The River Pinn Park Wood NFM Pilot: results and lessons

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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 River Pinn Park Wood 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 50 leaky dams in Park Wood, 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 (5% reduction in peak flow in a 1:2 year return period event, 3% reduction in a 1:30 year event) with only a small delay in peak timing (1 - 3 minutes). Dams potentially provide other benefits such as flood risk reduction by trapping sediment known to block the culvert immediately downstream of the wood 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 morphology. 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. In this project local community members formed part of the steering group and careful management of roles and expectations is required, especially around decision making. However, the local knowledge and dedication of local volunteers to recording behaviour of the dams, mending structures and reporting vandalism was invaluable. Volunteer contribution to ongoing dam maintenance beyond this project through adoption by the existing woodland habitat maintenance volunteer group was also 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.

Additional challenges for delivery of NFM in public, urban environments discussed by this report include vandalism of NFM structures and monitoring devices.

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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 the London Borough of Hillingdon and the local North Ruislip Flood Action Group (NRFLAG), reports on the above objectives and lessons learned from a Community Scale NFM project in Park Wood, located in the London Borough of Hillingdon in the catchment of the River Pinn in north-west London, Figure 1.

The River Pinn Park Wood NFM project 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 Woodland and River Management in Two Headwater Streams Project (London Borough of Harrow) and the Salmons Brook NFM Project (London Borough of Enfield), allowing comparisons to be drawn between projects.

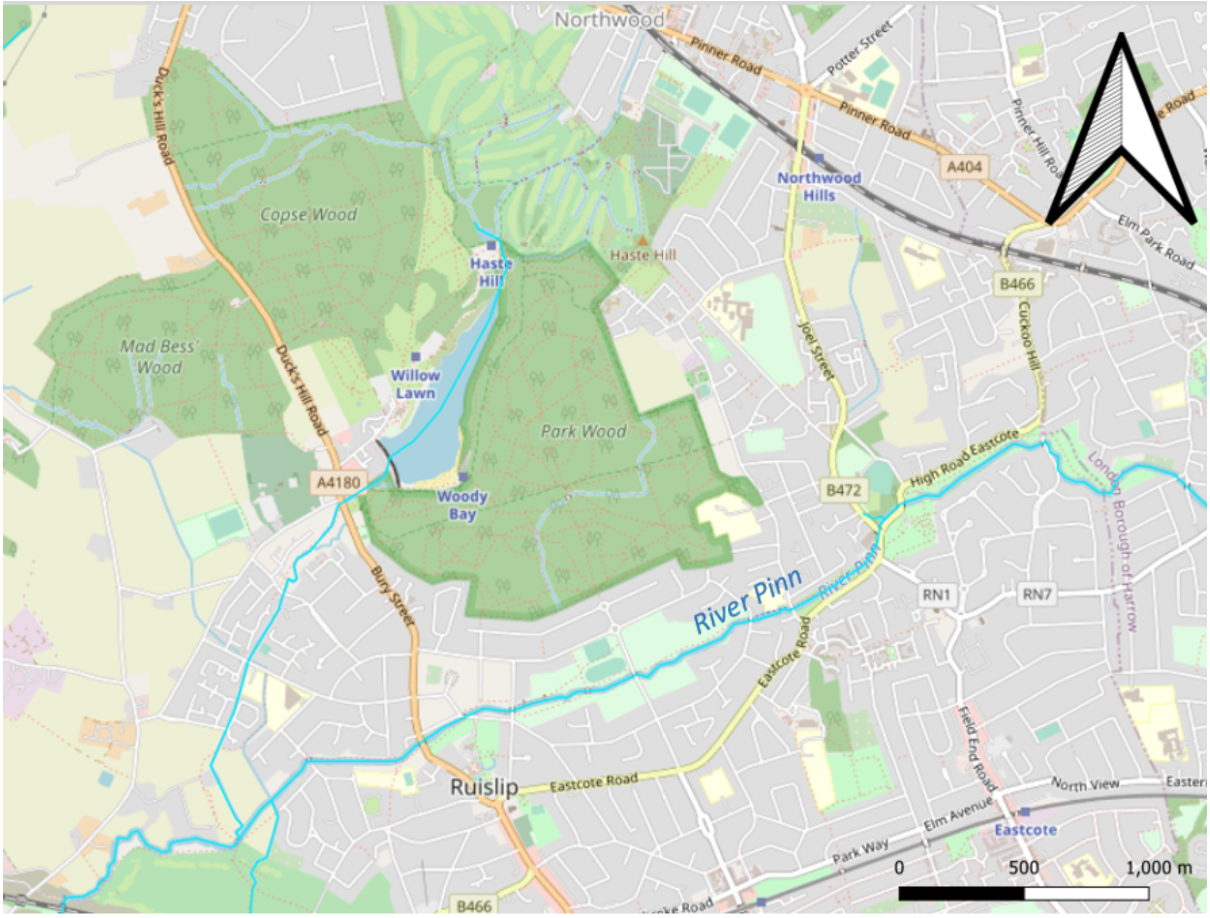

Figure 1: *Park Wood and the River Pinn.*

1.1 Park Wood and downstream flooding issues

Park Wood (51.589142, -0.423983) is a National Nature Reserve (NNR) and Site of Special Scientific Interest (SSSI), part of the wider Ruislip Woods SSSI, comprising some of the largest unbroken blocks of semi-natural, ancient woodland in Greater London. The predominantly oak-hornbeam-yew woodland is dissected by small valleys whose water courses and damp flushes drain into the River Pinn, located 330 metres from the woodland boundary.

There is a network of watercourses and informal flow paths within Park Wood that converge along the southern boundary of Park Wood where the watercourse is conveyed in a culvert beneath Park Avenue and Broadwood Avenue towards the River Pinn. As well as being artificially straightened in sections to speed up land drainage (left),

these watercourses are ephemeral and there is no summer base flow.
According to the British Geological Survey, the underlying geology is London Clay Formation with Lambeth Group clay, silt and sand. Soils are heavy and slow draining therefore prone to waterlogging, which creates a tendency for surface runoff and flooding downstream during heavy rainfall, particularly in winter.

The Environment Agency identifies approximately 80 properties at risk from surface water flooding in a 1 in 100 year event, Figure 2. Properties downstream of Park Wood have flooded four times in recent years due to heavy rainfall (in 1977, 1988, 2003 and 2016). Flooding in June 2016 inundated 8 properties internally and impacted many more. Whilst there is a flood warning service for the main River Pinn, the location of the gauges on the main River Pinn, do not cover the rise and fall of the ordinary watercourse tributary at Park Wood.

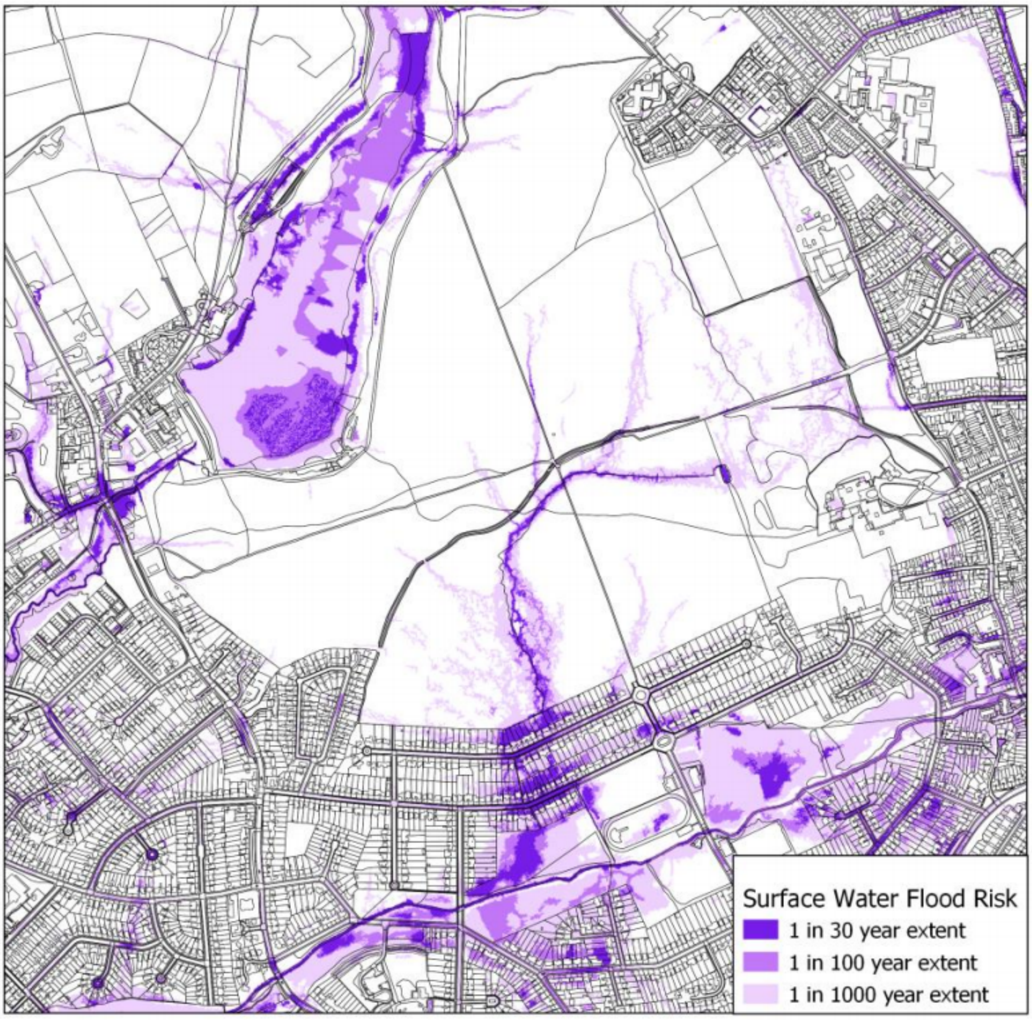

***Figure 2**: Environment Agency Risk of Flooding from Surface Water Map for the vicinity of Park Wood*

A number of affected households have formed the North Ruislip Flood Action Group (NRFLAG) and their input and local knowledge proved invaluable to this project as part of a citizen science approach to understanding flow dynamics within the wood and monitoring the effectiveness of the NFM installations.

Previous to the NFM pilot, the London Borough of Hillingdon installed a small number of trial woody debris dams within the main channel in Park Wood to hold flood water higher in the catchment. This NFM pilot project expands and develops this work, contributing to the multiple interventions being explored as part of the Ruislip - Park Wood and Pinn Meadows Project that is being led by the Environment Agency.

The Risk of Flooding from Surface Water (RoFSW) map provides a good representation of the known flow paths within Park Wood and produces flood outlines on Broadwood Avenue and Park Avenue that broadly align with the flow paths experienced in June 2016. While there is confidence in the modelling, the surface water flood map does not include a representation of the culverted watercourse upstream of Elma's Ditch, nor does it account for antecedent conditions in Park Wood.

The catchment is bisected by a Scheduled Ancient Monument (SAM) called the Park Pale, which constitutes an earth embankment and ditch that was historically used as an enclosure for a 'park for woodland beasts'. The presence of the SAM reduced the locations where interventions could be placed.

1.2 Aims and objectives

Delivery of DEFRA project objectives in Park Wood comprise the following:

- **Reducing flood risk to homes**

Through installation of 39 leaky dams and 11 tree trunk dams on ephemeral streams in Park Wood, guided by site walkovers and ecology surveys. Dams were designed to retain and spill high flows out of the ditches for storage within the woodland.

- **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 a SSSI.

- **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 in Park Wood. This included modelling the future opportunities for installation of leaky dams and creation of a bund feature within Park Wood. This was originally intended as a PhD project hosted by Brunel University but, due to lack of a suitable candidate, was ultimately carried out by Hillingdon Council officers.

ii) Trial of 'Freestations' (http://www.freestation.org/), innovative, low-cost water level monitoring devices developed by Kings College London, to monitor and evidence the performance of the NFM installations.

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

i) Through involvement of local residents and Councillors in decision making. The local NRFLAG group and the Ruislip Woods Management Advisory Group (RWMAG) were represented on the steering group and contributed valuable knowledge and advice to understanding the catchment and to a citizen science approach to monitoring and ensuring the long term effectiveness of the measures implemented.
ii) Enabling the local community to understand what is being undertaken, be involved in the delivery of work and why it's important, 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.
iii) Regular dissemination of progress and results with wider interested groups including the Environment Agency Ruislip - Park Wood and Pinn Meadows project and Colne Catchment Partnership.

2. NFM EVIDENCE APPROACH AND METHODS

2.1 Selecting locations for NFM assets

An opportunity appraisal report was produced by Hillingdon Council officers in July 2019 after project inception with collaboration of members of the project Steering Group. This appraisal (Version 2 from November 2019, Appendix 1) used the methodology set out in the Environment Agency NFM Toolbox and pulled together the understanding of the catchment, the project objectives and screened the potential NFM interventions.

Suitable sites for leaky dams were identified through consultation/catchment walkovers in conjunction with the local NRFLAG group, RWMAG members, and the London Borough of Hillingdon. Observations from local residents and Hillingdon Council officers regarding the flow of water through the catchment during rainfall events helped to validate surface water flood mapping and select the channels within which to site dams. The main flow paths were given reference names to improve decision making and help locate structures (Figure 3).

The main channel (Coppicers channel) was deemed most appropriate to construct leaky dams on, yet as the 3 other channels flowing north to south all flow directly into the Park Pale that could not be worked on, these were targeted as well.

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 by Hillingdon Council. Delays to payment transfers from DEFRA at the start of the project meant that the window of opportunity for carrying out ecological surveys as part of the permitting process did not go ahead in Autumn of the first year as planned. Instead, they occurred in Spring of the following year, causing knock-on delays to activities on the ground and requirement for management of expectations of volunteers who were expecting more immediate commencement of activities. Learning from this is the need for streamlining of the payment process.

The duration of the consent extended to August 2022 - beyond the formal end of the project funding in March 2021. This proved useful for carrying out adjustments to dams without reapplying for new permits.

Wood (up to 15cm in diameter) generated by previous habitat management was used to create the leaky dams

***Figure 3**: Named flow routes and other features in Park Wood. Symbols indicate locations of proposed and installed leaky dams and water level monitoring devices (FreeStation and gauge) comprising: leaky dams (purple circles) and tree trunk dams (blue squares) constructed as part of the DEFRA funded project, pre existing leaky dams (red circles), FreeStations (Crossed circles) and Hillingdon Council's flow gauge (plus symbol).*

It was initially the intention to use the flood modelling to guide the location of dams, however, no suitable PhD candidate was secured and responsibility for hydraulic modelling was transferred to the London Borough of Hillingdon. Due to time constraints, modelling of dams could only be undertaken retrospectively but will be used to inform future interventions in Park Wood.

2.2 Monitoring approaches used

Flood risk modelling

Hydraulic modelling was undertaken using the industry standard software InfoWorks ICM. This allowed for a two dimensional (2D) representation of the whole drainage catchment, as well as a one dimensional (1D) representation of the culverts, sewers and highway drainage network within the urban area.

The model approach applied rainfall directly to the ground surface and allowed for the alteration of parameters to account for different land use types (woodland canopy interception), surface roughness (smooth roads vs rough scrub./woodland), and infiltration into the shallow subsoil.

The model was calibrated by applying known rainfall to the model and reviewing the predicted extents of flooding downstream. In addition, calibration was also undertaken by comparing the response of the catchment in the model to the water level gauge installed just upstream of the culvert beneath Broadwood Avenue. Records from this gauge are only available from December 2019 and therefore do not capture historic events where properties have been flooded.

A recent event at the end of January 2021 where flow was observed in the channel was used as a calibration event. Based on Radar information across the whole of Hillingdon the rainfall for this event had a return period of between 2 years and 5 years, which corresponds to a probability of occurring in any given year of between 50% and 20%. The critical duration for this period was the 48-hour total rainfall. All other storm durations had a return period less than 2 years. The comparison of water levels between the model and the gauge at the downstream extent of Park Wood is provided in Figure 4.

The peaks occur at a very similar time and the magnitude is a close approximation**.** The comparison in the recession from the peak between the gauged and the modelled shows that there is more attenuation within the subsoil and shallow aquifer that continues to feed the watercourses and drain down over a longer time. Groundwater is not represented in the model and therefore the hydrographs do not show this additional attenuation. The length of gauge record and the location of the gauge at the inlet to a constrained culvert prevents a more detailed calibration exercise to take into account statistical methods.

For the same event, a comparison was made with field observations (Figure 5). There was generally a good representation of flood extents within the woodland, with accumulations and bifurcations broadly occurring in the correct location. As this was not an extreme event compared to design events, however, there is only limited value to these observations.

Data from the Freestations (described in more detail later) were not of sufficient quality or completeness to contribute to the calibration exercise.

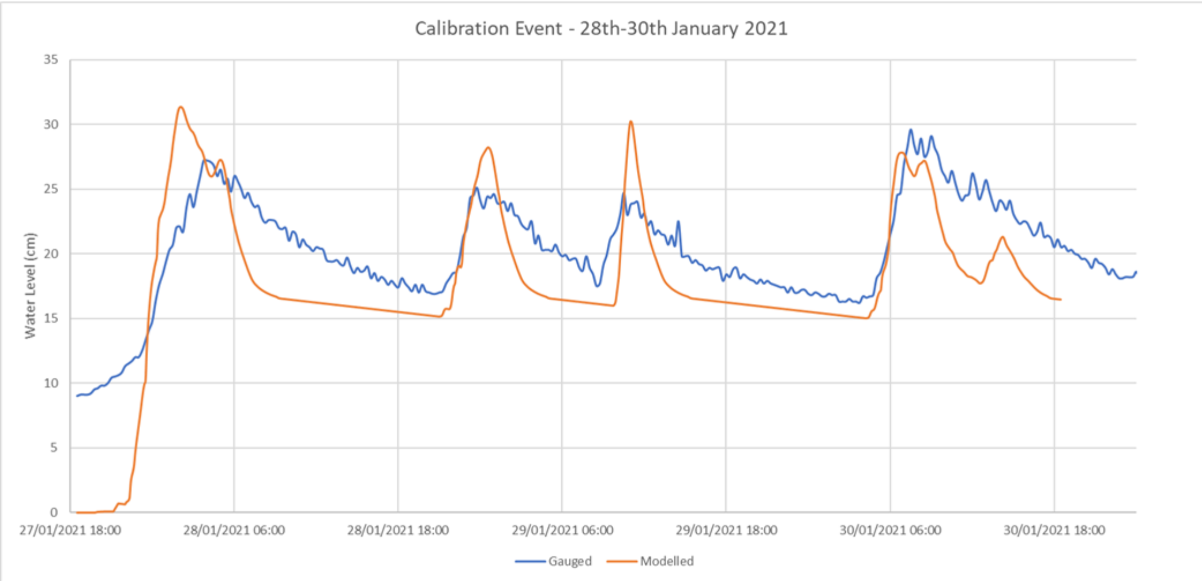

***Figure 4**: Modelled vs gauged water level for January 2021 event*

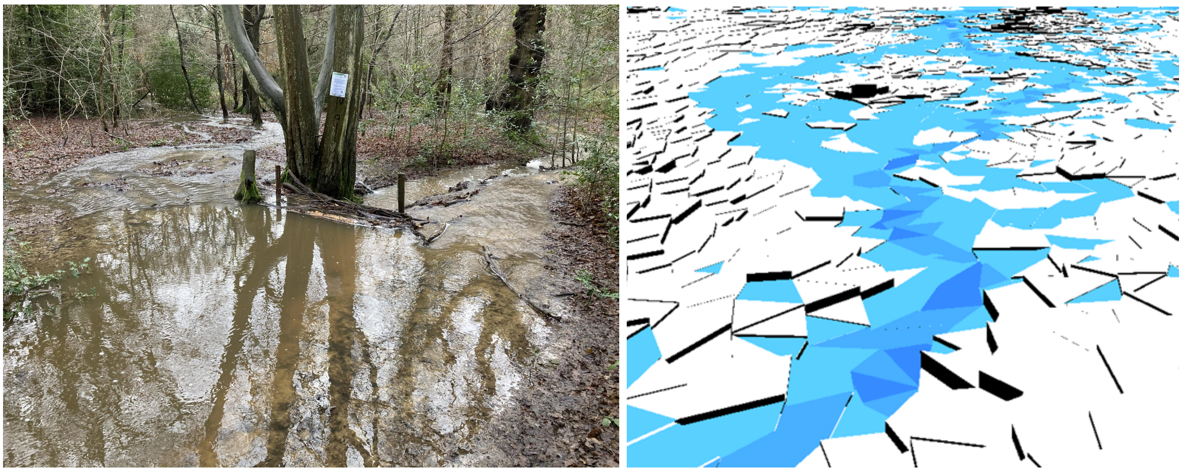

***Figure 5:** Field observations and model results for January 2021 event in approximately similar location (N.B. photograph not taken at event peak)*

Sensitivity testing was undertaken to determine the influence of antecedent conditions on the hydrological response of the catchment. As other research has found elsewhere, it has been observed that flow leaving Park Wood is highly sensitive to antecedent conditions such as soil moisture content and interception capacity (including relative humidity). An intense rainfall event in October 2019 flooded properties in the nearby area but there was no reported or measured flow leaving Park Wood. In addition, the modelling has been used to determine the critical storm duration for the catchment of Park Wood. The 30 minute, 60 minute (1 hour), 180 minute (3 hour), 360 minute (6 hour) and 600 minute (10 hour) storms were simulated through the model (Figure 6).

The 1 hour storm provided the peak in downstream response where the watercourse leaves the wood. While this is different from the Environment Agency storm duration for the fluvial model of the River Pinn, which uses the 7 hour storm, it corresponds to the observations where flooding has arisen during intense rainfall events on a saturated catchment.

Leaky dams have been represented in the model using Porous Walls with a set height. These structures represent the mechanisms of a leaky dam by allowing a set amount of water to leak through the wall, allowing water to weir over the top of the dam when the upstream depth becomes great enough, and allows for flow to bypass the ends of the wall should this be possible.

The model has also been used to test hypothetical scenarios for future interventions, including larger leaky dams within the wood and an earth bund across one of the valleys.

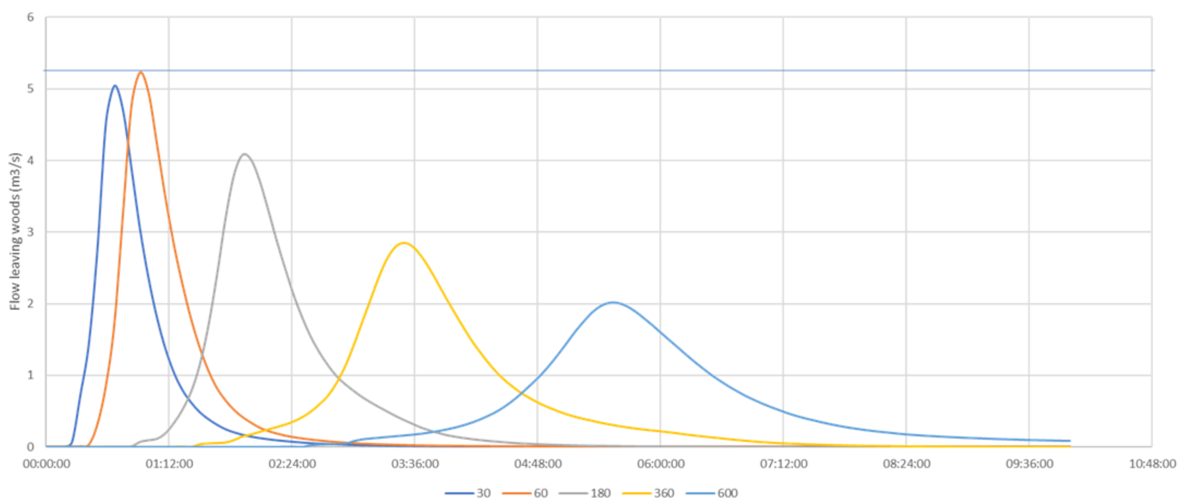

Figure 6: *Sensitivity of the model to rainfall storm duration*

The questions that were developed in collaboration with the wider steering group to interrogate the model included the following:

- What would flooding be like if Park Wood wasn't there and the land was instead agricultural fields?
- How effective are the leaky dams that have been constructed as part of the project?
- Are modifications required to maximise their effectiveness?
- Would larger dams be more effective? Or dams closer to the properties?
- How effective would an earth bund in the woods at the main footpath crossing be? What storage would it provide?

Dam surveys

A 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 by visual inspection during site visits. 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 (Figure 7), divided by the number of dams constructed within each sub-catchment.

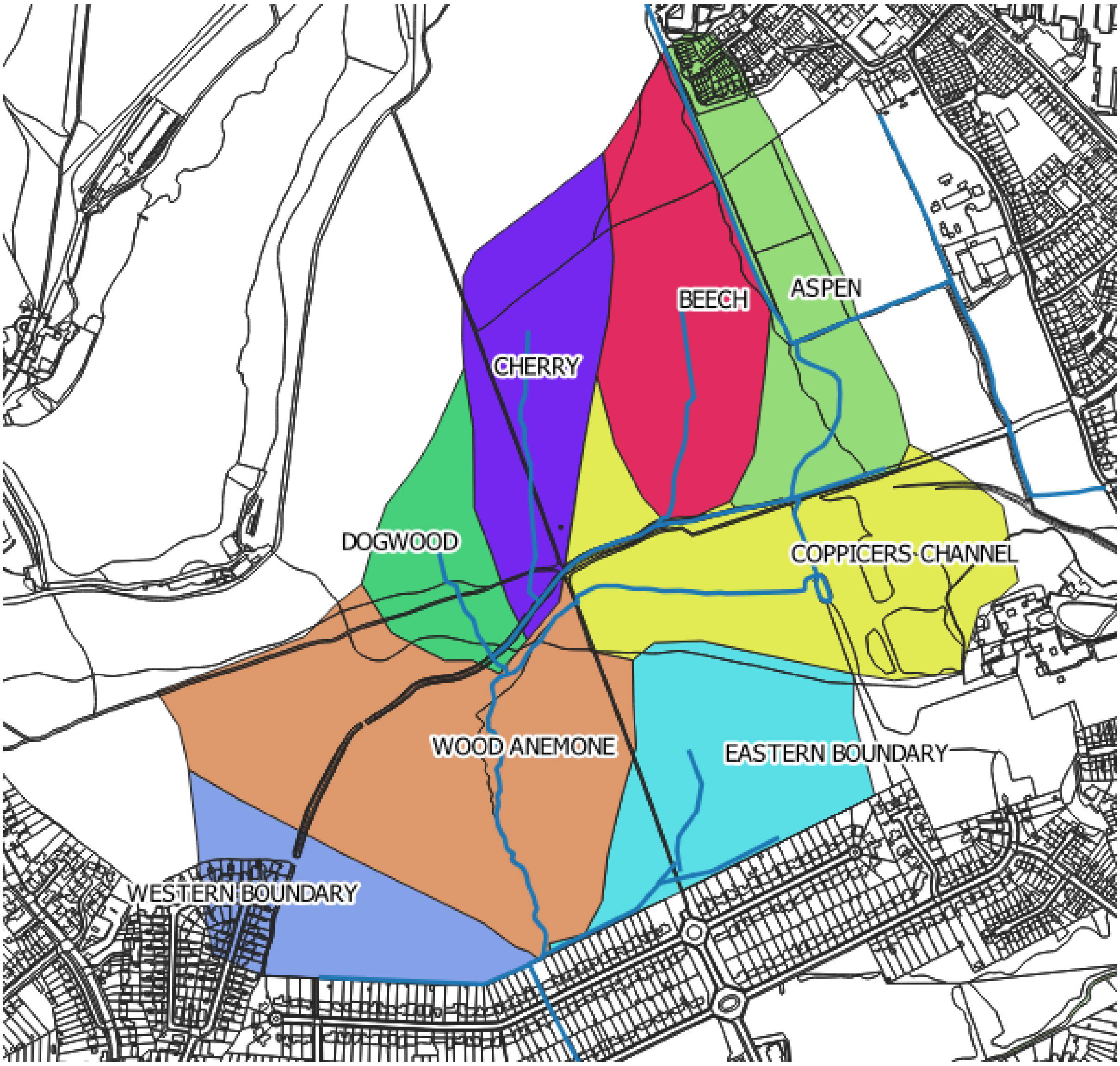

***Figure** 7: Approximate sub-catchment area for each flow path and watercourse in Park Wood.*

Modular River Surveys

Modular River (MoRPh) surveys were carried out to assess changes in physical habitat and hydrogeomorphological functioning associated with the leaky dams. Based on stream width, survey lengths of 10 m were assessed for physical structure of the channel and margins, generating 14 numerical indicators to characterise the surveyed length. In the majority of locations, a sequence of 10 adjacent surveys was carried out (MoRPh 10) to provide a more comprehensive audit of 100 m of channel up and downstream of the leaky dams, and 16 summary indicators per length. These indices can detect changes in hydraulic, sediment, physical habitat and vegetation characteristics, Table 1. Information on survey methods and access to the Modular River Survey database, freely available online, can be found on the MoRPh website. (https://modularriversurvey.org/morph-rivers/).

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).

In Park Wood, baseline surveys were carried out pre-installation of the dams or 'as built' shortly after dam construction in October 2019 and July 2020 and a repeat survey as late as possible in Spring 2021 was carried out.

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

Water level monitoring (FreeStations)

In order to evaluate the impact of leaky dams on the timing and height of peak flows, five low-cost level sensors (FreeStations) equipped with water level sensors (based on car parking technology) were deployed in Park Wood in February 2020. FreeStations (http://www.freestation.org/) are innovative, open source software, environmental loggers with various models capable of deploying a range of sensors (e.g. temperature, meteorological parameters, soil moisture etc). Data were recorded hourly and stored on board using an SD card and uploaded automatically to the FreeStation web platform via GSM.

Four sensors were deployed on the main channel as pairs up and downstream of two series of leaky dams (Figures 3 and 8). The fifth was deployed on a different ephemeral channel to assess the contribution of its catchment to flows through the lower part of the wood. Other channels of other ephemeral tributaries were undefined and shallow therefore less likely to record changes in water height.

Figure 8: *FreeStations deployed up and downstream of leaky dams in Park Wood.*

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.

A water level gauge operated by the London Borough of Hillingdon was installed in 2019 and is located at the entrance to the culvert along the southern (downstream) boundary of Park Wood (Figure 3). A rain gauge was also installed in Pinn Meadows by the London Borough of Hillingdon to provide local rainfall information. These gauges include telemetry and the live readings will shortly be shared with residents of Ruislip through a partnership with the Ruislip Residents Association.

Ecology surveys

Ground flora

Between 2018 – 2021, DJV Consultant Ecologist carried out a series of annual surveys 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

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 Park Wood over 4 days in June/July 2019 and repeated in May 2020 after the majority of dams had been installed. The 2021 survey is scheduled to take place in May/June after the issuing of this report yet will contribute to ongoing research.

All vascular plant species were recorded within 20m transects with a 3m buffer on all main streams in Park Wood. For minor streams, a single species list was created for the entire stream only. This was because very few wetland species were detected and there was little floristic variation, so transects were deemed unnecessary. 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.

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

In 2020 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 surveys paid attention to the locations of existing and proposed leaky dams.

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)

Bryophyte survey

The likely impact of the dams is in making their vicinity damper so, in March 2021, a bryophyte (mosses, lichens and hornwort) survey was carried out by DJV Consultant Ecologist in addition to the above surveys. The purpose was to establish an 'as built' baseline for comparison with any future surveys carried out after the dams become more established, beyond the timeframe of delivery of this project. The summary of findings was made available in time for inclusion in this report with the full report to follow in due course.

Bryophytes were collected along the stream and 3 m to either side of it in the area indicated in Figure 9 for later identification under microscope. A range of micro-habitats, ranging from stream-side banks to the woodland floor away from the stream were sampled. Only bryophytes living on soil were sampled as these species were the most likely to be affected by a change in hydrological regime.

It was intended that members of the RWMAG and the NRFLAG would assist with both the flora and bryophyte vegetation surveying so they could potentially take it over in future years. This did not come about due to Covid restrictions, but is hoped to occur in the May 2021 survey. Nevertheless, volunteers and local users of Park Wood were encouraged to submit observations and photos of habitat surrounding the dams via the SlowFlow app developed for the Thames21 NFM pilot projects (see below) or via our website.

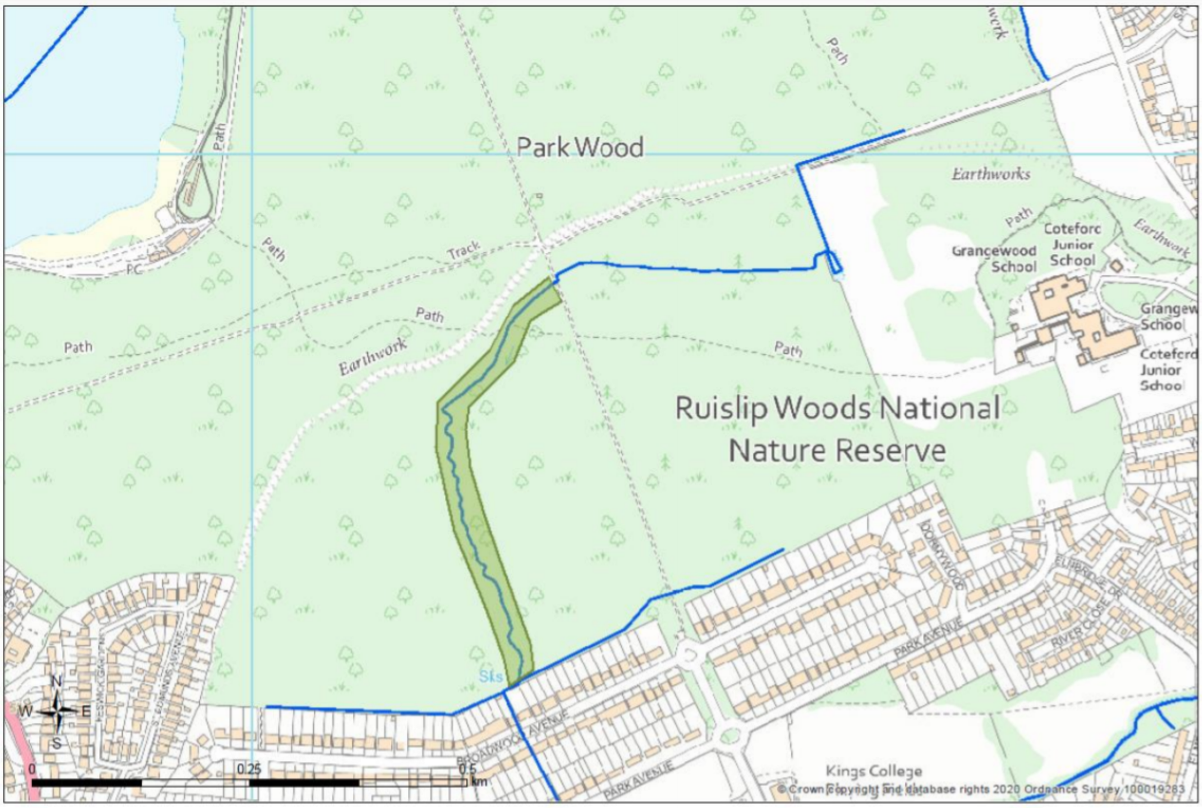

Figure 9: *Bryophyte survey area in Park Wood* *(from Vickers March 2021)*

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 Park Wood, 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, NRFLAG and RWMAG with the necessary skills to assist the London Borough of Hillingdon 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.

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 Park Wood (Figure 10) to further encourage woodland users and local residents to engage with the project 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.

Figure 10: *QR codes (blue disc at right) deployed on leaky dams in Park Wood.*

3. RESULTS AND EVALUATION OF THE NFM

3.1 Hydrological changes associated with the NFM assets

The characteristics of the 39 leaky dams and 11 tree trunk dams installed across ephemeral streams in Park Wood (Figure 3), 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 - predominantly hornbeam and sycamore, but including some hazel and holly.

Installation of woody debris dams across the channels slows the flow by temporarily storing water and increasing channel roughness. Additionally, many of the dams were designed to divert water out of channel to infiltrate into the woodland floor, thereby reducing the volume of water in channel. Examples of dams in Park Wood are shown in Figure 11. The increase in storage volume and area of channel roughness created are summarised in Table 4.

***Table 3**: Summary of construction characteristics of leaky dams in Park Wood*

Channel name	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 of dams
Coppicers	60.5	37.1	585.8	16.3	71.3	12
Aspen	51.5	25.5	403.2	9.2	70.0	11
Beech	35.1	11.9	321.4	8.3	67.9	7
Cherry	37.3	11.5	267.9	14.5	71.4	14
Dogwood	18.5	18.8	375.0	25.0	102.5	4
Other	n/a	n/a	186.7	n/a	57.5	2
W. Anemone	49.2	20.0	283.3	13.8	87.5	6
Overall	**42.4**	**20.8**	**346.2**	**14.5**	**78.4**	**50**

Channel names correspond to those in Figure 3.

***Figure 11**: Examples of leaky dams (left) and tree trunk dams (right) installed in Park Wood. The tree trunk dam in this example was intended to divert flow off the footpath to infiltrate in the wood. Note the notice beside the dam containing information about NFM and the project to deter vandalism of structures.*

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.

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

Channel name	Area (m2)	Storage volume (m3)	Mean channel roughness (m2)
Coppicers	126000	104	10500
Aspen	77000	52	7000
Beech	91000	21	13000
Cherry	80000	46	5714
Dogwood	41000	3.5	10250
W. Anemone	174000	57	29000
Overall			

Channel names correspond to those in Figure 3.

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

Modelling evidence

The hydraulic model was used to determine the performance of the existing NFM interventions in the catchment. The flow paths obtained through modelling of the catchment (Figure 12) were broadly in line with the observations from the field by residents and members of the steering group. The model represented the preferential flow routes along tracks and paths that had been observed on the ground.

The modelled flow hydrograph extracted at the downstream section of the catchment in Park Wood has been used as the benchmark where the scenarios are compared. Questions developed by the wider steering group to interrogate the model included:

i) How effective are the leaky dams that have been constructed as part of the project?

At the downstream section within Park Wood there was a 5% reduction in peak flow for 1 in 2 year event. The benefit was retained for the 1 in 5 year (4% reduction) and 1 in 30 year (3% reduction). The time to peak lagged by a few minutes (1-3 mins) when the constructed dams were taken into consideration.

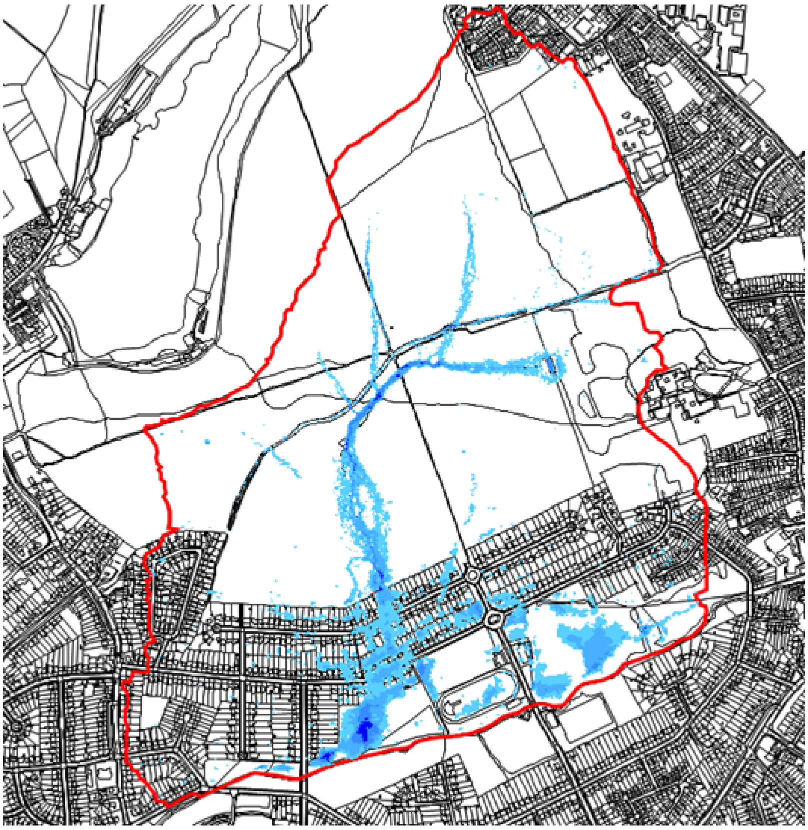

Figure 12: *Modelled flow paths through Park Wood towards the River Pinn. The extent of the modelled area is defined in red.*

ii) Are modifications required to maximise their effectiveness?

The hydraulic modelling exposed some deficiencies in the existing array of leaky dams, both in the siting and also the length of the dams. The modelling has shown that some of the dams on the upper reaches of the ephemeral flow paths, where there is only flow during significant events, do not attenuate enough flow as there are alternate flow paths that do not have dams.

An example is shown in Figure 13 where the approximate location of the dams (in pink) are occasionally bypassed by the main flow path. In these areas, longer dams are recommended so that the whole flow path is intercepted.

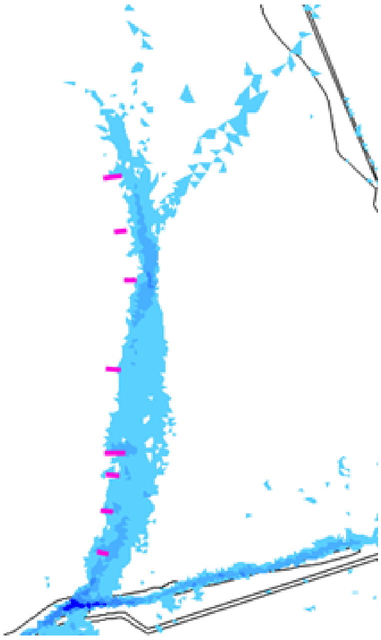

***Figure 13**: Results of hydrological modelling that indicate flow routes extend wider than and current leaky dams, indicating dams should be widened to intercept more flow (left); corroborated by photos taken in the wood during flow events (right).*

iii) Would larger dams be more effective?

Most of the structures are of relatively small scale (Tables 3 and 4) and therefore do not result in a considerable volume stored. A scenario whereby a flight of existing dams along one stretch of watercourse were increased in both length and height (1m) was simulated through the model. The flood extents and long section along the channel from the model are provided in Figure 14. While the scale of these dams may be disproportionate to what can practically be achieved in Park Wood, there was a marked difference in the response of the catchment downstream, with a 21% reduction in the 1 in 2 year peak flow and a 14% reduction in the 1 in 30 year peak flow.

The approach at the outset of the project was to implement an array of leaky dams throughout Park Wood on the majority of the tributary flow paths as the contribution from each of the individual watercourses was unknown. The model results from this scenario suggest that more substantial structures in a focussed position within the watercourse network could have a considerable benefit on top of the smaller distributed structures. This work also provides evidence for the added benefits of future work to modify and expand the existing structures.

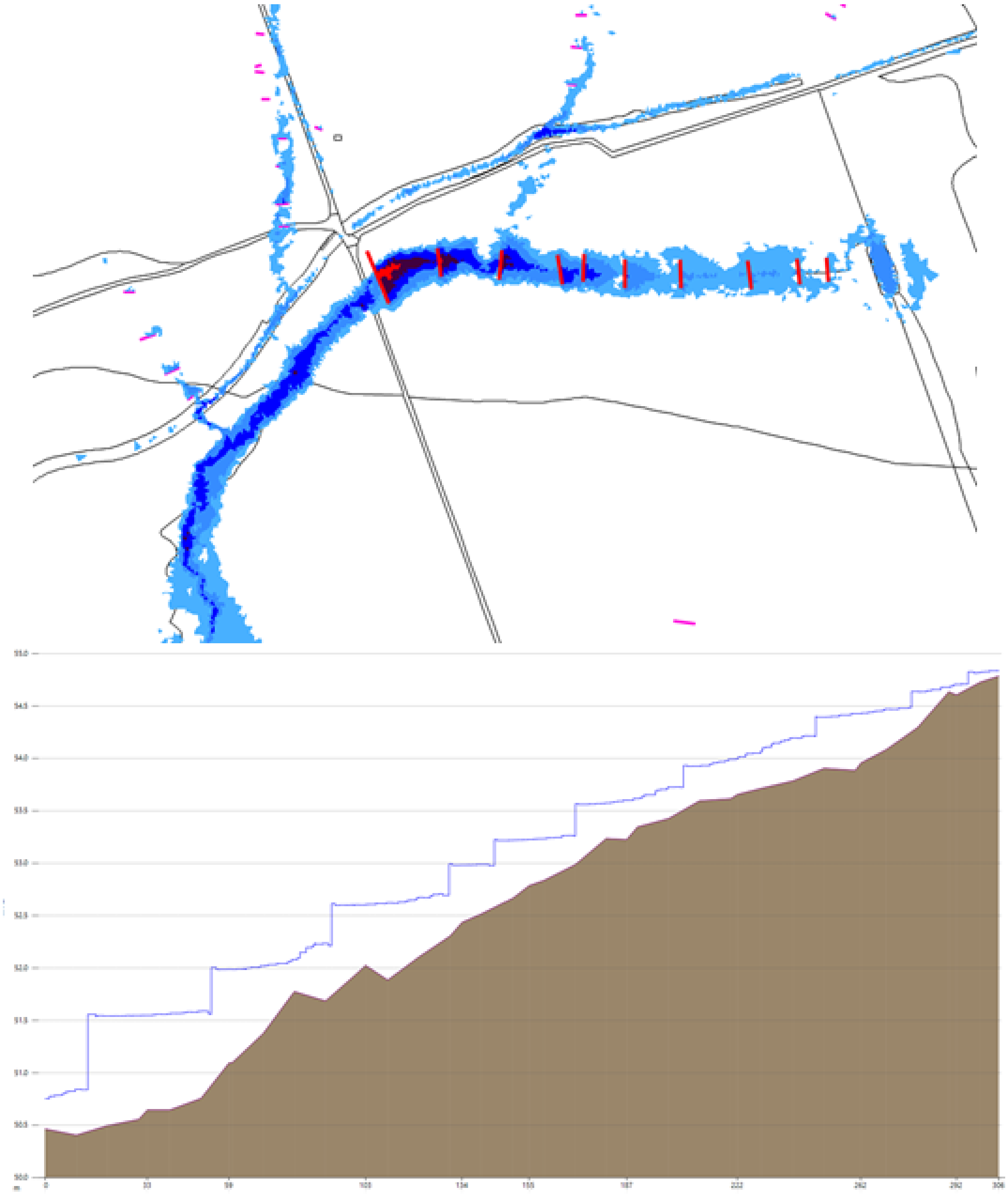

Figure 14*: Peak modelled flood extents (above) and long-section (below) for a scenario with taller (1 m), wider dams*

iv) How effective would an earth bund in the woods at the main footpath crossing be? What storage would it provide?

An earth bund within Park Wood was discussed as an option throughout the process of the project. A possible location for an earth bund was suggested at the intersection of Coppicers channel and the north-south footpath. A scenario in the model was undertaken to determine the benefit of an earth bund in this location, with a culvert allowing flow to pass through the structure (Figure 15). The bund provided an additional 14% flow reduction on top of the leaky dams and, based on the approximated dimensions, stored an additional 800m^3 of flood water. While the earth bund was not delivered as part of this project, there is considerable value in having the model to be able to test scenarios and inform future works.

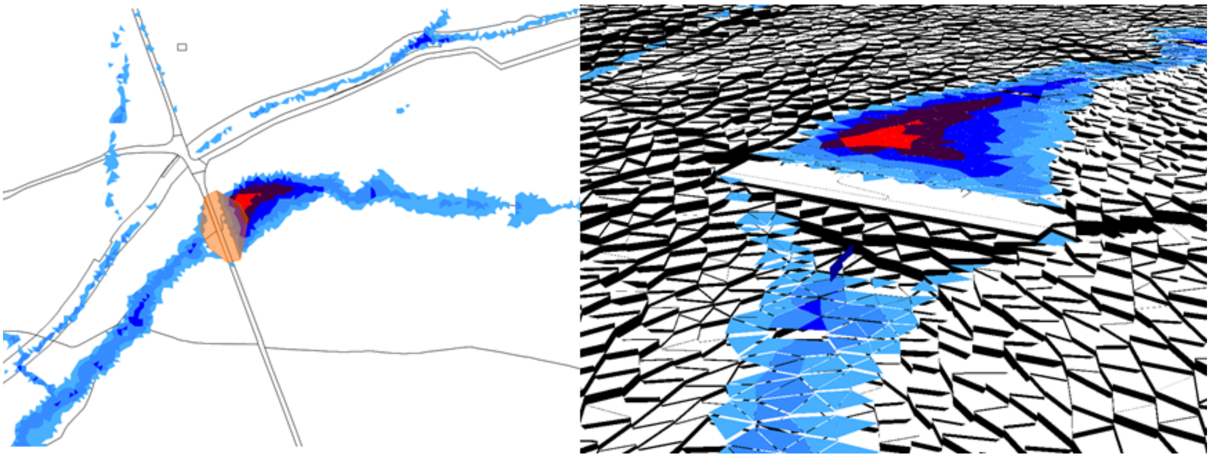

Figure 15: *Modelled flood extent (left) and 3D view of model simulation including the earth bund.*

v) What would flooding be like if Park Wood wasn't there and the land was instead agricultural fields?

As the majority of the catchment is already woodland, the potential for woodland planting as a form of NFM intervention was not possible. The benefit of the existing woodland on the risk of flooding and downstream flow, however, was modelled by altering the ground roughness and infiltration parameters to reflect agricultural land instead of established ancient woodland. Resulting flows were 78% higher than the baseline values for the 1 in 2 year event and the peak flow came approximately 15 minutes earlier as surface roughness was reduced and runoff volumes increased. These results demonstrate that the woodland is already providing a flood risk management function for the catchment.

The comparative hydrograph for the 1 : 2 year return period event for the modelled scenarios described above is presented in Figure 16.

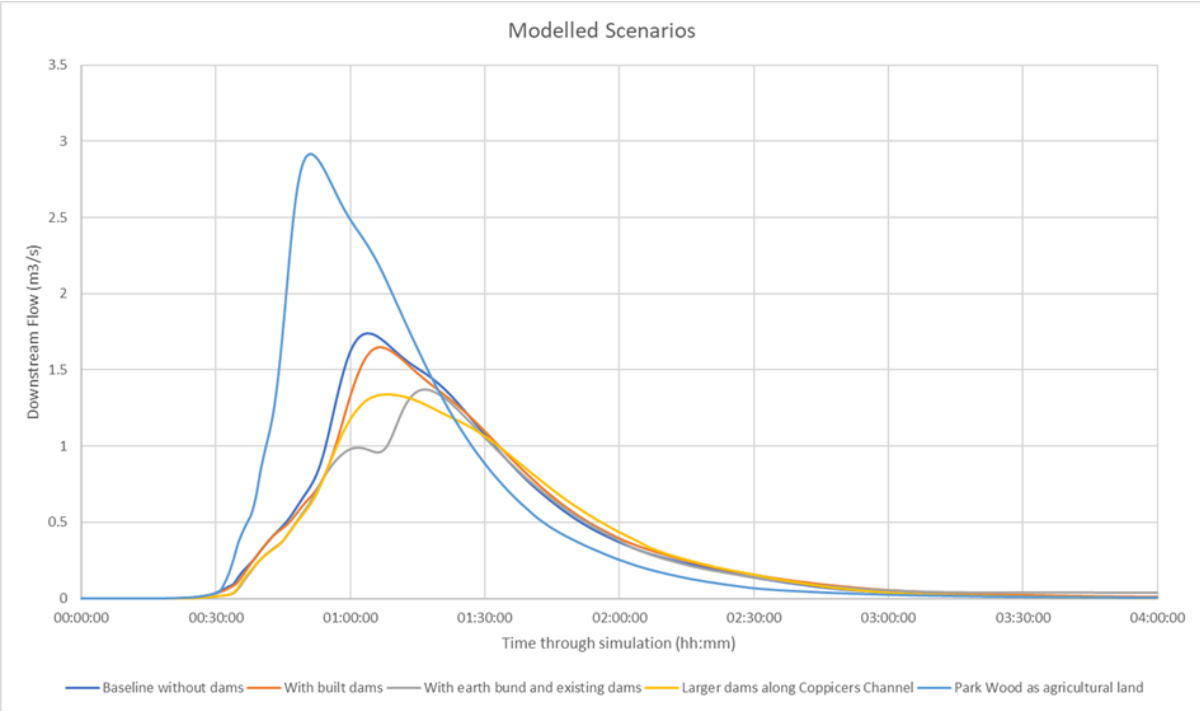

Figure 16: *graph showing comparative hydrograph for modelled scenarios at Park Wood*

Volunteer evidence of NFM performance

Volunteer members of the NRFLAG and RWMAG visited Park Wood to document the performance of leaky dams, out of channel flow paths and other rainfall related phenomena during and after the majority of rain events that occurred during this project (examples Figure 17). This resulted in an exceptional and detailed record of the behaviour of the dams and woodland during rainfall which was above and beyond the capacity of project officers to deliver and was more detailed than the questions devised for the SlowFlow App (discussed later). It was invaluable both for model and FreeStation validation and for characterisation of individual leaky dams.

***Figure 17**: Examples of flow attenuation by leaky dams (above) and out of channel flow paths (below) in Park Wood*

Measured evidence of NFM performance

FreeStations

Figure 18 shows example telemetry data recorded by one of the FreeStations in Park Wood incorporating two named storm events. However, due to a combination of site factors and teething issues in deployment, FreeStations were only marginally useful for characterising dam functioning, flow behaviour in the woods and for model calibration.

Trial and demonstration of technology developed by university teams (Kings College London, KCL) contributes to research and development of innovative, low cost sensors but requires considerably more time investment to support them compared to use of higher cost, commercially available sensors. Aside from time required to source parts, build, calibrate and test each FreeStation prior to deployment, the FreeStations in Park Wood suffered a variety of additional, time consuming challenges after deployment. The resulted in serious performance issues and data gaps in which stations were rarely functioning simultaneously during critical times. Ultimately, it was concluded that Park Wood is not suitable for telemetry devices such as FreeStations. Issues included:

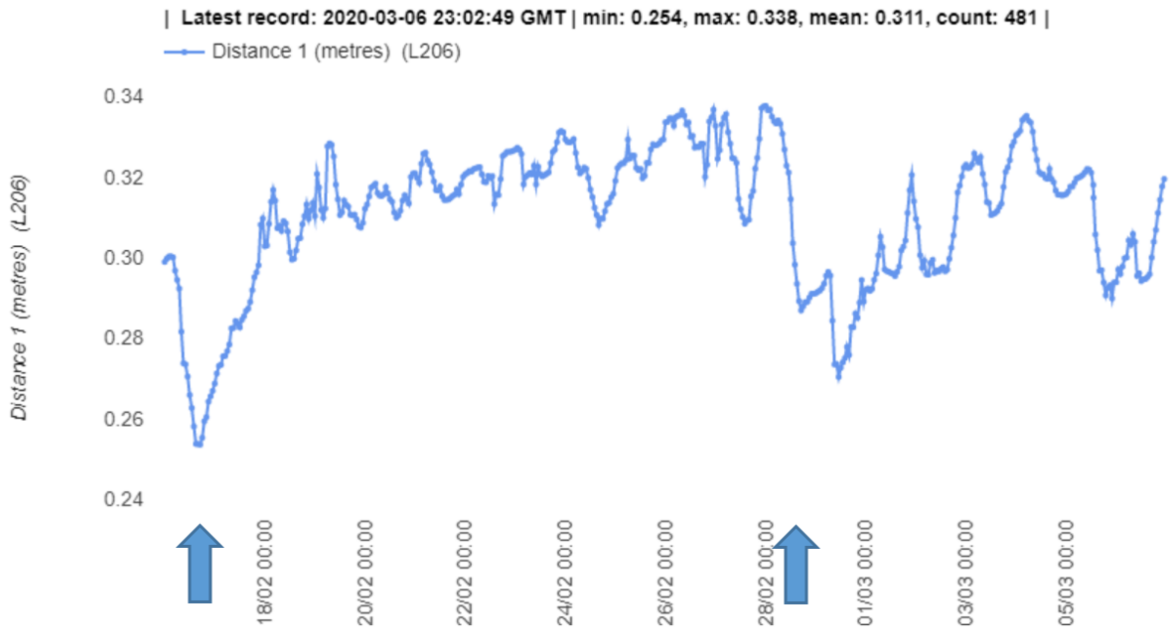

Figure 18: *Raw hourly FreeStation telemetry data from Park Wood recording distance from the sensor to the water level for the period 14 February - 6th March 2020 and encompassing two named storms: Storm Dennis (15-16th February) and Storm Jorge (28th Feb - 1st March), indicated by arrows.*

i) Poor signal for telemetry. Park Wood has poor GSM coverage which caused rapid battery drain through devices searching continuously for signal. This resulted in data gaps and requirement for frequent maintenance visits by project staff to replace batteries. Much later in the project, KCL modified the onboard firmware to prevent stations continuously searching for signal so they simply logged data on the onboard SD card. The intention had been to push FreeStation real time telemetry data to the London Borough of Hillingdon's website where it would be visible to the public alongside level and rain gauge data from sensors located at the edge of Park Wood, however, data were too intermittent and not live stream.

ii) Low rates of solar panel charging under heavy tree canopy. This compounded the above problem.

iii) Rapid vandalism of two of the five FreeStations, followed by theft of a third in the final month of the project. Vandalism included one thrown into the local pond and damage beyond repair of the second. Park Wood is a public wood and use was particularly heavy due the 'stay local' restrictions enforced by the Covid pandemic. Stations were sited in locations considered to be less vulnerable to damage (e.g. away from main footpaths) which were usually sub-optimal from the point of view of both the scientific objective to record immediately up and down stream of series of dams and for telemetry and solar panel charging through the canopy.

Other site factors that contributed to unsuitability for monitoring with FreeStations include the fact that i) channels are small so changes in water heights behind leaky dams were minimal (frequently ≤ 10 cm, Figure 16) and ii) considerable flow occurs overland and on the compacted soils of footpaths (Figure 15) before ephemeral streams activate.

In view of the issues and likelihood of recurrent vandalism, the steering group took the decision not to supplement or replace FreeStations in Park Wood during the project and, at the end of the project, to remove the remaining devices. Other forms of monitoring - such as time lapse photography - were considered in the initial stages of the project but rejected due to vandalism risk. 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 was considered worth the risk.

Local Hydrometry

While there was not sufficient time in the project programme to establish baseline monitoring of the response of the upstream catchments to rainfall events using the downstream water level gauge and the local rain gauge, the local hydrometry has provided very useful information regarding the flood mechanisms in the catchment.

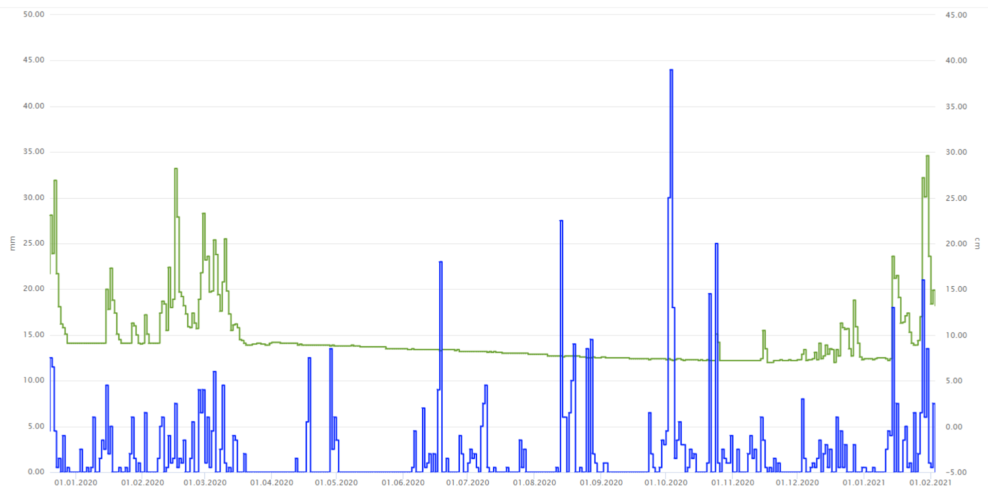

Figure 19*: Total daily rainfall (mm, in blue) and maximum daily water level (cm, in green) from December 2019 to January 2021 from the gauging at the culvert on the perimeter of Park Wood (location indicated in Figure 3).*

Daily waiter and rain data from the gaugue at the perimeter of Park Wood (Figure 19) confirms the ephemeral nature of the channels and shows that the woodland is capable of absorbing a considerable volume of water, with the five highest daily rainfall depths recording no notable response at the downstream culvert. Storm Alex in October 2020 included the wettest recorded day both locally and nationally, but there was no flow observed from Park Wood. Highest recorded water levels corresponded with larger storm events following extended periods of rainfall. It is noted that, historically, the largest flood event from Park Wood was June 2016 and not a winter event.

In addition to absorption by the woodland, a contributing factor to the low correlation between daily rainfall and the level of water at the culvert gauge could be interaction with groundwater. The aquifer is extensive in this area and a small section of it appears to follow the upper part of the valley through which Coppicers Channel runs. Future modelling work should consider this surface-groundwater interaction and its possible impacts on flood risk.

The local hydrometry provides context to the photographic and manual observations during flood events. The green line in Figure 20 shows the time at which corresponding photographic observations of the leaky dams storing water following a rainfall event were taken.

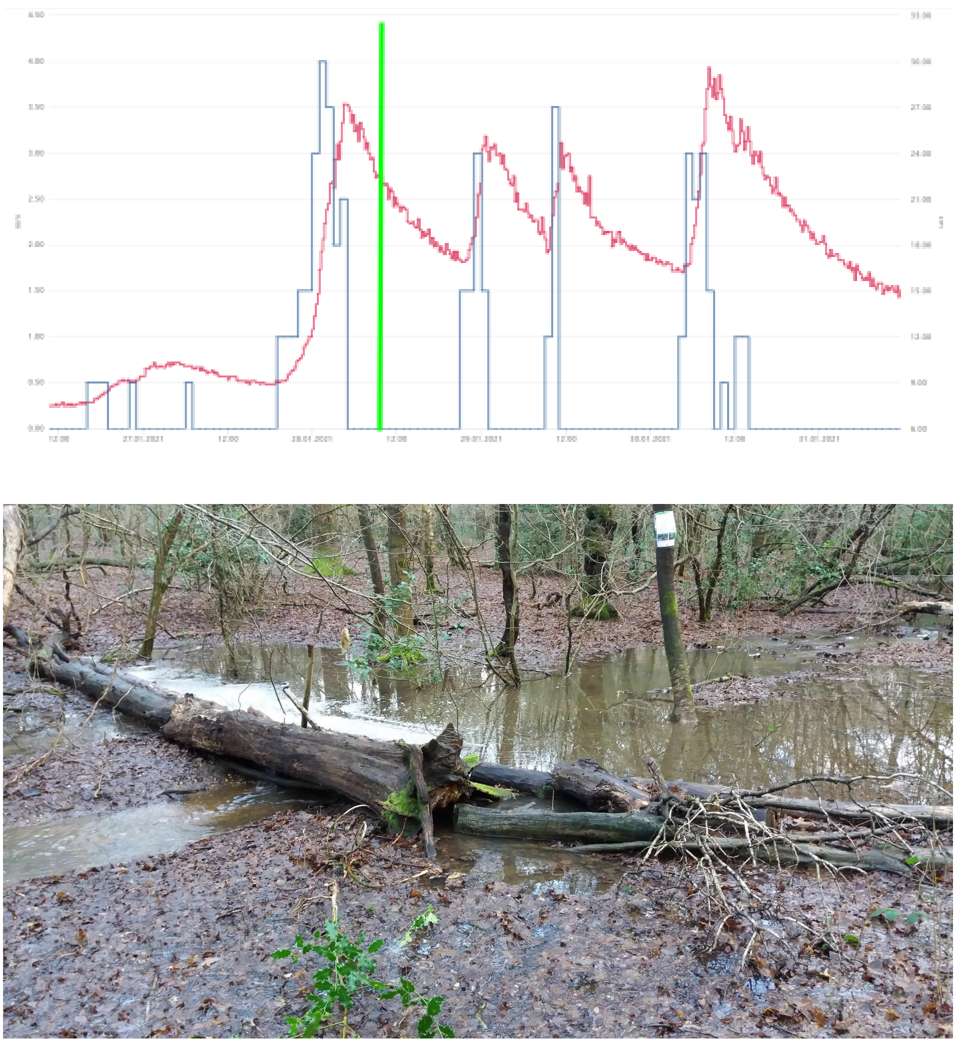

***Figure 20**: Total local hourly rainfall (mm, blue) and 15 minute resolution water level (cm, red) for a rainfall event on 28th January 2021 recorded by the gauging station on the perimeter of Park Wood (above), combined with photographic evidence of dam performance (below).*

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 21 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.

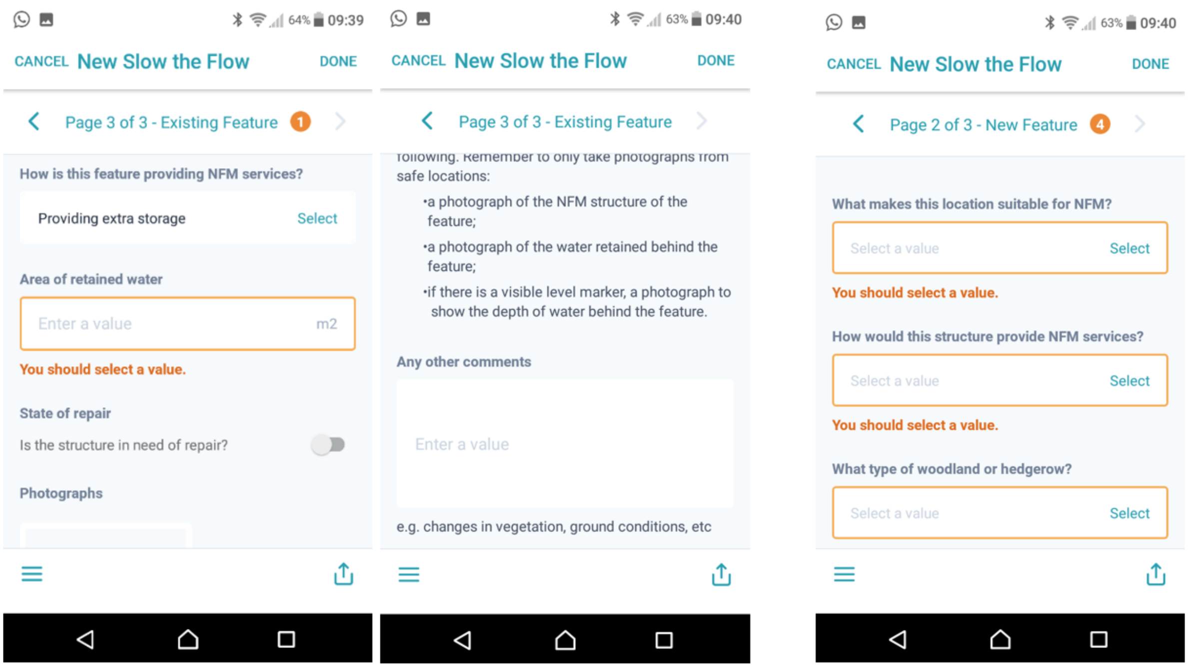

***Figure 21**: Screenshots of the SlowFlowCapture App for collection of data about the NFM assets by the public and trained volunteers. Left and centre: recording data for existing features; right: recording suggestions for a new NFM feature.*

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 (eg 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 the ephemeral channels in Park Wood were dry. Unless you are in the woods after heavy rain when the channels are active and the dams 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) Mobile phone reception in Park Wood is notoriously poor making it impossible or laborious to interact with the app whilst on site.

v) People were willing to travel to attend dam building practicals and training sessions but - unless they are regular users of Park Wood, or at risk of flooding - they were unlikely to return regularly to carry out dam surveys.

vi) Wet phone screens are difficult to interact with so members of the NRFLAG and RWMAG 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

Ecological benefits

The initial scoping/phase 1 assessment in 2018 and the 'DAFOR' transect survey undertaken in 2019 concluded that the only wetland area in Park Wood was Grub Ground pond close to Park Pale (feature indicated on Figure 3). There were very few wetland species (Ellenberg scores for moisture of >8) along any of the 10 surveyed streams, except for occasional stands of pendulous sedge and remote sedge and less frequent occurrence of skullcap *Scutellaria galericulata.* Streams are known to be dry most of the time, therefore the local flora reflected the species composition of the adjacent woodland (e.g. wood meadow-grass *Poa nemoralis*, enchanter's-nightshade, bramble and wood avens). Floristic observations reflect the fact that the ephemeral streams of Park Wood characteristically only flow in winter months when the ground is saturated. Due to homogeneity of geology and topography, little variation in ground flora was observed along the length of these streams and the overall conclusion was that installation of leaky dams along them would therefore likely be ecologically beneficial. There were no identified ecological constraints to locations of leaky dams. Full discussion of the results of the 2018/2019 and 2020 surveys, including species lists, notable and AWI species can be found the ecological reports, Appendix 2.

The transect data from 2019 was compared with the areas repeated in 2020 to assess any changes in species composition after 17 (44%) of the smaller 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 the same, Table 5. Of the species with Ellenberg values ≥ 8, yellow iris was a new species in 2020.

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

	Ellenberg values			
Year	**Mean**	**Min**	**Max**	**Species with Ellenberg values ≥ 8**
2019	5.8	4	8	pendulous sedge, remote sedge, skullcap
2020	5.8	5	9	pendulous sedge, remote sedge, skullcap, yellow iris

Other findings were that 16 of the species recorded in 2020 were AWI species, of which 5 were also notable in Greater London and two species (Slender St John's-wort *Hypericum pulchrum* and wood speedwell) were recorded in 2020 but not in 2019, Table 6. Common dog-violet Viola riviniana, was also observed in 2020 but not in 2019.

Table 6*: Ecological summary of Park Wood, May 2020*

Indicator	2020 score
Species richness	58
Ancient woodland Indicator species	16
London notable species	5
Ellenberg value ≥ 8	4
Mean (min, max) Ellenberg value	5.8 (5, 9)

There was one instance of a non-native invasive species (INNS), variegated yellow archangel *Lamiastrum galeobdolon subsp. Argentatum* in the targeted surveys of 2020. The wider ranging surveys of 2019 encountered 4 NNIS (rhododendron, snowberry, Wilson's honeysuckle, small balsam) along the surveyed area in the south of Park Woods close to the boundary with Broadwood Avenue. These should be removed and details of their location can be found in the survey reports, Appendix 2.

A further 22 leaky dams and 11 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 Park Wood, in view of the long, dry summer, ephemeral nature of the streams and very recent installation of the majority of the leaky dams, vegetation changes associated with them are not yet in evidence. 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.

Bryophyte survey

Of 40 species collected, 10 could be identified, Table 7. The majority of species sampled are very common and widespread throughout lowland Britain. Most are characteristic of acidic woodlands but are also found in a variety of other habitat types. As these species are found in a variety of habitats and are relatively common, it is considered extremely unlikely that there would be an adverse impact of installing dams along the length of the stream.

Table 7*: Bryophyte species recorded during surveying in Park Wood*

Species	Relative abundance	Notes
Atrichum undulatum	Frequent	Very common moss in lowland woodlands. Found in shaded, well drained places
Calypogeia arguta	Rare	A common liverwort of acid soils in woodland and other habitats.
Dicranella heteromalla	Occasional	A very common moss occurring in a variety of acidic habitats.
Fissidens bryoides	Occasional	A common moss on neutral or mildly acidic soil in woodlands and other habitats.
Fissidens exilis	Rare	A small, less common, but widely distributed, moss found on neutral or acid loam and clay growing in woodlands and damp fields in grassland.
Hypnum cupressiforme	Occasional	A very common moss found on acid or slight base substrates.
Kindbergia praelonga	Frequent	One of the commonest mosses in lowland Britain. It is found on banks, in turf, on the ground in woodland, on logs and ascends the branches of trees.
Mnium hornum	Occasional	A moss of acidic soils, logs, rock and tree bases. Often abundant in woodland.
Pseudotaxiphyllum elegans	Occasional	A widespread moss found in acid conditions on soil, rock, logs and tree roots.
Trichodon cylindricus	Rare	A widespread moss growing in a variety of acidic habitats.

Geomorphological changes

Changes in channel characteristics between the ‘as built’ baseline surveys of October 2019 and July 2020 and the final survey of Spring 2021 were difficult to interpret, therefore inconclusive. The majority of summary indices revealed no trend (Table 8) and deeper evaluation of the individual components of these indices also revealed no clear trends. Indices for channel complexity actually decreased, which is surprising and may not reflect ‘real’ change. Furthermore, the survey methodology did not adequately capture debris accumulation behind dams - although it is known from volunteer reports that the dams in Park Wood trap considerable amounts of organic debris and sediment during heavy rainfall.

Findings from this catchment are broadly similar to the MoRPh survey results from the other NFM pilot projects delivered by Thames21. Changes in key geomorphological characteristics were noted in some indices only and not consistently those most likely to be influenced by installation of structures in channel (e.g. scour and erosion features, bed features). The reasons for this are likely as follows:

- Too little time between dam construction to observe geomorphological changes.

The ephemeral streams in Park Wood are dry throughout the summer with little geomorphological process occurring during the majority of the time between baseline and comparison surveying. The presence or absence of flow during the survey also impacts summary index 8 (channel physical habitat complexity), which incorporates flow characteristics. Developers of MoRPh recommend re-surveying after 5 years to capture mature changes associated with channel restoration and interventions.

- Seasonal differences between surveys.

The three surveys in Park Wood were conducted in different seasons (autumn, summer and early spring) with associated differences in vegetation cover, structural complexity, flow and the interaction of these with the wetted channel (e.g. extent of shading, branches trailing into the river, etc.)

- Suitability of MoRPh for recording leaky dam features.

The scale at which some of the impacts of the leaky dams are seen are much smaller than the scale at which the MoRPh is designed to survey, e.g. recording changes in the channel width, erosional and depositional features immediately up and downstream of the leaky dams (within 1 m).

***Table 8**: MultiMoRPh indices calculated for the surveyed reaches in Park Wood comparing 'as built' baseline surveys with a final evaluation survey. Indices are described in Table 1.*

MultiMoRPh Indices	As built surveys (Oct 2019)	(July 2020)	Final survey (March 2021)
Index 1	1	1	2
Index 2	Dry	Dry	Smooth
Index 3	2	3	3
Index 4	Silt	Gravel-Pebble	Gravel-Pebble
Index 5		4.7	4.0
Index 6		Silt	Silt
Index 7	0	0	1.3
Index 8	3.3	4.2	3.0
Index 9	0	0	0
Index 10	3.0	3.4	2.9
Index 11	4.5	4.8	3.7
Index 12	6.5	3.5	5.5
Index 13	0	0	0
Index 14	0	0	0
Index 15	0	0	0
Index 16	0	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 is required to create nationally comparable data sets.

- Summarising 10 m stretches using categories ‘absent, trace, present, extensive’ means that some of the detail associated with leaky dams may be missed before they have matured. 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 and an index 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 in different seasons with different vegetation cover and variable amounts of flow in the channel (including dry bed). 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 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 22 estimates potential ongoing and future additional benefits offered by leaky dams in Park Wood, 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 woodland and into the culvert at the perimeter of Park Wood potentially contributes to flood risk through causing obstruction. This is particularly likely in Park Wood where debris accumulates for long periods in dry ephemeral channels before being washed into the culvert in rain events. The trapping of large and small woody debris and silt by dams is likely an unquantified benefit of the leaky dams and it is recommended that any future monitoring taking place in Park Wood should seek to evidence changes in sediment and debris trapping.

Health and wellbeing

The leaky dams in Park Wood potentially enhance health and well through two aspects. Firstly, installation of leaky dams 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'.

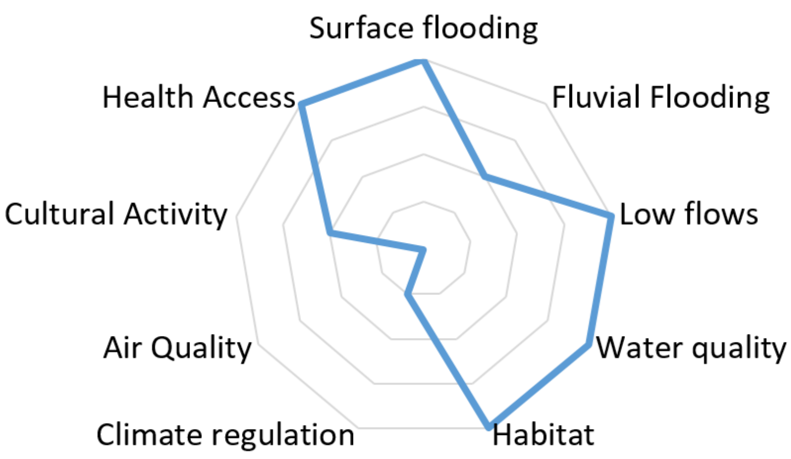

Figure 22: *Potential multiple benefits of leaky dams in Park Wood, after they are more established.*

Secondly, the project provided physical and mental health benefits through volunteering events to build leaky dams. Project legacy includes greater community cohesion as well as continuing volunteering opportunities through ongoing dam maintenance.

To increase the range of additional benefits, future projects in Park Wood should consider wider community engagement and involvement in building and management of NFM assets, including creation of education opportunities in schools and colleges. This could also include community visits to the dams 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 (London Borough of Hillingdon), and an NGO (Thames21) working closely with local resident groups (NRFLAG and RWMAG). Hillingdon council and Thames21 had worked together previously on projects but new links were forged by inclusion of local resident community groups. These links will continue and strengthen beyond the lifetime of the project as volunteer members of the RWMAG and NRFLAG have been upskilled to enable them to form an integral role to ongoing upkeep of the leaky dams in Park Wood and, it is anticipated, to repeat the ecological surveys.

In comparison to project delivery by the Environment Agency (EA), partnership working delivers time and cost saving benefits, in particular through in-kind contributions by project partners and the local community, which in this project were anticipated to total approximately £50,000. The London Borough of Hillingdon committed to £24,000 of in-kind contribution in staff time over the course of the project. This included, for example, support from their Woodland Officer (tree felling for leaky dam creation, attendance of NFM training courses on dam management and maintenance), attending regular steering meetings, liaising with local councillors and the local community and in-kind contributions towards hydrological modelling. This does not include valuable foundation work undertaken by the London Borough of Hillingdon prior to project commencement to engage the community and secure local project support.

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.

A further £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 exceptional reports submitted by committed local resident volunteers (discussed below) to understanding flow routes and documenting leaky dam behaviour cannot be over emphasised. Their anticipated contribution of time (therefore cost saving) to long-term dam maintenance and management is not quantified but has potential to be considerable.

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 EA. In this project, community engagement comprised several aspects, discussed further below:

i) Establishment of a steering group to ensure local community groups and those affected by flooding could input to development and delivery of the programme of works. Regular meetings were attended by members of the local flood action group (NRFLAG) and the woodland management group of the wider SSSI (RWMAG). These groups also supplied highly detailed reports of the dams after every heavy rain event and carried out regular surveys to check the state of repair of dams, carry out minor repairs and report incidence of dam vandalism.

ii) 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.

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

iv) Awareness raising about NFM and the project accessed via QR codes fixed to dams (Figure 10, discussed above).

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. Aspects including recruiting and training volunteers, supporting their data collection activities, sustaining momentum, providing regular feedback and managing conflicting opinions and expectations, as well as dissemination of project results to wider interest groups (e.g. the Catchment Partnership). There was insufficient budget in this project to fully engage the public using Park Wood and wider community (for example schools), so by necessity engagement and support was focused on the steering group.

However, whilst building relationships with invested community groups is key, a balance must be struck between time invested in collaborative working with the community and effective project delivery. To achieve this, roles and expectations of all partners in the steering group should be clearly defined from the outset. Whilst it is essential to work closely with and gain the opinions of local groups, management decisions must ultimately be made by the organisations responsible to the funders. This at times led to disagreement.

On the other hand, the benefits of an engaged local community are invaluable. The knowledge of the NRFLAG and RWMAG groups in understanding complex flow pathways and dynamics in Park Wood exceeded learning that could have been gleaned from standard desk top or catchment walk over techniques. Their ability to be reactive and go on site at the time of heavy rainfall and their willingness to compile extraordinarily detailed reports (complete with annotated maps of water movement and photographs) that documented flow and leaky dam behaviour were invaluable for a pilot project. This enabled behaviour of the leaky dams during heavy rainfall to be characterised and also resulted in documentation of out of channel flows along footpaths in the woods, both of which informed model calibration and general understanding. Residents were also invaluable in reporting vandalism of dams and monitoring equipment and, in many cases, carried out minor repair of dams. This frequency of site visits and response to events could not have been achieved with project officer time alone.

Engagement varied between volunteer participants but it is estimated that approx. 600 hours of in kind contribution was donated to the project by volunteers of the steering group alone. This equates to approx. 4 hours per person per month over 3 years and comprises expert local knowledge as well as unskilled time attending training courses and assisting with the building of leaky dams. This estimate does not take into account future hours maintaining dams as part of project legacy.

Beyond the project lifetime, ongoing monitoring and maintenance of the leaky dams by local residents will be of enormous benefit to the London Borough of Hillingdon, including in reporting vandalism and assistance with annual repair and maintenance. In addition, members of the NRFLAG and RWMAG have considerable expertise, including in ecological surveying, which will be important for project legacy and ongoing monitoring of vegetation changes associated with the dams in future years.

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 Park Wood. 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 insurance. This course was run once in Park Wood in September 2019 and completed by 6 participants, one of whom went on to lead their own leaky dam building event in Park Wood in which 3 dams were constructed.

After running the two-day course across all four NFM pilot projects, it was amended to a one-day course. This was because 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 short online session covering the theory of NFM and a practical element in Park Wood building dams. It was intended to widen the appeal to local users of Park Wood and an endeavour to recruit citizen scientists to participate in monitoring of dams with the Slow the Flow app. In total 41 trainees attended the online element (run on two occasions: October 2020 and March 2021). However, after the first session, only one attended the onsite dam building in Park Wood - the other registered attendees failed to show up on the day.

In addition to the training course, volunteers were recruited to assist with leaky dam building. In total 14 leaky dam building events were run in Park Wood by project officers between March 2019 and December 2020, involving 61 volunteers building 37 dams. Monitoring and the Slow Flow app were also introduced at these events.

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). However, the interest was mainly in dam construction and less in long term volunteering through monitoring and data capture via the Slow Flow App, as 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 dam building and monitoring;

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 and dam building 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.

Volunteers recruited from local users of the area, 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.

It is 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, often in very detailed reports 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.

Ongoing maintenance of NFM features beyond the project

Vandalism and informal dam building

As an urban greenspace, Park Wood is well used by the public and inevitably has a higher risk of interference with the NFM structures (well meaning and malicious) than private sites. This occurred despite displaying project information notices beside the majority of dams to inform the public of the purpose of the structures.

Over the course of the project incidence of vandalism to 4-5 dams at a time was reported on at least 4 occasions and required at least 4 project days to repair them. Types of activity recorded included:
i) Vandalism and complete destruction of dams - including incidence of dam timbers being set fire to.
ii) Alteration of formal dams by adding or removing timbers.
iii) Moving of large logs intended to divert flow out of channel into the woodland.
iv) Building informal dams across channels, not necessarily in ideal/permitted locations for holding water. Some informal structures were robust and moderately enduring and potentially contribute to holding back water and sediment and wetting the local woodland; others are more ephemeral with risk of creating debris blockages upon breakdown (Figure 23).

Figure 23*: Examples of informal dams in Park Wood*

The importance of an engaged, invested local community and Borough Council are once again highlighted. Vigilance by the NRFLAG meant that minor repairs were implemented almost immediately and work days by the RWMAG to undertake larger repairs were carried out quickly resulting in minimal loss of flood risk protection. The Hillingdon Council Community Woodland Officers, highly visible in Park Wood, was also integral in reporting vandalism and in engagement with several members of the public known to tamper with the dams. Through the Woodland Rangers, it became known that some members of the public were dismantling dams because they believed diverting water was making footpaths and the woodland wetter. This emphasises the importance that future projects seeking to install NFM in public spaces need to ensure there is sufficient budget to fully engage and educate the users of the space so they understand the aims of NFM and project intentions.

Vandalism risk contributed to learning in dam construction. Dams built early in the project strived to maintain a fully natural appearance. However, attributes common to all dams vandalised later in the project included i) lack of wiring or angled posts to prevent removal of horizontal timbers and ii) no substantial posts on the downstream side. On small, ephemeral channels in public places, learning indicates that dams need to look formal and include anti-tamper measures Figure 24.

Figure 24: *Wiring as a measure to deter vandalism and timber removal of leaky dams.*

Catchment plan for ongoing maintenance of NFM assets

The following plan for ongoing management and maintenance of the leaky dams in Park Wood has been agreed with project partners:

Oversight of dams in Park Wood

- The current project steering group will be dissolved at the end of the project but the leaky dams in Park Wood will be a standing agenda item in meetings of the Park Wood and Pinn Meadows Project Steering Group (PWPM PSG). This includes the London Borough of Hillingdon and the NRFLAG and RWMAG groups, the EA and others. During these meetings a brief report on the condition of the dams could be made (possibly quarterly), work plans devised to rectify any issues, and new funding opportunities for further NFM work discussed. This will ensure that all the progress made within this NFM pilot and the work prior to the pilot continues to provide the same level of flood risk reduction in the future.

State of repair surveys

- A simple survey and report of the current state of repair of the structures is recommended quarterly (potentially with additional surveys associated with extreme weather forecasts). Surveys should be devised with input from those who will be undertaking the surveys (eg the NRFLAG) and the PWPM PSG. They should be sufficient to guide future maintenance and repair works without being too onerous on the surveyor. Reports should be sent to the Chair of the RWMAG or to a member of the NRFLAG who will create a schedule for the work required.
- The Slow Flow Capture app developed for use by the four NFM pilot projects is available for use for state of repair reporting and members of the public and those who have completed the NFM training courses will still be encouraged to use the app to report state of repair and dam effectiveness. It has been proposed that data pertinent to Park Wood be sent to the Chair of RAWMAG or a member of the NRFLAG.
- Several members of the community have recently come forward to volunteer time surveying and helping to build/repair structures. Future enquiries will be directed to the RWMAG and the woodland working group, led by the London Borough of Hilingdon's Woodland Officer.
- The QR codes will remain on the dams and, once scanned, will take users to a project summary and the EA PWPM website. Content can be updated to suit evolving needs post project and this could include reporting repair of dams.

Maintenance

- As stated above, the repair and maintenance work will be scheduled by the Chair of RWMAG on a quarterly basis. The Woodland Officer and woodland working group have offered to support delivery of maintenance works using volunteers who already assist with a range of tasks and activities within Park Wood. Any maintenance must be done with a Hillingdon Council employee to ensure the group is properly insured.

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 will take place in May 2021 and will be circulated to the steering group. Repeat surveys commissioned in future should pay special attention to habitat complexity in the surrounding areas to the dams 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.
- Other forms of NFM might - eg larger (taller, wider) dams or bunds in Park Wood.
- Anecdotally, restoring natural processes by installing leaky dams may increase catchment resilience and flood risk reduction by providing benefits such as reducing debris and sediment entering the culvert downstream of the park.
- A June 2016 type event (for which the dams are designed) has not been experienced during the lifetime of the project and no properties have flooded, so the NFM measures have yet to be 'tested' in similar conditions.
- Due to the ephemeral nature of channels, it is too early to quantify the impact of NFM assets on ecology (or hydrogeomorphology) - instead survey methodologies and monitored baselines have been established against which future surveys can compare.
- Vandalism is an issue in heavily used urban settings with 3 of the 4 NFM pilot projects delivered by Thames21 experiencing this issue. Another issue is public creation of informal dams that are not robust. Metal wires to secure timbers in place can be a deterrent. 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.
- Park Wood seems to have been more seriously impacted by public tampering with dams than the other sites (Bentley Priory, Trent Park and Bedfords Park) though all sites suffered from vandalism. This could be due to the unusual circumstances created by Covid restrictions and people staying local, but more data would be required to confirm this.

ii. Monitoring tools

- *Freestations*. Do not work in a Park Wood type situation (ie heavy tree cover, poor telemetry). Higher cost commercially available loggers (placed on the culvert) generated more reliable data and required less officer time to manage and maintain, so were likely more cost effective overall to the project than the low cost stations.

- *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. difficulties in areas with poor network reception or when capturing data during rain). Many volunteers preferred alternative means of data submission and created detailed reports, which places a huge burden upon them.
- *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 in Park Wood. The baseline understanding of flood mechanisms was not dependent on hydraulic modelling as there was a considerable body of evidence from local residents. The hydraulic model results corroborated those observations on the ground, which increased trust in the model.
- *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 of survey questions to be targeted more towards capturing changes associated with leaky dams.
- *Ecology surveys based on soil moisture* – the survey method using ground flora transects and average Ellenberg moisture values has been set up to monitor changes in soil moisture and ecological complexity over time as NFM assets become established. This approach may be of use for future monitoring of other NFM projects.

iii. Community engagement and partnership working

- Community engagement is key - considerable local knowledge and willingness to react to rainfall events to record the dams operating generated extraordinary detailed reports above and beyond what was expected of the residents or what could have been achieved using project officers. This contributed enormously to understanding flow routes and dam functioning/state of repair and represents significant in-kind contribution to the project.
- 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.
- £50 K is not sufficient for LLFAs and NGOs to commit sufficient officer time for wider engagement of the community (e.g. schools, the wider public users of the woods). Focus in this project was, by necessity, limited to supporting the steering group.
- There is a big interest in natural flood management both from local residents and the professional waterways management sector. However the interest is mainly in the building of dams rather than monitoring with the slow catcher app, likely because:
  i) unless you live locally, regularly use the woods or have a house at risk of flooding, there is not much in it for the volunteer;

2) ephemeral streams in summer and glitchy apps are not very exciting.
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, rather than the wider public. Monitoring of NFM may be better integrated with other volunteering programmes happening in the park, for example habitat management.

- Attendees of NFM training courses are more likely to go on to contribute citizen science monitoring data to the project if recruited locally rather than from elsewhere in London. This is because they are frequent users of the area and invested in flood risk mitigation, unlike volunteers from further afield.
- QR codes need to be placed on NFM assets as soon as possible to encourage wider public engagement with the project, sign up of local park users to training courses and submission of photos and standardized reporting.

iv. Other learning

- Permitting process from Natural England needs streamlining. It was slow and held up project progress on the ground.
- 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.
- Project duration not long enough to create relationships, install features and measure quantifiable outcomes
- Reporting in March during the peak of the wet season means loss of a season on which to report

6. APPENDIX

Appendix 1

Opportunity appraisal report produced by Hillingdon Council officers in July 2019 after project inception with collaboration of members of the project Steering Group. (Version 2 from November 2019)

Appendix 2

Vickers: 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

Vickers: Bryophytes of Park Wood March 2021

Appendix 3

SlowFlow app questions