Holnicote Multi-Objective Flood Management Demonstration Project

An Analysis of the Impacts of Rural Land Management Change on Flooding and Flood Risk

A Position Paper by

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Introduction

Determining and predicting the influence and contribution that rural land management practices have on catchment scale flood risk management is a topic of national importance. The year 2000 was the wettest year in England and Wales for 270 years and the widespread flooding led to financial losses estimated at the time to be around £1 billion[1]. During the past decade flood events such as those at Boscastle (2004); Carlisle (2005); the summer floods of 2007 affecting a belt between Gloucestershire and Humberside costing Britain about £3.2 billion[2] and Cockermouth (2009), have highlighted the significant social and economic costs associated with flooding incidents. These recent events have prompted greater interest in the role of surface water runoff from the rural environment and the inter-relationships between river channels and floodplains. The notion that through changing the way our rural land is managed would positively contribute to reducing flood risk is very attractive[3] and a number of studies have been investigating this. However, it is still felt by key agencies, such as Defra and the Environment Agency, that insufficient quantitative evidence exists to provide the basis on which to shift resources and invest in land management change as a flood risk management measure (Parrott *et al.* (2009)[4].

In 2009, in response to one of the recommendations of the Pitt Review of the Summer 2007 Floods, Defra commissioned three new projects as part the Multi-Objective Flood Management Demonstration Scheme. This scheme aims to generate hard evidence to demonstrate how integrated land management change, working with natural processes and partnership working can contribute to reducing local flood risk while producing wider benefits for the environment and communities The Holnicote multi-objective demonstration project on a National Trust Estate in Somerset is being delivered by Penny Anderson Associates (PAA) and JBA Consulting. Driven by Defra, supported by the Environment Agency and managed by the National Trust, this project hopes to demonstrate that

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[1] Defra (2011). National Flood Emergency Framework for England. Department for Environment, Food and Rural Affairs. (http://www.defra.gov.uk/publications/files/pb13430-national-flood-101008.pdf - accessed 22/11/11)

[2] Environment Agency (2010). The costs of the summer floods of 2007 in England. Project Report SC070039/R1. Environment Agency. (http://publications.environment-agency.gov.uk/PDF/SCHO1109BRJA-E-E.pdf - accessed 22/11/11)

[3] Environment Agency (2010). Working with Natural Processes to Manage Flood and Coastal Erosion Risk. Environment Agency. (http://publications.environment-agency.gov.uk/PDF/GEHO0310BSFI-E-E.pdf - accessed 22/11/11)

[4] Parrott, A., Brooks, W., Harmar, O. and Pygott, K. (2009). Role of rural land use management in flood and coastal risk management. Journal of Flood Risk Management, 2, 272–284.

by looking at whole catchments and strategically targeting shifts in rural land management practices, sustainable support to flood management may be achieved. In addition, it is recognised that through rural land management change and intervention comes the opportunity to enhance the provision of a range of other ecosystem services. These include landscape quality, biodiversity, carbon stewardship, water quality, amenity and recreation.

The principal project objectives are:

- To establish a robust hydrological monitoring programme across the study area
- To identify potential catchment (hillslope and floodplain) interventions that may contribute to managing flood risk
- To demonstrate practical implementation of catchment interventions
- To assemble evidence, both from recorded datasets and hydrological/hydraulic modelling, about the impact of the catchment interventions on runoff and flood dynamics
- To assess what the evidence reveals about the potential or actual benefits, in terms of both flood risk management and the delivery of a range of other ecosystem services

The ecosystem services assessment being undertaken for the project aims to provide an evaluation of the range of goods and services provided by the existing ecosystems across the Holnicote Estate, and those anticipated following the range of expected habitat modifications scheduled as part of the catchment interventions. In addition, based on the most robust information available, the assessment provides an evaluation of the value of these anticipated goods and services relative to the capital investment.

The National Trust is also co-funding a PhD student at Exeter University to work on the Holnicote project. The aim of this PhD research is to establish whether the catchment management interventions being implemented can improve water quality. The research will complement the catchment-wide hydrological monitoring taking place with biological and chemical water quality monitoring to examine the effectiveness of the flood attenuation measures to also meet water quality objectives.

The study area covering the National Trust's Holnicote Estate is situated adjacent to the uplands of Exmoor, Somerset, and comprises around 40km^2 of land from Exmoor (in the south) northwards towards Porlock Bay. Two main rivers drain this area, namely Horner Water and the River Aller.

The key flood risk receptors in the Horner Water and Aller catchments are the villages of Allerford, West Lynch and Bossington. Properties in these villages are at risk of flooding from the watercourses, which are influenced by a legacy of flow constrictions within the drainage networks, such as narrow historic stone bridges, and the lack of undeveloped channel and floodplain capacity through the built-up areas.

This position paper describes the design and the commissioning of a comprehensive hydrometric monitoring network in the study area to meet the principal project objectives; the identification of possible land management interventions which could contribute to flood management and the development of hydrological and hydraulic models of the drainage network to explore the flooding mechanisms and patterns (both temporal and spatial). It then goes on to outline the plans that the project team have for the analysis of the hydrometric datasets being collected and the options available for utilising the hydrologic/hydraulic models to improve our scientific understanding of the impacts of rural land management on flooding and flood risk.

Catchment Description

The Horner Water catchment has an area of about 22km^2. The main river of this catchment, the Horner Water, is about 15km long and drains the hills of Exmoor to the confluence with the River Aller, from where the combined river flows into Porlock Bay by seeping through a large shingle ridge. The topography of the catchment is characterised by extensive high upland moors at the headwaters (Exmoor) at about 500mAOD; with rapid response steep wooded gullies and cloughs further downstream at about 300mAOD with very confined floodplains, sloping down through woodland, grassland and arable land uses towards the low lying areas (around 30mAOD) at the confluence with the River Aller. The uppermost 20% of the Horner catchment flows through a small water supply reservoir, Nutscale Reservoir, managed by Wessex Water, which does exert a control on stream flows in this area, before it passes through a nationally important area of ancient oak woodland called Horner Wood.

The Aller catchment has an area of about $17km^2$ and the main river, the River Aller, is about 7km long. The topography of the catchment is generally lower than that of the Horner catchment, ranging from about 400mAOD in the moorland headwaters to around 40-50mAOD in the middle reach of the Aller encompassing a range of woodland, grassland and arable land uses, together with the villages of Allerford and West Lynch. The middle and lower Aller catchment contains a wider floodplain than the Horner does and in parts this floodplain has been actively managed as flood meadows in the past. On average (depending on antecedent conditions and the actual rainstorm pattern) the peak runoff from the Aller catchment will reach the confluence with Horner Water about 1 hour before the peak runoff from the Horner Water catchment.

The catchment area downstream of the confluence of the Aller and the Horner drops down from 30mAOD in the river valley to sea level, containing mostly grassland and arable land uses with woodland on the eastern valley side and the village of Bossington.

Catchment instrumentation

A comprehensive analysis of the catchment characteristics (e.g. topography, drainage network, hydrology, rainfall pattern, soils, geology, land use, land management) and the existing Environment Agency hydrometric monitoring stations (including their data records) was undertaken to determine the preferred new hydrometric monitoring network that was needed within the catchment to meet the aims of the project. A nested catchment monitoring network was chosen, with the aim to capture hydrometric data that would reflect the key sub-catchment characteristics and, as important, the likelihood of specific land use/land management change being implemented in particular parts of the catchment. The hydrometric monitoring network is shown in Figure 1, consisting of existing or new stations recording river stage (level), flow (discharge) and rainfall.

With the exception of the stage recorder just upstream from Nutscale Reservoir on Horner Water, all the newly installed river gauges and raingauges are linked to a GSM (mobile phone network) data telemetry system providing real-time data supply to the consultancy team back at the PAA offices in Derbyshire. In addition, datasets from existing Environment Agency gauges in the catchment are also linked directly to the same hydrometric database managed by the project team.

A combination of repeated spot flow gaugings, together with hydraulic modelling techniques, will be used to derive stage-discharge relationships for all the new gauging stations. This spot gauging will continue for the duration of the project.

The project team have monitored the baseline (current) conditions for nearly 2 years (2010-2011) since the commissioning of the new gauging stations. The project team now hope to be able to monitor the effects of the various implemented land management changes across the catchment over a 3-4 year period (2011-2015).

Catchment Change Interventions

A range of assessment and analysis techniques were employed to explore how hillslope runoff generation and hydrologic connectivity issues could be tackled across the Aller and Horner Water catchments. The team has also identified where opportunities exist to enhance flood attenuation functions, either in-channel, on hillslopes or on the wider floodplain areas, through targeted interventions and modifications (Figure 1). The placement of these changes has been mindful of how they might affect the hydrological response downstream, which will also be explored as part of the modelling work.

A range of potential catchment change interventions have been explored across the study area, including:

1. Moorland restoration in the headwaters – including heather restoration, grip blocking, surface drainage management (on tracks, paths and roads)
2. Woodland extension up onto the edge of Exmoor
3. Encouragement of the development of in-channel woody debris dams
4. Implementation of best practice in-bye grassland and associated soil management
5. Implementation of best practice arable soil management
6. Intervention in direct hydrological flow pathways between hillslope runoff generation areas and receiving arterial watercourses

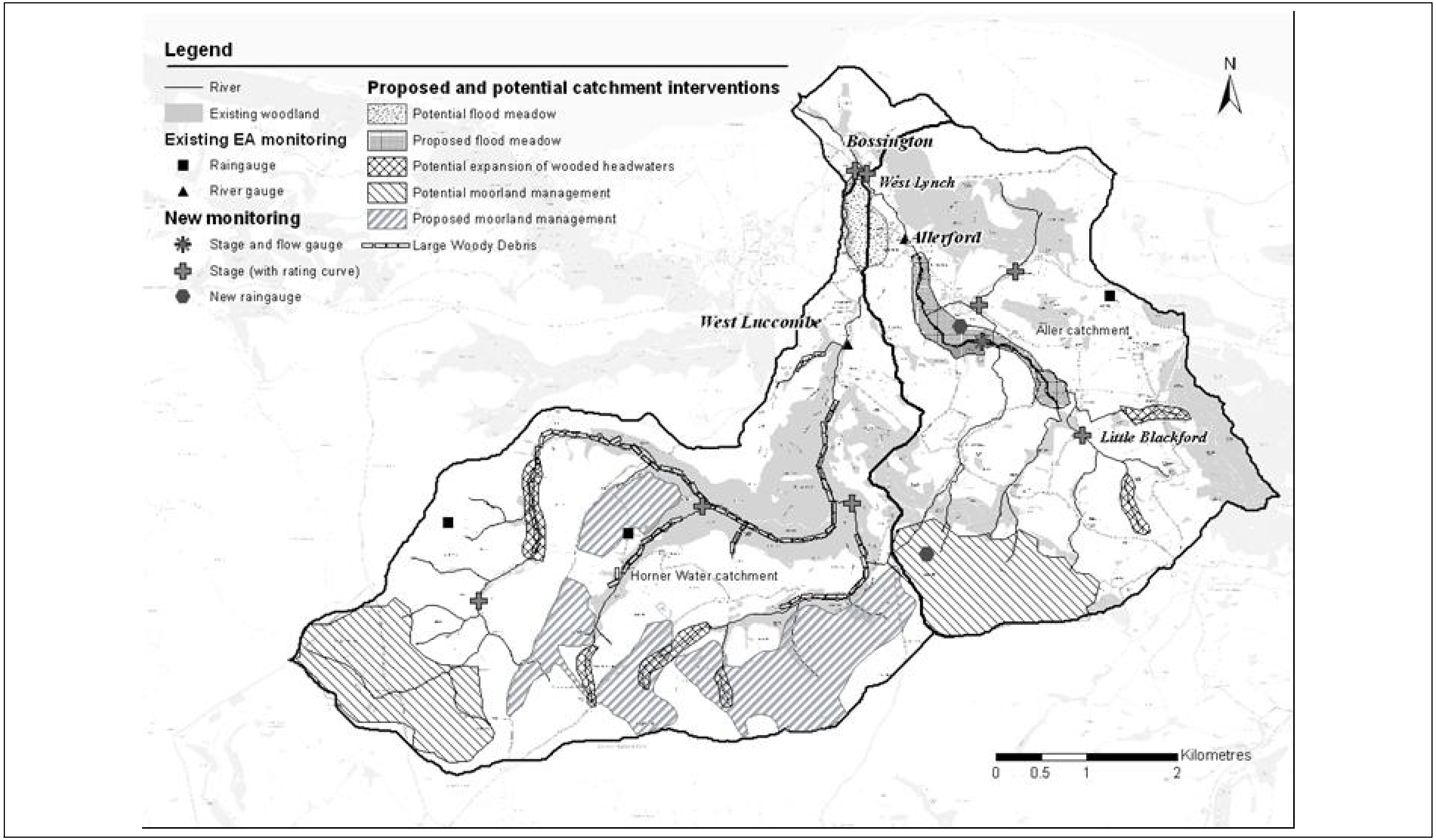
7. Creation of flood meadows on the middle Aller floodplain upstream of Allerford

Liaison and consultation with all the relevant National Trust farm tenants and other key stakeholders (e.g. Environment Agency, Wessex Water, Exmoor National Park Authority, Council Highways Department) was undertaken to determine the likelihood of individual interventions gaining support, formal planning approval and other regulatory authority consent.

For a number of reasons it has not been possible to immediately implement all the interventions listed above. The three main interventions being taken forward to date (as of November 2011), following the completion of the appropriate planning permissions and/or consenting procedures, were the surface drainage management on specific moorland areas within the Horner headwaters; the encouragement of the development of in-channel woody debris dams in Horner Woods; and the creation of flood meadows on the Aller floodplain just upstream of Allerford near Holnicote House.

Further investigations will continue to explore the possible implementation of the other interventions across the two catchments before the scheduled completion of the current project in 2015.

Figure 1. Study area hydrometric monitoring network and catchment change interventions.



Catchment Modelling

Another important element of the project is to explore the use of appropriate hydrologic and hydraulic models to represent the current (baseline) catchment conditions, validated against the new 15 minute time series flow records, and then the comparison of these outputs to those derived from models representing both actual future conditions based on the known land management changes that have been implemented in the catchments, and more theoretical future conditions implemented without constraints across parts of the study area.

Rainfall-runoff models, have been developed for the specific Aller and Horner Water sub-catchment characteristics using JBA's software implementation of the well-known Probability Distributed Model (PDM). A PDM enables not only the simulation of long periods of flow that can include both high flows and low flows but more importantly the model represents the catchment hydrological processes conceptually by a series of stores, through which water travels from when it falls as rain on the land surface to when it finally emerging as river flow. This, together with the model's representation of soil moisture store properties, enables considerable flexibility when investigating the impact of land management changes on runoff.

Hydraulic models of Horner Water and Aller have been developed (using the ISIS 1D software) based on newly acquired detailed channel and structure survey datasets of all the main watercourses in the catchments. These models also incorporate a representation of hydraulic roughness of the channel and the floodplain, and the meandering nature of the watercourses. The detailed model includes the upper, middle and lower reaches of Horner Water, together with the middle and lower reaches of the Aller, terminating downstream of the Horner Water-Aller confluence at the Bossington Beach shingle ridge. Inflows to the hydraulic models, generated by standard hydrological methods or imported from PDM outputs, are routed downstream where the combined of effects of hydraulic capacity, conveyance, connectivity and constrictions can lead to out-of-bank spilling onto floodplain areas, which are then mapped spatially using a linked floodplain model (implemented in the 2D TUFLOW hydraulic model software).

For the proposed Aller flood meadow areas a fully linked 1D-2D ISIS-TUFLOW model has also been developed in order to explore in detail the temporal flooding dynamics on the floodplain (both with and without this various design options for this scheme in place), the pathways of flood inundation, and a detailed evaluation of flood extents and depths using a Digital Terrain Model (DTM) of the floodplain.

Scientific Questions

The nature of the hydrometric monitoring network that has been set up within the study area, the high quality of the datasets being collected and the range of analysis and modelling techniques being applied will enable the project team to explore some fundamental scientific questions with respect to rural land management and flood risk, namely:

- Does a detailed analysis of individual flood event datasets and/or medium term (up to around 5 years) monitoring datasets enable us to draw any conclusions about the influence of the catchment management interventions on flood risk, both locally and downstream?
- Do observations in the catchment, including actual land management practices, help us to understand how effective targeted hillslope runoff management and floodplain interventions can be in modifying or attenuating high flows and reducing downstream flood risk?
- Can we learn anything from an analysis of flood event data about the application of hydraulic modelling techniques to plan specific floodplain interventions to maximise a flood attenuation function?
- How comparable are the findings of this project to those from other projects exploring this area of research?

Analysis

The distribution of hydrological monitoring equipment across the study area, together with our in-depth knowledge of the land management practices and hydrological processes taking place, enables us to examine both the sub-catchment effects of hillslope runoff management and flood attenuation interventions on the local flood hydrographs. Further, it allows us to investigate how these are propagated downstream through the arterial drainage network towards the flood risk receptors. The relatively short duration of the time series datasets that will be gathered over the course of the current project means that event-based analysis is likely to an important element of the analysis work as the datasets to determine long term trends will not be available.

The flow record from the Environment Agency West Luccombe gauging station on Horner Water (from 1992 to the present day), in conjunction with the local Environment Agency raingauge records in the catchment, will also be used to determine whether the current project monitoring period (2010-2015) is wet or dry when compared to the much longer term gauge records.

The monitoring datasets, both upstream and downstream of the flood meadow area, allows the linked 1D-2D modelled hydrograph outputs to be tested and compared directly to those derived from the gauge datasets being collected. This provides us with the opportunity to fundamentally test the operational performance of the hydrologic and hydraulic models being developed for this study.

A range of analytical investigations will be applied to the datasets being collected by this project or to the modelling being developed, though the final choice will be dictated by the resources available. The investigations could include the following:

1. Specific PDM parameters, reflecting both the characteristics of the soil moisture store and the runoff response function, could be adjusted to represent a number of theoretical unconstrained land management changes in order to determine scenario inflow hydrographs that can be applied into the 1D hydraulic models and routed downstream in order to assess the potential flood risk impacts in the villages
2. The PDM could be calibrated to the pre-change catchment characteristics (including gauged hydrographs) and compared to a PDM calibrated to post-change catchment characteristics. The analysis would explore how particular PDM parameters (e.g. representing the rate of response during either the rising or falling limbs of hydrograph) vary between the pre- and post-change scenarios. This will allow us to evaluate the degree of change within the context of the PDM parameters and then the application of these changes in further modelling of the potential impact of land management changes.
3. An application of standard Unit Hydrograph (UH) assessment techniques could be used to derive 'standardised' UH parameters (e.g. Lag, Time to Peak and Time to Rise, etc.) for pre-change and post-change conditions. This would allow any differences in spatial and temporal variations in rainfall patterns over the period of record to be removed from the analysis of the collected data.
4. Development of a simple spreadsheet based tool to test a range of the hydrological response variables (plus additional ones, if appropriate) put forward by Grayson *et al.* (2010)[5] on an existing hydrological time series dataset from a site where there has been monitored changes in land management (e.g. United Utilities Sustainable Catchment Management Project) in order to determine its potential applicability to the Holnicote datasets towards to end of this current project.
5. Exploration of the potential application of the flow variability indices method developed by Archer *et al.* (2010)[6] to quantify rates of change in flow and how these might respond to land management change.

Implications for Practice and Policy

It is hoped that the project outputs, both from practical experience gained and scientific analysis undertaken, will contribute to the wider understanding of catchment management issues with respect to flood risk and help to answer a number of important questions, such as:

1. Does the scientific evidence support any conclusions about what are the most cost-effective, practical, robust or achievable catchment management strategies to maximise a flood attenuation function, whilst also delivering other benefits to society?

[5] Grayson, R., Holden, J. and Rose, R. (2010). Long-term change in storm hydrographs in response to peatland vegetation change. Journal of Hydrology, 389, 336-343.

[6] Archer, D.R., Climent-Soler, D. and Holman, I.P. (2010). Changes in discharge rise and fall rates applied to impact assessment of catchment land use. Hydrology Research, 41.1, 13-26.

2. What lessons can be learnt about the practical, organisational and policy opportunities or barriers to the implementation of catchment management measures?
3. What modelling and assessment methods (including ecosystem services) are suitable to support policy, planning and decision making for this type of catchment management?

The implementation of larger scale land management interventions across the rural landscape, in or near watercourses, or on functional floodplain areas requires the careful consideration of all the local environmental, landscape, infrastructure and heritage constraints, and the successful completion of all the relevant planning and/or consenting requirements. This may require a considerable amount of consultation and dialogue with a range of stakeholders in order to adequately address and respond to particular issues, concerns and conflicts. Early and open consultation including, whenever necessary, face to face discussion meetings appear to provide the most effective process by which proposals of this nature can be considered by the appropriate planning and consenting authorities.

What Next?

This paper has set the scene for the work planned by the JBA and PAA project team over the coming 3 years at Holnicote and highlighted the opportunities that are present here to contribute to an important debate of national relevance in flood risk and catchment management.

In particular we want to draw attention to a number of significant benefits that will be achieved over the medium term, as follows:

- The continued monitoring in the catchment will over time generate an important scientific resource. This needs to be valued and used for maximum benefit, with appropriate custodianship and management of the information and datasets that are being collected.
- The managed implementation of interventions in the catchment, alongside the purpose-designed monitoring programme, should become an important test-bed for analytical techniques that could contribute valuable knowledge in this area.
- By working through the process of managed catchment interventions, the study will also generate operational lessons that will have wider relevance for policy and practice.
- The lessons learnt during the critical stakeholder engagement and consultation processes, during both the planning and implementation of any interventions, should be helpful to future projects charged with developing similar catchment management initiatives.