Appendix 12.4: Assessing the impact of floodplain woodland planting in the River Seven catchment

Introduction

There is increasing interest in pursuing opportunities for planting and extending relic areas of floodplain woodland for flood mitigation, but progress is highly constrained by a lack of information on the magnitude of the forest effect and how this is affected by woodland design and management factors. While most of these issues are being investigated by wider modelling work, a robust assessment requires a demonstration study.

The Defra funded, Slowing the Flow at Pickering project provided an ideal opportunity to establish a demonstration floodplain woodland. A positive result would help to strengthen the evidence base and support for using floodplain woodland as a sustainable method for downstream flood alleviation. The ability of floodplain woodland to benefit water quality and freshwater habitats offers the potential to develop win-win solutions, such as contributing to meeting ecological and chemical quality targets under the EU Water Framework Directive. It would also make a sizeable contribution to the regional target of creating an additional 300 ha of wet woodland under the UK Biodiversity Action Plan.

Aims and Objectives

The aim of this part of the project was to facilitate the establishment of a sizeable area (~30 ha) of floodplain woodland in the River Seven catchment to demonstrate and help communicate the benefits of this option for flood alleviation. The main task was to evaluate through modelling the impact of planting floodplain woodland at potential sites on flood flows and flood risk at Sinnington.

Site Selection

The boundaries of the Slowing the Flow at Pickering project extended beyond the Pickering Beck catchment into its neighbouring catchment, the River Seven, which runs through Sinnington, a village also prone to flooding. A total area of 40 ha of floodplain was identified as being potentially available and an ambitious target of creating an extended 30 ha demonstration floodplain woodland along the main watercourse was set by the project. All of the potential land lay in private ownership and was in agricultural use, comprising improved grassland or arable cropping. A total of six main landowners were identified and canvassed for their willingness to consider woodland planting, of which two expressed significant interest, two were uncertain and the remaining two were not interested.

Of the two potential sites with landowner interest, one comprised 3.7 ha and the second 2.1 ha of floodplain that would be inundated during a 1 in 100 year event, giving a total potential floodplain woodland area of 5.8 ha (Figures 1 & 2).

The River Seven is approximately 24 km in length and drains a 90 km^2 catchment upstream of the town of Sinnington. The catchment is mostly rural, comprising arable, improved grassland, some heather moorland and also a large area of forestry (Cropton Forest), which is drained by Cropton Beck, the main tributary of the River Seven.

The River Seven has a fast response time to rainfall events. Flood Estimation Handbook modelling (ReFH method) predicts the response to be as little as 5.5 hours.

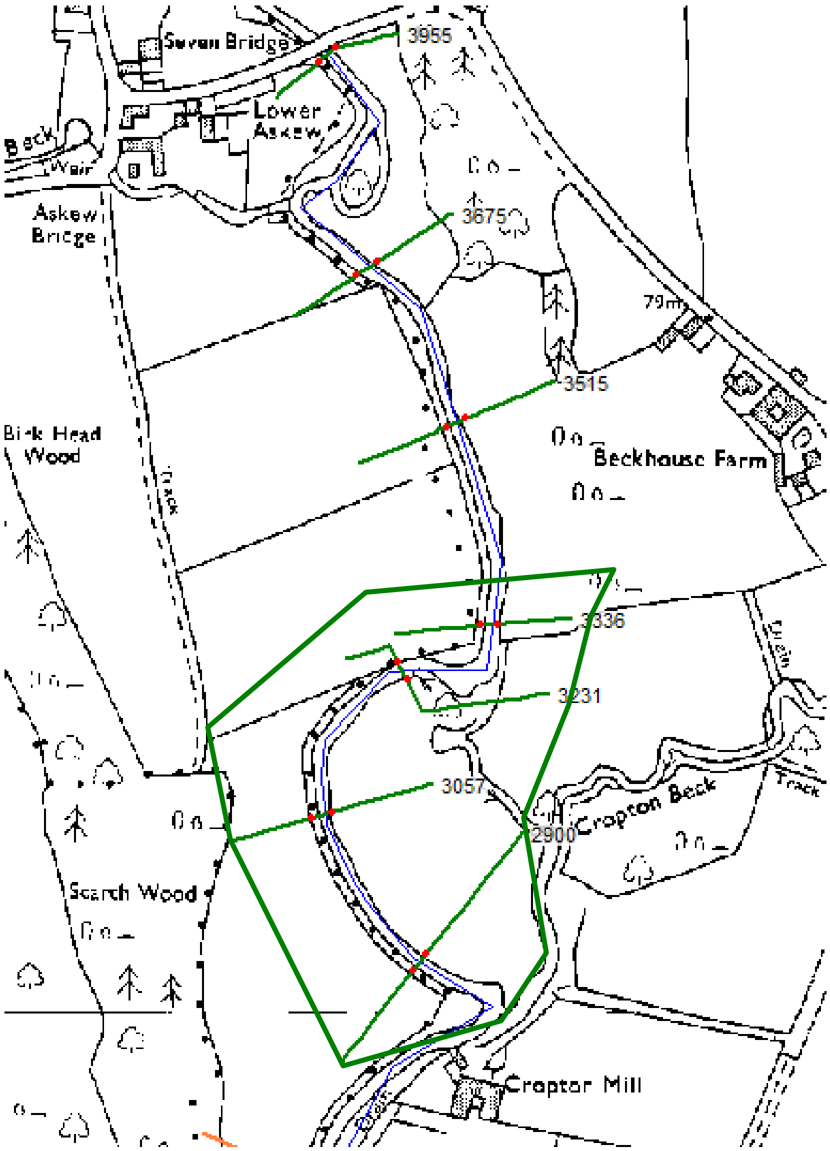


Figure 1 Location of upper potential floodplain woodland site (bounded by green line)

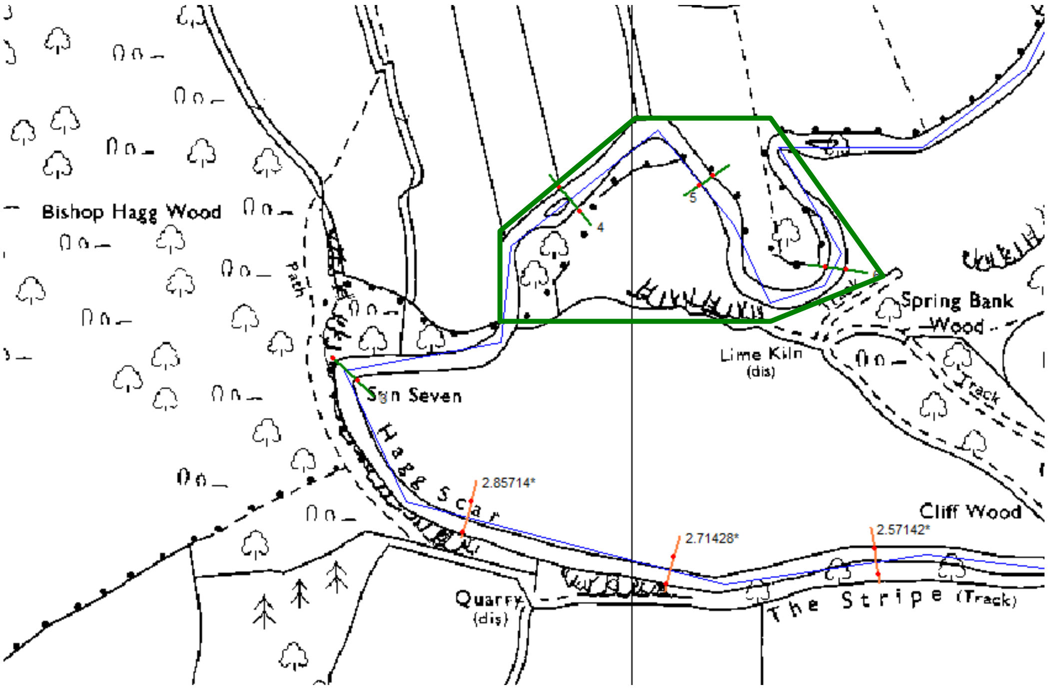


Figure 2 Location of lower potential floodplain woodland site

Site topography

Modelling the impact of planting floodplain woodland at the two identified sites on flood flows required detailed topographical data for the river channel, banks and floodplain, as well as the physical geometry of any man-made structures such as bridges, culverts and weirs. Existing LiDAR and cross section data were available for the River Seven but only extended just upstream of Sinnington. This study required topographic data for the reach between Lower Askew and Sinnington therefore an additional cross section survey was commissioned by a private contractor.

Application of the Hydraulic Engineering Centre - River Analysis System (HEC-RAS) model

The HEC-RAS model was selected for this study since it widely used by flood defence engineers in the UK and is considered by the Environment Agency to be an effective hydraulic modelling tool. The software is freely distributed by the US Army Corps of Engineers via their website and represents an integrated system of software containing three one-dimensional hydraulic analysis components designed for:

1) steady flow, water surface profile computations,
2) unsteady flow simulation, and
3) moveable boundary, sedimentary transport computations.

HEC-RAS is able to perform one-dimensional hydraulic calculations for a single river reach, a dendritic system, or a full network of natural and constructed channels. The steady flow, water surface profile component accommodates the effects of gradually varied flows and is capable of modelling subcritical, supercritical, and mixed flow conditions.

The underlying computational procedure is based on the solution of the one dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilised in situations where the water surface profile is rapidly varied. Allowance can also be made for the effects of various obstructions such as bridges, culverts, weirs, spillways and other channel and floodplain structures.

The model was set up for the reach of the River Seven between Lower Askew (SE 745 898) and upstream of Sinnington (SE 743 858). It required the input of river cross sections to represent the main channel and the floodplain, including flood bank levels to characterise out of bank flows. It was first constructed using the basic cross sections of the river channel obtained from the topographical survey. Initial conditions were obtained by carrying out a number of simulations using within-bank flows. The model was then developed to include the floodplain sections using the surveyed cross section data. Additional cross sections were added to improve the representation of the watercourse in the modelled reach.

Flood Estimation Handbook (ReFH) Modelling

Design hydrographs for four return periods were developed using the Revitalised Flood Estimation Handbook method (Table 1 & Figures 3-6).

Return Period	Total Rainfall (mm)	Peak Flow (m3)
10	29.1	38.8
25	36.7	46.4
50	43.5	53.3
100	51.6	61.7

Table 1 Flood Estimation Handbook (ReFH) derived values for selected flood return periods at Sinnington

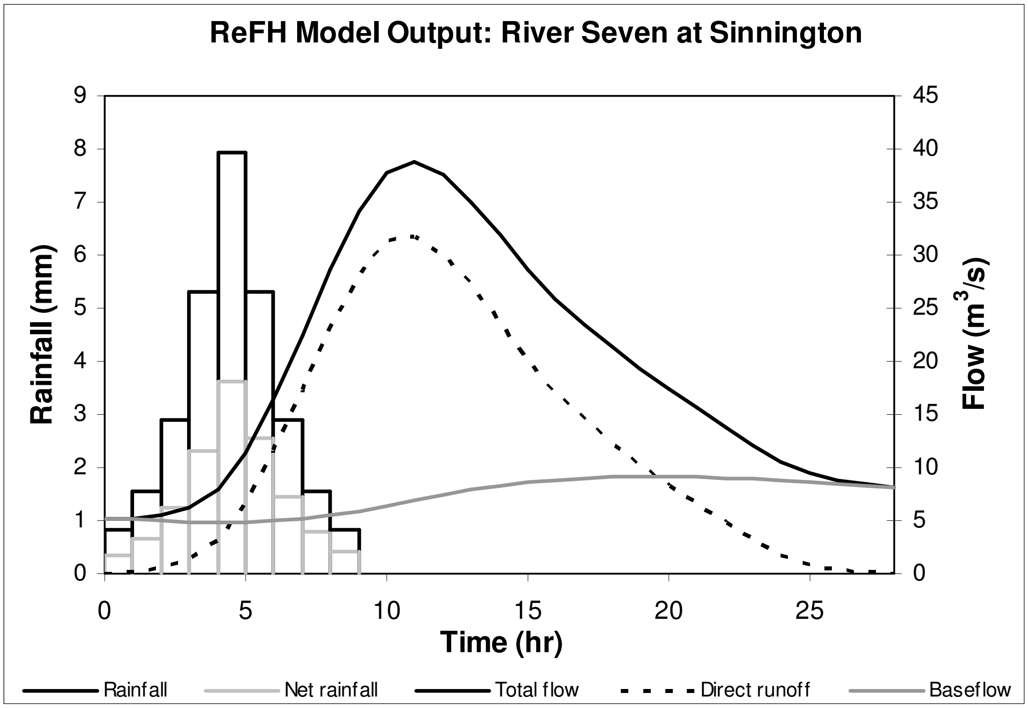


Figure 3 9 hour storm, 10 year return period

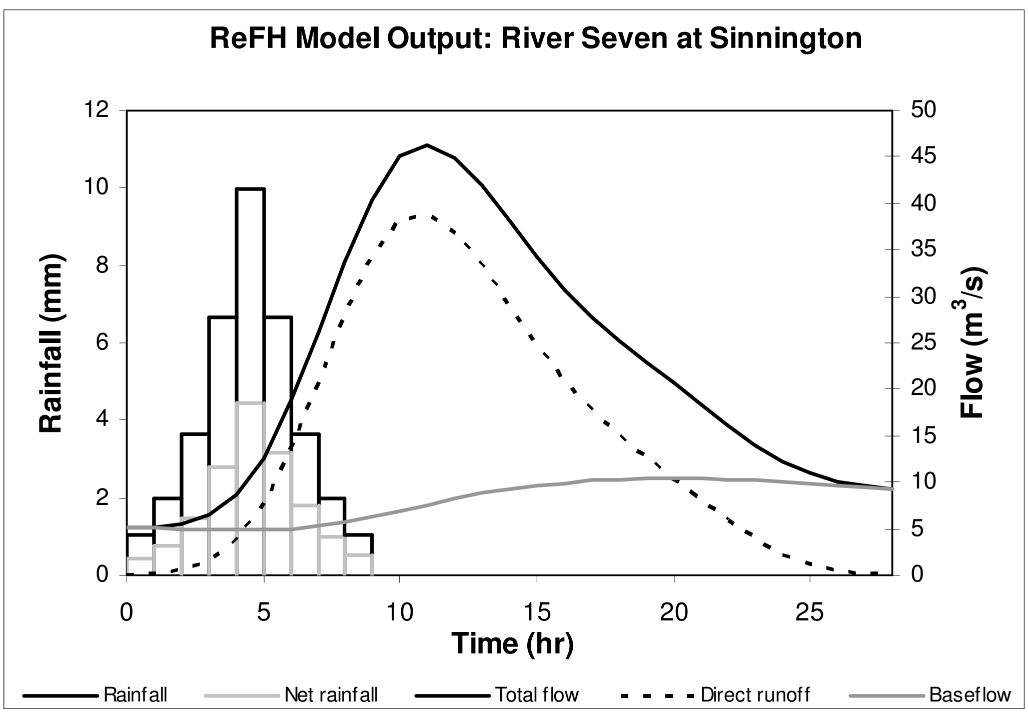


Figure 4 9 hour storm, 25 year return period

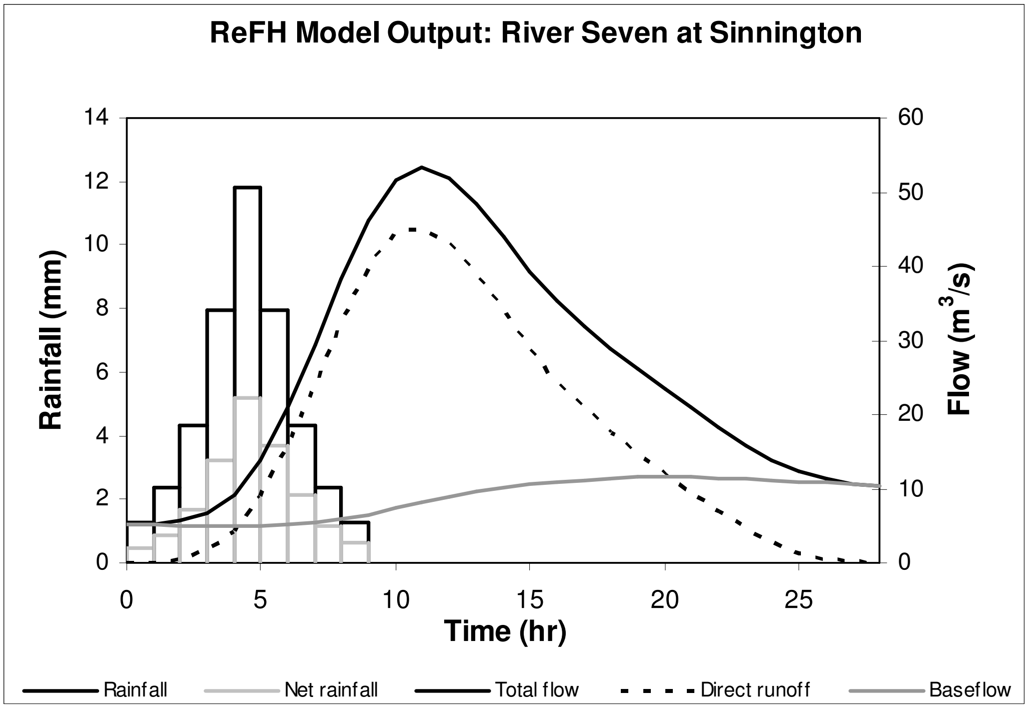


Figure 5 9 hour storm, 50 year return period

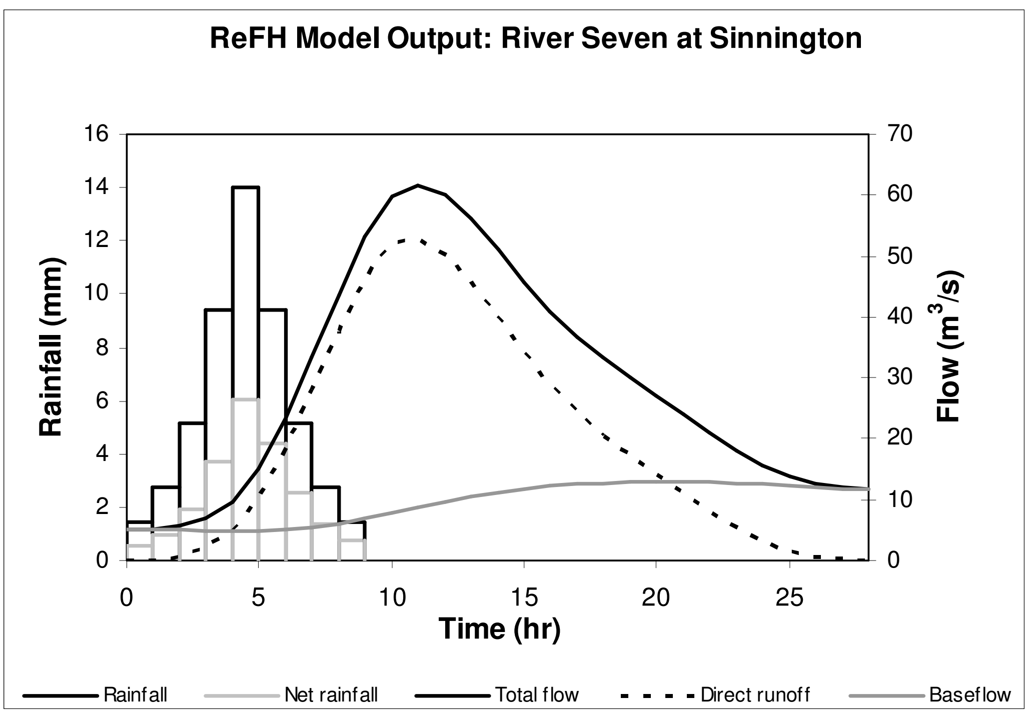


Figure 6 9 hour storm, 100 year return period

Channel and Floodplain Roughness

The principal effect of floodplain vegetation is to increase surface roughness. Modelling techniques in the past have treated vegetation in open channels and on floodplains as an additional flow resistance to be added to the bed roughness. The presence of submerged or non-submerged vegetation along riverbanks and/or across floodplains is often found to be the largest source of resistance.

A roughness coefficient is used to represent the energy lost from flowing water due to channel roughness. One of the most commonly applied uniform-flow formulae for open-channel computations is the Manning's formula, owing to its simplicity and to the satisfactory results that have been achieved in practical applications.

The selection of an appropriate value for the Manning's roughness coefficient (n) is crucial to the accuracy of the computed hydraulic parameters. The value of Manning's n is highly variable and depends on several factors, including: surface roughness; vegetation; channel irregularities; channel alignment; scour and deposition; obstructions; size and shape of the channel; stage and discharge; seasonal changes; water temperature; and suspended material and bedload.

There are a number of methods for calculating Manning's n for river channels and floodplains. The channel and floodplain are always treated separately as the degree of roughness can vary considerably between the two. The most important factors affecting channel n are the type and size of the material forming the riverbed and banks, and the channel's cross sectional shape. Floodplain n requires a base value for the natural bare sediment and soils, and a combined measure for surface irregularities, the presence of obstructions, and the nature of the vegetation.

Roughness values of 0.03 and 0.05 were assigned to the channel and floodplain, respectively, to represent the bed roughness associated with the nature of the existing river channel and the baseline grassland or arable land cover (Chow, 1959). The establishment of a cover of native floodplain woodland was represented by increasing the channel roughness to a value of 0.08 and the floodplain roughness to 0.12. The former was selected to represent the impact of the formation of LWD dams and multiple channels, while the latter was considered to be an average roughness value for floodplain woodland with some undergrowth, low branches and fallen trees. Large woody debris forms a very important component of the roughness/flow resistance of both the floodplain and river channel.

Model Results

The model was used to simulate the effect of planting floodplain woodland at each site on the depth, extent and velocity of flood flows in the River Seven.

Flood depth

The effect of woodland planting on flood depth along the modelled reach during a 1 in 100 year flood is presented in Figures 7-9. The results show that the greater hydraulic roughness associated with floodplain woodland would increase the flood depth along the two planted reaches by a mean of 0.45 m. Planting at the larger, upper site produced an average rise of 0.42 m, while the increase at the lower site averaged 0.47 m. The results concerning the effect on the flow hydrograph are considered below under the section on peak flow timing.

The model predicted that the woodland would create an extended backwater effect at each site, reaching a distance upstream of between 619-738 m (Figure 7). The extent of the backwater effect is primarily dependant on the river gradient, as well as the overall increase in water depth. This highlights the need for great care in site selection when planning new woodlands to ensure that the backing-up of floodwaters does not threaten local dwellings or other assets. The apparent rise in flood depth downstream of the woodland is an artefact of the spacing of the modelled cross-sections.

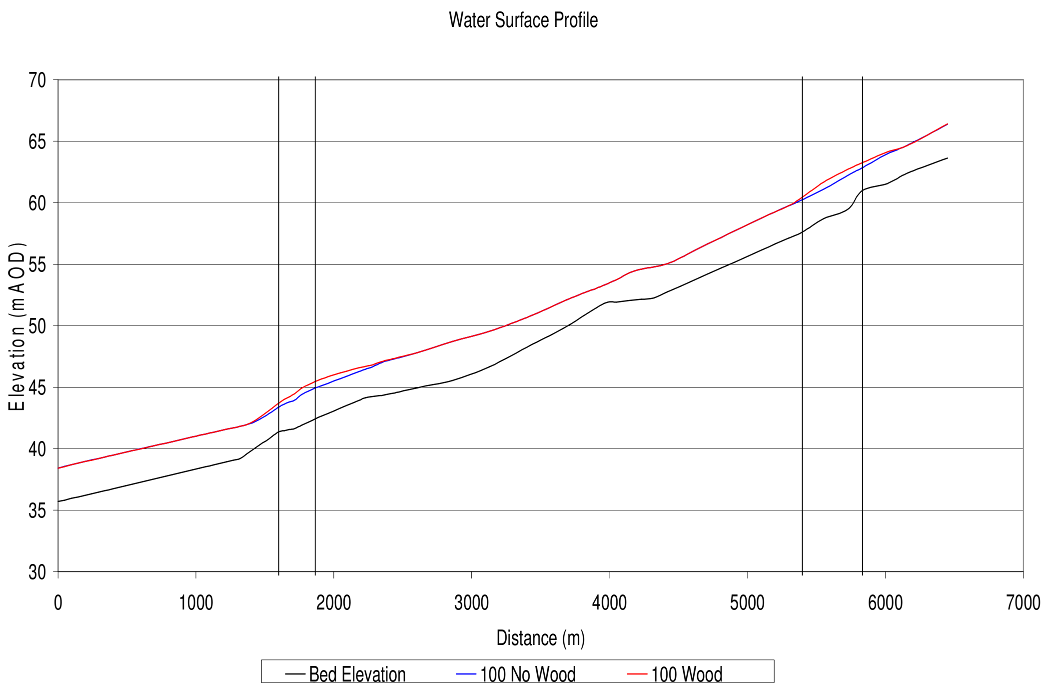


Figure 7 Long profile of the water level during a 1 in 100 year flood

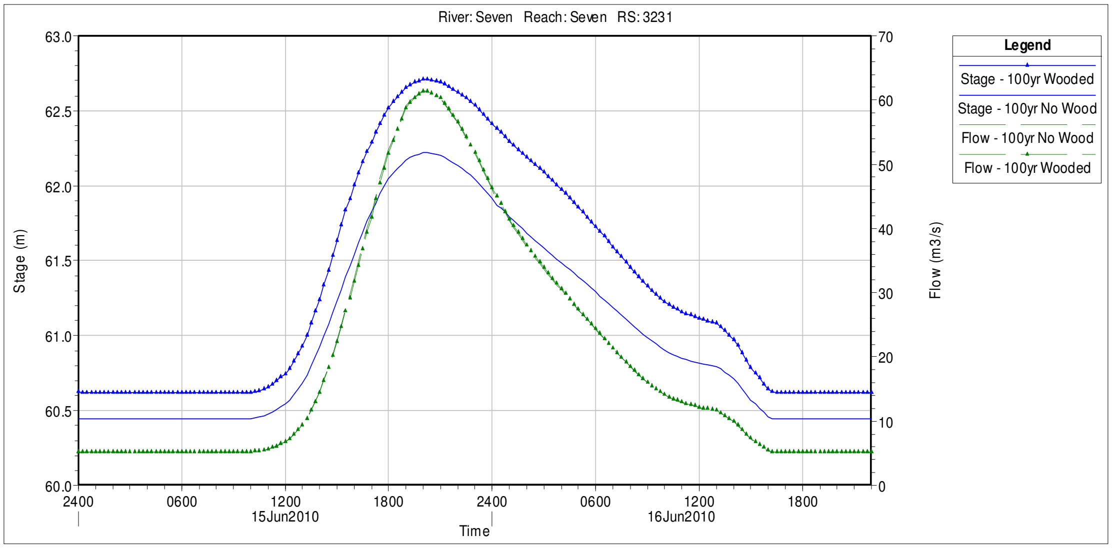


Figure 8 1 in 100 year return period stage and flow hydrograph at upper site (Bank-full water level = 62.1mAOD)

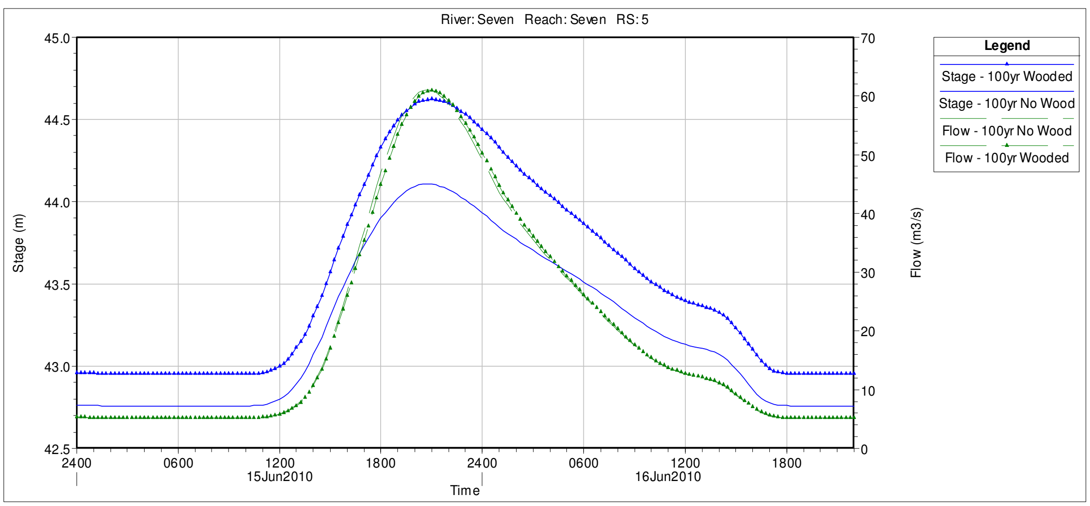


Figure 9 1 in 100 year return period stage and flow hydrograph at lower site (Bank-full Water Level = 44.5mAOD)

Flood extent

The use of GIS to combine LiDAR topographic and hydraulic modelling data onto an Ordnance Survey (OS) base map is an invaluable tool for determining the spatial extent and depth of flooding. It is particularly useful for determining whether the backing up of flood waters poses any risk to local properties or will affect neighbouring land. Maps comparing the extent and depth of flooding for selected flood return periods with and without woodland at each site are presented at the end of the report. The results show that the woodland planting would increase both the extent and depth of flooding within the planted reach across all events.

Flood velocity

Figure 10 shows the effect of planting floodplain woodland on the average flood peak velocities along the modelled reach at each site. As expected, the increased flow resistance resulting from the presence of trees, undergrowth and woody debris caused a significant reduction in flood velocity, up to a maximum of 1.1 m/s. It is the reduction in velocity that causes the rise in flood depth and expansion of the area flooded within and upstream of the planted woodland. As before, the lower velocities predicted below the woodland were an artefact of the spacing of the modelled cross sections.

Figure 10 The impact of planting floodplain woodland on flood flow velocity changes during a 1 in 100 year flood along the modelled reach

Peak flow timing

The impact of planting floodplain woodland at each site on the outflow hydrograph for a 1 in 100 year design flood for the River Seven at Sinnington is displayed in relation to the input hydrograph in Figure 11. Changes to the timing and size of the peak discharge are provided in Table 2, along with the combined effect of planting both sites. There was a negligible effect on peak height but a delay in the timing of the flood peak, with a lag of around 10 minutes for each site, giving a total delay of 20 minutes for the combined planting. The lag per unit area was 2.7 minutes per hectare for the upper site and 4.8 minutes per hectare for the lower site.

While one might have expected the delay in peak timing to bring about a larger reduction in peak height, the discrepancy between the two measures reflects the way the model handles woodland roughness. The woodland acts as a porous barrier, raising the flood level and delaying the downstream passage of the flood peak but having a limited affect on flood discharge. Although flood velocity is reduced, flood discharge is largely maintained by the raised flood depth/height in the river channel and across the floodplain. As noted above, the 1-D model is unable to allow for the increased flood storage that would be expected to result from the creation of multiple channels and depressions characteristic of natural floodplain woodland. Similarly, there is no allowance for any enhanced soil/ground water storage capacity, tree canopy interception or increased water use, although the latter would be limited during the winter leafless period.

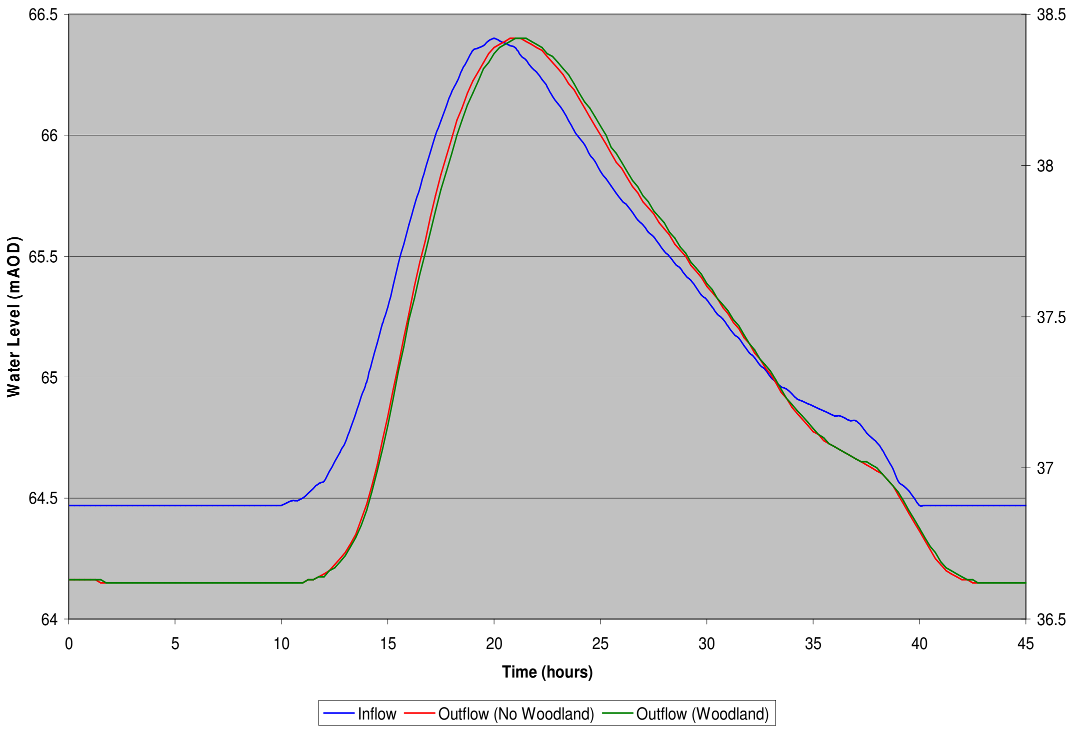


Figure 11 Peak flow timing at downstream limit of modelled reach near Sinnington with both sites planted

Scenario	Wooded Area	Peak Time	Dt	Dt
	ha	min	min	hr
Baseline	0	1230	0	0.00
Upper site	3.7	1240	10	0.17
Lower site	2.1	1240	10	0.17
Both Sites	5.8	1250	20	0.34

Table 2 Effect of woodland planting on peak flow timing for 1 in 100 year flood

Potential Changes in Flood Volume

The modelling exercise predicted that the 5.8 ha area of woodland planting could temporarily increase the volume of flood water within the modelled domain by 14% during a 1 in 100 year flood (Table 3).

Return Period	**Reach Volume (m3) No Woodland**	**Reach Volume (m3) Woodland**	**Change (m3)**	**Change (%)**
10	165,880	180,800	+14,920	+9.0
25	189,840	209,790	+19,950	+10.5
50	210,830	236,590	+25,760	+12.2
100	237,750	271,500	+33,750	+14.2

Table 3 Effect of floodplain woodland on flood volume within modelled domain for various return periods

Discussion

Application of the 1D model using appropriate roughness values suggests that the establishment of floodplain woodland on 2 sites within the modelled 6.5 km reach of the River Seven would have a significant local hydraulic effect on flood flows. The additional resistance presented by the woodland was predicted to reduce the velocity of water flow across the floodplain by around 54%, with the result that the depth of flood water within the woodland increased by 21–58 cm. This increased the volume of flood water temporarily held within the modelled domain by 14% for a 1 in 100 year event, amounting to around 34,000 m^3. This caused flood waters to back-up for a distance of up to 740 m upstream.

The magnitude of the local effects were relatively minor in the context of the impact on the main flood peak at Sinnington. Planting was predicted to have a minimal effect on the height of the flood peak, with the main contribution being to delay its downstream passage by around 20 minutes, providing some extra time for issuing a flood warning. This result is not surprising in view of the very small area of floodplain woodland planting in relation to the large size of the catchment of the River Seven (less than 0.07% of the total catchment area of 90 km^2). However, the results highlight the potential for a larger floodplain woodland or a series of similar-sized woodlands along the modelled reach to exert a much greater effect and help contribute to alleviating downstream flooding at Sinnington.

The ability of the floodplain woodland to delay the passage of the flood peak could be exploited by targeting planting to individual tributaries where it would have the greatest impact in terms of desynchronising sub-catchment contributions and therefore on reducing the size of the main flood peak. By the same token, it would be important to avoid sites where the effect would be to synchronise flows, potentially enhancing the flood peak.

The model predictions are based on using an average roughness value for floodplain woodland associated with little undergrowth and limited amounts of dead wood on the woodland floor. It should be possible to enhance channel and floodplain roughness by adopting appropriate management practices, such as to increase levels of dead wood or constructing LWD dams. Large woody debris forms a very important component of the roughness or flow resistance of both the floodplain and river channel, especially where it combines to form LWD dams. The formation of multiple channels and pools typical of natural floodplain woodland could also be expected to enhance floodplain roughness and flood storage. The obstruction provided by individual trees and debris dams restricts water flow and contributes to scouring and channel development.

The results of the 1D modelling exercise revealed that the benefits of floodplain woodland in terms of reducing the velocity of water flow across the floodplain and increasing flood depth were partly countered by a corresponding increase in water velocity in the main river channel. Opportunities exist for ameliorating this effect, such as by introducing LWD dams to dissipate the energy within the channel and divert more water onto the floodplain. Such structures would increase the frequency of flooding on the floodplain and so enhance the ability of floodplain woodland to alleviate flood flows. Concern has been raised about the backing-up of floodwaters upstream of floodplain woodland, which could threaten properties in the immediate vicinity. The modelling work demonstrated that water levels could be raised by up to 58 cm immediately above the woodland. The implications of this factor would need to be carefully considered on a site-by-site basis when assessing site suitability for the restoration of floodplain woodland.

Conclusions

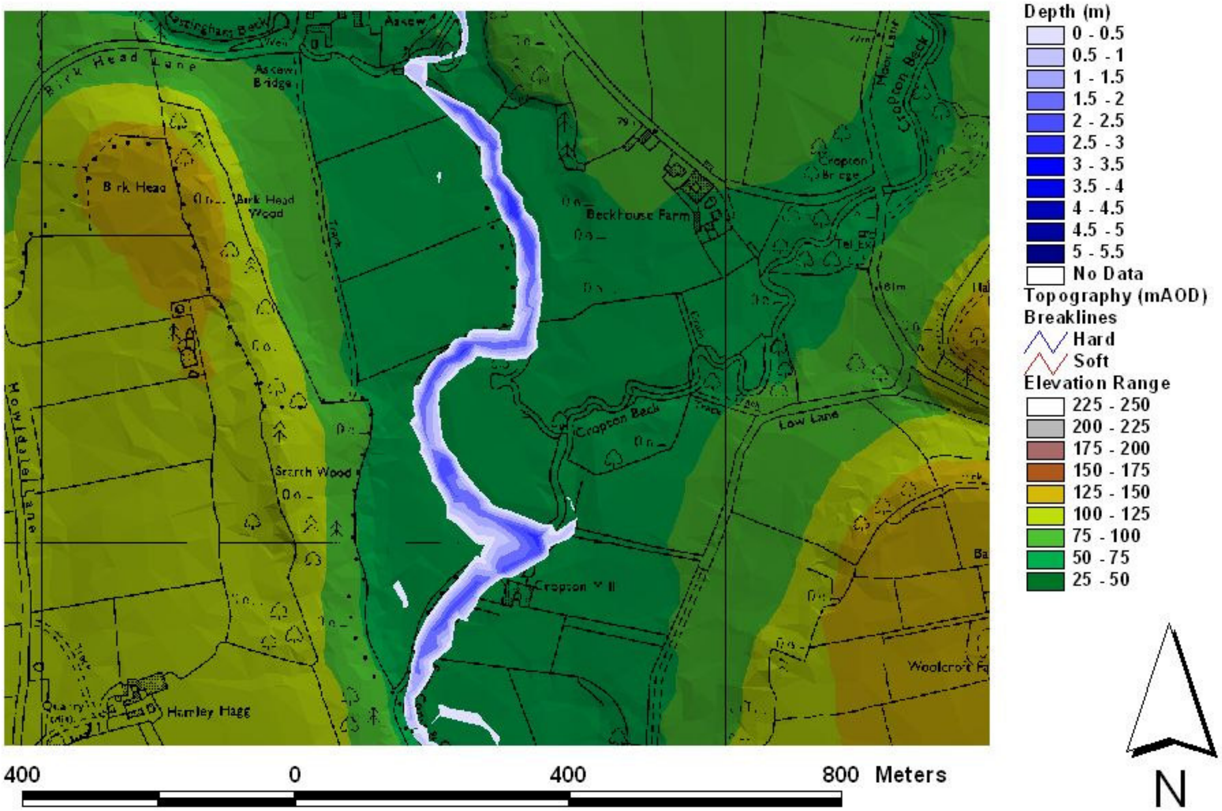
(1) Application of a 1D hydraulic model to a 6.5 km reach of the River Seven demonstrates that the planting of floodplain woodland would have significant local hydraulic effects on flood flows, including reducing the velocity of flood flows across the wooded floodplain by around 54%, increasing flood depth by 21–58 cm and increasing the volume of flood water temporarily held in the reach by 14% for a one in 1 in 100 year event, amounting to around 34,000 m^3. On the downside, flood waters could be expected to back-up for a distance of up to 740 m upstream of the woodland.

(2) The small area (~6 ha) of potential floodplain woodland modelled (in relation to the size of the catchment @ 90 km^2) resulted in the local hydraulic effects having a minor impact on the size of the flood peak at Sinnington. Its main contribution would be to delay the downstream passage of the flood peak by around 20 minutes, providing some extra time for issuing a flood warning. A larger floodplain woodland or a series of similar-sized woodlands would be expected to exert a much greater impact, especially if targeted to sub-catchments where the lag effect could be exploited to desynchronise tributary contributions.

(3) Although it is very unlikely that floodplain woodland on its own would be able to protect properties in Sinnington from future flooding, it could make a valuable contribution alongside other catchment measures to reducing future flood risk, as well as provide many other environmental benefits.

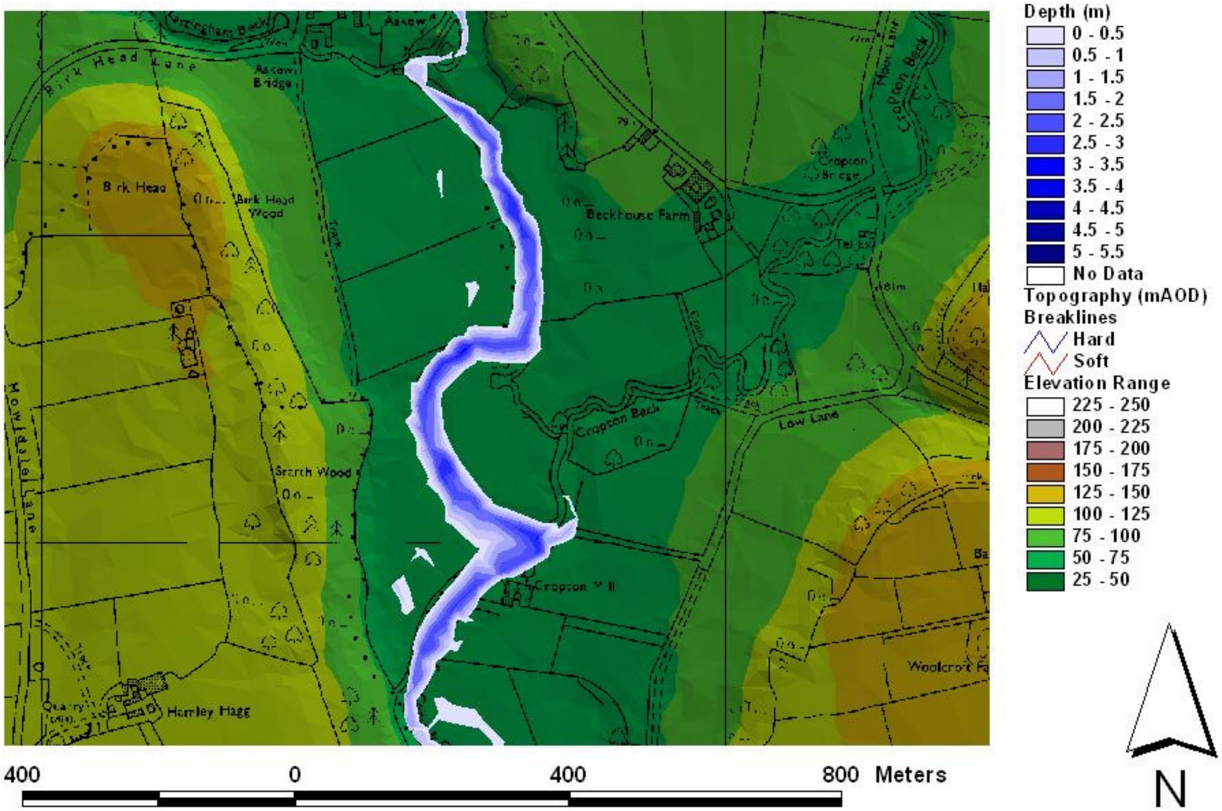
Flood Depth (m) 10 year flood (39 m3/s) - No Woodland

Beckhouse Site



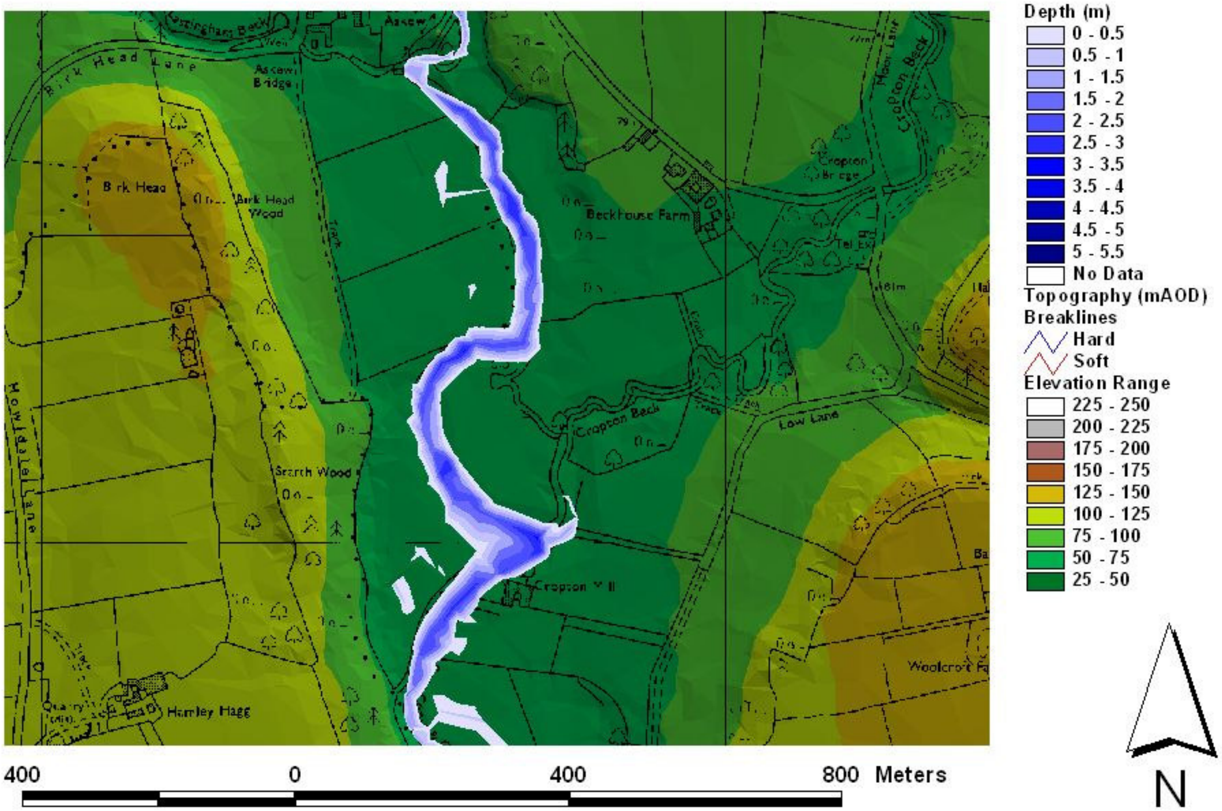
Flood Depth (m) 10 year flood (39 m3/s) - Woodland

Beckhouse Site



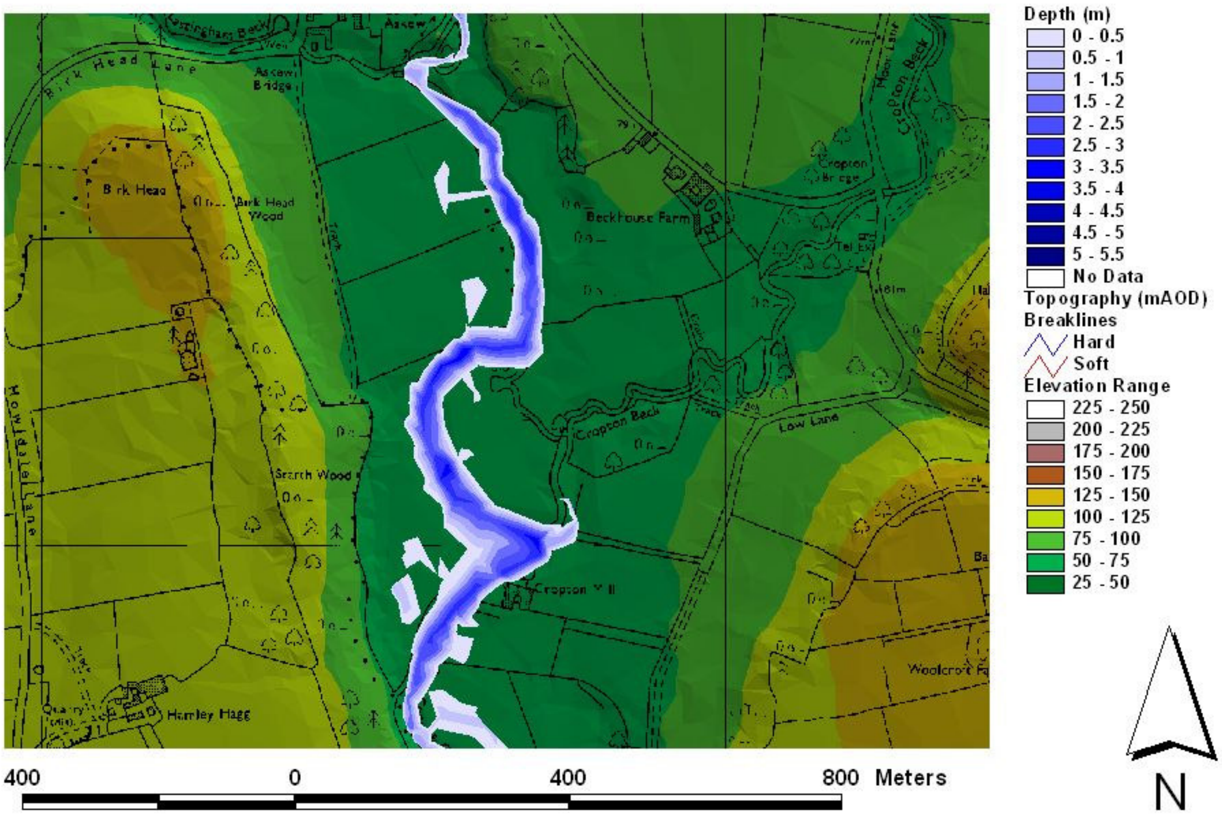
Flood Depth (m) 50 year flood (53 m3/s) - No Woodland

Beckhouse Site



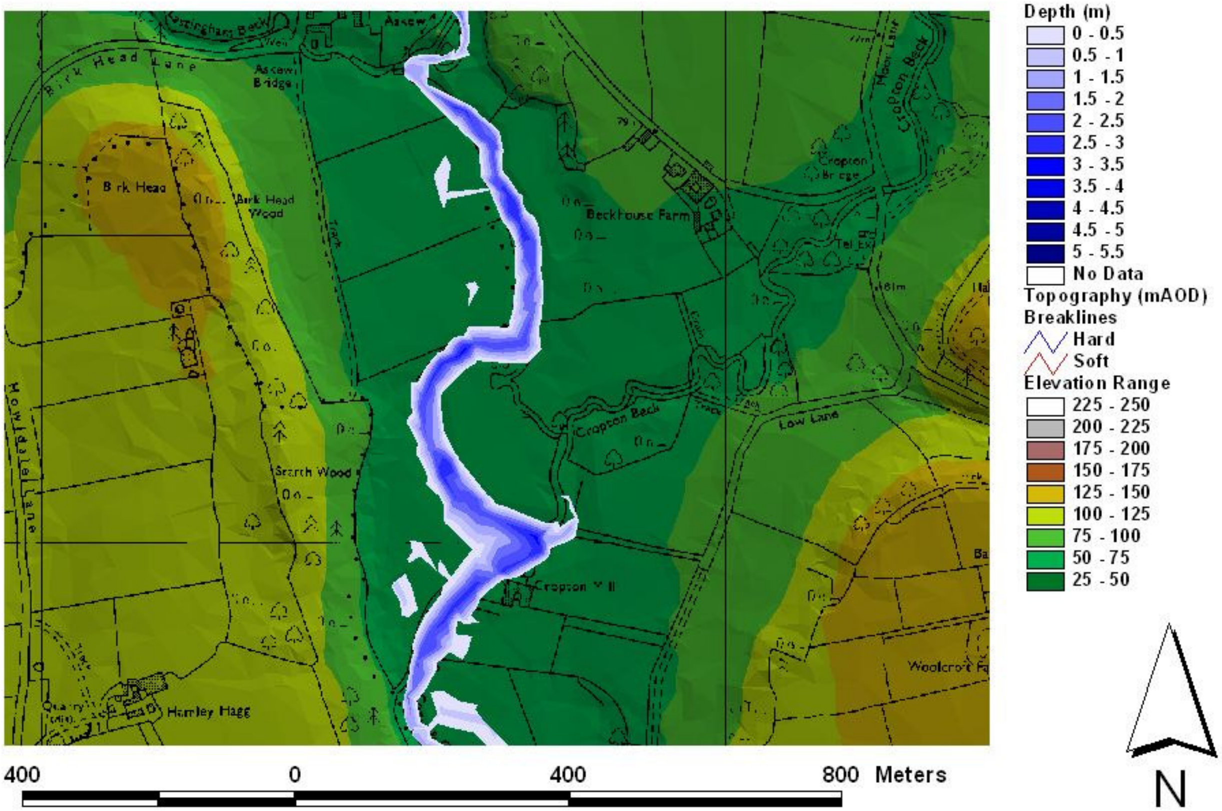
Flood Depth (m) 50 year flood (53 m3/s) - Woodland

Beckhouse Site



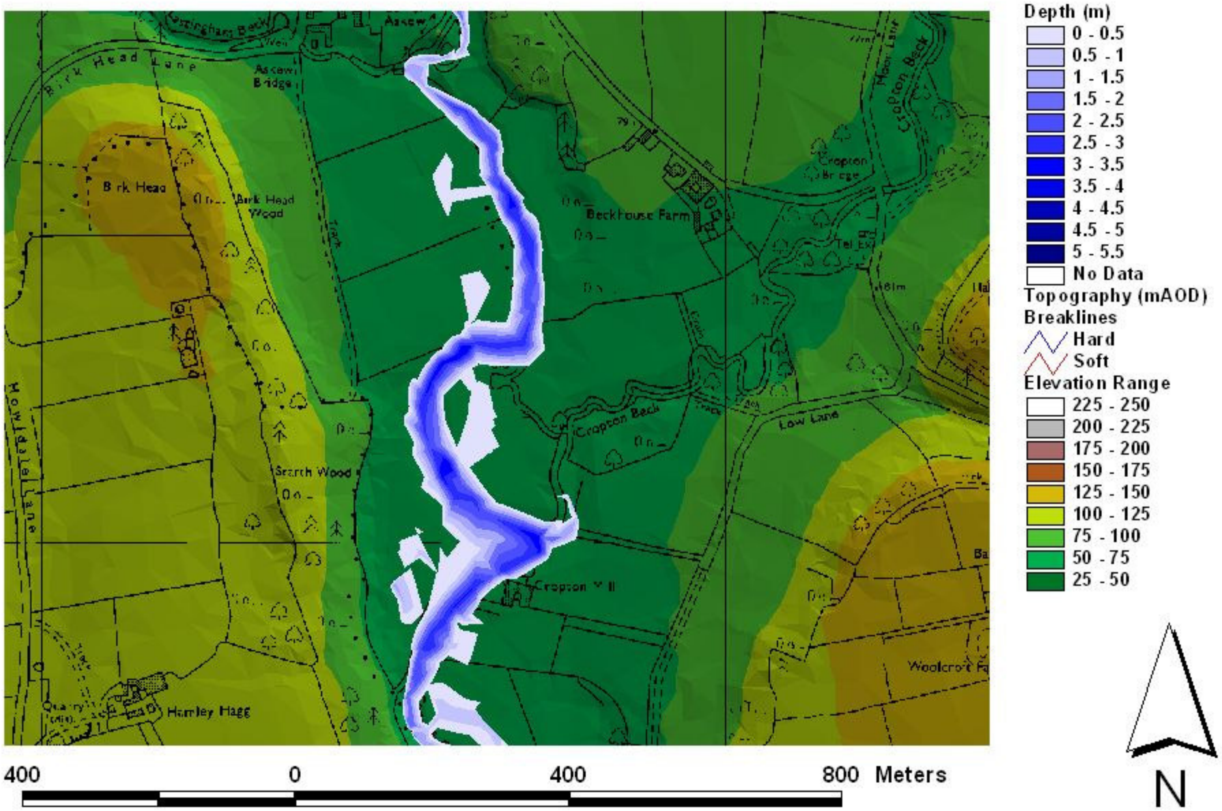
Flood Depth (m) 100 year flood (62 m3/s) - No Woodland

Beckhouse Site



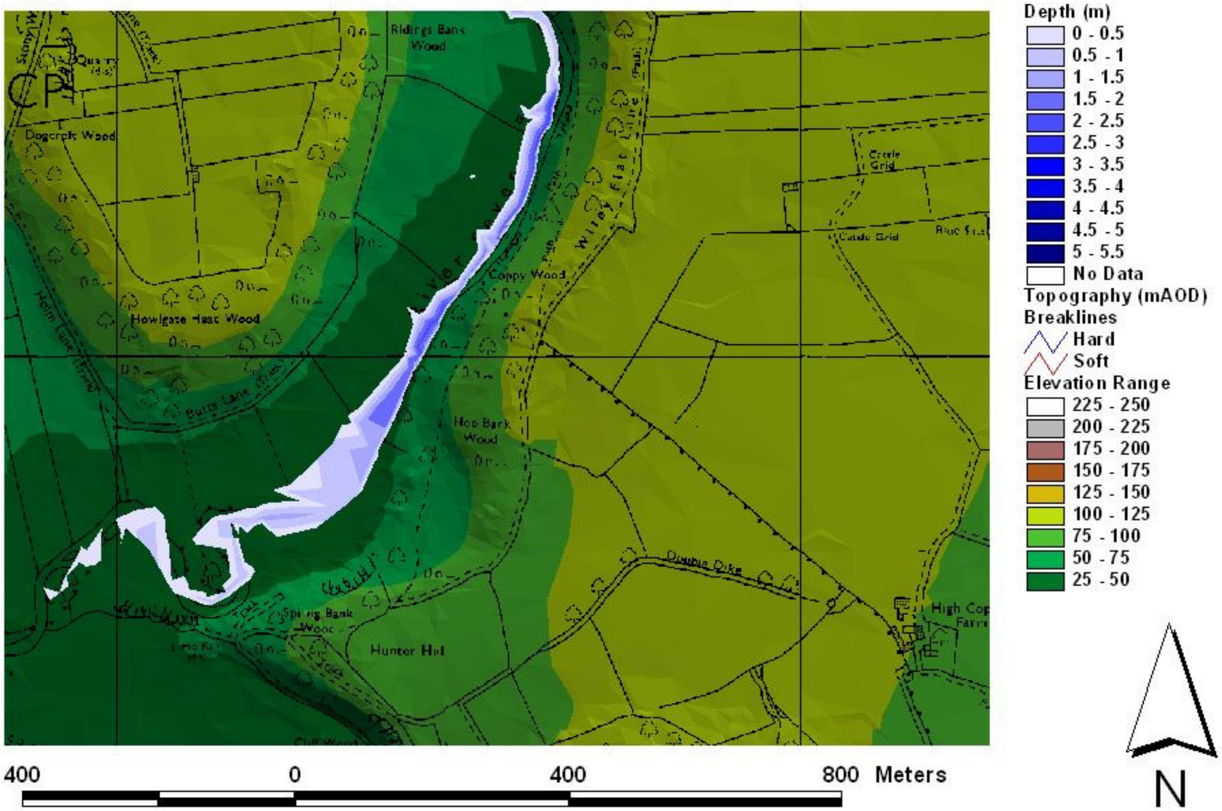
Flood Depth (m) 100 year flood (62 m3/s) - Woodland

Beckhouse Site



Flood Depth (m) 100 year flood (62 m3/s) - No Woodland

Bishop Hagg Site



Flood Depth (m) 100 year flood (62 m3/s) - Woodland

Bishop Hagg Site