Energy Crops and Floodplain Flows

Science Report – NA050

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned and funded by the Environment Agency's Science Programme.

Published by:
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: XXXXXXXXXX

Further copies of this report are available from:
The Environment Agency's National Customer Contact Centre by emailing:
enquiries@environment-agency.gov.uk
or by telephoning 08708 506506.

Author(s):
Steve Rose, Zdenka Rosolova

Dissemination Status:
Publicly available / Restricted

Keywords:
Energy crops, Miscanthus, Short Rotation Coppice Willow, Flood Risk Assessment, Floodplain

Research Contractor:
JBA Consulting, South Barn, Broughton Hall, Skipton, North Yorkshire, BD23 3AE. Tel: 01756 799919

Environment Agency's Project Manager:
Adam Baylis, Environment Agency, 21 Park Square South, Leeds, West Yorkshire, LS1 2QG

Science Project Number:
NA050

Product Code:
XXXXXXXXXXXX-E-P

Science at the Environment Agency

Science underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us and helps us to develop monitoring tools and techniques to manage our environment as efficiently and effectively as possible.

The work of the Environment Agency's Science Group is a key ingredient in the partnership between research, policy and operations that enables the Environment Agency to protect and restore our environment.

The science programme focuses on five main areas of activity:

- **Setting the agenda**, by identifying where strategic science can inform our evidence-based policies, advisory and regulatory roles;
- **Funding science**, by supporting programmes, projects and people in response to long-term strategic needs, medium-term policy priorities and shorter-term operational requirements;
- **Managing science**, by ensuring that our programmes and projects are fit for purpose and executed according to international scientific standards;
- **Carrying out science**, by undertaking research – either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen

Head of Science

Executive summary

Rural land use and land management on floodplains can have considerable impacts on flood dynamics and flood risk management. To date, research and modelling has explored the impact of land use changes such as floodplain afforestation, changes to management of upland moorlands or the re-establishment of wet meadows on flood generation, flood attenuation and flood storage. However, no such detailed investigation has been carried out into the impact on floodplain flows of growing new energy crops. In the UK, a strong emphasis is being given to the promotion of renewable energy, with grants available to growers through the Energy Crops Scheme (ECS). Farmers are encouraged to plant energy crops such as Miscanthus (harvested annually) or Short Rotation Coppice Crops (such as Willow, Poplar or Ash harvested every 3 years) in suitable locations, which typically exclude farmland in Flood Zone 3 (i.e. areas likely to be flooded by an event with a 100-year return period). However, there is a lack of understanding as to what impact, if any, the dense character of these crops planted on floodplains and how they are managed might have on flood risk elsewhere along the river. At present, no guidance or policy exists to advise whether allowing farmers to establish energy crop plantations in Flood Zone 3 could alter the existing flood risk both in the locality of a new plantings and/or further afield. In certain locations new energy crop plantations could potentially provide a flood risk management function, an economic return and additional environmental benefits.

To help fill in this gap in knowledge, this short term project has been undertaken in order to investigate the possible scale of impact that growing energy crops has on river and floodplain flows, flood depth and the overall impact on flood risk locally as well as upstream/downstream. Linked 1D-2D hydraulic modelling using ISIS-TUFLOW software was deemed to be the most appropriate approach for these investigations.

A review of the life cycle and management regime of Miscanthus and SRC Willow and their likely behaviour when flooded has informed the establishment of feasible modelling scenarios representing likely mature energy crop plantations in terms of their size, location, distribution, orientation to flow and percentage cover on the floodplain. A baseline scenario, assuming complete floodplain coverage with an arable crop cover (winter wheat), was included to enable comparison of results. Two existing Environment Agency Flood Risk Management models have been adapted for use as case studies in this project, the first on the River Severn at Uckinghall near Tewkesbury in the West Midlands, and the second on the River Isle at Ashford Mill near Ilminster in the South West. Additionally, a simple theoretical model was also set up in order to help define scenarios producing the greatest impacts, but excluding the effect of local subtleties that are different in each case study.

The model results have been used to assess how new energy crop plantations generate changes to i) river flow, ii) flow pathways on the floodplain, iii) flood depths, iv) flood velocities on the floodplain. Key model outputs 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 very dense nature of the main vegetative body of the mature 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.

- Where the energy crop plantation fully covers the floodplain the highest overall impacts on the flood dynamics (flood depth, velocity of flow, main channel flow hydrographs) are observed.
- 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.
- Plantation headlands and rides (with a short vegetative cover) provide faster preferential (short circuit) flow pathways than the main vegetative block.
- Distributed blocks or a central plantation block did not change the maximum flood extent significantly.

The outcomes of this project were used to develop a supplementary guidance note to the existing Environment Agency guidelines on this general subject area entitled - Flood Risk Management: Woodland, tree planting and flood risk. This guidance helps to inform the future decisions with respect to the establishment of woodland and other similar vegetative types, such as new energy crop plantations, on floodplains. It also provides advice on the selection of Manning's n roughness coefficients to use when energy crop plantations in hydraulic models.

Acknowledgements

The authors would like to acknowledge the contribution of the Project Steering Group made up of representatives from the Environment Agency, Natural England, Department of Energy and Climate Change, National Farmers Union, and the Countryside Land & Business Association. Thanks are also given to a number of organisations who provided helpful technical advice and comments on the characteristics and management of energy crops, and the representation of energy crops in hydraulic models, namely: Cardiff University (School of Engineering), Wales Biomass Centre, Rothamsted Research, ADAS and a number of JBA modelling specialists.

Contents

Tables

Figures

1 Introduction

1.1 Background

Under the UK's Renewable Energy Strategy the UK will aim to achieve 15% of its energy needs from renewable sources by 2020, with 30% of the renewable energy target coming from biomass, including energy crops (HM Government, 2009). Landowners and farmers are being actively encouraged through the Natural England managed Energy Crops Scheme (Natural England, 2009) to increase the amount of energy crops grown in England in appropriate locations. These crops will be used as a substitute for fossil fuels, so they can contribute to a reduction in greenhouse gas emissions and help to combat climate change. The Government believes that energy crops can also play an important role in contributing to sustainable development. The scheme is part of the Rural Development Programme for England (RDPE) and is funded by the European Union, through the European Agricultural Fund for Rural Development. It offers grants to farmers in England for the establishment of Miscanthus (to be harvested annually) and Short Rotation Coppice (SRC) (to be harvested every 3 years). An establishment grant is a payment designed to cover a percentage of the set up costs of establishing approved energy crops. This includes activities such as ground preparation, fencing, purchase of planting stock, planting, weed control and first year cutback. The eligible SRC crops are currently: Willow, Poplar, Ash, Alder, Hazel, Silver Birch, Sycamore, Sweet Chestnut and Lime. The European Union have now confirmed that the rate of grant offered to farmers to grow biomass crops (Miscanthus and SRC) under the Energy Crop Scheme (ECS) has been increased to 50% (from 40%), for all costs incurred after the 1st January 2010. The ECS has several years to run and the expectation is for a greater uptake by landowners and farmers as it progresses.

The Environment Agency provides advice to Natural England on the operation of the ECS with respect to Flood Risk. However, there is still a general lack of 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 upstream or downstream flood risk, particularly within the Environment Agency Flood Zone 3 areas. Within the fluvial flooding context Flood Zone 3 represents the area that could be affected, in the absence of defences, by flooding from a river by a flood that has a 1% (1 in 100) or greater chance of happening each year.

If the presence of appropriately designed energy crop plantations on the floodplain could potentially provide a coupled benefit of a renewable energy resource and a flood mitigation or attenuation 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).

1.2 This Project

While the Environment Agency recognises that developing a complete understanding of the potential impacts of energy crops on its Flood Risk Management responsibilities may take several years to achieve, there is an urgent need for some initial evidence to provide a steer for the relevant policy makers and scheme assessors in this area.

JBA Consulting was commissioned by the Environment Agency to carry out a short-term modelling project with the overall aim to investigate the potential impact of growing energy crops on river and floodplain flows and to quantify any changes these new plantings might make to upstream and downstream flood risk. The choice of energy crops under investigation was restricted to Miscanthus and SRC Willow.

1.3 Project Aims and Objectives

The overall project aims and objectives of the modelling work include:

- An investigation of how the impact of energy crop plantations on floodplains might affect the flood dynamics what implication this might have on flood risk. The background to this investigation should include a review of modelling approaches and the selection of the approach most appropriate for this study, a review of how the energy crops can be represented in the chosen models (i.e. resistance to flow), and the consideration of any related technical issues.
- The representation of energy crop plantations in the form of specific plantation scenarios and their reconciliation with the Project Steering Group. The results of the modelled scenarios should be compared against an agreed baseline flood condition in order to enable comparative quantitative and qualitative assessment of the potential impact of the energy crops on flood dynamics to be undertaken.
- A synthesis of the findings and their assessment in terms of providing supplementary material to the existing Environment Agency guidelines on this type of floodplain development entitled - Flood Risk Management: Woodland, tree planting and flood risk.

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.

1.4 Project and Report Structure

The research and modelling work for this project had to be limited to the 4 months of the commission. Therefore, it was crucial that the methodology, interim findings and any issues arising during the work were discussed as early as possible within the project team and parties relevant to both the technical and management aspects of the project. This ensured that the aims could be met within the restricted timescale. For this purpose, a Project Steering Group was set up at early stage and decisions regarding the model scenarios and the interpretation of the findings were consulted within the group, as well as reviewed in terms of the technical approach.

Chapter 2 of this report presents the background research, which was carried out in order to provide advice for the methodology chosen in this project. It includes a short summary of the characteristics of the energy crops in question, a review of the literature and research regarding the representation of floodplain vegetation in hydrodynamic models, a review of recent modelling approaches and a set of conclusions regarding the modelling methodology applied in this project.

Chapter 3 introduces the case study floodplains modelled in this study, alongside with more detailed information about the hydraulic models for each site.

Chapter 4 summarises the results analysed for each case study and presents an example of the complete set of results for one site only, the River Isle case study.

Importantly, the synthesis of the findings from all the case studies is presented in this chapter in the form of a summary results matrix, which provides qualitative, as well as quantitative interpretation of the findings.

Chapter 5 summarises the discussions and conclusions of this study, together with the assumptions and limitations that had to be adopted in order to meet the aims and objectives outlined above.

Chapter 6 presents recommendations for further modelling and monitoring work in this research area.

2 Modelling energy crop characteristics

2.1 Data review and consultation

A range of existing datasets, published academic papers, guidance notes and information sources on the planting, management and harvesting of Miscanthus and SRC Willow have been reviewed in order to better understand the likely behaviour of the energy crops when flooded. The timing and seasonality of the management operations, together with the typical planting configurations, was also reviewed.

A review was also undertaken of existing 1D and 2D modelling approaches to simulate the effects of these energy crops on floodplain flows. In particular, the review included the effect energy crops might have on floodplain roughness, generation of woody debris as barrier to flow and the physical response of the standing crop to an increase in floodplain depth, velocity and flow.

These reviews were further informed by consultation with the Project Steering Group and with a number of organisations with experience of either the planting and management of these crops (e.g. ADAS, Wales Biomass Centre), or the modelling of the hydraulic effect of these crops (e.g. Forest Research, Cardiff University, Rothamsted Research). Reconciliation of the findings helped establish the modelling approach for this short study.

2.2 Planting and Management of Energy Crops

2.2.1 Miscanthus

Miscanthus is a perennial, rhizomatous grass which can grow to heights of more than 3.5m, forming a plantation of dense bamboo-like canes (Defra, 2007). Miscanthus is planted in spring and once the plantation is established, it can stay in the ground for at least 15-20 years. Mature Miscanthus is harvested annually in the winter season, typically in February. New shoots appear in March each year and grow rapidly in June-July. Miscanthus then dies back in autumn and during winter, sheds its leaves and only the canes stay to be harvested. Figure 2-1 shows a mature Miscanthus plantation and its physical state at harvest.

In the UK, the establishment period for the first crop is 3 years. After this initial period, the crop is fully established for long term harvesting cycles. In the first year of planting, the crop reaches 1m – 2m height in August. The stems are usually unbranched and contain solid pith. This, together with the very dense character of the plantation, is likely to make them reasonably robust and sturdy when flooded with shallow water. From late July, the lower leaves start to dry, and by late autumn leaves fall off thereby developing a deep leaf litter. By February, the crop is composed of almost leafless canes. From the second season the crop can grow to its maximum height of 2.5m – 3.5m.

Figure 2-1 Mature Miscanthus and harvesting

2.2.2 SRC Willow

Willow, a Short Rotation Coppice crop, is a perennial crop that can produce acceptable yields for about 30 years after the initial planting. It is typically planted in spring in either single 1.5m rows or in double rows 60cm-70cm apart, potentially forming conveyance areas for flood propagation on the floodplain. Within the first year of its growth, SRC Willow can reach up to about 4m in height.

During the winter season after planting, the stems are cut back to ground level, which encourages further growth of multiple stems, causing the plantation to become quite dense. Willow can be established on a wide range of soil types, including clay, sandy soils or even reclaimed soil from gravel, making it a suitable plant for floodplain areas.

During the late autumn - winter period (typically October to December) after establishment, the crop is coppiced to a height of about 10cm above ground. The willow then grows back during the next two years. It can then be harvested again, and the plant grows back to the harvesting stage during the following 3 years. The 3 year cycle is then repeated throughout the lifetime of the plantation. SRC Willow can grow to about 8m in height.

Figure 2-2 shows SRC Willow in mature state and during harvesting operations.

Figure 2-2 Mature SRC Willow plantation and harvesting

2.3 Hydraulic Modelling

2.3.1 Representation of energy crops on floodplains

Floodplain vegetation such as rough grass, brush or wet woodland including stems, branches and leaves on the ground, can increase the surface roughness and hence the hydraulic resistance of the floodplain to water flow. Conversely, smooth vegetation such as short grass or most arable crops, provide little resistance to flow and therefore are likely to contribute to the conveyance of floodplain flows downstream. Therefore, vegetation cover on floodplain can have greater or lesser impact on propagation of flooding downstream, depending on the degree of hydraulic resistance of the cover to flow.

The physical characteristics of floodplain vegetation, in terms of their impact on floodplain flows, are determined not only by type of plant stems, tree trunks or leaf material, their quantity and distribution on the floodplain, but also by other aspects such as the proportion of the vegetation submerged when flooded, the potential of blockage of flow path, impact of turbulence and flow structure. The effects of all these factors 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 agricultural floodplains with coverage of cereals, grassland, and woodland. Wet woodlands or wet meadows have recently been seen as potential flood mitigation and flood attenuation measures on floodplains and these have been subject to a small number of hydraulic modelling studies such as those undertaken by Forest Research (Nisbet and Thomas, 2008). In the USA, a number of studies have investigated roughness characteristics of densely vegetated floodplains (e.g. Acrement *et al.*, 1989). However, there is very little or no information specifically on appropriate values of roughness of energy crops such as Miscanthus or SRC Willow.

The roughness effects of some vegetation types are discussed for example in The Roughness Review (Defra, 2003), by Acrement *et al*. (1989), Chow (1959) and Thomas *et al*. (2004). Cardiff University and other institutions, such as Rothamsted Research, have also reported on resistance to flow, particularly in terms of SRC Willow.

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 (e.g. long grass) 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 Darcy friction factor, which is a parameter describing friction losses in open channel flow and can empirically be related to Manning's n roughness (Chow, 1959). The greater the friction factor, the greater Manning's n coefficient. The study showed that the friction factor was mostly dependent on flow depth in the case of leafless willows and on the flow velocity for willows with leaves. Crucially, Järvelä demonstrated that for velocities up to 0.5m/s, willow 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 roughness coefficient increases significantly as the flow depth approaches 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 (2009) have shown changes in flow resistance of SRC Willow with depth and flood velocities (Wilson, 2009).

Table 2-1 summarises the typical Manning's n roughness coefficients for vegetation types most relevant for this study. Although the values are quoted from specific research papers, they represent a synthesis of information in the literature.

Table 2-1 Typical floodplain roughness values

Manning's n	Description of floodplain
0.15	The vegetation of the floodplain is a mixture of large and small trees, including oak, gum and ironwood. The base is firm soil and has minor surface irregularities caused by rises and depressions. Obstructions are negligible (some expose roots). Ground cover is negligible and undergrowth is minimal.
0.18	The vegetation of the flood plain is large trees, including oak, gum, pine and ironwood. The base is firm soil and has minor surface irregularities caused by rises and depressions. Obstructions are negligible. Ground cover and undergrowth are negligible.
0.20	The vegetation of the floodplain is a mixture of small and large trees, including oak, gum and ironwood. The base is firm soil and has minor surface irregularities. Obstructions are minor. Ground cover is medium, and the large amount of undergrowth includes vines and palmettos.
0.20	The vegetation of the floodplain is a mixture of small and large trees, including oak, gum and ironwood. The base is firm soil and has minor surface irregularities. Obstructions are minor (some downed trees and limbs). Ground cover is medium and the large amount of undergrowth includes vines and palmettos.

Source: Acrement *et al.* (1989). NB: Although the above values relate to procedures limited to the selection of roughness coefficients for application of 1D open channel flow, they do specifically consider dense vegetation on floodplains.

Table 2-2 Typical floodplain roughness values (continued)

Manning's n			Description of floodplain
Average	*Lower*	*Upper*	
0.035	0.030	0.050	High grass (*)
0.040	0.030	0.050	Mature field crops (*)
0.150	0.110	0.200	Dense willows, summer, straight (*)
0.100	0.080	0.120	Stiff grass, height 1.8 (height of water depth 1.4m) (**)
0.047	0.040	0.055	Stiff grass, height 1.8m (height of water depth 2.5m) (**)
Source: (*) Chow (1959), (**) Defra (2003).			

Table 2-3 An extract of overview of floodplain roughness coefficient and its variability with flooded depth for various floodplain vegetation, and specifically for SRC Willow at the lowest and highest velocities as presented by Wilson (2009).

Manning's n			Description of floodplain and inundation	
Average	*Lower*	*Upper*	*Flood velocity (m/s)*	*Flood depth (m)*
			Floodplain vegetation – Corn (*)	
0.060	n/a	n/a	n/a	< 0.6
0.070	n/a	n/a	n/a	0.9
0.070	n/a	n/a	n/a	1.2
0.060	n/a	n/a	n/a	> 1.2
			Floodplain vegetation – Brush and waste (*)	
0.110	n/a	n/a	n/a	< 0.6
0.100	n/a	n/a	n/a	0.9
0.090	n/a	n/a	n/a	1.2
			Floodplain vegetation - SRC Willow (**)	
0.181	0.106	0.274	1	< 0.5
0.204	0.120	0.307	1	1.0
0.229	0.134	0.345	1	2.0
0.105	0.062	0.158	3	< 0.5
0.118	0.069	0.177	3	1.0
0.132	0.077	0.199	3	2.0
Source: Chow (1959) (*), Wilson (2009), *pers. comm. (**)*				

As can be seen in Table 2-3, according to Chow (1959), Manning's n usually varies with the stage of submergence of the vegetation at low stages. Chow points out, however, that the vegetation has a marked effect only up to a certain stage and the roughness coefficient can, usually, be considered constant for determining overbank flow discharges. Wilson, as indicated in the table, found different results for SRC Willow. The resistance to flow increases with increased flow depth, but less so with increased velocity.

For the purpose of this study, the following main assumptions regarding the energy crop plantations were adopted:

- The energy crops are modelled as fully grown, well established mature plants (e.g. 3m tall dense Miscanthus or even taller SRC Willow) in order to avoid additional complexity should different growing stages also be concerned.
- The bamboo-like stems of Miscanthus when flooded were assumed to have a uniform character in terms of its behaviour throughout the flood inundation. The hydraulic character of SRC Willow was assumed to be more likely to vary with flooded depth due to the changing physical character of the stems (Wilson, 2009).
- The crop is assumed not to be fully submerged during the flood events (as it is highly unlikely that flooding as deep as over 3m would occur on a floodplain where the energy crops would be planted). In such conditions, the resistance of the vegetation to flow is likely to remain constant for deep flows (Defra, 2003). This could be particularly likely for the case of Miscanthus, because the vegetative characteristics of these plants, when mature, are reasonably uniform throughout their height.
- Headlands and rides, which are typically present bordering or within the plantations respectively, are assumed to be managed as short grass.

The baseline condition, against which the impact of the energy crop plantations are compared, is represented by an arable cereal crop – winter wheat grown across the floodplain.

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. **Error! Reference source not found.** shows the final Manning's n coefficient adopted in this project.

Table 2-4 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 mature 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 mature SRC Willow on floodplain flows.
Headlands/Rides	0.04	Manning's n typically used for managed short 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.

2.3.2 Hydraulic Models

A range of different hydraulic modelling approaches are currently used in practice. The choice of the approach to modelling a river system with its floodplain as a complex, linked entity with accurate simulation of water transfer between the two systems, is crucial. It can be approached in a number of ways, namely:

(1) Using a 1D model to represent the river system and a linked 2D model to represent the floodplain system (as used in this study). These two systems communicate via a 1D-2D boundary which has to be set up separately within the 2D model. When the linked 1D-2D model is run, the water levels in the 1D component are compared with the ground levels in the 2D model and water can spill into the floodplain when the former are higher than the latter at the borderline area defined by the 1D-2D boundary (e.g. a riverside embankment). Alternatively, the model can be set up to exchange flow directly using lateral spill set up in the 1D river model. The underlying principle here is that the fluxes are exchanged horizontally.

(2) An alternative to the above, and increasingly more in practice, is an exchange of fluxes vertically. This can be achieved by nesting the 1D model component "underneath" the 2D floodplain model. The advantage of this approach is that there is no need to define the 1D-2D boundary through which the two models exchange water, while still conserving the momentum. Therefore, the uncertainties related to design of the 1D-2D boundary (largely dependent on judgement of the modeller) are eliminated. This also means that one of the main sources of instability in the 2D model, the transition between the 1D and 2D models, is almost eliminated and the transition is smooth.

(3) Both the river system and the floodplain system can be modelled by a single 2D model, i.e. with no need for the 1D model component. This modelling approach offers better description of physical processes in the near channel area than the two methods above. However, this approach is much more demanding on data input and model run time (due to more complex representation of the in-channel flows than when using a 1D model), but less demanding in terms of model set up. In order to represent the river

channel accurately, a detailed sonar bathymetry survey (obtained, for example, by the EA) of the channel would be needed.

(4) The river and floodplain may be modelled as a series of 1D cross sections, but with a more physically-detailed approach to the lateral distribution of velocity. The Conveyance Estimation System (Knight *et al*., 2010; McGahey, 2006) embodies this approach and may be thought of as a "1.5D model with 3D features" that captures some important physical processes in the turbulence and internal circulation patterns that occur within the flow. However, this approach could be inappropriate where there are complex lateral flows over the floodplain, as may be the case for flows along the rides in between plantation blocks.

(5) A fully 3D modelling approach could also be applied here; however this would be very expensive and demanding on model set up, input data needs and computational time.

The choice of models for application in this study needed to satisfy the following criteria:

- Appropriate representation of the floodplain and floodplain features, and the capacity to capture the change of the floodplain hydraulic properties caused by the energy crops in sufficient degree of detail (e.g. surface roughness, conveyance).
- Availability of suitable existing models for this project.
- Reasonable complexity and calculation time for the models to complete the modelling scenarios within the timescale of this project.

With these criteria in mind, the 2D approach to representation of a floodplain in hydrodynamic models is deemed most suitable and the linked 1D - 2D ISIS TUFLOW is an appropriate software package for the purpose of this study.

The model versions used in this study were TUFLOW 2009 07 AE and ISIS v3.3.0.88. Appendix A provides detailed information on the linked 1D-2D ISIS TUFLOW modelling.

2.4 Modelling Scenarios

In order to meet the aims of this project, a list of crop plantation configurations to be modelled was established in consultation with the Project Steering Group. These included a maximum impact scenario (dense, fully mature energy crop plantation with 100% coverage on the floodplain).

The scenarios chosen considered namely planting location, size of planting (typically 1ha-3ha), and planting configuration. A winter wheat cereal crop is represented in the baseline (control) model against which the results of the modelled scenarios are compared.

Table 2-5 summarises the modelling scenario characteristics adopted (combined into specific modelling scenarios as listed in Section 3). A balance between a practical number of model scenarios that could realistically be analysed within the scope of this project, and the need to capture appropriate plantation characteristics was achieved.

It is necessary to note that the intention was not to repeat each scenario type for both Miscanthus and SRC Willow. Rather, the main modelling focus was on Miscanthus first and the model scenarios with potentially the greatest and the least impact were analysed first as a sensitivity test, which helped determine the magnitude of change to be expected. This test, further modelling and consultation with the Project Steering Group then determined the scenarios taken forward as modelling scenarios for SRC Willow, or any additional scenarios required. The total number of the final scenarios modelled was 40 (including those for the baseline condition), ranging from 9 to 16 scenarios per case study.

An example of the layout of a selection of the modelling scenarios can be seen in

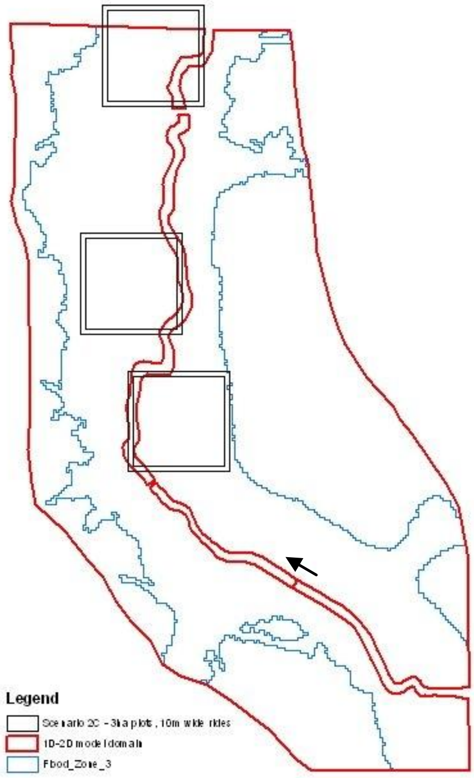
Figure 2-3 An example of modelling scenario layouts (2D model domain in red, extent of Flood Zone 3 in blue and plantation plots with rides around in black, arrow signifies the direction of flow)

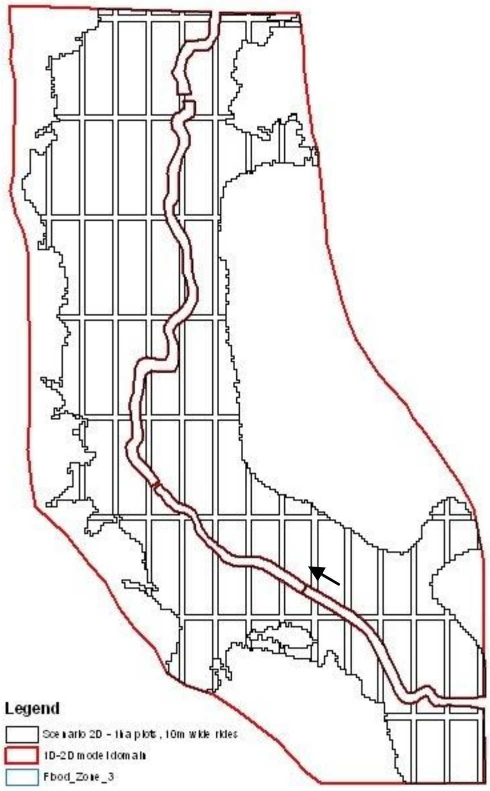
. As can be seen in the figures, classification of rides “parallel” and “perpendicular” to floodplain flow can be somewhat confusing depending on the meandering nature of the river channel and the shape of the wider floodplain. Also, it was not possible within the scope of this project to include scenarios with more realistic plantation shapes that would, for example, follow existing field boundaries or ownership boundaries. Design of such a plantation configuration would have to be created manually and would have been extremely time consuming. Instead, a bespoke procedure was developed in the GIS environment, which allowed automated generation of the desired plantation layouts.

Table 2-5 Summary of modelling scenario characteristics for Miscanthus and SRC Willow

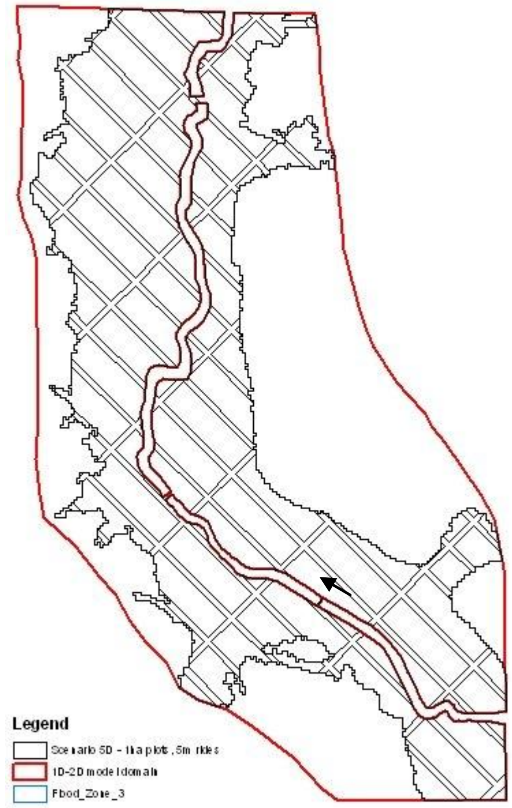
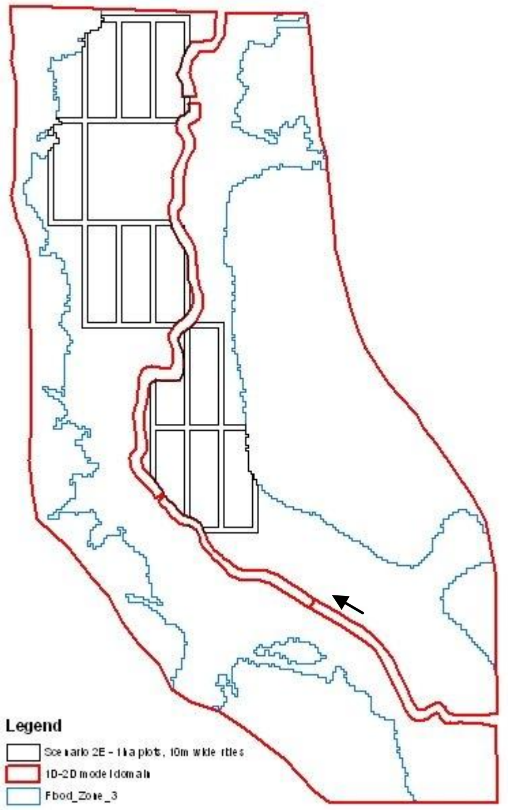
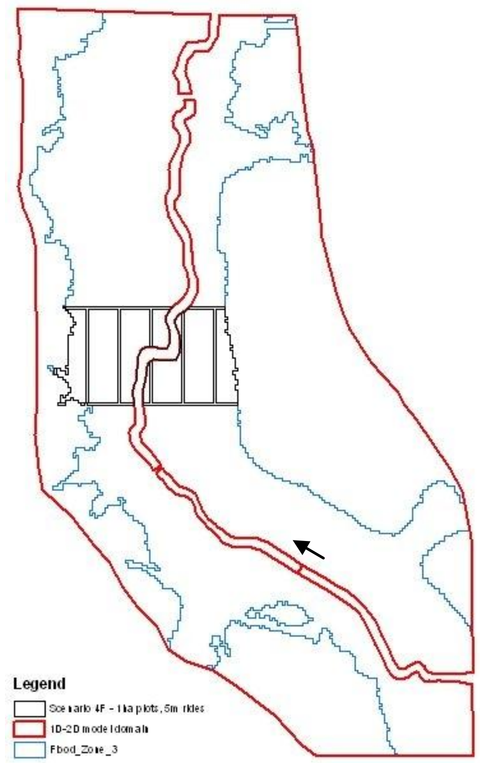
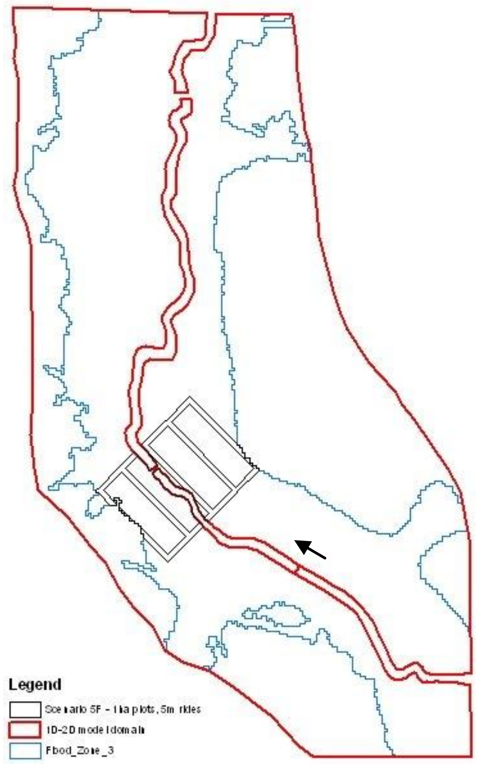
	Modelled flood magnitude 1% AEP (100-year return period)
Plantation characteristics	**Description**
Size	3ha blocks
	1ha blocks
Configuration	10m rides/headlands parallel to river
	10m rides/headlands perpendicular to river
	5m rides/headlands parallel to river
	5m rides/headlands perpendicular to river
Location	One side of river
	Both sides of river
Coverage	100%
	Up to 30%

Figure 2-3 An example of modelling scenario layouts (2D model domain in red, extent of Flood Zone 3 in blue and plantation plots with rides around in black, arrow signifies the direction of flow)

<table>
<tr><td>Scenario 2C – 3ha Miscanthus plantation blocks with 10m rides around, floodplain coverage 30%, and distributed plots.</td><td>Scenario 2D – 1ha Miscanthus plantation blocks with 10m perpendicular rides, floodplain coverage 100%.</td></tr>
<tr><td>


</td><td>


</td></tr>
</table>

Scenario 5D – 1ha Miscanthus plantation blocks with 10m parallel rides, floodplain coverage 100%.	Scenario 2E – 1ha Miscanthus plantation blocks with 10m perpendicular rides, floodplain coverage 30%; distributed plots.
	
Scenario 4F – 1ha Miscanthus plantation blocks with 5m perpendicular rides, floodplain coverage < 30%.	Scenario 5F – 1ha Miscanthus plantation blocks with 10m parallel rides, floodplain coverage < 30%.
	

3 Case Study Floodplains

Given the nature, scope and time constraints of this study, it was not possible to build, calibrate and validate appropriately detailed new hydraulic models, and therefore existing models suitable for adaptation were sought. In consultation with the Project Steering Group floodplains where these crops might realistically be grown within the ECS scheme were identified. Of these, those floodplains having major physical constraints that might make the interpretation of the results difficult (such as narrow bridges and high river embankments) were discarded. Further criteria included: complete / good quality LIDAR topographic coverage of the floodplain, reasonably short model run times and, ideally, design inflow hydrographs.

From an assessment of a number of possible models that were identified, two real case study floodplains were chosen for this project. These were the River Severn at Uckinghall (near Tewkesbury in the West Midlands) and the River Isle at Ashford Mill (near Ilminster in the South West). A third simple theoretical (or "idealised") model was set up in order to help determine which scenarios gave rise to the biggest impacts, without introducing local floodplain subtleties that are different in each case study. The case studies are briefly presented in this chapter, alongside with the complete set of modelling scenario configurations for each site.

The key characteristics of the three case study floodplains are summarised in Table 3-1.

Table 3-1 Key characteristics of the case study floodplains

Floodplain	100-year flood magnitude (m^3 s^{-1})	Extent of modelled river reach, i.e.1D river model (km)	Extent of modelled floodplain, i.e. 2D floodplain model (km^2)
Severn at Uckinghall	763.5	7	4.4
Isle at Ashford Mill	61.3	1.8	0.8
Theoretical model	409.8	2.2	5.3

3.1 River Severn at Uckinghall

An existing linked 1D – 2D ISIS – TUFLOW model was available for a 7km stretch of the River Severn at Uckinghall. The river reach runs in north-south direction through a valley with steep slopes on the right (western) side of the river and with about a 1km wide floodplain on the left (eastern) side. The left floodplain was represented in the 2D domain of the linked model. Deep flooding to about 3.5m was observed in places within the baseline model results on this floodplain, which is a high depth of flooding that could, in reality, discourage farmers from establishing plantations in such a location.

The existing land use on the floodplain is predominantly arable (horticulture) or grassland, which makes it a suitable potential candidate for energy crop plantations. An overview map of the study site and the modelled floodplain boundary are presented in Figure 3-1.

3.1.1 The 1D-2D model

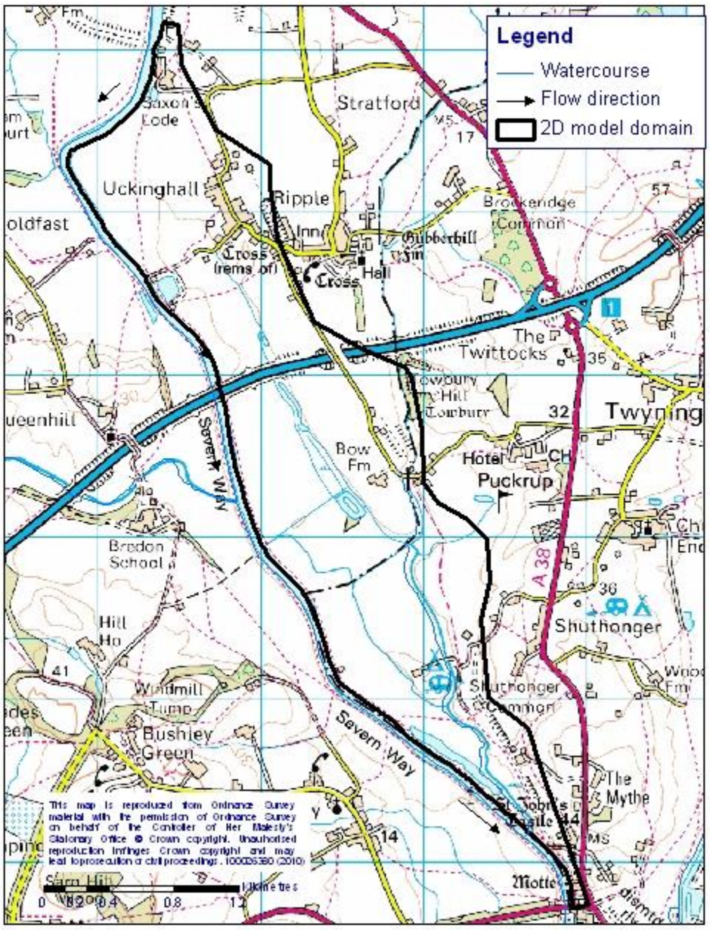
The area of the floodplain modelled in the 2D model is 4.4km^2, of which 3.3km^2 falls within the Environment Agency's Flood Zone 3 (i.e. the area potentially at risk of flooding by a 100-year flood event). There are several water bodies on the floodplain including old drainage channels and a few ponds. The M50 motorway embankment cuts across the floodplain and acts as a partial barrier to the flow on the floodplain, though the bridge opening is very wide.

The complete model including an inflow hydrograph with a peak at 763.5m^3/s (100-year return period) and a complete set of baseline results were available for this study. A 10m wide buffer strip of grass was also simulated along the river banks in order to ensure that the plantation remained set away from the river channel. This 10m strip was already included in the baseline model.

The 2D model domain resolution as received for this study was 10m, which made it possible to satisfactorily simulate the 10m wide rides around the plantation plots. A sensitivity test was, however, carried out in order to determine whether the 10m cell size was too coarse and water could have artificially been prevented from flowing along the rides. The sensitivity showed that the 10m resolution gave satisfactory results, and therefore the model as supplied was used.

Unfortunately, a model run time of 11.5hours restricted the exploration of a greater range of scenarios and further development of the methodology here. The modelled scenarios were therefore restricted to the basic plantation configurations as described in Section 3.1.2 below.

Figure 3-1 The River Severn at Uckinghall – site location

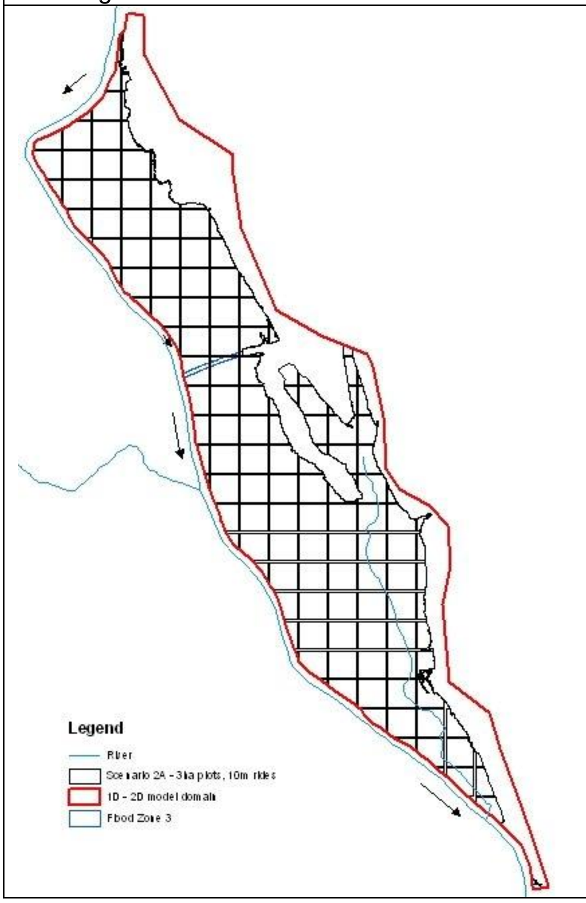
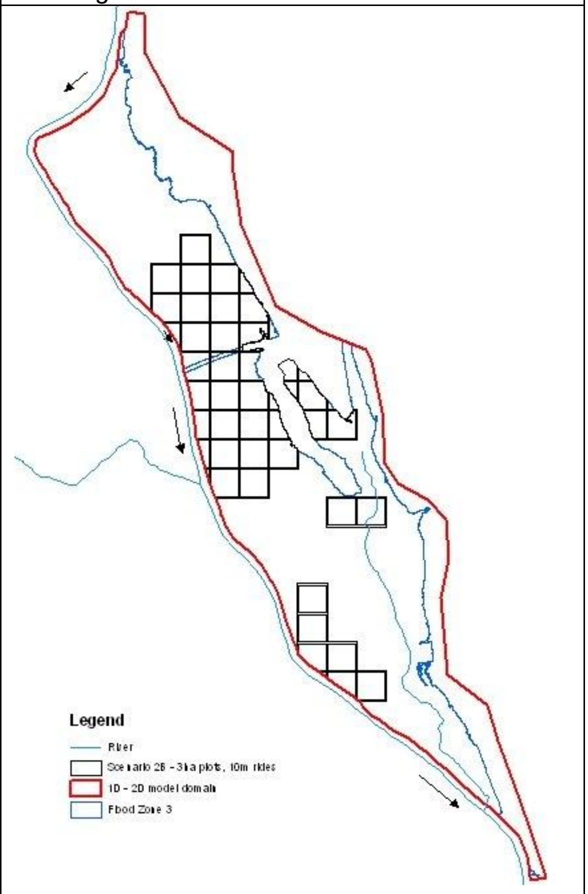


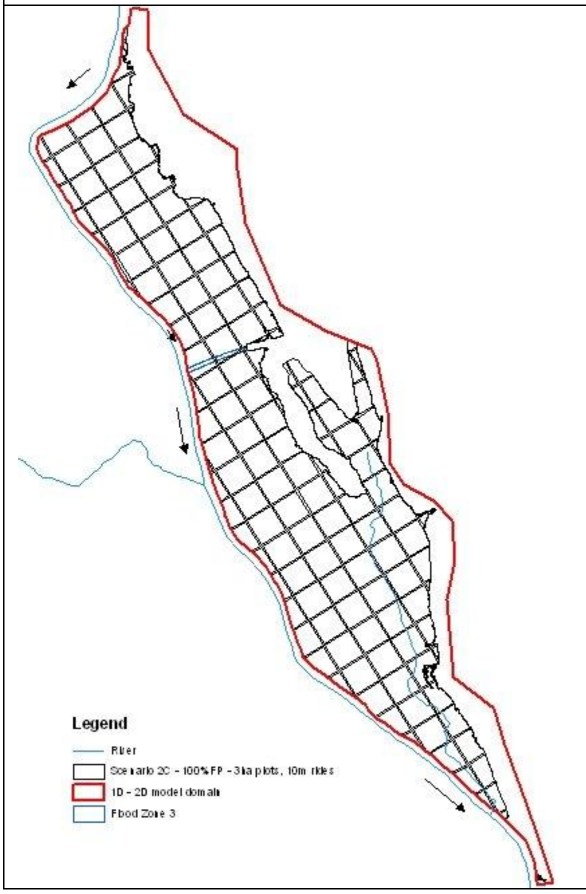
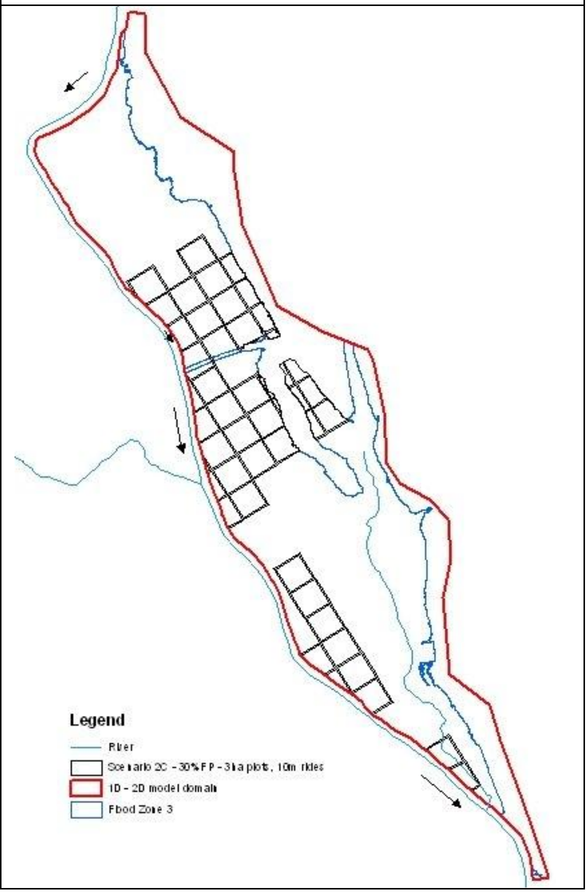
3.1.2 Severn at Uckinghall – Modelled scenarios

The 1D-2D model was run to simulate 8 different scenarios – 4 for Miscanthus and 4 for SRC Willow.

Figure 3-2 presents the layout of each modelled scenario (the 2D model domain in red, Flood Zone 3 in blue and the energy crop plantation plots with 10m headlands/rides in black).

Figure 3-2 Modelled scenario configurations for Severn at Uckinghall (the modelled floodplain area is shown in red, rivers and Flood Zone 3 outline in blue, plantation configuration with rides/headlands in black and the arrows signify the direction of river flow)

Scenario 2A/3A – 3ha Miscanthus/SRC Willow plots, 10m perpendicular rides, floodplain coverage 100%	Scenario 2B/3B – 3ha Miscanthus/SRC Willow plots, 10m perpendicular rides, floodplain coverage 30%
	

Scenario 2C/3C – 3ha Miscanthus/SRC Willow plots, 10m parallel rides, floodplain coverage 100%	Scenario 2C/3C – 3ha Miscanthus/SRC Willow plots, 10m parallel rides, floodplain coverage 30%
	

3.2 River Isle at Ashford Mill

The second case study model is a small 1D-2D ISIS – TUFLOW model of the River Isle in South West Region. In this case the modelled river reach is only 1.8km long, flowing in south-north direction. The floodplain is relatively wide particularly on the right (eastern) bank side, and narrower on the left (western) side at Ashford Mill Farm. There are two bridges, one in the middle section of the model area and one further downstream, and one gauging station operated by the EA (Ashford Mill, NRFA ref. 52004). The land use is predominantly arable with localised areas of grassland. Figure 3-3 shows the location of the River Isle and the 1D – 2D model extent.

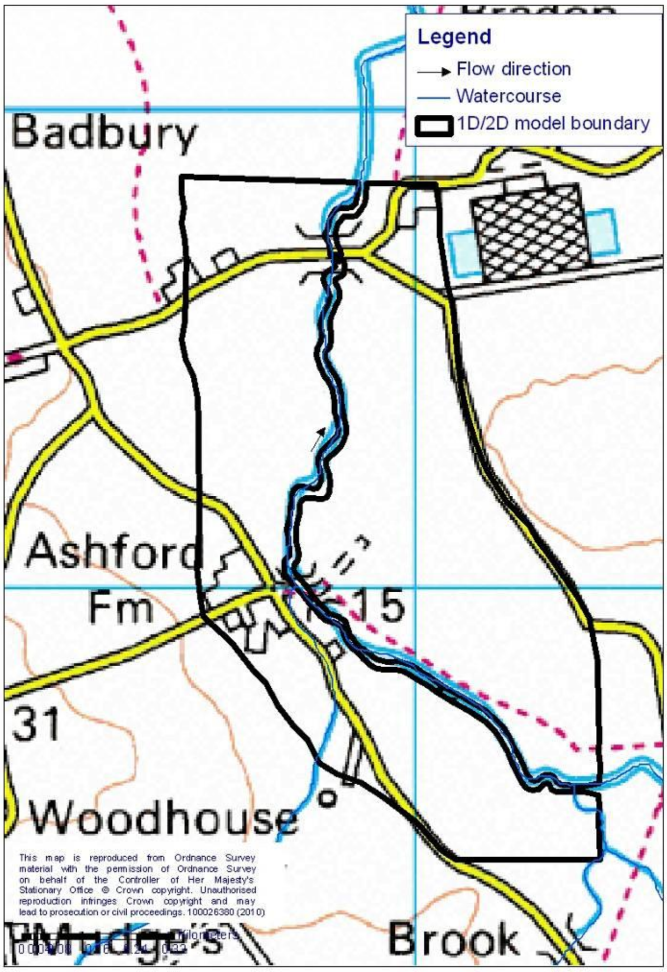
3.2.1 The 1D-2D model

The modelled floodplain has an area of 0.8km^2, of which 0.5km^2 falls within Flood Zone 3. The 100-year return period peak flow is 61.3m^3/s.

As the original baseline model employed a 4m resolution on the floodplain, which together with the much smaller size of the floodplain offered greater flexibility in the range of scenarios to test, e.g. rides/headlands narrower than 10m. Also, the shape of the floodplain allowed a greater range of scenarios to be tested than at Uckinghall, such the plantations on one side of the floodplain only and plantation plots alternating on opposite sides of the floodplain. A 10m buffer strip of grass along the river banks was also included in the model (represented as a strip of roughness typically used for rough bank vegetation) in order to prevent immediate interaction of the plantation with the river banks, which would not happen in reality. The buffer strip also helps stabilise the interaction between the 1D and 2D components of the model.

The coupled 1D – 2D model run time was only 1.5hours, which enabled a wide range of scenarios to be tested in a very time efficient way.

Figure 3-3 The Isle at Ashford Mill – site location



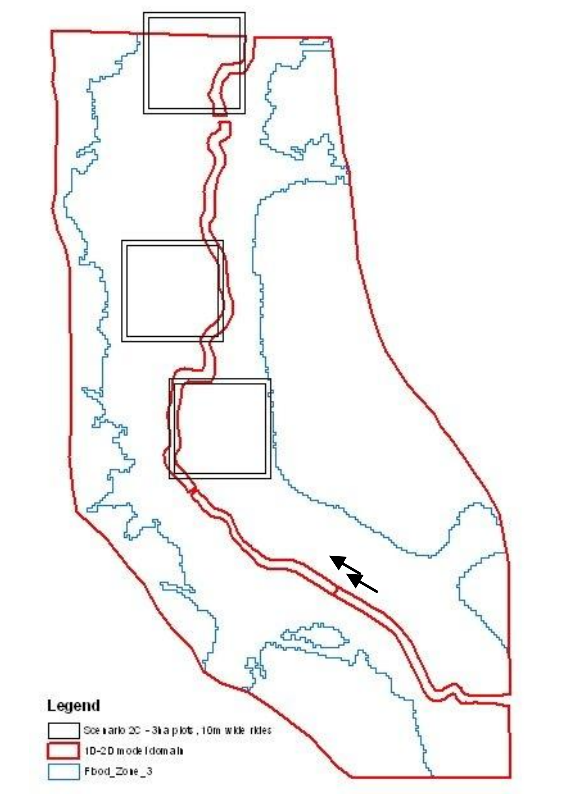
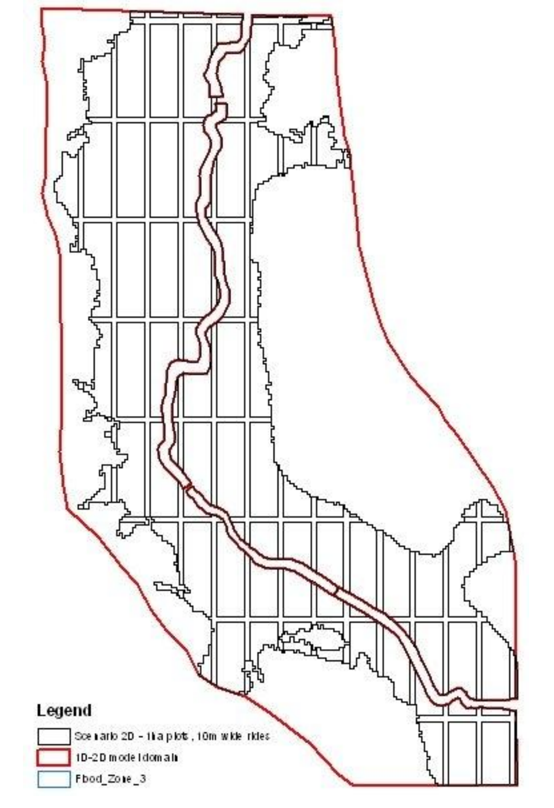
3.2.2 Isle at Ashford Mill – Modelled scenarios

In total, 14 scenarios were simulated both for Miscanthus and SRC Willow plantations. An initial emphasis was given to Miscanthus. Further development of the plantation configuration types was then based on the initial results. Due to the small size of the floodplain, a 1ha plantation was applied (with the exception of Scenario 2C), which allowed a greater range of spatial combinations of the plantation configuration to be tested than if only the maximum size 3ha plots were used like in the Uckinghall case study (Figure 3-4).

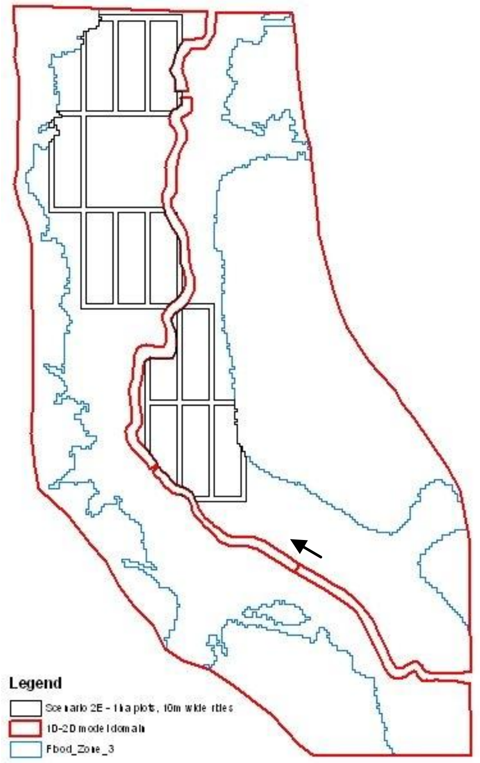
At first, the full floodplain coverage scenarios (i.e. Scenario D series) and the 30% floodplain coverage scenarios (i.e. Scenario E series) were tested in order to determine an 'envelope' for the scale of change to flood depths, flood extent, velocities on the floodplain and peak flow in the river at key locations. Further scenarios were then designed that examined, for example, the impact of plantation plots in a single block across the floodplain acting as a barrier to the flow (e.g. Scenarios 2F, 4F or 5F), plots with narrower rides (e.g. Scenarios 4D, 6D or 4F), plots with perpendicular versus parallel rides (e.g. Scenarios 5D, 5F or 6D) or a single block of Miscanthus plantation covering one side of the floodplain without rides (e.g. Scenario 2C).

The majority of the scenarios modelled Miscanthus. The SRC Willow was represented by three main scenarios (e.g. Scenarios 3D, 3E and 3F). Figure 3-4 presents the complete set of the various plantation configurations used in the modelled scenarios. As mentioned before, the classification of ‘perpendicular’ and ‘parallel’ relative to the floodplain flow could be disputable in some of the scenarios, as the floodplain flow direction changes alongside with the general river channel shape. The river channel runs from south-east to north-west direction in its upper section and changes direction in the middle of the modelled floodplain to northerly.

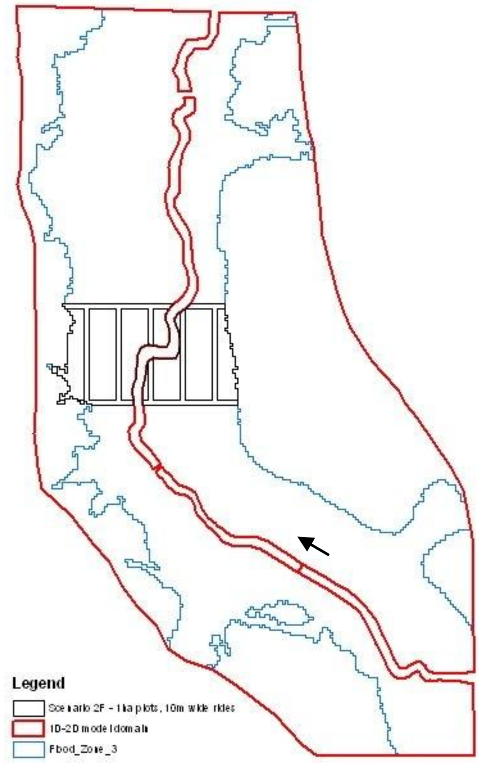
Figure 3-4 Modelled scenario configurations for Isle at Ashford Mill (the modelled floodplain area is shown in red, Flood Zone 3 outline in blue, plantation configuration with rides in black and the arrows signify the direction of river flow)

Scenario 2C – 3ha Miscanthus plots, 10m parallel rides around, floodplain coverage 30%	Scenario 2D/3D – 1ha Miscanthus/SRC Willow plots, 10m perpendicular rides, floodplain coverage 100%
	

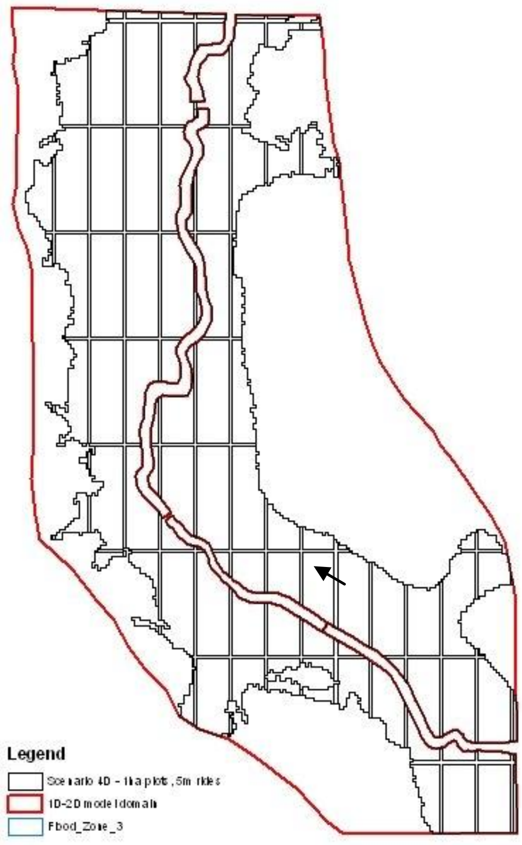
Scenario 2E/3E – 1ha Miscanthus/SRC Willow plots, 10m perpendicular rides, floodplain coverage 30%, distributed plots



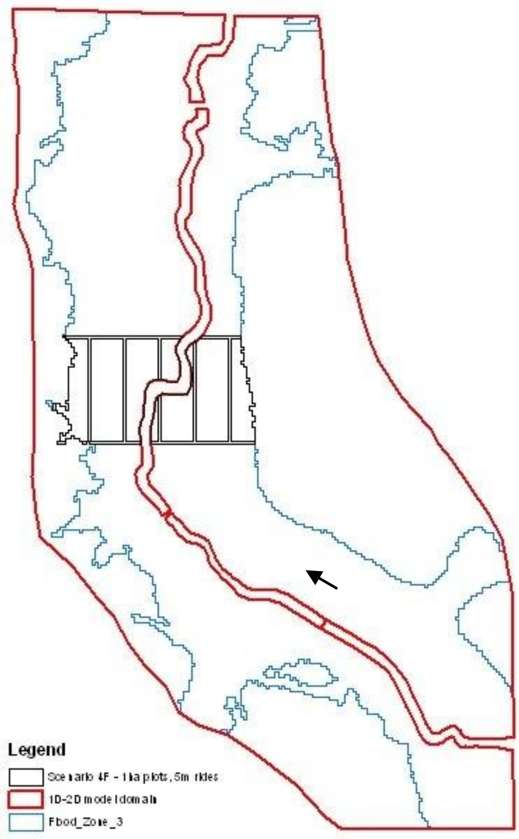
Scenario 2F/3F – 1ha Miscanthus/SRC Willow plots, 10m perpendicular rides, floodplain coverage < 30%



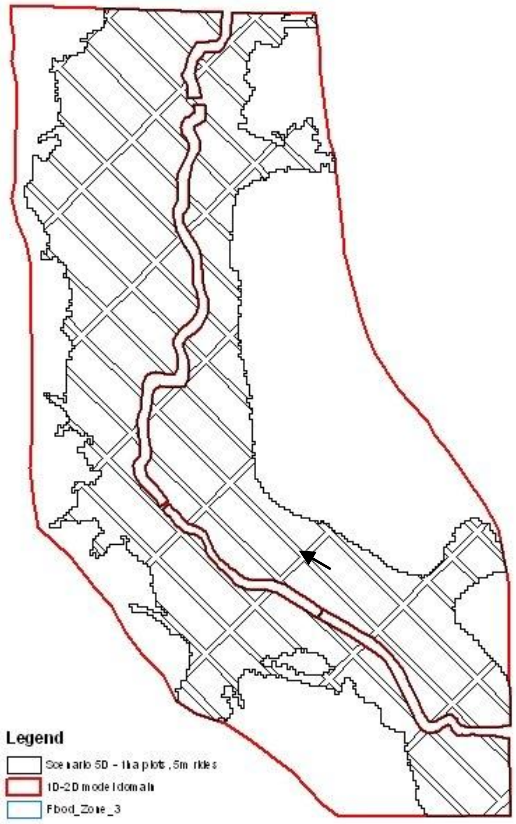
Scenario 4D – 1ha Miscanthus plots, 5m perpendicular rides, floodplain coverage 100%



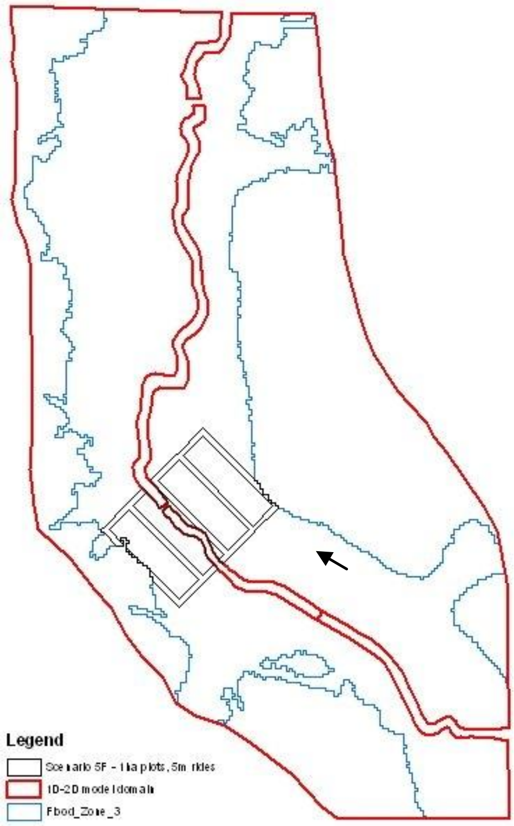
Scenario 4F – 1ha Miscanthus plots, 5m perpendicular rides, floodplain coverage < 30%



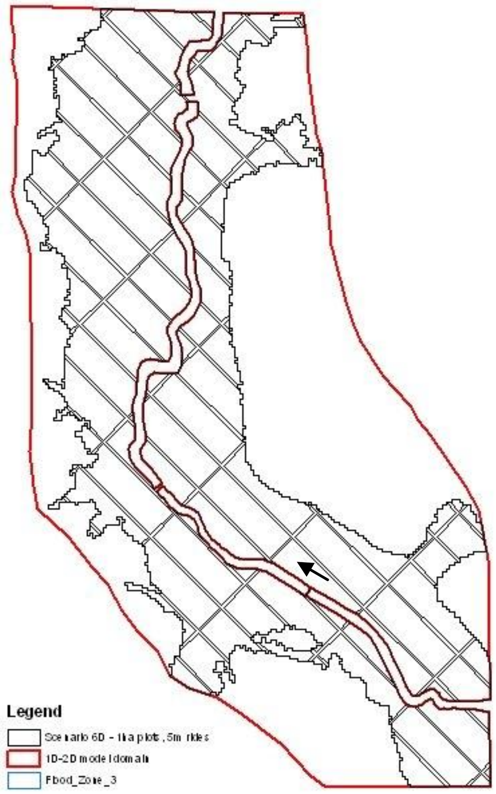
Scenario 5D – 1ha Miscanthus plots, 10m parallel rides, floodplain coverage 100%

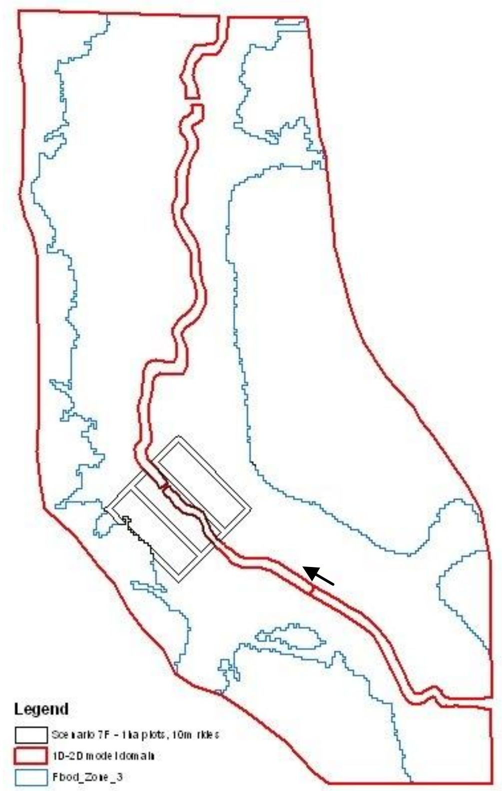
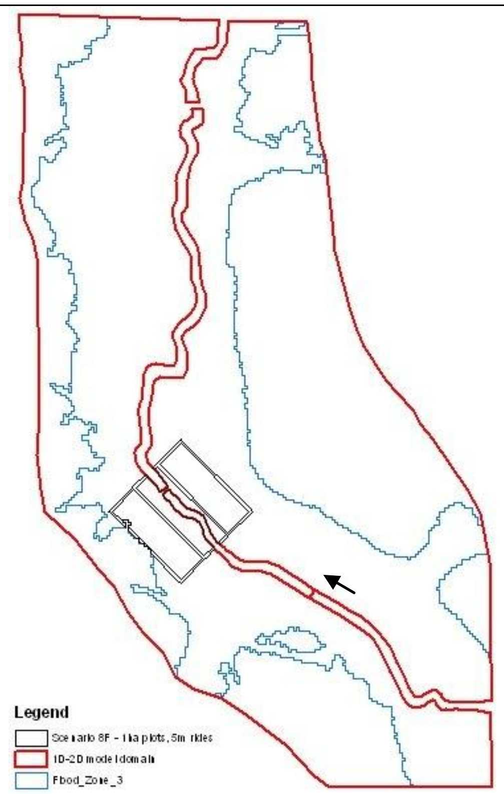


Scenario 5F – 1ha Miscanthus plots, 10m parallel rides, floodplain coverage < 30%



Scenario 6D – 1ha Miscanthus plots, 5m parallel rides, floodplain coverage 100%



Scenario 7F – 1ha Miscanthus plots, 10m parallel rides, floodplain coverage < 30%	Scenario 8F – 1ha Miscanthus plots, 5m parallel rides, floodplain coverage < 30%
	

3.3 Theoretical Model Floodplain

A simple theoretical 1D-2D ISIS – TUFLOW model was constructed for this project in order to enable the energy crop scenarios to be tested on an idealised, wide U-shaped floodplain, where the influence of particular local features in the floodplain topography, its shape or the presence of constrictions on the floodplain, is minimised. However, the model needed to be realistic in terms of the magnitude of flow, river channel shape and slope.

To aid this, various features of an existing 1D-2D model of the River Exe at Thorverton was used to help design the theoretical river model cross sections, the channel slope and sinuosity. The theoretical model also needed to represent a reasonably large floodplain on both sides of the river (ideally a size between the small floodplain of the River Isle at Ashford Mill and the larger floodplain of the River Severn at Uckinghall).

3.3.1 The 1D-2D model

The resulting model represented an idealised river stretch of 2.2km, flowing in north-south direction. The altitude of the river banks was taken from the River Exe floodplain and used to develop a new digital terrain model of a smooth, flat 1km wide U-shaped floodplain gently sloping downstream, following the longitudinal slope of the theoretical river.

The river was represented by 12 uniform 1D ISIS cross section units spaced 200m apart. The generic dimensions of the river cross sections and the 100-year inflow hydrograph were taken from the River Exe model. No structures such as bridges or weirs were included in the model set up. An example of the typical theoretical river cross section and the floodplain cross section can be seen in Figure 3-5Figure 3-6.

Figure 3-5 Theoretical model river cross section

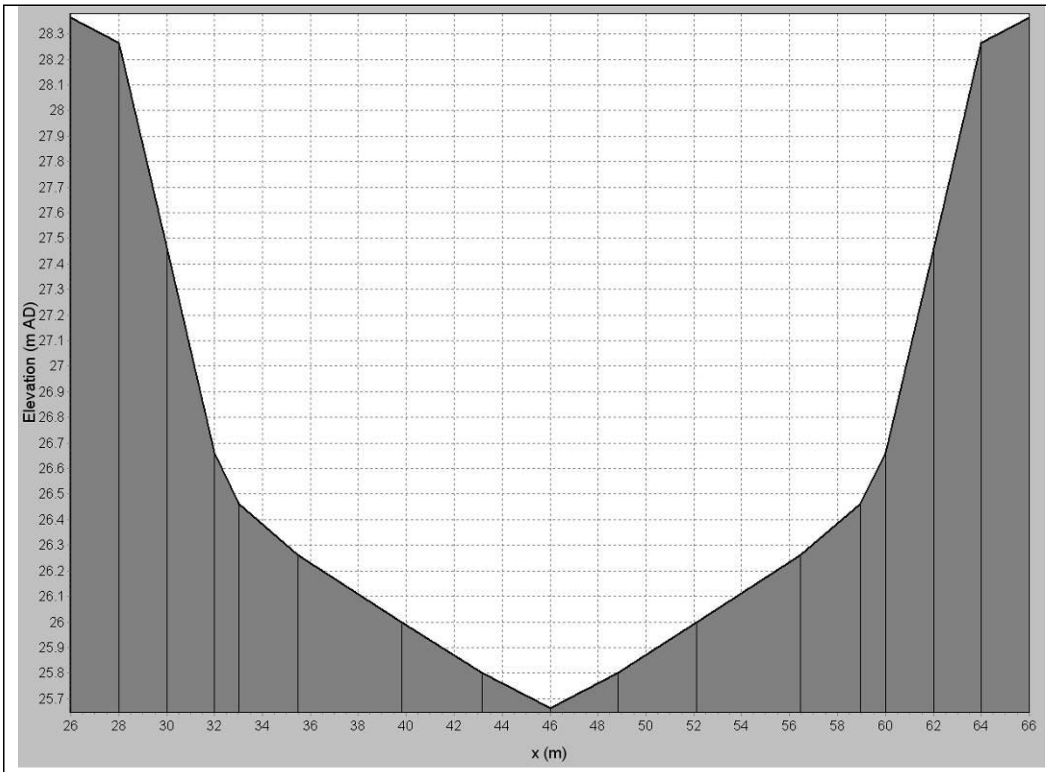
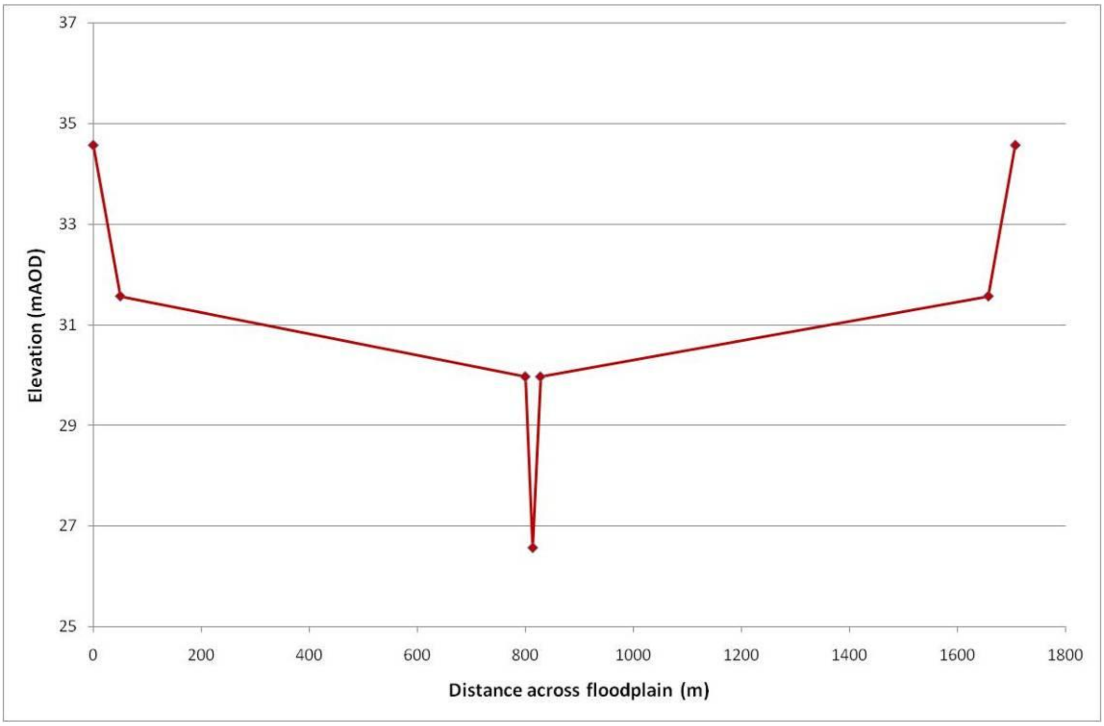


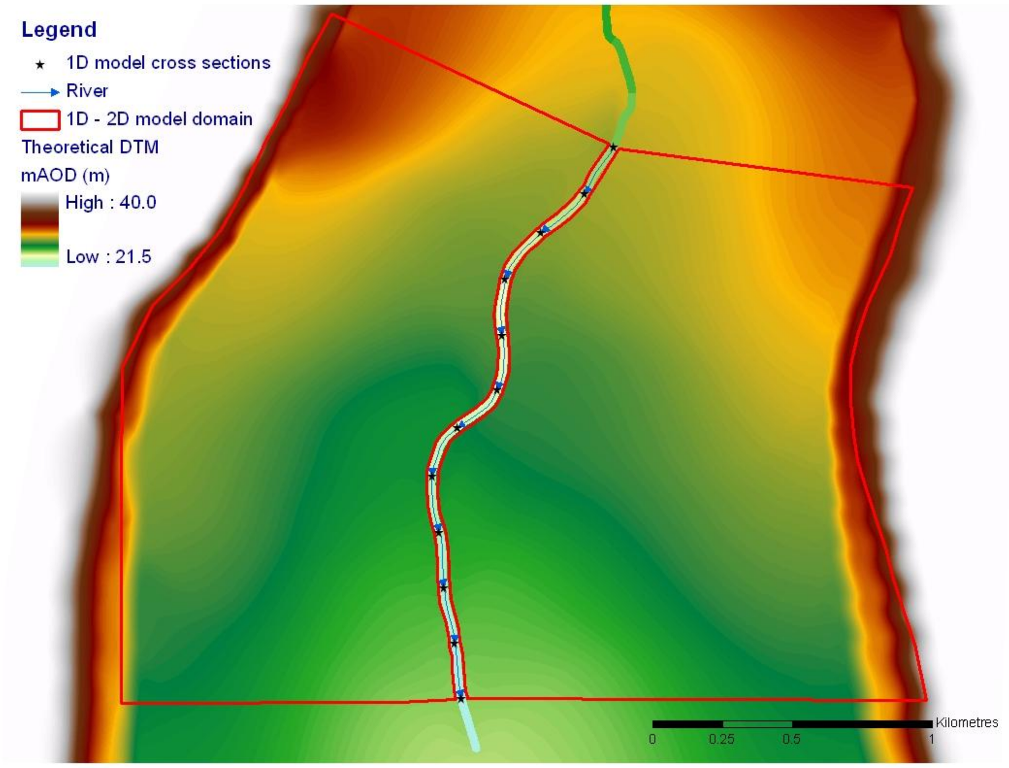
Figure 3-6 Theoretical model floodplain cross section



The modelled floodplain area was 5.3km^2, 2.3km^2 of which were inundated during the simulations. The peak flow of the inflow hydrograph was 409.8m^3/s. The baseline model was set up with 4m model domain resolution. As with the previous models, a 10m buffer strip of grass along the river banks was included. The coupled 1D – 2D model run time was 8 hours.

Figure 3-7 shows the layout of the theoretical model and the underlying topography designed for the model.

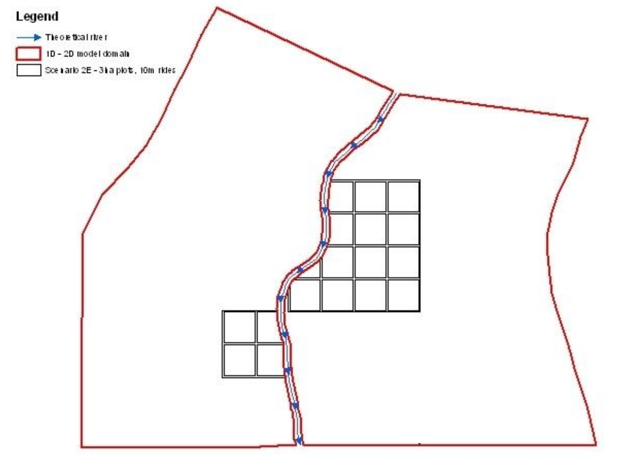
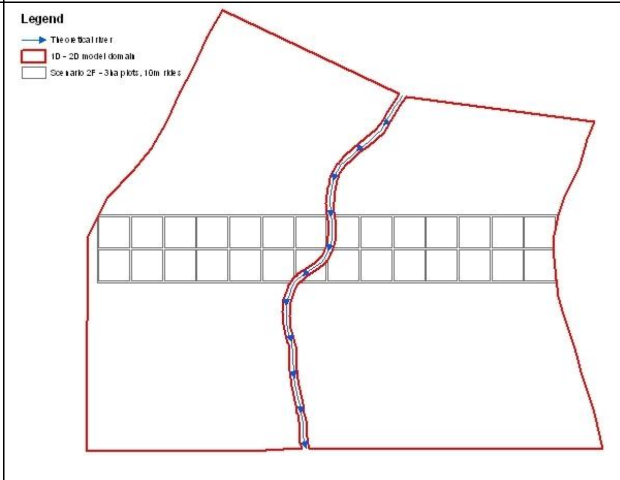
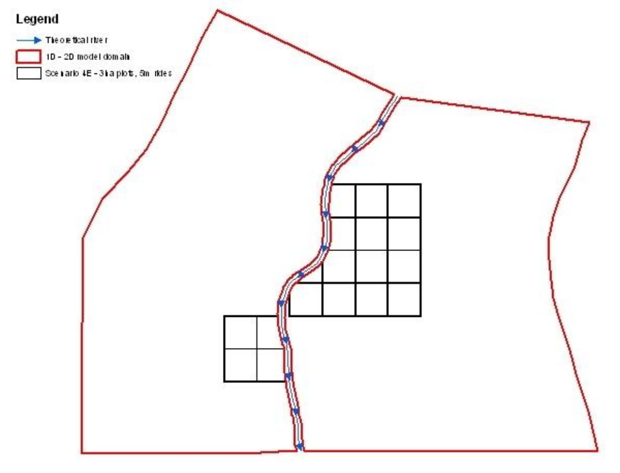
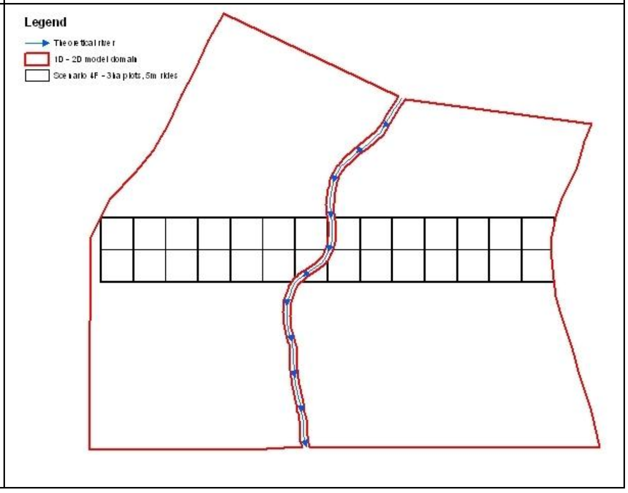
Figure 3-7 The Theoretical Model – model layout and topography



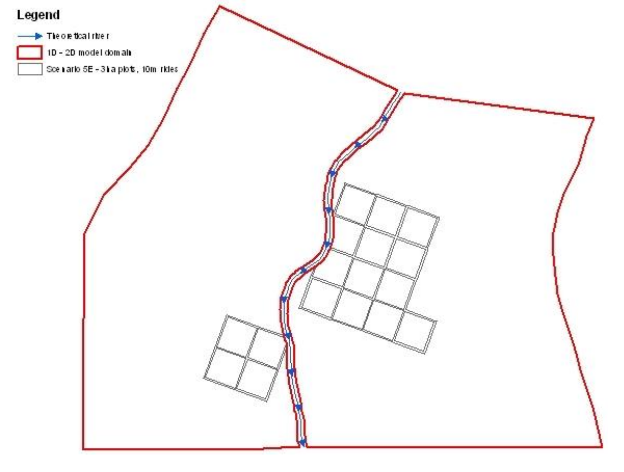
3.3.2 Theoretical Model – Modelled scenarios

In total, 16 scenarios including the baseline were simulated in the theoretical model both for Miscanthus and SRC Willow plantations. The scenarios used primarily 3ha plots with 10 or 5m rides/headlands around or within. Unlike in the other case studies, the 100% floodplain coverage scenario was not represented. Instead, focus was given to using the shallow floodplain on both sides of the river and examining scenarios with plantations placed across the entire floodplain (e.g. Scenarios 2F, 4F, 5F or 6F), distributed on both sides (e.g. Scenarios 2E, 4E, 5E or 6E) and an additional scenario that aimed at investigating the effect of the plantation set further away from the river (Scenario 9E). Figure 3.8 illustrates the scenarios modelled.

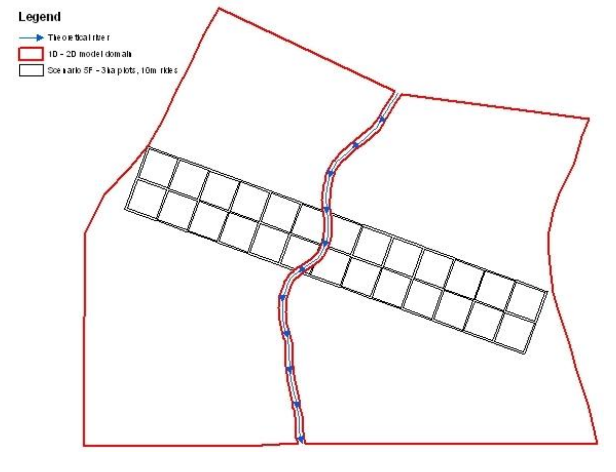
Figure 3-8 Modelled scenario configurations for Isle at Ashford Mill (the modelled floodplain area is shown in red, river in blue, plantation configuration with rides/headlands in black and the arrows signify the direction of river flow)

Scenario 2E/3E – 3ha Miscanthus/SRC Willow plots, 10m perpendicular rides, floodplain coverage 30%	Scenario 2F/3F – 3ha Miscanthus / SRC Willow plots, 10m perpendicular rides, floodplain coverage < 30%
	
Scenario 4E – 3ha Miscanthus plots, 5m perpendicular rides, floodplain coverage 30%	Scenario 4F/4F Willow – 3ha Miscanthus / SRC Willow plots, 5m perpendicular rides, floodplain coverage < 30%
	

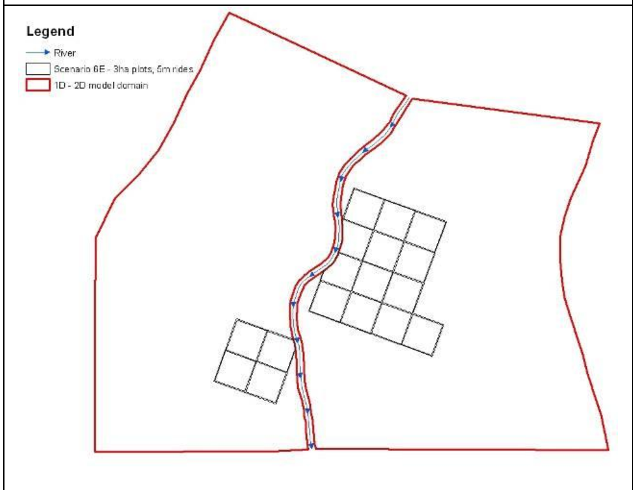
Scenario 5E – 3ha Miscanthus plots, 10m parallel rides, floodplain coverage 30%



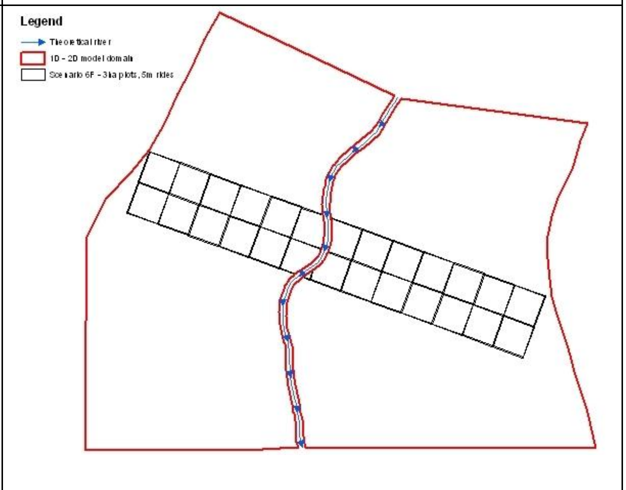
Scenario 5F/5F Willow – 3ha Miscanthus / SRC Willow plots, 5m parallel rides, floodplain coverage < 30%



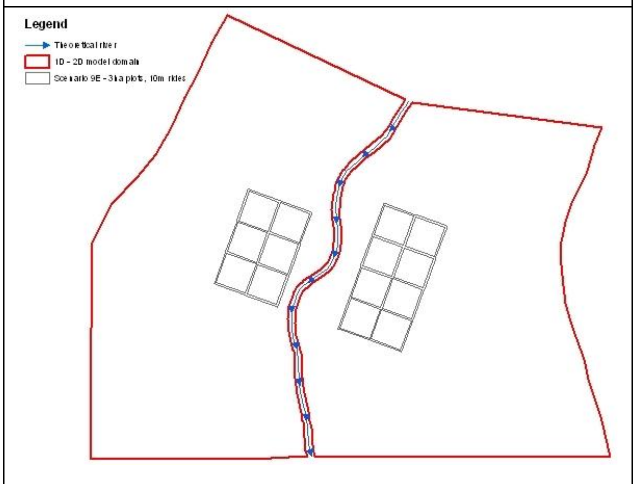
Scenario 6E/6E Willow – 3ha Miscanthus / SRC Willow plots, 5m parallel rides, floodplain coverage 30%



Scenario 6F – 3ha Miscanthus plots, 5m parallel rides, floodplain coverage < 30%



Scenario 9E/9E Willow – 3ha Miscanthus / SRC Willow plots, 10m parallel rides, floodplain coverage < 30%



4 Case Study Modelling Results

Table 2.5 lists the final set of modelling scenarios that were taken forward for the 100-year flood event.

The 100% floodplain coverage scenario provides an insight into the maximum possible impact of a plantation on flood dynamics, although is unlikely to apply in practice. The scenarios with a much more distributed and/or dispersed pattern of plantation blocks across the floodplain better reflect actual plantings regimes. Plantation blocks that extended across the central portion of the floodplain, therefore acting as a form of a 'leaky green dam', are also considered.

For each particular scenario flood depth on the floodplain, velocity and in-channel flows were extracted from the model results. .

4.1 River Isle at Ashford Mill

An example set of the final modelling scenarios for the River Isle at Ashford Mill are presented below for one particular distributed plantation configuration for both Miscanthus (Scenario 2E) and SRC Willow (Scenario 3E), and compared to the baseline floodplain scenario (complete coverage of the floodplain with a winter wheat crop). A comprehensive set of results graphics for all the case studies are given in digital form in Appendix B. A summary matrix that encapsulates all the modelling results from all the case studies is given in Section 4.

4.1.1 Flood Depth

Modelling scenarios - Miscanthus

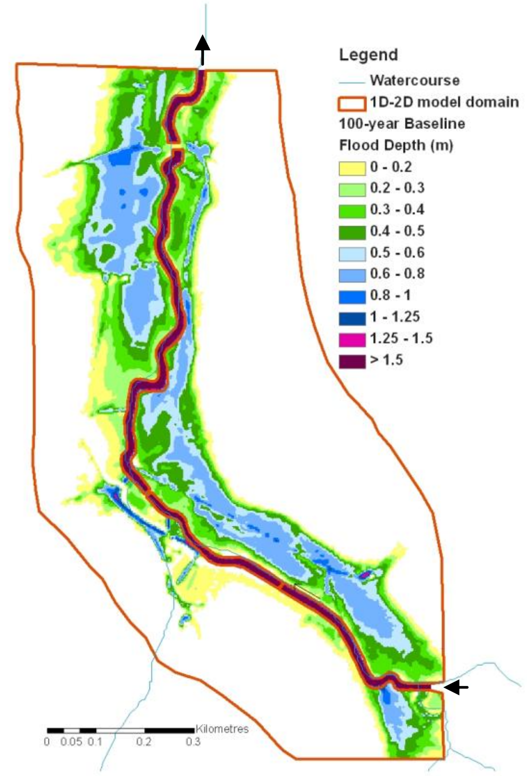
When compared to the baseline condition the Miscanthus plantation blocks (Scenario 2E) act to generally hold the water levels up both within the plantation block itself and within an area immediately upstream of the plantation block, with maximum flood depth reaching 0.8m -1m (Figure 4-1A). This had the effect of widening the maximum flood extent slightly. Figure 4-1B shows the actual increase or decrease in maximum flood depth when compared to the baseline condition. Increases in maximum flood depths of 10cm-20cm are observed within the two northernmost plantation blocks and for a distance up to about 80m immediately upstream of the block. The most southern block produced a slightly higher increase in maximum flood depth of 10cm-30cm both within the plantation and up to about 200m immediately upstream of the block. Across the rest of the floodplain increases in flood depth were less than 10cm.

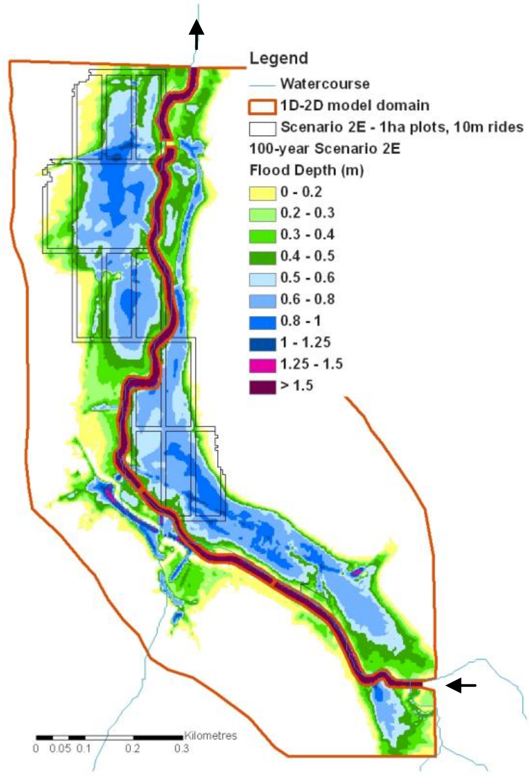
Interestingly, both the central block and southern block, both of which extend across one half of the floodplain width did force some of the flood water to preferentially move over to floodplain on the other side of the main river and raise the water levels there. This water diversion effect may be quite important on those floodplains where land ownership does not extend both sides of a river.

Modelling scenarios – SRC Willow

In contrast to Miscanthus, the blocks of SRC willow in the same configuration and coverage (Scenario 3E) produced much smaller impacts on the maximum flood depths when compared to the baseline (Figure 4-1C). This can be attributed to the decreased roughness for smaller depths of flood inundation when compared to Miscanthus. The maximum flood level was only increased by 10cm-20cm on the upstream edge of the southernmost block. Throughout the rest of the floodplain flood depths changed by less than 10cm compared to the baseline.

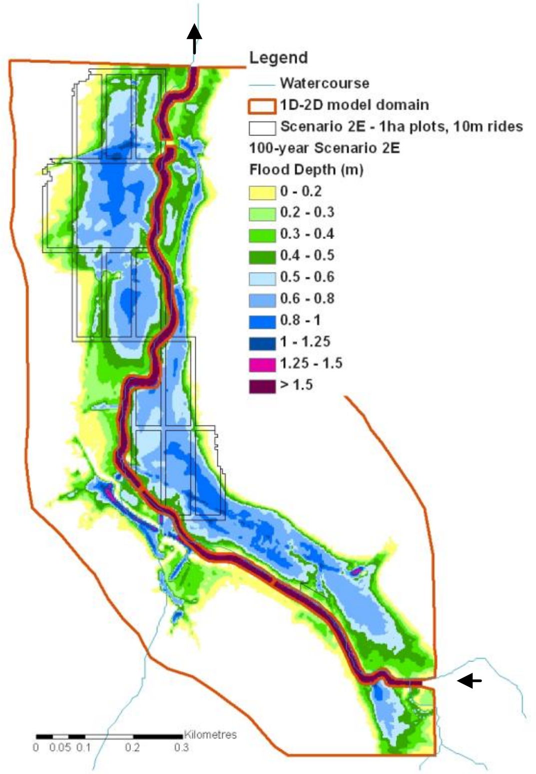
Figure 4-1 Isle at Ashford Mill – Flood depth patterns

<table>
<tr><td>A. Flood Depth (Max) Baseline (winter wheat across entire floodplain)</td><td>A. Flood Depth (Max) Scenario 2E (1 ha Miscanthus plantation blocks with 10m rides, 30% floodplain coverage)</td></tr>
<tr><td>


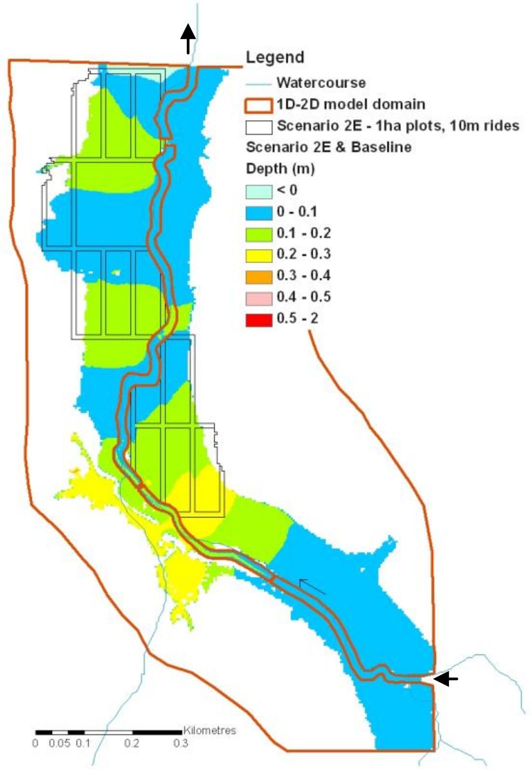
</td><td>


</td></tr>
</table>

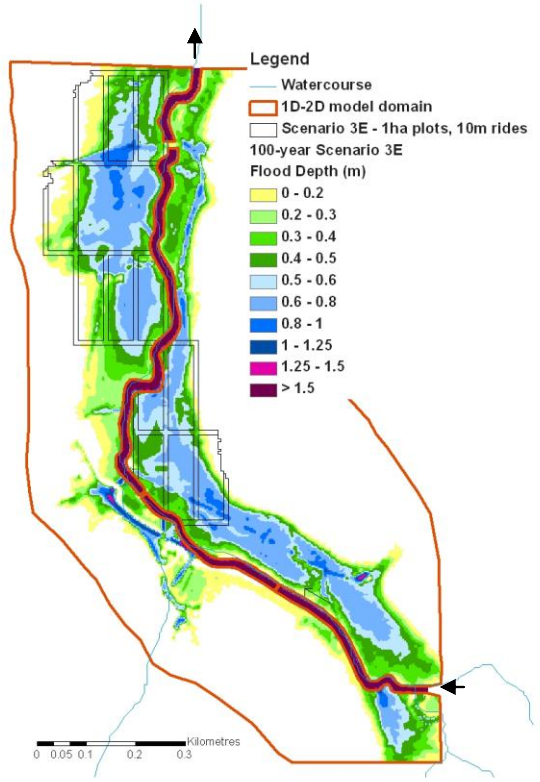
B. Flood Depth (Max) Scenario 2E Miscanthus



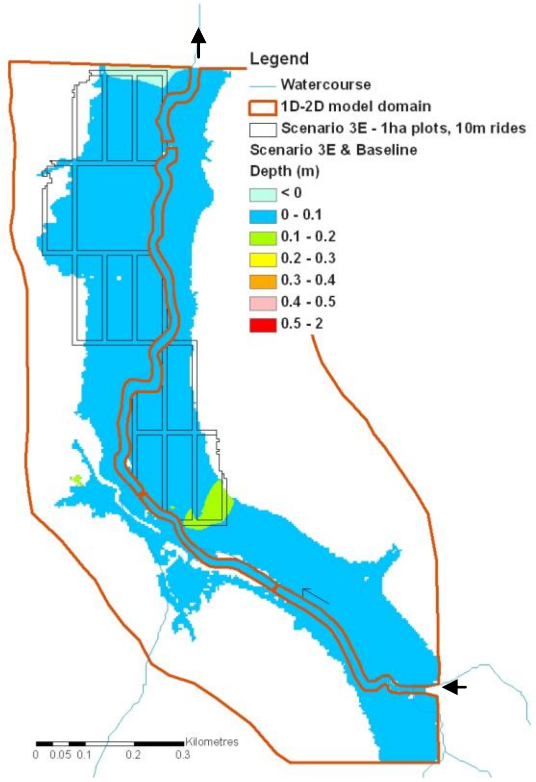
B. Flood Depth (max) Difference (Miscanthus) - Scenario 2E minus Baseline



C. Flood Depth (Max) Scenario 3E (1 ha SRC willow plantation blocks with 10m rides, 30% floodplain coverage)



C. Flood Depth (max) Difference (SRC willow) - Scenario 3E minus Baseline



4.1.2 Flood velocity and floodplain flow pathways

The configuration of the plantation blocks also influenced the velocity (speed) of water movement across the surface of the floodplain, together with the flow pathways or routes that the flood water took across the floodplain (through and around the plantation blocks). When the floodwater reached the plantation area, it either travelled through the main body of the plantation (over and/or around the surface vegetation, debris, plant stems and tree trunks), along the vegetated headlands (surrounding the perimeter of the plantations) or along the vegetated access rides (that pass through the plantations). This enforced split of the flood flow into multiple pathways caused the floodwater to change speed depending on which pathway was taken.

Modelling scenarios - Miscanthus

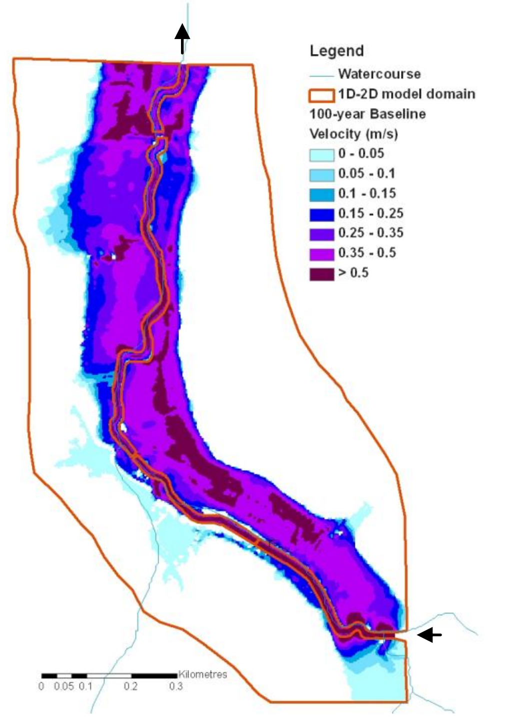
When compared to the baseline, the Miscanthus plantation blocks (Scenario 2E) caused a reduction from over 0.5m/s to 0.15m/s-0.25m/s in the maximum flow velocity within the main vegetative body of the plantation. Faster preferential flow routes (or 'short circuit' pathways) were created along both the rides and headlands (Figure 4-2A). Where flood water was forced across onto the other side of the floodplain due to the presence of the plantation block, the extra flood water on the opposite floodplain also flowed faster than the baseline condition. The maximum flow velocity along the headlands and rides (>0.5m/s) was similar to that predicted over the unrestricted baseline floodplain. This is a consequence of the basic hydraulic characteristics of the vegetation within the headlands and rides being very similar to those of the baseline (winter wheat) condition.

Modelling scenarios – SRC Willow

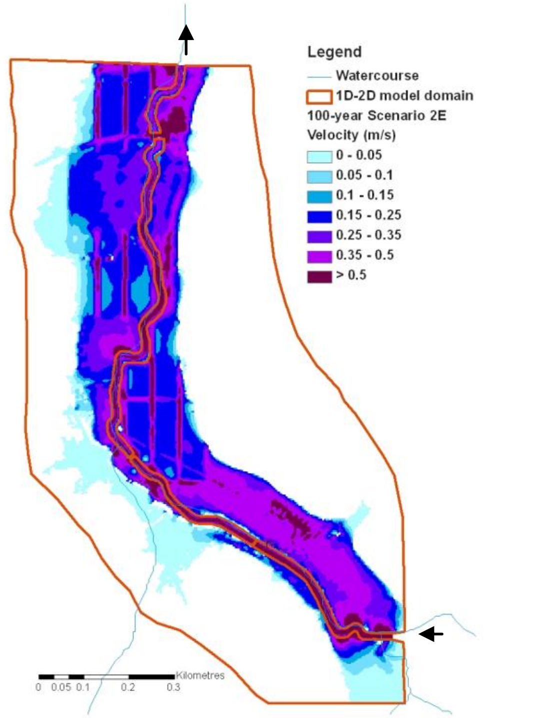
As observed for flood depths, SRC Willow (Scenario 3E) had a smaller impact on flow velocities than an equivalent plantation of Miscanthus (Figure 4-2B). Flow velocities within the main vegetative body of the plantation were only reduced from about 0.5m/s to 0.25m/s-0.35m/s. The changes in the pattern of the new flow pathways caused by the SRC Willow plantation blocks were, however, very similar to those for Miscanthus.

Figure 4-2 Isle at Ashford Mill – Flood velocity patterns

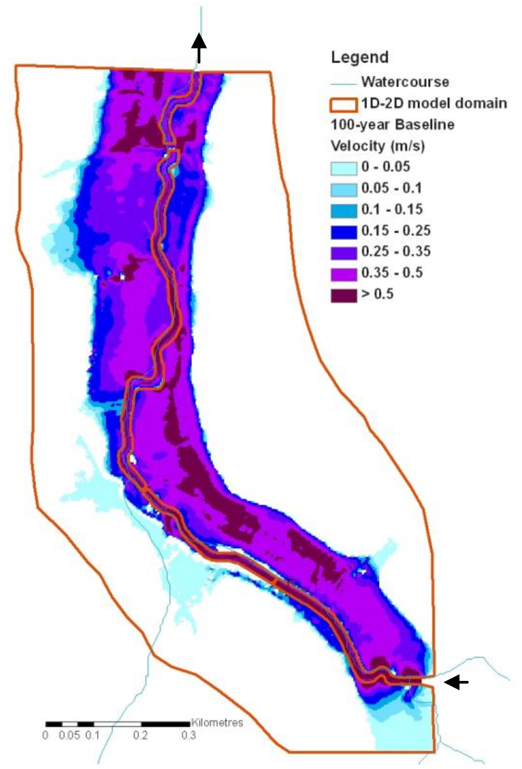
A. Flood Velocity (Max) Baseline (winter wheat across entire floodplain)



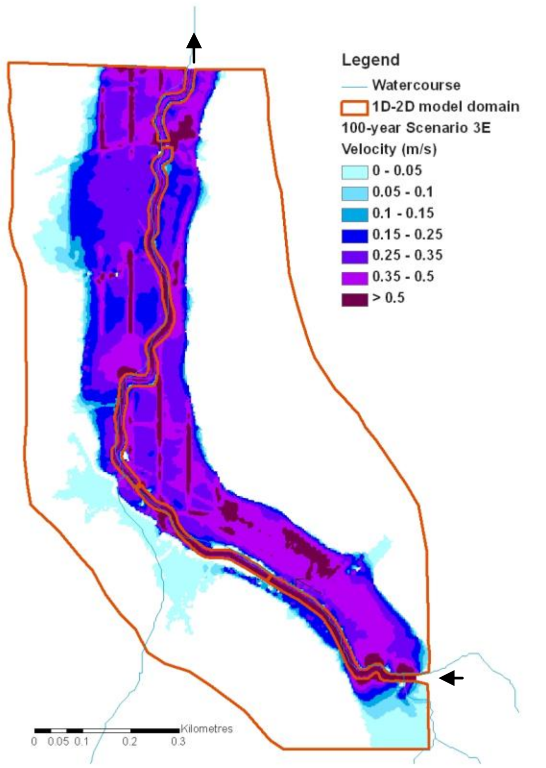
A. Flood Velocity (Max) Scenario 2E (1 ha Miscanthus plantation blocks with 10m rides, 30% floodplain coverage)



B. Flood Velocity (Max) Baseline (winter wheat across entire floodplain)



B. Flood Velocity (Max) Scenario 3E (1 ha SRC Willow plantation blocks with 10m rides, 30% floodplain coverage)



4.1.3 Flood hydrographs

The modelled in-river channel hydrograph for the 100-year flood event (i.e. 1% AEP) was generated for each model cross sections in order to explore how flow in the main channel interacts with, and is also influenced by, out of bank floodplain flows.

Figure 4-3 shows the in-channel hydrographs (i.e. as modelled in the 1D ISIS river channel model) for a number of the model nodes along the River Isle. In all cases shown, the black line is the baseline case, the red line is Scenario 2E (i.e. 1ha Miscanthus plantation blocks with 10m rides, 30% floodplain coverage) and the blue line is Scenario 3E (1ha SRC Willow plantation blocks with 10m rides, 30% floodplain coverage).

Impact on in-channel river flows upstream of the plantation

At a location about 400m upstream of the first (most southern) plantation the in-channel hydrograph (i.e. showing only the flow in the river, regardless of the flow on floodplain) is not affected by the presence of the plantation further downstream (Figure 4-3A). However, at a distance of about 200m upstream of the plantation the presence of the plantation, whether Miscanthus or SRC Willow, has caused the in-channel flood peak flow to be lowered when compared to the baseline (Figure 4-3B). The influence of the Miscanthus block is greater (7% decrease in peak flow) than that of SRC willow (3% decrease). More water is being directed onto the wide eastern floodplain in this area by the plantation blocks further downstream, thereby creating a decrease in the flow rate within the main channel.

Impact on in-channel river flows at the plantation

In contrast, within the main body of the plantation (Figure 4-3C) the localised effect of the vegetation locally causes an increase in in-channel flows (by 7% for Miscanthus and 5% for SRC willow). This increase in peak flow continues downstream within the plantation (Figure 4-3D), where the interactions with the Miscanthus plantation caused the peak flow to increase by 10% and by 3% for SRC willow. The narrowness of the floodplain width on the eastern bank restricted floodplain flow to the near river corridor (inc. riverside headland area). In the area in between two plantation blocks (Figure 4-3E), where water is able to more freely flow over a more unrestricted floodplain, the influence of the plantation decreased (Miscanthus 5% increase, SRC willow 2% increase).

Impact on whole floodplain flows

In general, increased flood depth and decreased flood velocities were, by implication, associated with decreased floodplain flows due to the water moving at slower rate through a larger greater area (imposed by the increased depths).

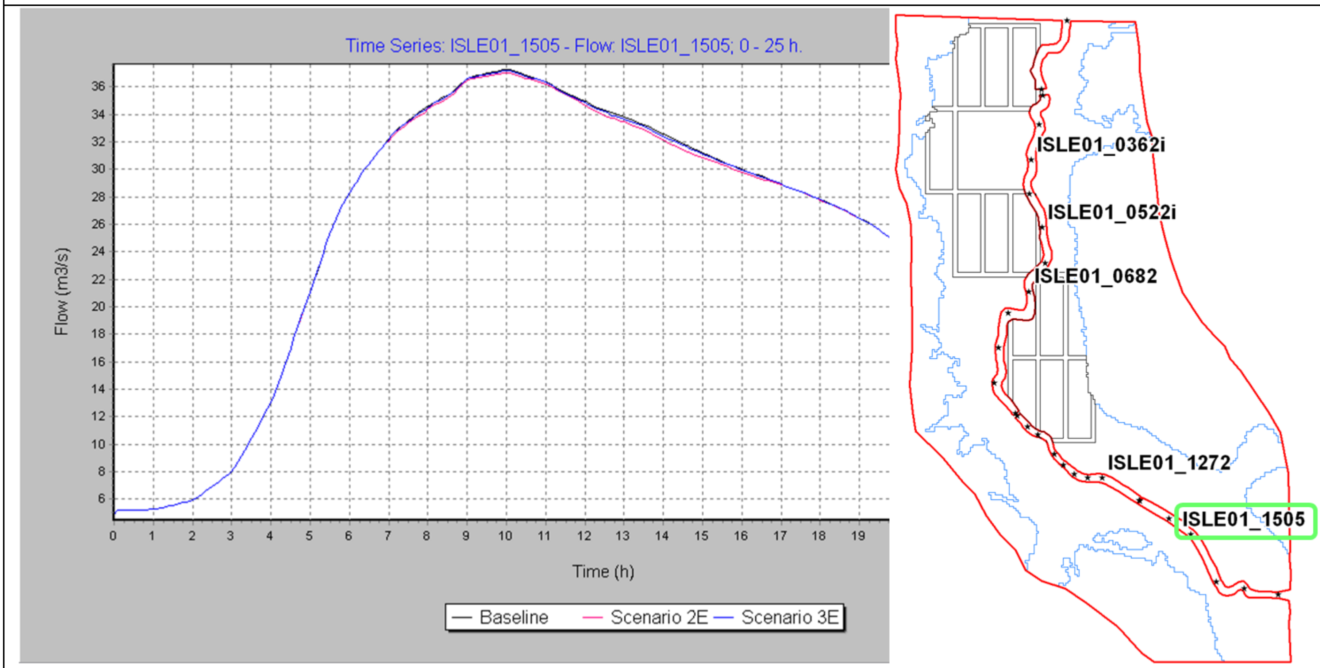
The floodplain hydrographs were extracted for a selection of scenarios and the magnitude of the change ranged as follows:

- 14 – 23% decrease of flood peak on the floodplain for Scenario 4D (1ha Miscanthus plots with 5m perpendicular rides, 100% floodplain coverage)
- up to 8% decrease along the Miscanthus plantation plots for Scenario 2E (i.e. the distributed 1ha plots with 10m rides, 30% floodplain coverage)
- up to 32% decrease directly at the Miscanthus plots for Scenario 4F (i.e. a stripe of 1ha Miscanthus plantation plots with 5m rides) and only up to 1% decrease elsewhere

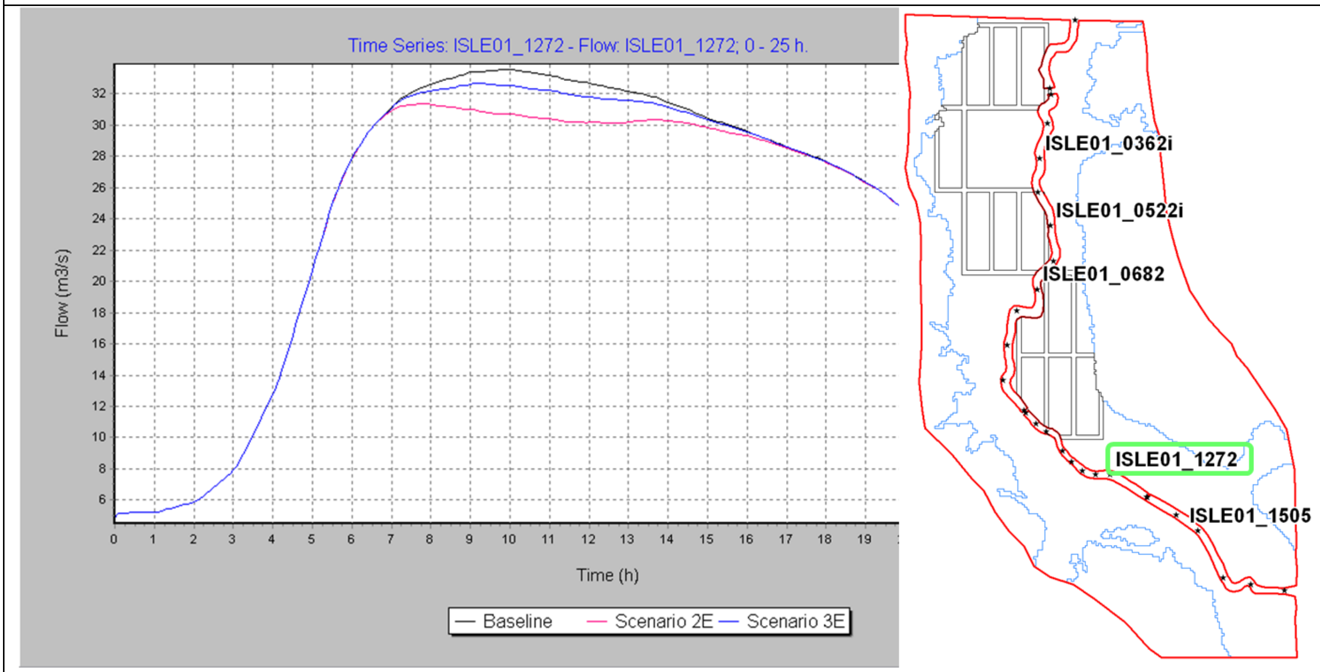
- up to 14% decrease directly at the SRC Willow plantation plots for Scenario 3F (i.e. a stripe of 1ha SRC Willow plots with 10m rides) and only negligible decrease elsewhere

Figure 4-3 Isle at Ashford Mill – Main channel flood hydrographs (modelled floodplain in red, plantation layout in black and Flood Zone 3 extent in blue)

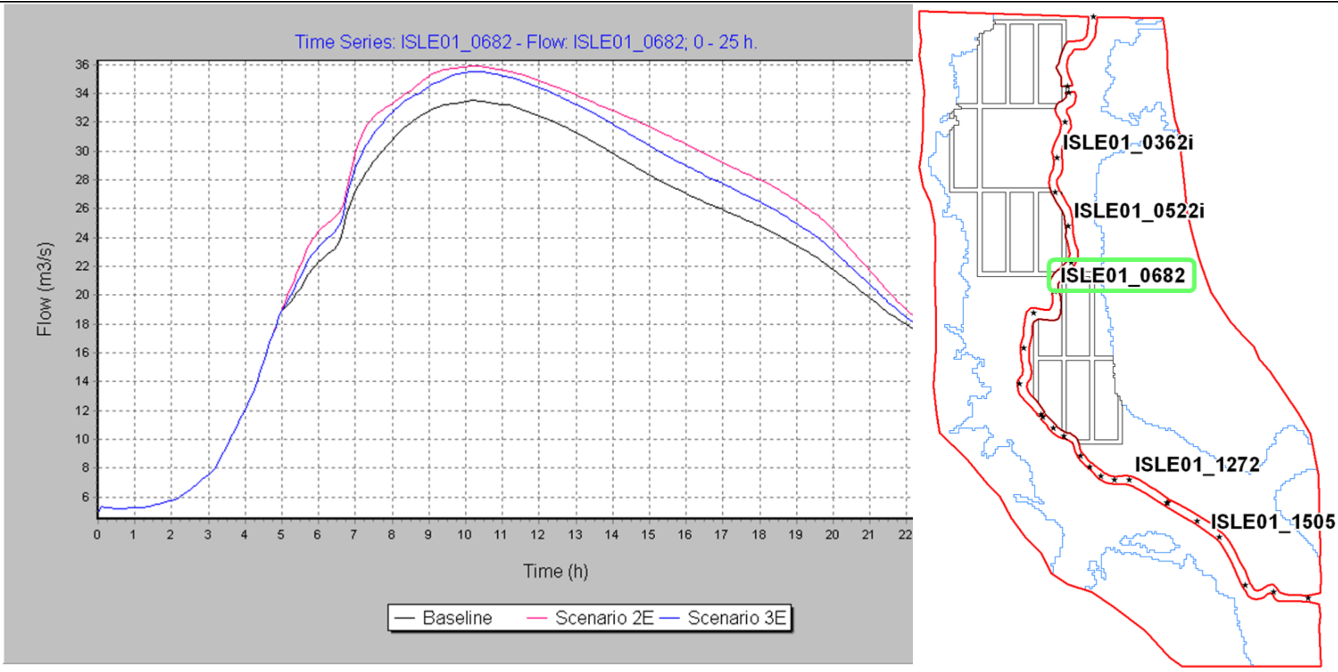
A. 400m upstream of plantation (model node 1505).



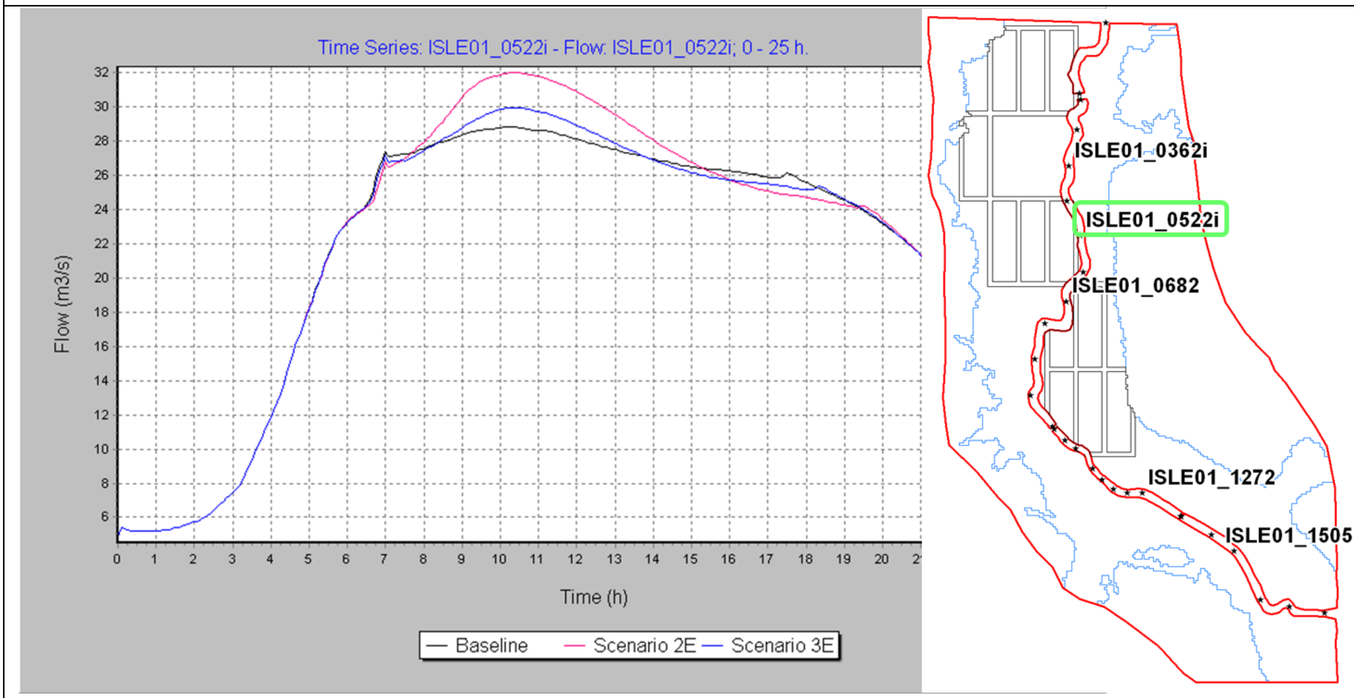
B. 200m upstream of plantation (model node 1272).



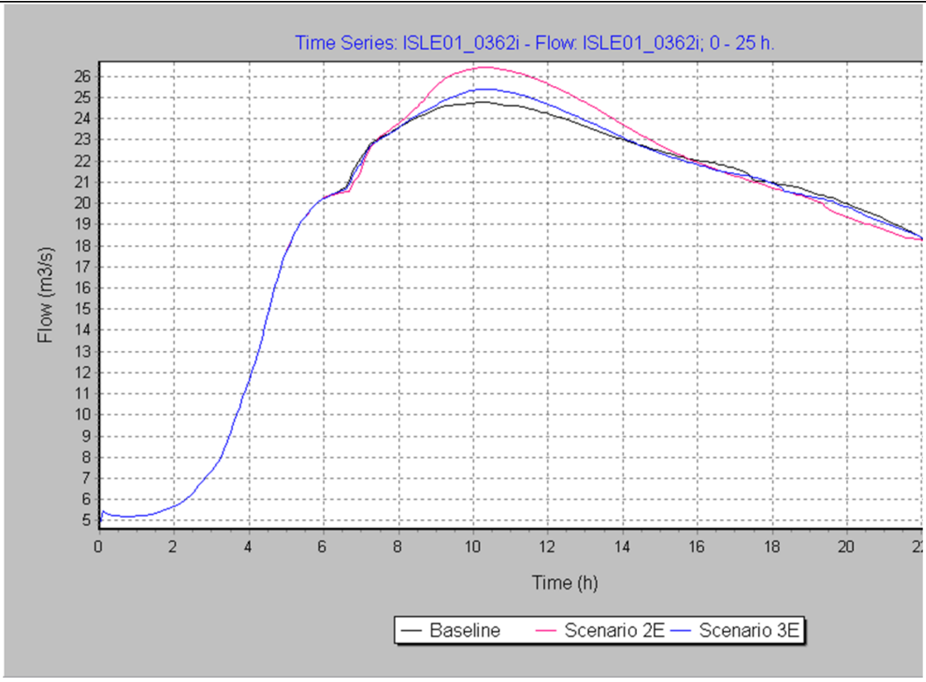
C. Next to small plantation on eastern floodplain (model node 0682).

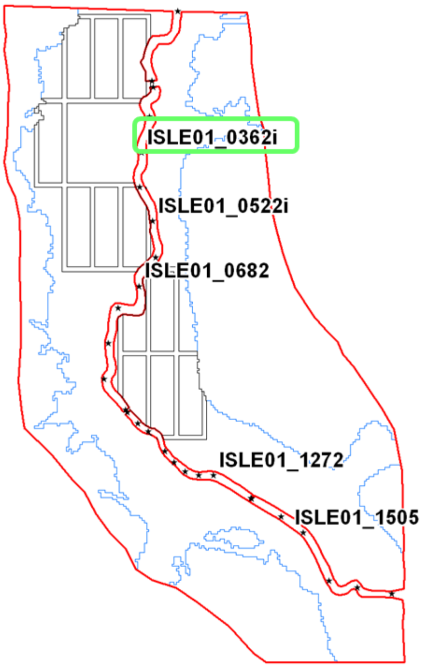


D. Next to larger plantation on western floodplain (model node 0522)



E. Between two plantation blocks (model node 0362)





4.2 Summary results presentation

In total, 40 scenarios were modelled and their results analysed for all the three case studies. Based on the analysis, it was possible to generate a summary results matrix (Table 4-1) which represents a synthesis of the model predictions for the 100-year flood event over the range of scenarios explored across the three case study floodplains. The matrix presents the findings from the modelling scenarios in a generic, qualitative way and hence allows a general understanding of the results in wider context with regard to the location of energy crop plantations on a floodplain.

It is very important to note that the modelling scenarios do not represent an exhaustive set of floodplain plantation configurations and therefore neither does the matrix.

Table 4-1 Summary results matrix.

Plantation Configuration On Floodplain	Flood depth (max)			Flood velocity (max)				In-channel flood flow (max)		
	upstream plantation	within plantation	downstream plantation	upstream plantation	within plantation	within ride	downstream plantation	upstream plantation	within plantation	downstream plantation
Complete (100%) coverage	n/a	+/++	n/a	n/a	--	+	n/a	n/a	+	n/a
Distributed blocks (30% coverage)	+	+/++	+/0	-	--	+	-	-/0	+	+/0
Central block (full floodplain width)	++	++	-	-	--	+	0	-/0	++	+/0
Central block (part floodplain width)	+	+	-	0	--	0	0	-/0	+	+/0

Table notes

Symbol	Definition	Max flood depth change	Max velocity change	In-channel peak flow change
++	Increase	>20cm increase	>40% change	>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

5 Discussion & Conclusions

5.1 Assumptions and limitations

5.1.1 The modelling approach

A number of assumptions had to be made in the way the energy crops were represented in the hydraulic models. These were based on a review of recent publications and research available, but effectively no specific field study datasets were available to verify exactly what floodplain roughness values should be used for mature Miscanthus and SRC Willow vegetation. There are still gaps in knowledge in this area, despite recent advances about how to represent roughness (for example as part of the Conveyance Estimation System) and how it should vary with scale within 2D models. Interest in the impact of various vegetation types (including energy crops and woodland) on floodplain flows and on the floodplain environment has increasingly become the subject of recent research.

5.1.2 Representation of energy crop plantations

A number of limitations were present in the modelling work that related to the simulated plantation configurations (i.e. no allowance was included for the local field boundary structure), the plantations were square/rectangular (which would not be the case in the reality), and it was not possible to properly assess the concept of 'parallel' and 'perpendicular' rides/headlands next to a meandering river channel.

The life cycles of both Miscanthus and SRC Willow include a period of time every year in the case of Miscanthus, or once in three years in the case of SRC Willow, when the crops are harvested and the bare earth is exposed before the re-growth occurs. This implies that the resistance to flow of the plantations would be expected to be much less than that of the fully grown mature crop. This same condition would apply also during the establishment period after planting the energy crops. Such situations were not part of the investigations in this project, and therefore the modelling scenarios tested only included the fully grown mature crop just before harvest.

There is a lack of 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 occur after repeated coppicing.

The choice of the depth-varying hydraulic roughness for SRC Willow was based on the recent findings by Wilson (2009) that focused specifically on this type of vegetation cover. However, data in the Roughness Review by Defra (2003) seem to suggest that the effective value of Manning's n should decrease as the degree of submergence of the floodplain vegetation increases. This is deemed applicable for grass cover, but not for agricultural crops (such as wheat) or coniferous trees.

The scenarios could not have been, within the scope of this project, exhaustive and were not aimed at exploring all the possible combinations of the plantation configurations on the floodplain. The aim was to give a flavour of the likely scale of the impact on the river and floodplain flood dynamics in order to identify whether certain combinations of the plantation are acceptable on a floodplain (i.e. within Flood Zone 3) without increasing flood risk elsewhere.

5.2 Discussion

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 in-channel river flows next to plantation blocks that extended near to the main river channel (due to less water being able to escape onto the floodplain). The magnitude of these effects could potentially be important in flood management terms. A predicted 5-10cm rise in water level would be deemed by the Environment Agency 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. People and property are the most important flood risk receptors. In a rural floodplain context the property element (which could include the farmland) would need to include the potential impacts on third party land. However on some floodplain there may also be important environmental (e.g. Sites of Special Scientific Interest) and heritage (e.g. Scheduled Ancient Monuments) receptors that require careful consideration.

The spatial extent of the hydraulic effect of a plantation block (whether fully or partially covering the floodplain width) 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 and Nisbet (2008) for a floodplain woodland modelling case study on the River Cary in Somerset. It should be noted that this study was limited to three case study floodplains and could not fully examine the impact further downstream without coming quite close to the downstream boundary of the model, where the simulated results can be influenced by the boundary conditions more than by what is happening on floodplain (although any backwater effect was minimised).

In order to meet the modelling aims and objectives of this study the 2D approach to representation of a floodplain was selected to be the most suitable and the linked 1D - 2D ISIS TUFLOW was chosen as an appropriate software package. However, it should be noted that 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 is because it governs the transition of water between the 1D river model and the 2D floodplain model. This link is crucial, therefore, in determining the amount of water spilling onto the floodplain and the interaction between the flows in the river and on the floodplain. One of the test cases in a recent benchmarking study of 2D hydraulic models (including ISIS and TUFLOW) explored the linkage of the 1D river and 2D floodplain interaction and the relationship between in-channel flood flow and floodplain flood flow (Neelz *et al*., 2009). The study highlighted discrepancies between the tested models in simulated peak water levels on floodplains (i.e. once the river embankments were overtopped), which depend critically on river bank overtopping discharges and on flow through structures. The study concluded that large differences in modelled results of the predicted floodplain water levels originated from differences in how accurately the models represented the geometry of the embankments. However, this is critical to accuracy in overtopping discharge, especially for shallow overtopping depths.

The increase in flood depth and water levels around the plantation blocks, as modelled in this study, is in line with expectations. The apparent increases in flow within the river channel (Figure 4-3) may deserve further investigation. In linked 1D-2D models, it is known that the precise way in which the links are set up influences the results. Case studies carried out in the Environment Agency's 2D model benchmarking study for the River Severn illustrate this point. 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. For example, Knight *et al.* (1989) showed how the retarding effects of the shear layers between slower moving floodplain flows and faster moving main channel flow were apparent in detailed measurements for overbank flows at the Montford Bridge on the River Severn. 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 flow that may be, at least in part, an artefact of the modelling approach.

As the mathematical complexity of 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 which there is rarely a good basis for making such adjustments). In this study the default values were used.

Environment Agency and Natural England staff involved in the assessment of new ECS applications can use the findings from this study to determine, in general terms, the potential effect of a particular plantation configuration on the local flood dynamics. However, the limitations and uncertainties of the results associated with the modelling approach and uncertainty in the crops' representation have to be kept in mind when applying the results. The assessors should hopefully be able to determine those applications that would not increase the flood risk, bearing in mind any local landownership issues, and may actually provide a valuable downstream flood risk management function. Alternatively, those applications that appear to have the potential to generate larger impacts (either locally or further afield) could then be put forward for a more detailed level of assessment, including the potential need for a formal Flood Risk Assessment to be provided by the applicant.

5.3 Conclusions

The general findings from this short-term modelling work simulating the potential impacts of mature 1-3ha energy crop plantations (with integral managed rides or headlands) on the 100-year return period flood magnitude are as follows:

- 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.

- Where the energy crop plantation fully covers the floodplain the highest overall impacts on the flood dynamics (flood depth, velocity of flow, main channel flow hydrographs) are observed.
- 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.
- The extent of the hydraulic effect of a plantation block (whether fully or partially covering the floodplain width) or distributed plantations is generally less than 300m upstream or downstream of the plantation edge.
- Plantation headlands and rides provide faster preferential (short circuit) flow pathways than the main vegetative block.
- Varying of the headland and ride width (from 5 to 10m) did not significantly change the flood dynamics.
- Varying the ride orientation relative to the main river channel orientation did not significantly change the flood dynamics.
- Distributed blocks or a central plantation block did not change the maximum flood extent significantly.
- The greater the plantation coverage the more water is forced to move in the vicinity of the main channel (and at greater flow velocity and flow rate).

The outcomes of this project were used to develop a supplementary guidance note to the existing Environment Agency guidelines in this general subject area entitled - Flood Risk Management: Woodland, tree planting and flood risk. This guidance helps to inform the future decisions with respect to the establishment of woodland and other similar vegetative types, such as new energy crop plantations, on floodplains. It also provides advice on the selection of Manning's n roughness coefficients to use when representing energy crop plantations in hydraulic models.

6 Recommendations for further work

6.1 Modelling

Given the nature and scope of this short term modelling study 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 the following recommendations for further modelling work are suggested:

1. Consider and compare the use of 1D or 2D models only. Particularly, the use of a 2D model to simulate both the river and floodplain flows, or only floodplain flows in a simplified case, is believed to be an appropriate method. Alternatively, 3D hydrodynamic models could be used. However, these are a “step up” in terms of cost, input data and computational power demands. The modelling packages that could be used include HEC-RAS, ISIS-CES and MIKE11 (1D models), TELEMAC and MIKE21 (2D models), and CFX, PHOENICS (3D models) and others. For analysis using 2D models and, in particular linked 1D-2D models, the results of the Environment Agency’s 2D model benchmarking study should be taken into account.
2. Explore and improve the model representation of the dynamic nature of the variation in the roughness characteristics of energy crops through their growing and harvesting cycles. This could be based on results of recent research being carried out for example by the Hydro-Environmental Research Centre at Cardiff University, where studies of hydrodynamic drag caused by flooded vegetation and the resistance of flexible and stiff vegetation depending on depth and velocity of flooding and other parameters have been carried out (for example by Xavier, 2010).
3. Apply the approach to additional case study floodplains, including more complicated floodplain situations (such as those with flow constrictions or flood embankments).
4. Systematic analysis of a wider range of flow conditions in terms of depth (relative to vegetation height) and velocity.
5. Improve the methodology to consider more realistic plantation shapes and field boundary characteristics (i.e. hedges, walls, fences) on the floodplain.
6. Analysis of the potential long term effect of energy crop plantations on river and floodplain sediment dynamics due to the considerable alteration in flow velocities both in-channel and on the floodplain surface during out of bank flood events.

6.2 Experimental Studies

Quantitative evidence of the impacts of energy crop plantations on floodplain flows in order to both inform and validate the modelling approach could be obtained through laboratory and field studies. Laboratory studies, involving the actual physical representation of energy crops, in terms of their hydraulic characteristics, could be undertaken in a large flume facility where close control and measurement can be made over flow rates, flood depths and water velocities. Cardiff University have used such a facility recently to explore the roughness characteristics of SRC willow and how this varies with water depth and with the dynamic seasonal growth characteristics of these trees. Publication of the final results from this research work is expected in the near future. To date, very little data exist on the hydraulic characteristics of Miscanthus grown as an energy crop and this is an area where the knowledge could be substantially improved through additional flume based research.

The setting up of field studies on floodplains (containing energy crops plantations) with the ability to comprehensively measure the parameters of flood depth, flow rates and floodplain water velocities could prove to be very costly to implement and manage to the level of detail needed to validate the hydraulic models. In addition, the uncertainty in the occurrence, frequency and magnitude of natural flood events suitable for measurement and analysis would also make the successful completion of this investigation somewhat uncertain, especially if the study had a limited duration. However, relatively simple monitoring of water levels upstream and downstream of an energy crop plantation (both for a baseline period before the crop was planted and then during the course of a number of subsequent growth and harvesting cycles) using automatic water level recorders with integral data loggers would provide some very useful datasets on how the plantation influences the flood levels in the locality. Ideally, this would be replicated in some way across a range of floodplains. A similar simple approach was implemented by Forest Research for an investigation on the possible effect of new floodplain woodland plantations on flooding dynamics in the Ripon catchment in North Yorkshire (Nisbet & Thomas, 2008). Unfortunately, during the baseline monitoring period of this study the decision was taken by the landowners not go ahead to plant the trees and the work could not be completed.

References

ACREMENT 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.

NÉEZ, S. AND PENDER, G. 2009. Benchmarking of 2D hydraulic Modelling Packages. Draft of Science Report. SC080035/SR

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.

Appendices

Appendix A

Background to 1D – 2D ISIS – TUFLOW Hydraulic Modelling

TUFLOW is a 2D inundation model that simulates the hydrodynamics of water flowing over the land surface by solving the shallow water equations for both momentum and continuity. The shallow water equations represent components of the depth-averaged velocity in two directions. 2D models allow for calculation of flow patterns on the floodplain during partial inundation and drainage, where topography typically plays major role in controlling the direction and velocity of the flow.

A TUFLOW 2D model is structured as a set of layers (in the format of MapInfo Geographic Information System (GIS) files) which define model topography for the floodplain, model boundary conditions, roughness of the floodplain, features such as buildings, roads or water bodies. The 2D model outputs include floodplain flood depths, flood levels and velocities, optional level monitoring sections across the floodplain that output floodplain flood hydrographs and the variation of the Manning's n floodplain roughness with depth of inundation (if specified). The model results can be viewed using specific software such as Surface-Water Modelling System (SMS), or exported in a MapInfo grid format for presentation within a GIS.

The model topography layer is defined by the underlying high resolution Digital Terrain Model (DTM) and the features on floodplain are typically defined by polygons or lines to represent buildings and roads as per OS mapping background. All these features influence the flood propagation across the floodplain and help represent the floodplain inundation in a realistic way. The accuracy of the modelled floodplain inundation depends, among other aspects, on the resolution of the model domain. It can be only as accurate as the underlying DTM (for example 1m cell size); however, such a high degree of detail requires very long computational time for the model to complete the simulation. The computational time can be, in the case of large models, up to several days in duration. Therefore, the model domain resolution is decreased (i.e. the cell size increased) so as to achieve practical model run times, whilst retaining sufficient detail of the topography. Typically, smaller models are set up with a 4m cell size, or 10m cell size for larger models or models where the floodplain inundation is not the major modelled element.

The model layers can easily be modified outside TUFLOW in a GIS environment. This is a crucial practical advantage of the TUFLOW model particularly within the context of this project, because it allows the different energy crop plantation layouts to be easily represented and modified for the various scenarios.

The 2D model can be linked with a 1D hydraulic model (e.g. ISIS Flow) of the river system in the area of interest via a set of 1D-2D boundary conditions. While the 1D model simulates the flow and water levels in the river channel, the 2D model simulates flood propagation onto and across the floodplain. The 1D component provides inflows into the 2D model every time the modelled river water level overtops the river banks. The proportion of the flood hydrograph that overtops the river banks then enters the 2D model and is routed on the floodplain within the 2D model domain. Conversely, the inundation can flow back from the floodplain into the channel further downstream, depending on the topography and water levels. Thus, the propagation of the flood water in the river (1D model) and on the floodplain (2D component) is modelled as a complex, fully linked unit.

Outputs from 1D-2D ISIS-TUFLOW models include flow hydrographs at each modelled river cross section in the channel (within the 1D component) and at specified locations on the floodplain (within the 2D component), water levels associated with these flows, floodplain water level, velocities, depth and flood extent.

Using a linked 1D - 2D modelling approach for this project allows changing patterns of flow pathways associated with different types of surface resistance represented by the friction coefficient, and its ability to simulate a wide range of different energy crop plantation configurations (e.g. a single block of Miscanthus or SRC Willow on one side of the floodplain, a full coverage of the floodplain with a network of rides/headlands between the blocks, or spatially distributed plantation blocks of different sizes) to be modelled. This versatility, together with availability of suitable existing 1D-2D models and their reasonable run times, were the main reason for the choice of this modelling approach for this short term project.

The model versions used in this study were TUFLOW 2009 07 AE and ISIS v3.3.0.88.

Appendix B

Digital Appendices (model scenario results)

Exe at Uckinghall

Isle at Ashford Mill

Theoretical Model

We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

Published by:

Environment Agency
Rio House
Waterside Drive, Aztec West
Almondsbury, Bristol BS32 4UD
Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk