

Chapter 12

Natural Flood Management in the Thames Basin: Building Evidence for What Will and Will Not Work



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Highlights

- We write for those planning to implement or evaluate the effectiveness of, natural flood management (NFM) interventions.
- We describe application of spatial Policy Support Systems and the spreadsheet-based Eco:Actuary Investment Planner to help understand the investment costs and benefits associated with different types and magnitudes of NFM.
- We also outline example deployments of low-cost FreeStation, //Smart: monitoring equipment to evaluate existing NFM interventions particularly leaky debris dams, retention ponds and regenerative agriculture as deployed in the Thames Basin of the United Kingdom.
- Our guidance is focused on organisations lacking technical and/or financial capacity for NFM effectiveness evaluation, since we document applications of open-access, user-friendly, novel, low-cost decision support tools, monitoring equipment and protocols, using examples from the Thames Basin.

12.1 Introduction

This chapter is written to support those considering the use of natural flood management (NFM) interventions or wanting to monitor the performance of existing interventions. We focus on three types of NFM interventions – leaky debris dams, retention ponds and/or regenerative agricultural techniques such as low tillage (Box 12.1) – within the Thames basin. In 2017 the UK's Department of Environment, Food and rural

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Box 12.1: Natural Flood Management (NFM) Interventions Considered in this Chapter (Source: Authors' Own)

NFM are landscape management activities that aim to retain more water in the landscape and reduce the speed at which water travels downstream thus reducing the concentration of runoff during a rainfall event and thus flood risk to downstream assets. NFM therefore has the potential to reduce flooding.



Leaky Dams are a flood mitigation technique in which logs are anchored across a stream to slow river flow. They store floodwaters upstream and encourage floodwaters to spill out of bank in low impact areas (such as forests and farmland) upstream of the assets at risk. There are many designs, most of which represent only a partial barrier.



Retention Ponds are bespoke topographic depressions that provide additional storage capacity for floodwater and slow its flow into agricultural drainage systems and thus rivers. They are particularly common in the lower parts of agricultural fields

(continued)



Regenerative Agriculture is a land management technique that involves no or low tillage, the use of cover crops and diverse crop rotations to help restore soil structure to a more natural state, encouraging infiltration and reducing runoff generation. This management technique has the potential to increase the water storage capacity of the soil, thereby reducing downstream runoff generation and flood risk.

Affairs (DEFRA) released £1 million for local governments and community groups to apply for grants up to £50,000 to fund the building of NFM measures in pilot projects to help build the evidence base. Most projects opted to invest in leaky debris dams. Subsequently, the government released a further £14 million funding for larger scale projects in the north of the UK. An obligation of the DEFRA funding was that organisations monitor how well the interventions worked and thus help build the evidence base for NFM. However many organisations lacked the technical and/or financial capacity to monitor NFM effectiveness within the £50,000 budget limit. We therefore developed and deployed monitoring equipment and evaluation protocols to help these organisations fulfill their reporting obligations, since this equipment was also needed for our own investigations of the effectiveness of NFM. We also developed model-based decision support tools to assist organisations whilst planning scales and types of NFM interventions they might make. The methods for these tools are described in Chap. 4. In this chapter we show the results of two of these tools: the Eco:Actuary Investment Planner and the FreeStation //Smart: monitoring system.

12.2 Study Site: Thames Basin Context

The Thames River is in the south of the United Kingdom and runs about 350 kilometres through the counties of Gloucestershire, Wiltshire, Oxfordshire, Berkshire, Surrey, London, Essex and Kent before reaching the North Sea. The Thames basin (Fig. 12.1) is home to around 13 million people, the majority of which live in Greater London. The catchment is approximately 16,000 km² in size and is predominantly peri-urban with urban centres (i.e. Swindon, Oxford, Reading, Slough, London) surrounded by suburbs interspersed with pockets of rural land. The 2013/14 winter storms lead to widespread flooding in the basin with clean-up costs of over £1 billion (Thompson et al. 2017). London has been identified as one of the most at-risk cities globally for flood hazard due to high levels of economic activity and asset value at risk (EA 2009). Part of this risk derives from coastal inundation and part of it from fluvial flooding.

Within the UK there has been a general move away from traditional flood defences towards a flood risk management framework based upon more holistic approaches to flood management including use of natural solutions (DEFRA 2012) – so called natural flood management (NFM). Most of the risk however is still managed through traditional engineered defences, with £930 million invested during 2014–2015, and a further £180 million spent on maintenance in the same period

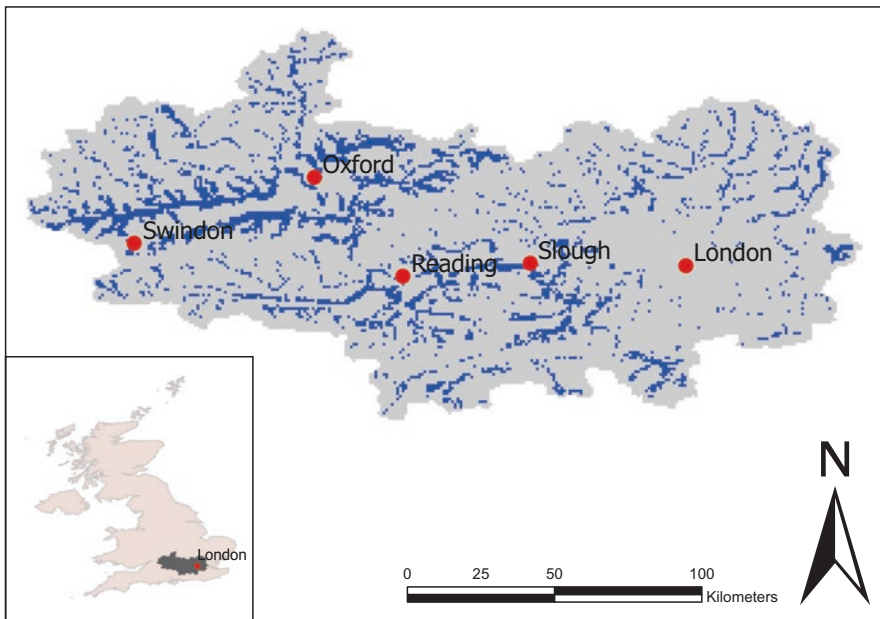


Fig. 12.1 *Main*: Thames non-tidal catchment and floodplain areas, outside London (Mulligan 2019), showing the position of the five largest cities and inset the position of Thames basin in the UK. The following map from the Eco:Actuary Policy Support System was used in the figure: topographic floodplain

(EA 2014). Despite the interest in NFM within the UK, barriers exist towards implementation of NFM interventions within the Thames basin. These include lack of space, high cost of land, potential resistance from landowners and lack of funding. NFM are also considered an unproven technology and may be more suited to mitigation on smaller streams and rivers (see Chap. 4).

12.3 Risk Assessment

Here we apply the Co\$tingNature, WaterWorld and EcoActuary Policy Support Systems to provide an assessment of flood risks and natural flood mitigation in the Thames basin. We start by using the Co\$tingNature Policy Support System (Mulligan 2015; methods: www.policysupport.org/costingnature) at 1 km spatial resolution to assess the Thames basin for its potential for, and exposure to, ecosystem relevant natural hazards (Co\$tingNature is a globally applicable model that includes the following hazards: cyclones, tsunamis, landslides and floods). Hydrological flood is the greatest hazard for most of the Thames, with only landslides having a greater risk in some areas (Fig. 12.2). The greatest hazard potential is located along the main channel of the Thames, followed by its major tributaries. With regards to socio-economic exposure, high levels of exposure exist all along the main channels of the Thames with the greatest levels where the Thames runs through the cities of Oxford, Reading, Greater London and the Thames Estuary developments (Fig. 12.2). Within towns and cities, population and GDP have the greatest exposure, whereas for the rest of the basin it is agriculture; although, there are some isolated pockets throughout the basin where infrastructure has the most exposure (particularly roads and bridges). The urban areas of London, Windsor, Reading, Oxford and parts of the Thames Valley all have high hazard and exposure (Fig. 12.2).

Flood hazard is determined not just by precipitation events but also by the configuration of green infrastructure (water stores within the landscape) such as: floodplains, canopies, soil, water bodies and wetlands. Urbanisation removes these stores as cities spread into the surrounding landscape removing canopies and wetlands, channelizing rivers and concreting over soil stores. According to the natural flood storage module of WaterWorld (Mulligan 2013; methods: www.policysupport.org/waterworld), within the Thames basin, every year some 8.5 km³ of water is stored by green infrastructure (Fig. 12.3). At the catchment scale most of this storage occurs in the form of floodplains, canopies and soils, only negligible amounts of water is stored in water bodies and wetlands, since these are sparsely distributed. However, only one-third of this green infrastructure within the Thames is protected, and thus much of this infrastructure is at risk from land use change and/or intensification. Damage to this green infrastructure will increase flood risk of downstream assets.

However, it is not just the presence of green infrastructure which is important but also its location within the catchment relative to rainfall and runoff generation and assets at risk. The main river channel of the Thames and many of its major tributaries have insufficient water storage capacity to accommodate the water generated

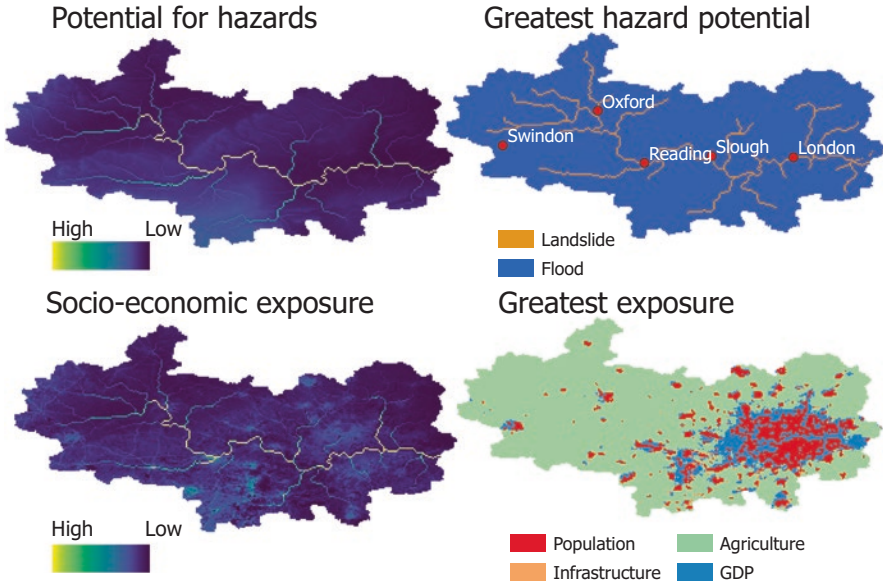


Fig. 12.2 Spatial distribution of hazard potential and socio-economic exposure within the Thames basin (Mulligan 2020a) Hazard and exposure are both expressed in relative terms from low (0) to high (1) within the Thames basin. In this context, hazards refer only to ecosystem relevant hazards i.e. inland floods, cyclones, coastal inundation, landslides and soil erosion. Clockwise from top left: Potential for hazards; highest potential along the main channel of the Thames; Greatest hazard potential are erosion (orange) and hydrological flood (blue); Socio-economic exposure, from low (purple) to high (yellow); with greatest levels along the lower Thames; Principal socio-exposure to natural hazards is agriculture, GDP, population, and infrastructure. The following maps from Co\$ting Nature were used in the figure; *clockwise from top left*: Relative potential for ES (ecosystem service) relevant hazard, Dominant hazard potential, Relative socio-economic exposure to ES relevant hazard, Dominant exposure. (Source: own elaboration)

during precipitation events as shown in Fig. 12.4 by application of the EcoActuary Policy Support System (methods: www.policysupport.org/ecoactuary). With insufficient stores in the landscape, flood risk increases and encourages dependency on protection from grey infrastructure. As both flood hazard and exposure is anticipated to increase in the future, action needs to be taken to reduce the fluvial flood risk within the Thames basin. Hazard is expected to increase due to changes in timing and magnitude of rainfall events and changes in land-use (Garner et al. 2017; Wheeler and Evans 2009). Exposure is also expected to increase in the future due to increases in population and assets (Sayers et al. 2018). Without suitable mitigation this will likely lead to greater flooding and flood damage in the future (Wheeler and Evans 2009; Ashley et al. 2005). The Thames basin has several physical and social characteristics which leave it vulnerable to flooding: notably, low elevation, high population density, high value assets, limited natural flood storage/drainage coupled with many commuters and pressured transport infrastructure and systems. Whilst our focus is fluvial flooding throughout the basin, key commercial and residential areas in central London are also at risk of coastal inundation.

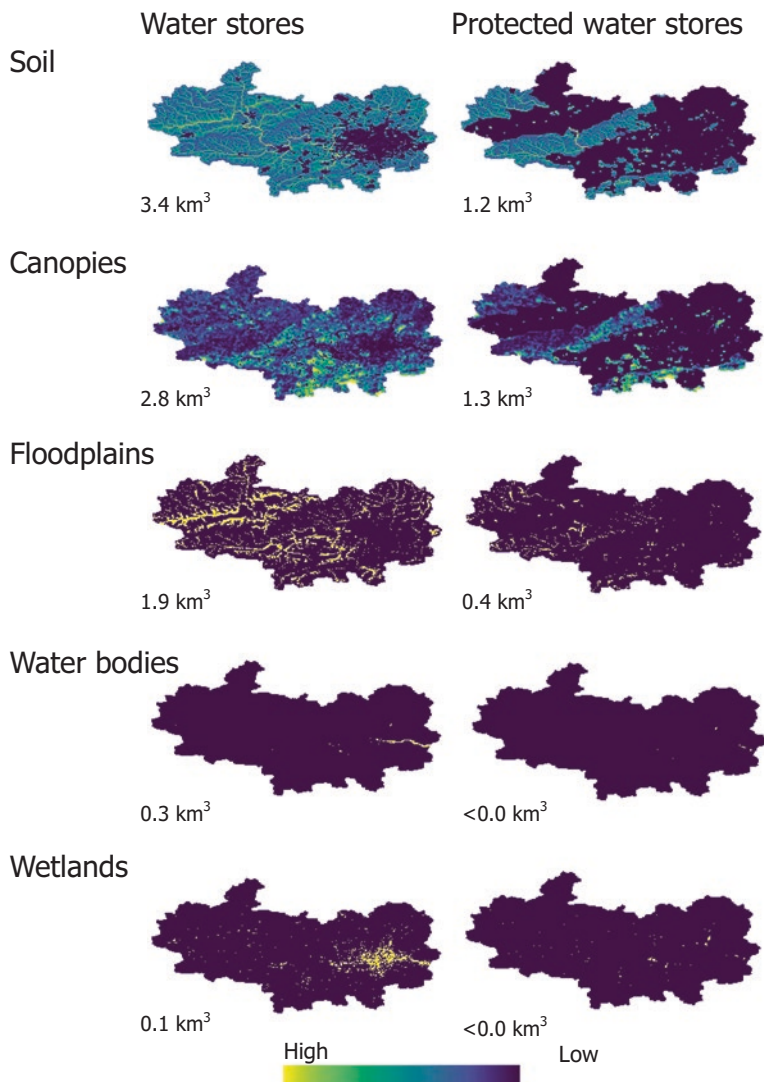


Fig. 12.3 Spatial distribution and annual total water storage of the green infrastructure within the Thames basin; all water stores (*left*) versus protected water stores (*right*) (Mulligan 2020b). Purple areas have no storage and yellow areas have high storage. Numbers provided relate to the amount of water stored per year in km³. Every year 8.5 km³ of water is stored within the green infrastructure of the Thames, with soil and canopies acting as the greatest stores. Only one-third (2.9 km³/year) of this storage is protected. The following maps from WaterWorld were used in the figure, top to bottom and left to right: soil storage capacity, soil protected storage capacity, canopy storage capacity, canopy protected storage capacity, floodplains total storage capacity, floodplains protected storage capacity, water body storage capacity, water body protected storage capacity, wetland storage capacity, wetland protected storage capacity. Note that the wetland areas is overestimated in the urban area since the road surfaces pond water during rainfall and store it temporarily. (Source: own elaboration)

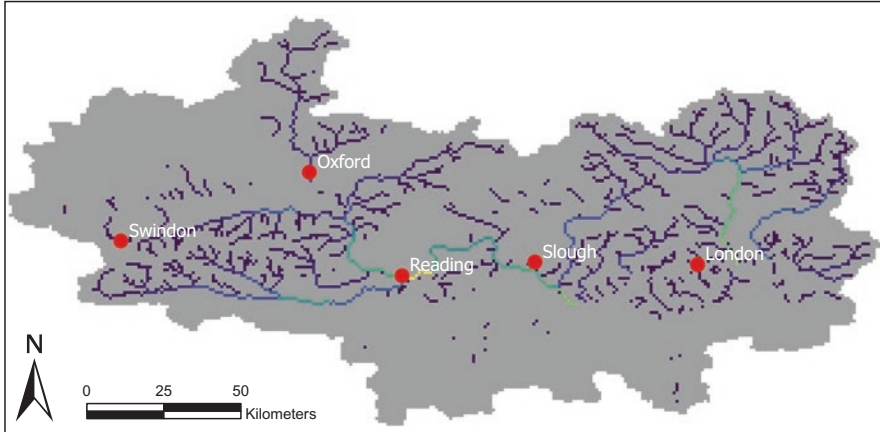


Fig. 12.4 The river non-tidal network of the Thames basin showing locations where there is insufficient water storage upstream of the landscape to accommodate runoff events (Mulligan 2020c). As the colour of the river lightens the greater the excess water surplus; Reading, Slough and east London are particularly vulnerable to fluvial flooding. The Thames through London is tidal and thus not considered here. Potential water stores within the landscape are canopy, soil, wetlands and water bodies but see Fig. 12.3 for differences in storage capacity. The following map from Eco:Actuary was used in the figure: accumulated realised excess over permanent stores. (Source: own elaboration)

12.4 Natural Flood Management (NFM) Effectiveness

In order to assess the impact of NFM interventions within the Thames basin we created and applied novel monitoring and modelling techniques – namely the Eco:Actuary Investment Planner (EIP) and //Smart: monitoring sensors (methodological detail provided in Chap. 4). First, using the Eco:Actuary Investment Planner we identified the scale of investment required for different types of NFM intervention to achieve a given reduction in peak flow at key river sites. For this we focused our analysis on four sub-catchments of the Thames: the Lee, Stort, Mole, Coln and one adjacent catchment: the Medway (Fig. 12.5, Table 12.1). For the second part of our analysis we used //Smart sensors to monitor the ability of existing NFM interventions to store or slow the flow of water at sites in the basin. We primarily present results of NFM within the Thames basin but also present results from interventions in neighbouring catchments where these results add value. The monitoring and modelling methods complement each other and allow stakeholders to both plan for new interventions and assess the effectiveness of existing ones.

In order to evaluate the effectiveness of the NFM interventions, we (1) applied FreeStation //Smart: to assess the ability of the interventions to hold water within the landscape, (2) applied the EIP to evaluate the financial cost associated with the interventions to achieve a 15% reduction in flood peak downstream, and (3) applied Co\$tingNature to assess the co-benefits associated with each intervention. We consider that the ‘best’ intervention is one which offers good value for money from a flood mitigation perspective.

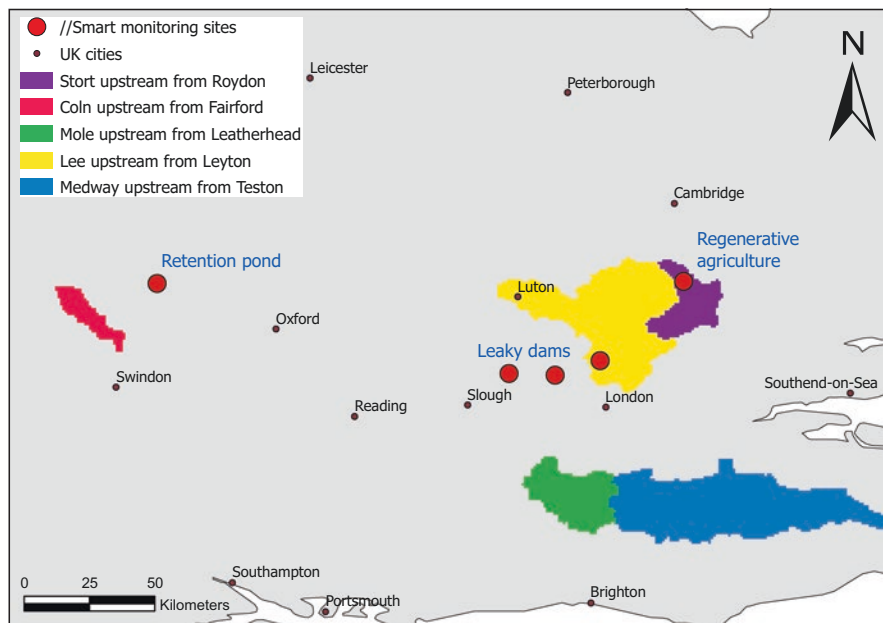


Fig. 12.5 Sub-catchments of the Thames Basin with Locations of EIA simulation (Table 12.1) and locations of //Smart monitoring. Thames basin outline in dark grey

Table 12.1 Sub-basins of the Thames Basin and adjacent (Medway) used as study sites for application of the Eco:Actuary Investment Planner

Study sites	Upstream catchment area (km ²)	Predominant geology
Lee River	663	Chalk
Stort River	175	Chalk
Mole River ^a	54	Weald Clay
Coln River	80	Limestone
Medway River	793	Weald Clay

^a Complex geomorphology and steep river gradient contribute to very high flood risk

12.4.1 Ability of NFM Interventions to Hold Water in the Landscape

Regenerative Agriculture

Regenerative agriculture is a system of principles and practice that increases biodiversity, enriches soils, improves watersheds and enhances ecosystem services (TGI 2017). There are three main tenets: minimising/avoiding tillage, eliminating bare soil and encouraging plant diversity (Burgess et al. 2019). It is thought that these practices improve the structure of the soil which increases the infiltration of rainwater rather than the water flowing as surface runoff. Therefore land managed this way will store and slow more water and thus cope better with extreme weather events.

The fields become less prone to waterlogging and less prone to becoming parched during drought. This infiltrated water also better drains to aquifers, meaning that rivers continue to flow for longer in the dry season.

We deployed FreeStation //Smart: sensors at four farms practicing regenerative agriculture – one in each of the following counties: Hertfordshire, Lincolnshire, Buckinghamshire and Suffolk. Here we present the results of the farm in Hertfordshire which has been practicing regenerative agriculture for 9 years. The FreeStations included soil moisture sensors installed on neighbouring fields, one cultivated using regenerative agricultural techniques and the other using conventional methods. The two fields have the same soil, geology and climate. The soil in the regenerative agriculture field responds much more dynamically to rainfall than the adjacent field (Fig. 12.6). There is greater infiltration in response to rainfall and quicker drainage in the regenerative agricultural field. In contrast, in the adjacent field there is much less drainage and the soil is waterlogged. During this period the 2.57 ha regenerative agriculture field stored 2000 m³ more water than a similar area in the neighbouring field (Fig. 12.7).

Retention Ponds

We deployed //Smart: at two retention ponds to test their effectiveness in flood reduction. The first was a large retention pond on the Pipp Brook, a tributary of the

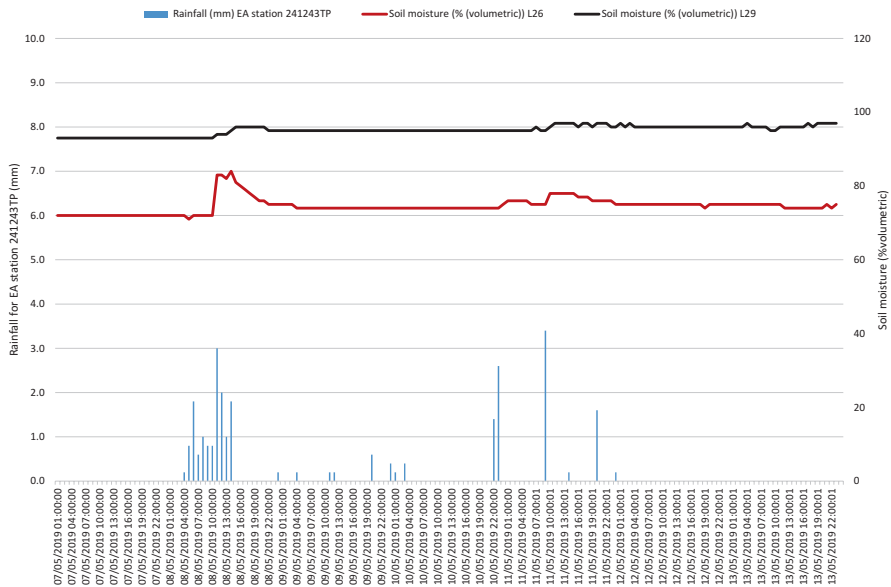


Fig. 12.6 Volumetric soil moisture in fields practicing regenerative (*red*) and conventional (*black*) agriculture in Hertfordshire, UK, and nearby rainfall for a week in May 2019. As the conventionally managed soils (black) are water logged (100% soil moisture), rainfall is unable to infiltrate and thus flows over the surface as runoff. In comparison the soil managed using regenerative agricultural practices (red) is able to respond to rainfall events due to the lower soil moisture and quicker drainage, meaning less runoff and slower flow of water to the river system

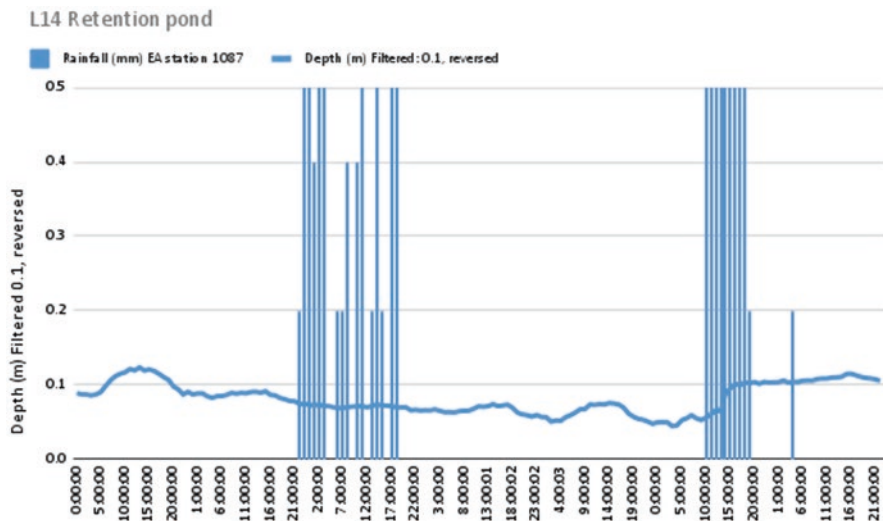


Fig. 12.7 Cumulative water storage in fields practicing regenerative (*red*) and conventional (*black*) agriculture in Hertfordshire, UK for a week in May 2019. The soil managed using regenerative agricultural practices stored 2000 m³ more than a similar area under conventional agriculture at the end of this week. Storage value calculated using the ‘Mitigation of flood risk by this soil management intervention’ function in //Smart:River online interface for this FreeStation

River Mole in Surrey. The second pond was a small retention pond on agricultural land within the Stour River catchment in Warwickshire.

We present the results of the small retention pond on agricultural land for a week in July 2019. Both water level and soil moisture responded to the rainfall event (Fig. 12.8). About a day after the rainfall event the soil moisture returned to its previous level but water level in the retention pond remained high. Over that same period of time, the pond stored an additional 6 m³ of water over the pond surface area of 2500 m² (Fig. 12.9). The amount of water stored in the soil was much higher owing to the large increase in soil moisture (from a dry start) and larger wetted area (10,000 m²) than the reservoir. The soil stored approximately an extra 6000 m³ during that event, assuming the rainfall event wetted an area of 1 ha (10,000 m²) around the storage pond.

Leaky Dams

We deployed //Smart: at four leaky dams within the Thames catchment: two located on Silk Stream, a tributary of Brent River; one on Merryhills Brook, a tributary of Salmons Brook; and one on a tributary of Blackwater River.

We present here the results of a run of 31 leaky dams on the River Stour at Paddle Brook for a week in January 2021. A FreeStation stage logger is set upstream of the 31 dams and another downstream of them. The downstream logger shows discharge with lower peaks and higher troughs (longer recession) than the upstream and this indicates correct functioning of the dams. Over the course of the week the level of the river increased in height by up to 0.7 m (1.5 m³/s) upstream but only 0.6 m³/s

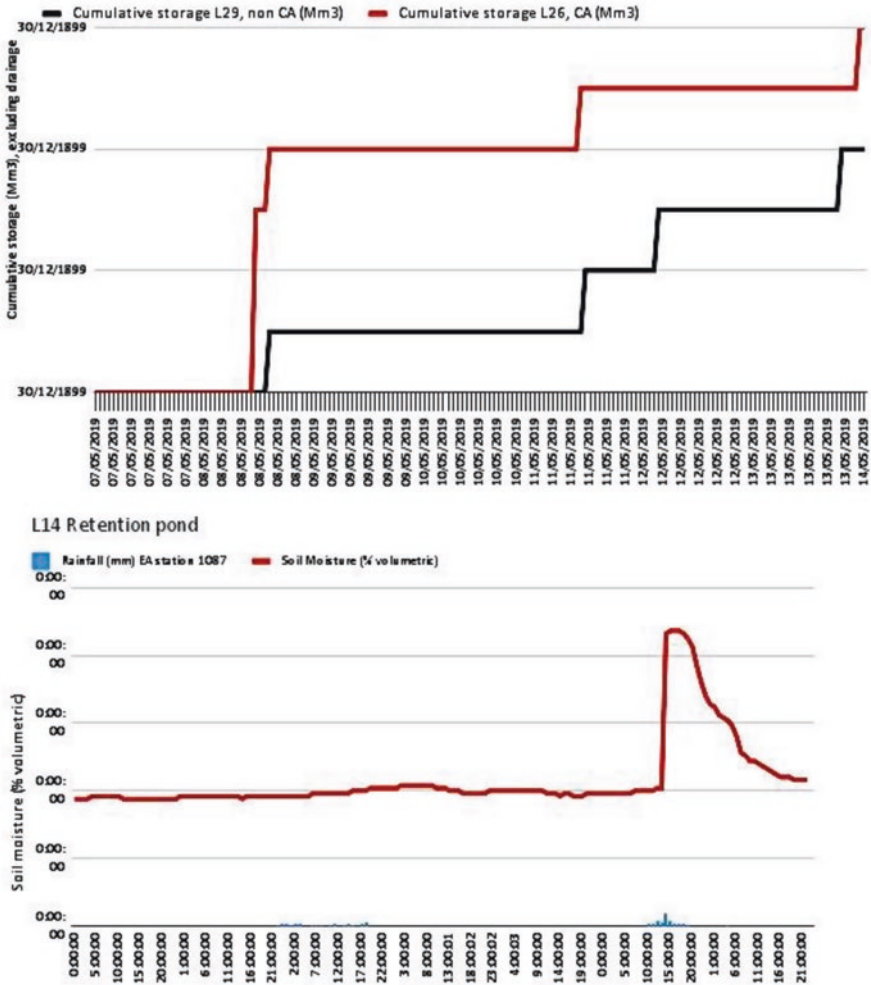


Fig. 12.8 (upper): Water level and nearby rainfall in the farm retention pond for a week in July 2019. (lower): Volumetric soil moisture as measured by a soil moisture probe immediately next to the retention pond for the same week. Both the water level of the retention pond and the adjacent soil moisture increased in response to the rainfall event. Soil moisture quickly returned to pre-rainfall levels but the water level in the retention pond remained elevated and drained slowly through the narrow outlet

downstream (Fig. 12.10) so around 25% of peak flow is mitigated. The following month the impact is even greater (1.0 m³/s) for some events. 1.0 m³/s represents 0.09 m³/s (3.6%) reduction of peak flow per dam. Estimating the cumulative difference in discharge between the upstream and downstream dam for the same week in January (Fig. 12.11) shows the total slowed volume over the period represents 1.75 m³ or 0.06 m³ per dam over the period.

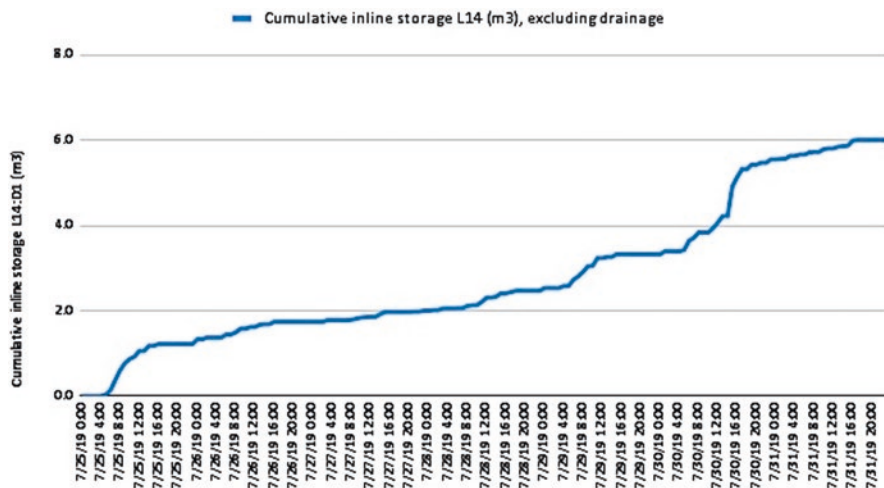


Fig. 12.9 Cumulative water storage in farm retention pond in Stour catchment for a week in July 2019. The retention pond stored an additional 6 m³. Storage value calculated using the ‘mitigation of flood peak by inline storage intervention’ function in //Smart:River online interface

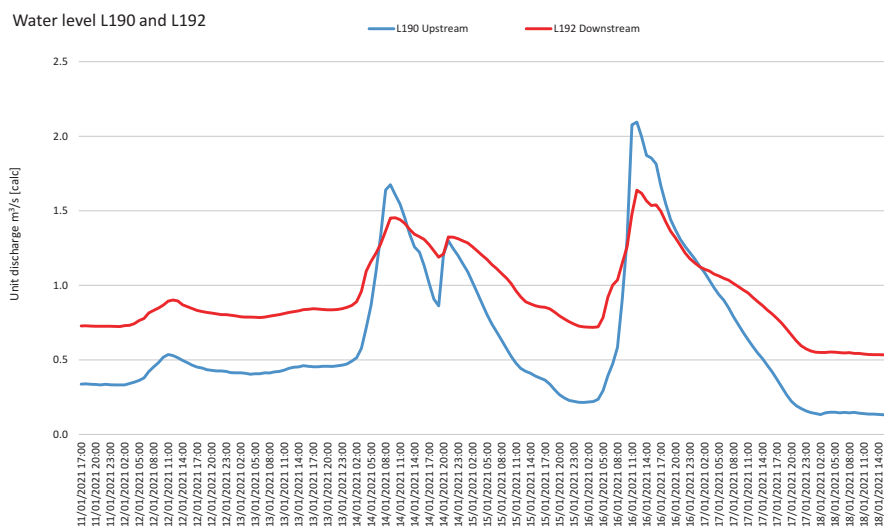


Fig. 12.10 Water level upstream and downstream of 31 leaky dams on the River Stour at Paddle Brook for a week in January 2021 showing a series of peaks associated with rainfall events. The discharge upstream of the dams is flashier than downstream with the peaks mitigated by almost 0.5 m³/s or 25%

During a 7 day period, we calculated that the small retention pond stored 6 m³, leaky dam reduced flow by a maximum of 0.09 m³/s (totalling 0.16 m³/s over the week) and regenerative agriculture field 2000 m³. These values should not be directly

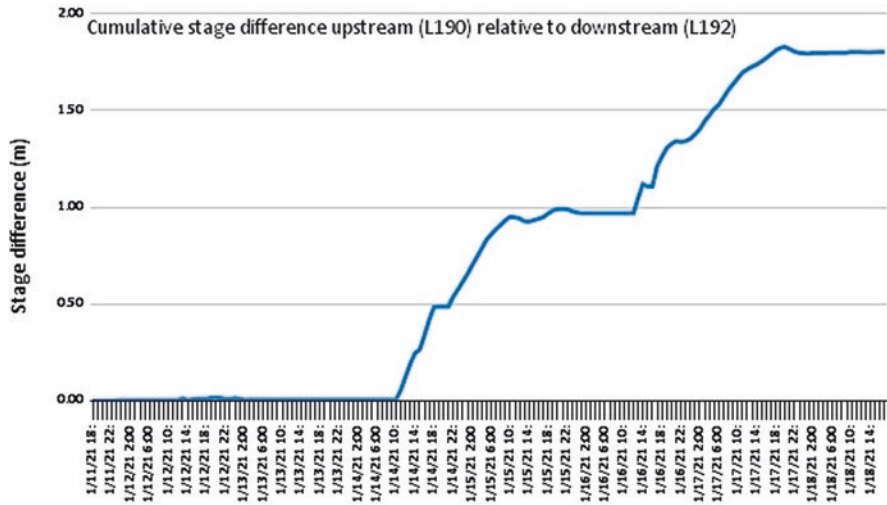


Fig. 12.11 Cumulative difference in discharge between gauges upstream and downstream of 11 dams. The total slowed storage over the period represents 1.75 m^3 or 0.06 m^3 per dam. Calculated using the Difference in stage change either side of dam in FreeStation //Smart

compared because of differences in intensity of rainfall events, antecedent conditions and size of interventions. However rough magnitudes of differences can easily be observed: large area based interventions such as regenerative agriculture have a greater potential to reduce flood risk than point based interventions such as leaky dams and retention ponds. Regenerative agriculture is more scalable as well. The additional 2000 m^3 stored by using regenerative agriculture is based on a single 2.57 ha field. Therefore a farmer implementing regenerative agriculture on a 86 ha farm (UK average farm size), with similar soil conditions as described here, would therefore have the capacity to store an extra $67,000 \text{ m}^3$ relative to the counterfactual.

This section has provided illustrative examples of how the //Smart: system can be used to investigate the effectiveness of natural flood management interventions. We presented snapshot data to give an indication of the possible magnitude of water storage of each intervention type. With wider deployment of these monitoring stations we will be able to create a stronger evidence base for the relative water storage and flow-slowing capabilities of these interventions under a wide variety of environmental and weather conditions.

12.5 Cost Effectiveness of NFM

NFM interventions are often cheaper to install than traditional grey infrastructure (e.g. Vineyard et al. 2015). This is particularly the case if being used in areas of low land prices upstream of urban centres. However NFM interventions can still be

costly to build and to maintain at scale. We have estimated the investment costs of three types of NFM per unit of storage for the next 20 years based on literature (for example, Burgess-Gamble et al. 2018) and discussions with stakeholders implementing NFM interventions in the Thames basin. *Leaky dams*: There is great variability in costs of installing leaky dams but reported capital costs per dam range from £100 to £3000 with median cost range of £175–£500. The reported lifetimes of leaky dams are also variable, although most estimates are around 10 years. There is very little information on maintenance costs of leaky dams. They need to be inspected frequently (Quinn et al., 2013; Dodd et al., 2016). Labour costs for maintenance are estimated at £50/h but hours needed are dependent upon type and location of dam.

Retention Ponds Construction of retention ponds typically requires heavy machinery meaning costs range from £2000–£6000 per pond with storage capacity of around 1500 m³, £2.3 to £4 per m³ (Shipston Area Flood Action Group, *pers. comm*). Costs of maintenance are mainly for dredging and these are estimated at £0.1–1 per m³ of per year. The opportunity cost of installing a retention pond on farmland is high variable. This is estimated here as the potential annual value of producing a wheat crop in the area occupied, around £100/year for a retention pond of 1500 m³, i.e. £0.07 per m³ per year. *Regenerative Agriculture*: The cost of adjusting soil and crop management practices is generally quite low or negligible. However, purchase of specialist soil management and cultivation machinery may be required. Posthumus et al. (2015) describe the investment cost of reduced tillage or zero tillage as zero. However, equipment maintenance costs are estimated at £50 and £67 per hectare respectively. The loss of production is estimated to be £32 per hectare based on cereal crops. In order to convert maintenance cost per hectare (an average of £58.50 per year) into the cost per cubic metre of extra soil storage for floodwater provided by Regenerative Agriculture (RA), we used the soil moisture data measured in one of our paired sites, where soil moisture was measured in adjacent RA and non-RA plots under the same soil type, slope, and meteorological conditions and the difference in storage calculated. A hectare that costs £58.50 per year in maintenance is equivalent to £0.08/m³ additional water stored. Opportunity costs (loss of production) are estimated to be £32 per hectare per year, which is £0.05 per m³/year, based on the estimated 700 m³ of extra storage per hectare.

The trade-offs between the cost of building and maintaining NFM interventions in comparison to their benefits in flood mitigation have yet to be evaluated for the Thames catchment. We use the Eco:Actuary Investment Tool to undertake this comparison for five sites within the Thames (Table 12.1). We calculated the approximate cost of investment required to achieve the mitigation goal (enough storage for a 15% reduction in downstream flood peak) for each of the three NFM interventions. For the cost per m³ of mitigation (GBP/m³) for each intervention we used the following values for the Thames: £61.63/m³ for leaky dams, £16.82/m³ for retention ponds and £2.85/m³ for regenerative agriculture.

Each river requires a different volume of flood storage in order to mitigate peak flows by the required 15%, depending on the characteristics of the flow regime (Fig. 12.12). The costs of achieving the 15% reduction varies by intervention and

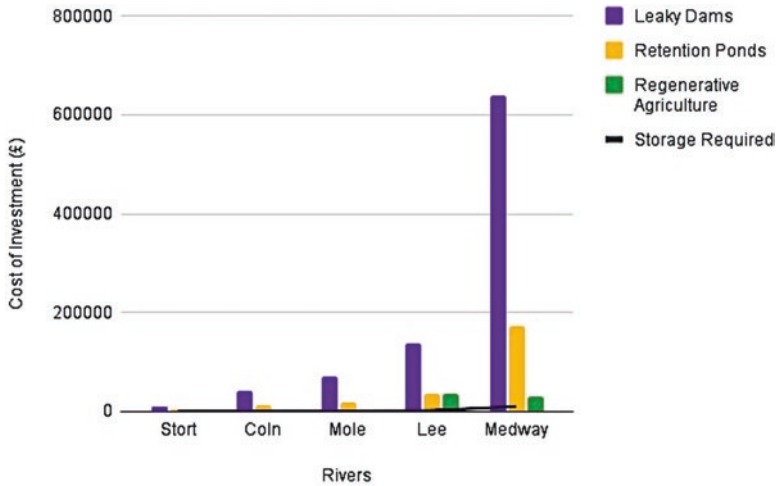


Fig. 12.12 Investment required to achieve 15% flow mitigation for each of the five study rivers (Table 12.1). Consistently, regenerative agriculture is the cheapest flood mitigation option. Whereas leaky dams are the most expensive option, with retention ponds being intermediate. The locations of modelled at-risk-assets are Roydon for the Stort River, Fairford for the Coln River, Leatherhead for the Mole River, Lea Bridge for the Lower Lee and Teston Bridge for the Medway River

the flow conditions of each river. For the same volume of flood storage, the most cost efficient method in all cases is regenerative agriculture. The most expensive in all cases were leaky dams, as they have such a small impact per dam. So, although leaky dams are individually low cost, they are not as cost effective as other measures since they are challenging to scale. In regards to the differences between rivers in the amount of storage required to mitigate flood risk, the historic flow condition data used by the EIP tend to be a more important predictor than catchment size. For example, the River Coln at Fairford has one of the largest catchments, but the volume of flood storage needed to reduce the flood peak by 15% is low as much of the catchment overlies chalk (Table 12.1).

12.6 Co-benefits of NFM

Co-benefits represent the additional benefits to people provided by NFM interventions, beyond flood mitigation. In order to evaluate these, we consulted previous research, literature and reports. Leaky dams provide no co-benefits. Although The Flood Hub (2019) assessed leaky dams as having the co-benefits of improving water quality and habitat provision, this benefit does not extend to the leaky dams we surveyed, which are installed on ephemeral/winterbourne rivers and with a gap between the base of the ‘dam’ and the riverbed. This means that these dams do not permanently hold water back and are therefore not creating habitat. The gaps are

sufficiently large that there is also no filtering function for water. Retention ponds have the potential to provide many more co-benefits including: water quality enhancement through settling of water-borne sediment and biological degradation of pollutants; biodiversity benefits through the generation of new aquatic habitat; amenity and aesthetic benefits and in some cases recreation and health benefits (Susdrain 2019; Berry et al. 2017; Brown et al. 2012; Alves et al. 2018). The degree to which these benefits are provided depend on the size of the pond, the geophysical context as well as the at risk asset distribution downstream.

Regenerative agriculture has many co-benefits including reduction in soil erosion, improved water quality, improved soil health and increased biodiversity (Mitchell et al. 2019; Palm et al. 2014). Because of the large geographic area that regenerative agriculture can be applied to, it has the greatest ability of the three NFM interventions studied to provide co-benefits in addition to the primary benefit of flood mitigation. Also, because regenerative agriculture can lead to the storage of more carbon in the soil (Mitchell et al. 2019) its co-benefits have national and global importance.

12.7 Lessons Learned and Advice

We find that leaky dams, which have attracted recent funding in the UK due to their low capital cost and relatively simple implementation, are generally not cost-effective natural flood management interventions. Our study shows that they provide little flood storage ability in many cases, they provide no co-benefits and require building at scale – and thus significant investment – to achieve a meaningful reduction in river flow for large rivers. They also have significant maintenance costs and can be a flood risk liability as they can be undermined by extreme events and break up, blocking culverts and other grey infrastructure and thus can even lead to more serious flooding (Woodland Trust 2016). However, where leaky debris dams raise flows and encourage activation of flood plains on low value land they can have much greater impact on downstream flows, particularly for smaller rivers or where the assets at risk are nearby downstream. Similarly building the dams from Willow or other species that can bind together and continue to grow instream as a ‘living dam’ provides the potential for self-maintenance, reducing maintenance costs and downstream risks. Thus careful planning and professional installation of leaky debris dams can maximise their benefits and minimise associated risks. Retention ponds provide a variety of co-benefits but are expensive to build for the volumes of water stored and take up valuable farmland. In comparison, regenerative agriculture provides flood storage for considerably less investment. In addition, regenerative agriculture can provide notable local and global co-benefits such as increased soil biodiversity (Kertész, and Madarász 2014), reduced soil erosion (Hobbs et al. 2008) and enhanced carbon sequestration (West and Post 2002). The challenge with land-based NFM such as regenerative agriculture is the requirement for landowner/farmer investment and buy-in. Encouraging farmers to change long-held

agricultural management practices can be challenging and requires incentives and risk management, both to ensure that farmers incomes are protected against adverse impacts on productivity and to meet the capital costs of transitioning machinery. Building leaky log dams in rivers is easier since there are no opportunity costs since the streams are not farmed. Land owners still require reassurance that they will not be held liable for any negative downstream impacts of the dams.

The specific results discussed in this chapter are relevant only to these study sites but the open-access Eco:Actuary Investment Planner and //Smart: monitoring equipment can be readily applied elsewhere. The Eco:Actuary Investment Planner uses Environment Agency data as standard so can easily be applied to other parts of the UK. However, the tool can still be used outside of the UK if long term flow and stage records are available. //Smart: technology has been designed for use globally in a wide variety of contexts. As the design and build instructions are freely available, the component parts can be purchased inexpensively and the stations require no coding capabilities, these sensors remove many of the existing barriers to low cost environmental monitoring. The decision as to whether to use the Investment Planner or //Smart: system depends on whether the NFM intervention is being planned or already in place (Fig. 12.13). If the NFM intervention is already in place then the //Smart: system is the best choice for assessing the effectiveness of the intervention. If not, the Eco:Actuary Investment Planner is the most suitable for understanding cost benefit and likely effectiveness ahead of deployment. Figure 12.13 supports users through the process of identifying whether the tools are appropriate for their situation.

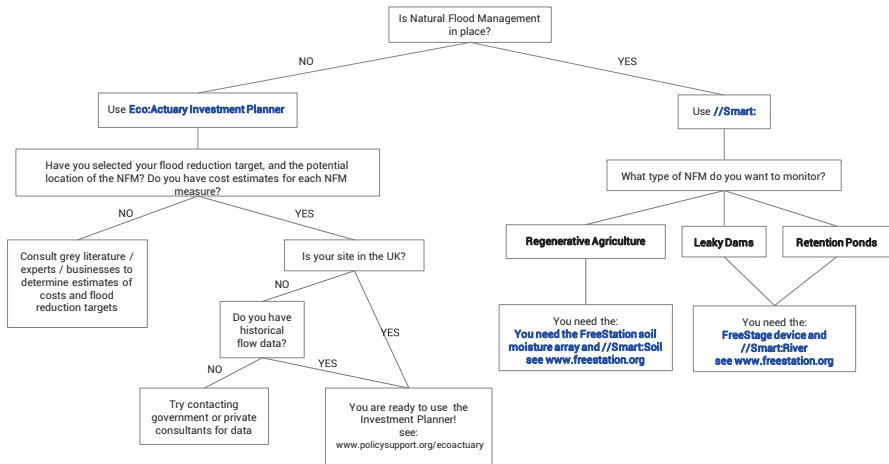


Fig. 12.13 Decision tree to support the application of the //Smart: monitoring system and the Eco:Actuary Investment Planner. As //Smart: sensor technology and user documents are continually being updated please consult <http://www.freestation.org/> for the most up-to-date guidance on materials as well as build and installation instructions. The Eco:Actuary Investment Planner is available at <http://www.policysupport.org/ecoactuary>

12.8 Practical Advice for those Intending to Deploy // Smart: Sensors

Field monitoring in a range of rural, peri-urban and urban environments is not always easy to do well, especially at low cost. Adhering to the following recommendations will ensure accurate and long-term data:

- To reduce theft and vandalism we recommend providing an explanation on the outside of the sensor about the purpose of the device and stating that it does not have any monetary value (Fig. 12.14). We found this beneficial as it allows interested people to find out about the device whilst also decreasing people's curiosity to open it to see what is inside. In urban settings, where the risk of vandalism or theft is particularly high, install the station out of reach, out of sight, and with steel cable ties. Ideas for urban camouflage include bat/bird boxes and using coloured camouflage tape / paint. Devices should always be installed with land-owner permission.
- Have a local steward or champion who lives or works in relatively close proximity to the device(s). With someone nearby the device can be quickly reset if it develops problems and/or can be easily checked on for signs of vandalism, tree-fall or other issues (see points 3 and 4).
- When building stations be mindful of what wildlife may interact with the sensors or equipment. Rabbits can chew through low-lying cables which connect the soil moisture sensors to the main station, or sometimes even the cables higher up on

Fig. 12.14 Signage on FreeStations. Communicating the purpose of the station helps to reduce theft and vandalism



What is this?

This is a low-cost, open source **flood** monitoring system installed to help manage flooding from this river by providing a real-time river level monitoring system and by testing the effectiveness of natural flood defenses upstream. It is of no commercial value since it uses open source hardware and is built by volunteers.

What does it do?

It measures the distance between the instrument and the water to detect when the water is rising rapidly or when defenses are storing water. It sends this information to a freely accessible database at www.freestation.org.

Contact us at: www.freestation.org

the station itself (e.g. from solar panel to logger housing). This problem is solved by encasing vulnerable wires in steel conduit tubing and by placing all other cables high out of reach.

- The stations need good mobile reception which is affected by topography between the station and the proximity of the local phone mast. We found that raised external aerials mounted on a 3 m fibreglass extendable, windproof pole helped to increase mobile reception. If signal is poor, then: i) select a different location (such as further upslope – the phone signal can vary significantly over a short distance); or ii) change to a FreeStationLocal that does not connect to the internet and relies on a local steward to download the data every month using the Freelay system or mobile phone tethering (www.policysupport.org).
- When siting the station, keep in mind the orientation and positioning of the device so that the solar panels receive maximum light, avoiding large trees and structures to the south (for locations north of the equator). If locating a soil moisture sensor in an agricultural field, be mindful of the maximum height of the crop so that the solar panel is mounted high enough to be unaffected by the crop. We found maize and mustard cover crops particularly problematic in this regard. If necessary, the logger and solar panel can be separated from the sensor by long wires. This is useful for when a thick tree canopy overshadows a stream, in this instance the logger with the solar panel can be separated from the river level sensor with an extended cable so that the logger/solar panel can be installed outside the canopy on the bank with a clear view south. The solar panel also needs to be kept clean.
- It is very important that the area under the footprint of the sonar water depth sensors used on FreeStage devices is kept clear of vegetation and debris to allow the sensor a clear view of the water surface. Regular vegetation clearance of reeds, brambles and trash from upstream may be necessary. Always install the sensor facing downstream of any instream mounting post.
- It is best to fix stations to permanent infrastructure, particularly in a flood risk zone, but only if this provides a clear view of the water. For example, the sensor can be affixed to a bridge or wall but only if cantilevered out to avoid the wall interfering with the sensor. The simplest installation is to mount from a bridge where there is a clear view downwards. This is because the structure is secure and there is little chance of vegetation growing under the bridge. If there is no structure, make sure to place a post firmly into the stream bed with a post driver and mount the station to the post.
- When deploying sensors in agricultural fields, good communication with the farmer is imperative so that the monitoring equipment is compatible with their farming equipment and/or can be retrieved, if necessary, while the soil is being tilled or seeded or the crop harvested. With regards to compatibility, ensure sprayer arms are able to operate over top of the stations, and only use an extended aerial pole in agricultural fields if necessary or if no spraying will take place.

Ideally locate stations between tractor “tram lines” so that the stations line up with the end of the spray arms and are as far as possible from the tractor.

12.9 Achievements and Remaining Barriers to NFM in the Thames

Progress has been made in the evaluation and use of natural flood management interventions in the Thames Basin. We have developed low-cost, open-source tools for monitoring NFM interventions *in situ* and a modelling tool for planning the scale of deployment necessary to achieve a defined mitigation target in a gauged basin. Through the deployment of this monitoring and modelling capability across a range of interventions in the Thames Basin, in partnership with the UK Environmental Agency, landowners, river and wildlife trusts and water companies we have increased knowledge on the effectiveness of three different types of NFM intervention in a variety of different contexts. Though the evidence base to evaluate effectiveness of NFM investments now, barriers to the use of NFM still exist.

These include: deployment, monitoring and maintenance barriers. With regards to deployment, within the Thames there is a lack of public land to install NFM interventions which makes implementation more difficult. This problem is further compounded because private landowners may be hesitant to host NFM measures, due to: i) the potential for litigation (i.e. if a leaky dam fails and causes damage downstream, or someone drowns in a retention pond), and ii) the opportunity cost of losing land to an NFM intervention and uncertainty around longevity of any incentive or compensation scheme as well as liability for long term maintenance or replacement costs.

With regards to the remaining barriers for monitoring, areas of low sunlight and low mobile phone signal are difficult to monitor with live systems. Non-networked monitoring stations require monthly visits to download data and check for problems and this substantially increasing the operation costs for monitoring systems distributed, like NFM measures, across large landscapes.. This is one example of why a local champion is particularly beneficial.

A key barrier remaining for NFM interventions long term is maintenance as this is pivotal to whether NFM interventions actually maintain their utility within the landscape. The best interventions are ones that are income generating such as retention ponds that also have another purpose (i.e. marinas or fishing ponds) and regenerative agriculture (which can reduce the costs of crop production). Leaky dams can require substantial maintenance, as the soil around the dam can erode during high flows thus weakening the structure and making the logs vulnerable to being swept downstream. These maintenance costs need to be factored into cost:benefit calculations for different NFM interventions, but they are difficult to estimate and are often overlooked.

12.10 Conclusion

Our results show that regenerative agriculture has a greater ability to reduce flooding than leaky dams or retention ponds in situations like the Thames basin, since RA can be applied cheaply over large areas. This result is particularly interesting considering the United Kingdom's departure from the European Union and its replacement of the EU's Common Agricultural Policy with a new subsidy scheme. The government's proposed plans centre around the idea of landowners receiving public money for the provision of public goods (i.e. ecosystem services), whilst private goods (crop production) are supported by the market. Our research has implications for this newly developed policy in two notable ways. First, our results show the positive and scalable flood alleviation effect of regenerative agriculture. Second, our development of a monitoring system that can quantify the amount of water stored (and thus benefit provided by agricultural land) serves as a starting point for developing parametric subsidies based directly on ecosystem service provided by land.

The UK government has invested into small-scale NFM projects, many of which funded pilot studies with leaky debris dams. We find that these can be an ineffective method of flood reduction because they are difficult to scale. Only in rare cases where many dams are built closely upstream of assets at risk of flood on small rivers, or when these dams activate large floodplains on low cost land do we find these effective. Our results illustrate the value of providing an evidence-base for decision making. The DEFRA pilot project scheme, combined with our technology and the efforts of project partners, has been instrumental in providing that evidence based. Natural flood management interventions clearly have a role to play in ecosystem based adaptation to climate change and flood risk reduction, but investments need to be carefully planned with respect to the type of NFM used, its placement and scale, and the evidence base for its efficacy. Scaling and maintenance considerations are paramount. Open access, practical and bespoke NFM tools now exist in Eco:Actuary and //Smart: to support organisations make such evidence-based decisions.

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