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Capturing the multiple benefits associated with nature-based solutions: lessons from a natural flood management project in the Cotswolds, UK

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Abstract: Following severe flooding in 2007 a decision was taken in 2012 to explore nature-based solutions in 250km2 river catchment in the southern Cotswolds in the UK. The project involves working with landowners to create in channel, riparian, field and woodland structures aimed at attenuating high flows or increasing infiltration rates to reduce flood risk. After three years it is clear that the threshold for effectiveness requires the implementation of measures throughout large areas of the upstream catchment. Early results suggest that social, as well as natural, capital has been enhanced through the project. What is clear is the beneficial role of working with multiple stakeholders to implement natural flood management on a catchment wide scale. In this sense the project has adopted a co-management approach which brings together the knowledge of hydrologists, ecologists, farmers, woodland owners and the local community to implement locally agreed solutions within a broader project framework. This paper will outline the initial findings and the governance structure within a theoretical framework of co-management and suggest how this type of framework is suitable for a range of nature-based solutions across Europe. However, the challenge remains in capturing the multiple-benefits that such projects offer as these are often missed through conventional approaches like cost-benefit analysis. The paper concludes by presented along with a potential way forward for a proof-of-concept for nature-based solutions.

Key words: adaptive co-management, Europe, natural flood management, nature-based solutions, stakeholder engagement

1. Introduction

Nature-based solutions (NBS) are the latest in a number of terms that are beginning to influence policy debates on urban regeneration (Marton-Lefevre, 2012; Kabisch *et al.,* 2016), responses to climate change (Cohen-Shacham *et al.,* 2016; European Environment Agency 2017) and sustainable development (Maes & Jacobs, 2015) as well as nature conservation (Eggermont *et al.,* 2015; IUCN 2016). As with many new terms it lacks a clear definition (Potschin *et al.,* 2016), but its presence within the European Commission's (EC) Horizon 2020 Societal Challenge 5 'Climate Action, Environment, Resource Efficiency and Raw Materials' programme (EC, 2015) and as a key programme for a major conservation NGO (IUCN, 2016), means that it is a term that will be receiving significant attention for the next few years. In general, NBS is considered to be a broad definition covering the conserving, enhancing and use of biodiversity by society in a sustainable manner, while also integrating social factors such as socio-economic development and effective governance (Balian *et al*., 2014; Cohen-Shacham *et al.,* 2016). The EC defines NBS to societal challenges as 'solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience' (EC, 2015).

NBS is most often used as a term to signify an approach for increasing resilience to the impacts of climate change and has been a focus of World Bank investment in climate mitigation and adaptation projects (MacKinnon *et al.*, 2008). The IUCN has also explored the theme of 'Nature+', which highlights the role of nature in enhancing resilience in areas of meteorological risk to society such as flooding, coastal erosion and drought. This has been incorporated into the NBS priority programme area within the IUCN who view NBS as a way of applying the strength, resources, and abundance of nature to global environmental and social challenges (IUCN, 2016). The IUCN define NBS as actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, 2016).

There is the added benefit that NBS solutions are able to increase natural capital and the provision of ecosystem services and are therefore promoted as 'win-win' solutions (IUCN, 2012). In this sense NBS is an eye-catching phrase as it clearly links nature and society and offers a 'solution' to challenges that are frequently discussed across Europe, and globally. Balian *et al.*, 2014 identified the knowledge gaps around NBS, these included: systematic assessment of economic, social and environmental benefits; developing indicators and cost-effective assessment of NBS; and, exploring the political and social resistance to NBS. The need for transdisciplinary methods and participatory approaches to share the lessons on NBS was also stressed.

The aim of this paper is to examine key aspects of NBS implementation, both social and environmental, through an example from a medium-sized UK river catchment that implemented natural flood management (NFM) practices to reduce flood risk. The objective is to examine environmental data, such as changes in peak flow across the catchment, as well as assessing the cost-effectiveness of interventions and combined social and natural multiple benefits. We will be referring to those NBS that focus on introducing natural and semi-natural structural changes on land used for agriculture and forestry, and are designed to enhance resilience and reduce flood risk to people and property. The principles concerning both governance and changes to land management that are presented are relevant to wider NBS settings.

It is important to outline the connection between NBS and NFM. Throughout this paper the term NBS is used to describe soft engineering approaches that are aimed at increasing the resilience of territories and societies affected by meteorological events and therefore reducing the economic, functional, cultural and social damage disruption that such events cause (Potschin *et al.*, 2016). The term NFM is used here to refer to the utilisation or restoration of 'natural' land cover and channel-floodplain features within catchments (i.e. the actual interventions) to increase the time to peak and reduce the height of the flood wave downstream and is therefore a sub-set of NBS.

In Europe flood risk management has traditionally been dominated by technical driven approaches, resulting in engineering flood defense schemes to control and drain water (Cook *et al.,* 2016). In western cities, grey infrastructures have often been adopted to also handle runoff water, often resulting in increasing flood risk with highest "rate of storm water due to climate change and soil sealing" (Davis & Naumann, 2017, p.124). As a consequence of major flood events, climate change adaptation and societal pressure, a sustainable flood management approach emerged as a "philosophy which prioritises risk reduction through a range of measures that can include structural measures, but are more economically and environmentally sustainable than relying on structural measures alone" (Waylen *et al.,* 2018, p.S1078). According to Wayen *et al.* (2018) this new approach includes NFM alongside related terms, such as "Making space for the river", "Working with Natural Processes", "Working with Nature", "Ecosystem-based Flood Risk Management" or "Engineering with Nature". NFM may involve altering multiple elements of a catchment water balance by promoting interception, infiltration and groundwater storage, enhancing water losses through evapotranspiration, lengthening hydrological pathways and increasing flow resistance (Iacob *et al.*, 2014; Forbes *et al.*, 2016).

In this sense both NBS and NFM are inclusive terms that outline the overall purpose of restoring and enhancing the natural functions of catchments, landscapes and coastal regions. The concept of NFM is to enhance catchment processes and to reduce flood hazard, while also sustaining or enhancing other potentially significant co-benefits including enhanced ecosystem services. These include biodiversity, improved soil and water quality, carbon sequestration, reduced soil erosion, agricultural productivity and improved public health and well-being (Dadson *et al.,* 2017).

A key similarity between NBS and NFM is that they are place-based responses requiring integrated spatial management, with activity spread over a significant area. As a result they are likely to require dialogue with local communities, landowners, land managers and risk management officers to achieve the threshold of interventions that will provide the required impact to reduce risks from water-based natural disasters (SNH, 2010). Whilst NBS and NFM offer new opportunities and bring added-value, they both encompass existing ideas and require the inclusion of local knowledge and lessons from the past (Eggermont *et al.*, 2015). It is therefore important in both initiatives to use all relevant sources of expertise and knowledge when developing and implementing interventions, and to identify the lessons-learned within and across local projects (Nesshöver *et al.*, 2017). Consequently, this paper utilizes a trans-disciplinary approach to report on an NFM initiative covering the physical and social characteristics and interdependencies from one hydro-meteorological risk perspective. This approach enables the quantification of the effectiveness of an existing NBS project, permitting the operationalisation and replication in different local situations. The intention is that this will allow similar NBS and NFM projects to become both widely accepted and incorporated in policy development and in practical implementation.

The introductory section of the paper has explained what connects NBS and NFM by showing how the NFM activities fit within the NBS framework. The Materials and Methods section outlines the study site, providing background and key details to the project, including the governance structure and examining the interventions that have been implemented. The Results section presents the evidence of change in the catchment after three years. The Discussion assesses the challenges of defining 'success' in NBS projects, including the issues of causality and measuring effectiveness of NBS interventions. Here the task of attributing resulting changes to the approach taken can be difficult and it is important to assess the role of co-management in terms of decision-making and the contribution of different knowledge to implementation of NFM and NBS. In the final section the role of governance in NBS is outlined alongside the need for an adaptive co-management approach in order to capture the multiple benefits resulting from NBS. A proof of concept for NBS is proposed that can be tested on other NBS projects.

2. Materials and Methods

2.1 Study site

The study site is located in the catchment of the Stroud River Frome (referred to as the Stroud Frome (SF) Catchment from now on) in South West England (Figure 1). There are several major towns within the SF Catchment, including Stroud (population of 13,000), Painswick, Nailsworth and Stonehouse, as well as a large number of villages and smaller settlements (estimated total SF Catchment population 80,000). The SF Catchment drains into the River Severn (one of the major rivers in the UK) and lies within the protected lowland landscape of the Cotswold Area of Outstanding Natural Beauty, which is characterised by permanent pasture and broadleaved woodland in steep valleys and flat topped hills with both arable and pasture on upper plateau. The soils are thin calcareous clays and loams overlaying Jurassic Oolitic Limestone and the area has a mean annual rainfall of 679 mm.

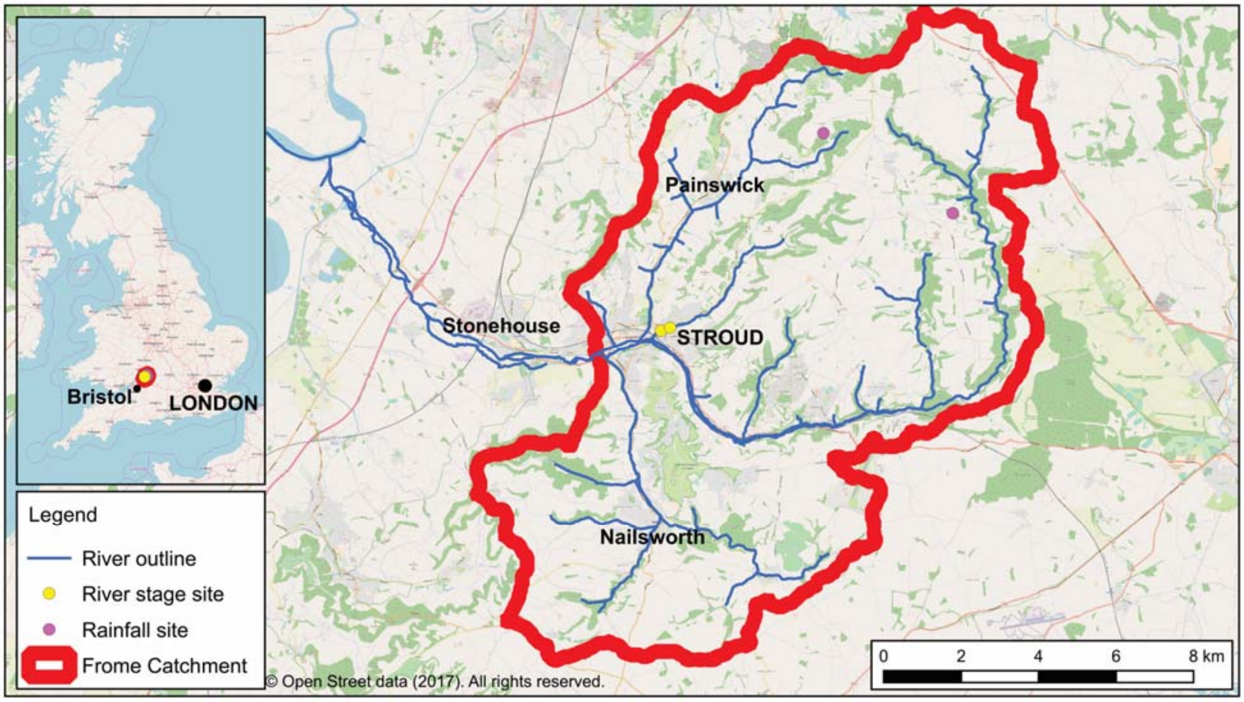

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Figure 1: Location of NBS case-study contained within the Stroud Frome catchment (outlined in red) and its position within the UK

For centuries, the SF Catchment has been used for drinking water, agricultural and industrial purposes resulting in numerous physical modifications to manipulate and control flow. Many of these remain in place but off-line and derelict, with the Lower Frome remaining heavily industrialised. There is increasing and ongoing residential development of former industrial sites and mill buildings. The key water use in the Frome today is local drinking water (within the SF Catchment and the nearby city of Bristol). The SF Catchment was designated as a Drinking Water Protection Zone by the Environment Agency (EA) in 2016 to ensure water quality is safe for public supply.

The upper river valleys are narrow with natural flat valley bottoms, which were historically adapted to provide storage pools for mills, dwellings and farms. Tributaries were also developed for water-powered industry, and this is still evident with complex networks of mill leats and artificial channels, storage pools or pipes. The functional retention of the numerous mill pool systems remains important from a heritage and aesthetic viewpoint. Throughout the SF Catchment, many spring outflows have been adapted and impounded to form pools for ornamental features and to create fisheries. In addition, many springs provide private water supplies to remote dwellings and farm areas through the use of siphons and hydraulic rams – some of these still function.

Historical fluvial flood events, dating from 1820 to the 1960s, reveal that Nailsworth Stream and the Frome below its confluence frequently flooded (BHS, 2018). According to local accounts, Painswick Stream rarely flooded as it remained mostly in open channel through Beeches Green (Stratford Mill) until the 1970s. However, there are documented events in November 1875, October 1882, December

1900, December 1929 and December 1965 caused prolonged flooding downstream of Stroud (Williams & Archer, 2002). Summer flooding occurred in July 1907 and August 1931, with one event reported to have risen 10 feet in 15 minutes. The two largest flood events on record occurred in 1965 and 1968 with a large number of properties along the Frome valley flooded (Williams & Archer, 2002). Following these events the Ebley Mill gauging station was installed (Figure 1). More recently, in July 2007 flooding in the upper Frome affected over 200 properties (Pitt, 2010), and floods in the winter of 2012 impacted 15 properties (BHS, 2018). The Slad Brook area of the SF Catchment was designated as a Rapid Response Catchment in 2012, with 112 properties at risk (Atkins, 2013). The consensus from these events is that most widespread flooding occurs after sustained periods of rainfall, caused by increased groundwater levels combined with increased runoff response from overland (Atkins, 2013).

Flood risk assessment and feasibility studies for contemporary flood defence schemes have been undertaken at various stages, including post-2007. During extensive community consultations, it was concluded that hard-engineering protection against major flood events was not viable and would have an unacceptable impact on the local environment and landscape. The local community proposed that NFM options should be considered and in 2012 the outputs from a series of community walkovers and additional catchment analysis were reviewed in a Scoping Study (Atkins, 2013).

The regulatory landscape is complex with the 2009 Flood Risk Regulations (which transposes the 2007 EU Floods Directive in England) and the 2010 Flood and Water Management Act designating the EA and Lead Local Flood Authorities as competent authorities for flood risk management. The Lead Local Flood Authority in the Frome is Gloucestershire County Council (GCC), which has responsibilities for the management of flood risk related to groundwater, surface runoff, and ordinary watercourse flooding, referred to as "local flood risk" (GCC, 2014), and involves developing a local flood risk management strategy, whereas the EA has strategic overview on flood risk management for all types of flooding and is responsible for main rivers, reservoirs, estuaries, and the sea. However, in 2012 GCC devolved powers to undertake enforcement to maintain proper flow of water within ordinary watercourses without a necessary consent to the local district councils, which for the Frome was Stroud District Council (SDC). In the SF Catchment, the English Severn and Wye Regional Flood and Coastal Committee (RFCC) established by the EA also need to be consulted to ensure the consent to local levy funded scheme for flood risk alleviation.

Following discussion among key stakeholders a three-year partnership (extended for a further three years in 2016) led by SDC was established with local flood levy funding. A full-time Project Officer was appointed in May 2014 along with RFCC funding to facilitate ongoing establishment of NFM interventions. The Project Officer reports to a strategic group chaired by an elected member of SDC and includes members of the local community flood action groups. The governance arrangements include a strategic group, with representatives from local and national authorities and NGOs with SDC in charge of delivery under the guidance of the EA. As a result of the way in which the Stroud Frome (SF) Project has developed there are a wide range of stakeholders involved and using Balian *et al.*'s (2014) typology of NBS, the project clearly fits within Type 2: *the modifying and management of existing social-ecological systems to better deliver a range of ecosystems services*.

2.2 Community involvement

Post-2007 the communities of the Stroud Valleys formed four flood action groups to work towards the adoption of better flood management and better use of the watercourses for wildlife and biodiversity. These were instrumental in the adoption of the NBS in the SF Catchment and have been actively involved since; being involved in the recruitment of the Project Officer and with representation in the strategic group.

The local community wanted measures delivered on the ground, therefore the Project Officer focused on working with sympathetic environmental NGO landowners, developing and delivering a wide range of NFM measures. The initial delivery programme provided the basis for demonstrating and promoting the project approach to a wider landowning community, building confidence and promoting dialogue. The Project now has an extensive network of supportive landowners either already undertaking, or planning to implement, measures on their own land.

The purpose of the knowledge exchange, through site visits, joint meeting and volunteer activities, that occurs within and between the various stakeholders involved in the SF project is that it enables them to develop a shared vision for the Project and undertake practical activities that meet concerns connected to the reducing in flooding (Wenger *et al.*, 2002; Barton & Tusting, 2005). By participating in this collective process those involved in developing and deploying NBS learn through involvement in action, communication, and negotiation (Barton & Tusting, 2005). Such regular and directed interactions (in-the-field and face-to-face) result in new ways of seeing the world, and learning collectively how to better address or deal with complex issues through a shared repertoire of resources and practices (Short, 2015). Such multi-stakeholder and collaborative activity is crucial to underpin the paradigm shift that the widespread introduction of NBS would require across Europe, and this paper will highlight how experiences gained from the SF Project would serve as good practice to ensure successful implementation in other catchments.

2.3 NFM interventions

NFM interventions have been constructed across the SF Catchment in a wide variety of ways using a range of methods. Monthly meetings between the Project Officer and the flood action groups agreed a programme of action, including the location and choice of NFM intervention to be implemented. The Project Officer then walked the areas in question and contacted the local landowners where the land was considered to have potential. One-to-one meetings with individual landowners and land managers including detailed discussions on the exact siting of interventions and the work involved. The Project Officer completed all the required regulatory consents to undertake the work, and contracts for construction and installation are awarded on a hierarchy that favours construction by the landowner or farmer as first option. Where this was not possible construction by the landowners' preferred contractor, was offered, and only if these two options were not possible was the work offered under open tender. Using local labour re-cycles the economic benefits for the local community and increases the local knowledge capacity for future work on NFM. The materials for the interventions were always from the immediate vicinity thus ensuring that the environmental impacts associated with construction were reduced. On some locations where the access was suitable and the landowner was willing, community members assisted in the creation of interventions under the supervision of the Project Officer.

By July 2018 the Project had worked with 16 different land managers (12 Private and 4 NGO's) and over 400 interventions had been delivered, including: 170 large woody debris (LWD) dams, 1 dry-stone wall deflector, 3 spring fed and 3 solar cattle drinking troughs, 5 large earth bunds, 10 small earth bunds/check dams, 6 gulley systems stuffed with wood, 1.7km streamside fencing, 1 large dry pond, 400 trees planted and many minor interventions such as diverting water away from tracks. As a result, over 20% of the SF Catchment (an area of 52.5 km^2) now flows through NFM interventions. Some further detail will now be provided on the main types of NFM interventions used.

Table 1: Guidelines and criteria used for the building of LWD in the Stroud Frome Catchment, note that trees and woody material are sourced from as close as possible to the site using trees coppiced or felled in the riparian area of floodplain

Guidelines and criteria	
1	In watercourses with permanent baseflow, baseflow should be allowed to continue un-impeded wherever possible
2	Tree trunks and branches should be left as long as possible and with branching in place to reduce possibility of movement. Ideally the length of sections of tree should be 1.5-2.5-times the channel width
3	Tree trunks should be pinned using reinforced steel pins to create complex structures and ensure tree trunks do not float during high flow events. However, in some cases wood may be left in-situ without pinning

2.3.1 In-channel & floodplain LWD

LWD consists of tree trunks or major branches locally sourced from a variety of native hardwood species that span a whole river channel (see Table 1 for further building guidelines) with the aim of slowing the flow during flood events, creating in-channel and on-floodplain attenuation, and/ or diverting high flows into preferential storage areas. LWD improve water quality by holding back sediment (De *Visscher et al*., 2013) and providing a nutrient take-up service, they also increase the hydrological roughness and introduce pools (Cashman *et al.*, 2016) which increases the habitat diversity and restores biodiversity (Thompson *et al.*, 2018). The species of tree used includes alder (*Alnus glutinosa)*, ash (*Fraxinus excelsior)*, willow (*Salix fragilis*), hazel (*Corylus avellana)*, poplar (*Populus tremula*) and oak (*Quercus robur*), with soft woods used if there was no alternative. The construction of the in-channel LWD structures is based on three basic designs (Figure 2): natural (appears that tree has fallen and left with roots untouched); semi-natural (the tree trunks and large branches were cut and positioned); and, structured (arranged and positioned purposefully). The design choice was decided by landowner preference and feasibility of the location. LWD can be used on floodplains to attenuate floodplain flow

(Figure 3a) and as flow deflectors to divert flow into attenuation areas where they are temporarily stored until they evaporate or infiltrate (Figure 3b).

Figure 2: Examples of LWD implemented in the Stroud Frome Catchment: (a) natural, (b) semi-natural design, (c) structured

Figure 3: Examples of (a) LWD used to attenuate floodplain flow and (b) flow deflectors used to divert flow overland to designated attenuation areas

2.3.2 Gully stuffing

A related technique is that of gully stuffing, where erosion gullies and ravines are filled with brash (term used to describe thin upper branches) and logs to impede erosion and flow and increase infiltration (Figure 4). These water bodies are largely seasonal and the brash and logs reduce the impact of surface runoff and slow the flow. This intervention is particularly useful in a steep catchment where wood extraction might be difficult as it provides some justification for management activity in areas where none might previously have been undertaken.

Figure 4: Example of gulley stuffing in the Stroud Frome Catchment using brash and small logs to reduce surface runoff in the steep-sided valley

2.3.3 Earth bunds

Earth bunds were constructed using soil, sub-soil and clay obtained in-situ (no material is imported to the sites). The construction process involves removing top soil and turf and placing to one side, the sub-soil and clay are reshaped to form the bund before replacing the top soil and turf (Figure 5a). The bunds attenuate water and reduce the speed of surface runoff during a storm event (Figure 5b), while there are largely unnoticed at other times.

Figure 5: An example of an earth bund installed in the Stroud Frome Catchment, (a) immediately post-construction and (b) retaining water during storm event

2.3.4 Grips and culverts

Tracks can become a focal point for storm water during rain events causing both erosion of the track and transportation of track material and water into watercourses where it negatively impacts the ecological status. The Project requires improvements to track drainage coupled with measures that will slow and attenuate consequent runoff using traditional track management techniques such as culverts (Figure 6a) and grips (roadside ditches, Figure 6c)) but increasing the frequency of these. Non-traditional enhancements have also been added through the creation of track side storage areas, soakaways and catch pits where possible (Figure 6b), to increase infiltration rates and allow silt and sediment to be removed from surface waters, thus improving water quality.

Figure 6: Examples of the culvert and grip interventions that have been implemented in the Stroud Frome Catchment to reduce surface runoff and material transportation from tracks (a) large culvert pipe and stone soak away in a catch pit under the inlet pipe, (b) a track-side storage area (c) grip created alongside tracks

2.4 Methods

A full cost benefit analysis of the Project has not been undertaken and the Project is still in the early stages of implementation meaning that there are only three-years of data to analyse. There are limited monitoring points across the SF Catchment to compare pre- and post-NFM installation however some coarse analysis of the rainfall and flow data at the catchment scale can be undertaken. The hourly rainfall measured at two sites, Ebworth and Miserden, and hourly stage height data from two gauging stations, Merrywalks and Slad Road, in the SF Catchment (Figure 1) were analysed in pre-NFM (2010-2014) and post-NFM (2014-2017) time periods. Statistics on the average rainfall and event frequency were extracted to provide information on the rainfall characteristics, and compared with the stage height data recording. To examine this in more detail, two comparable rainfall events (recorded at Miserden) of similar magnitude and duration but one that occurred pre-NFM and the other post-NFM were evaluated to determine the impact of river stage recorded at the Slad Road gauging station. The key variables that determined these events as comparable were:

- Soil moisture deficit: 2012 = 0; 2016 = 0;
- Intensity of rainfall: 2012 = 36.6 mm; 2016 36.2 mm;
- Duration of event: 2012 = 12 hours; 2016 = 12 hours
- Seasonality: 2012 = 24 November 2012; 2016 = 9 March 2016

- Effectiveness of gauge figures: 2012 = fully calibrated; 2016 = fully calibrated.

The total capital cost for each intervention was calculated for six sites (amounting to c. 250 NFM interventions) across the SF Catchment; confidentiality prevented the calculation of full capital costs for the Project. This was determined by the actual cost, where the work was undertaken by a contractor, or as a contribution 'in-kind', where the work was undertaken as a donation by the landowner or local volunteers. For the latter, a standard cost per hour was used to cover the work dependent on the skills level required. This also includes the cost for time, machinery hire and materials. The number of each intervention was then used to calculate a total cost for each intervention type.

There is no baseline data available in the SF Catchment on the effectiveness of local interventions on biodiversity, geomorphology and local hydrology as the priority was on implementation rather than evidence collection, however evidence has been gathered through observations and informal monitoring by the authors and partner organisations, supplemented by a series of community and student projects. This has provided information on the impact of NFM on the sediment characteristics, river channel habitat, the habitat provided by the NFM interventions and the local hydrological and ecological response of the channels.

3. Results

Exploring the rainfall characteristics in the locality (Table 2) there have been minimal changes in the period before and after the installation of NFM interventions, with a slight increase in the average rain recorded at Ebworth (+0.11 mm) and a minor reduction (-0.18 mm) at Miserden. The occurrence of high rainfall events recorded (Table 3) are remarkably similar for both rain gauges between the two periods, and it can therefore be assumed that the amount of rainfall into the SF Catchment has not altered since the start of the Project in 2014 and so any reduction in water flow must be attributed to other factors. The river stage, however, shows that there has been a reduction in the average stage height recorded since NFM interventions have been implemented (Table 3) for both gauging sites in the SF Catchment; given that the amount of rainfall has not altered the most likely cause of this reduction are the NFM interventions attenuating water during high flow events and promoting infiltration rather than surface runoff and thereby dampening the peak flow and therefore the stage height recorded further downstream.

Table 2: Average rainfall and river stage measurements from before and after NFM interventions were installed in the Stroud Frome Catchment (see Figure 1 for the location of the sites)

	Rainfall average (mm)		**River stage average (mASD)**	
	Ebworth	**Miserden**	**Merrywalks**	**Slad Road**
Pre-NFM (2010-14)	2.29	2.61	0.252	0.130
Post-NFM (2014-17)	2.40	2.43	0.204	0.113

Table 3: The number of times average daily rainfall exceeded a specified amount from the period both before and after NFM interventions were installed in the Stroud Frome Catchment (see Figure 1 for rain gauge locations)

	Ebworth		**Miserden**	
	Pre-NFM (2010-14)	**Post-NFM (2014-17)**	**Pre-NFM (2010-14)**	**Post-NFM (2014-17)**
No. rain events exceeding 20 mm	19	19	27	21
No. rain events exceeding 30 mm	4	4	5	5
No. rain events exceeding 40 mm	1	0	0	0

Figure 7 shows the rainfall and river stage patterns over a 24-hour period comparing two similar rainfall events from 2012 and 2016, and the hydrological response (i.e. river stage) of these. This suggests there is a clear indication that the NFM interventions have reduced the amount of water in the channel and the peak level by almost 1.4 m. It is interesting to note that a similar trend was also recorded at the Merrywalk gauging site but with a lower stage height difference (approximately 0.2 m lower in 2016 during the peak of the event than in 2012); the data from this gauge is susceptible to blockages and so cannot be adequately calibrated for this event and so the data is not shown. Figure 7 demonstrates that the downstream maximum water height has been reduced, thus minimizing the flood peak and associated flood risk downstream. Based on location information no properties reported flooding in 2016; 53 properties in the SF Catchment are in the *Very Significant Flood Risk* category and could potentially have flooded in this event if it had been at the 2012 river level. The FCRM Partnership Calculator estimates the economic benefits of protecting these properties at £605,000 (US$770,000), with an estimate of damages avoided at £1,590,000 (US$2,030,000), for this single rainfall event. However, more comparable events are required before a clear trend can be determined and the level of benefit can be confidently assessed.

Evaluating the percentage of the SF Catchment area draining through features provides some indication of potential impact. In the three years since the start of the Project approximately 20% of SF Catchment is now draining through NFM features. However, in the Slad Valley, approximately 80% of sub-catchment is draining through NFM interventions, and the influence that this has had on the hydrology is evidenced by the stage heights recorded by the Slad Road gauge station (Table 2 and Figure 7). However, the effectiveness of NFM at a particular location is dependent upon many site specific local variables such as geology, ecology, land management practices and timings, and therefore determining how transferable the benefits and influence of different types of NFM to a range of environments is a crucial area of future research.

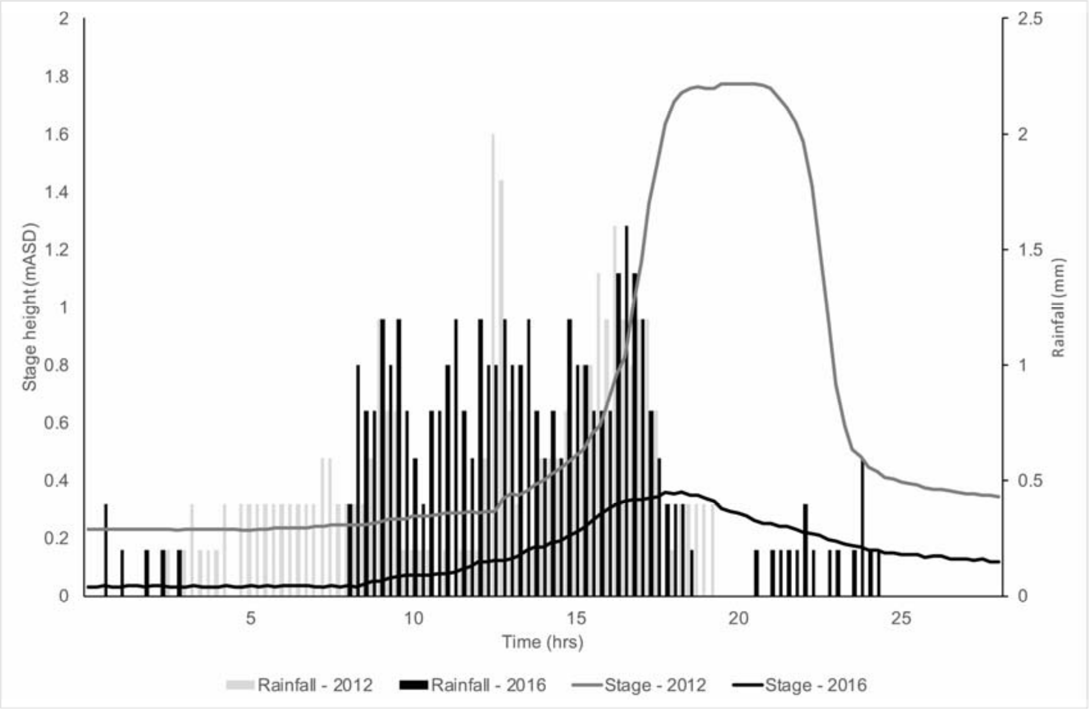

Figure 7: Comparing the hourly rainfall and river state heights for two peak events in 2012 (pre-NFM) and 2016 (post-NFM) using data from the Miserden rain gauge and the Slad Road gauging station suggesting a reduction in river state heights and in amount of rainfall to reach gauge station due to installation of NFM interventions.

The capital cost of the interventions for the SF Catchment have been calculated and are shown in Table 4. Each site differs in terms of accessibility and terrain and therefore the estimated cost of each intervention varies from one site to another. The low capital costs of the NFM interventions are evident, which the total for 250 interventions amounting to about £30,000 (under US$40,000) (Table 4), suggesting that it is possible to achieve the estimated threshold of measures with a relative modest capital investment. However, this is dependent on the social capital being present to secure access to appropriate sites as well as in-kind contributions, and it should be noted that this figure does not include the revenue costs (i.e. the salary of the Project Officer). It should be noted that key factor in locating NFM interventions within the SF Catchment was striking a compromise between positioning them to effectively reduce peak flows whilst also minimizing the impact on the farm or woodland business, with siting of individual measures involving discussion and negotiation with the landowner. By working with landowners and co-designing the NFM interventions (e.g. selecting the natural, semi-natural or constructed option of LWD) there has been full cooperation, and financial compensation has not been required and therefore no cost has needed to be allocated to this.

Table 4: Estimation of the capital cost of individual interventions and total capital cost on each type of NFM intervention in Stroud Frome Catchment (data supplied by SDC 2017).

Intervention	Estimated cost range per intervention (min – max)	Total cost (total number of interventions)
LWD leaky dams	£77 - £400	£29,024 (170)
Gully stuffing	£131 - £270	£1,453 (6)
Earth bunds	£15 - £20/metre	£2,750 (15 = 150 m)
Culverts	£500	£4,000 (8)
Grips	£20	£1,000 (50+)
	Total	**£38,227**

In the recent EA assessment (Burgess-Gamble *et al*., 2017) the SF Project was used as one of three case studies to show the benefits of NFM, this showed overall costings of £280,000 (US$357,000) over three years (made up of £150,000 (US$190,000) revenue for the Project Officer and £130,000 (US$166,000) capital costs). The overall benefits to the town of Stroud were calculated to be £1.7 million (US$2.16 million) over the same period, calculated as the number of businesses and domestic properties not at risk from flooding. This gives a benefit-cost ratio of about 6:1 (Burgess-Gamble *et al*., 2017). This was based on LWD and no figures for the other NFM categories (river restoration, river floodplain and floodplain-wetland restoration) were provided, highlighting the challenge of providing a full cost-benefit analysis of all of the interventions and impacts of a NBS.

As with all NBS projects, the NFM measures that have been implemented are designed to maximise multiple benefits. Early evidence from the SF Project suggests that LWD has improved in-stream habitat by impeding the progress of silt downstream and improving downstream channel habitat. The creation of pool-riffle sequences downstream of LWD has increased the number of hydraulic biotopes present, and the change in flow and sediment transport around the wood has created a more diverse range of river habitats. The woody debris itself creates habitat for invertebrates, fungi and lower plants. By using local trees for the LWD the woodland has been coppiced and this has allowed light to reach the woodland floor and increase the plant diversity, with an increase in the number of herbs and shrubs in these areas. To provide protection to the NFM interventions, where appropriate, livestock is fenced out of watercourses; this has reduced poaching along the channel banks and has reduced the amount of erosion and decreased the amount of silt that is entering the watercourses. One of the most significant benefits of the Project to date has been that it has enabled the local community to be actively engaged in a positive partnership with the Project Officer, local council and the EA to constructively manage their flood risk. This has provided the local community with a sense of 'ownership' of the NFM, thereby facilitating further implementation and a shared understanding of the aims and limitations of the Project (supported by the findings of Carnelli, 2018). The range of environmental and social benefits to be gained from implementation of NBS within the SF Catchment needs further research to enable quantification of each of the benefits, but initial observations demonstrate improvements to the environmental and ecological conditions.

4. Discussion

The results presented indicate that the NFM interventions that have been implemented in the SF Catchment have been beneficial, whilst also uncovering the challenges of defining the success of the scheme. The hydrological evidence presented indicates that the SF Catchment is behaving differently following the implementation of NFM interventions, and these have reduced the average stage height (Table 2) and reduced the peak flow when comparing two similar events (Figure 7). The reduction in stage height, and this flow, can be attributed to the following mechanisms:

- Attenuating water by using and maintaining the capacity of ponds, ditches, channels and floodplain areas that have been created as flood storage, thereby storing water and reducing the magnitude, and timing, of the flood peak;
- Increasing soil infiltration and therefore reducing surface runoff. The Jurassic Oolitic Limestone underlying the SF Catchment is highly porous and can promote percolation of water into groundwater systems;
- Slowing water by increasing resistance to flow. Surface roughness has been increased by constructing LWD and by gully stuffing, and coppicing of woodland has increased woodland floor and riparian vegetation growth.

Clearly more data is required to confirm this and quantify the contribution of each mechanism within the SF Catchment, but the results to date do serve to challenge one of the concerns raised about NFM that slowing the flood waters and temporarily storing the excess water could result in an unintended synchronisation of flood waters as they converge downstream. The SF Catchment suggests that in some catchments, most likely those with a porous geology where groundwater systems can become activated, this is less likely to occur, because once pushed out of the river channel, flood waters infiltrate into the soil and find other routes, including into ground water.

The SF Project shows that it is possible for NBS to have an impact on reducing flood risk without the need for further hard-engineering or traditional flood defences. In most European projects NBS are used in combination with more conventional flood risk techniques, such as culverts, flood walls and engineered dams (Burgess-Bamble *et al.,* 2017; the evidence from Stroud suggests that minor flood events have been nullified by the numerous NFM interventions installed across the SF Catchment. The idea that NBS could be utilised as a flood defence mechanism does present some challenges to the traditional cost-benefit framework as much of the evidence regarding the impact of NFM interventions (i.e. LWD) is modelled rather than observed and there is therefore little information on the performance, longevity and operation and maintenance of such structures (Burgess-Gamble *et al.*, 2017; Dadson *et al.*, 2017) to be able to effectively cost these. In the SF Project, it is generally accepted that LWD will need managing but that the structures can be replaced or reinforced during normal woodland or farm management practices using material on site or nearby.

The engagement of local people and the inclusion of local knowledge is one of the factors driving the use of NBS in the SF Catchment, and therefore highlights the importance of the social benefits of this method; something that is only briefly explored in the EA evidence directory (Burgess-Gamble *et al*., 2017) and is often not considered at all (i.e. Dadson *et al.,* 2017). Evidence from Carnelli (2018) suggests that the SF Project has substantial social benefits in terms of local commitment to the Project and this provides both social and cultural benefits. The involvement of local community flood forums in narration of recent rainfall events, and increasing the awareness of how water behaves in a catchment and the role of NBS as a flood mitigation method, is indispensable. Community engagement and the use of local knowledge is necessary for the implementation of any NBS and key to ensuring its longevity and success. However, although community engagement is vital it can add complexity to the Project. This is in part due to the governance framework that results from working with and involving multiple stakeholders, to ensure that there is adequate knowledge exchange (Wenger *et al.*, 2002; Barton & Trusting, 2005; Short, 2015). In this response the SF Project benefitted from the SF Catchment being almost exclusively in one administrative area, in this sense it is an optimal organizational position. Of course this is not always possible as river catchments do not always align with administrative boundaries but in such situations some shared responsibility should be possible. For many involved with the SF Project it is the act of talking, walking and looking, which is responsible for building relationships. These relationships result in a growing awareness of flood risk issues, a general increase of local knowledge and a better understanding of the surrounding environment and flood risk institutional dynamics (Carnelli, 2018). This has also the potential to reduce ambiguity and uncertainty for local stakeholders involved with flood risk management and, given that the SF Project depends on the goodwill of landowners and farmers to implement NFM measures, the issue of social acceptability remains a key element.

For the SF Project, and NBS in general, there remains a risk of not being able to show that the Project has been a ‘success’. Enhancements to the local environment is difficult to prove within the first three years of the Project, and requires longer term monitoring of the hydrology, geomorphology and ecology within the SF Catchment. However, the early signs are that there has been a positive impact on the flow variability, channel functions, and the riparian habitats, and the use of locally sourced materials (timber, soils) has reduced the environmental impact associated with construction and maximizes the likelihood of the benefits. For the most part the actual interventions are invisible, as their characteristics and location are designed to allow them to fit within the landscape. The process required to reach this point is one that requires a strong and robust engagement process and knowledge sharing, therefore these parts of the process need to be included in any measure of ‘success’ or effectiveness in addition to the flood mitigation and environmental benefits. The visibility of the Stroud NFM interventions lies with the education and knowledge-base that has been built up in the local community, and therefore the similarities can be drawn with the ‘levee effect’ (Collenteur *et al.*, 2015) that is encountered with hard-engineering projects, i.e. a false perception of safety when living close to a hard-engineering feature that can reduce the likelihood of being prepared for a flooding event. The NBS implemented in the SF Catchment will reduce flood risk for certain properties and hopefully nullify smaller floods, however, if an extreme event like that in 2007 occurs again there will still be flooding. So there remains a challenge in terms of educating the local population that NBS will reduce but not eradicate the risk of future flooding.

5. Conclusions

This paper introduced the SF Project and showcased the potential for NFM implementation to mitigate flood risk and to provide multiple environmental and social benefits. The costs of implementation are relatively small compared to hard engineering and with a small pot of money (c. £40,000, just over US$50,000) over 400 NFM interventions have been established around the SF Catchment with more planned in the second phase of the Project. We acknowledge that there is limited evidence to date and a body of evidence needs to be built up over a longer time period, but initial evaluation of the rainfall and river stage records indicates some significant success in the three years that the Project has been operational, and the positive environmental and societal benefits have been outlined.

The Stroud example highlights the benefit of having a revenue focused project, as this enabled the social aspects of the NBS to be fully developed, and the importance of key roles, such as the Project Officer – who has oversight of the whole Project and was fundamental in shaping the relationships between the community flood groups and the local landowners where the NFM interventions are installed. In this respect it is distinct from conventional flood management approaches, which are often capital focused due to the hard engineering nature of the work. The organizational structure needs to be robust and adaptive so that it can respond to what does and does not work, therefore it might be that a locally accountable base, such as Stroud District Council, is able to respond more quickly than a national or statutory agency. Whatever the context, it is difficult to see how either NFM or NBS can be delivered by a single organization working alone, the approach necessitates a collaborative and transdisciplinary approach and the development of a flexible shared vision.

As a result of our research around the SF Project, we have four key findings/recommendations that we consider to be vital for the successful implementation of NBS going forward:

- The role of governance in NBS is critical and should be included from the outset; the process of introducing NBS should be seen as a co-management and adaptive one (Becker *et al.,* 2015; Carlsson & Berkes, 2005) that evolves over time to reflect the local context and current state of knowledge and capacity to introduce the agreed interventions. The approach of the SF Project to integrate local flood action groups in the decision-making from the outset has created local ownership of the project, and the use of local landowners and contractors increases the local knowledge and capacity for NBS and will aid the long-term sustainability of the Project.

- Experimentation enables the partners to consider and combine different types of knowledge and practices. In the SF Project the NFM interventions vary across the atchment and have been adapted to suit the needs and preferences of local partners. This stresses the need for local understanding and bespoke implementation, and again highlights the benefits of continual communication regarding planning and progress (both positive and negative) with national and local partners.

- Public participation has developed co-learning contexts by building relationships, framing local knowledge and acting on the social dimensions of risk. A shared desire to reduce risk through (what established flood management professional would call) ‘unconventional means’, has provided a common meeting place for a range of partners and this has in turn led to a strong social capital aspect across the Project. Capturing these benefits is a critical area of future research.

- Finally, it is clear that there is a need for continuous monitoring to be able to quantify the impact of NBS, this includes hydrological data over a range of events but also monitoring of the geomorphology and ecology of the SF Catchment. Ideally this would be with a pre-intervention comparison, however this may not always be possible. There also needs to be further discussion on how to capture the multiple benefits arising from NBS, ideally with the development of a robust common framework that would enable local data collection over a range of spatial scales.

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