Woodland and river management in two headwater streams, NFM Pilot: results and lessons

Prepared by Dr Nathalie Gilbert
Evidence Programmes Manager
Nathalie.gilbert@thames21.org.uk

Questions to John Bryden
Head of Improving Rivers
John.bryden@thames.org.uk

MARCH 2021

EXECUTIVE SUMMARY

Natural Flood Management (NFM) works by emulating and restoring natural river and floodplain processes in order to slow and retain water flows to reduce downstream flood risk, enhance biodiversity and improve water quality. The aim of DEFRA's £15m Natural Flood Management programme was to implement and learn from installation of various types of NFM in 60 pilot projects nationwide with a view to formulating national guidance.

The Harrow headwaters NFM project is one of four Community Scale NFM pilots awarded £50,000 and delivered by Thames21 in partnership with the local council and community. This report discusses key results and lessons learned from the installation and monitoring of 29 leaky dams and 11 tree trunk dams in Bentley Priory and Stanmore Country Park, West London, by evaluating NFM effectiveness and the process of partnership working. Evaluation of the dams comprised hydrological modelling, water level sensors and volunteer reports and photographs, including development of an app. Wider benefits of the NFM were assessed by geomorphological surveys (MoRPh) and ecology surveys.

In summary, modelling of the dams concluded that their contribution to flood risk reduction was minimal (2% reduction in peak flow in a 1:20 year return period event) but peak flood level reduction in Bentley Way of up to 50cm. A scenario for an overflow channel and balancing pond was also modelled and indicated potentially 20% reduction in peak flows in a 1:20 year return period event and corresponding decreases in peak water heights in Bentley Way. However, some disbenefit in the form of increased water levels at properties downstream was also noted and will require further modelling to investigate.

Dams potentially provide other benefits such as flood risk reduction by trapping sediment that may otherwise enter and block culverts; and biodiversity benefits through diversification of channel morphology and creation of wet areas. However, there was insufficient time between dam installation and final surveying for detection of significant and conclusive changes to flora and geomorphology. Surveys carried out as part of this project therefore establish an 'as built' baseline against which future surveys can be evaluated.

A key lesson from partnership working is not to underestimate the time required to build and maintain relationships with local volunteers. However, the local knowledge and dedication of local volunteers to recording behaviour of the dams and building structures was invaluable. Successful engagement of the wider community in monitoring NFM was challenging due to teething issues with the reporting app and also the fact that, in dry weather, dams are not very exciting to record with no immediate results. Key volunteers were local users of the wood whose properties were at risk of flooding, giving them vested interest in supporting project activities.

CONTENTS

1. INTRODUCTION

Natural Flood Management (NFM) is already known to be a useful tool for flood risk management and improving the environment in both coastal and freshwater situations. It works by emulating, enhancing and restoring natural river and floodplain processes in order to slow the flow of water - which can also benefit biodiversity, water quality and climate change resilience.

In order to understand how NFM approaches can be used most effectively, in Summer 2017, DEFRA's £15m Natural Flood Management programme allocated funding to 60 projects across England with the aim of learning lessons from them, as stated in the 25 Year Environment Plan. Of these pilots, 34 are community scale projects led by charities including Thames21, the others are catchment scale projects led by Flood Risk Management authorities. Through the experiences of these three- year projects, DEFRA seeks to understand what approaches work best and how working collaboratively can deliver effective solutions through four primary objectives:

- Reducing flood risk, or coastal erosion risk, to homes
- Improving habitats and increasing biodiversity
- Contributing to research and developing NFM techniques and interventions
- Supporting and developing partnership working with and between communities

This document, delivered in collaboration with Harrow Council, reports on the above objectives and lessons learned from a Community Scale NFM pilot project delivered on two headwater streams of the River Brent, the Edgware Brook and Silk Stream, located in the London Borough of Harrow in north-west London, Figure 1.

This river management in two headwater streams NFM pilot is one of four Community Scale NFM pilots awarded £50,000 and delivered by Thames21, the others being the Rise Park Stream NFM project (London Borough of Havering), the River Pinn Park Wood NFM Project Project (London Borough of Hillingdon) and the Salmons Brook NFM Project (London Borough of Enfield), allowing comparisons to be drawn between projects.

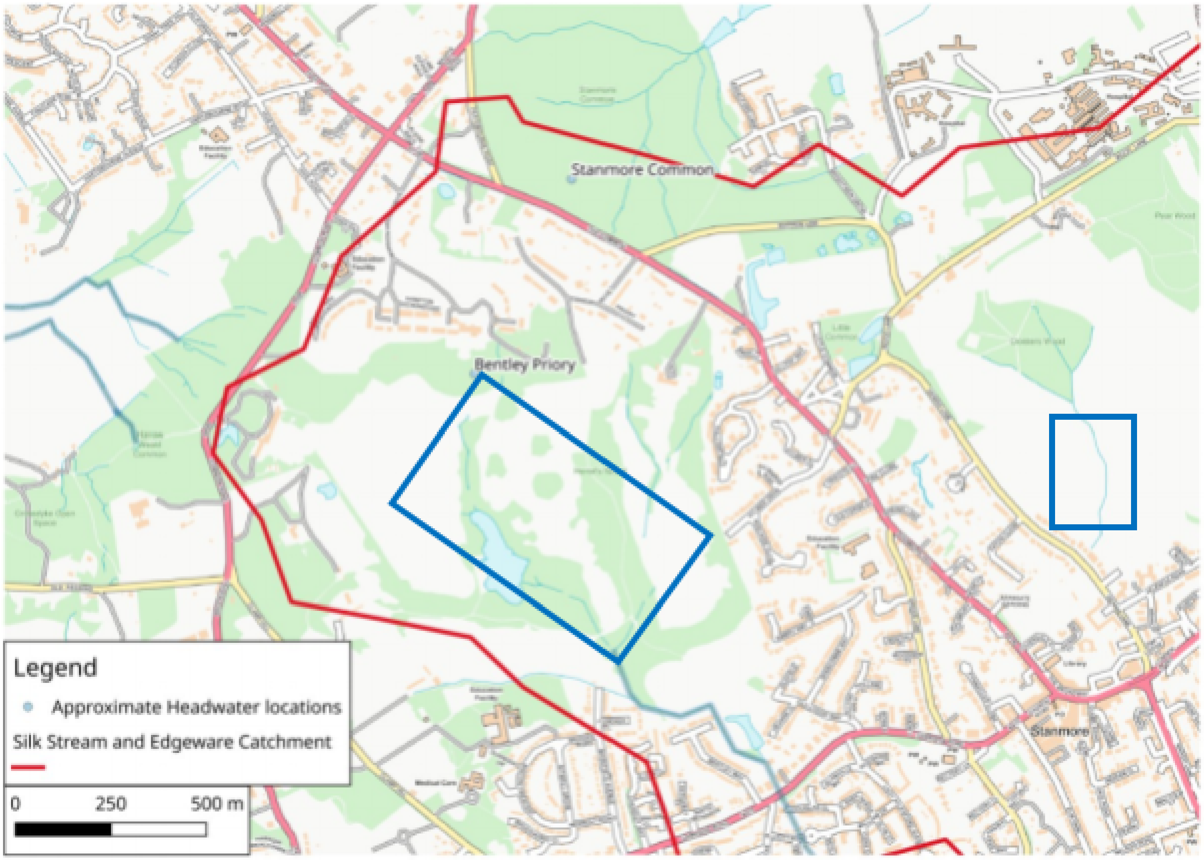


Figure 1*: The Edgeware Brook and Silk Stream catchments indicating in blue the areas where leaky dams were installed.*

1.1 Bentley Priory and Stanmore Country Park and downstream flooding issues

The headwater streams are located in the upper reaches of the Edgware Brook and Silk Stream in Harrow with a combined catchment area of 60 hectares. According to the British Geological Survey, the bedrock comprises heavy, impermeable London Clay overlain by a ridge of more freely draining sedimentary beds including Pebble Gravels, Claygate beds and Stanmore beds of sand and loam. Both streams rise from springs in small woodlands (Bentley Priory and Stanmore Country Park) at the junction between the impervious London Clay and the more permeable overlying beds, before flowing into culverts upon encountering urban areas.

Bentley Priory (51.621573, -0.331564) is a Site of Special Scientific Interest (SSSI), and Local Nature Reserve comprising a mosaic of unimproved, neutral grassland, ancient and long established woodland, scrub, wetland and open water. This habitat mix is uncommon in Greater London and supports flora and fauna that are rare or scarce in Greater London. Project works were focused on two converging arms of the Edgware Brook, one flowing from Summerhouse Lake via a spillway the other tributary flowing into the site from a private deer park. Summerhouse Lake includes EA managed flood defences to defend downstream properties from flooding.

Stanmore Country Park is a Local Nature Reserve and Site of Metropolitan Importance for Nature Conservation. Formerly grazing land, it has largely become secondary woodland since the 1950s. Project activities focused on the Silk Stream in the lower half of the Country Park. In the southern portion of this site, balancing ponds were constructed in the 1980s to protect the underground car park nearby from flooding.

Soils at both sites are heavy and slow draining therefore prone to waterlogging, which creates a tendency for surface runoff and flooding downstream during heavy rainfall. The Environment Agency identifies 78 properties downstream of the site at risk of flooding from surface water (1 in 30 flood extent) and fluvial flooding (1 in 25 year event) and many more in a 1 in 100 event Figure 2. A number of flood events have been experienced in the area previously including in August 1977, May 1988, Sept 1992, Oct 1993, June and August 1999, November 2000, August 2002 (surface water flooding), Jan 2003, July 2005 and August 2015 although detailed data are limited. Flooding also occurred during the project in October 2020 after heavy rain, Figure 3, attributed to a blocked surface water sewer.

A number of other flood alleviation investigations were undertaken further downstream with potential for this project to work in combination with these projects (Temple Ponds, Harrow Council led and Silk stream FAS, EA led). The Catchment Partnership is organising these discussions and development activities with the relevant stakeholders and this project will feed into this development. There is a Flood Alert area and a more specific Flood Warning Area on the Edgware Brook and Silk Stream.

***Figure 2**: Environment Agency Risk of Flooding from Surface Water Maps showing fluvial (top) and pluvial (bottom) flood risk for the Edgware Brook and Silk Stream headwaters of the River Brent in a 1:100 year event.*

© Crown copyright 2013

A number of households at risk of flooding, particularly in Bentley Way just downstream of Bentley Priory, supported project activities and their input and 'eyes on the ground' was invaluable to monitoring the effectiveness of the NFM installations and understanding flow dynamics within the wood - for example Figure 3.

Figure 3: *Flooding on 24th October 2020 after heavy rain, taken by a volunteer*

1.2 Aims and objectives

Delivery of DEFRA project objectives in the Edgware Brook and Silk Stream headwaters comprise the following:

- **Reducing flood risk to homes**

Flood risk reduction of 78 properties through installation of 29 leaky dams and 11 tree trunk dams on the Edgware Brook in Bentley Priory and the Silk Stream in Stanmore Country Park. Modelling assessed the flood reduction potential of an additional proposed NFM feature at Bentley Priory – a bund, high flow channel and balancing pond.

- **Improving habitats and increasing biodiversity**

Creation of leaky dams also restores and creates enhanced damp woodland and wetland features and improves the ecological value and habitat complexity of the wood and channels; monitored through biodiversity and geomorphology surveys and as part of delivery of works on Bentley Priory SSSI.

Due to the significant ecological value of Bentley Priory and the need to gain consent from Natural England, an annual ecological monitoring programme was commissioned that ran for the length of the project. This identified locations particularly suitable for creation or enhancement of wetland habitat (e.g. southern end of the site), but also a number of wetland areas with associated wetland species that may be sensitive to altered flows that should be avoided (in particular north of Summerhouse Lake).

- **Contributing to research and developing NFM techniques and interventions**

i) Flood modelling to contribute to the national debate on flood risk by assessing effectiveness of leaky dams and to guide selection of future NFM interventions (alongside ecology surveys) in Bentley Priory and Stanmore Country Park. Modelling occurred in parallel to installation of the leaky dams installed as part of the DEFRA pilot but also modelled future opportunities for installation of leaky dams and creation of a bund and high flow relief channel feature within Bentley Priory.

This was originally intended as a PhD project hosted by Brunel University but lack of a suitable candidate meant that ultimately Edenvale Young Associates Ltd (www.edenvaleyoung.com), a civil engineering consultancy specialising in fluvial environments, carried out the work for three of the NFM pilots delivered by Thames21 and partners - the others being the Rise Park Stream NFM project (London Borough of Havering) and the Salmons Brook NFM project (London Borough of Enfield).

ii) Trial of innovative, low-cost water level monitoring devices to monitor and evidence the performance of the NFM installations. Namely ‘Freestations’ (http://www.freestation.org/), developed by King's College London, and a water level and turbidity logger in development at Imperial University, London.

- **Supporting and developing partnership working with and between communities**

i) By undertaking the works by combination of London Borough of Harrow – the land owner and lead local flood authority (LLFA) and coordinated and delivered by Thames21 in partnership with local interest groups.

ii) Outside of those at immediate risk (for example the residents of Bentley Way), awareness of flooding in the area was known to be relatively limited. However there are a number of local volunteer groups who are extremely passionate about the ecological and amenity value of the sites, for example the Harrow Nature Conservation Volunteers. Enabling the local community to understand what is being undertaken, be involved in the delivery of work and why it’s important, is essential to ensure buy-in and ownership to the solutions delivered. This was achieved through NFM training workshops and leaky dam building events delivered by Thames21 and the creation of an app for surveying and recording changes associated with the leaky dams and inviting local riparian residents to host level monitoring devices. Their detailed local knowledge and ability to be ‘eyes on the ground’ to record dam and woodland dynamics during rainfall events enable the project to achieve maximum results.
iii) Regular dissemination of progress and results with wider interested groups including the with other flood projects in the borough and the River Brent Catchment Partnership.

2. NFM EVIDENCE APPROACH AND METHODS

2.1 Selecting locations for NFM assets

Suitable sites (Figure 4) for installation of leaky dams and 10 tree trunk dams on the Edgware Brook in Bentley Priory (16 leaky dams, 10 tree trunk dams) and the Silk Stream in Stanmore Country Park (13 leaky dams, 1 tree trunk dam), plus proposed locations for further dams were identified through consultation/catchment walkovers in conjunction with Harrow Council and guided by ecology survey results of Bentley Priory SSSI. Following guidance from the Working with Natural Processes; Evidence Directory, dams were initially proposed in sets of 5. Following the site visits, some proposed locations were deemed not suitable due to channel characteristics and bankside flora restricting access. It was considered and to relocate these would result in dams being very close together that could reduce effectiveness and appear less aesthetically pleasing. It was initially the intention to use the flood modelling to guide the location of dams, however, due to time constraints, modelling of dams and other NFM features could only be undertaken retrospectively but will be used to inform future interventions.

Due to the designation of the site as a SSSI, consent under Section 28E(3)(a) of the Wildlife and Countryside Act was obtained from Natural England. The duration of the consent extends to August 2022 - beyond the formal end of the project funding in March 2021. This was to enable adjustments to be made as required according to project findings.

Wood (up to 15cm in diameter) generated by previous habitat management was used to create the leaky dams. In addition, contractors were used to fell more substantial trees across flow paths.

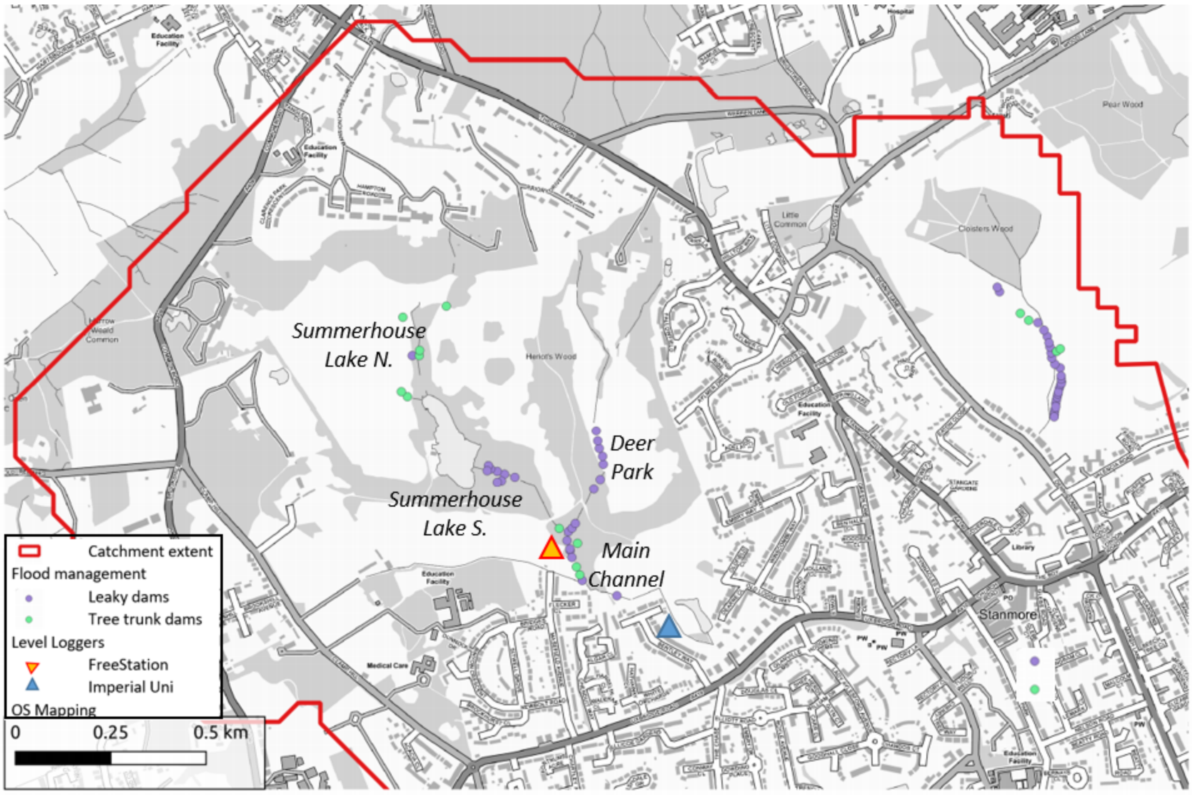


Figure 4: *Locations of leaky barrier and tree trunk dams constructed in Bentley Priory and Stanmore Country Park; and water level monitoring devices (a FreeStation and a trial level sensor from Imperial University). Channels were named to aid identification.*

2.2 Monitoring approaches used

Flood risk modelling

Hydraulic modelling was carried out in ESTRY-TUFLOW, a one and two-dimensional distributed hydraulic model used for representing floodplain flow. The extent of the model is shown in Figure 5. It incorporated an existing model (1D-2D FMP-TUFLOW model) created by JBA Consulting Ltd in January 2019 for the Environment Agency which was shared with the project. Publicly available terrain data, OS Mastermap data and Cranfield soils data were incorporated in the 2D component.

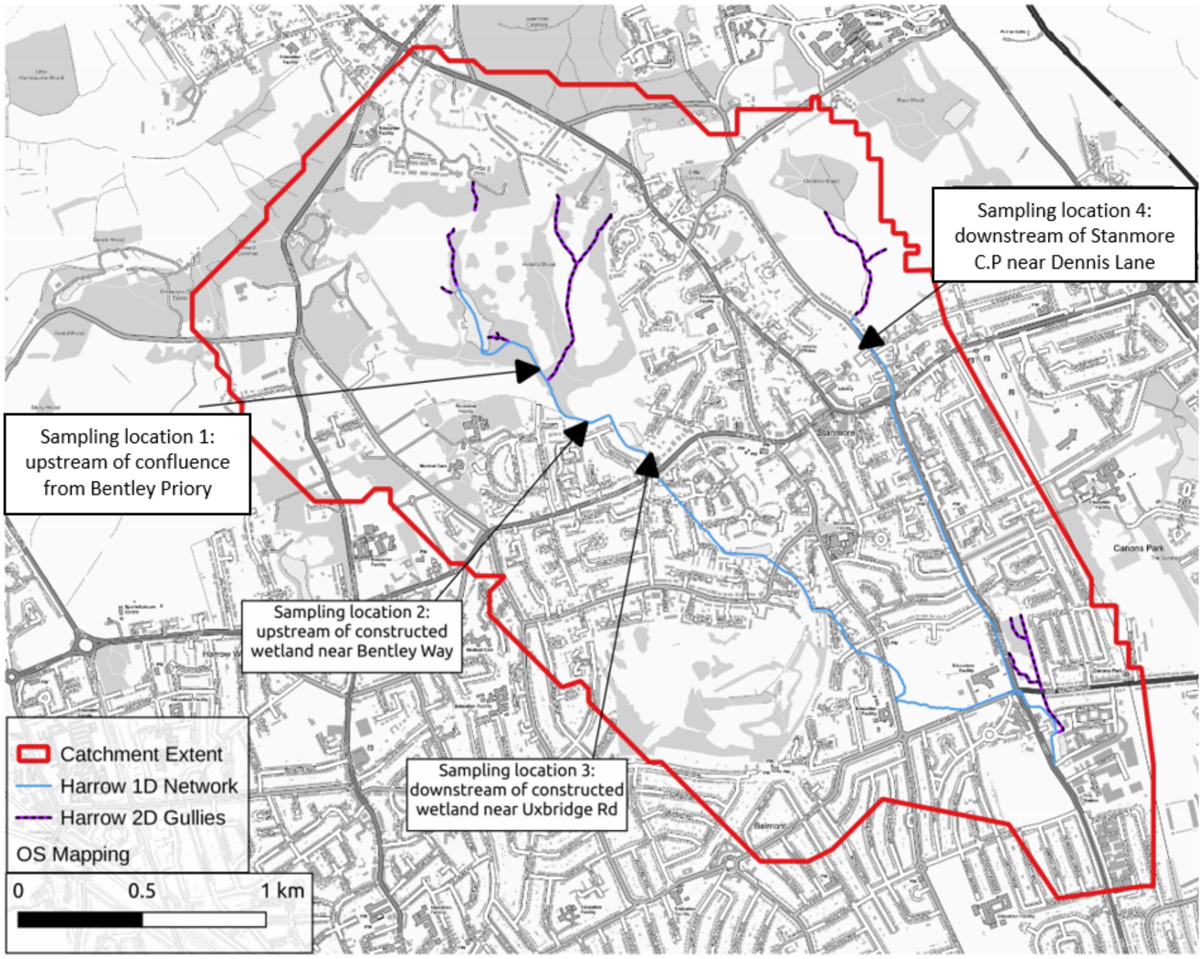


Figure 5*: Extent of the model created by Edenvale Young Associates Ltd, indicating the extent of the 1D and 2D components and the locations where hydrographs of modelled results were taken.*

The modelling approach is discussed fully in Appendix 1 but, in brief, the model was calibrated by amending the Green Ampt model parameters until they matched the Flood Estimation Handbook (FEH) catchment descriptor SPRHOST (Standard Percentage Runoff (SPR, %) of each Hydrology Of Soil Types (HOST) soil class) for an event in August 2015 in the first instance. It incorporated data from 3 rain guages and 2 flow gauges, all nearby but not within the modelled area. Hydrology (baseflow and rainfall hydrographs) were calculated based on standard FEH methods. Assumptions were made to approximate data gaps in the surface water drainage network of the catchment, supplied by Thames Water – for example concerning up and downstream inverts and pipe diameters. Baseflow was explicitly represented in conjunction with rainfall (15 minute totals) inflows for a fully distributed hydrological approach.

The model was validated against out of bank extents from a minor flood event that occurred in October 2020 (images Figure 3, data Figures 24 and 25) and infiltration parameters adjusted to match. The model was truncated below Bentley Priory and Stanmore C.P. in order to focus on the catchment and flood risk areas of interest whilst minimising model run times. Freestation data was, as yet, short term so less useful in model calibration.

The following NFM scenarios were investigated and optimised to demonstrate their effectiveness and tested for the October 2020 event and 1:20 and 1:100 year return period events against a baseline scenario without NFM interventions. They comprised:

i) The effectiveness of multiple leaky dams installed in Bentley Priory and Stanmore Park.

The locations of 50 leaky dams and 11 tree trunk dams (built and proposed, Figure 4) were passed to Edenvale Young along with photographs and 'as built' dimensions corresponding to those uploaded to the AGOL portal. Built information (height above bank, orifice height and width, 'leakiness' based on photographs) was used to approximate layered flow constriction values. Due to grid size, each dam was represented as 10 m wide. Leaky barriers not yet built were set to 0.3 m above bank top with an assumed blockage of 90% and a form loss coefficient of 1.8. Dams were represented by changing the Manning's roughness.

ii) Assessment and optimising of potential locations of future leaky dams, identified as part of this project

iii) The impact on downstream flood risk of a bund, drainage channel and balancing pond at Bentley Priory above Boot pond.

This bund starts in an area where water is already known to pool to the north of properties in Bentley Way (Figure 6). It follows the left bank of the channel and wraps around the balancing pond. It is initially at the existing ground level, rising to 200mm above existing ground level near the channel before returning back to existing ground level. The drainage ditch and balancing pond were both modelled as 2m deep, with materials and soils and with a pipe connecting the balancing pond to Boot Pond represented as 300mm in diameter. This Drainage was therefore simulated in order to show surface water attenuation and flood risk reduction, rather than the pond simply filling up.

iv) Scenarios of combined leaky dam and bund-pond measures to indicate maximum benefit in Bentley Priory

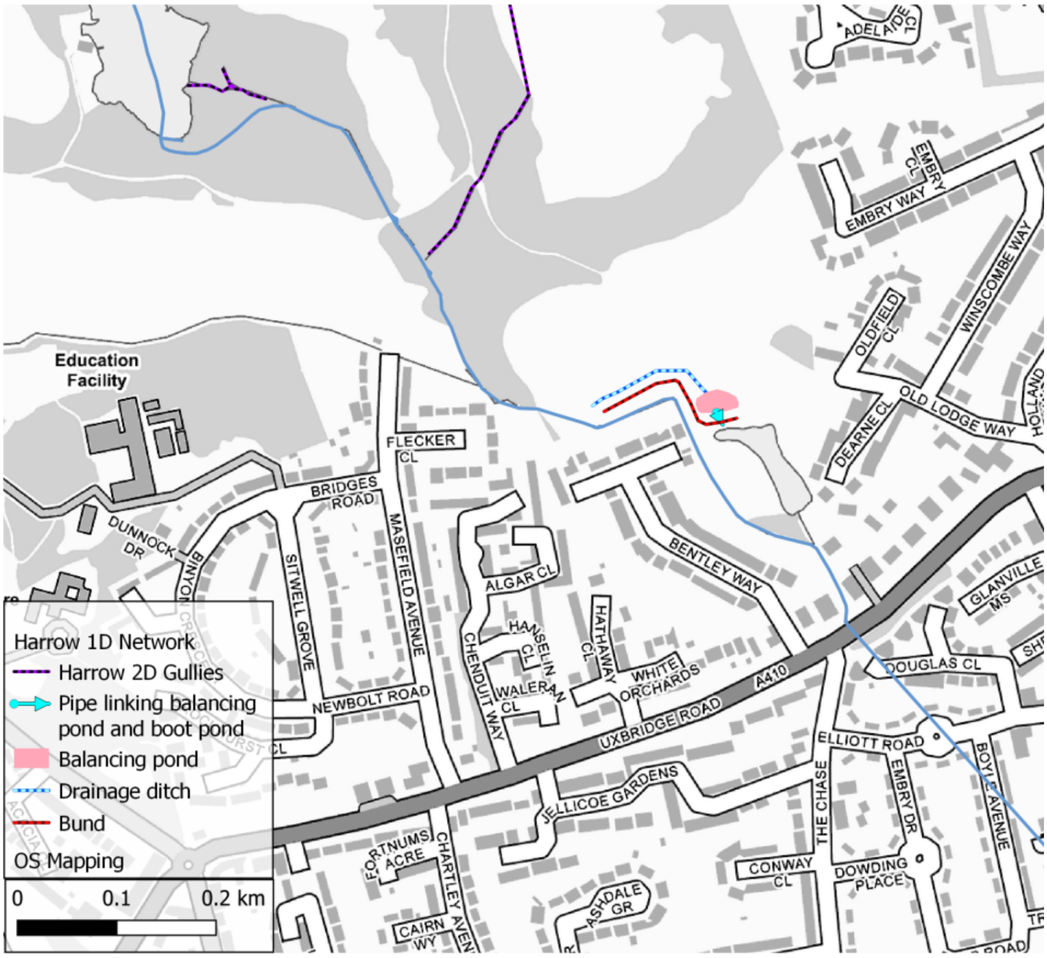


***Figure 6**: The bund, high flow channel and balancing pond modelled in Bentley Priory*

Dam surveys

DEFRA reporting requirements include measurement of the built characteristics of NFM solutions installed and upload of data to the national reporting GIS database (CaBA's ArcGIS Online –AGOL portal). This includes dam dimensions (width, height above bed, height above bank full), timber width and species but also estimates of water storage volumes and roughness increases.
The storage potential of individual dams (m^3) was estimated visually during site visits and by noting the extent of debris tidelines indicative of pooled water extents.

Area of roughness created was measured as per the reporting guidance, by estimating the area of catchment draining to the lowest in a series of dams, divided by the number of features.

Modular River Surveys

Modular River (MoRPh) surveys assess changes in physical habitat and hydrogeomorphological functioning associated with the leaky dams at both sites. Based on stream width, survey lengths of 10 m were assessed for physical structure of the channel and margins. In the majority of locations, a sequence of 10 adjacent surveys was carried out (MultiMoRPh / MoRPh 10) to provide a more comprehensive audit of 100 m of channel incorporating leaky dams, and generating 16 numerical summary indicators to characterise the surveyed length. These indices can detect changes in hydraulic, sediment, physical habitat and vegetation characteristics, Table 1.

Table 1: Summary indices derived from MoRPh surveys

Index	Descriptor
Channel characteristics	
1	Number of present/extensive flow types
2	Highest energy present/extensive flow type
3	Number of present/extensive bed material types
4	Coarsest present/extensive mineral bed material type
5	Average alluvial bed material size (phi units)
6	Average alluvial bed material size class
7	Extent of superficial bed siltation
8	Channel physical habitat complexity
9	Number of aquatic vegetation morphotypes
Riparian characteristics (bank face and bank top)	
10	Average riparian physical habitat complexity
11	Maximum riparian physical habitat complexity
12	Riparian vegetation structural complexity
Human Pressures	
13	Degree of human pressure imposed by bank top land cover
14	Channel reinforcement
15	Non-native invasive plant species extent
16	Number of non-native invasive plant species

Information on survey methods and access to the Modular River Survey database, freely available online, can be found on the modularriversurvey.org website.

Evaluation of results considered both temporal change in the same survey reach but also spatial change between surveyed sections in a MultiMoRPh to assess broader impacts of the dams. Particular focus was given to changes that may be associated with dam installation. This included indices associated with scour and deposition (e.g. changes in bed material size and sediment layers, bed features) and changes in soil moisture assessed as abundance of moisture loving flora in channel, on channel margins and the riparian zones (e.g. abundance of mosses and liverworts).

At both sites, a baseline survey (carried out pre-installation of the dams or ‘as built’ shortly after dam construction) and a repeat survey as late as possible in Spring 2021 was carried out. In Bentley Priory, surveys took place in May 2020 and the comparison survey in February 2021. In Stanmore C.P., three sets of surveys were conducted, the first pre dam installation in February 2019 (3 surveys), then post installation of several dams in March 2019. The final set of surveys was carried out as late as possible in the project (March 2021) in order to allow maximum time for geomorphological changes to occur. This final survey comprised 5 surveys, 4 repeated previous surveys).

Water level monitoring (FreeStations)

In order to evaluate the impact of leaky dams on the timing and height of peak flows, options were explored to deploy ‘FreeStations’, low-cost sensors equipped with water level sensors (based on car parking technology) at both sites. FreeStations (www.freestation.org) are innovative, open source software, environmental loggers developed by King's College London with various models capable of deploying a range of sensors (eg temperature, meteorological parameters, soil moisture etc). Data are recorded hourly and stored on board using an SD card and uploaded automatically to the FreeStation web platform via GSM.

FreeStations are for DIY construction using readily available parts sourced online. Inviting volunteers to assist in building them had great potential as an opportunity to engage local communities in concepts of NFM and to encourage interest and ownership in the project. In practice, assembly was technical (involving soldering and electronics) and procurement of a workshop whose risk assessments permitted more than one volunteer per staff member proved challenging, so the stations were assembled by project staff.

Due to issues sourcing parts for construction and Covid restrictions, installation of FreeStations in this catchment was delayed. However, this allowed the project to benefit from learning from installation experiences in other catchments. FreeStations installed in heavily used public greenspaces in other catchments were vandalised. This included the only one in Bedfords Park (Havering) and three of the five stations installed in Park Wood

(Hillingdon). It was also noted that those located within woodland environments experience light and signal problems as they require solar panels to keep the battery charged.

It was therefore concluded that neither Bentley Priory nor Stanmore C.P. had suitable sites due to the level of public access and the dense canopy cover created by the woodland.

However, Bentley Priory had the benefit of the water course flowing through the private residences of gardens on Bentley Way immediately after exiting the wood, Figure 4. After entering into discussions with local residents, a FreeStation was installed in one of these gardens in August 2020, Figure 7.

Figure 7: *FreeStation water level monitoring device installed in a private garden in Bentley Way immediately downstream of Bentley Priory and the area where leaky dams were installed.*

This would not inform about changes in timings of hydrographs associated with individual dams, but had potential to capture the behaviour of the channel downstream of interventions during flow events, which may inform modelling. It was also an opportunity to engage local residents who were at risk of flooding.

In public places, battery (rather than solar) powered level monitoring devices that log data on board (rather than live streaming) are clearly more suitable because they can be hidden more discreetly. Imperial University are in the early stages of trialling such a logging device and one was attached to a leaky dam in Bentley Priory (Figures 4 and 8) upstream of a series of leaky dams. This was deployed in October 2020 in order to compare with the FreeStation downstream. Prior to installation, the Imperial logger was deployed in parallel with a FreeStation in the Salmons Brook catchment for a period of several months and it was ascertained that data were directly comparable between devices.

Figure 8*: Imperial level logger (left) and deployed discreetly into a leaky dam in Bentley Priory (right)*

Ecology surveys

Between 2018 – 2021, DJV Consultant Ecologist carried out a series of annual surveys in Bentley Priory (and sister project Park Wood) and devised a bespoke vegetation survey, using quadrats, to establish a baseline from which trends and meaningful changes in vegetation can be identified during and beyond the lifetime of this project (Appendix 2). Design focused on existing flora (e.g. sedges and rushes) indicative of usually wet or low-lying land. The aims were to:

i) Inform about the ecological value of the watercourses and influence of potential works in the project area, particularly in relation to features cited in the designation of the site or features of notable value.

ii) Identify areas that are particularly valuable and which should remain untouched or areas that are ecologically appropriate or could be enhanced through the project.

iii) Inform the application for consent from Natural England for delivery of project works on a SSSI.

iv) Establish the basis for a long-term monitoring programme to explore the ongoing successes and limitations of this project.

An initial scoping/phase 1 survey in autumn 2018 was carried out in likely areas of NFM interventions to identify areas that should not be disturbed and highlight areas that would benefit ecologically from NFM solutions; also to devise the survey method.

It was recommended that the subsequent quadrat surveys be carried out in spring/early summer to ensure Ancient Woodland Indicator species (AWIs) were recorded. Consequently, surveys were undertaken in Bentley Priory over 3 days in the second half of May 2019 and repeated in the same half of May 2020 after the majority of dams had been installed. The 2021 survey is scheduled to take place in May after the issuing of this report, but will contribute to ongoing research.

All vascular plant species were recorded within 20m transects with a 3m buffer along the main streams. This comprised the two branches of the stream converging above Summerhouse Lake and the two streams that converge in the woods below the lake (one arriving from the lake, the other from the deer park). The relative abundance of each species was recorded using the DAFOR scale (D=Dominant, A=Abundant, F=Frequent, O=Occasional and R=Rare). The Ellenberg value for moisture was also recorded for each species, Table 2. Moisture values are from 1-12; species with a value of 1 are indicators of extreme dryness and species with a value of 12 are plants which are permanently or almost constantly underwater.

Table 2*: Ellenberg's moisture indicator values*

Code	Explanation
1	Indicator of extreme dryness, restricted to soils that often dry out for some time
2	Between 1 and 3
3	Dry site indicator, more often found on dry ground than in moist places
4	Between 3 and 5
5	Moist site indicator, mainly on fresh soils of average dampness
6	Between 5 and 7
7	Dampness indicator, mainly on constantly moist or damp soils, but not on wet soils
8	Between 7 and 9
9	Wet site indicators often on water-saturated,, badly aerated soils
10	Indicator of shallow water sites that may lack standing water for extensive periods
11	Plant rooting under water, but at least for a time exposed above, or plant floating on the surface
12	Submerged plants which are permanently or almost constantly under water

(after Hill et al 2004 in Vickers 2019 and 2020)

The status of a plant in the locality (e.g. notable in Greater London, an AWI, recognised invasive non-native species (INNS), red list etc.) was also recorded to facilitate future analysis of significant changes in floral composition as the project progresses.

In subsequent years, the survey was refined. All transects were walked but detailed surveys were only repeated where 2019 transects contained ground flora associated with damp or low lying land (Ellenburg moisture values ≥8). It is these areas where flora composition is most likely to be influenced by changes in soil moisture resulting from NFM installation. Pendulous sedge *Carex pendula* was excluded because it is associated with a wide variety of habitats, not just moist areas, and is locally abundant. In addition, the 2020 (and 2021) surveys paid attention to the locations of existing and proposed leaky dams.

Volunteer engagement, training and the SlowFlow app

An education and training program, developed and delivered by Thames21, comprised an accredited two day course covering aspects of NFM installation, maintenance and monitoring and permitting, as well as practical experience of constructing leaky dams. Targeted at local residents and users of Bentley Priory and Stanmore C.P., the purpose was to increase public understanding of flood risk in the area, NFM as a flood risk solution and to empower and equip the local community with the necessary skills to assist with ongoing inspection and maintenance of leaky dams beyond the current project. This was subsequently amended to a one day course involving some theory and dam building practice, then, due to Covid-19 lock down, an online webinar with an optional practical element to take place after lock down.

Volunteer monitoring of the dams focused on training attendees to use the SlowFlow app on their mobile phones. This app, developed by Thames21 in conjunction with Cartographer (https://cartographer.io/), prompted users to upload photos and answer a series of questions to capture information about either functioning and state of repair of existing dams or locations identified as possibly suitable for installing NFM features in future (Appendix 3). It also invited users to upload photos of leaky dams retaining water in high flow events and/or comment on ecological, ground conditions or other changes of interest in the vicinity of the leaky dams.

Volunteer photos and estimates of water storage area behind the dam, collected via the app, were intended to assist with assessment of functioning of individual dams in different weather conditions, corroborate data generated by the FreeStations and inform the calibration of the flood risk model.

***Figure 9**: QR code (blue disc) deployed on a leaky dam in Bentley Priory.*

Feedback from course attendees and evaluation of the app by users was incorporated into tailoring and development to better suit user needs.

After construction of the majority of dams, QR codes were installed on or near selected dams in Bentley Priory and Stanmore C.P. to further encourage woodland users and local residents to engage with the project (Figure 9) and as part of project legacy. Scanning the QR code connects users to Thames21's project web page containing information about NFM for flood risk mitigation, project volunteering opportunities and links for reporting dam state of repair and functioning.

3. RESULTS AND EVALUATION OF THE NFM

3.1 Hydrological changes associated with the NFM assets

The characteristics of the 12 leaky dams and 10 tree trunk dams in Bentley Priory and 13 leaky dams in Stanmore C.P. (Figure 4), are summarised in Table 3 and reported in full via the DEFRA pilot reporting portal (AGOL).

Dams were constructed from timber harvested from management of the local woodland area and comprised a mix of species. In Bentley Priory this was predominantly sycamore and hornbeam with some ash and willow. In Stanmore C.P. dams were predominantly hazel but including sycamore, holly and some hornbeam. Contractors felled entire trees across the channel in Bentley Priory and Stanmore C.P. in order to create more substantial tree trunk dams.

***Table 3**: Summary of construction characteristics of leaky dams in Bentley Priory and Stanmore Country Park*

Location	Mean height above channel bed (cm)	Mean height above bank full (cm)	Mean timber length (cm)	Mean timber width (cm)	Mean channel width (cm)	No. dams
Bentley Priory						
Summerhouse Lake N.	48.3	42.5	666.7	35.0	50.0	6
Deer park stream	83.6	-15.0	254.3	11	78.4	7
Main channel	57.2	-22.2	537.8	19.8	112.4	9
Sub total	*63.0*	*5.3*	*486.2*	*21.9*	*80.3*	*22*
Stanmore C.P.						
Main channel	136.5	-35.6	229.5	8.6	107.3	13
Overall	**81.4**	**-7.6**	**422.1**	**18.6**	**87.0**	**35**

Channel names correspond to those in Figure 4.

Installation of woody debris dams across the channels slows the flow by temporarily storing water and increasing channel roughness. Additionally, rather than storing water, many of the dams were designed to divert flows out of the channel to infiltrate into the woodland floor, thereby reducing the volume of water in the channel. Examples of dams in Bentley Priory and Stanmore C.P. are shown in Figure 10. The increase in storage volume and area of channel roughness created are summarised in Table 4.

Once the storage area behind the dam is full, it ceases to detain any further flow and water weirs over the top of the dam. The degree of 'leakiness' of dams in terms of how much water is let through the structure and also the speed with which water infiltrates into the underlying substrate (related to antecedent weather conditions as well as geology) will impact the storage capacity of dams and its ability to impact the timing and volume of peak flows. The impact of these aspects was characterised by flood risk modelling and from volunteer reports during flow events.

Figure 10*: Examples of leaky dams and tree trunk dams installed in Bentley Priory and Stanmore Country Park . The tree trunk dam in the bottom example was intended to divert flows out of channel to infiltrate into the woodland floor.*

Table 4*: Estimated hydrological characteristics of the leaky dams in Park Wood*

Location	Storage volume (m3)	Mean channel roughness (m2)
Bentley Priory		
Summerhouse Lake N.	29	1912.8
Main channel	109	6774.5
Deer park stream	89	12219.2
Sub total	*227*	*20906.5*
Stanmore C.P.		
Main channel	175	5950.4
Overall	**402**	**26856.9**

Channel names correspond to those in Figure 4.

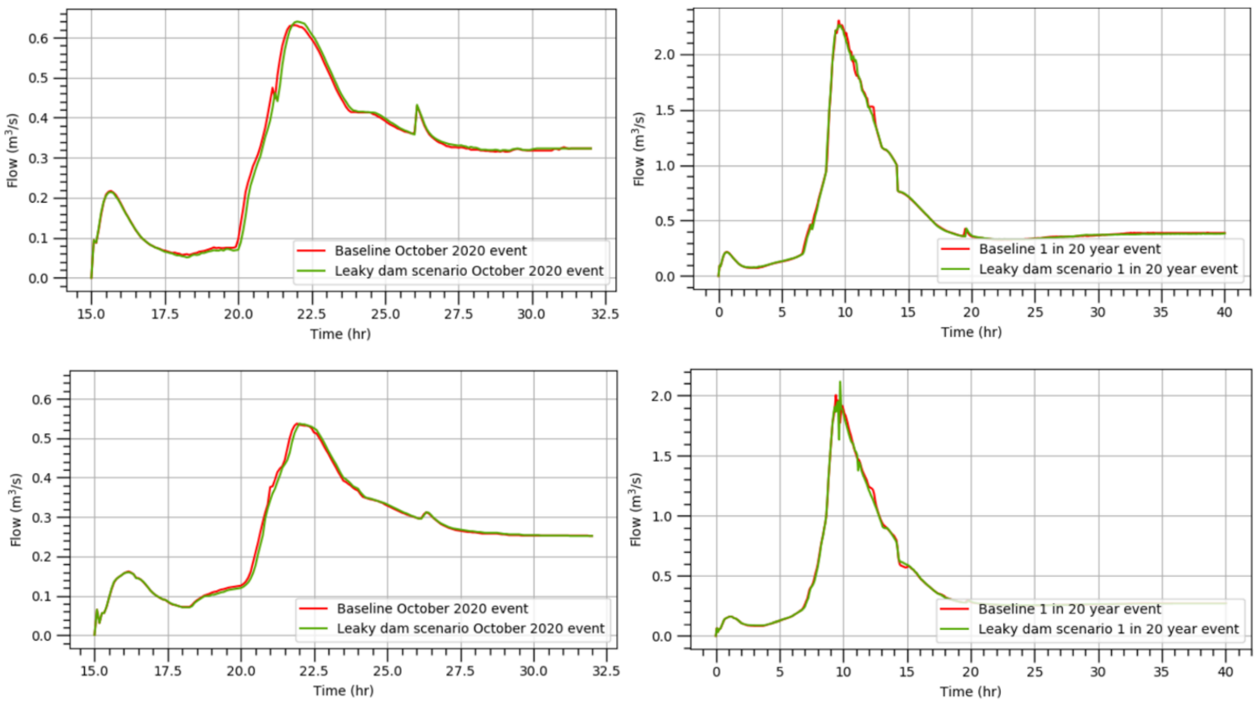
3.2 NFM performance – are the assets working as designed to reduce flood risk?

Modelling evidence

The scenarios with the leaky dams model the situation as it currently is after the DEFRA pilot project. The scenario with the channel and bunds explores the potential of an NFM option and its contribution to flood reduction in the urban area below Bentley Priory. However, to date, no funding has been sought for its implementation.

Effectiveness of leaky dams in mitigating flood risk

All dams (proposed and built) were modelled and results indicate only a marginal impact on downstream flood risk at either site. The maximum reduction in peak flows is approximately 3% near Bentley Way during the October 2020 event, with no meaningful change in peak timing. This drops to 2% reduction in peak flow in a 1:20 year return period event and no reduction in peak volume or timing in a 1:100 year event, Figure 11, Appendix 1. This means the effects of the leaky and tree trunk dams are only detected in smaller rainfall events. In Stanmore C.P., there is no perceived impact in the timing or height of the flood hydrograph taken at any temporal scale, Figure 12.



October 2020 | 1 : 20 return period

***Figure 11**: Hydrographs of performance of leaky dams in Bentley Priory during the October 2020 event (left) and a 1:20 year return period event (right). Scenarios with (green) and without (red) the leaky dams were sampled from top: just north of Bentley Way and; bottom: at the southern end of Bentley Priory at Uxbridge Road (locations 2 and 3, Figure 5).*

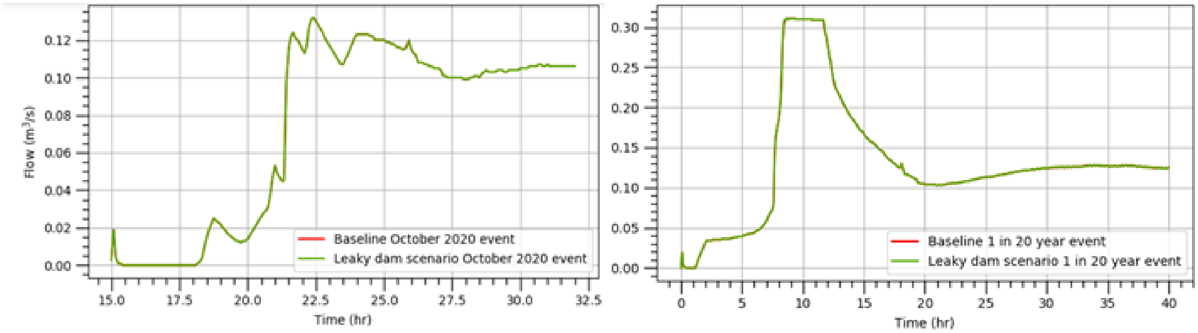


***Figure 12**: Hydrographs of the performance of leaky dams in Stanmore C.P. during the October 2020 event (left) and a 1:20 year return period event (right). Scenarios with (green) and without (red) the leaky dams were sampled from Dennis Lane (location 4, Figure 5).*

This means that leaky dams are only minimally effective at reducing flood risk. These results are consistent with the modelled results of the performance of the leaky dams in the other three NFM pilots - all of which found minimal or no impact of leaky dams on flood risk reduction.

Peak water level difference mapping indicates an increase in water levels in Bentley Priory and Stanmore C.P. of 250 mm and 29 mm respectively. This is associated with the dams holding back water and is contained within the woodland and therefore does not increase risk to properties, Figure 13.

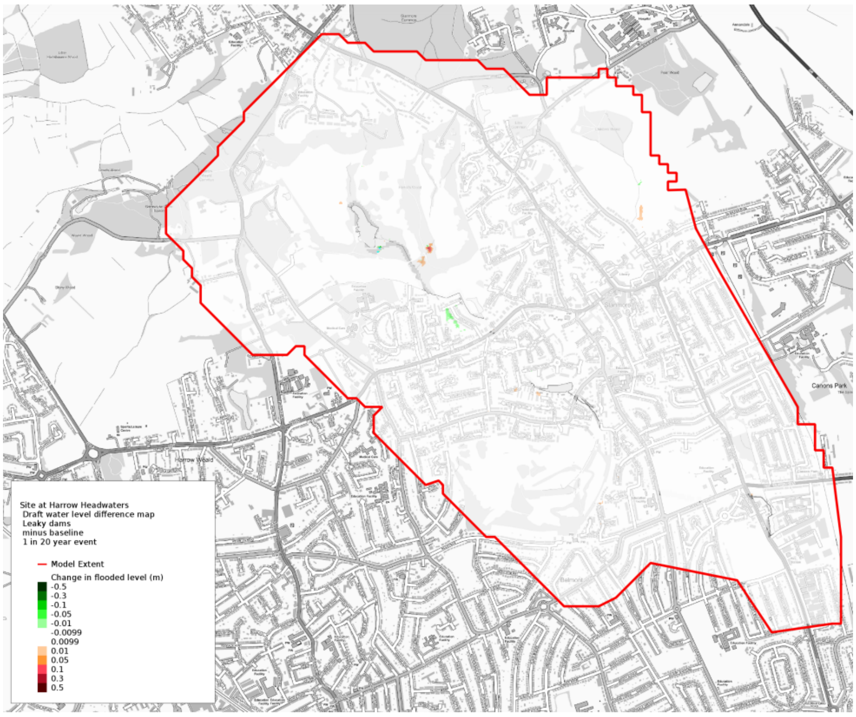


***Figure 13**: Modelled peak water level differences between the scenario with the leaky dams and a baseline scenario with no dams during a 1 : 20 year return period event.*

Figure 14 focuses on areas of interest from Figure 13. In particular the reduction in peak flood water levels (by approx 50 mm) in Bentley Way during a 1 : 20 year return period event. The increased water levels by approx 15 - 20 mm in Robb Road (Figure 14c) is unlikely to represent a 'real' increase in flood risk. This location is far downstream of the leaky dams and there are many other inflows between the dams and this location - not least from Thames Water's surface water drainage network, which was modelled with many assumptions.

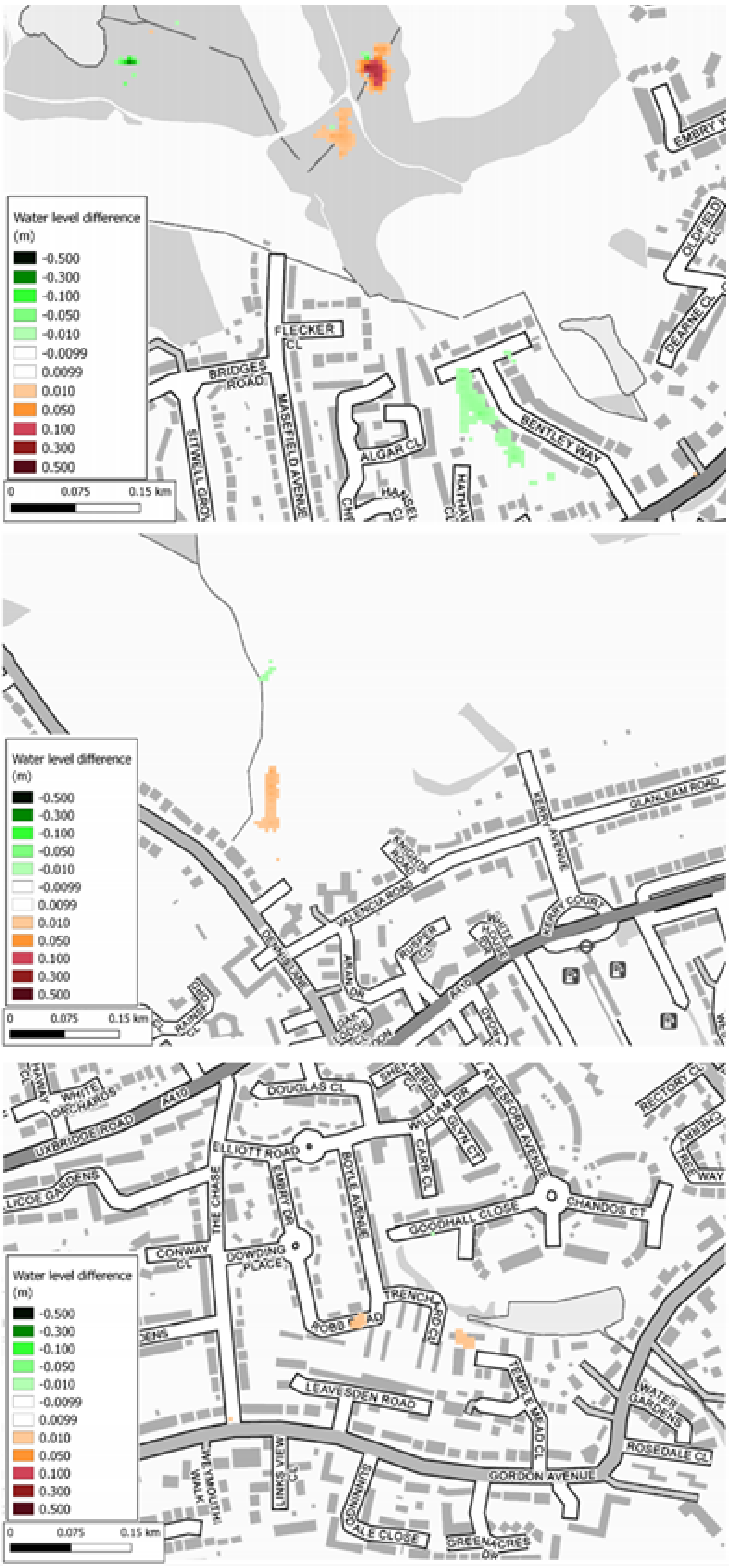


Figure 14: *Peak flood water level differences in a scenario incorporating leaky dams compared to the baseline without leaky dams during a 1:20 year return period event, taken from Figure 13: a) Bentley Priory, b) Stanmore C.P. and c) downstream in the vicinity of Temple Pond.*

During a 1 : 100 year event, peak water level difference mapping indicates water level increases in Bentley Priory (260 mm) and Stanmore C.P. (62 mm) respectively in association with the leaky dams. There is also a possible increase in water level at the location of one house on Dennis Lane (11 mm) and downstream at Wolverton Road (42 mm), Figures 15 and 16. There is no change in peak height or timing demonstrated in the hydrographs (Appendix 1).

Once again, it must be stressed that modelled results are unlikely to be the results of the leaky dam interventions, in particular the elevated water heights far downstream in the Temple Pond area during the October 2020 and 1 : 20 year return events.

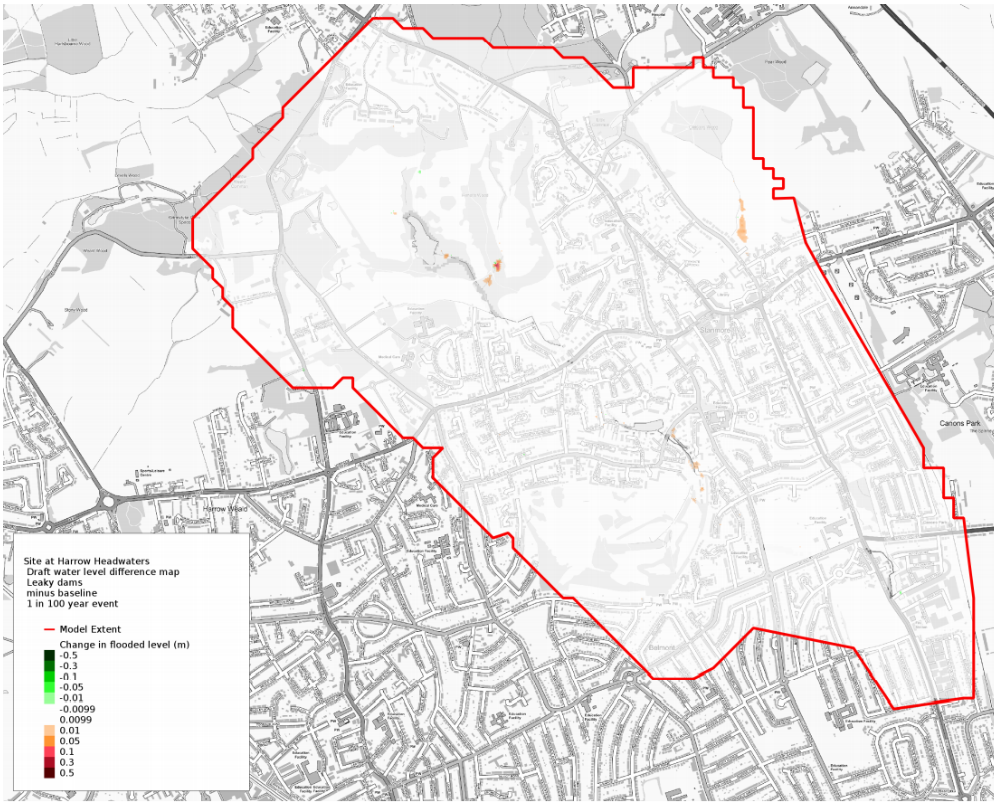


Figure 15: *Modelled peak water level differences between the scenario with the leaky dams and a baseline scenario with no dams during a 1 : 100 year return period event.*

Figure 16: *Peak flood water level differences in a scenario incorporating leaky dams compared to the baseline without leaky dams during a 1:100 year return period event, highlighting key aspects of Figure 15 at: a) Bentley Priory, b) Stanmore C.P. and c) downstream in the vicinity of Temple Pond.*

Effectiveness of a bund, high flow channel and balancing pond in Bentley Priory at mitigating flood risk

The initial proposal supplied by Harrow Council included raising the height of the bund of Boot Pond to provide additional flood storage, however, initial results indicated this increased flood risk to properties immediately downstream, for example by blocking the flow route from Dearne Close to the pond. The design was therefore optimised to the option presented in Figure 6 and comprised: a bund to prevent water overtopping the balancing pond and reentering the channel, a 2 m deep ditch and a 2 m deep balancing pond with a 300 mm diameter culvert. This feature could contribute to biodiversity and links to management plans for a chain of linked ponds across the site - already under discussion.

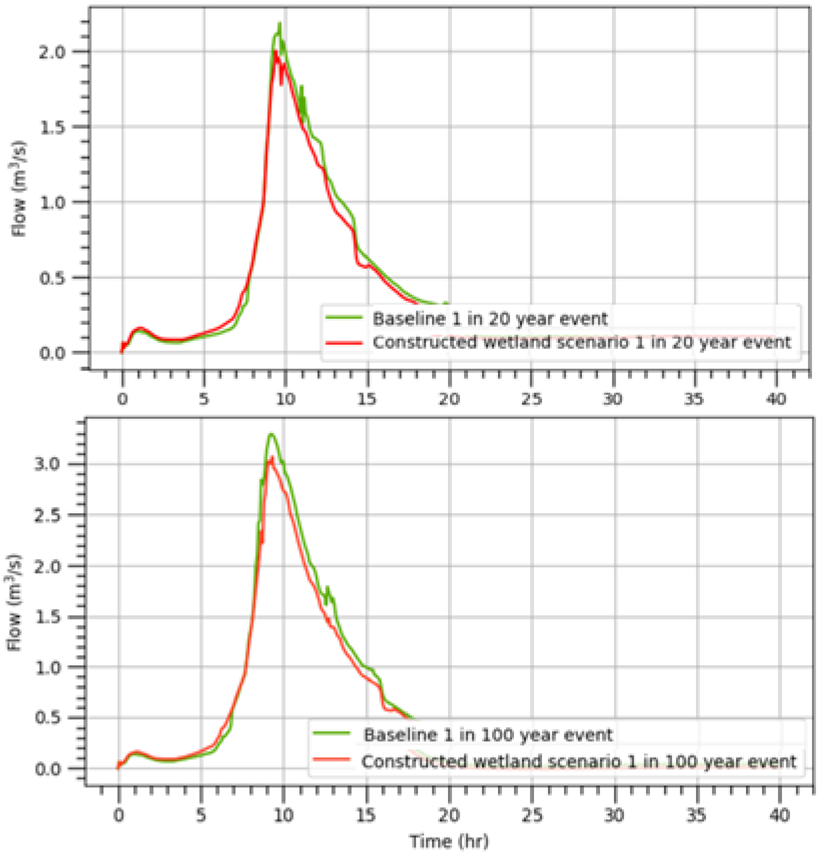


Figure 17: *The performance of bund and balancing pond in Bentley Priory during a 1:20 year (top) and 1 : 100 year return period event (bottom) without (green) and with (red) the leaky dams. Hydrographs were sampled from just below the pond feature near Uxbridge Road (location 3, Figure 5).*

Overall the constructed wetland scenario results in 20% reduction in peak flows downstream of the wetland during both a 1 : 20 and 1 : 100 year return period event in comparison to the baseline, Figure 17. There was no reduction in peak flow or timing during the October 2020 event (Appendix 1). Water level difference mapping of a 1 : 20 year event indicates flood height reduction along Bentley Way (of 105 mm) but an increase in maximum water level heights at Uxbridge Road (of 51 mm) and downstream at Kenneth Gardens (of 35 mm), Figures 18 and 19. During a 1 : 100 year event, peak water levels on Bentley Way are reduced by 75 mm with no disbenefit in the form of elevated maximum water levels downstream in the Temple Pond area, Figures 20 and 21.

Note, once again that modelled elevated water level estimates in the vicinity of Temple Pond are unlikely to be 'real' increased risk. However, it is recommended that modelling is revisited should the bund and pond option proceed to design stage in order to ensure any increased flood risk to property is mitigated.

Pond and bund scenarios also proved significantly more effective compared to leaky dam options in modelling undertaken in the Salmons Brook and Rise Park NFM Pilots. This is likely because features can be engineered to retain and store significantly more water and at the appropriate times compared to leaky dams where storage behind the dam is relatively small.

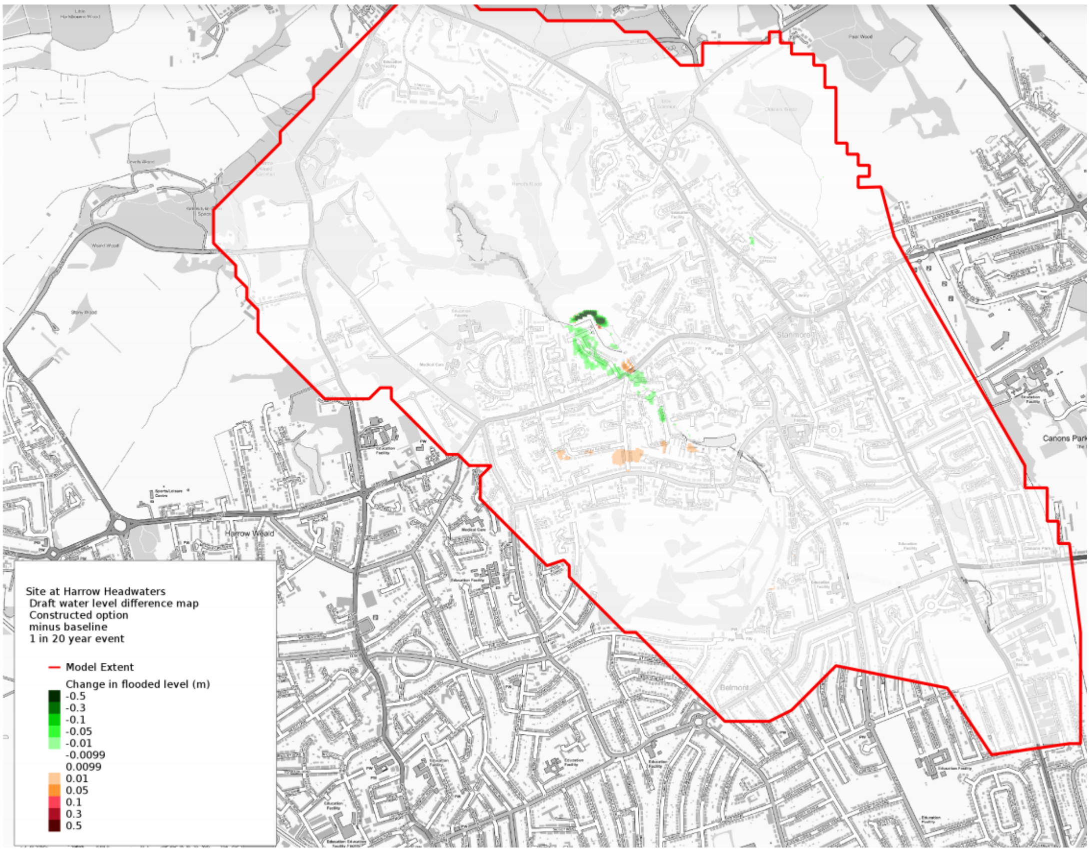


Figure 18: *Modelled peak water level differences between the scenario with the channel and balancing pond and a baseline scenario without during a 1 : 20 year return period event.*

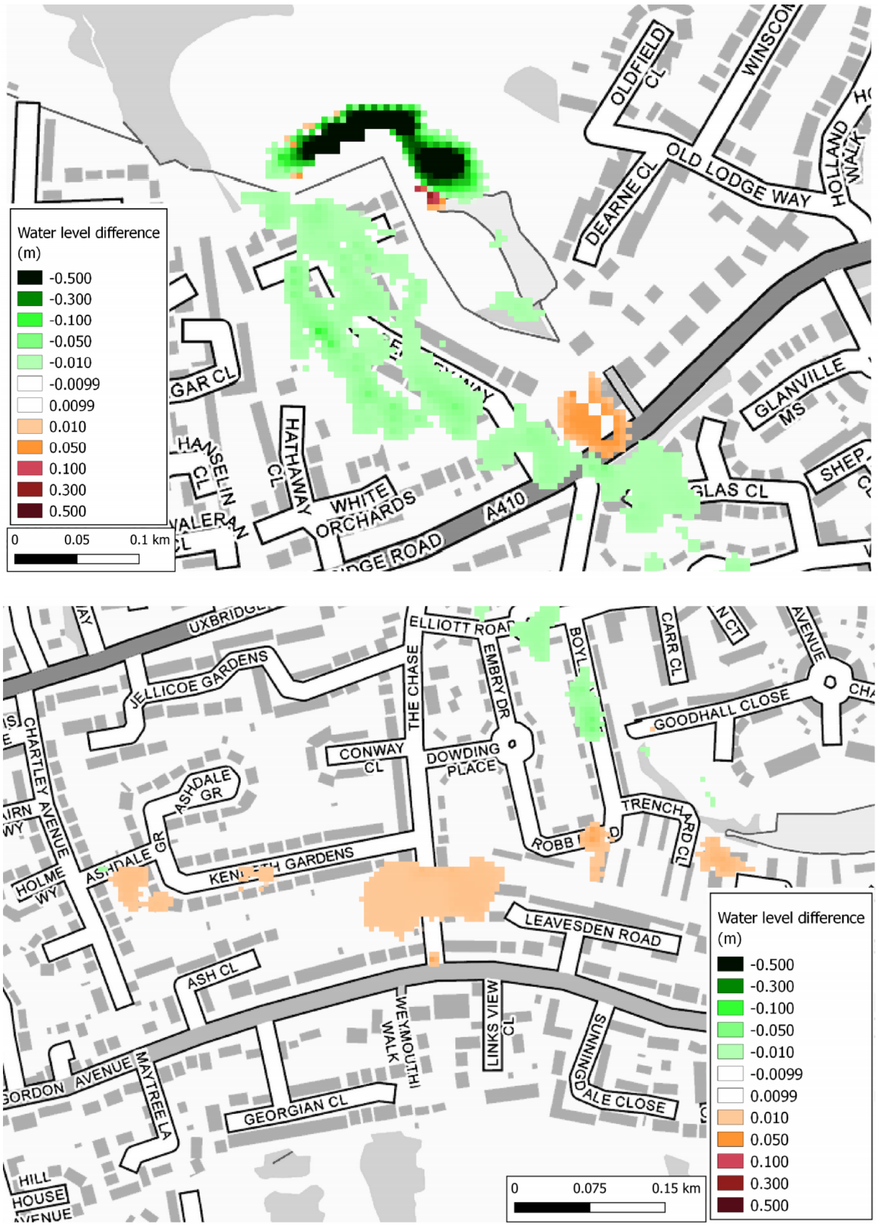


Figure 19: *Peak flood water level differences in a scenario incorporating the balancing pond and bund compared to the baseline without during a 1:20 year return period event, highlighting key aspects of Figure 18 at: Bentley Priory (top) and downstream in the vicinity of Temple Pond (bottom).*

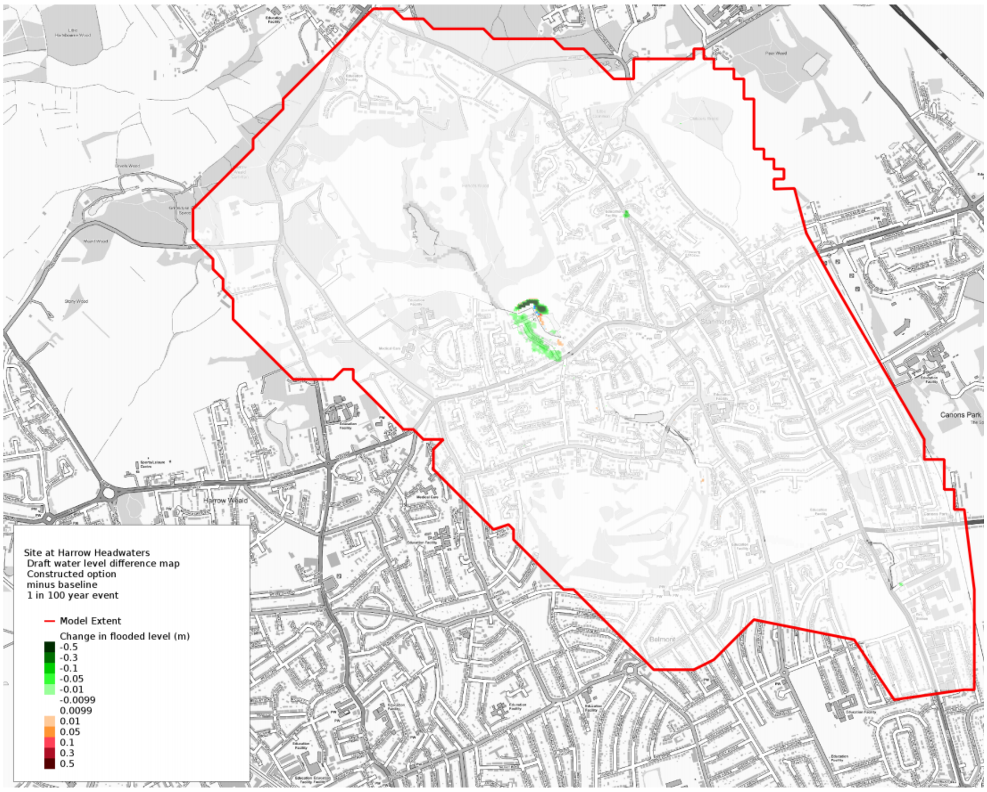


Figure 20: *Modelled peak water level differences between the scenario with the channel and balancing pond and a baseline scenario without during a 1 : 100 year return period event.*

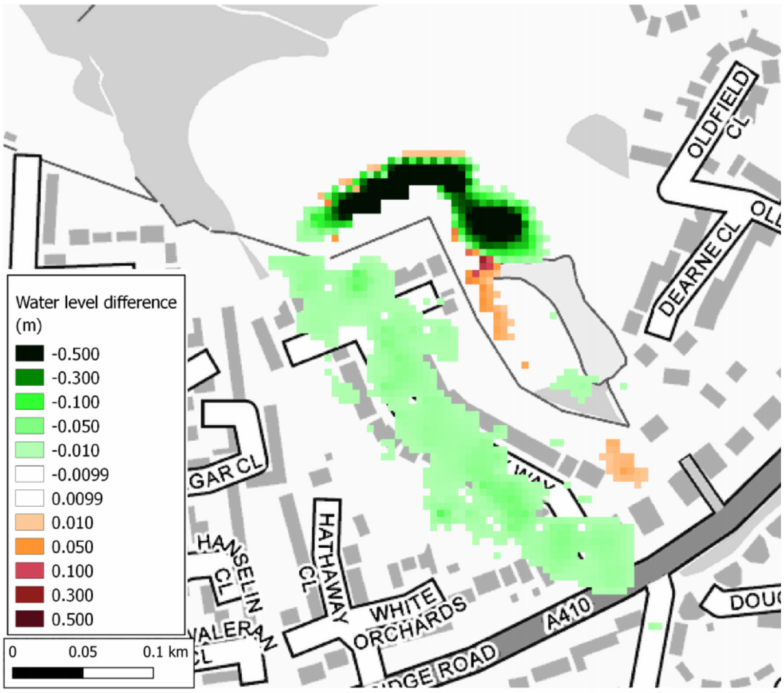


Figure 21: *Peak flood water level differences in a scenario incorporating the balancing pond and bund compared to the baseline without during a 1:100 year return period event, highlighting key aspects of Figure 20 at Bentley Priory.*

Volunteer evidence of NFM performance

Volunteers at flood risk from the vicinity of Bentley Priory visited the woods and documented behaviour of the woodland and leaky dams during rainfall, including an event (linked in part to blocked drains) that resulted in flooding in October 2020 (Figures 3, 22 and 24). As shown in these figures, photographs submitted by volunteers create useful snapshots of Bentley Priory under certain conditions and increased understanding of overland flow paths through the woods, known to activate in high rainfall. This was above and beyond the capacity of project officers, who cannot be reactive to events as they occur. In this way it was discovered that significant flow was exiting the channel upstream of the dam to which the Imperial level logger was fixed, therefore informing that the logger was recording an incomplete picture of flow events. It also informed that flow held behind some dams was spilling onto footpaths which prompted tweaks to the design. It also identified places where flow deflecting timbers should be placed to keep flow in channel. Photos and characteristics of events were sent to Edenvale Young to help inform the modelling.

***Figure 22**: Volunteer photos of flow behaviour in Bentley Priory after heavy rainfall caused flooding in October 2020. Volunteer photos were invaluable for documenting significant overland flow through the woods (left, yellow arrow) that bypassed a dam with a water level logger (green arrow) and overland flow occurring on footpaths (right). Note also the river channel still had capacity, despite flooding gardens.*

Volunteer ‘eyes on the ground’ were also invaluable to inform project staff when concealed loggers were tampered with to ensure speedy rectification of the situation before logger theft and so data loss was minimal. Figure 23 shows an example of the logger from Imperial university removed from the dam and placed beside it on the bank, submitted by a volunteer.

Thames21 led training courses and development of the SlowFlow Capture app for recording NFM asset performance and maintenance data are discussed in sections below. However, little data from Bentley Priory was captured via this app.

Figure 23: *Volunteer photo alerting project staff to the Imperial data logger removed from its place of concealment within a leaky dam in Bentley Priory.*

Measured evidence of NFM performance

FreeStations

Figure 24 shows example telemetry data recorded by the FreeStation in the private garden in Bentley Way, incorporating the October 2020 event described above. The continuous data record demonstrates the potential of FreeStations as low cost level monitoring devices when deployed in ideal circumstances.

Deployment conditions that are optimal both from a data collection perspective and also for sensor functionality are challenging to find in peri-urban environments and, from the experience of these four NFM pilot projects, are usually only met on private land. FreeStations deployed in suboptimal situations in the other NFM pilot catchments experienced prolonged teething problems with poor signal, inadequate battery charging and data loss (as well as theft and vandalism in public spaces). For discussion of these issues, see the reports related in particular to the NFM pilot in Park Wood, but also the Salmons Brook and Rise Park.

Figure 24*: Example telemetry data for the period 15th August 2020 – 31st December 2020 from a FreeStation hosted by a volunteer in a private garden on Bentley Way (Figure 7), just downstream of the area of Bentley Priory where leaky dams were installed. Data show distance in metres between the sensor and water surface, the October 2020 event that led to garden flooding is indicated as a blue arrow.*

The station was deployed later than those in the other pilots, once many issues had been resolved, and was located in ideal conditions – i.e. an exposed location with good sunlight receipt for battery charging and adequate distance from trees, bridges and other structures to generate and upload data continuously. An added benefit of installation in the private garden of a volunteer was immediate detection and rectification should the sensor be knocked out of alignment (e.g. by animals rubbing their heads on it or debris in high flows) or by vegetation or spider webs interfering with the beam.. It therefore requires little maintenance by project staff after installation.

It had been hoped that pairs of FreeStations could be deployed in the area of project works in Bentley Priory up and down stream of leaky dams to monitor their effectiveness at attenuating flows. The deer park at the head of the site was approached to host a station but declined. Due to requirements for charging and telemetry and risk of vandalism on the site itself, in practice, it was only sensible to deploy one FreeStation further downstream of the works.

More discrete in public spaces are the level loggers in development at Imperial University (Figure 8) which do not require line of sight to the sky for telemetry and battery charging and operated without issue from first deployment. Not only was this very useful from the perspective of officer time but it also allowed system set up for more frequent data collection (every 5 minutes vs hourly for FreeStations). This is better temporal resolution for monitoring flashy catchments where water levels rise and fall rapidly. Example data for the October 2020 model calibration flood event are shown in Figure 25.

Whilst representing a much better choice for peri-urban catchments, it should be noted that deployment of the level loggers from Imperial University still has its challenges. The sensor requires mounting over the water therefore deployment on the underside of bridges or incorporation into leaky dams are options. In both these locations the sensor had a tendency to inundate in the highest flows resulting in loss of data at the peak of the hydrograph. The alternative would be to mount the sensor on a post mid channel above high water level, but the compromise is loss of discretion and increased vandalism risk.

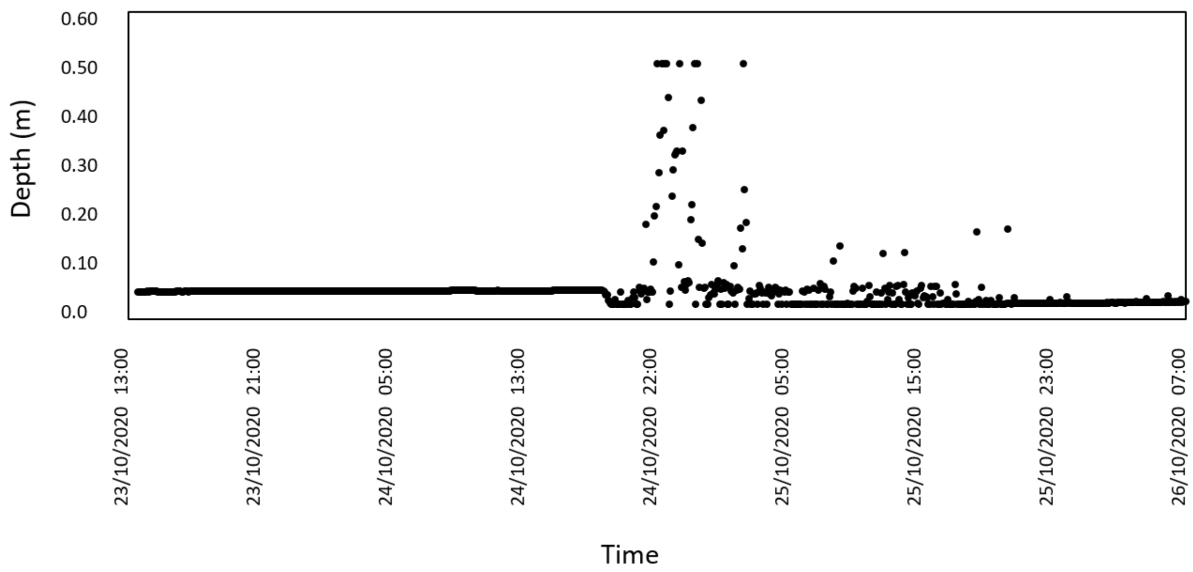


Figure 25*: Water depth at a leaky dam in Bentley Priory during the October 2020 flood event used in model calibration. Data are derived from a level logger supplied by Imperial University. (Levels not to ordnance datum). Note, significant water flow bypassed the upstream logger as overland flow so data are not representative of channel flows (see Figure 22).*

SlowFlow App

Data collection options included both i) suggestions for sites in the four NFM pilot locations that may be suitable for installation of NFM and ii) information about state of repair and functioning of existing NFM features. Figure 26 shows screenshots of the app, which also prompt the user to upload photos and more general comments about changes that may be associated with the leaky dams.

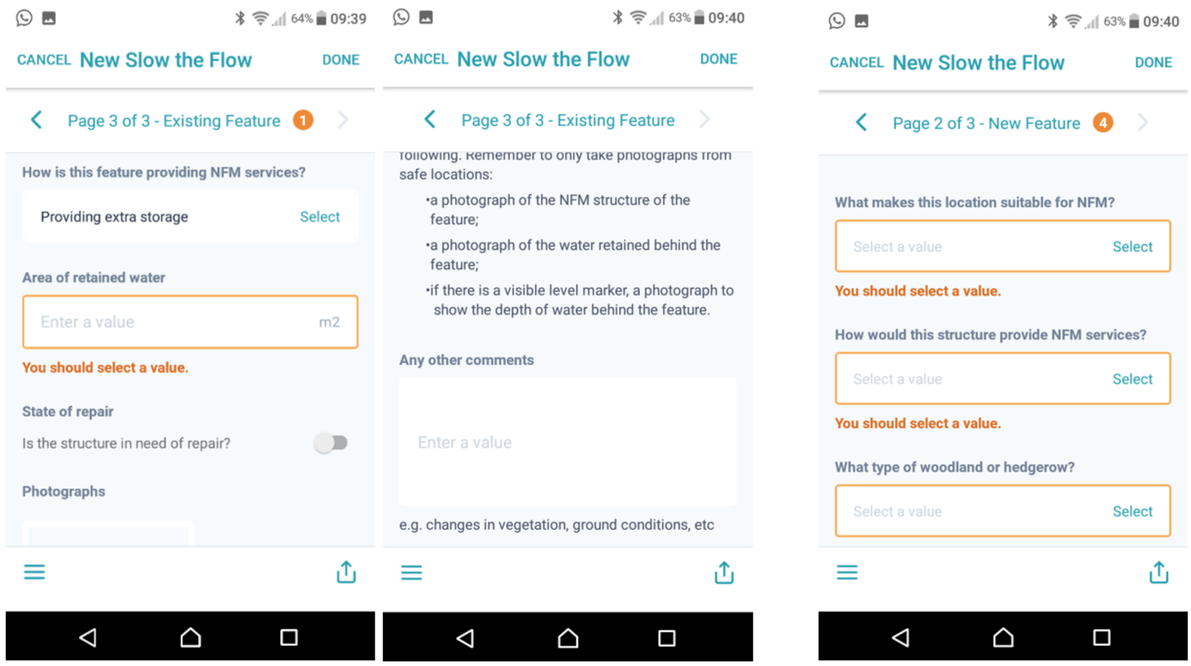


***Figure 26**: Screenshots of the SlowFlowCapture App for collection of data about the NFM assets by the public and trained volunteers. Left and centre: recording data for existing features; right: recording suggestions for a new NFM feature.*

However, uptake and use of the Slow Flow app by attendees of training courses (discussed below) was low, resulting in little data submission through the app. There are many reasons for this, collated from volunteer and project officer feedback:

i) Teething issues with the app. The app was developed in parallel with delivery of training and early versions were prone to glitches, repetitive data input processes (e.g. repeated requirement to input your location) and were only available for android phones, not iphones. Later versions were only in Beta testing mode on iOS. These aspects were a barrier to uptake and use by the public.

ii) Demographic of volunteers. Many expressed preference for data recording using paper forms rather than interacting with a smartphone app.

iii) Lack of immediate results to sustain volunteer interest. Dam building and training events took place when flows were low. Unless you are in the woods after heavy rain when the leaky dams are holding water there is little to survey and photograph around a newly built dam. This means there is no immediate result, unlike, for example with riverfly monitoring where you achieve reliable, informative data instantly. It also means it is hard to sustain volunteer interest in monitoring.

iv) People were willing to travel to attend dam building practicals and training sessions but - unless they are regular users of Bentley Priory or Stanmore C.P., or at risk of flooding - they were unlikely to return regularly to carry out dam surveys. In Stanmore C.P., the properties at risk of flooding were several kilometres downstream from the sites where NFM is being implemented. This creates a disconnect in public thinking between flood prevention measures and areas at risk of flooding.

vi) Wet phone screens are difficult to interact with so feedback from this and the sister NFM projects was that users were electing not to use the app when out on site during the type of events the project was interested in recording.

vii) Delivery of training was interrupted by officer furlough and restrictions on event delivery resulting from the Covid pandemic, so it was difficult to sustain momentum through building a community of active volunteers.

viii) Speedier deployment of the QR codes on the dams with direct links to monitoring surveys may have encouraged more uptake - although more complete integration of guidance for survey completion into the app (e.g. how to estimate storage volume of water behind the dam) would be required to ensure consistency of data generated by casual users who did not attend training courses.

3.3 Additional benefits from the NFM

Habitat benefits of the project

The initial scoping/phase 1 assessment of 2018 and the 'DAFOR' transect survey undertaken in 2019 concluded that, to the north of Summer house lake, flora along the stream was not significantly different from surrounding areas of woodland along most of its length. The main exception was a large wetland area where the two tributaries converged. Here wetland species (Ellenberg scores for moisture of >8) comprised great horsetail, wavy bittercress, pendulous sedge and small stands of Indian balsam (an INNS).

To the south of Summerhouse Lake, the tributary descending from the lake merges with a stream coming from the deer park. Once again, the ground flora was found to be typical of the surrounding woodland – or non-existent in deeply shaded areas. However, wet marginal vegetation was encountered along wider sections where the banks were less steeply inclined and the woodland canopy more open, as well as in a large wetland area, The Dell. These areas support a variety of wetland species, including frequent pendulous sedge, occasional remote sedge, soft rush *Juncus effusus*, brooklime *Veronica beccabunga*, purple-loosestrife *Lythrum salicaria* and water-pepper *Persicaria hydropiper*.

These wetland areas with associated wetland species may be sensitive to altered or reduced flows. It was therefore recommended that no dams be installed within 50 m upstream of these features and dams within 50 - 100 m under careful consideration (Figure 27). Areas where the streams have shallow sloping banks and an existing wetland flora were highlighted as opportunities to create new, or enhance existing, wetland/marginal areas through installation of leaky dams. The proposed locations of leaky dams in Bentley Priory were shared with the consultant ecologist carrying out the surveys and deemed appropriate from an ecological perspective.

Full discussion of the results of the 2018/2019 and 2020 surveys, including species lists, notable and AWI species can be found in the ecological reports, Appendix 2.

***Figure 27**: Opportunities and constraints for NFM interventions in Bentley Priory identified from ecology surveys undertaken in 2019 and 2020* *[Denis J Vickers (Consultant Ecologist)]*

The transect data from 2019 was compared with the areas repeated in 2020 to assess any changes in species composition after a number of the leaky dams (none of the larger tree trunk dams) had been installed. In particular, changes in average Ellenberg values for wetness can be used as a basis for assessing the impact of the leaky dams on ground flora. Species recorded in 2019 and 2020 were broadly similar and the mean Ellenberg value, derived from the collated vascular plant list from transects, was very similar, Table 5. Of the species with Ellenberg values ≥ 8, no new species were recorded in 2020 compared to 2019.

Future surveys should compare results with the refined transect data from 2020 (Table 6). Findings in 2020 were that 16 of the species recorded are AWI species, of which 5 were also notable in Greater London and a further two species (Brown sedge *Carex disticha* and Thin-spiked Wood-sedge *Carex strigosa*) were recorded in 2020 but not in 2019. Other not necessarily rare but significant finds, recorded in 2020 but not in 2019, were: sweet vernal-grass *Anthoxanthum odoratum*, cuckooflower *Cardamine pratensis*, compact rush *Juncus conglomeratus* and blackthorn *Prunus spinosa*.

Table 5*: Ellenberg values from collated vascular plant lists from repeated transects*

	Ellenberg values			
Year	**Mean**	**Min**	**Max**	**Species with Ellenberg values ≥ 8**
2019	6.05	4	10	pendulous sedge, remote sedge, great horsetail, celery leaved buttercup, brooklime, great willowherb, wild angelica
2020	5.94	4	10	

Table 6*: Ecological summary of Bentley Priory, May 2020*

Indicator	2020 score
Species richness	89
Ancient woodland Indicator species	16
London notable species	7
Ellenberg value ≥ 8	10
Mean (min - max) Ellenberg value	5.94 (4 - 10)

There was one instance of a non-native invasive species (INNS), Rhododendron ponticum in the targeted surveys of 2020. The wider ranging surveys of 2019 also encountered Indian balsam in the marshy area north of Summerhouse Lake. These should be removed and details of their location can be found in the survey reports, Appendix 2.

A further 9 leaky dams and 10 tree trunk dams were installed after the survey in May 2020 and will be assessed in the survey scheduled for May 2021. Overall, although the ecological reports are of the opinion that leaky dams will have a positive impact on biodiversity within Bentley Priory, in view of the recent installation of the majority of the leaky dams, lack of detected change is unsurprising since it is too soon for any changes in soil moisture to be evidenced in the ground flora.

The series of surveys commissions as part of this project have established a survey methodology and ecological baseline with which future surveys can be compared. Further vegetation monitoring beyond 2021 is recommended to detect any trends in ground flora as the leaky dams become more established and to increase degree of certainty in results. In particular, significant changes from observations recorded in the 2020 targeted transects, Table 6, should be noted.

Geomorphological changes

Stanmore Country Park

Of the four NFM pilot projects delivered by Thames21, the first dams were installed in this location, therefore they had longer to establish and for trends in geomorphological characteristics to develop compared to the other sites. Comparing the three survey phases (i) baseline survey without dams; ii) a month after installation of the first dams and iii) Spring 2021, 2 years after the installation of the first dams, the following trends were noted:

- Scouring of the bed and deposition of the scoured gravels downstream of the dam - detected as changes in the abundance of gravel-pebble sized bed material as early as one month after dam installation (change from ‘trace’ to ‘present’ in survey data) and after two years abundance increased from ‘present’ to ‘extensive’.
- Trapping of silt and organic materials in the vicinity of dams was also detected with silt initially recorded as ‘present’ in the baseline survey but ‘extensive’ in the final survey 2 years later. Organic material was reported as ‘trace’, but ‘extensive’ by the final survey.
- The bankfull width of the river behind the dam increased from 0.8 m during baseline surveying to 2.4 m in 2021.
- Vegetation indices (Indices 9 - 12) also suggest increasing complexity in particular in channel and riparian vegetation.
- Trends in other indices were absent or difficult to interpret, likely due to insufficient time between dam installation and surveying.

***Table** 7: MultiMoRPh indices calculated for the surveyed reaches in Stanmore Country Park. The indices were calculated from 3, 10 and 5 modules surveyed during baseline, as built and final evaluations respectively. Indices are described in Table 1.*

MultiMoRPh Indices	Baseline (Feb 2019)	As built (Mar 2019)	Final (March 2021)
Index 1	3	2	2
Index 2	Unbroken standing wave	Rippled	Rippled
Index 3	4	3	3
Index 4	Gravel-Pebble	Gravel-Pebble	Gravel-Pebble
Index 5	4.0	-2.4	3.0
Index 6	Silt	Gravel-Pebble	Sand
Index 7	0.1	4.9	2.2
Index 8		5.8	5
Index 9	0	1	3
Index 10	4.0	3.5	3.77
Index 11	4.2	5.6	4.4
Index 12	5.5	6.5	6.5
Index 13	0	0	0
Index 14	0	0	0
Index 15	0	0	0
Index 16	0	0	0

Bentley Priory

It was not possible to directly compare some of the May 2020 surveys with the Spring 2021 because the same reaches were not surveyed in each case. However, it was possible to detect some trends based on survey reaches containing dams and comparisons with control reaches, Table 8 and summarised as:

- Scouring and deposition - detected in the presence of sand ('present') in the reach with the dam and only in 'trace' quantities downstream. Similarly discrete accumulations of organic material present as 'trace' in the reach containing the dam and 'absent' downstream. Gravel was abundant in both the reach with the dam and the control reach without.
- Vegetation complexity - Differences in the vegetation data on the bankface and bank top were detected (index 8), however that could be the result of seasonal variation.

As the majority of dams were installed in Bentley Priory in summer 2020, it was felt that there was insufficient time to observe changes in many of the indicators. Some of the changes noted in the surveys may be seasonal (e.g. vegetation indices), temporal (e.g. associated with storm events) or due to the judgement of individual surveyors. More surveys over a longer time period are required to detect true trends. Evaluating both sites, it is encouraging that sediment and organic debris trapping was observed in Stanmore C.P. as this is potentially a huge benefit of leaky dams for biodiversity, flood risk reduction and water quality improvement. Next steps would be to investigate why the same was not observed at Bentley Priory. Some of the earliest dams constructed in Stanmore C.P. were designed very differently to the later ones. They were lower and permit even low flows to weir over the top, whereas later ones were taller and included an orifice to permit normal flows to pass unimpeded. This potentially made early dams less efficient as flood prevention assets but potentially more efficient at sediment trapping.

Table 8: *Indices of the 2020 and 2021 MultiMorph surveys calculated from 4 surveyed reaches in Bentley Priory.*

MultiMoRPh Indices	Baseline (May 2020)	Final (Feb 2021)
Index 1	2	5
Index 2	Smooth	Chute
Index 3	3	5
Index 4	Silt	Gravel-pebble
Index 5	8.1	1.8
Index 6	Silt	Sand
Index 7	0	0.4
Index 8	4.2	7.9
Index 9	2	2
Index 10	3.2	4.0
Index 11	2.5	5
Index 12	1	10
Index 13	N/A	0.3
Index 14	0	0
Index 15	0	0
Index 16	0	0

The MoRPh surveying technique was developed to monitor changes associated with river restoration, not specifically leaky dams. Should DEFRA decide to take leaky dams forward into their suite of NFM tools, it would be well worth developing a MoRPh survey technique specifically tailored towards monitoring of leaky dams. The following feedback has been given to the developers of the MoRPh survey as part of the contribution of this project to research and development:

- A consistent surveying methodology is required regarding where in the survey reach the dam is located (for rivers surveyed in this project, the reaches were 10 m long). Some data were difficult to interpret because dams were positioned in different places within the surveyed length, with consequences for the recording of sediment accumulation, scour and bedforms etc. We recommend that, ideally, dams be located at the upstream or downstream end of a survey section, not at the midpoint. This means only the upstream or downstream section of a dam is recorded in a single survey stretch, which means the average indices generated are not formed from features recorded both upstream and downstream of a dam.

- The MoRPh 10 technique (10 linked surveys, in this case 100 m of river) is a useful tool for assessing changes away from the dam (e.g. scour further downstream if sediment is retained upstream behind a dam). However, depending on the location of the dams along the channel, this can mean that dams feature in the beginning or midpoint of a survey module where dams are clustered together, or in the case of scattered dams, requirement for successive MoRPh 10 surveys, which can be very time consuming. Standardized protocols for decision making around these circumstances to allow for data sets that are nationally comparable is required.
- Summarising 10 m stretches using categories 'absent, trace, present, extensive' means that some of the detail associated with leaky dams is missed. For example, sediment accumulating upstream of a dam, or exposed gravels downstream may be recorded as 'trace' because, relative to the entire 10 m stretch, this is how the surveyor perceives it. However this is an important detail for assessing geomorphological change associated with a dam. We recommend that specific questions regarding scour/deposition in the vicinity of the dam are created. This could also include an estimate or measure of sediment depth.
- Surveying the channel pre installation of a dam is not advised. It is better to carry out an 'as built' survey directly after dam construction as the baseline. Dams may not be installed where initially imagined and it is important for subsequent surveys that the dam be located in the same place in the surveyed stretch. Also, some reaches were pre-surveyed with MoRPh10 surveys but then project thinking evolved and the dams eventually were installed elsewhere - even on different tributaries in the same woodland.
- Some of the surveys occurred when channels were dry, at other times when there was flow. This has consequences for channel complexity in MoRPh10 summary indices.
- The leaky dam structure needs to be recorded as large wood in the modules on the channel bed, bankface and bank top, which makes it hard to understand if there is an accumulation of large wood in the channel upstream of the dam, or if it is just the structure that was recorded.
- Indices referring to silt and clay were confusing at times. Riverous training or more clarification is required around these features.

Additional benefits

Project funding and time was not sufficient to quantify the full array of potential benefits that NFM can deliver, however Figure 28 estimates potential ongoing and future additional benefits offered by leaky dams in Bentley Priory and Stanmore C.P., in particular once the dams have become established. Potential impacts on flows and habitat have already been discussed above, but benefits have been anecdotally observed in the following additional areas:

Water quality

Sediment and debris washing off the woodlands and into the culvert below the sites potentially contributes to flood risk through causing obstruction. This is particularly likely because entrainment of leaf litter, debris and sediment in overland flows were evidenced at both sites (for example, Figure 22). Sediment and debris build up behind leaky dams has been observed during MoRPh surveys at Stanmore C.P., discussed above. The trapping of large and small woody debris and silt by dams is therefore likely an unquantified benefit of the leaky dams and it is recommended that any future monitoring taking place at these sites should evidence changes in sediment and debris trapping. Moreover, many pollutants of concern are known to bind to sediment (e.g. phosphate, heavy metals) so sediment trapping is also an effective method of pollution removal.

Any future monitoring taking place in the catchment should seek to evidence changes in sediment and debris trapping.

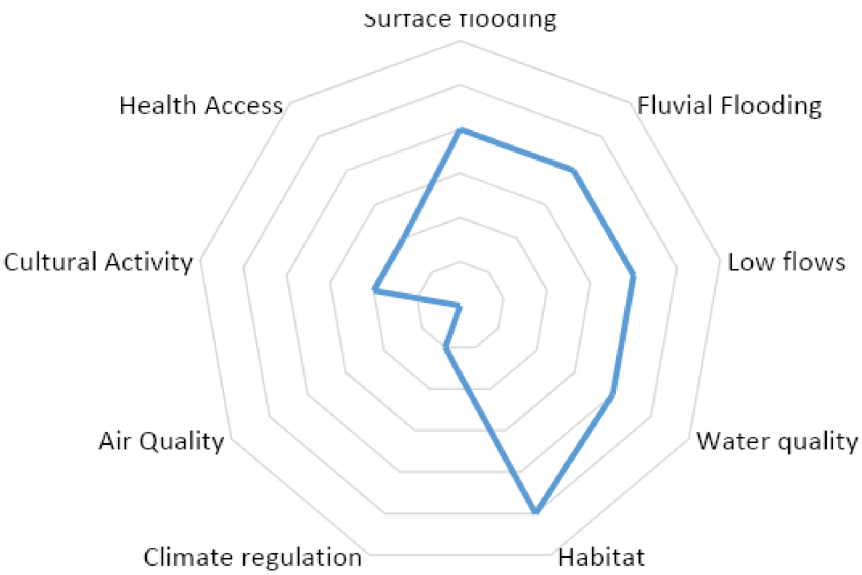


Figure 28*: Potential multiple benefits of leaky dams in Bentley Priory and Stanmore C.P., after they are more established.*

Health and wellbeing

The leaky dams in Bentley Priory and Stanmore C.P. potentially enhance health and well through two aspects:

1- *Stress and anxiety relief.* Installation of flood risk reduction measures and understanding their impact on downstream flood risk may contribute to relief of stress and anxiety of homeowners whose properties are at risk through observing that 'something is being done' and through being informed through modelling results of the level of protection these measures may provide. The findings that installation of a bund and balancing pond potentially contribute to flood risk reduction both in the immediate vicinity of Bentley Priory and downstream at Temple Pond could be of interest to at-risk homeowners. However, sharing of model results with owners of at-risk properties downstream who have not already been engaged with the project is not recommended until the potential disbenefit of this installation is understood.

2- *Volunteering opportunities*. Additional physical and mental health benefits were provided during the project through volunteering events to build leaky dams (discussed below). Ongoing NFM activities in the catchment may provide additional opportunities to foster community cohesion – for example, volunteering events focused on ongoing dam maintenance or planting of the high flow channel and pond, should works go ahead in Bentley Priory. NFM installation funded in future in Harrow should consider wider community engagement and involvement in building and management of NFM assets, including creation of education opportunities in schools and colleges, also community visits to learn about natural flood management techniques.

4. PARTNERSHIP WORKING

Benefits of partnership working

The project was delivered by a partnership of the local council, lead local flood authority and land owner (Harrow Council), and an NGO (Thames21). Harrow Council and Thames21 had worked together previously on projects but new links were forged by engagement of the local community, in particular in the vicinity of Bentley Priory.

In comparison to project delivery by the Environment Agency (EA) or similar contractors, partnership working ensures greater time efficiency (therefore cost saving) because local partners already have the necessary contacts and mechanisms in place to facilitate delivery. For example, the local authority can use their own staff (complete with local knowledge), established relationships, equipment and facilities, rather than necessarily bring in contractors and setting up an onsite compound as an Environment Agency led project would do. Training of local professional partners and the community to undertake ongoing maintenance and management of NFM assets introduces resilience beyond the lifetime of the project, rather than falling to the Environment Agency.

Approximately £24,000 of in-kind contribution was anticipated through involvement of the local community in contributing local knowledge and in dam creation, monitoring and management - discussed in the next section. The value of the local knowledge and ‘eyes on the ground’ photographs submitted by committed local resident volunteers to understanding flow routes and documenting leaky dam behaviour cannot be over emphasised and is beyond the capacity of project officers to deliver.

Community engagement, training and volunteering

Partnership working offers opportunities for greater public and stakeholder engagement with project aims and delivery than is traditionally the case with works delivered solely by the Environment Agency. In this project, community engagement comprised several aspects, discussed below:

i) Delivery of two and one day courses on NFM and leaky dam building to equip volunteers with the necessary skills to participate in dam building, maintenance and monitoring during and beyond the project lifetime; and lead their own leaky dam building events.

ii) Leaky dam building events involving volunteers, led by a project officer

iii) Awareness raising about NFM and the project accessed via QR codes fixed to dams (see figure 9).

Partnership working incorporating the local community

The effort required to create and sustain project partnerships involving the local community requires considerable time investment and ongoing support and this should not be underestimated by DEFRA in future projects. Public engagement activities in the Edgware Brook – Silk Stream catchments include: recruiting and training volunteers for leaky dam building, collection of NFM monitoring data; sustaining momentum and supporting volunteers. Furthermore, after the October 2020 event, there was consultation and engagement of the public to highlight the aims of this project and to encourage discussion and submission of volunteer evidence concerning flow routes and behaviour of water in the woodland.

Volunteer engagement and training opportunities

Thames21 initially developed a two day accredited training course to support public learning about flood risk, NFM and the project activities taking place in the Edgware Brook – Silk Stream catchment, and the other three NFM Pilot projects. Completing this course equipped participants with the necessary skills to lead their own dam building events with volunteers (dam locations guided and agreed by project plans), fully protected by Thames21 liability insurance. This course was delivered in the catchments of the other NFM pilots but low sign up in Harrow prompted revision of the content to a one-day course.

Course leaders felt two days of training was not pitched towards those it was trying to appeal to. It was insufficient to enable participants to independently select NFM asset types and suitable locations, but was more detailed than required for leading leaky dam building events to a predetermined project plan - there was no need for in depth discussion of permitting, for example. It was therefore hard to define concrete outcomes of the two day course for the participants.

The one day course comprised a combined day of theory and practical experience building leaky dams. It was intended to widen the appeal to local users of Bentley Priory and Stanmore C.P. and an endeavour to recruit citizen scientists to participate in monitoring of dams with the Slow the Flow app. This one day course was run with 4 participants in January 2020. Due to the impacts of Covid, the course then became an online element (run on three occasions: October 2020, February 2021 and March 2021) attended by 55 trainees in total and a subsequent practical dam building event in each catchment. Three trainees attended the practical dam building day in Bentley Priory in October 2020.

In addition to the training course, volunteers were recruited to assist with leaky dam building. In total 8 leaky dam building events were scheduled but due to Covid-19 restrictions only 2 went ahead in Bentley Priory. These took place between November 2019 and December 2020 and involved 7 volunteers building 5 dams. In Stanmore C.P., 7 dams were built by 8 volunteers over 2 events, Figure 29. Monitoring and the Slow Flow app were also introduced at these events.

Figure 29*: Leaky dams constructed with volunteers in Stanmore CP.*

Overall, it was felt that there was good interest in the concepts of NFM, both from local residents and also the professional waterways management sector, including attendees from the Environment Agency (who built 5 dams in Park Wood as part of one of the other NFM pilots involving Thames21). However, the interest was mainly in dam construction and less in long term volunteering through identifying new sites and monitoring via the Slow Flow App (discussed above).

Future projects should give careful thought to the types of volunteers and trainees they wish to engage and plan the amount of training and support (therefore budget requirement) accordingly. Ideally there should be a combination of events ranging from:

i) a light-touch engagement approach - potentially delivered whilst walking through the area where works are taking place;

ii) events tailored towards participating in NFM (e.g. woodland planting, leaky dam building) and monitoring of assets;

iii) a more thorough series of linked training sessions leading to accreditation upon completion of all the steps. This would be aimed at upskilling local authority staff and established volunteer groups in various aspects of NFM creation and maintenance - including follow-up sessions for those leading their own NFM creation events.

iv) support of the above with a short video and online resources.

This project did not have sufficient resources for full-scale public engagement. In these circumstances, volunteers recruited from local users of the site where NFM is being installed, or those at risk of flooding have more vested interest and are therefore much more likely to fully engage with the project and participate in long term data collection than those attending from further afield. Engagement of the local community from a flood risk perspective attracted new volunteers, as well as interest from those already committed to environmental volunteering through other projects (such as riverfly monitoring). To sustain momentum in NFM monitoring and management beyond the project, it is therefore desirable to integrate this as a volunteering opportunity into pre-existing volunteer initiatives

It is also crucial that monitoring tools, such as the Slow Flow app, are fully operational from the outset to facilitate ease of use by the public. In this project, the lack of standardized data collection resulted in alternative means of data submission, which, whilst excellent for understanding, place an onerous time burden on the volunteers.

The app is now fully functioning and available for use by similar future projects and by the London Boroughs involved in the four NFM pilot projects to assist with ongoing leaky dam repair and management, in combination with QR codes which will remain permanently on the dams.

Funding

Learning from this project has, in part, simulated submission of an application for the Innovative Flood Resilience by the LLFA, Harrow Council, in partnership with the Catchment partnership, recently successfully awarded.

Ongoing maintenance of NFM features beyond the project

Vandalism and informal dam building

As urban greenspaces, Bentley Priory and Stanmore C.P. are well used by the public and inevitably have a higher risk of interference with the NFM structures (well meaning and malicious) than private sites. However, no vandalism was reported at either site and there was also a lower incidence of public creation of informal leaky dams that blocked the channel. In contrast, the three other NFM pilots (in Hillingdon, Enfield and Havering) experienced high incidence of dam vandalism, including their complete destruction and also creation of informal dams. In Park Wood, NFM project information notices were displayed beside the majority of dams to inform the public of the purpose of the structures and hopefully deter tampering. No project notices were displayed in Bentley Priory, Stanmore C.P. or the other two pilot sites, other than QR codes on the dams.

Some of the smaller, unsecured tree trunk dams were removed in Bentley Priory as part of works to cut back overhanging vegetation and remove dead wood from the channel in response to flooding that occurred in October 2020. It is believed these were well intended works carried out by the EA but it highlights the importance of i) good communication between project partners and teams operating on site; and ii) the need to strike a good balance between clear identification of NFM features whilst also maintaining the natural appearance of the woodland.

The horizontal elements of leaky dams constructed early in the project were not secured in place. Based on learning from the other pilot projects where vandalism was experienced, dams built later were secured with discrete wiring to prevent tampering, Figure 30. QR codes should be installed on the smaller, less formal-looking trunk dams in order to prevent accidental removal.

Figure 30*: Wiring as a measure to deter vandalism and timber removal of leaky dams in Stanmore C.P.*

Catchment plan for ongoing maintenance of NFM assets

In view of the recent success in the Innovative Flood Resilience application (above), Harrow Council and Thames21 are currently in discussion over the wider vision and next steps for flood management in the borough. One aspect of this includes reviewing the modelling evidence generated by this report and taking decisions over the long term usefulness of the leaky dams. Another aspect includes discussions over the potential of the balancing pond and relief channel in Bentley Priory.

In the short term, the arrangement is that Thames21 will maintain the leaky dams and the monitoring equipment on behalf of Harrow Council. This includes regular inspection of the dams and contact with volunteers who may report repair needs. The Imperial level sensor in Bentley Priory and the FreeStation below it will stay active in order to inform and evidence future works as part of the Innovative Flood Resilience funding.

QR codes will continue to take users to Thames21's website.

Future monitoring

- Thames21 will endeavour to survey the dams in 12 - 36 months time to learn about their durability and guide future NFM projects. Any findings will be shared.

- The final repeat ecology survey in Bentley Priory will take place in May 2021 and will be circulated to relevant stakeholders. Repeat surveys commissioned in future should pay special attention to habitat complexity in the surrounding areas to the dams (specifically the transects surveyed in 2020) as this is something that will capture the long term changes that have not been recorded in this pilot due to timescales.
- Future NFM funding should seek to repeat MoRPh surveys in order to track geomorphological changes associated with the leaky dams.

5. SUMMARY OF LESSONS LEARNED

Project partners acknowledge the huge amount of experience that has been gained through undertaking the full process of delivery of NFM measures to mitigate flood risk. From a starting position with many unknowns towards better understanding of what types of NFM might be most effective and best practice for their delivery and monitoring in collaboration with the local community. In addition, Thames21 delivered four NFM pilot projects in peri-urban environments around London, enabling comparisons and identification of common themes across the four projects. Key learning outcomes that should be considered by DEFRA to feed in to future working both nationally and locally are summarised below:

i. Performance of NFM assets

- According to the modelling, leaky dams do not offer significant reduction in flow peak or timing of heavy rainfall events. However, anecdotally, restoring natural processes by installing leaky dams may increase catchment resilience and flood risk reduction by reducing debris and sediment entering water courses, as well as providing biodiversity and water quality benefits. It may therefore still be relevant to install them, particularly in locations hard to access or where other options have been exhausted.
- Based on the modelling undertaken, other forms of NFM have much greater impact on downstream flood risk than leaky dams, namely wetland pond creation in particular pond and bund creation as concluded in this catchment but also in the Salmons Brook (Enfield) and Rise Park (Havering) NFM pilots. Woodland planting was assessed as being a useful flood mitigation tool in the Salmons Brook catchment..
- It is important to model the contribution of different forms of NFM to flood risk reduction (both immediately and as they mature) to ensure that, through changes in timing and volume of flood peaks, they do not coincide to result in negative impact.
- A 1:25 return period event (used by the model to test scenarios) has not been experienced during the lifetime of the project, so the NFM measures have yet to be ‘tested’ in similar conditions.
- It is too early to quantify the impact of NFM assets on ecology or hydrogeomorphology. Instead, survey methodologies and monitoring baselines have been established against which future surveys can compare.
- Vandalism of leaky dams and monitoring equipment is an issue in heavily used urban settings and three of the four FM Pilot sites suffered from vandalism of NFM assets.

Metal wires to secure timbers in place can be a deterrent to tampering with leaky dams. In public areas dams may decline at faster rates than on private land due to public 'fixing' or vandalising them, and this must be taken into account in maintenance schedules.
- Incidence of public vandalism of dams could be due to the unusual circumstances created by Covid restrictions and people staying local, but longer term data would be required to confirm this.
- Public education campaigns around the NFM assets, and an engaged local community could potentially reduce issues around vandalism, but require adequate budgeting.

ii. Monitoring tools

- *Water level sensors*. Suitable deployment locations that are discrete to avoid theft whilst also being suitable from a data collection perspective are surprisingly hard to find in peri-urban environments. Careful thought should be given to the selection of monitoring devices as both loggers and telemetry require sensors mounted over the channel which is a significant risk of vandalism in public spaces. The loss of low cost sensors is less significant for the project than high cost devices and, in some circumstances, may generate valuable data, so their deployment might still be worth the risk.
- *Data capture app* (Slow Flow App) – Future projects should endeavour to have data capture apps for use by the public ready at the start of the project to facilitate user uptake and standardise data collection and curation. When using digital data capture methods, careful consideration must be given to the circumstances of use (e.g. the demographic of volunteers, difficulties in areas with poor network reception or when capturing data during rain).
- *Hydraulic modelling*. Modelling has been a useful exercise in contributing to the body of evidence for NFM and has enabled the testing of future scenarios and identification of optimal locations for installation of measures.
- *Geomorphology surveys* (MoRPh) – The current survey method is designed as a tool to assess river restoration projects pre- and post-delivery. It has potential as a tool for monitoring of leaky dams and other features but requires refinement.

iii. Community engagement and partnership working

- Community engagement is key and is rewarded with contributions of considerable local knowledge and willingness to react to rainfall events and be 'eyes on the ground' above and beyond what can be achieved using project officers.
- Whilst building relationships with invested community groups is essential, a balance must be struck between time invested in collaborative working with the community and effective project delivery. Roles and expectations of all partners must be clearly defined at the outset, including responsibility for management decisions. This balance was better struck in this project than in others where volunteers were more heavily involved at the steering committee level.
- £50 K is not sufficient for LLFAs and NGOs to commit sufficient officer time for wider engagement of the community, so, by necessity, focus in this project was training and support for NFM creation.

- There is a big interest in natural flood management both from local residents and the professional sector. However the interest is mainly in creating NFM (leak dam building) rather than monitoring of NFM. This is likely because, unless you live locally or have a house at risk of flooding, there is not much in it for the volunteer and not much to monitor except during heavy rainfall, and with no immediate results. The volunteer journey therefore needs careful planning, tools need to be ready before training and training needs to be targeted at the community in the immediate vicinity of the NFM or zones at risk of flooding, rather than the wider public. Monitoring of NFM may be better integrated with other volunteering programmes happening in the park, for example habitat management.

iv. Other learning

- Project duration was not sufficiently long enough to create relationships, install features and measure quantifiable outcomes, in particular as the reporting period coincided with the end of the winter season when the ground is most saturated.

- Duration of consent from Natural England should extend beyond the project lifetime to facilitate adjustment of NFM installations - based on learning from modelling and monitoring - without requiring additional permits.

6. APPENDICES

Appendix 1:

Harrow Headwaters Hydraulic Modelling Report - Edenvale Young 2021

With appendices:

A Hydraulic simulation;
B Harrow Catchment Delineation Technical Memorandum;
C Salmons Brook, Harrow Headwaters, Rise Park Stream and Pymmes Brook NFM Modelling Calibration Report

Appendix 2:

Ecological surveys of Bentley Priory SSSI and Park Wood (part of Ruislip Wood SSSI and NNR), to help inform Natural Flood Management Demonstration projects Year 2: July 2019

Ecological surveys of Bentley Priory SSSI and Park Wood (part of Ruislip Wood SSSI and NNR), to help inform Natural Flood Management Demonstration projects Year 3: June 2020

Appendix 3:

Slow flow App questionnaire.