Modelling the effects of floodplain woodland in flood mitigation A short-term case study

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Abstract
Three floodplains were selected for study in the Mawddach catchment, just north of the town of Dolgellau in Central Wales. Vegetation cover scenarios were modelled for each site using the hydrodynamic model River 2D. The first two sites provided no real potential for using floodplain woodland in flood mitigation, although modelled water depths increased by up to 50 cm due to the presence of dense vegetation on the floodplain. At the third site, dense woodland, with an average basal area of 0.10 m^2/m^2, reduced modelled peak discharge by 45 m^3sec^{-1} when compared with grassland. This also delayed peak discharge by more than 30 minutes and created a backwater effect that increased water depths by more than 1.2 m for a distance of 1.3 km upstream of the floodplain. Two other vegetation scenarios, sparse and clustered woodland, were also modelled for the third site. Although sparse woodland had just 45% of the basal area of the clustered woodland, it had a similar effect in mitigating modelled flood levels downstream.

Keywords
Hydrodynamic modelling, floodplain woodland, soft-engineered flood defences

Introduction
Floodplain woodlands are highly dynamic ecosystems, subject to complex but critical flooding events (Hughes and Rood 2003). They are typically a mosaic of vegetation communities of varying age. Natural floodplain woodlands are rare in Europe; and are listed in Annexe 1 of the Habitats Directive as "a priority forest habitat type" (Hughes and Rood 2003). Their characteristics and role include high biodiversity and productivity, mitigation of diffuse pollution, contribution to landscape diversity, and flood control (Tir Coed 2001, Kerr and Nisbet 1996, Thomas and Nesbit 2007).

Role of floodplain woodlands in flood control
The potential of floodplain woodlands for flood control has been examined and demonstrated at several sites throughout central and eastern Europe (Poulard et al. 2003), as well as in the UK (Thomas and Nesbit 2007). The role of such habitats in flood control could be increasingly valuable given the predicted impact of climate change in increasing rainfall intensity. Extreme flood events in the UK are predicted to become 10 to 50 times more frequent by the year 2090 (Friends of the Earth 2000). Currently, the Environment Agency (EA) of England and Wales spends an average of £260 million per year on costal and river flood defences. The Department of the

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Environment, Food and Rural Affairs (DEFRA) budgeted £436 million for flood management activities in 2007/08.

The use of floodplain woodland for flood control may prove to be effective from both an environmental and an economic viewpoint. Furthermore, the move from hard engineered structures such as dykes and dams to sustainable and environmentally friendly methods of flood control such as floodplain woodland is evident throughout most of Europe, often coming under the description Integrated Flood Management (Dworak and Hansen 2003).

The principal hydrodynamic factor involved in flood mitigation in floodplain woodland is hydraulic roughness (Fisher and Dawson 2001). Allowing the floodwaters of a river surge to spill onto a natural floodplain will greatly increase the temporary storage capacity of a river. Floodplain woodland vegetation offers one of the highest natural friction coefficients in a riparian landscape, and therefore is one of the most effective natural vegetation types at reducing velocities and retaining flow, thereby dissipating subsequent downstream discharge rates (Arcement and Schneider 1990). Factors that affect the ability of floodplain woodland to contribute to flood amelioration include vegetation density, stem distribution and floodwater depth (Environment Agency 1997). Vegetation, especially if it is erect and flexible, will create local turbulence, and so reduce the magnitude of instantaneous velocity due to a drag force on the moving water (Environment Agency 2003). As velocities are reduced, water depths and flood extent increase, thereby attenuating the peak of the flood through temporary storage on the floodplain. While the level of attenuation depends on local topography, soil type and other factors, the overall result is often a reduction in the peak discharge of the river downstream, manifested as the outflow hydrograph assuming a more gradual curvature (Thomas and Nesbit 2007).

Methods

Site characteristics

In June 2004, three sites located on the river Mawddach (Figure 1), north of the town of Dolgellau in central Wales (52°47'48" N, 3°52'35" W) were selected for hydrodynamic modelling. The sites varied in size, shape and topography and are referred to here as Floodplain 1, 2 and 3, based on their location on the river system.

The Mawddach catchment covers a significant proportion of the Harlech Dome, a geological folding sequence of lower Palaeozoic rocks, consisting of one of Europe’s best examples of Cambrian, Ordovician and Silurian strata (Hall and Cratchley 2005). The catchment is bounded to the east by the Aran Fawddwy massif and to the west and north by the Harlech Dome, which forms a watershed just south of Llyn Trawsfynydd. The Harlech Dome consists of numerous fracture zones with the general orientations north/south and south-west/north-east. Such fractures have implications for the drainage patterns and orientation of streams within the Mawddach river system (Hall and Cratchley 2007).

Aran Fawddwy, 504 m above sea level, is located at the highest point of the Mawddach catchment, with the town of Dolgellau located 8 m above sea level. The catchment has a total area of 164.58 km^2. The hydrological influence of several other tributaries was taken into account (Figure 1) when modelling floodplains 2 and 3, which made catchment area difficult to quantify.

The River Mawddach has an overall length of 14.2 km, with an average drop of 35 m per kilometre. The rivers within the Mawddach catchment exhibit a range of morphological characteristics within the general downstream progression of reach types: colluvial, cascade, step pool, plane bed, pool riffle and dune ripple (Hall and Cratchley 2005).

Floodplain 1

Floodplain 1, located in Tyddyn Gwladys, was the smallest and highest of the three sites examined in the catchment. The floodplain area was 0.4 ha, with a river length of 370 m. The inflow boundary was located 500 m downstream from the Environment Agency's rain gauge station. The river channel mainly comprised large cobblestones and boulders, with some areas of rock outcrop (Figure 2). The bed profile was relatively uniform, with river channel width ranging from 7–12 m and depth from the top of the bank to the river bed ranging from 1.5-3.5 m.

The vegetation of Floodplain 1, which is part of the Coed y Brenin forest, was comprised almost entirely of a mix of mature, semi-natural woodland and conifer plantations (Figure 3), with some regeneration occurring under canopy gaps in

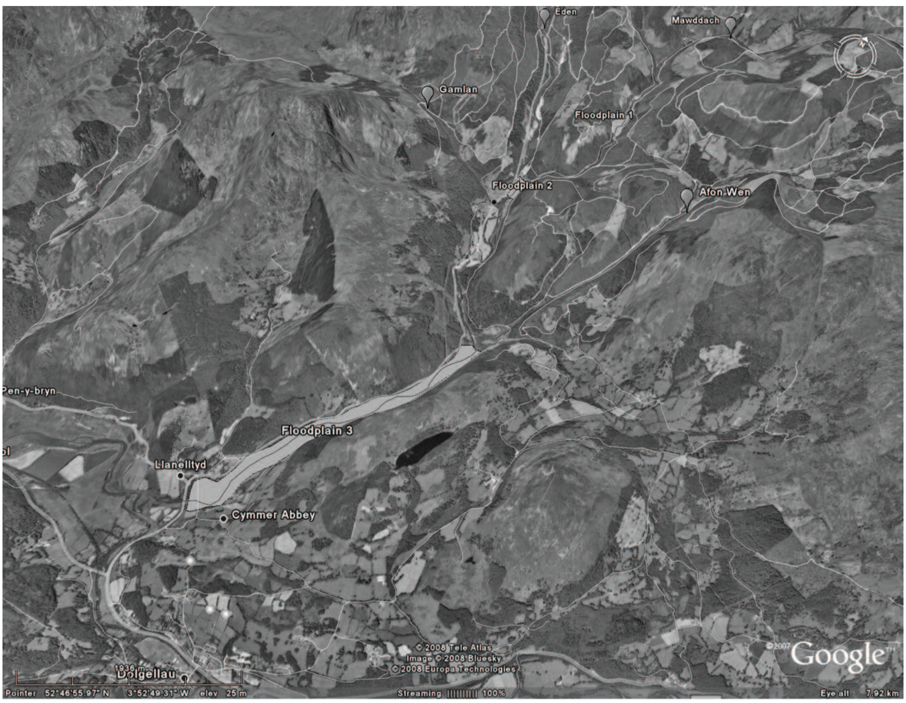

Figure 1: Location and spatial extent of the three floodplain sites on the River Mawddach. Permission granted by Google Earth™ mapping service.

Figure 2: View upstream at the inflow boundary of Floodplain 1.

Figure 3: Typical vegetation structure in Floodplains 1 and 2.

mature woodland. Vegetation density was assessed in accordance with Arcement and Schneider (1990), with the average ranging from 0.011 m^2m^{-2} to 0.265 m^2m^{-2}.

Vegetation plots (with larger sized plots in less dense vegetation) were established at each site. The number of plots was dependent on vegetation type and its apparent density.

Floodplain 2

Floodplain 2, located in Cefn Deuddwr, was 27.2 ha in area. It was located at the confluence of the Eden and the Mawddach rivers, 2 km downstream from Floodplain 1. The profile of the riverbed upstream of the confluence was a mixture of rock outcrop and constricting gorge sections (3-6 m wide) as well as a 4 m high waterfall (Figure 4). A large open flow channel occurs downstream of the confluence, which in turn carries most over-channel flow. Vegetation was of a similar age and type to Floodplain 1, with average density ranging from 0.018 m^2m^{-2} to 0.082 m^2m^{-2}.

Figure 4: Floodplain 2, view upstream with bridge and gorge section in background centre and the open flow channel in the foreground.

Floodplain 3

Floodplain 3 was considerably larger than Floodplains 1 and 2. It comprised a 3.7 km stretch of the River Mawddach, from the confluence of the Wen and Mawddach rivers, to the tidal point of the river, located just west of the bridging point of the A470. This area was a natural floodplain basin, located at the mature stage of the

Figure 5: A location 800 m upstream of the outflow section of Floodplain 3, showing typical topography and vegetation at the site.

River Mawddach, with a floodplain area of 100.8 ha. Its location has important considerations for over-channel flow potential, as the undulating topography of the surrounding landscape aids in the storage of excess flow from the river (Figure 5). Vegetation was mainly grassland with short (0.25 km) stretches of mature oak (*Quercus petraea*) and sycamore (*Acer pseudoplatanus*) located close to the river bank.

Hydrodynamic modelling

Based on previous studies (Thomas and Nesbit 2007, Ghanem et al. 1995, Waddle et al. 1996), the 2D Depth Averaged Model, River2D, developed by Steffler and Blackburn at the University of Alberta <http://www.river2d.ualberta.ca>, was chosen as the preferred hydrodynamic model as it provided an acceptable level of accuracy, modelling capability, presentation, and user-ability.

River 2D is a two dimensional depth averaged model, based on finite element solution of governing equations. Roughness coefficients are expressed as effective roughness height. This method of expressing roughness tends to be more accurate than Manning’s n, because it remains constant over a wider range of depths (Blackburn and Steffler 2002). Calibration of the model is achieved by adjusting the roughness values and transverse eddy viscosity distributions until the water depths and discharge of the model is equal to that of the outflow hydrograph. River 2D is made up of three sub programmes; R2D Bed, R2D Mesh and River 2D 0.90 (see Blackburn and Steffler op cit. for further detail).

Topographical data

Elevations were determined using an optical level, with a 50 m Digital Elevation Model (DEM) used in areas of uniform topography. Interpolation between points of known elevation and distance from a fixed datum was used to provide a topographical representation of each site. Points (or fixed nodes) were a maximum of 10 m apart in flat topography and up to 0.5 m apart in undulating terrain (for example near the river bank). The location of points (with respect to other points) was sketched in the field, with at least two (often three) known distances to each point, as well as an elevation with respect to the datum being noted. The x, y and z coordinates obtained in the field were transferred into R2D Bed for triangulation (Blackburn and Steffler 2002).

Because of the uniform topography of Floodplain 3, and the large scale of the study area, a 50 m DEM was used to obtain the over-bank elevation data. However, the relatively coarse resolution of the DEM necessitated additional field surveying adjacent to the river channel to achieve a sufficient topographical representation of the site.

Manning's roughness (n) values

Roughness or friction values are also assigned in R2D Bed, with the variation in friction values being directly attributed to the number of fixed nodes (points obtained in the field). Field vegetation density measurements were converted to Manning's roughness values using Arcement and Schneider's (1990) equation:

$$(n) = no\sqrt{(1+Vegd(C^*)(1/no)^2(1/wlh)(h)0.75}$$

where no is the number of roughness values for the floodplain,
Vegd is the vegetation density,
C* is the drag coefficient for vegetation,
l and w are the length and width of the vegetation plot and
h is the hydraulic radius, equal to water depth on the floodplain.

Friction values for the riverbed were evaluated in the field using Arcement and Schneider's (1990) tables for assessing the roughness values (n) of the riverbed and floodplain. Roughness height is calculated in R2D Bed via the roughness converter. Roughness height (ks) is a function of Manning's roughness (n) and water depth (R) with:

$$k_s = \frac{12R}{e^m}$$

Arcement and Schneider's (1990) tables include friction values for variations in channel cross section, the effect of obstructions in the riverbed and the floodplain, vegetation density, the degree of river meandering and the degree of topographical irregularity. The values are dimensionless coefficients, and with the exception of vegetation density, are based on observation.

Computational mesh
R2D Mesh is the subprogram used to create the computational mesh for calculating water depth and velocity (Figure 7). The density and location of floating nodes is critical and will have a direct effect on the accuracy and performance of any hydrodynamic model (Steffler and Blackburn 2002).

R2D Bed uses a Quality Index (QI) value to determine the accuracy of the computational mesh. A QI value of 0.5 is typical of a natural environment (Steffler and Blackburn 2002). Table 1 outlines the computational mesh properties of the three floodplains.

Table 1: Computational mesh properties of the three floodplain sites.

Floodplain	*Floating Nodes*	*Elements*	*QI Value*
Floodplain 1	1333	2551	0.359
Floodplain 2	573	1055	0.449
Floodplain 3	1995	3674	0.376

Model calibration
On 3 July 2001, the Mawddach catchment and surrounding areas experienced a severe flood event. The storm was tracked across the Irish sea early in the morning, by 16.30 hours it was centred over the northern half of the Mawddach catchment, releasing up to 34 mm rainfall per hour in the Wnion catchment alone (Barton 2002). Figure 6 shows the discharge rate for the river Mawddach during the 3 July event, which had an estimated return period of 200 years.

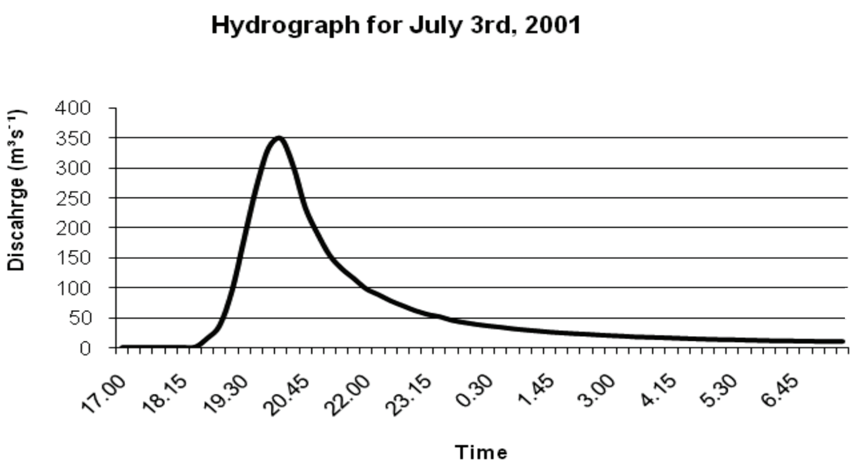

Figure 6: Stage hydrograph for river Mawddach for 3 July 2001 recorded by Environment Agency, 500 m upstream of inflow of Floodplain 1.

The vegetation scenarios of Floodplains 1 and 2 were calibrated by running the 3 July hydrograph (Figure 6) in order to achieve existing hydrodynamic conditions by adjusting the turbulence parameters (bed and transverse shear) in River 2D, until modelled water surface elevations were equal to observed flood debris lines and photographs of water levels from the July 2001 event. In River 2D, the transverse shear parameter (_3) of the eddy viscosity coefficient (Boussinesq type) was primarily used to adjust water surface elevations during the calibration process, as this was the dominant flow parameter when dealing with a submerged floodplain (deep water, high transverse velocity and reticulation). Once calibrated, Floodplains 1 and 2 produced _3 values of 1.20 and 1.35, respectively.

Model simulation

River 2D is essentially a transient model, but provides for an accelerated convergence to steady-state conditions. It has several simulation parameters including: time increment, goal time increment, maximum number of iterations, solution tolerance, and implicitness. The time step increment was set at 100 seconds and the solution tolerance was set between 0.01 and 0.05, depending on the RAM requirements of the site in question. The maximum number of iterations is the maximum number of Newton-Raphson iterations per time interval per node in the computational mesh, and was set at 10 for all three sites.

Inflow and outflow conditions have several options in River 2D. Inflow had a time varying discharge (hydrograph). The outflow condition was based on a depth/unit discharge relationship. Once the model was calibrated, a transient (unsteady state) simulation was run using the 3 July hydrograph.

There was more than 2 km between sites 1 and 2, but the outflow hydrograph from the calibrated simulation of Floodplain 1 was used as the inflow hydrograph for Floodplain 2, as the deep gorge between the two sites meant that the variation in flow was minimal. The _3 value remained unchanged while modelling the various vegetation scenarios, with the exception of grassland, where it was changed to 0.1, to reflect the effect of grassland on turbulence (Blackburn and Steffler 2002).

Because of the absence of an inflow hydrograph for Floodplain 3, as well as the lack of detailed evidence of flood extent for the 3 July flood event (debris lines and photographs), it was not possible to calibrate the model for the site. Instead, Floodplain 3 was treated as a test site, with the outflow hydrograph of Floodplain 2 being tested on four vegetation scenarios for Floodplain 3.

Vegetation scenarios

Once model calibration was complete, three different vegetation scenarios were assessed for Floodplains 1 and 2: dense woodland, grassland and the calibrated scenario. Floodplain 3 had four vegetation scenarios: dense woodland, sparse woodland, clustered woodland and grassland.

Table 2 shows Manning's roughness for the riverbed and floodplain of the three sites. The calibrated scenarios were a result of vegetation density analysis of Floodplains 1 and 2. The dense, sparse and clustered woodland and grassland

Table 2: Manning's roughness for riverbed and floodplain vegetation cover scenarios.

Site	*Scenario*	*Manning's n*
Floodplain 1	*River bed*	0.058-0.072
Floodplain 2	*River bed*	0.039-0.080
Floodplain 3	*River bed*	0.039
Floodplain 1	*Calibrated*	0.104
	Grassland	0.035
	Dense woodland	0.207
Floodplain 2	*Calibrated*	0.105
	Grassland	0.035
	Dense woodland	0.208
Floodplain 3	*Grassland*	0.035
	Clustered woodland	0.207
	Dense woodland	0.207
	Sparse woodland	0.112

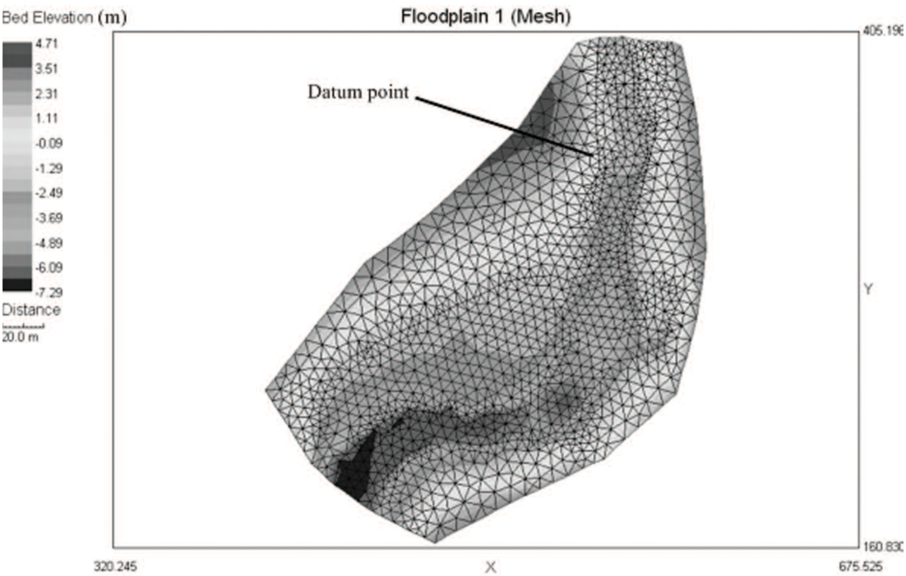

Figure 7: Shaded topographical representation (relative to the datum point) of Floodplain 1 with the overlying computational mesh. Datum point indicates 0 elevation of topographical data.

scenarios were obtained from Arcement and Schneider's (1990) Manning's roughness tables. The clustered woodland scenario in Floodplain 3 had the same roughness as the dense woodland scenario; however the vegetation was distributed throughout the floodplain in clusters rather than as a continuous cover (Figure 8).

Figure 8 shows the distribution of clustered woodland in Floodplain 3. The ks values are relative to a 2 m water depth, which was calculated from records and observations for the floodplain and adjacent areas, during and after the 3 July 2001 flood event (Barton 2004, Hall and Cratchley 2005). CS2 and CS4 indicate the location of cross sections 2 and 4, with results presented in Figures 12, 13 and 14.

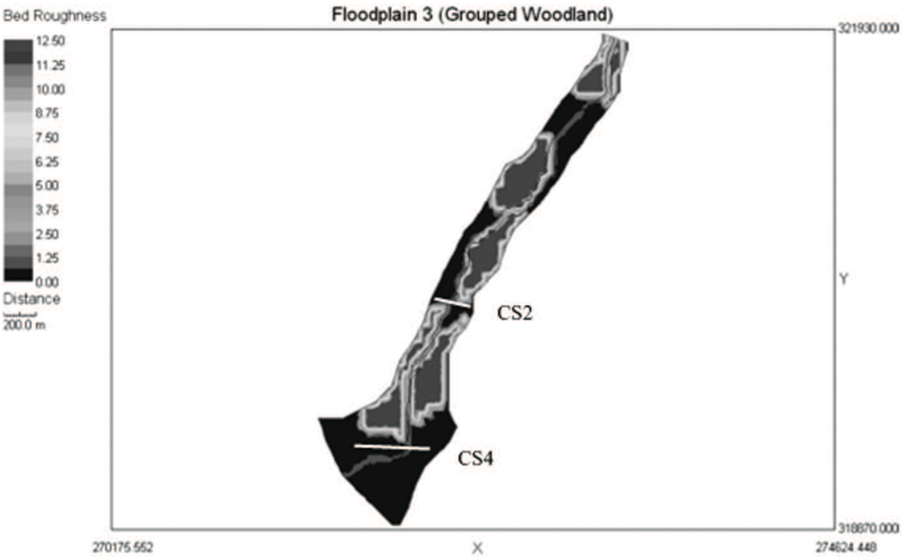

Figure 8: The distribution of Manning's roughness height (ks) with respect to a water depth of 2 m for the clustered woodland scenario in Floodplain 3.

Results

Results of each simulation were obtained by taking cross sections at hydrologically important locations (for example at the outflow boundary) within each reach (Figure 8), with the model producing numerical values for water surface elevations (m above OD) and discharge (m^3sec^{-1}) as the simulation progressed. Water is displayed in m (Figure 12).

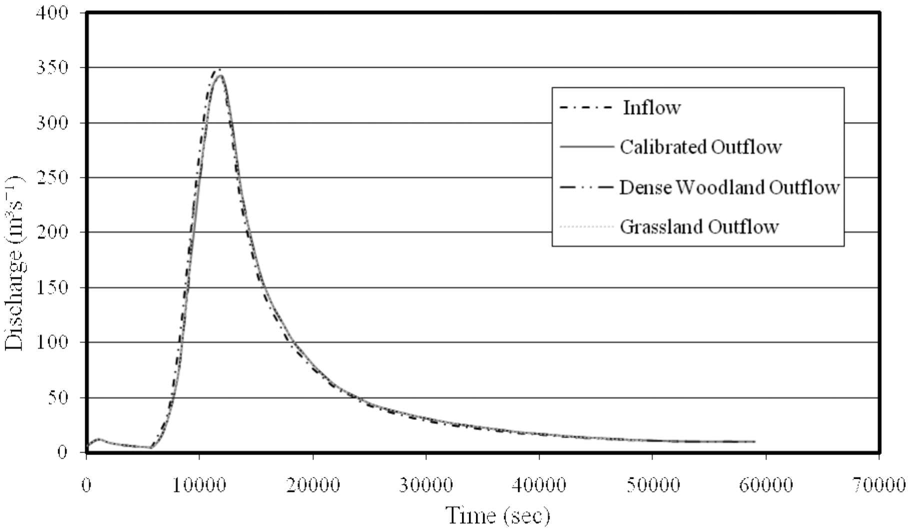

Figure 9: Modelled inflow and outflow hydrographs for the three vegetation scenarios in Floodplain 1.

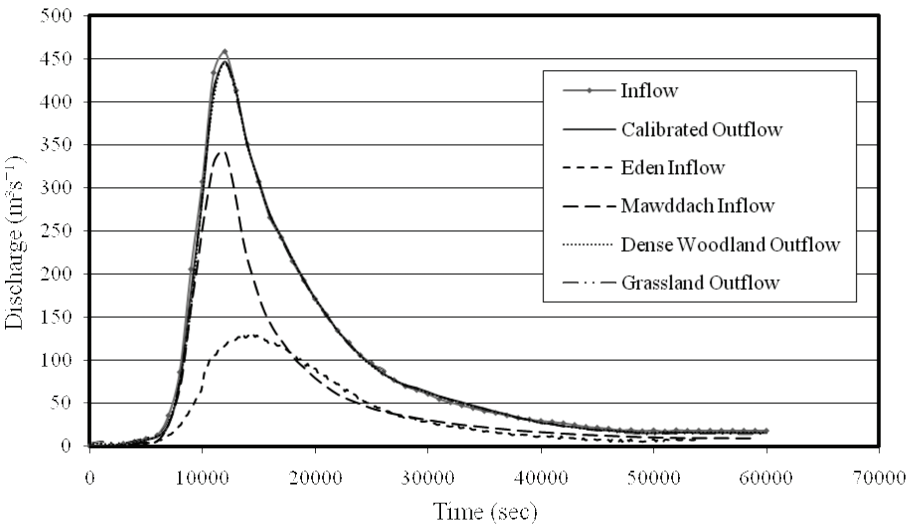

Figure 10: Modelled inflow (cumulative and individual) and outflow hydrographs for the three vegetation scenarios in Floodplain 2.

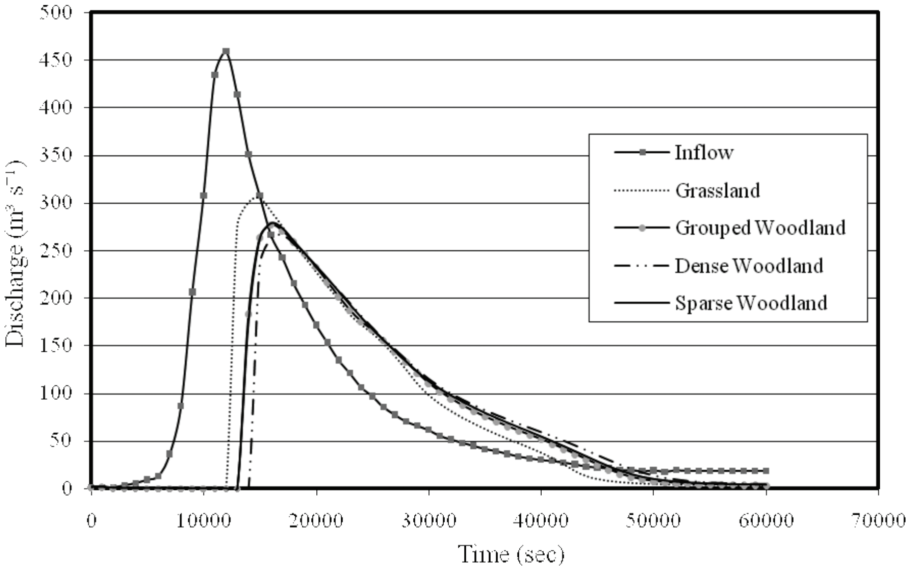

Figure 11: Modelled inflow and outflow hydrographs for the four vegetation scenarios in Floodplain 3.

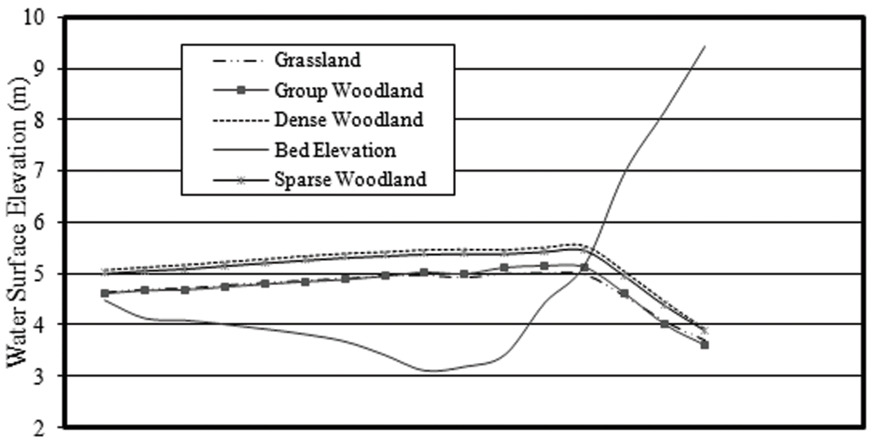

Figure 12: Modelled water surface elevations above OD at cross section 4 at the peak of the flood for the four vegetation scenarios in Floodplain 3. See Figure 8 for cross section location.

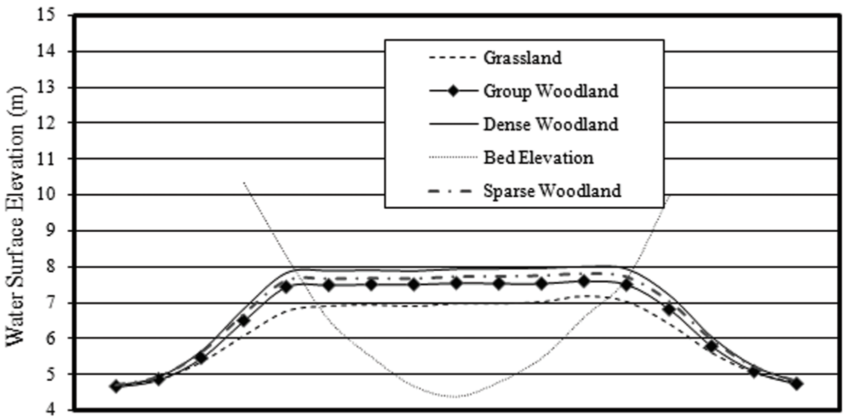

Figure 13: Modelled water surface elevations above OD at cross section 2 at the peak of the flood for the four vegetation scenarios in Floodplain 3. See Figure 8 for cross section location.

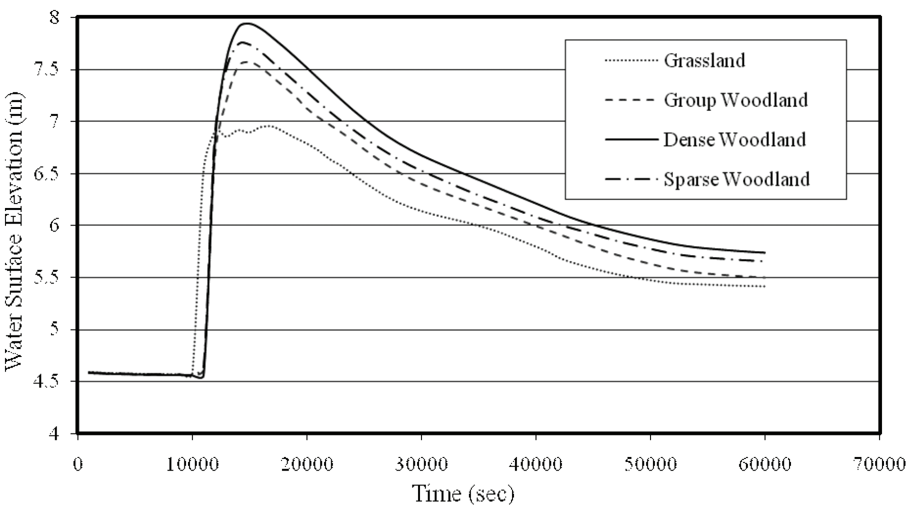

Figure 14: Modelled water surface elevations above OD for the four vegetation scenarios at Point 7 (located at the centre of CS2) in Floodplain 3.

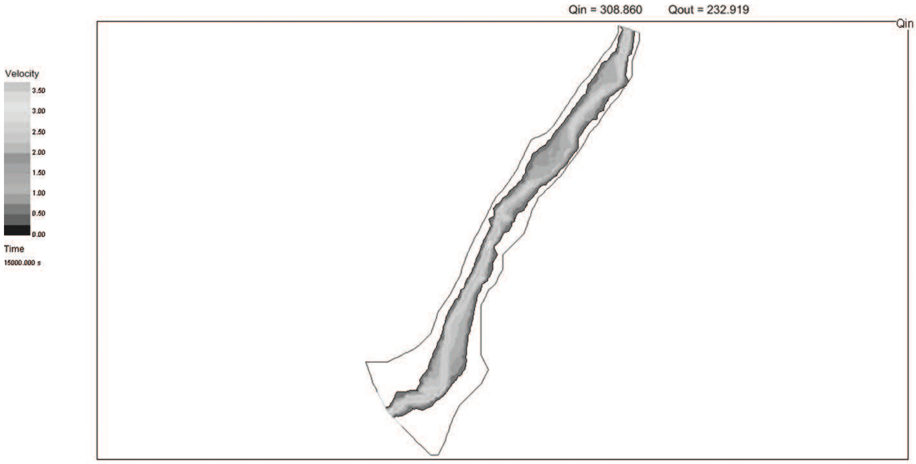

Figure 15: Modelled velocity distribution (ms^{-1}) across Floodplain 3 at and around the peak of the flood for dense woodland. Qin and Qout are inflow and outflow rates in m^{3}sec^{-1}.

Figure 16: Modelled velocity distribution (ms^{-1}) across Floodplain 3 at and around the peak of the flood for grassland. Qin and Qout are inflow and outflow rates in m^{3}sec^{-1}.

Discussion

Floodplains 1 and 2

It is evident from Figures 9 and 10, as well as from water surface elevations, that Floodplains 1 and 2 had similar inflow and outflow hydrographs. For either reach to be effective in flood mitigation, the outflow hydrographs of the more heavily vegetated scenarios (for example dense woodland) should produce a more attenuated (less flashy) form, with a lower peak and slower response time, relative to the inflow.

None of these characteristics were detected in either reach. A scenario such as dense woodland should also produce higher water surface elevations and lower discharge intensities than a scenario such as grassland. This was not the case in Floodplain 1, where modelled water surface elevations never increased more than 5 cm during the peak of the flood, when compared with dense woodland and grassland. The homogeneous nature of the water surface elevations resulted in almost identical outflow hydrographs for the various vegetation scenarios in Floodplain 1, with grassland producing a peak discharge of 342 m^3s^{-1} at approximately 20.45 hours and dense woodland producing a peak discharge of 341 m^3s^{-1} some 15 minutes later. While some mitigation did occur, it was small, as illustrated by the closely aligned outflow hydrographs in Figures 9 and 10. Preferential flows rates between the river and the floodplain are to be expected, but because Floodplain 1 had a very small area, the ability of the floodplain to store water was limited, as well as the fact that the river channel is quite deep at this location, as it took 35% (or 125 m^3s^{-1}) of the peak of the inflow hydrograph to overtop the river bank. A similar pattern was found in Floodplain 2, with water surface elevations only varying by 10 to 25 cm for the vegetation cover scenarios.

Floodplain 3

Water surface elevations modelled in Floodplain 3 were far more variable in response to the inflow hydrograph than in the other floodplains. Figure 12 shows that the dense woodland scenario resulted in water surface elevations some 65 cm above that of grassland and clustered woodland. Results were consistent at each of the cross sections within the reach. Figure 13 shows water levels about the peak of the flood at cross section 2 (see Figure 8). Dense woodland leads to modelled water depths of over 1m greater than grassland. Figure 14 gives water surface elevations at the centre of cross section 2 for the duration of the flood. Here grassland resulted in lower modelled water surface elevations (maximum 6.95 m) when compared with dense woodland (maximum 7.92 m). Another point to note is that floodwater first encountered grassland, and subsequently the other vegetation types. This led to the delay in the occurrence of peak water depth, as the more heavily vegetated scenarios held back the river surge more effectively than grassland.

Modelled water surface elevations in dense woodland were 1.05 m higher than grassland at the inflow boundary at the peak of the flood. This difference may be attributable to the backwash effect of the dense woodland scenario, as the hydraulic roughness would not have influenced water depth at the inflow boundary. In fact, the backwash effect was detected for over 1.3 km upstream of the inflow boundary. Such a large increase in water depth and subsequent upstream water volume may have implications for infrastructure, housing and landuse potentially impacted by backwash, and will be an important consideration for future floodplain woodland projects (Thomas and Nesbit 2007).

Figures 15 and 16 show the difference in velocity between dense woodland and grassland at the peak of the flood, indicating that grassland may lead to higher water velocity throughout the site, approximately twice the velocity of dense woodland.

Because grassland has much higher velocity rates than dense woodland, the resulting outflow hydrograph will be more closely related to the inflow hydrograph (Figure 11), resulting in a much more intense and flashier flood event and. Increased turbulence induced by erect rigid vegetation, such as trees and shrubs, will reduce downstream flow velocity through conversion of linear kinetic energy into turbulent motion (Fischer-Antze et al. 2001). The reduction in down-channel flow and increase in cross-channel flow will increase water depths in and around the floodplain, employing a temporary storage area for the peak of the flood event, thereby reducing peak surges downstream of the floodplain.

For Floodplain 3 sparse woodland resulted in higher modelled water surface elevations at all cross sections, when compared with clustered woodland. This appears counterintuitive, as sparse woodland had half the basal area of clustered woodland. However, the velocity discharge maps indicate a lack of a continuous turbulent/transverse flow regime in the clustered woodland scenario, which may limit its potential to mitigate flood events, when compared with sparse woodland. Clustered pockets of dense woodland may simply constrict flow, thereby increasing velocity locally, with little effect on outflow pattern.

Dense woodland reduced modelled peak discharge by over 45 m^3s^{-1} compared with grassland. Sparse and clustered woodland led to similar results. The discharge from grouped woodland at the peak of the flood was 32 m^3s^{-1}less than grassland, not as effective as dense woodland, but it would also seem to provide significant flood mitigation. Overall, grassland cover seems to lead to higher discharge velocities compared with woodland, from the onset of the flood. However, the modelling indicates that after the peak, subsequent discharge from the woodland types begins to equal and exceed discharge from grassland. This may be a result of woodland holding the peak of the flood on the floodplain until the floodwaters begin to recede, with a gradual release of surface storage into the river.

Conclusions

Floodplains 1 and 2

Figures 9 and 10 indicate that Floodplains 1 and 2 offered little potential for flood mitigation: water depths showed little variation between the modelled vegetation types. This was probably due to the topography, size and location in the river system of the floodplains. The short reach of Floodplain 1 (370 m) would promote only temporary turbulent flow. As discussed, the river bank in Floodplain 1 was relatively high; it took 35% (or 125 m^3s^{-1}) of the peak of the 3 July 2001 flood for them to be over-topped.

Despite the undulating topography of Floodplain 2, it provided little potential for flood mitigation mainly, as in the case of Floodplain 1, because of its small size relative to potential high flows. Modelled velocity discharge indicated complex hydrodynamic effects operating over this reach, especially during extreme flood events.

Floodplain 3

Floodplain 3, on the other hand, did show divergence between the four vegetation types. The topography of the reach is a typical floodplain, and its width varied from 50 to 250 m, with a reach of 3.7 km.

The clustered woodland scenario in Floodplain 3 resulted in modelled water surface elevations being 25 cm lower than in sparse woodland, despite having twice its basal area. As already mentioned, the location of the woodland clusters can have significant effects on the outflow hydrograph.

An unbroken stretch of rigid vegetation, leading to transverse/turbulent flow, is critical to the reduction of flow velocity in a floodplain. A high vegetation density on the floodplain resulted in a backwash effect (detectable 1.3 km upstream in Floodplain 3), which could have consequences for infrastructure and housing that would otherwise be unaffected by flooding (Thomas and Nesbit 2007). However, a reach with a low vegetation density in the floodplain will have obvious consequences for downstream flood mitigation; therefore site specific analysis of the most appropriate vegetation density is important to estimate the effects on water level and discharge rate.

Although the use of floodplain woodlands in flood mitigation does show potential, more detailed analysis is needed on the hydrodynamic influence of the Mawddach tributaries on the downstream hydrographs. It is unlikely that floodplain woodlands alone will be the complete answer to the increased flood risks accompanying climate change. Nonetheless, the introduction of strategically placed weirs and other man-made structures would increase over-bank water depths, thereby increasing the potential of the floodplain to ameliorate peak flows (Hall 2008). The reduction of 45 m^3s^{-1} in modelled peak discharge between grassland and dense woodland for Floodplain 3 was considerable, as well as the 30-minute delay to peak discharge. Such reductions and delays in discharge are likely to considerably aid in flood control for towns further downstream, such as Dolgellau.

Coupled with this is the fact that floodplain woodland provides increased habitat biodiversity and enhanced landscape and recreation amenities for local communities. Furthermore, because of high growth rates, a coppice system with the potential for biofuel production could be practised in such a landscape. However, the effect of such silvicultural practices on hydrodynamic properties needs to be further investigated.

The use of floodplain woodland as an environmentally sustainable and perhaps financially effective means of flood defence has potential. Any flood defence system is however site specific, particularly floodplain woodland. Further work needs to be done in quantification of the hydrological influence of vegetation type on floodplain overflow. The use of high resolution topographical data such as LIDAR would aid in modelling larger study areas with greater accuracy.

The location of floodplain woodland in a river system appears to be important in flood mitigation efficiency. Further work needs to be done on establishing a relationship between floodplain woodland location and flood amelioration potential.

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