Opportunity mapping of natural flood management measures: A case study from the headwaters of the Warwickshire-Avon

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Opportunity mapping of natural flood management measures: a case study from the headwaters of the Warwickshire-Avon Grammatically, should the title read: Opportunity Mapping of Natural Flood Management measures: a case study from the headwaters of the Warwickshire-Avon

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Abstract

The use of natural flood management (NFM) measures to address severe flooding received considerable public attention during December 2015–January 2016 storms. Within the Warwickshire-Avon Catchment, UK, high arable and improved grassland land cover with small, isolated communities at risk, lead to the exploration of novel techniques that use farmland high up in flood-prone catchments to hold water and reduce outflow discharge. This paper will discuss the methodology used to identify areas in the Warwickshire-Avon, which could be used to install NFM measures to attenuate the storm peak and provide wider ecosystem services, principally addressing total phosphate and sediment entering the receiving watercourse. This involved constructing a GIS database of catchment geomorphological characteristics whilst simultaneously engaging with those significant stakeholders of farmers and landowners to capture local input and produce a model for applied NFM for future projects looking to explore the role of working with natural processes (WwNP) for flood risk reduction within the agricultural environment. The advantages, disadvantages and key lessons learnt are also presented in this paper, to recognise the benefits and limitations of communities and catchments exploring such methods for flood risk management (FRM).

Keywords

Natural flood management
Opportunity mapping
Engagement

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Introduction

Natural flood management (NFM) is defined here as techniques used to manage flood risk by altering, or enhancing, natural processes in a catchment (Dadson *et al.* 2017). This broad term applies to multiple identical practices examining the role of the rural environment to manage downstream flood risk, also referred to as natural water retention measures (NWRMs) in continental Europe and nature-based features in the USA. Scottish Environment Protection Agency (SEPA) (2016) recognised there are two fundamental methods that either *restores* a system to a more 'natural' state, e.g. reintroduce meanders of straightened watercourses, and/or *alters* the existing function of the farmed scape for the purpose of flood risk management, including attenuating runoff and increasing hydraulic roughness (Nicholson et al. 2012; Blanc et al. 2012; Woods-Ballard et al. 2015) via:

1. Retaining water in the landscape: water retention through management of infiltration and overland flow, as well managing conveyance and hydrological connectivity

2. Making space for water: floodplain conveyance and attenuation, providing 'room for the river' and its floodplains in times of heavy rainfall (Fokkens 2007).

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Recent reports, notably the Environment Food and Rural Affairs (Efra) committee (2016), have built on responses to large events, including Pitt (2008) after July 2007 summer floods and the subsequent Flood and Water Management Act (2010), recognising that *defence* to the relatively unknown of climate change scenarios is not feasible, and a long-term strategy to managing flood risk across a catchment scale is needed (EU Floods Directive 2007 and Avery 2012). Furthermore, many of these 'defensive' strategies are not engineered in a way to capitalise on multiple-benefits, failing to consider the holistic approach required in current flood and coastal erosion risk management (FCERM). Therefore, emerging interest has been placed on supplementing defensive structures with NFM features. These supplemented measures would be located in the upper reaches of catchments, across the agricultural environment, and thus require a great deal of support from landowners and farmers.

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Furthermore, O'Connell et al. 2004) raised concerns of how the agricultural environment has been managed in recent decades, with local scale (> 10 km^2) evidence of the implications from degraded soils, reduced capacity for infiltration and ultimately greater runoff into ever increasingly incised watercourses. Modern tillage practices, under-drainage and field enlargement that removed historic and established hedgerows have also represented more intensive farming practices that cultivate year round if arable, or higher stocking densities if pastured grassland (O'Connell et al. 2007). However, it is worth recognising there is still a great deal of uncertainty of such implications to flood risk across larger hydrological scales (< 100 km^2) (Dixon *et al.* 2016)Odoni 2014), and therefore a greater need for empirical evidence to illustrates NFM performance to multiple flood risk scenarios at larger catchment scales (Parrott et al. 2009).

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Whilst there has been a recent uptake in public interest around these techniques, it must be recognised that these structures and practices are not new in terms of international agricultural land drainage and catchment management (Defra 2004 and Waylean *et al.* 2017). However, what all of these studies have a common is the superseding 'opportunity mapping' scope prior detailed hydrological or hydraulic modelling, to characterise and inform what features can be installed in precise locations (Hankin et al. 2016). The River Tay employed an opportunity mapping study to identify suitable locations for woodland creation to improve water quality and reduce flood risk (Broadmeadow et al. 2013). The catchment is impacted by a number of water issues, principally 26% of rivers and lochs failing good ecological status (GES) under the Water Framework Directive (WFD) (European Commission, 2000), as well as considerable flooding issues, with over 1300 residential and 270 non-residential properties at risk. The assessment undertaken to produce to opportunity maps where based upon the

Environment Agency's method for the identification of catchments sensitive to land use change (Environment Agency 2008).

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This method recognises there are four key parameters that enhance downstream flood risk and agricultural runoff; land cover, soil type, slope and standard average annual rainfall. These were ranked based on significance in enhancing risk accordingly to generate a map at the resolution of 250 m × 250 m grid cells, to show areas of medium and high potential for runoff reduction to strategically inform where NFM features could be most effective, but not to direct opportunities of where features could be installed, and require full cooperation of landowners to be installed. This method was reflected in the Environment Agency NFM Toolkit ~~(in press),~~ and guidance on how to map and model catchment processes (Hankin et al. 2016) using remote data to target areas for land use alteration but reflecting on the need to have local stakeholders informing the scope and decision-making.

The element of local engagement is commonly under considered in NFM scopes, preventing landowners and farmers participating in early phases of opportunity mapping. Waylean et al. (in press) found that overall uptake of NFM had been poor in targeted areas in Scotland due to a multitude of reasons, principally economic incentives and reservations around long-term ownership, management and maintenance. In addition, the Centre for Expertise of Waters (CREW) recognised that early engagement can assist in supporting farmer's decision making and support a process that enables farmers to be more receptive to the idea of altering their land and practices with NFM (Holstead and Wilkinson, 2013).

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Examples of participatory approaches used in flood risk planning are well report reported (Demeritt and Nobert, 2014), with some methods applied to scoping NFM features in targeted catchments. The Tweed Forum found that participatory mapping of NFM features with the farmer and landowner greatly informed the schemes whilst simultaneously supporting the likelihood of uptake (Forrester and Cinderby 2012). Methods of participation include open workshops allowing farmers to collaboratively identify particular problem areas across their holdings (e.g. high overland flow routes, points of ponding, etc.) and particular features that would not impact their business.

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In North Yorkshire, the River Laver and Skell catchments are an example of participatory approaches, in which farmer's perceptions of NFM were explored using the Floods and Agricultural Risk Matrix (FARM) tool (Posthumus, 2008 and Quinn, 2007) during stakeholder workshops. Farmers had found these features to be beyond good farming practice and something outside of landowner responsibility. Hence, research and delivery gaps around WwNP have sort to better understand methods and means of trying to encourage farmers in these targeted areas of the catchment to deliver NFM features (Barlow et al. 2014). This paper provides an overview of a scoped NFM scheme in a particular target sub-catchment in the headwaters of the Warwickshire-Avon, using remote data sources and on the ground input from a participating landowner to agree an NFM scheme to implementation.

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Study area

The study catchment (see Fig. 1), which lies in the Warwickshire-Avon, UK, was chosen as the focus for the investigation due to the long history of frequent flooding to small downstream towns and villages, including Chipping Campden, Blockley, Paxford, Cherington, Lower Brailes, Long Compton and Shipston-on-Stour that individually do not qualify for large-scale Grant-in-Aid hard engineered schemes to provide alleviation from fluvial and pluvial flood risk (Capita Symmonds 2010). The headwaters catchment extent is 187 km^2, and consists of three major sub-catchments, in order of size; Knee Brook (85 km^2), River Stour (68 km^2) and Nethercote Brook (34 km^2).

Fig. 1

Study catchment, headwaters of the Warwickshire-Avon (Rural), UK. Data contains OS Data © Crown Copyright and Database 2016

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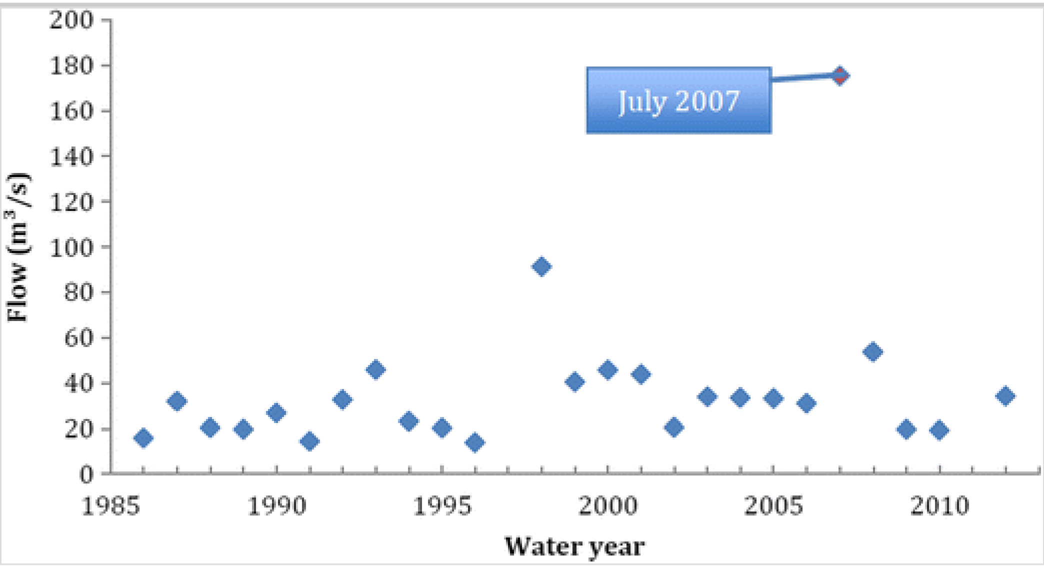
The catchment is predominantly rural with mixed arable and grazing land, mostly arable cereal crops in the uplands and improved grasslands sheep and cattle grazing in the lowlands. The highest point of elevation is sourced at the headwaters of the Knee Brook (245 m AOD) before it follows approximately 12.2 km before reaching the downstream extent, Shipston on Stour, to the river flow gauge (number 54106). The river alters typology drastically across the catchment. In the eastern and western headwaters, it is fed by spring sourced ephemeral streams, further north (downstream) the channels become incised (some of which straightened) (Environment Agency 2008), and greatly constricted by culverting, gardens, walls, fences, hedges and residential structures within the towns and villages. Giving rise to a flashy flood response inundating properties and businesses and generating ‘muddy’ flows (Capita Symonds 2010).

The standard average annual rainfall for the catchment is 723 mm (data sourced: FEH 2016), with soil conditions greatly influenced by the underlying hydrogeology, land use and geomorphology that arises to general flashiness of the runoff regime. The pedology of the area, determined by the Hydrology of Soil Type (HOST) series (Boorman et al. 1995), classifies the headwaters the be comprised of the Cotswold Escarpments free draining limestone (HOST class 2 at 18%) and the downstream extent to be largely impermeable heavy clays (HOST 20–65%), with the remainder includes silty alluvial deposits within the floodplain, some of which slowly permeable (CEH 2016). As we enter a ‘flood rich period’ (Dadson et al. ~~in press~~2017) in our climate across the Severn River Basin District, a rise of perception that flooding has increased (supported by peak over threshold data, Fig. 2) has led to local communities looking to find cost-effective solutions. However, whilst there has been historic alterations to the fluvial profiles, land management practices and several unusual prolonged and intense rainfall events (notably, July 2007 and December 2012), it is difficult to identify the critical cause between land use change, natural climatic change or urban creep (Beven et al. 2008).

Fig. 2

Peak over threshold analysis, Shipston on Stour Gauge, outlier July 2007



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This study used a proactive and integrated approach with local landowners and communities to target and subsequently engage prioritised sub-catchments that generate high levels of runoff from upstream agricultural land cover. The Defra Pathfinder Project (Twigger-Ross et al. 2015) provided a platform to engage with local communities and farmers around their land management and drainage practices. This study does not highlight the modelled assessments as part of the latter phases of research, but aims to provide future projects with an exemplar of how to collaborate with upstream farmers when seeking to deliver NFM options. The motivation for this study was to explore the role of using remote data and early engagement to identify potential locations and achievable features to slow, store, disconnect and filter flows. Whilst performance is being assessed through further modelling, the need for a collaborative scope using informative data provides a platform to generate a more holistic catchment approach.

Identifying NFM opportunities: local scale example

This section will highlight the steps taken to scope and subsequently engage farmers and landowners around NFM, using the Cam watercourse as the local scale example, with an area of 5.6 km^2 as a sub-catchment of the Knee Brook, headwaters of study site. There were three phases to the screening of interventions, adapting existing screening methods employed in Scotland (Scottish Environment Protection Agency (SEPA), 2016), Belford, Northumbria (Nicholson et al. 2012) and applied with Woodland for Water data sets (Spence 2015 and Broadmeadow et al. 2013) to incorporate more participatory methods:

I. Physical characterisation: Broadly characterising the catchment area in terms of relief, pedology, geology, hydrological contributions, channel network and hydrology, including flood history and water quality pressures.

II. Land cover and use analysis: Further analysis of historic and current land cover, including existing attenuation features picked up from habitat action plans (e.g. buffer strips) and aerial imagery, including reconnaissance surveys with the landowners and farmers to collaboratively identify 'problem areas', those areas with high levels of overland flow (ground truthing LiDAR and updated flood maps for surface water). As well 'opportunities', those locations suitable for particular features from portfolio of donor catchment studies.

III. NFM overlay: Opportunities overlain on map and presented to farmer/landowner.

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The cam The Cam

Prior engaging the landowner, it was imperative to remotely assess the sub-catchment area via a physical characterisation. This includes delineating the sub-catchment feed to consider its relief, hydrological contributions, geology, pedology and indicative land cover. This assessment involved a degree of 'data mining', the process to which data is extrapolated and explored so it may be utilised for suitable outputs. These outputs produced a series of base-maps (outlined in Fig. 3), that enabled a clear platform to which the farmers and landowner can be engaged and collaboratively discuss their holdings in relation to flood generation, propagation and the role of NFM. By discussing maps of the estate in relation to drainage and hydrological contributions, all stakeholders were able to comment and provide detailed insight into different contributions, either overland, sub-surface piping and in-channel. Wider influential land management issues were also discussed including hedgerow cutting, coppice routines, margin widths and any tillage practices. Whilst predominantly arable, it was identified the farms do not practice tillage and margins were left ≥ 8 m from all ditches and watercourses, most of which were included in the lands Higher Level Stewardship agreement. Therefore, as part of the collaboratively scoping, these agreements were also discussed by the landowner to ensure any NFM proposals do not generate permanent ineligible features (PIFs) that could incur fines on the farm. Further consultation with Natural England was required.

Figure 3.

NFM Opportunity Mapping stages, **a**) LiDAR and surface water flood maps, **b**) Hydrology of Soil Type (HOST) class, **c**) Bedrock geology, **d**) Land Cover (LCM2007) and, **e**) Participatory Mapping outputs, including landowner comments to inform prioritisation and section of features across estate. Data contains: OS Data © Crown Copyright and Database 2016, CEH 2016 and BGS 2016. contains: OS Data © Crown Copyright and Database 2016.

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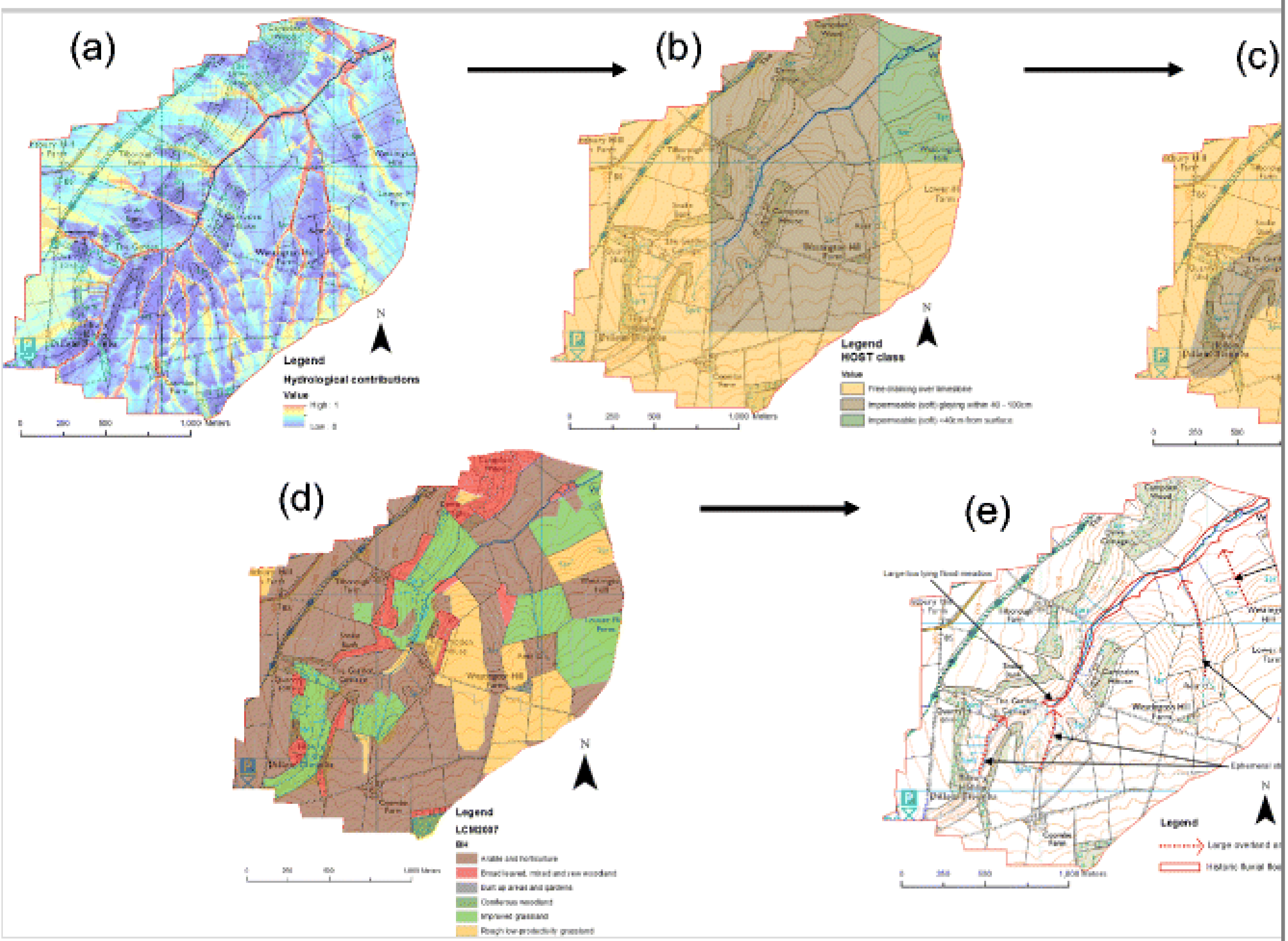
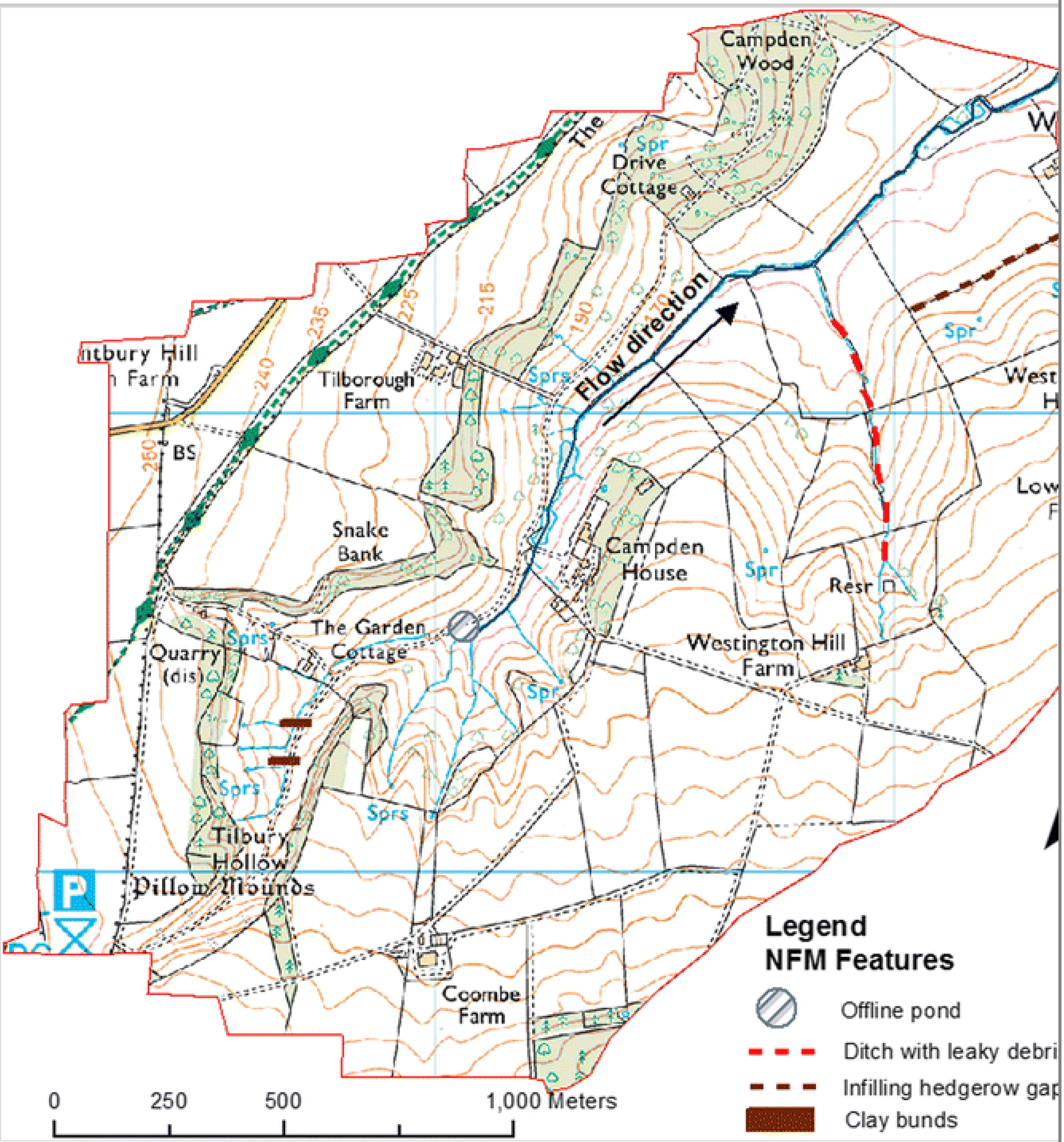


Key data sources for the base-mapping elements included LiDAR, Land Cover Map (LCM) 2007, Hydrology of Soil Type (HOST) (Boorman et al. 1995; Centre for Ecology and Hydrology (CEH), 2016a), Bedrock Geology (British Geological Society 2016), Ordinance Survey MasterMap Water Network (OS 2016), aerial imagery (Google Earth 2016), Flood Risk from River (FRfR) and Flood Risk from Surface Water (FRfSW) data (where available). Figure 3 outlines the series of maps presented to the landowner during the second phase of Opportunity Mapping to inform greater land cover ad use analysis. The maps were annotated before and after an extensive field-walk of the estate, outlining the areas of greatest runoff, early use of floodplain and potential locations for NFM opportunities that would not infringe on current Environmental Stewardship agreements and productivity of the farm business. The annotations were collated and presented to the landowner in a single coherent map that includes site images, Fig. 4, outlining possible features in precise locations. This method enabled a useful means of utilising local knowledge from the landowner in terms of key runoff pathways, points of erosion, incision and areas of limited infiltration, whilst also presenting NFM options to address these hydrological issues.

Fig. 4

NFM Opportunities. Data contains OS Data © Crown Copyright and Database 2016



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Proposals

The opportunities for NFM across the Cam sub-catchment are outlined in Table 1 and Fig. 4. These features were situated to intercept runoff and increase floodplain/channel interactions during high flow periods, identified from flood depths and extents. They are ideally positioned in areas of high surface connectivity or areas where the river and floodplain are able to interact to increase lag-times of peaks with earlier use of the adjoining floodplain (Environment Agency, 2017). The overall scheme was proposed to slow, store, filter and disconnect the storm flow that enhances downstream flood risk to Chipping Campden and further downstream settlements. Ultimately, by affecting the flood generating parameters at the source of the Cam it would reduce to peak downstream, as demonstrated in Eq. 1, in which features aim to reduce the frequency with which river stage (h) exceeds the critical threshold (h_c) at which flooding creates risk (lane 2017).

$$h = Q\left(\frac{1}{wV}\right) + Z_b \tag{1}$$

Table 1

NFM proposals, including ~~gird references and~~ hydrological functions combined with some wider benefits sort in the design phase

Features	Functions
Clay bunded soakaways	To intercept ephemeral and overland flows in sheep grazed grassland. Allowing baseflow to continue unimpeded but becoming active in larger storms, spreading flood flows onto adjacent floodplain with greater propensity for filtration. These features also aim to remove sediment from the flush of a storm peak travelling downstream.
Offline attenuation pond	Divert peak channel flows onto adjacent floodplain, increasing the volumes and levels of water within the floodplain and increasing the lag-time of the peak. This feature also aims to increase habitat provision for farmland wading birds, including Common Snipe, a particular target breed for Gloucestershire and Cotswold AONB.
Leaky debris dams	To intercept peak flow travelling through a trapezoidal ditch, entering the Cam watercourse. Allowing baseflow to continue unimpeded but intercepting peak flow and altering afflux level of channel flow. This These features also provides provide perches for aquatic mammals, e.g. otters and watervoles.
Hedgerow filling	Gaps in hedgerows provide conduits for overland flows, in-filling the gap provides a green buffer that intercepts ~~clear~~ flow routes entering the watercourse. These routes also carry diffuse pollutants including total suspended solids (sediment) and phosphates enhancing eutrophication, whilst increasing farmland habitat.

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Reduction of discharge (Q) indicates a manipulation of upstream flows, in which strategically NFM aims to reduce h in the proximal downstream settlement during the flood peak. The proposals aim to achieve this reduction in peak via online and offline storage methods, as well as increasingly land use roughness (Manning’s n value) and encouraging more natural stream processes (Metcalfe et al. 2017 and Shaw et al. ~~2010~~2011). The features have been consented under the

Land Drainage Act (LDA) 1991, in accordance with Ordinary Watercourse regulations reviewed by the local authority due to their function in impeding and altering channel flow. A further incentive that ascertained approval from the landowner was the additional aim to improve habitat provision for farmland wading birds (e.g. common snipe) and aquatic organisms by reducing sediment loadings and phosphates (enhancing eutrophication).

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Reconnaissance survey: site images

The application of NFM is widely recognised to be a 'grounded' approach, in which opportunities must be visualised on the ground with the necessary stakeholders in order to encourage uptake and implementation (Waylean et al. ~~in press~~2017). Figure 5 highlights the different parts of the sub-catchment in which NFM is being implemented, with supporting reconnaissance survey images.

Fig. 5

Site images, indicating locations to be implemented with NFM. Data contains OS Data © Crown Copyright and Database 2016.

Figure 5a illustrates an ephemeral stream underlain by Oolite limestone and sheep grazed pasture, highest elevation at 262.4 mAOD with high levels of overland flow. Figure 5b provides and overview of the large offline attenuation area, as the lower lying area of floodplain, increasing volumes and levels in peak by enforcing spillway that is active at critical height of specific event. Figure 5c trapezoidal ditch with high flow rates from arable fields potential for leaky debris dams, height of intercepting debris set by historic high water marks assessed on site with landowner discussing previous events. Figure 5d indicates the gap in the hedgerow to which arable fields and steep relief contribute overland flows to receiving watercourse.

Discussion

GIS scoping and engagement as part of this study reveals a high number of landowners and farmers to be interested in implementing NFM features across their holdings. Of the 13 estates and holdings engaged in the catchment area, 12 have agreed to implement interventions that aim to reduce hydrological connectivity between the farmed scape and the receiving watercourses. These positive responses illustrates many farmers are sympathetic to downstream flooding and consider making small changes to their practices in order to manage an ever increasing problem for downstream communities and their businesses, in terms of soil loss, erosion and wider water management. As similarly found from previous engagement studies, including Posthumus, 2008) in North Yorkshire, Holstead et al. (2016) in the Scottish borders and extensive workshops in Scotland conducted by Holstead and Wilkinson (2013), this project has highlighted that farmers could be willing to make changes to their land for flood risk and wider environmental benefits, if appropriately engaged in the early stages of the project design to ensure local input. Furthermore, many of these farmers agreed post implementation, they would accept management and maintenance responsibilities. This crucial responsibility is a clear concern for many looking to explore such schemes, with reservations of what were to happen to features and river flows if left unmanaged (Wheater et al. 2008). In terms of total storage and standards of protection provided by these features, further assessments are required to quantify the overall effectiveness, for example, if the aim is to alleviate the 1 in 100 year flood with inclusion of climate change allowances, additional modelling and sustained monitoring would be required to inform if further features are required to meet necessary design standards.

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Conclusion

The upper Warwickshire-Avon catchment has been impacted by multiple floods over the past 60 years. Whilst it is not possible to recognise the ultimate cause of increased flood risk between enhanced climatic-influenced flood-rich period, urban creep or agricultural land use change, the exploration of NFM offers at the catchment scale the platform to better understand the sources and pathways of flood flows and proactively seek to reduce their effects. The small communities do not qualify for Environment Agency Gant-in-Aid to invest in a large hard-engineered infrastructure scheme. The method discussed outlines a targeted approach, with an exemplar shown of a hydrologically downscaled sub-catchment. A key output from this project is that the decision about how many features required and where they can be situated, whilst a technical quandary that the project is exploring through further modelling and monitoring networks, must first be approved by the landowners and farmers, and thus reliant on their 'good will'. The lack of recognition of this fact prevents an acceptance that farmers are the foundation of any catchment-based NFM project, and without their input and ultimately support alteration for flood risk and wider environmental benefits cannot be undertaken. The drive to adopt NFM reflects a considerable interest from landowners, astute to a changing political and scientific consesus, willing to accept various changes to their land use to ameliorate downstream flood risk and meet wider environmental interests. However, adopting new practices is associated with new challenges and this study indicates that without considerable explanation and local engagement early in the scheme, uptake will be hindered. Better links between research, policy and practitioners seems essential in sharing learning and providing lessons on incentivising landowners to alter their land use for NFM purposes. In regards to this research, such a platform has provided a means of collecting future long-term, tangiable quantiative evidence around the performance of features to multiple flood risk scenarios to be explored in further works.

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Compliance with ethical standards

Competing interest The authors declare that they have no competing interest.

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