Energy crops on floodplains – flood risk or benefit?

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Abstract

Under the Renewable Energy Strategy the UK aims to achieve 15% of its energy needs from renewable sources by 2020, with 30% of the renewable energy target coming from biomass. Farmers are being encouraged through the Energy Crops Scheme to plant energy crops such as Miscanthus or Willow in suitable locations. However, there is little understanding of the impacts that dense plantings of these crops might have on flood dynamics and flood risk, This has often led to some applications for the crops being, potentially unnecessarily, refused on a precautionary basis.

A short-term project was carried out to help bridge this gap in scientific knowledge. Two case study floodplains were selected, namely the River Severn at Uckinghall (Tewkesbury) and the River Isle at Ashford Mill (Ilminster). Additionally, a theoretical model was designed to help define scenarios with the biggest impacts, without introducing local subtleties specific to each case study.

This paper describes the approach and provides outputs of the modelled scenarios, including changes to river and floodplain flows, flood depths, velocities, and the overall likely impact of the energy crops upstream and downstream. The conclusions discuss how the findings inform new guidance and practice regarding energy crops on floodplains, and how such a change can inform national policy in this area.

Keywords: Miscanthus, SRC Willow, 1D-2D hydraulic modelling, resistance to flow, floodplain roughness, Manning's n, flood risk

Introduction

As part of the Renewable Energy Strategy in the UK, landowners and farmers are being actively encouraged through the Natural England managed Energy Crops Scheme (ECS) to increase the amount of energy crops grown in England (Natural England, 2009). The scheme is part of the Rural Development Programme for England (RDPE) and offers grants to farmers in England for the establishment of Miscanthus and Short Rotation Coppice (SRC), e.g. SRC Willow. The UK's Environment Agency (the EA) provide advice to Natural England on the operation of the ECS with respect to Flood Risk , particularly within the EA Flood Zone 3 areas, i.e. the areas that could be affected, in the absence of defences, by fluvial flooding by a flood with a 1% (1 in 100) or greater chance of happening each year. However, there is still little understanding of the potential impacts (both positive and negative) that dense plantings of these energy crops on the floodplain might have on fluvial flooding dynamics and flood risk,

If the presence of appropriately designed energy crop plantations on the floodplain could provide a coupled benefit of a renewable energy resource and a flood risk mitigation function, then this should be actively encouraged. There is a need to be able to provide robust evidence based advice on the topic, in time for the next round of grant applications (for new plantings scheduled for 2011).

Developing a complete understanding of the impacts of energy crops on Flood Risk Management may take several years to achieve. However, there is an urgent need for some initial evidence to provide a steer for relevant policy makers and scheme assessors. With this in mind, a short modelling study was commissioned to investigate the potential impact of growing energy crops on river and floodplain flows and to qualitatively assess any changes these new plantings might make to upstream and downstream flood risk. The energy crops under investigation were Miscanthus and SRC Willow.

This study used the linked 1D-2D modelling approach in three case study floodplains (i.e. 1D hydraulic model simulating the river channel flows and 2D model simulating out-of-bank flows on the adjacent floodplain). The choice of these case studies was determined mainly by the availability of existing hydraulic models with an appropriate level of detail, and the location and character of the floodplain where the energy crops could realistically be planted. This project was seen as an initial phase of work in this area, a forerunner of further phase(s) to follow if a need was identified, particularly in terms of further modelling or the validation of the modelling work with the collection of monitoring datasets from new field studies.

Energy crops in hydraulic models – a review

The effects of floodplain vegetation on flow are represented empirically in hydraulic models by the use of roughness coefficients (such as the Manning's n roughness coefficient for example). Appropriate roughness coefficient values for different substrate and vegetation types are well documented. Roughness values have also been published on floodplain vegetation such as wet woodlands or wet meadows, which have recently been seen as potential flood mitigation measure on floodplains. These have been subject to a small number of hydraulic modelling studies, e.g. by Forest Research (Nisbet and Thomas, 2008). In the USA, a number of studies have investigated roughness characteristics of densely vegetated floodplains (Acrement *et al*., 1989). However, there is little information specifically on appropriate values of roughness for energy crops such as Miscanthus or SRC Willow.

Miscanthus is a perennial, rhizomatous grass which can grow to heights of more than 4m, forming a plantation of dense bamboo-like canes (Defra, 2007). It is planted in spring and once established, it can stay in the ground for 15-20 years. Mature Miscanthus is harvested annually in the winter season, typically in February. SRC Willow is a perennial crop that can be productive for about 30 years. It is planted in spring in either single 1.5m rows or in double rows 60cm-70cm apart. SRC Willow is harvested once in 3 years.

Roughness effects of some vegetation types are discussed in a number of publications, for example in The Roughness Review (Defra, 2003), Acrement *et al.* (1989), Chow (1959) and Thomas *et al.* (2004). A number of field and laboratory experiments exploring how the type, density and placement of vegetation, flow depth and velocity influence the resistance to flow, both for submerged and non-submerged flexible or stiff (e.g. willow) vegetation, have been reported. For example, Järvelä (2002) used laboratory experiments to investigate the impact of grasses and willows (both with leaves and leafless) on the friction factor (which can be related to Manning's n as documented for example by Chow, 1959). Crucially, Järvelä demonstrated that for velocities up to 0.5m/s, the willows stems do not bend and stay more or less erect. Wilson *et al.* (2002) studied the flow resistance of flexible vegetation when submerged in a laboratory flume and concluded that Manning's n increases significantly as the flow depth approached the vegetation depth, tending towards a constant value at higher levels of submergence. On average, the Manning's coefficient for the tested conditions was found to be greater than the values traditionally applied for grassed floodplains. Further investigations by Wilson have shown changes in flow resistance of SRC Willow with depth and flood velocities (Wilson, 2009).

The following assumptions regarding representation of the energy crops on floodplains were adopted in this study:

- The energy crops were modelled as fully mature plants. Headlands and rides within or around the plantations were modelled as managed grass and the baseline (control) plantation was modelled as winter wheat.
- The bamboo-like stems of Miscanthus had uniform character throughout the flooded depth. The hydraulic character of SRC Willow was more likely to vary with flooded depth (as presented by Wilson, 2009).
- The crop was assumed not to be fully submerged during the flood events (as it is highly unlikely that floodplains with flooding deeper than 3m would be chosen for energy crop production). In such conditions, the resistance of the vegetation to flow is likely to remain constant for deep flows (Defra, 2003).

Table 1 shows the final Manning's n coefficient adopted in this project. As noted by Defra (2003) there remains a need for further research to provide calibration and verification data for 2D analysis of roughness. There are also questions remaining about exactly how the effective resistance to flow should be partitioned between boundary friction and from drag, how the total resistance is affected by flow depth, and how best to represent the influence of vegetation height, density and rigidity. In situations where vegetation is present, the amount of plant submerged or emerging and plant type are both important parameters in defining the relationship between roughness coefficient and flow depth. In this study there is also a need for a pragmatic approach and so the literature has been reviewed to draw out values for the Manning's n coefficient that could correspond to the postulated energy crop vegetation types, albeit subject to uncertainty owing to the difficulty in representing the factors discussed above.

Table 1. Floodplain roughness coefficients (Manning's n) adopted for Miscanthus, SRC Willow, Baseline (arable cereal – wheat) and headland/rides.

Vegetation type	*Manning's n*	*Comments*
Miscanthus	0.2	Manning's n applied for the full depth of inundation. This value is representative of dense vegetation with firm stems and thick undergrowth with minor irregularities in the ground.
SRC Willow	0.1 – 0.34	Manning's n varies linearly with depth of inundation between the following values (typical for flood velocities at 1m/s, which is the value closest to the velocities achieved in the baseline and scenario case studies): n=0.1 flooded depth 0.5m n=0.34 flooded depth 2.0m These values are a synthesis of the Manning's n values presented by Wilson (2009) and comprise the low to upper recommended values, which help give an indication of the envelope (and sensitivity testing) for the expected impact of SRC Willow on floodplain flows.
Headlines/Rides	0.04	Manning's n typically used for managed grass for the full depth of inundation.
Baseline	0.06	Manning's n typically used for arable crop (wheat) for the full depth of inundation.

A range of different hydraulic modelling approaches are currently used in practice. The criteria for the selection of the most suitable modelling approach for this study included availability of suitable existing models (as it was not possible within the timeframe of this project to build, calibrate and validate detailed models), representation of the floodplain in detail suitable for modelling energy crops and reasonable calculation time for the models to complete the modelling scenarios within the allocated timescale. With these in mind, the linked 1D-2D ISIS TUFLOW was chosen as the appropriate software package for this study. The model versions used were TUFLOW 2009 07 AE and ISIS v3.3.0.88.

Modelled scenarios

A list of energy crop plantation configurations to be modelled was established in consultation with the Project Steering Group. They included a maximum impact scenario (dense, fully mature energy crop plantation with 100% coverage on the floodplain). A balance between a practical number of scenarios and the need to capture the variety of appropriate plantation characteristics, such as plantation location or size (typically 1-3ha), was achieved. A winter wheat cereal crop was represented in the baseline model. The scenarios with a much more distributed pattern of plantation blocks across the floodplain were thought to be the more realistic for actual plantings that may occur on the ground. Extra scenarios were also included for plantation blocks that extended across the central portion of the floodplain, therefore acting as a form of a 'leaky green dam', in order to explore the hydraulic effects both upstream and downstream.

The initial modelling focused on the Miscanthus scenario with the greatest and least potential impact (i.e. plantation covering 100% or 30% of the floodplain, respectively) as a sensitivity test.

Table 2 summarises the modelling scenario characteristics adopted (for the modelled flood magnitude at 100-year return period, i.e. 1% annual exceedance probability). Figures 1 – 4 show an example of the layouts of a selection of the modelling scenarios.

Table 2. Summary of modelling scenario characteristics for Miscanthus and SRC Willow.

Plantation characteristics	*Description*
Size	3ha blocks
	1ha blocks
Configuration	10m rides/headlands parallel to river
	10m rides/headlands perpendicular to river
	5m rides/headlands parallel to river
	5m rides/headlands perpendicular to river
Location	One side of river
	Both sides of river
Coverage	100% of floodplain
	Up to 30% of floodplain

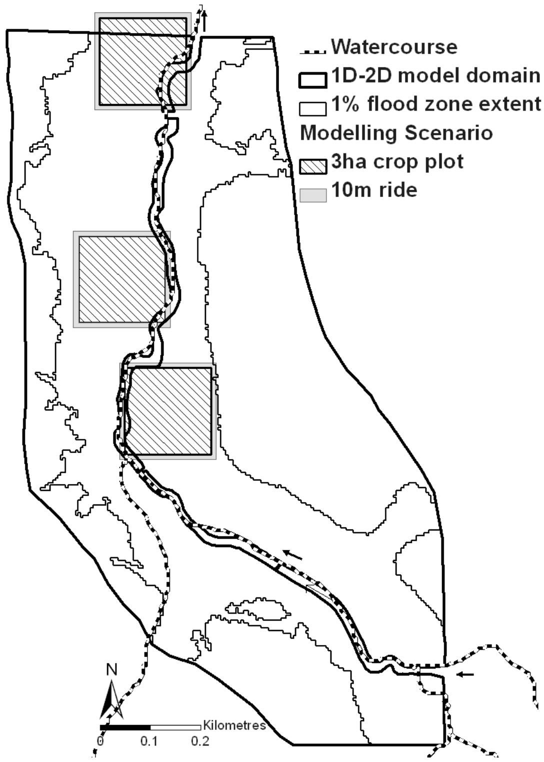

Figure 1. An example of plantation configuration on the River Isle floodplain (plantation coverage: 30% of floodplain).

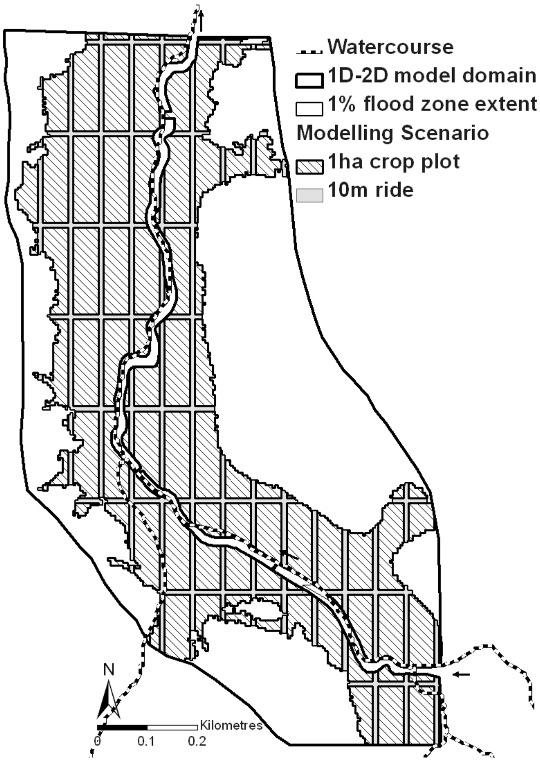

Figure 2. An example of plantation configuration on the River Isle floodplain (plantation coverage: 100% of floodplain).

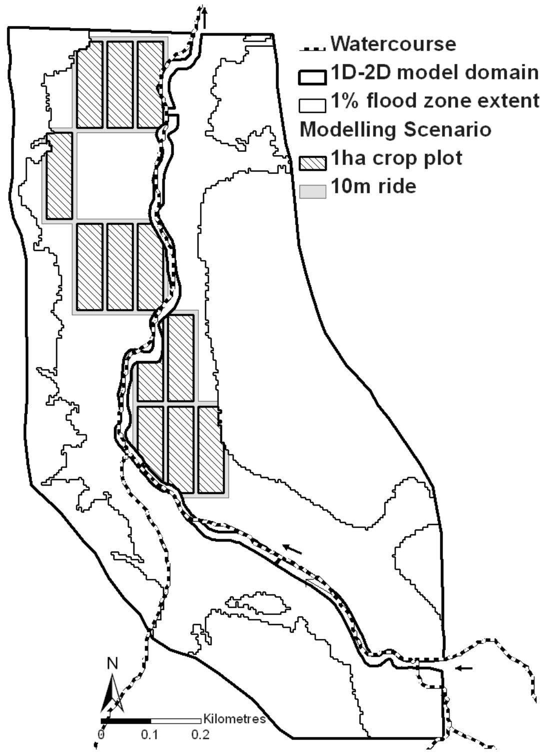

Figure 3. An example of plantation configuration on the River Isle floodplain (plantation coverage: 30% of floodplain).

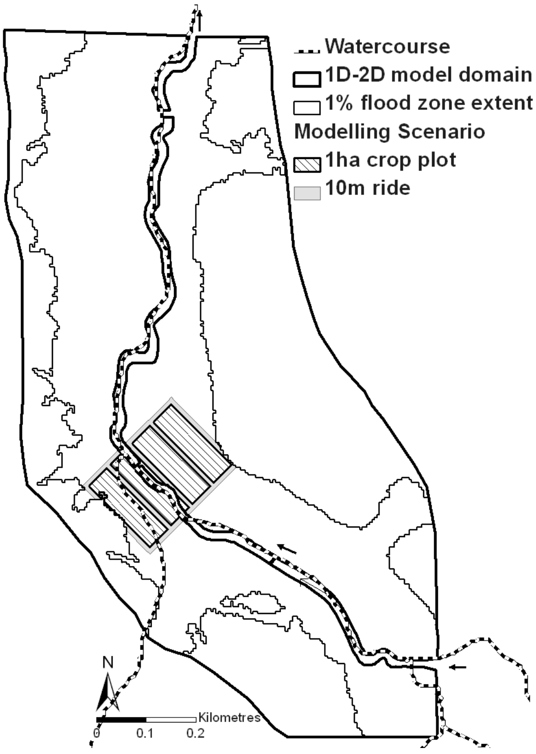

Figure 4. An example of plantation configuration on the River Isle floodplain (plantation coverage: <30% of floodplain).

Case study floodplains

The case study floodplains were the River Severn at Uckinghall (near Tewkesbury in the West Midlands), the River Isle at Ashford Mill (near Ilminster in the South West) and an idealised model, set up to help define the scenarios with the biggest impacts, without introducing local floodplain subtleties that are different in each real case study. The criteria for the choice of the case studies included suitable model topographic and soil characteristics of the floodplain, the availability of existing hydraulic models with suitably detailed representation of the floodplain and a suitable model run time.

This paper presents only the summary results drawn from all the case studies and scenarios modelled. The complete results, alongside with more detailed information about the project, will be available from the Environment Agency website (www.environment-agency.gov.uk).

Results

The total number of the final scenarios was 40 (including those for the baseline condition), ranging from 9 to 16 scenarios per case study.

Each particular scenario of plantation configuration, floodplain coverage and distribution on the floodplain generated a range of impacts with respect to modelled flood depth and flow on the floodplain, the velocity and pathways of flow across the floodplain and the main river channel flood hydrograph. Some of these impacts were very localised and others extended for longer distances across the floodplain. Overall, the impacts caused by Miscanthus and SRC Willow plantations were found to be broadly similar, as expected. The dense nature of the plantations acted as a 'green leaky dam' that held water back both within and immediately upstream of the plantation and slowed the speed of water propagation across the floodplain. A corresponding decrease in flood levels occurred in the area immediately downstream. Well distributed and dispersed plantations with less than 30% floodplain coverage produced only very localised effects with the extent of the hydraulic effect less than 300m upstream or downstream of the plantations. Plantation headlands and rides provided faster preferential flow pathways through the plantation area. Neither varying of the ride width, nor the ride orientation relative to the river flow changed significantly the flood dynamics. As expected, the greater the plantation coverage the more water is forced to move in the vicinity of the main channel (at greater flow rate).

A summary matrix that encapsulates the findings from all the three case studies is given in Table 3. This summary aimed at qualitative interpretation of the results rather than restricting presentation of the outputs solely quantitatively. The matrix was used to supplement the Environment Agency national guidelines regarding the development of woodland (including energy crops) on floodplains and Flood Risk.

It is important to note that the modelling scenarios do not represent the exhaustive combinations of floodplain characteristics and the plantation configurations that are possible. However, they do cover both: the extremes with the biggest likely impacts; and the most likely planting scenarios.

Table 3. Summary results matrix.

	Flood depth (max)			*Flood velocity (max)*				*In-channel flood flow (max)*		
*Plantation configuration on floodplain**	*u/s*	*within*	*d/s*	*u/s*	*within*	*within ride*	*d/s*	*u/s*	*within*	*d/s*
Complete (100%) coverage	n/a	+/++	n/a	n/a	--	+	n/a	n/a	+	n/a
Distributed blocks (30% coverage)	+	+/++	+/0	-	--	+	-	-/0	+	+/0
Central block (across floodplain)	++	++	-	-	--	+	0	-/0	++	+/0
Central block (part floodplain width)	+	+	-	0	--	0	0	-/0	+	+/0

*u/s = upstream of plantation; within = within plantation, d/s = downstream of plantation

Table notes

Symbol	*Definition*	*Max flood depth change*	*Max velocity change*	*In-channel peak flow change*
++	Increase	>20cm increase	>40% increase	>10% increase
+	Slight increase	5-20cm increase	10-40% increase	2-10% increase
0	Minimal effect	±5cm increase/decrease	±10% increase/decrease	±2% increase/decrease
-	Slight decrease	5-20cm decrease	10-40% decrease	2-10% decrease
--	Decrease	>20cm decrease	>40% decrease	>10% decrease
n/a	Not applicable (not in model domain)	n/a	n/a	n/a

Assumptions and limitations

No field study datasets were available to verify the floodplain roughness values that should be used for Miscanthus and SRC Willow, as there are still gaps in knowledge in this area. A number of limitations were present in the modelling work that related to the simulated plantation configurations, the plantations were square/rectangular (which would not be the case in reality), and it was not possible to properly assess the concept of 'parallel' and 'perpendicular' rides next to a meandering river channel. The scope of this study did not include investigation of flood risk associated, for example, with bridge or culvert blockages by woody debris potentially washed out from the plantations. There is little knowledge regarding the behaviour of the energy crops when they are inundated with deep floodwater and/or fast flood water velocities, and the associated change this would generate on their resistance to flow. No account could be taken for the leaf litter as an additional barrier to flow, or for the potential modifications to near ground levels due to the root system and (particularly regarding SRC Willow) the thick tree trunk-like stems that typically occur after repeated coppicing.

Discussion

The magnitude of the effects on water levels seen in the results of this study could potentially be important in flood management terms. A predicted 5-10cm rise in water level could be deemed by the EA to be important in terms of the potential impact of building developments on the floodplain. The most important consideration is the proximity of important flood risk receptors to the influence of an increased flood risk. In a rural floodplain context the receptors could include third party land, environmental or heritage receptors.

The general trend of the results, for the scenarios and case study floodplains examined, was for the increased floodplain roughness due to the presence of the energy crop plantations to cause the flood depths to increase within and upstream of the plantation, and increased river flows next to plantation blocks that extended near to the main river channel. The greater the plantation coverage the more water seemed to be forced to move in the vicinity of the main channel (and at greater flow velocity and flow rate). However, this finding raises further questions about the use of the 1D-2D linked models in this application and how they represent the physical processes at the transition between the river channel (1D) and the floodplain (2D), as also discussed further below. As documented by Knight *et al.* (2010), the physics would suggest that resistance from the floodplain transfers into the main channel flow and therefore the increased river channel flows observed in the results here could be related to the representation of the 1D-2D link in the model, rather than solely the effect of the energy crops on the floodplain.

The 1D – 2D model linkage configuration can have an important impact on the model results, particularly when the floodplain area near the river banks is concerned, as is the case in this project. This link is crucial in determining the amount of water spilling onto the floodplain and the interaction between the flows in the river and on the floodplain. The increase in flood depth and water levels around the plantation blocks is in line with expectations; however, apparent increases in flow in the channel may deserve further investigation. Linked ISIS-TUFLOW models exchange mass across the links between the main (1D) channel model and the floodplain (2D) model according to the relative water levels at each side of the link. In reality, there are also transfers of momentum at the interface between channel and floodplain flows, with complex patterns of turbulence created in some circumstances. It is possible that if these processes are not represented in a 1D-2D linkage then elevated water levels on a rough floodplain could raise water levels in the main channel leading to an increase in channel flow that may be, at least in part, an artefact of the modelling approach.

As the mathematical complexity of a model increases, so, in general, do the number of coefficients options that can influence the precise solution obtained in any particular simulation. The TUFLOW software used here includes a number of options that influence exactly how the model represents certain features of the physical system and also how numerical techniques are used to solve the flow equations. The solution of the shallow water equations is based on an alternating direction implicit (ADI) scheme. The model includes a treatment of turbulence, which is modelled using two additional equations to account for the energy in the turbulence and the scale of the turbulence. This turbulence closure includes coefficients that may influence the model predictions but that are rarely adjusted (and for this study the default values were used).

The spatial extent of the hydraulic effect of a plantation block or distributed plantations was generally for a distance less than 300m upstream or downstream of the plantation edge. A similar predicted distance of influence was reported by Thomas *et al.* (2004) for a floodplain woodland modelling case study on the River Cary in Somerset. It was not possible in this study to fully examine the impact further downstream without coming close to the downstream model boundaries, where the boundary conditions might influence the results more than the processes on the floodplain. This includes hydraulic factors that influence backwater length in the model, e.g. slope, and therefore the results in this area may be different for different floodplains.

Conclusions

The findings of this study include those expected as a result of the modelling approach and the methodology used for representation of the energy crops, and importantly those that add new information to the subject and also raise further questions (particularly regarding modelling the energy crops on floodplains).

In general, the expected results include:

- The impacts caused by Miscanthus and SRC Willow plantations are broadly similar; however, shallow floodplain flooding up to about 1m is likely to be more affected by Miscanthus than by SRC Willow primarily due to the different roughness characteristics up to this depth. The difference is expected to disappear with deeper flooding (e.g. greater than 2m depth).

- The very dense nature of the main vegetative body of the plantation acts like a 'green leaky dam' to hold water back both within and immediately upstream of the plantation and slow the speed of water propagation across the floodplain. In most cases there will be a corresponding, but smaller, decrease in flood levels in an area immediately downstream of the plantation.
- Full floodplain coverage of an energy crop plantation generated the highest overall impacts on the flood dynamics (flood depth, velocity of flow, main channel flow hydrographs).

The new information found by this study include:

- Well distributed and dispersed plantations with less than 30% floodplain coverage, set away from the main channel, and not significantly blocking the floodplain width (and therefore the flow of water across the floodplain) would only produce very localised effects.
- Varying of the headland and ride width (from 5 to 10m) did not significantly change the flood dynamics. However, this might need further investigation using, for example, higher resolution of the 2D model to simulate the floodplain processes in more detail.
- Varying the ride orientation relative to the main river channel orientation did not significantly change the flood dynamics.
- Distributed plantation blocks or a central plantation block did not change the maximum flood extent significantly.

The results from this modelling work have been used to supplement an existing guidance note to Environment Agency Development & Flood Risk staff, and to Natural England ECS advisors, who are assessing the potential impact of the proposed energy crop plantations on flood risk. The Environment Agency could work with farmers and the ECS to help deliver CFMP actions. The new understanding, based on the findings of this study, should ensure that suitable applications are made that do not impact on flood risk in a detrimental way.

Given the nature and scope of this project, it was only possible to consider a relatively simple modelling approach that was applied to limited number of case study floodplains. In order for a more robust and comprehensive consideration of the impacts of energy crop plantations on floodplain flows and flood risk, recommendations for further modelling work include the use of, for example, 2D hydrodynamic modelling approach for both the river and floodplain, wider range of modelled flood flows, and importantly, laboratory and field test studies.

References

Arcement JR, G.J. and Schneider, V.R., 1989. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. *United States Geological Survey Water-supply Paper 2339.*

Chow, V.T., 1959. Open Channel Hydraulics, McGraw-Hill.

DEFRA, 2007. Planting and Growing Miscanthus. Best Practice Guidelines. Department for Environment, Food and Rural Affairs.

DEFRA, 2004. Growing a Short Rotation Coppice. Best Practice Guidelines. Department for Environment, Food and Rural Affairs.

DEFRA, 2003. Reducing Uncertainty in River Flood Conveyance: Roughness Review. Project W5A-057. Department for Environment, Food and Rural Affairs and Environment Agency Flood and Coastal Defence R&D Programme.

Ghavasieh, A.R., Poulard, CH., Paquier, A., 2005. Effect of roughened strips on flood propagation: Assessment on representative virtual cases and validation. *Journal of Hydrology*, 318 (2006), 121 – 137.

HM Government, 2009. The UK Renewable Energy Strategy. ISBN: 9780101768627.

Järvelä, J., 2002. Flow resistance of flexible and stiff vegetation: A flume study with natural plants. *Journal of Hydrology*, 269, 44-54.

Knight, D. W., MCGahey, C., Lamb, R. and Samuels, P., 2010. Practical Channel Hydraulics: Roughness, Conveyance and Afflux. CRC Press.

MC Gahey, C., 2006. A practical approach to estimating the flow capacity of rivers, *PhD Thesis*, Faculty of Technology, The Open University (and British Library), pp. 1–371.

Natural England, 2009. Rural Development Programme for England. Energy Crops Scheme. Establishment Grants Handbook (3rd Edition). Natural England, Department for Environment, Food and Rural Affairs, European Union, Forestry Commission, and Department for Energy and Climate Change.

Nisbet, T.R. and Thomas, H., 2008. Project SLD2316: Restoring Floodplain Woodland for Flood Alleviation. *Final Report.* Defra & Forest Research.

Sellin, R.H.J., Bryant, T.B., Loveless, J.H., 2003. An improved method for roughening floodplains on physical river models. *Journal of Hydraulic Research*, 41 (1), 3 -14.

Thomas, H. and Nisbet, T.R., 2004. An assessment of the hydraulic impact of floodplain woodland. Final Report to the Forestry Commission.

Wilson, C.A.M.E. and Horritt, M.S., 2002. Measuring the flow resistance of submerged grass. *Hydrological Processes*, 16, 2589-2598.

Wilson, C.A.M.E., 2009. *Personal communication.*

Xavier, P.A., (in preparation 2010). Hydraulic impact of floodplain woodland. Cardiff School of Engineering, Cardiff University. *PhD Thesis.*