Robinwood

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The Robinwood Robinflood report:

Evaluation of Large Woody Debris in Watercourses

Forest Research
TECHNICAL DEVELOPMENT

Comisiwn Coedwigaeth Cymru
Forestry Commission Wales

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CONTENTS

Robinwood

This report has been produced as a result of the Robinwood Project, a 45 month European Interreg 111c Regional Framework Operation project – a first for Wales and delivered by Forestry Commission Wales on behalf of the Welsh Assembly Government. It looked at how we should manage our trees and forests to provide solutions to hydrological issues, increase the amount of wood used in heat and energy and the key role they play in helping to regenerate rural communities across Europe.

The Italian project leaders named the project after Robin Hood – a deliberate play on the UK folk hero best known for taking from the rich and giving to the poor. Research carried out by the project now provides valuable new information on how forests can provide all kinds of opportunities for the future.

An Evaluation of the Impact of Large Woody Debris in Watercourses on Flood Flows

1. Introduction

Interest in the role of land use and floodplain management in controlling flood flows has stimulated research into the effects vegetation and woody debris have on flow conveyance. Large woody debris (LWD) is a term applied to pieces of dead wood larger than 0.1 m in diameter and 1.0 m length (Linstead and Gurnell, 1998). The term can be used to refer to entire trees, roots, trunks, logs, branches and other large pieces of wood that can accumulate within river systems (Plate 1).

Plate 1 Large woody debris accumulation in a Canadian river near Johnson Gorge.

When a piece of LWD falls into a watercourse and lodges against the stream bed and bank, smaller pieces of wood and leaves can gather behind it. The accumulating structure is known as a debris dam. The presence of LWD creates a variety of in-stream flow conditions depending on the depth of the water relative to the height of the LWD. Where the water level is low, a piece of LWD lying across an entire channel will result in slow flowing pools forming upstream. Water will cascade over the LWD creating turbulent aerated zones. When water levels are high, LWD can become submerged and flow conditions less variable.

LWD dams affect woodland river environments in four main ways, all of which are a direct consequence of their impact on flow hydraulics:

1) They increase the hydrological interactions between the river channel and its floodplain by controlling the local distribution and intensity of overbank flows, and by enhancing flows around the site of the debris dam.

2) They enhance the storage and attenuate the transport of sediments, organic material and solutes within the river system.

3) They affect the geomorphology of wooded river channels, resulting in greater variability in channel size, an increase in the occurrence of pools and riffles, and greater overall channel stability. As a result the physical habitat diversity of the woodland river system is increased.

4) They provide a diversity of habitat patches which can support a wide range of organisms at different stages of their life cycle. LWD accumulations can have an important role in regulating water quality and in sustaining refuge habitats to protect biota during pollution episodes and high flows. In addition, LWD accumulations provide important food sources for aquatic biota.

2. Input mechanisms and distribution of LWD in watercourses

The quantity and distribution of LWD within wooded river channels is controlled by the supply of LWD to the woodland floor and directly to the river, the decay rates of the debris, the delivery mechanisms which transport the LWD from the riparian zone into the river, and the export and deposition mechanisms within river channels (Gurnell et al., 1995).

Mechanisms of LWD delivery to streams can be separated into continual and episodic delivery processes. Continual mechanisms include the regular introduction of wood as a result of natural tree mortality or gradual bank undercutting. These processes tend to add small amounts of wood at frequent intervals. In contrast, episodic inputs, including windthrow, fire or severe floods, occur more infrequently but can add large amounts of wood to the channel network.

The zone from which LWD is supplied to the channel varies as a function of the topography of the streamside area, characteristics of the channel and direction of the prevailing wind (Steinblums et al., 1984; Grette, 1985; Murphy and Koski, 1989). Input to small or medium sized constrained channels tends to be dominated by windthrow (Keller and Swanson, 1979). Additional input mechanisms include transport from upstream reaches during flood flows or mass failures (Swanson et al., 1982).

Amounts of LWD are generally higher in small streams and decrease with increasing stream size. Larger channels tend to have a greater ability to transport wood more easily, leading to a reduction in LWD frequency due to flushing of smaller pieces downstream and out of channels onto floodplains (Fetherston et al., (1995), Gurnell et al., (1995)). The size of individual LWD accumulations increases downstream, while their frequency decreases (Swanson et al., 1982).

The amount and distribution of LWD is also influenced by the species composition of the riparian vegetation (Fetherston et al., 1995). Species which reach a larger size produce more stable, longer-lived debris than smaller species. Research in North America by Harmon et al. (1986) noted that in general, deciduous woodland produces less LWD than coniferous forest, with the largest rates associated with old-growth stands.

A major factor in the distribution and density of LWD dams is the size of the debris in relation to the width of the stream. Lienkaemper and Swanson (1987) noted that the movement of debris in streams was strongly related to the length of the individual pieces; most pieces that moved were shorter than bankfull width. In small streams, the pattern of LWD accumulations largely reflects the pattern of input, since the streams have insufficient power to move large pieces of debris. In intermediate streams, a greater proportion of the LWD can be moved during floods. Pieces larger than the width of the active channel can remain stable and smaller pieces of LWD accumulate behind them. In larger watercourses, the channel width exceeds the length of most LWD and virtually all of the material will move at high flows.

3. The hydraulic effect of LWD dams

A simple classification of LWD dams was produced by Gregory et al. (1985) to reflect their relative hydraulic influence. Active dams completely span the channel and cause a step in the water surface profile, even at low flows; complete dams span the channel but are sufficiently leaky to have no noticeable effect on the low flow water surface profile; and partial dams do not completely span the channel. It is likely that active dams have the greatest hydraulic influence because of their impact on the energy gradient at all flow stages, whereas partial dams can be expected to have a limited effect on flows.

A number of hydraulic changes are expected to occur with the presence or addition of LWD dams. The mean depth of water will increase upstream of a LWD dam, caused by the restriction of flow in the channel and the consequent backing up of water behind the dam. It is likely that plunge pools will form downstream of LWD dams as a result of water flowing over the dam crest to an area of lower water level. The deeper areas of water associated with upstream backwater pools and downstream plunge pools form important refuges and rest areas for aquatic fauna, as well as increasing physical habitat diversity. The effects of a LWD dam on low and high flows are shown in Figure 1.

Reach mean velocity is likely to decrease when LWD dams are present. Tracer experiments carried out on the Highland Water in the New Forest, Hampshire by the University of Birmingham (Linstead and Gurnell, 1998), recorded velocities of 0.038 $m\ s^{-1}$, 0.059 $m\ s^{-1}$ and 0.084 $m\ s^{-1}$ for reaches with active/complete, partial and no dams, respectively. Overall, there was a 55% decrease in average velocity between non-dammed and dammed reaches.

Velocity distributions across the channel are expected to become more variable below LWD accumulations due to the way in which flow passes through LWD dams. When flowing through or over a dam the flow concentrates where there are gaps in the LWD matrix or at the lowest points of the dam, resulting in threads of high velocity downstream. The increase in the variability of the velocity distribution creates good feeding habitat for salmonid fish.

LWD dams form major roughness elements within the river channel, influencing the spatial distribution and range of flow depth and water velocity, thus increasing the diversity of hydraulic conditions within the channel. The increase in channel roughness has the greatest influence on small compared to extreme flow events. Experiments on the Highland Water by Linstead and Gurnell (1998) derived Manning's n values of 0.963 and 0.286 for active dams and control reaches, respectively. The greater roughness created by LWD can be expected to significantly enhance the local upstream flood hazard due to the backing-up of floodwaters.

The backwater effect increases the width and depth of flow and velocities are greatly reduced, resulting in a more uniform distribution of velocity across the channel. At the reach scale, the impact of multiple debris dams holding back water and inducing variable amounts of flow diversion, is likely to be a more pronounced attenuation of flood peaks than would be the case in the absence of LWD dams (Gurnell et al., 1995). Ehrman and Lemberti (1992) found that debris dams in third order streams retained water for 1.5 to 1.7 times longer than those with minimal LWD, but noted that reaches with lateral accumulations of LWD had a smaller impact on hydraulic retention. Thus for in-channel flows and those which exceed the channel capacity to a small degree, debris dams modify the flood hydrograph by reducing the magnitude of the discharge peak, and increasing the duration of the flood and the downstream travel time (MacDonald et al., 1982; Gregory et al., 1985).

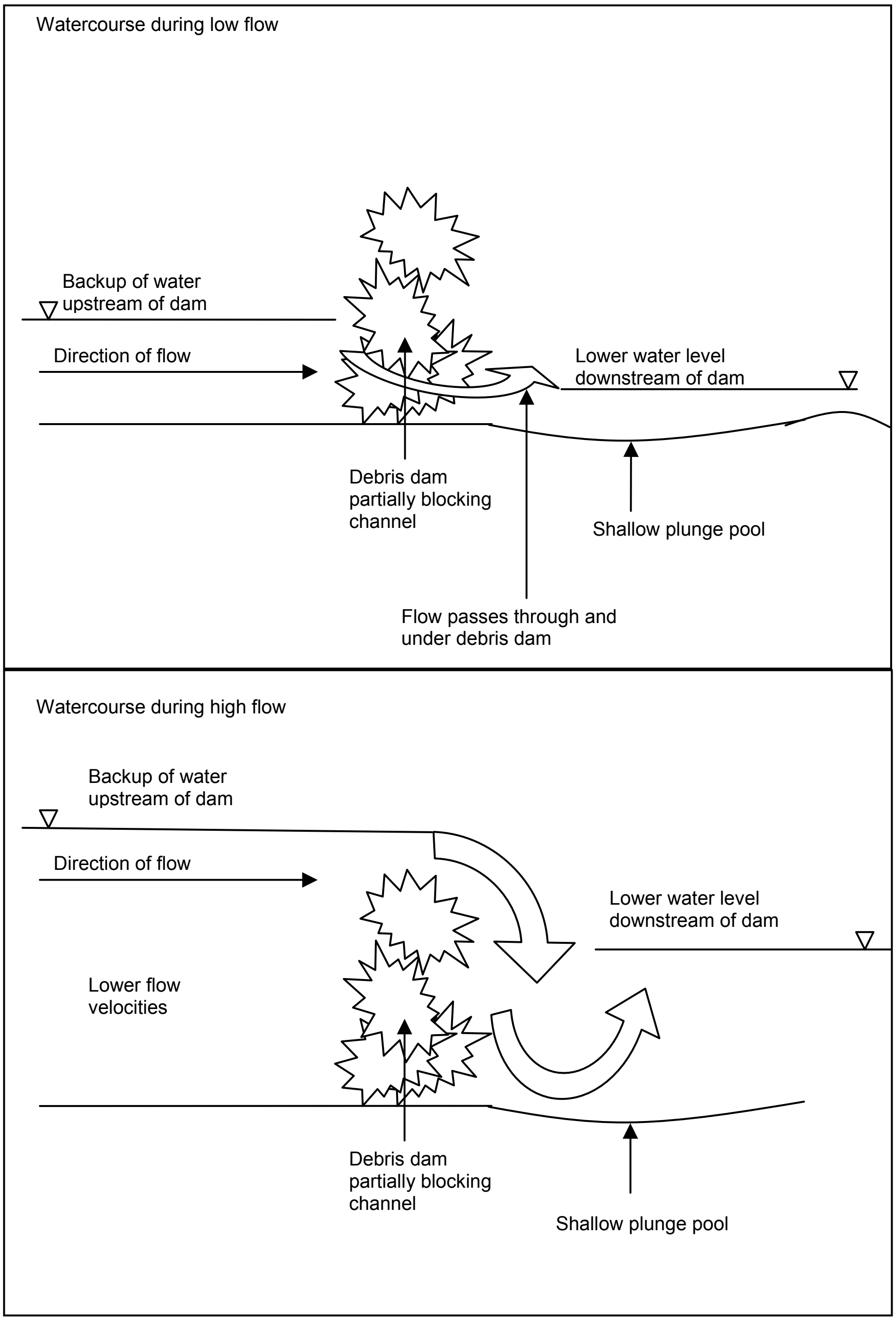


Figure 1 **The hydraulic effects of LWD dams during low (top) and high (bottom) flow conditions.**

Gregory et al (1985) observed a difference in travel time of over 100 minutes along a 4 km reach with and without dams for a discharge of 0.1 $m^3 s^{-1}$, decreasing to 10 minutes at a higher discharge of 1.0 $m^3 s^{-1}$. This finding suggests that LWD dams in headwater streams are more effective at increasing travel times of small compared to large flood events.

Flume experiments carried out to investigate the hydraulic effects of LWD (Young, 1991) have attempted to quantify the influence of different amounts and orientations of LWD on flood levels. These concluded that the limited amounts of debris found in large lowland rivers will seldom have a significant effect on flood levels. However, where debris is present, re-orienting individual pieces has the potential to increase local water levels. This work indicates that efforts to increase LWD dam formation for downstream flood alleviation are best concentrated in the middle to upper reaches of a catchment, where channel sizes are smaller and the supply of woody debris to the system is likely to be larger.

4. Artificial placement of LWD dams in river systems

The artificial addition of LWD to degraded rivers can help to increase the hydraulic complexity of river channels and provide a soft engineering approach to flood alleviation. The selection of correctly sized LWD is critical for dam stability. Complex placements that mimic natural conditions tend to be more stable because they have the greatest flexibility in adapting to changing channel and flow conditions (Abbe and Montgomery, 1996). Care is required in avoiding sites where the washout of debris can block downstream bridges and culverts, thereby increase flood risk.

There are four common methods of LWD placement in rivers to create dams, which are listed below in order of preference for habitat formation:

1. No anchors – where wood is supplied to the stream and allowed to be moved by the flow.

2. Passive anchors – where the weight and shape of the structure is the anchor, and movement at some flow levels is acceptable

3. Flexible anchors – such as tethering the structure so there is some degree of movement and flexibility with varying flows

4. Rigid anchors – holding the woody debris permanently in place with no movement allowed.

A number of anchoring methods can be employed to increase the stability of LWD dams, including:

1. Ballast – the addition of weight to the structure, e.g. gravel or local channel bed material

2. Pilings – used to trap large wood behind or between wood poles, driven into the river bed or banks.

3. Cable/Chain – securing large pieces of wood together or to other objects

4. Pinning – used to trap large wood in existing vegetation or attach one log to another with pins or bolts

5. Deadman anchors – the use of buried objects to secure large woody items and resist removal by virtue of the weight of the soil mass above them

6. Anchoring to bedrock and boulders – large wood is held down by a chain or cable attached to the bedrock

7. A combination of the above methods to suit individual site conditions.

The amount of engineering required for an individual LWD dam will depend on site conditions, the availability of local material, the size of the dam, the predicted flow conditions during flooding events, and channel morphology and composition. Key factors are considered below.

Ballast

Any object that adds to the weight and frictional resistance of a structure is considered ballast, for example, gravel or other rock found on the riverbed (Plate 2). Ballast composed of similar material to the riverbed is vulnerable to removal during flood events.

Pilings

Where access allows and soil conditions are favourable, LWD dams can be anchored with piles (Plate 3). Pilings are appropriate in streams with moderate to fine-sized bed material. They can be driven into the channel bed or be placed horizontally into river banks, as long as the soil composition is suitable and can provide stable foundations.

The matrix of pilings, logs, sediment and vegetation may be all that is necessary to hold a structure in place. If required, pins or cables can be used to attach materials to pilings. Woody debris can be wedged between pilings and held in place by water pressure or ballast, or alternatively, by using cable strung between a number of the pilings. This is particularly effective in holding smaller woody debris together and encourages the deposition of fine sediment. A typical piling anchor design requires one-half to two-thirds of the piling length to be buried below the streambed surface.

Cabling or Chaining

This method includes anchoring pieces of large wood with various materials, including cable, wire, rope, or chain. Where a permanent, rigid anchor is required, cable or chain is the most appropriate. However, where an anchor is only needed until the LWD dam matrix forms and stabilises naturally, the use of hemp rope or other biodegradable natural fibres may be best.

Pinning

One method involves using steel pins to connect individual pieces of large wood together or to other anchors, including adjacent live trees or the stream bed.

Anchoring the material against or between bankside trees is a more natural way of forming debris dams and should be favoured whenever possible (Plate 4).

Plate 2 **LWD dam anchored using ballast (Stream Habitat Restoration Guidelines (2004)).**

Plate 3 **LWD dam using piling for stabilisation (Stream Habitat Restoration Guidelines (2004)).**

Deadman Anchors

A 'deadman' is a common form of anchor using a wide array of different materials. The concept is to bury the anchor into the stream bed or bank, which pushes against a wedge of undisturbed soil when tensioned. Advantages are that they can be placed in the bank away from the potential erosion zone and do not require heavy equipment to work within the stream. At least two deadman anchors are needed for each structure or a combination of a deadman anchor and another method. Examples of deadman anchors include boulders, logs, concrete blocks, or steel structures.

Plate 4 **Log pinned by standing tree on channel bank (Stream Habitat Restoration Guidelines (2004)).**

Combining anchoring methods

Several anchoring methods are often used together to improve stability (Plate 5). For example, artificial placement of LWD dams may consist of logs cabled to each other pinned between pilings and ballasted with boulders. The use of large, standing trees, bedrock and channel material to passively anchor or establish LWD are techniques that can create stable dams and habitats that emulate the natural formation of these structures.

Plate 5 **LWD dam anchored using a combination of rock ballast, cabling and pilings (Stream Habitat Restoration Guidelines (2004).**

5. Other design considerations

It is important to consider the impact of LWD dam placement on local flood flows and possible flow diversions at the planning stage. An understanding of the geomorphology, hydrology and hydraulics of the site will help in this respect. It is recommended that where possible existing on-site woody debris is used in any construction.

6. Case Study – Great Triley Wood, near Abergavenny in South Wales

Overseas research and experience suggests that large woody debris dams can exert a significant effect on flood flows. LWD dams typically occur every 7 to 10 channel widths in natural woodland streams and the combined impact of multiple debris dams along wooded reaches could make a significant contribution to downstream flood alleviation. Unfortunately, the potential flood control benefit of LWD dams has largely been lost in many countries due to the clearance of riparian woodland for farming and the removal of LWD by fishery groups and others. Consequently, there is great scope for restoring this function through regeneration/new planting and improved management of existing riparian woodland.

This study was set up to evaluate the flood control benefit of LWD dams and investigate the stability of artificially constructed dams under UK conditions. A positive outcome could yield significant socio-economic benefits by demonstrating the value of woodland for helping to protect local communities from future flooding. There is also an opportunity to integrate this function with the ability of LWD to increase sediment storage and reduce erosion, with benefits for water quality and ecological status.

6.1 Project Objectives

The main objective of the study was to test the hypothesis that LWD dams in riparian woodland streams increase flood storage and make a significant contribution to attenuating downstream flood flows. A second objective was to assess the stability and performance of constructed debris dams to determine whether this is an effective option for speeding up the process of their formation within degraded watercourses.

6.2 Location of Study Site

Great Triley Wood lies two kilometres north of Abergavenny in South Wales (Figure 2). It is owned and managed by the Woodland Trust and comprises some 6 ha of mainly mature, semi-natural, broadleaved, wet woodland, with alder, willow and hazel dominating the wettest areas, and oak and birch on the higher ground. The woodland straddles the full floodplain and occupies a 500 m length reach, including one main tributary, of the River Y Fenni. This drains into the River Usk immediately below Abergavenny.

6.3 Catchment Hydrology

The Y Fenni catchment, a tributary of the River Usk, covers an area of approximately 9.2 km^2 to the downstream limit of the study site. Figure 3 shows a 3D image of the catchment with a 1:50,000 Ordnance Survey map overlay. Most of the catchment is agricultural land, comprising a mixture of arable and livestock grazing. Altitude ranges from 44 m to 486 m and the annual rainfall is approximately 1080 mm.

The catchment and watercourse are ungauged and therefore a hydrological modelling exercise was carried out using the Flood Estimation Handbook (Institute of

Hydrology, 1999) in order to determine the flood frequency and magnitude of various events.

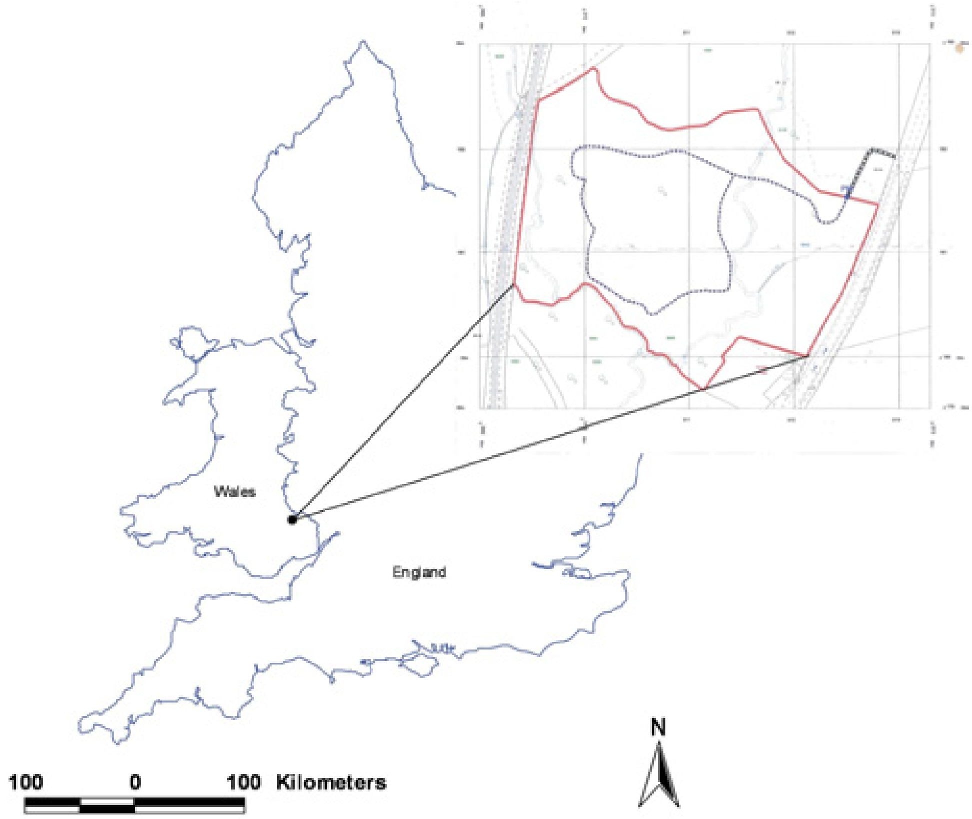


Figure 2 Location of Great Triley Wood in south Wales.

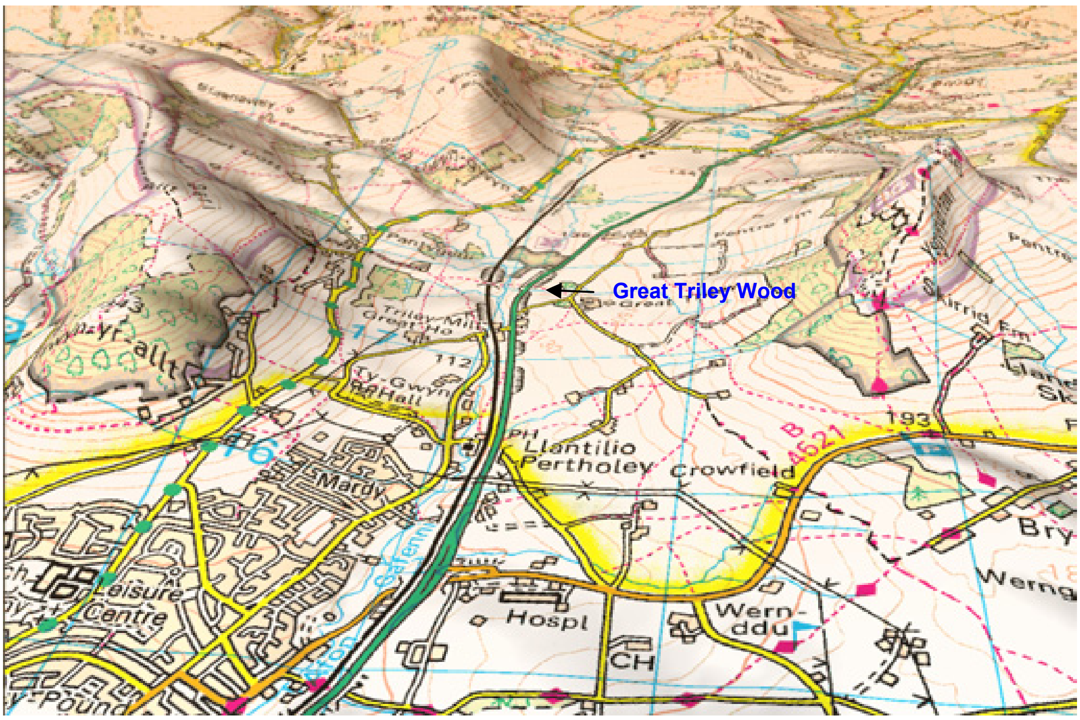


Figure 3 3D image of the Y Fenni catchment with 1:50,000 Ordnance Survey overlay.

6.4 Artificial LWD dam placement

The section of the Y Fenni that flows through Great Triley Wood contained some LWD which formed a few partial dams. The amount of woody debris within the channel was considered to be very deficient compared to a natural wet woodland stream. Based on the expected natural spacing of one LWD dam every 7 to 10 channel widths, it was estimated that Great Triley Wood should contain between 10 and 15 active dams (channel width averaged 5 m in the wooded reach). This formed the target for dam restoration and appropriate sites for construction were selected during a walk-over survey.

A simple method was used to construct the dams, mimicking natural processes where possible. The selected design is displayed in Figure 4 and all wood was obtained from within the wet woodland utilising a mixture of fallen logs, overhanging trees and recent thinnings. Five dams were placed within the main watercourse and a further four constructed in the main tributary in January 2007. Plate 6 shows examples of constructed and natural LWD dams.

The exact construction method of each dam varied according to local site conditions and the availability of woody material. Most were built around an existing fallen or overhanging tree, which was often cut to allow one end to drop down into the channel. Another log was then dragged into place to form a criss-cross shape. Some dams in faster flowing reaches were reinforced using wooden stakes driven into the streambed on the downstream face to improve their stability during high flows. The matrix was left reasonably open to observe how quickly the dam developed naturally by catching woody debris washed downstream.

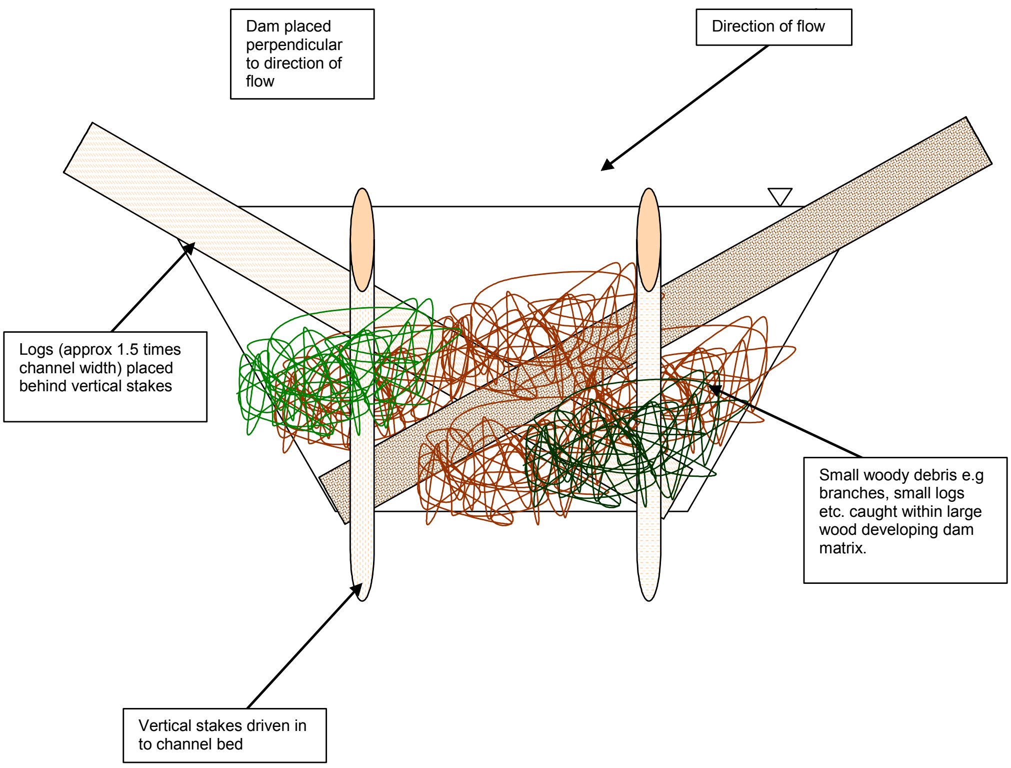


Figure 4 Conceptual design of artificially constructed large woody debris dams.

Plate 6 **Comparison of artificially constructed (top) and natural (bottom) LWD dams in Great Triley Wood.**

6.5 Fieldwork Monitoring Methodology

A monitoring programme was established to assess the impact of the constructed LWD dams on river water levels and flow velocities within the floodplain woodland. Four water level recorders had previously been installed upstream, downstream and within the wooded reach to establish baseline conditions. These recorded water levels at 5 minute intervals. Velocity measurements were taken across the river channel at each site using a handheld current meter before and after construction of the LWD dams. A tipping bucket rainfall gauge was installed in the open near the woodland to record rainfall events at the same temporal resolution as the water level recorders. Regular photographs of the LWD dams were taken throughout the project to record the rate of dam development and their response to flood events.

6.6 Topographical Survey

A 700 m reach of the Y Fenni floodplain was surveyed at the start of the project to provide detailed topographic data for hydraulic modelling. Complete profiles were obtained for a total of 15 river channel and floodplain cross sections. Subsequently, a LiDAR survey was commissioned to provide higher resolution (2 hits per m^2) topographic data for the whole floodplain. This greatly facilitated the modelling work and the assessment of flood levels for different sized events.

6.7 Mathematical Modelling

A 1-D mathematical/hydraulic model of the River Y Fenni floodplain was set up for the wooded reach and upstream and downstream sections. The selected model was the Infoworks RS river modelling software package, which is able to model complex looped and branched networks, and is designed to provide a comprehensive range of methods for simulating floodplain flows. The Infoworks/ISIS mathematical modelling engine incorporates both unsteady and steady flow solvers, with options that include simple backwaters, flow routing and full unsteady simulation. The engine provides a direct steady-state solver and adaptive time-stepping methods to optimise run-time and to enhance model stability.

A key feature of Infoworks RS is its ability to model a wide range of hydraulic structures, including common types of bridges, sluices, culverts, pumps and weirs. Reservoirs are included to represent flood storage areas, while junctions permit the modelling of flows and water levels at channel confluences. Wherever possible, standard equations and methods are incorporated into the software to improve the representation of flood level and discharge relationships.

Infoworks RS provides full interactive views of the model data and results using plan views, long sections, form based editing tools and time series plots. Results can also be reported in text and tabular formats. The package combines the ISIS Flow simulation engine, GIS functionality and database storage within a single software environment. The application, once established, produces flood inundation and extent maps with relative speed, accuracy and ease.

The mathematical model requires the input of river cross sections to represent the main channel, the floodplain, including flood bank levels to represent out of bank flows, and the physical geometry of man-made structures such as bridges, culverts and weirs to characterise flow constrictions. The model was initially 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 by extending the cross sections using the LIDAR data. Additional cross sections were added to improve the representation of the watercourse in the modelled reach. A diagrammatic representation of the model, including the LIDAR image is shown in Figure 5.

Further model runs were carried out using the design event data to obtain a series of baseline simulations for the watercourse. A number of scenarios were devised to assess the effect of large woody debris dam placement at various locations along the watercourse. The debris dams were represented within the model by using a partial blockage function in the Infoworks RS package. This allows the user to determine the exact proportion of the channel cross section to be blocked in order to simulate the presence of a debris dam.

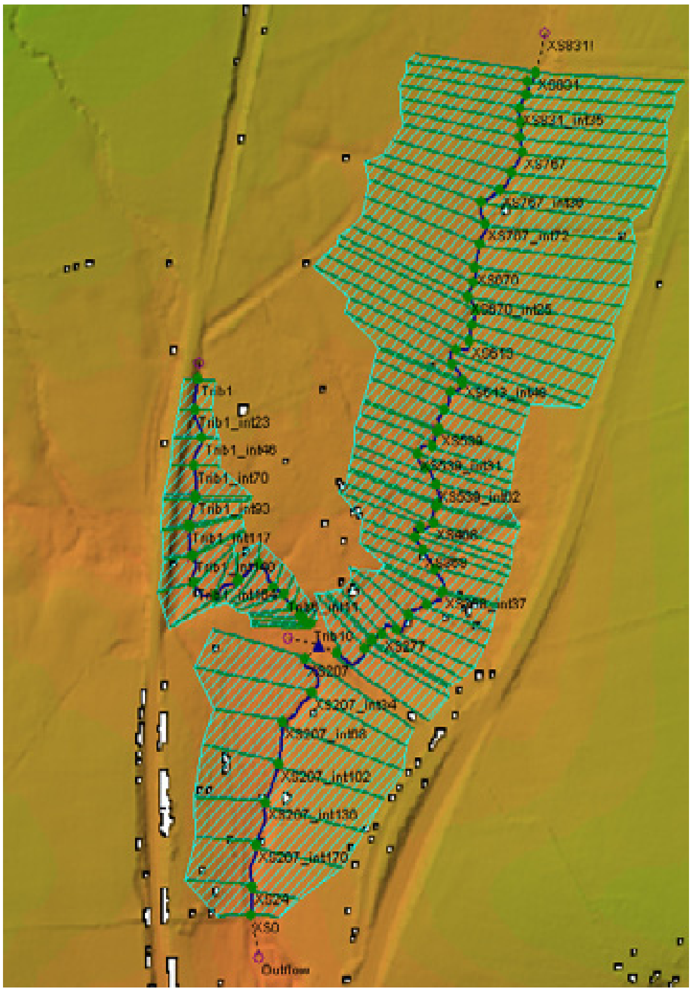


Figure 5 Diagrammatic representation of the modelled reach.

Model Calibration

Mathematical river models require calibration against historical flood events to increase confidence in model predictions. The degree of model calibration that can be carried out depends on the quantity and quality of recorded water level and flow data. Ideally, the events should cover a range of sizes from moderate in-bank events to out-of-bank floods. Calibration involves adjusting certain model parameters until reasonable agreement is obtained with recorded water levels and flows.

The accuracy of prediction of water levels for design events is based upon how well the main channel and floodplain are represented in the model. In general, mathematical river models are calibrated for both in-bank and out-of-bank flow events. In-bank flow conditions are used to adjust the roughness coefficients within the main channel, while out-of-bank conditions are used to modify the roughness coefficients representing floodplain channels and flows to and from these. A good calibration event is one with observed water levels (normally in the form of peak levels) at critical locations within the modelled area and where the corresponding flows are known. In the case of the Great Triley Wood site, calibration against known water levels was only possible for in-channel flows since no significant out-of-bank floods had occurred since monitoring began in 2004.

Model Design Flow Simulations

As previously mentioned, the Flood Estimation Handbook was used to derive a "design" flow for the simulation. This gave a QMED (i.e. the flow that is expected to occur once in every 2 years, and used as a basis for the flood frequency calculation in the FEH) of 2 $m^3 s^{-1}$ for the Y Fenni, based on a series of catchment descriptors derived from the FEH. Table 1 shows the return periods for a range of flood events.

Annual Probability Event (%)	**FEH Statistical Peak Flow ($m^3 s^{-1}$)**
50	2.012
20	2.758
10	3.304
4	4.094
2	4.776
1	5.555
0.5	6.444

Table 1 FEH derived Peak Flows for a range of flood events for the Y Fenni.

It was decided that an extreme event such as the 1% a.p.e. (1-in-100 year) would be appropriate for providing a robust test of the hypothesis that large woody debris dams can exert a significant influence on flood propagation. Figure 6 displays the event hydrograph that was used as the input boundary for the model application. The effect of placing five LWD dams in the main watercourse and a further four in the main tributary was assessed.

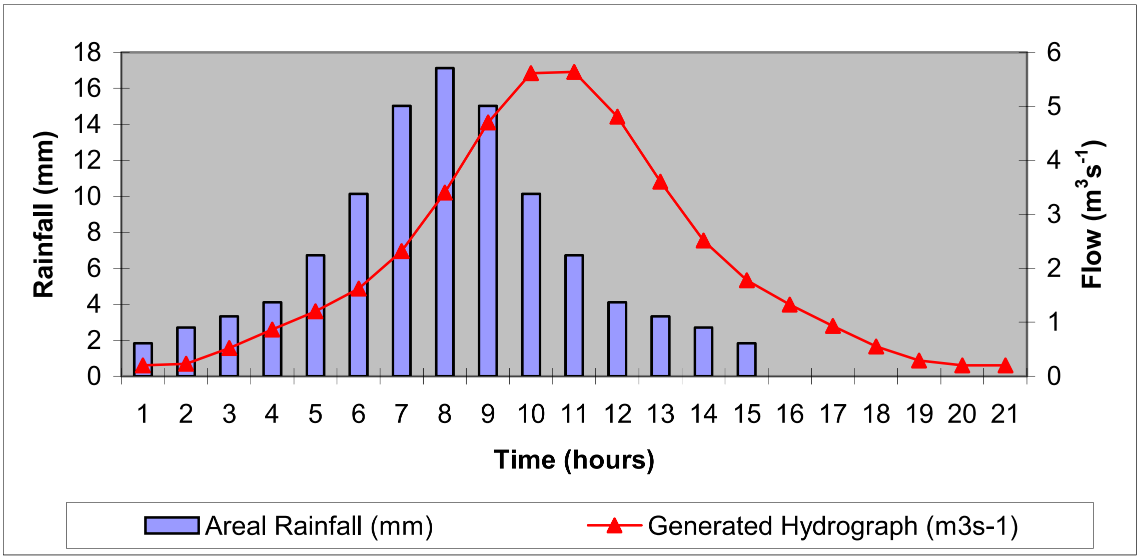


Figure 6 Design 1% a.p.e used as the input boundary for the model.

6.8 Model Results

Water Level

Figure 7 shows that the addition of large woody debris dams into the watercourse could be expected to have a marked effect on upstream water levels. The model predicted that the flood level would increase by up to 1.46m immediately upstream of the dams. This created a localised backwater effect that extended approximately 165m beyond the dammed section (the distance is dependent on local conditions such as bed slope/gradient and will vary with location).

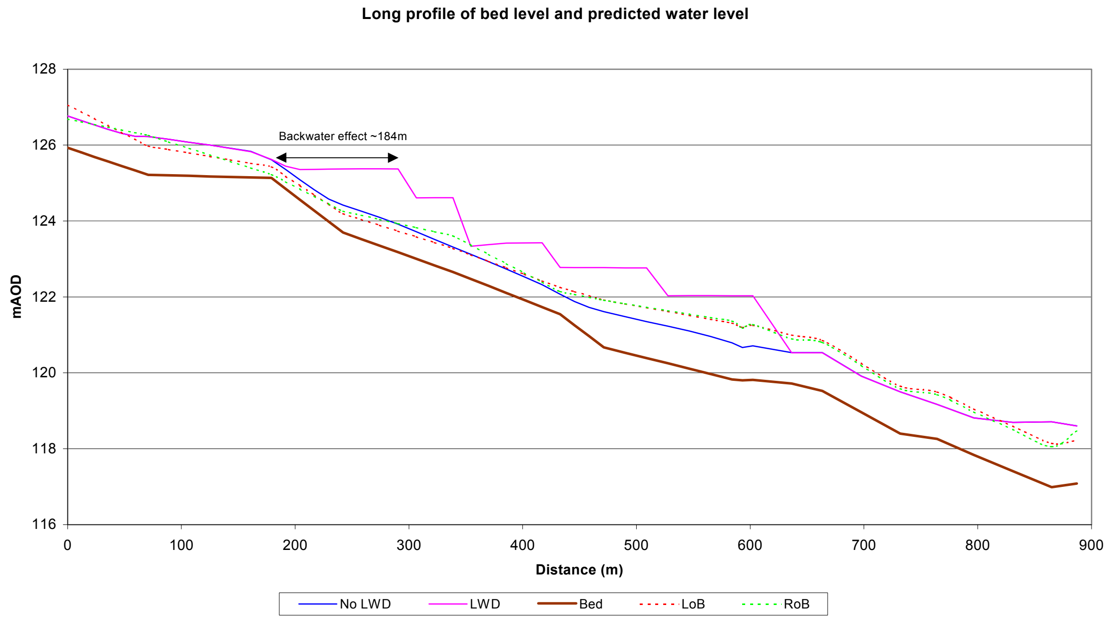


Figure 7 **Long profile of modelled reach showing effect of debris dams on local water levels. RoB and LoB refer to elevation of right and left banks of the channel.**

The effect of an individual LWD dam on the flood hydrograph is displayed in Figure 8. This shows that at the height of the flood the maximum difference in flood level could reach 1.3 m. It also demonstrates that LWD dams will encourage out-of-bank flows in certain areas where it would not normally occur if no dams were present.

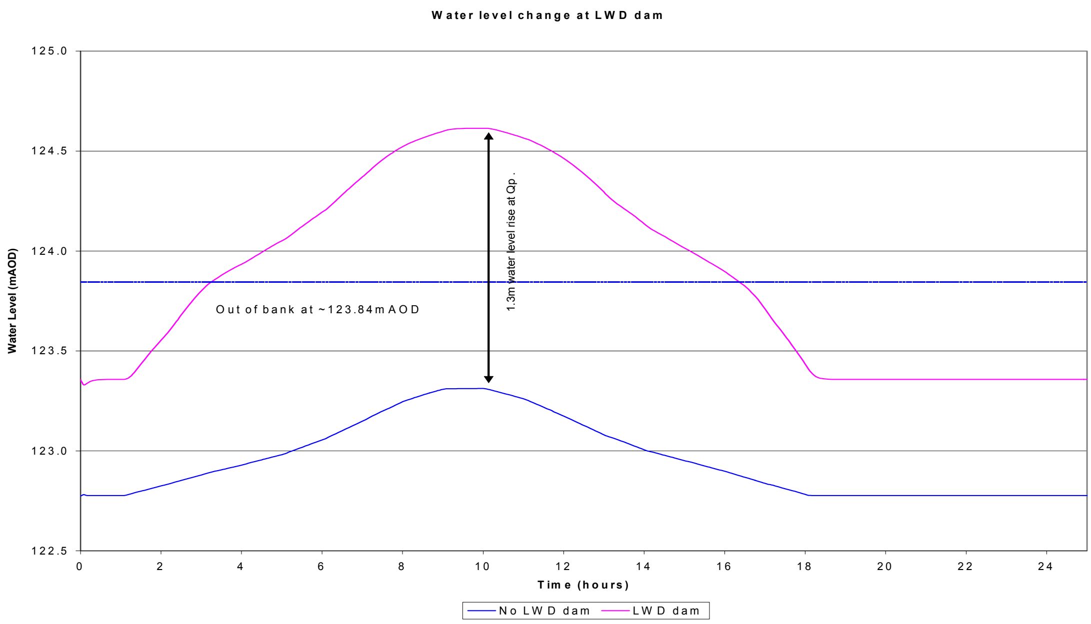


Figure 8 **Water level change at cross section with and without LWD dam for a 1 % a.p.e.**

Flow Velocity

The presence of a LWD dam can be expected to exert a marked effect on water velocity until it is completely submerged. In the case of the Y Fenni, the model predicts a maximum reduction of 2.1 m s^{-1} at peak flow immediately upstream of the dam (Figure 9).

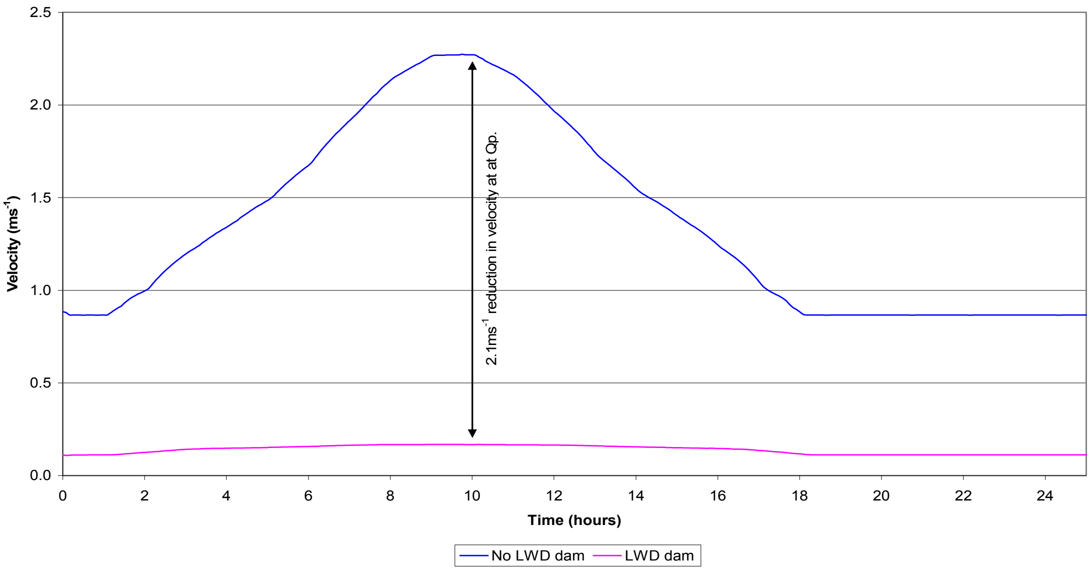


Figure 9 Effect of LWD placement on average flow velocity.

Flood Peak Travel Time

Flood peak travel time is an important factor to consider when assessing the impact of LWD dams. The placement of 5 dams along a 0.5 km reach of the modelled watercourse had the effect of delaying the travel time of the flood peak for the 1% a.p.e. by as much as 15 minutes (Figure 10). This effect was also apparent in the modelled tributary, where the placement of 4 LWD dams over a 0.3 km reach delayed the flood peak by around 10 minutes (Figure 11). Somewhat surprisingly, neither of these delays had a significant effect on the height of the flood peak.

6.9 Field Monitoring Results

The aim of the field monitoring programme was to record and compare a number of flood events before and after the placement of the LWD dams in order to ascertain whether their presence had a significant affect on the local flood hydrodynamics. These observations would also allow the performance of the hydraulic model to be tested.

Unfortunately, both the baseline and short post LWD dam construction periods were characterised by relatively dry weather conditions with no significant flood events. Only a few heavy rain storms occurred and their effect was limited to the inundation of small areas of the floodplain for short periods. This precluded an assessment of the effect of the LWD dams on pre- and post-treatment flood hydrographs.

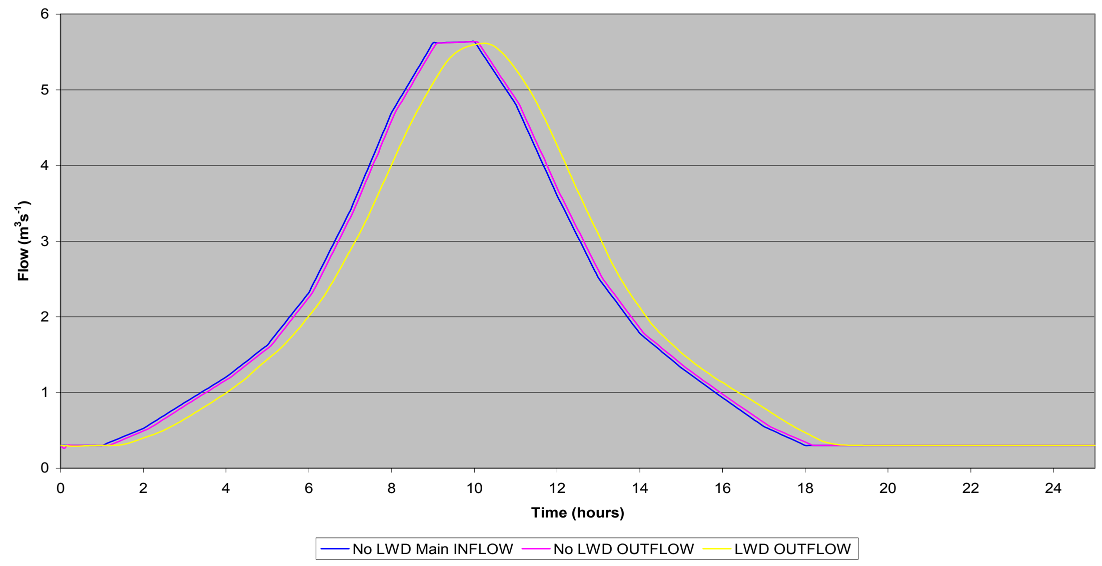


Figure 10 **The effect of LWD dam placement on flood peak travel time within the main watercourse.**

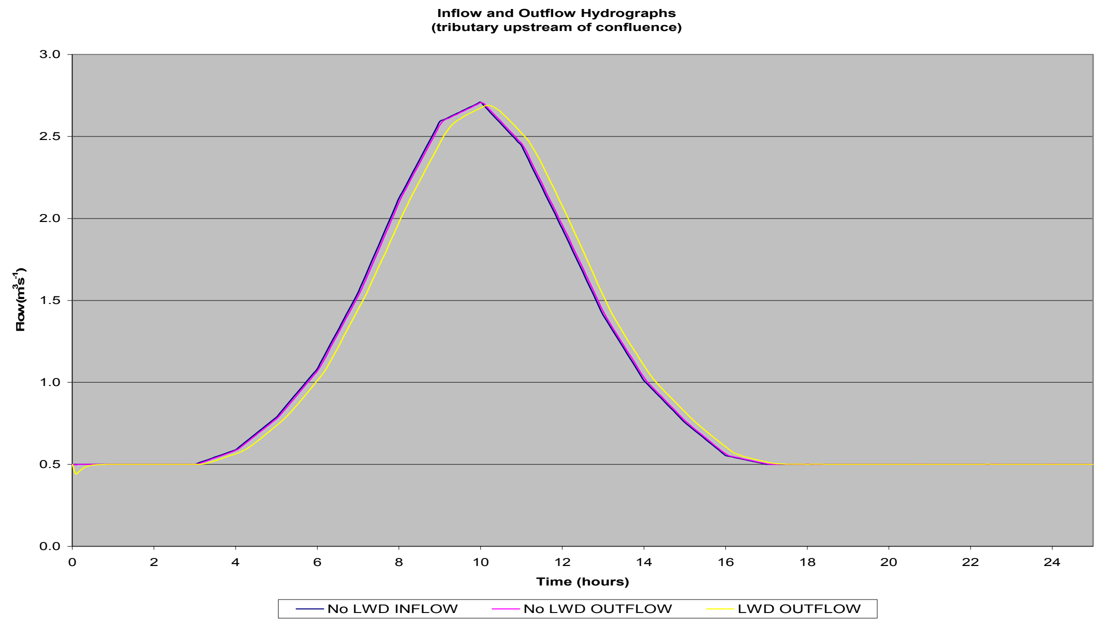


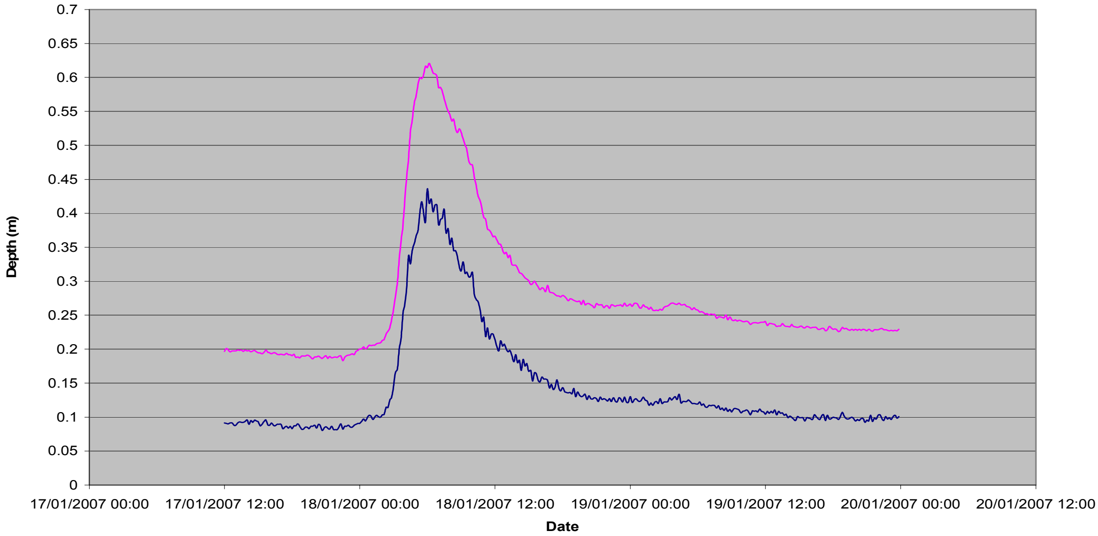
Figure 11 **The effect of LWD dam placement on the flood peak travel time within the main tributary.**

Another problem was the complex hydrology of the instrumented reach, with the high flow peaks not behaving as expected. For example, in many cases the downstream site would "peak" *before* the upstream ones, which was thought to be due to the more rapid response of a number of smaller, intervening tributaries draining the adjacent farm land and possibly the local main road.

Only two comparable storm flow events were captured before and after the LWD dam placement to allow an assessment of the effect on peak flows. These are displayed in Figure 12 and show that the inflow hydrographs were similar in magnitude and duration, with peak flows of 0.45 $m^3 s^{-1}$ and 0.41 $m^3 s^{-1}$ for the pre- and post-placement periods, respectively. In comparison, the downstream peak flows showed a marked difference between periods, with values of 0.71 $m^3 s^{-1}$ and 0.47 $m^3 s^{-1}$, respectively. This suggests that the LWD dams were causing a significant reduction in peak height of around 50%. Interestingly, the dams appear to be having little effect on the timing of the flood peak.

These results are contrary to the model predictions, which display a time lag effect but little impact on flood peak height. However, it is not possible to draw any firm conclusions in view of the single event examined to date and its relatively low magnitude in relation to the modelled 1% a.p.e. flow.

Before



After

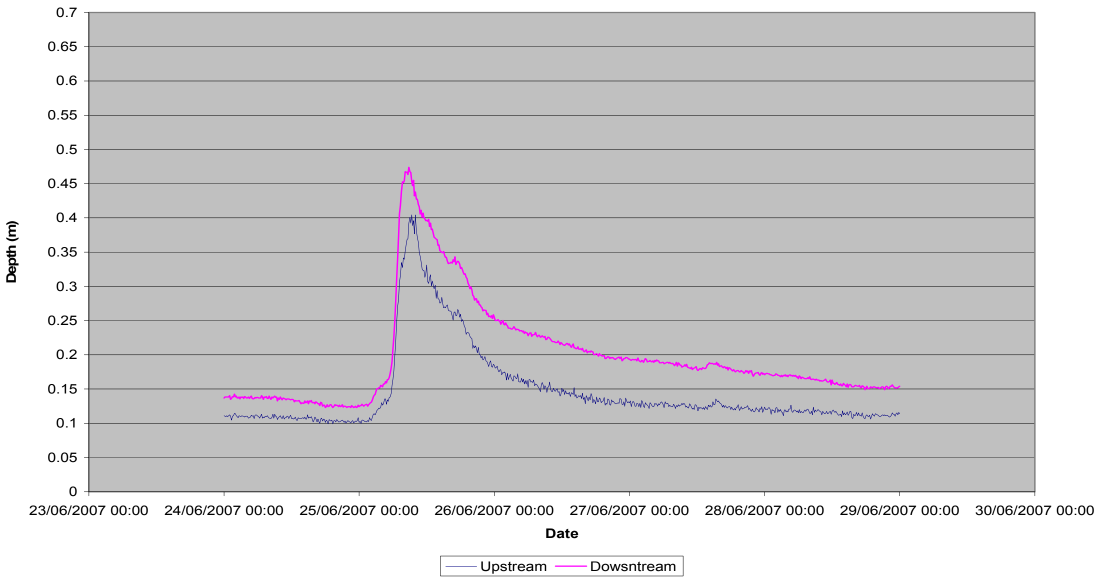


Figure 12 Storm hydrographs before and after LWD dam placement.

A series of water velocity measurements were taken at three locations above the LWD dam sites before and after their construction. The results showed that the dams reduced average channel velocities for in-bank flows by 54%. This was less than the model predicted for a 1% a.p.e. but nevertheless highly significant.

6.10 Discussion

The results of the hydraulic modelling strongly suggest that the presence of LWD dams can help to reduce downstream flood flows. The hydraulic roughness created by the open dams acted to slow down water flows for a 1% a.p.e. by up to 2.1 m s^{-1}, raising water levels upstream by up to 1.5 m over a distance of 165 m. Surprisingly, the dams appeared to have little effect on the height of the flood peak but its passage was delayed by an average of 2-3 minutes per dam. Of particular note was the ability of the LWD dams to raise water levels above bank height, promoting out-of-bank flows and further increasing temporary flood storage. The results support the use of LWD dams as a viable soft engineering technique for downstream flood mitigation, although to be effective at a larger scale would require an extensive series of dams across the upper and middle reaches of a catchment. Their ability to raise water levels and re-connect river channels to their floodplain also has benefits for restoring riparian wetland habitats and improving water quality (see below).

Unfortunately, the field data could not be used to confirm the model predictions due to the lack of recorded flood events and the relatively short post-treatment period. It was only possible to assess one comparable pre- and post- storm event and the results of this were contrary to those of the model, with a 50% reduction in peak height and no lag in peak timing. The relatively small size of this event precluded any detailed analysis.

Field observations on the performance of the dams provide support for the model results. Dam construction led to high rates of sedimentation in upstream pools, as depicted by the comparison of pre- and post- conditions in Plate 7. It was estimated that over 1.5 m^3 of sediment had been deposited behind this single dam by April 2007, raising the bed level and influencing the direction of water flow in the channel. Vegetation has already begun to colonise the sediment "bank" on the right hand side of the channel, introducing additional roughness and constraining flows. The net effect will be to raise water levels and reconnect the channel to its floodplain. Another benefit will be improved water quality resulting from the removal of sediment and associated nutrients such as phosphate. This is of particular importance in catchments like that of the River Y Fenni where sediment run-off from surrounding agricultural land is a cause of diffuse pollution.

Field observations of the gradual development of the dams provide strong evidence of their effectiveness in promoting out-of-bank flows. Past river management and removal of woody debris in the River Y Fenni has resulted in a relatively incised channel that is disconnected from the floodplain in many places. The dams have raised bed and water levels to a sufficient degree to produce out-of-bank flows even for relatively small storm events. Plate 8 (a & b) displays the sediment trace upstream of one of the dams that previously showed little evidence of flooding.


0 months


3 months

Plate 7 **Time lapse photographs showing the gradual development of one of the LWD dams and its effect on sedimentation and channel flow.**

Another example is provided by one of the dams on the main tributary of the Y Fenni. Plate 9 shows that the dam has resulted in heavy sedimentation that has almost completely filled the river channel. The LWD dam is located approximately 10m downstream to the left of the photograph. This has encouraged the development of a braided main channel and several side channels, partly influenced by the formation of additional smaller debris dams. Once out of bank and onto the floodplain, the flood flow follows routes of lower elevation through the woodland, creating multiple small channels and pools. Further inputs of sediment and woody debris creates additional roughness and will eventually result in the classic complex and diverse hydraulic channel structure typical of natural floodplain woodlands.

There is concern that the introduction and build up of LWD dams within rivers will lead to the increased washout of material during floods and greater flooding downstream where this material blocks bridges and culverts. This study allowed the development and stability of constructed dams to be assessed. Observations showed that some of the dams proved relatively unstable resulting in the movement of logs and washout of lighter material during high flow events. However, nearly all of this material appeared to be caught by the next downstream dam, further enhancing and strengthening its structure. These main dams are now very robust and while they remain to be tested by a significant flood event, their dimensions in relation to the size of channel and expected flow suggest that they may be able to resist.

Monitoring will continue to try and evaluate the effect of the dams during a major flood event and to properly test the model predictions. The extended record will also allow the performance and future stability of the dams to be assessed.

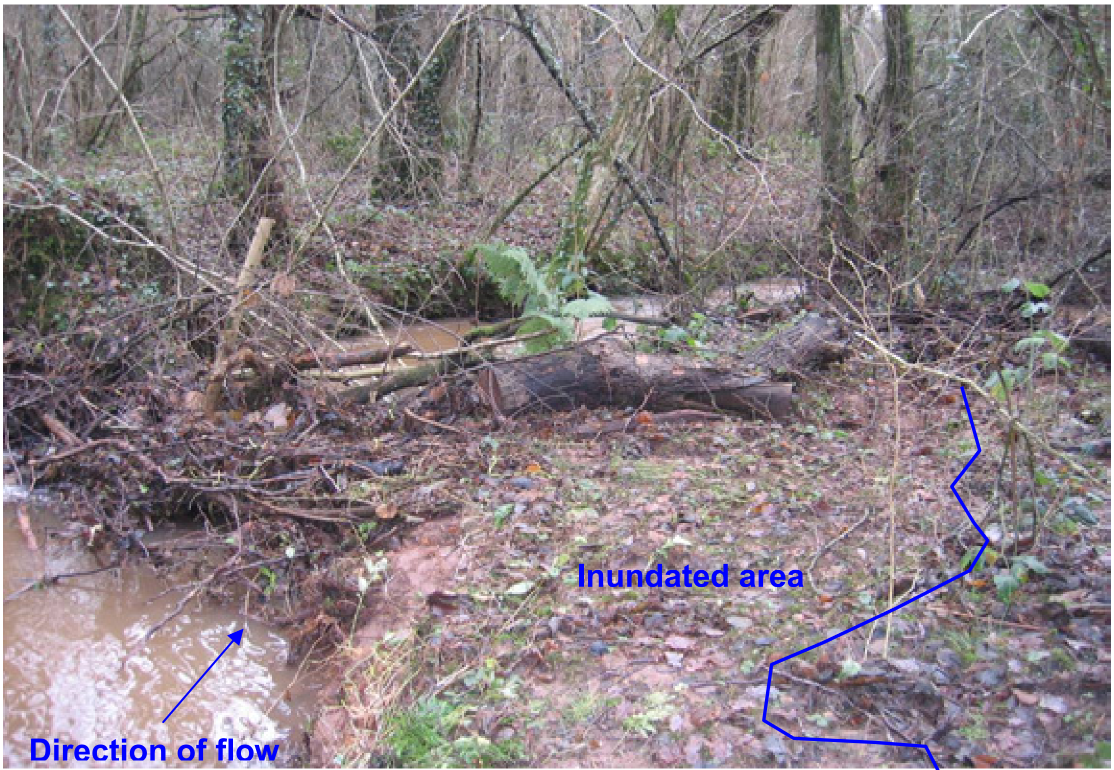


Plate 8a Evidence of a LWD dam generating out of bank flow within a previously incised channel reach.

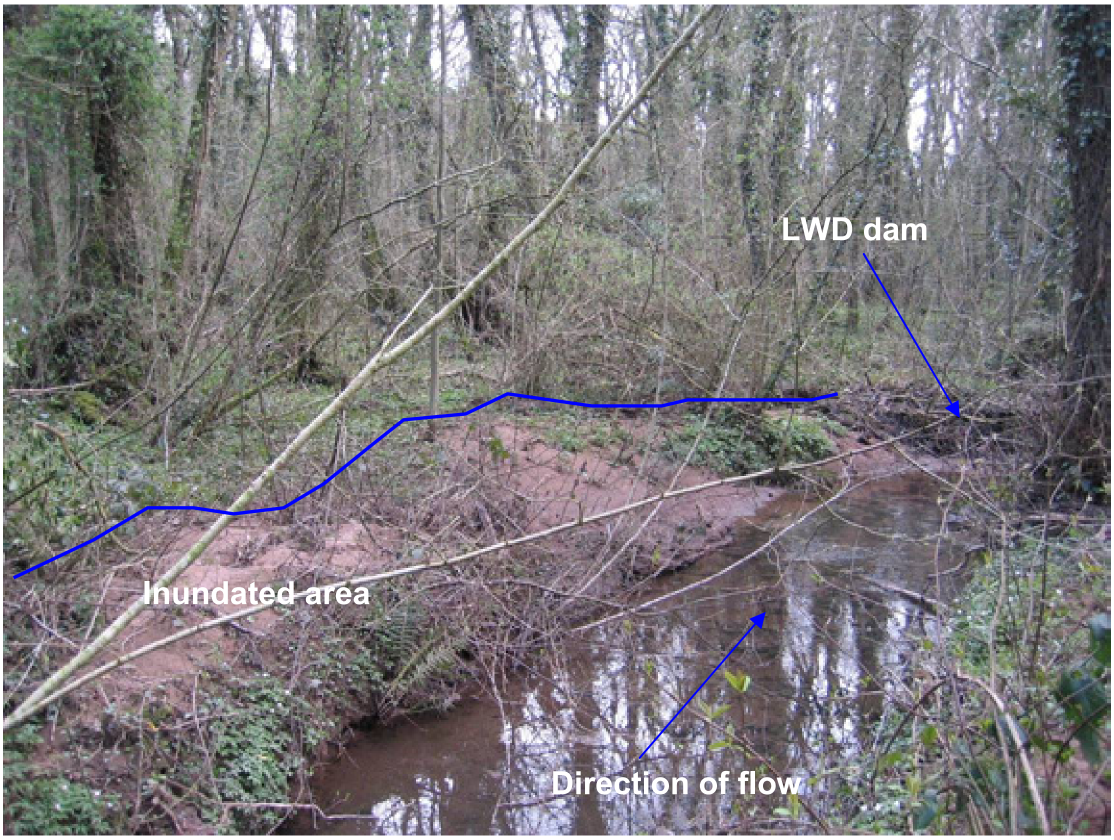


Plate 8b **Evidence of a LWD dam generating out of bank flow within a previously incised channel reach.**

Plate 9 **Classic formation of braided water channels above a LWD dam.**

6.11 Conclusions

This study provides support for the role of LWD dams in mitigating downstream flooding. Model predictions show that the hydraulic roughness created by LWD dams in the River Y Fenni catchment acted to slow down water flows for a 1% a.p.e. by up to 2.1 m s^{-1}, raising water levels upstream by up to 1.5 m over a distance of 165 m. Although the dams appeared to have little effect on the height of the flood peak, its passage was delayed by an average of 2-3 minutes per dam. Of particular note is the ability of LWD dams to raise water levels above bank height, promoting out-of-bank flows and further increasing flood storage. While the lack of flood events during the monitoring period precluded testing of the model predictions, observations of the development of the dams suggest that they are functioning as expected.

The results support the use of LWD dams in streams and small rivers as a viable soft engineering technique for downstream flood mitigation. To be effective at a larger scale, however, would require an extensive series of dams across the upper and middle reaches of a catchment. The results also confirm that the artificial construction of debris dams is an effective way of restoring degraded and incised reaches. Some dam failures were recorded but released debris was largely retained by downstream dams. These appear to have developed into stable structures although remain to be tested by a significant flood event. The ability of LWD dams to raise water levels and re-connect river channels to their floodplain also has benefits for restoring riparian wetland habitats and improving water quality.

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