°31'05.51 N, 2°31'42.02" W (downstream boundary of the Gaythorne Hall Farm estate) following a 1-in-10 year design rainstorm is shown with a red line ('baseline'). The JFLOW-simulated effect of CS interventions is shown with the grey-purple line.

The step in the recession relates to drainage from behind the redesigned wall culverts; where the effect reduces quickly once the ponded water-level behind the wall drops below the top of the culvert. The delay between the pre-intervention simulated flood peak and the largest of the two peaks following the intervention is 25 minutes (5x 5-minute time-steps). The total amount of water under the (infiltration-excess component of the) flood hydrograph post intervention is 99 percent of that pre-intervention, as the extent of tree and hedge planting as a proportion of the whole Scale Beck headwater, and hence enhanced opportunity for removal of water by wet-canopy evaporation, is here very small. Indeed, the hydrograph change resulting from the particular CS interventions within this catchment relate primarily to the effects of the reduced size of the drystone wall culverts along the main channel. The depth of ponding at the peak of the hydrograph for the three drystone walls is shown with coloured shading in Figures 4, 5 and 6.

Moving downstream, the effect of the redesigned culverts on temporary flood storage increases because the area contributing flow to the culvert similarly increases. Water depths upstream of the central and downstream wall exceed 0.9 m during the 1-in-10 year rainstorms simulated, underlining the need to reinforce the structure of the drystone walls crossing the valley floor.

As noted earlier, the effects of infiltration-excess overland flow running onto areas of reinstated hedgerow or woodland cannot be simulated within JFLOW. The effects of hedgerows or woodland on the infiltration of overland flow running onto these areas once the vegetation is fully established may be considerable through changes to the near-surface saturated hydraulic conductivity (Chandler and Chappell, 2008). The simulated surface-flow hydrograph for the land immediately upslope of the proposed location for the re-establishment of a 1 km length of hedgerow (Figure 2) has been calculated by JFLOW and is shown with a grey line in Figure 7 ('Line 37' in Figure 2). This surface flow comprises of channel flow and infiltration-excess overland flow on slopes. The channel flow component is dominated by flows along two channels, where their flow is calculated at 'Lines 11 and 5' in Figure 2. If these flows are removed from the total surface flow crossing 'Line 37', then the remaining surface flow is mostly 'infiltration-excess overland flow'.

If after full establishment of this hedgerow, the near-surface saturated hydraulic conductivity has been able to increase to such an extent that it is able to infiltrate all infiltration-excess overland flow reaching the hedge, then this may be removed from the infiltration-excess overland flow component of the Scale Beck flood hydrograph. The additional effect of the 1 km hedge on capturing infiltration-excess overland flow on the Scale Beck flood hydrograph is shown with the dark blue line in Figure 8.

If the **1 km hedge did capture and infiltrate all the infiltration-excess overland flow reaching it**, then the infiltration-excess overland flow component of the Scale Beck flood hydrograph would reduce further from 87 percent to **82 percent of the pre-intervention flows for a 1-in-10 year rainstorm** (Figure 8).

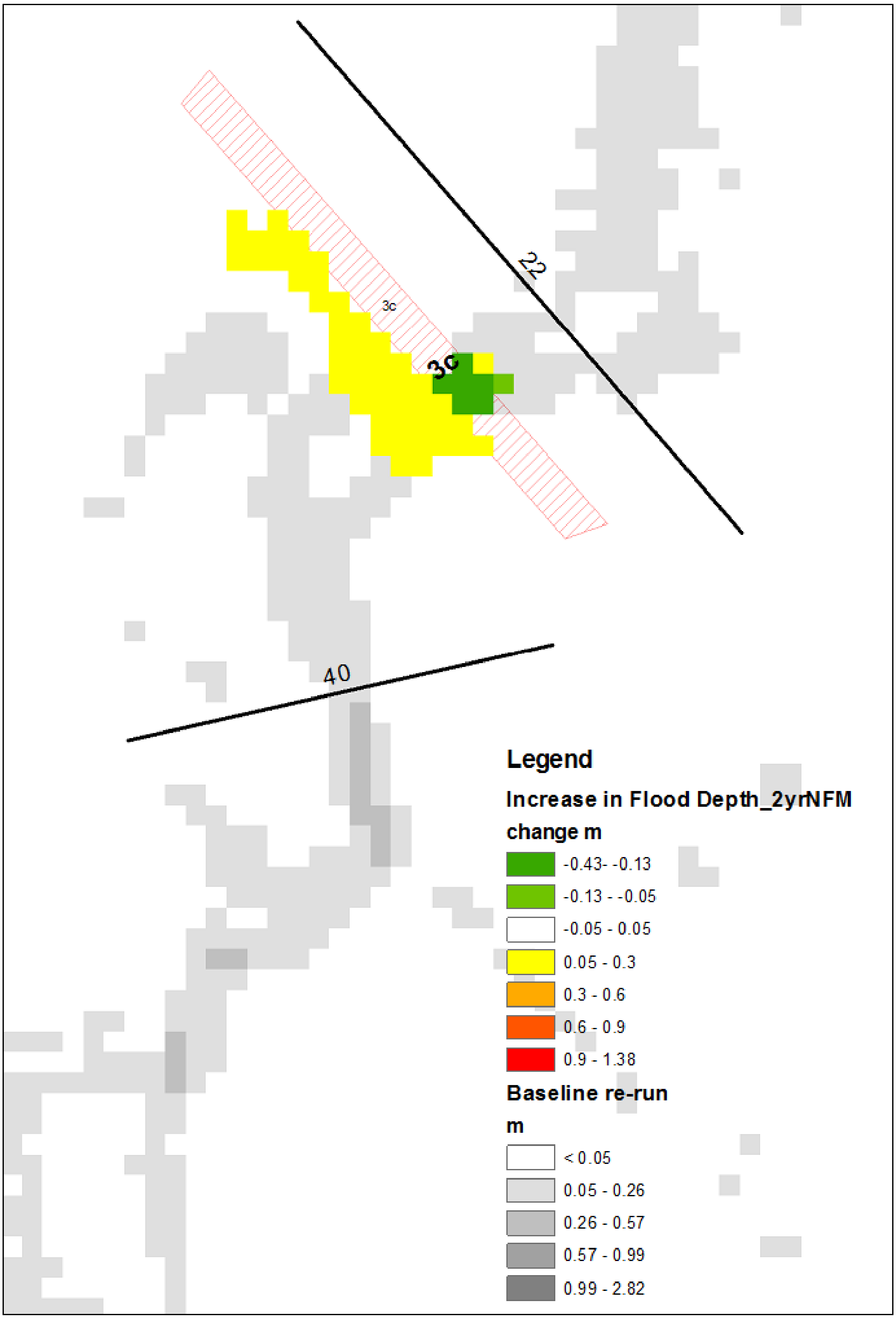

Figure 4. Maximum spatial extent and depths of ponding upstream of the most upstream drystone wall (‘wall 3a’) with the culvert capacity reduced to 0.5 m^3/s.

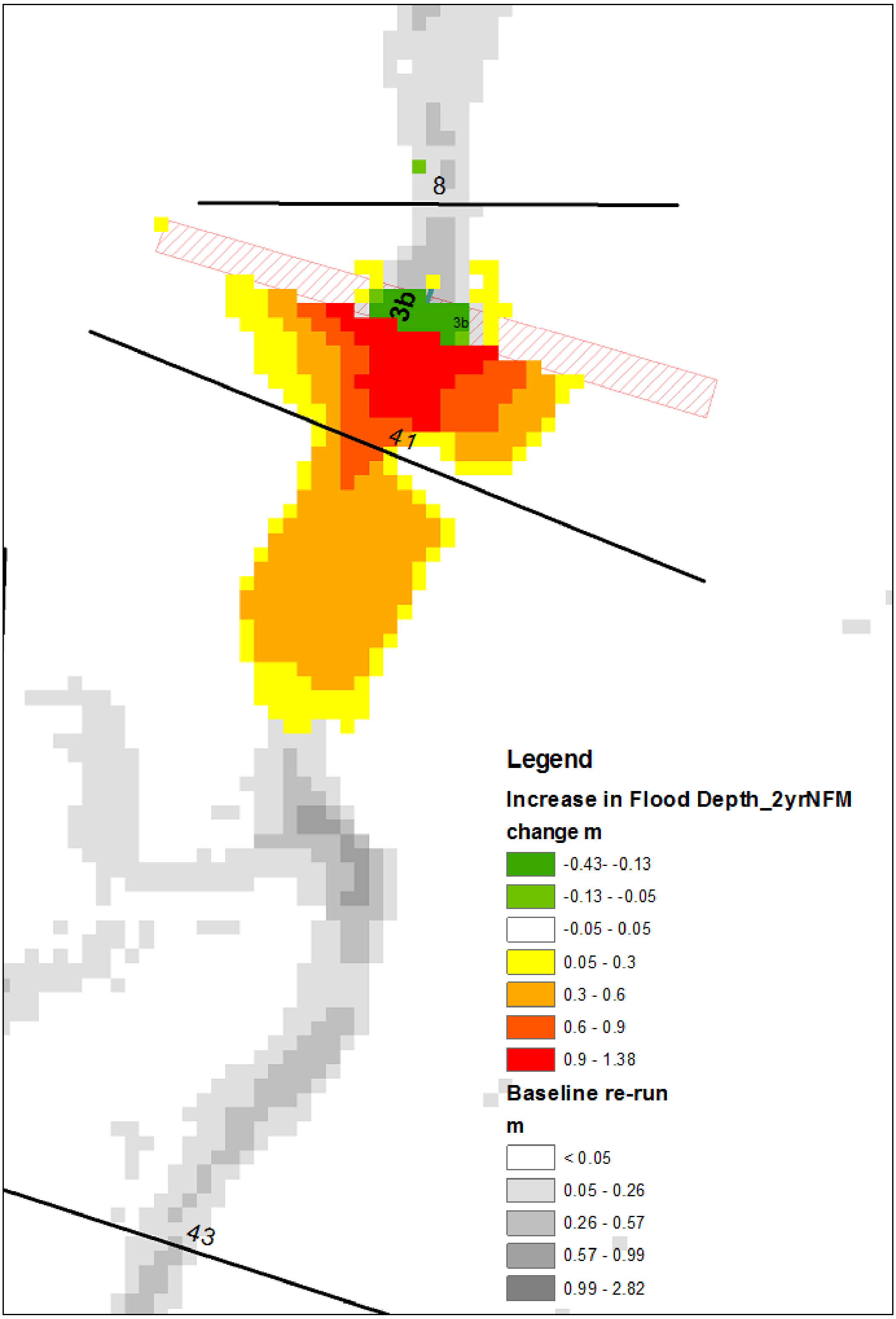

Figure 5. Maximum spatial extent and depths of ponding upstream of the central drystone wall ('wall 3b') with the culvert capacity reduced to 0.5 m^3/s.

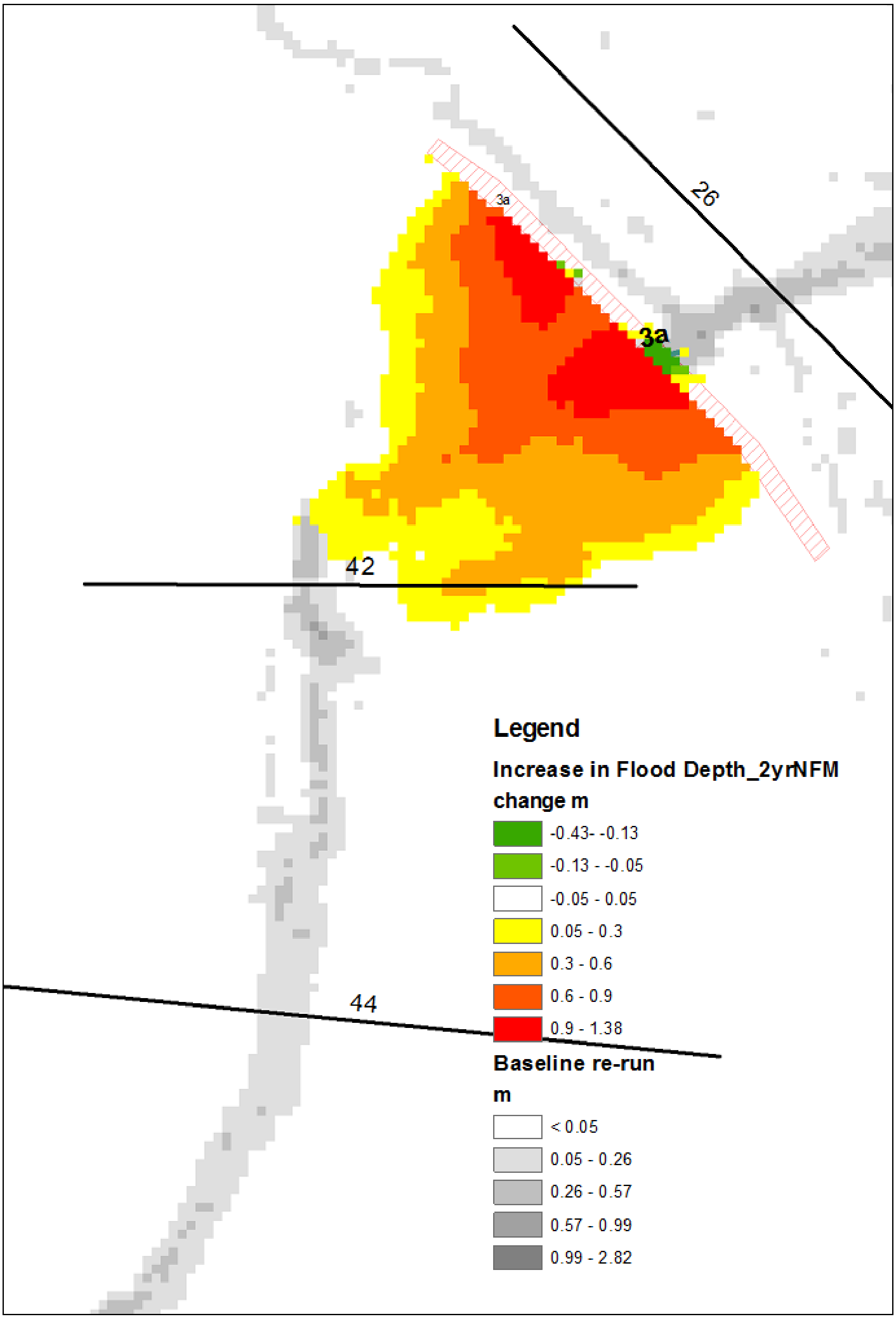

Figure 6. Maximum spatial extent and depths of ponding upstream of the downstream drystone wall ('wall 3c') with the culvert capacity reduced to 0.5 m^3/s.

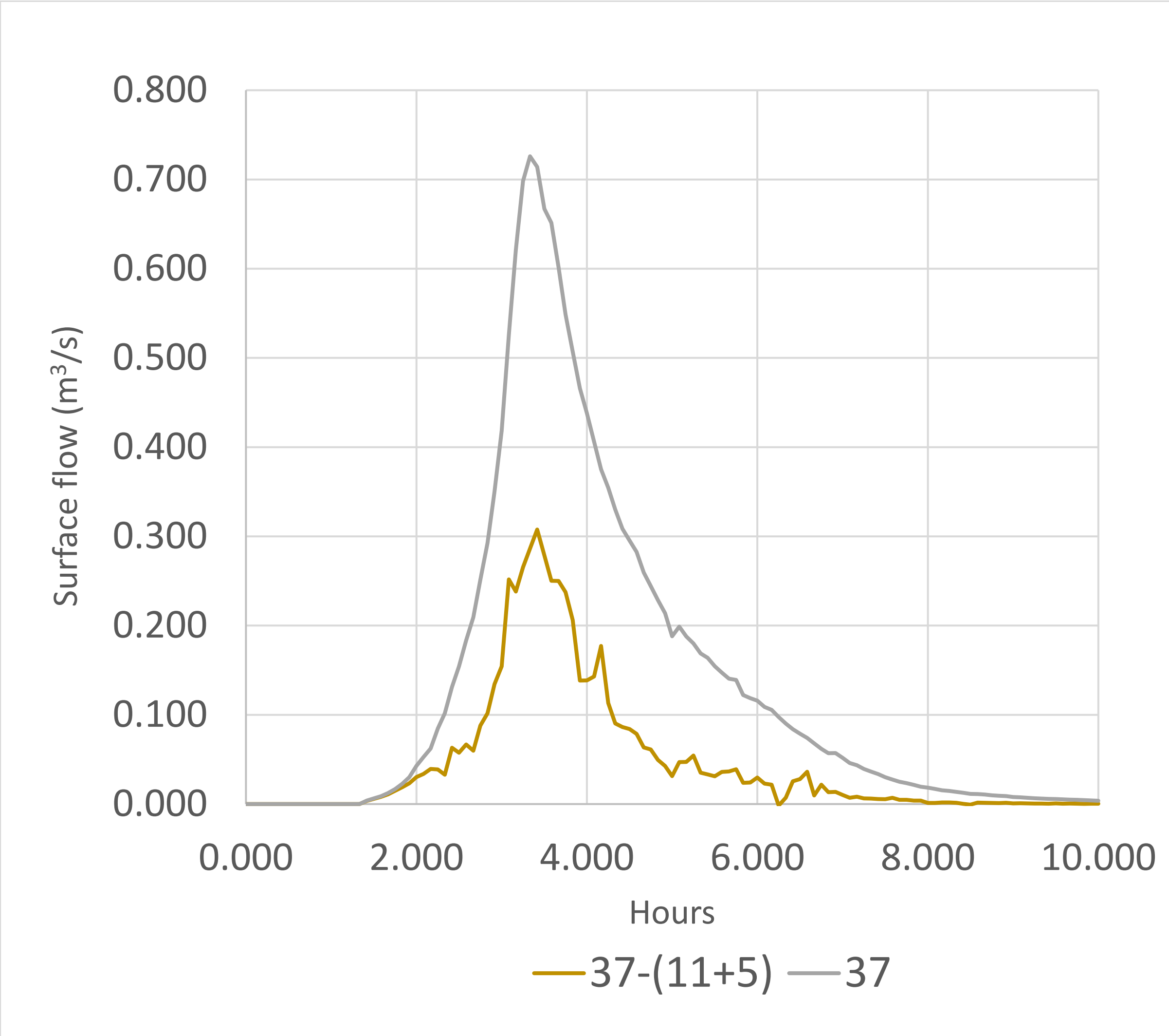

Figure 7. Surface flow moving downslope at 'Line 37' in Figure 2 just upstream of a proposed 1 km length of reinstated hedgerow (grey line), and the resultant surface flow when the two dominant channel flows ('Lines 11 and 5') through the proposed hedge line are removed.

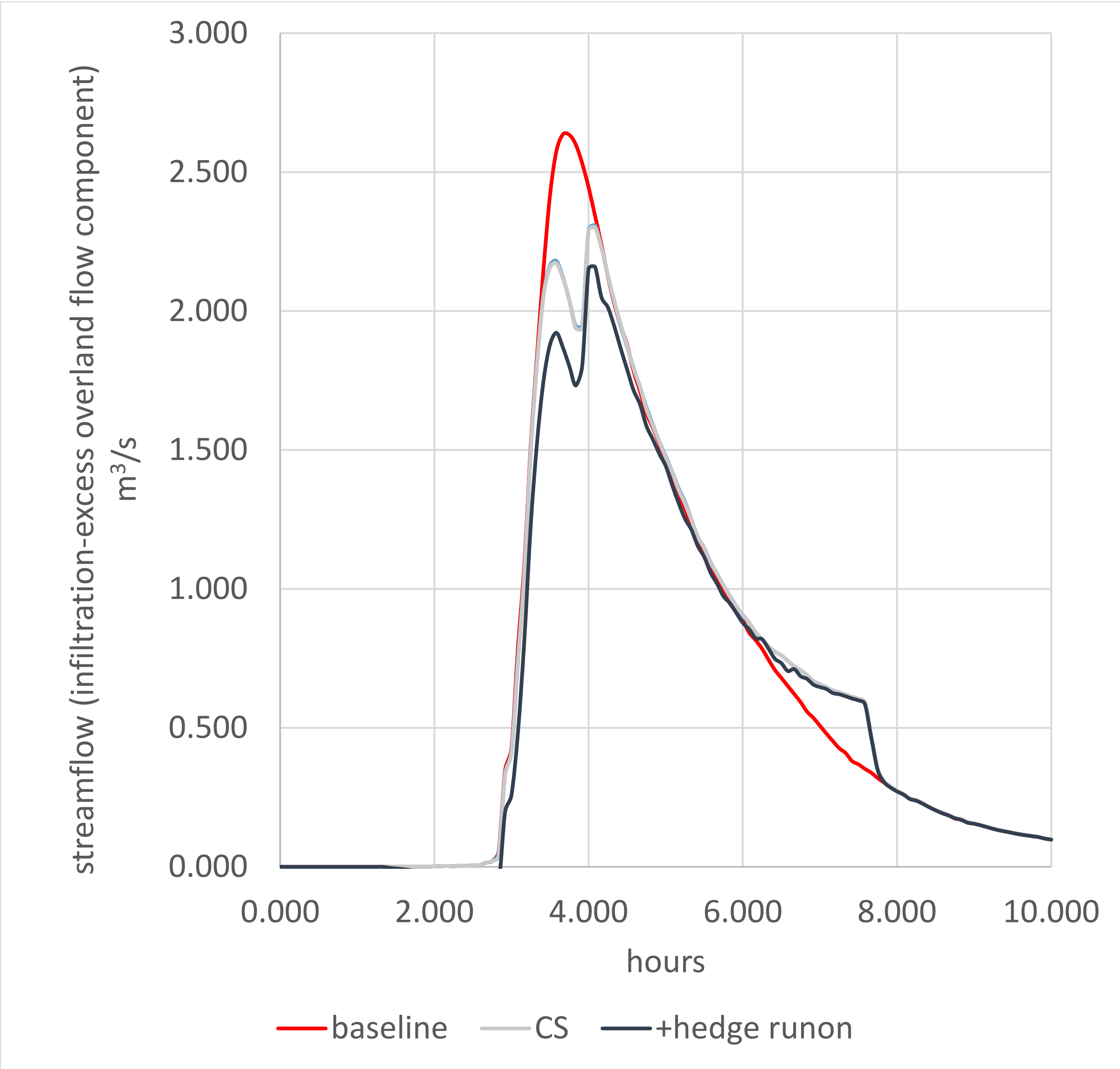

Figure 8. The ‘infiltration-excess overland flow’ component of flood hydrograph for the Scale Beck at 54°31’05.51 N, 2°31’42.02” W (downstream boundary of the Gaythorne Hall Farm estate) following a 1-in-10 year design rainstorm is shown with a red line (‘baseline’). The JFLOW-simulated effect of CS interventions is shown with the grey-purple line. The additional effect of the reinstatement of 1 km hedge, if this removes all infiltration-excess overland flow from upslope areas (that has not entered micro-tributaries before reaching the hedge) is shown with the dark blue line

Summary of principal modelling findings

The study is based solely on modelling the effects of farmer-defined interventions 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 the interventions on hydrological processes in the Scale Beck headwater catchment were not available to strengthen the modelling. Further the modelling tool used only simulates the effects of (infiltration-excess) overland flow and this component of flow in stream channels.

With this modelling approach, the **farmer-defined interventions were seen to reduce the peak streamflow to 87 percent of that without the interventions, primarily through the effects of redesigning just three stream culverts within three drystone walls that cross the valley**. Changes to specific drystone walls (culvert size reductions and wall strengthening) would, therefore, have a significant environmental benefit of flood mitigation in this headwater valley of the River Eden. The proposed interventions involving 'leaky dams' on micro-channels, enhancement of a series of wildlife ponds for flood storage and two local extensions to 'scrub' woodland planting did affect the stream response, but the effects were small. The effects of the other 'Natural Flood Management (NFM)' measures were small, largely because their size is very small relative to the size of the Scale Beck headwater basin. The effects of a proposed reinstatement of a 1 km length of hedgerow along the contour of the south-eastern side of the basin could not be fully simulated with the model used. However, the model was used to simulate the amount of water arriving at the hedge line within channels and across the land surface. If this hedge line were to be designed and allowed to fully develop to capture and infiltrate all the water reaching it from the upslope land (except that already in channels), then the effect on the whole headwater basin could be very significant. **Potentially, the addition of these hedge line infiltration effects to those of the drystone wall redesign, could reduce the overland flow component of peak streamflow during a 1-in-10 year flood to 82 percent of that without such interventions. The environmental interventions proposed by the farmer at Gaythorne Hall farmer have the potential to have a significant NFM benefit in the 3 km^2 headwater of Scale Beck, upstream on the River Eden.**

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