Salmons Brook Natural Flood Management 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 Salmons Brook 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. It is one aspect of a much larger program of natural flood management and floodplain restoration (woodland planting and earth bund creation), the activities of which are also relevant for DEFRA's investigation into NFM. This report discusses key results and lessons learned from the installation and monitoring of 27 leaky dams in Trent Park, North London, but also aspects of the wider NFM. It evaluates the effectiveness of the NFM 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)..

In summary, modelling concluded that there was no impact of the leaky dams on flood risk reduction in terms of peak flow heights or timing. Other measures such as woodland planting and creation of bunds delivered far more impact with the combination of measures currently proposed (200 ha woodland planting, 75% channel width reduction and 46 bunds in the rural catchment) having potential to deliver at least 50% reduction in peak flow and 10-30cm reduction in peak water levels in the urban areas downstream in a 1:25 year return period event -increasing once the woodland matures. A further option for 415 ha of woodland, 90% channel width reduction and 46 bunds) was simulated and offered 65% reduction in peak flow and widespread reduction in peak water height of 30-50 cm in the urban catchment. However, significant inputs of water from the urban area dilute some of the effects of the NFM downstream.

Anecdotally leaky dams may be providing other benefits, such as flood risk reduction and water quality improvement by trapping sediment; and biodiversification 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.

Key lessons from partnership working include not to underestimate the amount of time and resource involved to build and maintain relationships with local stakeholders and volunteers. However, the local knowledge and willingness to facilitate the project by hosting sensors and equipment was invaluable. Successful engagement of the wider community in monitoring NFM was challenging due to teething issues with the reporting app and also the fact that, in dry weather, dams are not very exciting to record with no immediate results. Key volunteers are local people whose properties were at risk of flooding, giving them vested interest in supporting project activities. However, in this case there was a disconnect between the NFM measures in rural areas and the flood prone area downstream in the urban Enfield.

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

CONTENTS

1. INTRODUCTION

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

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

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

The Salmons Brook NFM pilot is one of four Community Scale NFM pilots awarded £50,000 and delivered by Thames21 and partners, 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 River Pinn Park Wood NFM Project (London Borough of Hillingdon), allowing comparisons to be drawn between projects.

This document, delivered in collaboration with the London Borough of Enfield, reports on the lessons learned from delivering the above objectives in the Salmons Brook catchment, a tributary of the River Lea located in the London Borough of Enfield north-west London. Activities carried out through this project are nested with a much wider programme of ongoing floodplain restoration and NFM works taking place within the borough, guided by Enfield's 2016 Local Flood risk Management Strategy. This identified a need for exploring NFM opportunities in the upper catchment to protect properties downstream from flooding, which are now being implemented in the Salmons Brook and Pymmes Brook catchments. This document therefore also serves as an interim report encompassing elements of the wider Salmons Brook scheme of relevance for DEFRA.

1.1 Salmons Brook and downstream flooding issues

The Salmons Brook is a tributary of the River Lea rising in Enfield Chase and flowing for 12.8 km to its confluence with the Pymmes Brook and subsequently the River Lea in Edmonton (Figure 1). The rural headwaters contain several tributaries flowing through arable, pasture and woodland area predominantly owned by Enfield Council, which makes this catchment particularly suitable for coordinated implementation of NFM. There are also several Sites of Importance for Nature Conservation (SINC), according to Enfield Council's core strategy, including Trent Park (320 ha), Plumridge, Vault Hill & Little Beechhill Woods.

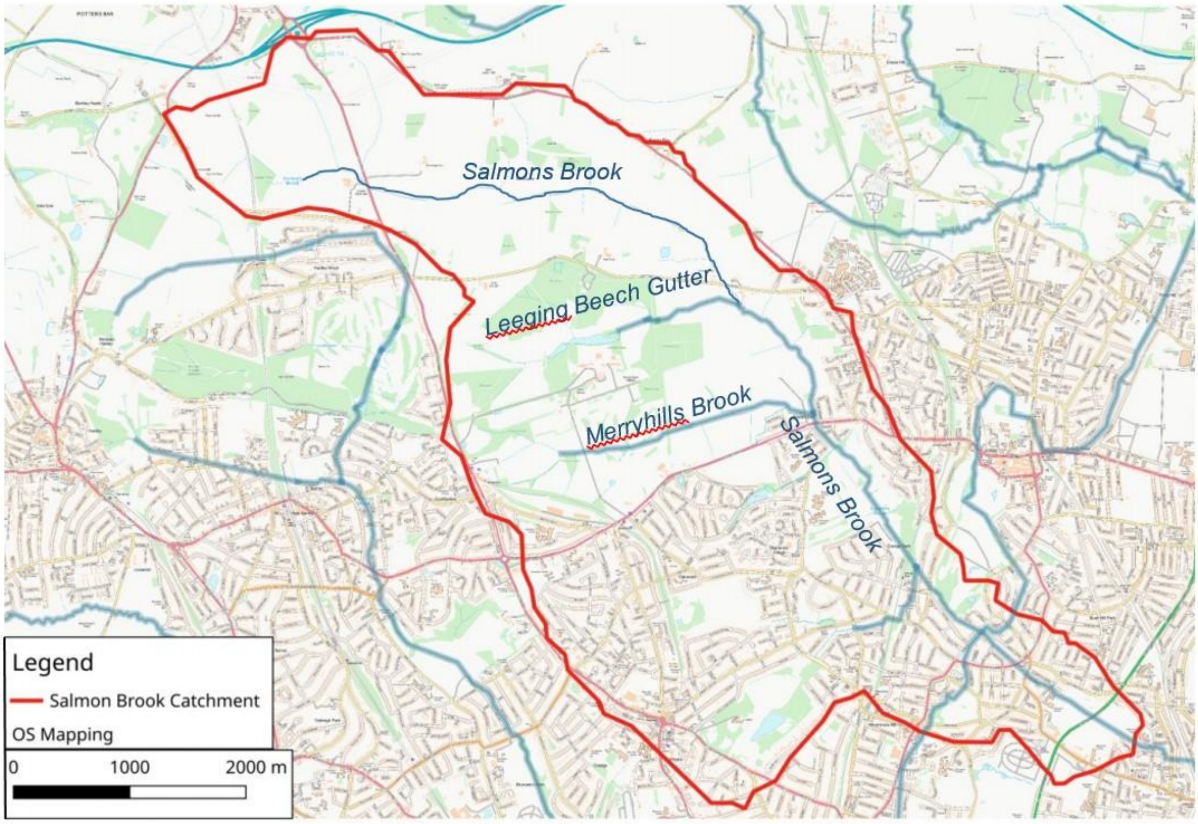

***Figure 1**: The Salmons Brook Catchment.*

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 in the urban zones during heavy rainfall.

Enfield's Local Flood Risk Management Strategy (published 2016) identified the need to explore opportunities for installing NFM in the rural headwaters to reduce flood risk in the downstream urban areas, in particular because opportunities to use traditional flood defences have been exhausted. Following flooding of several hundred properties in October 2000, the Salmons Brook Flood Alleviation Scheme (SBFAS) was delivered by the Environment Agency. Completed in early 2016, it reduced flood risk to 2000 properties in the Salmons

Brook catchment. However, due to technical and cost constraints, 20 properties in the Bush Hill area of Enfield (Figure 2) were excluded from the SBFAS and continue to have an annual risk of flooding of 5% (1:20). In addition, climate change impacts in the next decades are predicted to reduce the protection offered by the SBFAS. Exploration of opportunities for a wide range of NFM measures in the rural catchment could therefore mitigate existing flood risk and the impact of climate change.

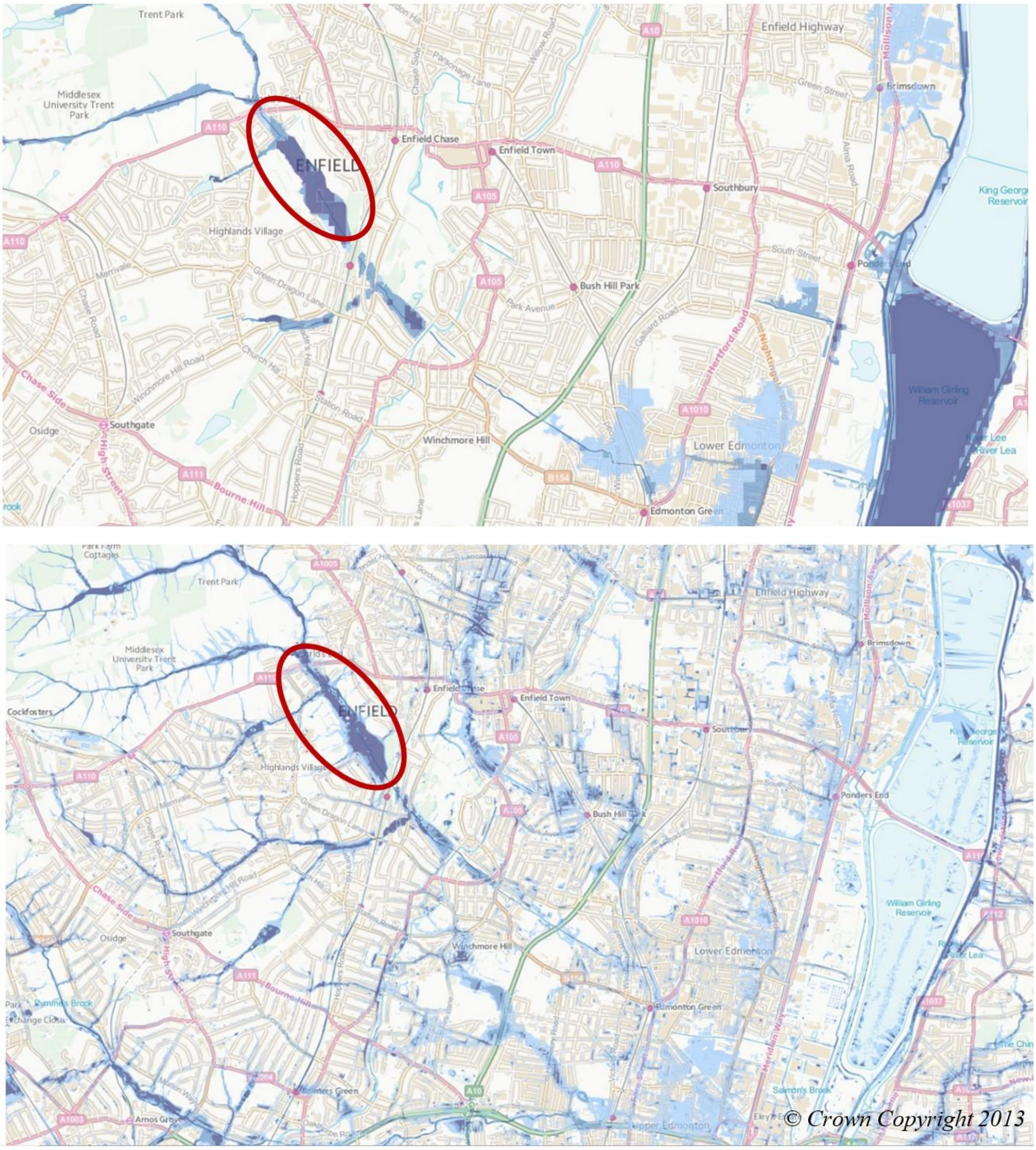

Figure 2*: Environment Agency Risk of Flooding from Surface Water Maps showing fluvial (top) and pluvial (bottom) flood risk for the downstream, urban Salmons Brook catchment in a 1:100 year event. The location of the 20 properties with an annual flood risk of 5% is indicated.*

The catchment has also been selected as a demonstration area for London by the Greater London Authority (GLA) who has identified this as one of the strategic priorities for interventions around the Lee Valley.

In view of these significant opportunities for flood risk mitigation, the DEFRA Community Natural Flood Management project pilot is just one aspect of NFM works simultaneously being delivered over 4 years in the rural headwaters of the Salmons Brook. An overall budget of £343,000 has been created with additional funding from the Thames Regional Flood and Coastal Committee (TRFCC), the Environment Agencies Water Environment Improvement Fund (WEIF), and Enfield Council, with funding from the Forestry Commission for tree planting. It will identify and deliver various NFM measures across the upper catchment as part of a wider vision for the rewilding of Enfield and renaturalisation of the rural floodplain. This includes flow interception and storage through earth bund and wetland creation, woodland planting and leaky dams (Figure 3).

This demonstrates how the initial £50K awarded by DEFRA helped gain additional funds. Since inception, additional contributions by the Greener City Fund and Heritage Lottery Fund (HLF) have expanded ambitions for rural SuDS and tree planting.

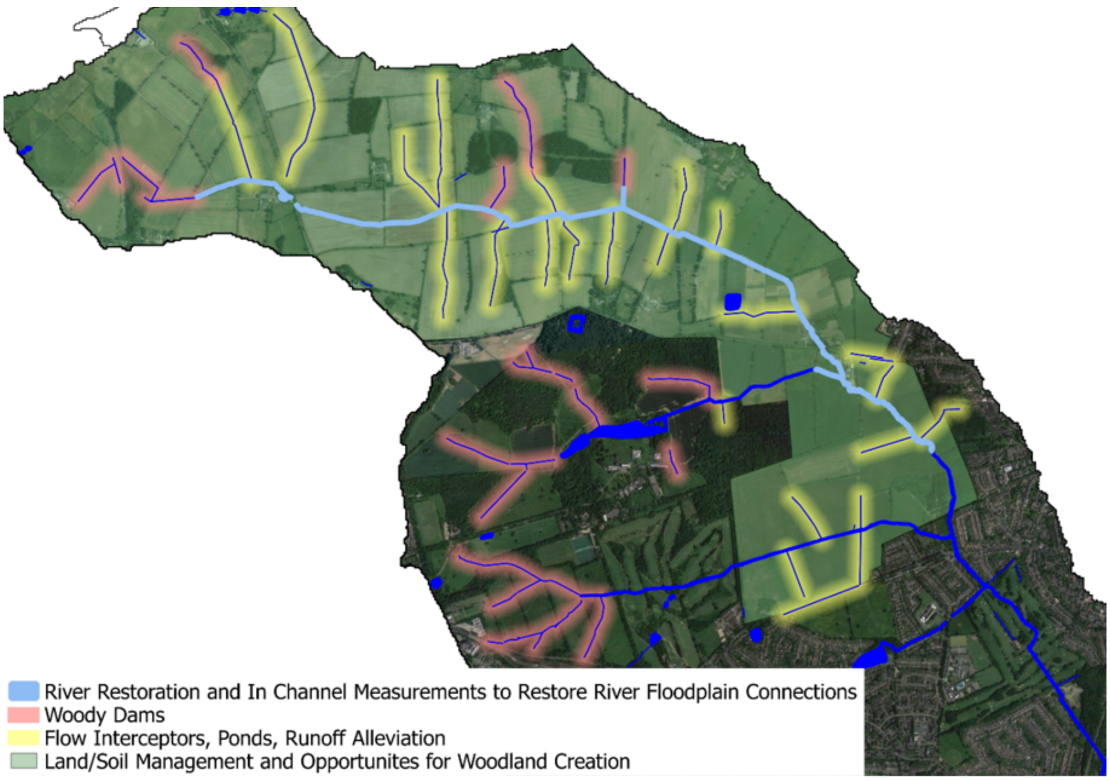

Figure 3*: The different NFM measures being considered in the Salmons Brook as part of a large-scale rewilding and flood risk mitigation programme in the catchment. The DEFRA pilot component comprised installation of leaky dams.*

1.2 Aims and Objectives

Activities undertaken to deliver DEFRA project objectives in the Salmons Brook catchment are outlined below and focus on delivery and monitoring of leaky dams in Trent Park. However, the simultaneous and complementary nature of the wider rewilding scheme underway in the Salmons Brook catchment (Figure 3) have also yielded insights which are relevant to inform the national debate around NFM so are included in this report.

- **Reducing flood risk to homes**

Flood risk reduction to 20 properties in the Bush Hill area of Enfield (plus extension of benefits of the SBFAS through increased resilience to the predicted impacts of climatic change) through installation of 26 leaky dams on small tributaries of the Merryhills Brook and Leeging Beech Gutter (Figure 1) in Trent Park. Dams were designed to allow low flows to continue unimpeded but to retain and spill high flows out of the streams for storage within the local area.

Also underway in the catchment as part of the wider scheme of works is the creation of 25 flood retention ponds (30-40 by March 2022) and the conversion of arable land and riparian borders into 60 hectares of new woodland, with a potential for a further 200 hectares in the near future.

- **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 channel and surround area; monitored through geomorphology (MoRPh) surveys.

Benefits for habitat complexity and biodiversity of wetland pond creation and through converting arable land into woodland as part of the wider project are best quantified once they have become established and are not assessed by this report.

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

i) Flood modelling to inform the national debate on flood risk through evaluation of the combined and individual contributions to flood risk reduction of the different NFM measures proposed for the catchment (woodland creation, earth bunds, wetland ponds, leaky dams). Modelling was originally intended as a PhD project hosted by Brunel University but lack of a suitable candidate meant that ultimately Edenvale Young Associates Ltd (www.edenvaleyoung.com), a civil engineering consultancy specialising in fluvial environments, carried out the work for three of the NFM pilots delivered by Thames21 and partners - the others being the Rise Park Stream NFM project (London Borough of Havering) and the Woodland and River Management in Two Headwater Streams Project (London Borough of Harrow). Modelling occurred in parallel to installation of the leaky dams installed as part of the DEFRA pilot but will guide selection and location of NFM proposed as part of ongoing works.

ii) Trial of 'Freestations' (http://www.freestation.org/), innovative, low-cost water level and soil moisture monitoring devices developed by Kings College London. These were installed along the main channel of the Salmons Brook to calibrate the hydrological model and establish hydrological and soil moisture baselines for the rural catchment as part of long term monitoring of rewilding and restoration activities.

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

i) 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 and other NFM installations.

ii) Through consulting and working with local stakeholders, park operatives, and farmers to collaboratively install and manage the NFM measures delivered in the catchment to ensure the long term effectiveness of measures implemented. This included creation of a Farmers Forum to disseminate project updates and address concerns.

iii) Regular dissemination of progress and results with wider interested groups including the Environment Agency and Thames Regional Flood and Coastal Committee (RFCC).

2. NFM EVIDENCE APPROACH AND METHODS

2.1 Selecting locations for NFM assets

Suitable sites (Figure 4) for 27 leaky dams were identified through consultation/catchment walkovers in conjunction with Enfield Council. For example, GoApe, who operate a centre within Trent Park lease land that the Merryhills Brook flows through, so they were concerned how NFM interventions may affect safety routes for their outdoor high rope centre. Although suitable locations were found on main rivers, several influencing factors - including EA consent applications - meant the dams were concentrated on ordinary watercourses. The significance of each ordinary watercourse was calculated depending on the area of the sub-catchment. This was achieved using open source DTM data from gov.uk to 50cm resolution. Through the use of GIS and r.watershed and r.water.extract GRASS tools sub-catchments and flow routes were delineated. Suitable locations were then ground truthed to ensure that any water spread out of the channel would not increase flood risk to property or infractruste and that suitable materials to build the dams were in close proximity. Due to time constraints, modelling of dams could only be undertaken retrospectively but will be used to inform future interventions.

Figure 4*: Locations of leaky dams (provisional and constructed) in Trent Park and the informal channel names used as identifiers by this report.*

2.2 Monitoring approaches used

Flood risk modelling

Hydraulic modelling was carried out in ESTRY-TUFLOW, a one and two-dimensional hydraulic model used for representing floodplain flow, incorporating the one dimensional model supplied by the Environment Agency. This model was developed by Halcrow Ltd in 2009 to delineate flood extent, flows and levels; updated in 2016 to incorporate flood alleviation schemes constructed in the catchment and was converted into ESTRY format to be compatible with TUFLOW.

Assumptions were made to approximate data gaps in the surface water drainage network of the catchment, supplied by Thames Water – for example concerning up and downstream inverts and pipe diameters. Publicly available terrain data, OS Mastermap data and Cranfield soils data were incorporated in the 2D component.

The modelling approach is discussed fully in Appendix 1 but, in brief, the model was calibrated by amending the Green Ampt model parameters until they matched the Flood Estimation Handbook (FEH) catchment descriptor SPRHOST (Standard Percentage Runoff

(SPR, %) of each Hydrology Of Soil Types (HOST) soil class). Hydrology (baseflow and rainfall hydrographs) were calculated based on standard FEH methods. Assumptions were made to approximate data gaps in the surface water drainage network of the catchment, supplied by Thames Water – for example concerning up and downstream inverts and pipe diameters. Baseflow was explicitly represented in conjunction with rainfall (15 minute totals) inflows for a fully distributed hydrological approach.

The model was calibrated to the October 2000 high flow event (approx 1 : 25 year return period, Figure 5) and verified for three additional flood events using EA hydrometric data from the Lower Edmonton flow gauging station within the catchment at Bush Hill (Clarendon Arch, 51.638706, -0.087644). The October 2000 event was also selected to test proposed NFM interventions. After calibration, the model was truncated at the Enfield flow gauging station (Figure 6) in order to focus on the catchment and flood risk area of interest whilst minimising model run times.

Time series available from FreeStations (described in more detail below) were too short to contribute to model calibration but were used to elucidate and compare with modelled behaviour of the upper catchment during scenarios modelling.

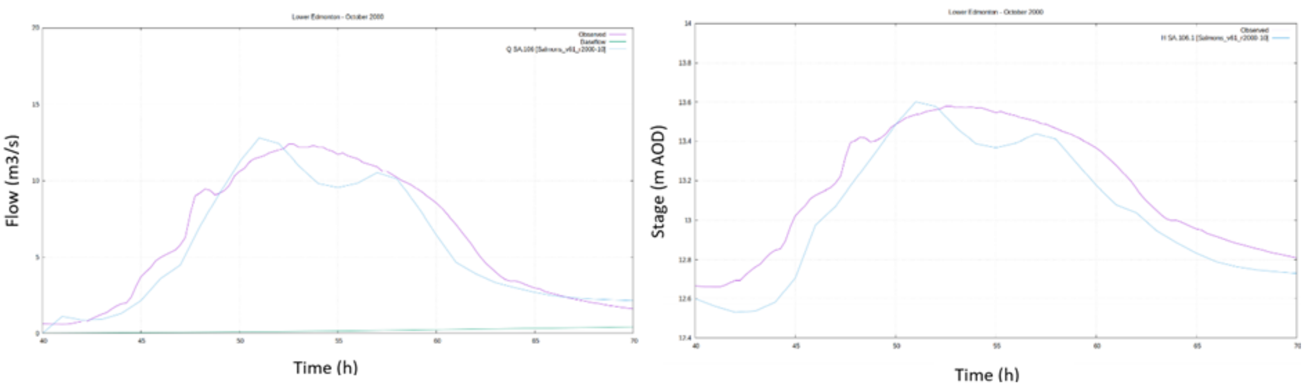

Figure 5: *Observed (purple line) and modelled (green line) flow and stage hydrographs at the Lower Edmonton gauge for the October 2000 (approx. 1 : 25 return period) event used in model calibration and to test NFM scenarios.*

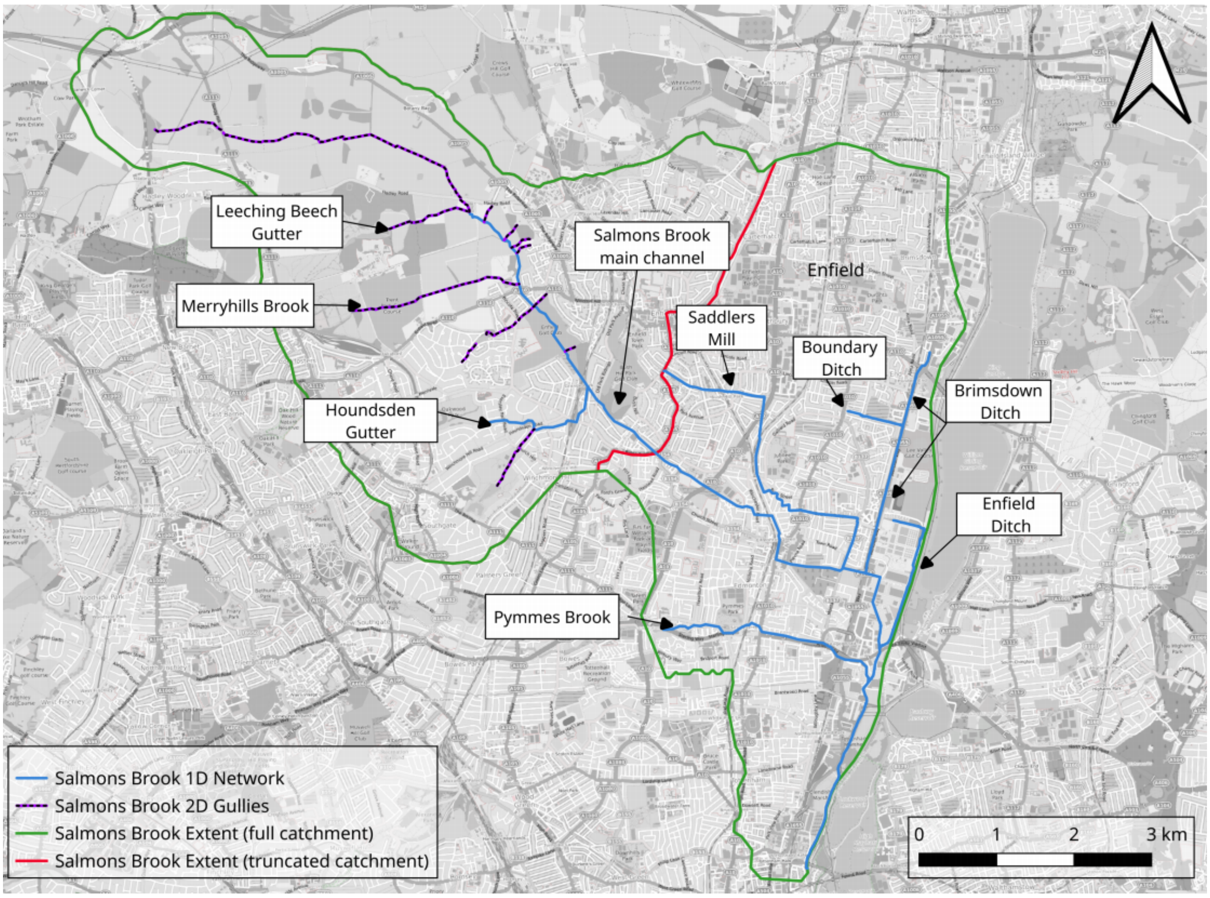

Figure 6: *Modelled Salmons Brook catchment naming the tributaries and indicating the 1D and 2D components. All to the left of the red line is the truncated model, all encompassed in the green line is the full modelled catchment.*

The NFM scenarios investigated were optimised where possible to demonstrate their effectiveness at flood risk reduction and tested for the October 2000 event (approx. 1 : 25 return period), 1 : 20, 1 : 100 return period events and incorporated climate change impacts by modelling 1 : 100 year return periods with 25%, 35% and 70% more rainfall. They comprise:

i) Leaky dams - The locations of 63 leaky dams (27 completed, 36 proposed) were passed to Edenvale Young along with photographs and 'as built' dimensions corresponding to those uploaded to the AGOL portal. Built information (height above bank, orifice height and width, 'leakiness' based on photographs) was used to approximate layered flow constriction values. Due to grid size, each dam was represented as 10 m wide. Leaky barriers not yet built were set to 0.3 m above bank top with an assumed blockage of 90% and a form loss coefficient of 1.8. Dams were represented by changing the Mannings roughness.

ii) Woodlands of various extents and maturity - proposed woodland of 200 ha, 415 ha and 639 ha distributed in the rural catchment. Soils of doubled hydraulic conductivity and a

Manning roughness of 0.1 were applied to represent woodland areas. A further scenario tripled the hydraulic conductivity of the soils to represent more mature woodland.

iii) The effectiveness of converting individual farms to woodland - separate scenarios for woodland planting at 6 local farms (Chase and Slopers Pond Farm, Plumridge Farm, Parkside Farm, Beech Barn Farm, Ferny Hill Farm, Botany Bay Farm).

iv) Permeable bunds (wetland ponds, 'rural SUDS') – The potential locations of 46 wetland ponds in and around fields and field boundaries in the rural catchment was optimised after initial simulations indicated they were not suitably located based on LiDAR and flow paths. They were implemented as horseshoe shaped bunds ~60 m long, 1 m high above local ground level fitted with a 10m long pipe of 150mm diameter, each inspected to ensure the invert height was realistic (ground elevation minus 500 mm). Water stored behind the bund (2D) flowed through the 1D pipe and re-surfaced in the 2D domain downstream of the bund. The height of some bunds was later raised to prevent overtopping.

v) Rural channel restoration by various amounts of channel pinching to reduce its capacity and encourage out of bank flooding to activate the floodplain. Two restoration scenarios applied flow constriction and storage reduction factors to the upstream river corridor of 75% and 0.25 then 90% and 0.25 respectively.

vi) Scenarios of combined NFM measures comprising:

vi.i - *Proposed NFM options*: 200ha woodlands (implemented as doubled hydraulic conductivity and Manning roughness of 0.1, as above) with proposed river restoration/channel width reduction (75% flow constriction and 0.25 storage reduction factor in the upper catchment) and 46 rural SUDS (permeable bunds).

vi.ii - *Proposed NFM options for maximum benefit*: 415 ha woodlands (implemented as above) with proposed river restoration/channel width reduction (90% flow constriction and 0.25 storage reduction factor in the upper catchment) and 46 rural SUDS (permeable bunds).

Each NFM option proposed by Thames21 has been investigated for the October 2000 flood event (1 : 25 year return period), while a combined NFM scenario was investigated for the 1: 20 year and 1: 100 year return period design events. Results are presented in the form of peak water level difference mapping and baseline vs proposed NFM hydrograph plots. Hydrograph plots were reported from two locations: i) downstream of the rural catchment and ii) at the downstream end of the truncated model at Clarendon Arch, Bush Hill, Figure 7.

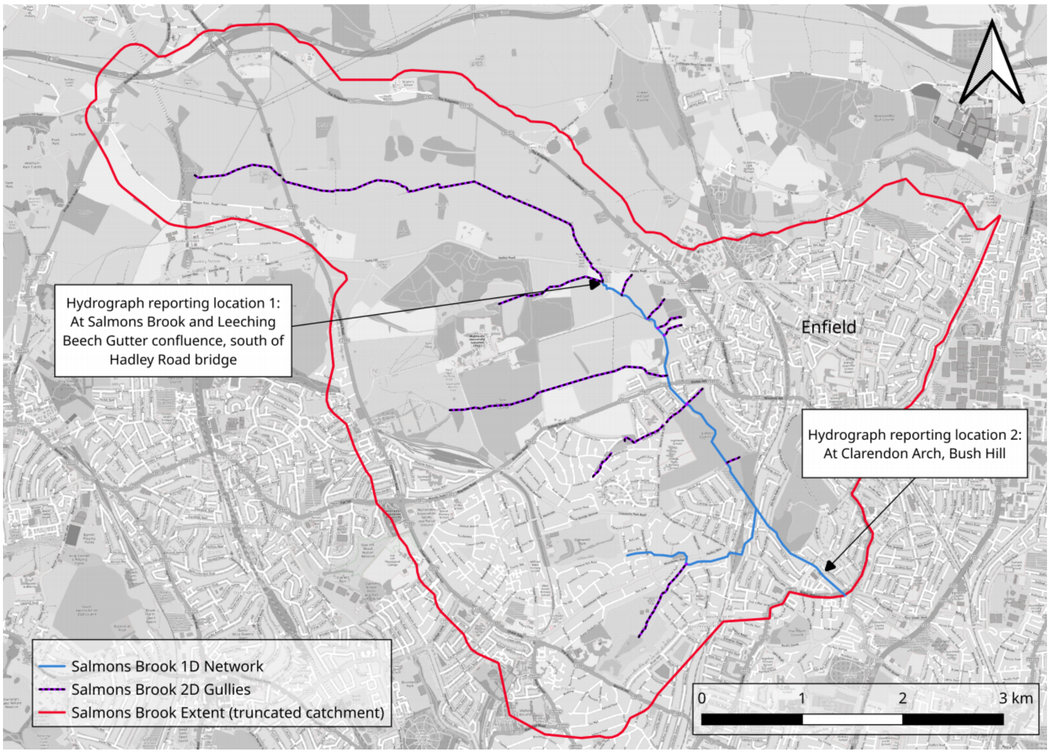

***Figure** 7: Hydrograph reporting locations in the truncated Salmons Brook catchment model*

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 and estimates of water storage volumes (m3), estimated from site visits. The width and height of the orifice in the dams was also recorded - although not a DEFRA requirement. These characterize the degree of dam 'leakiness' in permitting passage of normal flows so were useful for characterization of the dams for modelling purposes. It is therefore recommended these be captured in future.

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

Modular River Surveys

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

Table 1: *Summary indices derived from MoRPh surveys*

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

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

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

In Trent Park a baseline survey was carried out pre-installation of the dams or 'as built' shortly after dam construction in October 2020. The survey was repeated in February 2021, as late as possible before the reporting deadline, to maximise the time to observe changes.

Water level and soil moisture monitoring

In order to inform model calibration and establish baselines from which to evaluate the long term impact of the multiple NFM measures happening in the catchment, low-cost sensors (FreeStations) equipped with either water level or soil moisture sensors were installed and will remain permanently in place beyond the lifetime of the DEFRA project.

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.

Five FreeStations with water level sensors (based on parking sensor technology) were deployed along the main channel of the Salmons Brook in February 2020, Figure 8 to provide more detailed information about the timing and height of peak flows in the rural catchment, upstream of the Environment Agency gauging stations in the urban catchment. Sensors were deployed from bridges, trees or on posts mid channel, Figure 9, on a mix of private and public accessible locations.

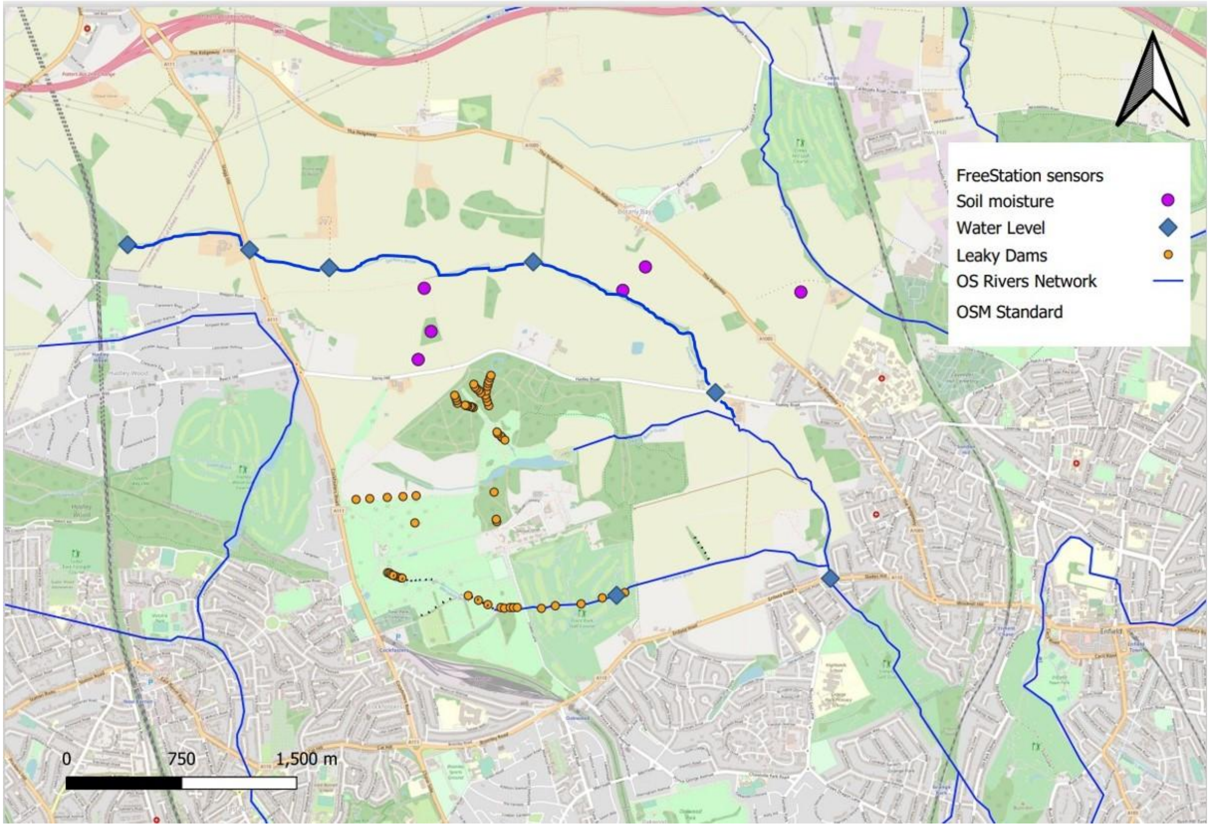

Figure 8*: Locations of FreeStations in the rural upper catchment of the Salmons Brook. diamond symbols indicate water level sensors, purple dots indicate soil moisture sensors, leaky dams (provisional and constructed) are indicated as orange dots..*

Figure 9*: FreeStations equipped with water level sensors deployed on the Salmons Brook main watercourse. Left: mid catchment on a bridge on private farmland, right: at the bottom of the rural catchment catchment on a road bridge.*

Soil moisture

Six FreeStations equipped with soil moisture probes (Figures 8 and 10) were deployed as a transect across the valley of the Salmons Brook in order to capture long term changes in relative water content of the soil associated with large-scale woodland creation in the same location.

Installation took place in August 2020, prior to the start of tree planting, at locations reflecting different current land uses and elevations comprising: arable set aside (top and bottom of the valley), established woodland, arable (wheat), grazing pasture (mid and low elevation). The calibrated SoilWatch10 sensors were buried at a consistent depth of 30 cm where they can remain for extended periods without impact on accuracy. Hourly data upload automatically to the FreeStation data platform.

Figure 10*:FreeStations equipped with soil moisture probes deployed as a transect across the Salmons Brook valley (Figure 8) in different current land use types. Left: set aside for woodland planting; middle: established woodland; right: arable farmland.*

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 .

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 in the Salmons Brook catchment and users of Trent Park, the purpose was to increase public understanding of flood risk in the area, NFM as a flood risk solution and to empower the local community to participate in monitoring and maintenance of leaky dams. To increase uptake, 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. A further training course was run to equip Enfield Council staff with the necessary skills to manage and maintain the dams beyond the current project

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

3. RESULTS AND EVALUATION OF THE NFM

3.1 Hydrological changes associated with the NFM assets

Leaky dams as part of the DEFRA funded project

The characteristics of the 27 leaky dams installed across ephemeral streams in Trent Park (Figure 4), are summarised in Table 2 and reported in full via the DEFRA pilot reporting portal (AGOL). Dams were constructed from timber harvested from the local woodland area (up to 15cm diameter) and comprised a mix of species - predominantly hornbeam and sycamore, but one constructed entirely of holly.

Table 2*: Summary of construction characteristics of leaky dams in Trent Park.*

Channel name	Mean height above channel bed (m)	Mean height above bank full (cm)	Mean timber length (m)	Mean timber width (cm)	Mean channel width (m)	Total no. dams
Obelisk left	1.01	1.3	2.64	9.0	0.81	8
Obelisk right	0.51	12.3	4.07	8.5	1.14	10
Go Ape	1.30	43.3	258.3	7.3	151.7	3
Obelisk lower	0.85	5.0	2.40	7.5	1.00	2
Overall	**0.92**	**15.5**	**2.92**	**8.1**	**1.12**	**26**

Channel names correspond to those in Figure 4.

Installation of woody debris dams across the channels slows the flow by temporarily storing water and increasing channel roughness. Additionally, many of the dams were designed to divert water out of the channel to infiltrate into the woodland floor, thereby reducing the volume of water in the channel. Examples of dams in Trent Park are shown in Figure 11. The increase in storage volume and area of channel roughness created are summarised in Table 3.

Figure 11: *Examples of leaky dams installed in Trent Park.*

Table 3: *Estimated hydrological characteristics of the leaky dams in Trent Park*

Channel name	Total storage volume (m3)	Mean channel roughness (m2)
Obelisk left	75	4112.8
Obelisk right	51	4438.2
Go Ape	30	5973.5
Obelisk lower	25	24121.3
Overall	**211**	**38645.8**

Channel names correspond to those in Figure 4.

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

Constructed wetland as part of the DEFRA funded project

Through the efforts of The Friends of Trent Park and existing environmental organisations such as Froglife, funding for ecology surveys, monitoring, and on the ground improvement works continue. By partnering with amphibian and reptile conservation charity Froglife, Thames21 and Enfield Council were able to match their current fundraising and contribute time in-kind towards construction quality designs, planting plans and planning application submissions. Three sites were chosen within the registered parks and gardens due to their connection with existing watercourses and proximity to other suitable habitat for declining toad species. Single applications were submitted to avoid one stalling progress of the others. The designs incorporated deeper areas and shelves as well as enough freeboard to accommodate ample flood water storage.

Despite the support from several teams within Enfield Council, Natural England, and the Friends of Group, due to the locations being within a historic environment, Historic England have strongly opposed the construction on the grounds that they are not in keeping with the designed landscape and will disrupt vistas. This resulted in the financial contribution from Froglife being redirected to another of their projects due to funders requirements and the money set aside from this project being redirected to rural SuDS in Enfield Chase. Additional money has since been sourced through other funding grants and pressure has been increased to gain final decisions from the Enfield planning department.

NFM measures as part of the wider scheme of works

NFM provides flood risk benefit by modifying the hydrological characteristics of the catchment, including storage, roughness and by increasing infiltration and evapotranspiration. Woodland planting contributes to slowing overland flow into watercourses by increasing catchment roughness, intercepting rainfall and increasing rates of evapotranspiration of water from soil and stored on the canopy. Tree planting also improves soil structure, therefore permeability, which increases infiltration rates.

To date 11of 25 of wetland ponds have been created to intercept and store water rilling off fields before it runs into water courses.

The total area of land over which NFM interventions from all works (leaky dams, woodland planting and pond creation) have increased storage volume and catchment roughness so there is less water running into water courses are summarised in Table 4.

***Table 4**: Storage and catchment roughness increases in the Salmons Brook catchment resulting from NFM installations through this and other projects to date.*

NFM intervention	Total storage volume (m3)	Area of increased roughness (m2)	Number
Woodland	-	101776.5	200 ha
Ponds	46000	-	46
Leaky dams	211	38645.8	26
Overall	**46211**	**140422.3**	

Leaky dam totals from Table 3.

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

Modelling evidence

Modelling tested the impact on flood risk of different NFM measures being installed in the Salmons Brook catchment as part of the DEFRA NFM pilot but also associated with the much wider scheme of NFM delivery works underway in Enfield borough. Conclusions from the latter are also of interest for informing the national debate about selection and effectiveness of NFM, so key results are incorporated into this report. Full discussion of modelling results can be found in the report produced by Edenvale Young (appendix 1)

Each NFM option was investigated for the October 2000 event (a 1 : 25 year return period event), whilst the two combined NFM scenarios were also investigated for the 1 : 20 year and 1 : 100 year return period design events.

i) The impact of leaky dams on reducing flood risk

There is no impact of the 63 leaky dams (26 completed, 36 proposed) in Trent Park on the hydrographs sampled at either the Hadley Road Bridge (Figure 12) or downstream at Bush Hill, Edmonton (Appendix 1). This means that, had the leaky dams been present during the October 2000 event, they would have had no impact on the timing or height of the flood peak and are therefore not effective as a means of reducing flood risk in this catchment.

Water level difference mapping indicates locations of storage and attenuation in the rural Merryhills Brook channel in the immediate vicinity of the dams, but no change in water levels in the downstream catchment and areas prone to flooding (Figure 13). Lack of impact on the hydrograph could be due to further inputs of water into the main channel of the Salmons Brook downstream of the dams in Trent Park but before the Bush Hill reporting location -notably from the Glenbrook and Houndsden Gutter. However, these results are consistent with the other NFM pilot projects which also reported minimal or no impact in the effectiveness of leaky dams on flood risk mitigation.

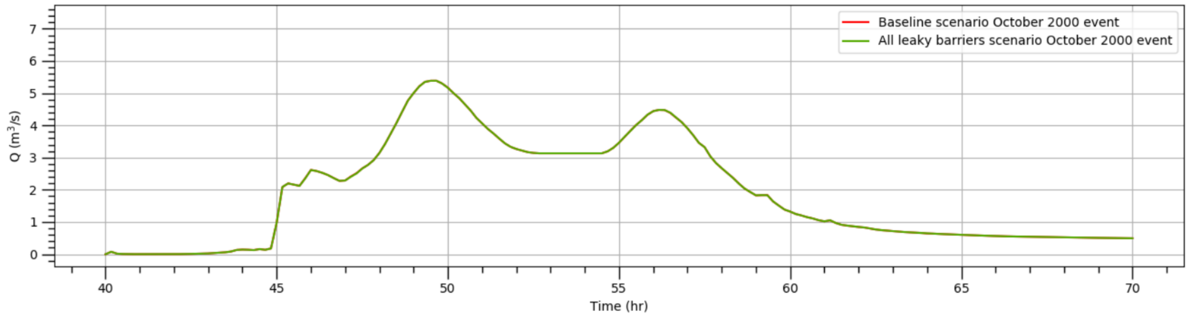

Figure 12: *Hydrograph at the Hadley Road Bridge (location 1, Figure 7) for the October 2000 1: 25 year return period event with (green) and without (red) all 63 leaky barriers (built and proposed) in Trent Park.*

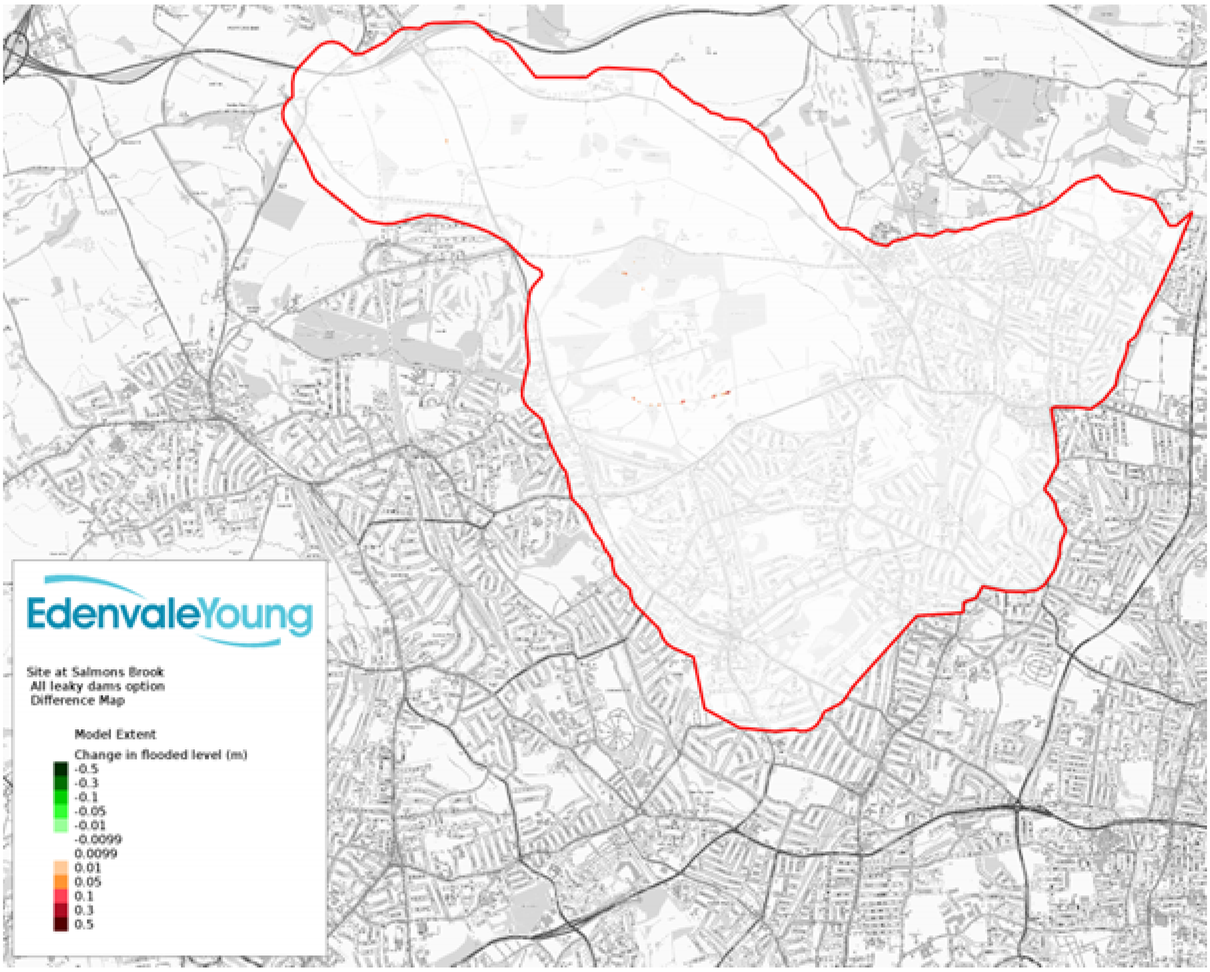

Figure 13: *Peak water level difference between the scenario with all leaky dams (completed and proposed) and the baseline scenario with no NFM interventions for the October 2000 1 : 25 year return period event.*

Although not contributing to flow attenuation at the catchment scale, the leaky dams are not impacting negatively on flood risk and may be delivering additional benefits not qualified by this project, such as sediment trapping, improving water quality and creating damp marginal areas for greater biodiversity. Sediment trapping may be mitigating flood risk by reducing the chance of sediment and woody debris blockages in culverts in the urban catchment, but further data would be required to support this.

A larger benefit arising from sediment trapping is likely to be improvements in water quality - although this was also not quantified. In particular, a problem pollutant that run off from agricultural fields is phosphate (a plant fertiliser that causes excessive plant growth and eutrophication in rivers) and this is known to bind to suspended sediment. Toxic metals from rural roads and the M25 may also be entering these water courses and are also associated with sediment. Trapping sediment therefore reduces pollution and turbidity of water, thereby improving water quality and benefiting aquatic life.

ii) The impact of woodland of various extents and maturity on reducing flood risk

Woodland extents of 200 ha, 415 ha and 639 ha, distributed in the rural catchment, were evaluated as both saplings in the herb layer and as mature woodland. Downstream of the woodland at Hadley Road Bridge, peak flow is reduced by 10%, 30% and 45% respectively , increasing to 20%, 50% and 70% respectively once the woodland matures (Figure 14). Hydrographs extracted at the most downstream end of the catchment at Clarendon Arch, Bush Hill (Figure 15) show reduced impact compared to the baseline (max 15% for the 639 ha mature woodland senario). This is due to inputs of water from the Houndsden Gutter and surface runoff from the urban catchment diluting the impacts of measures upstream.

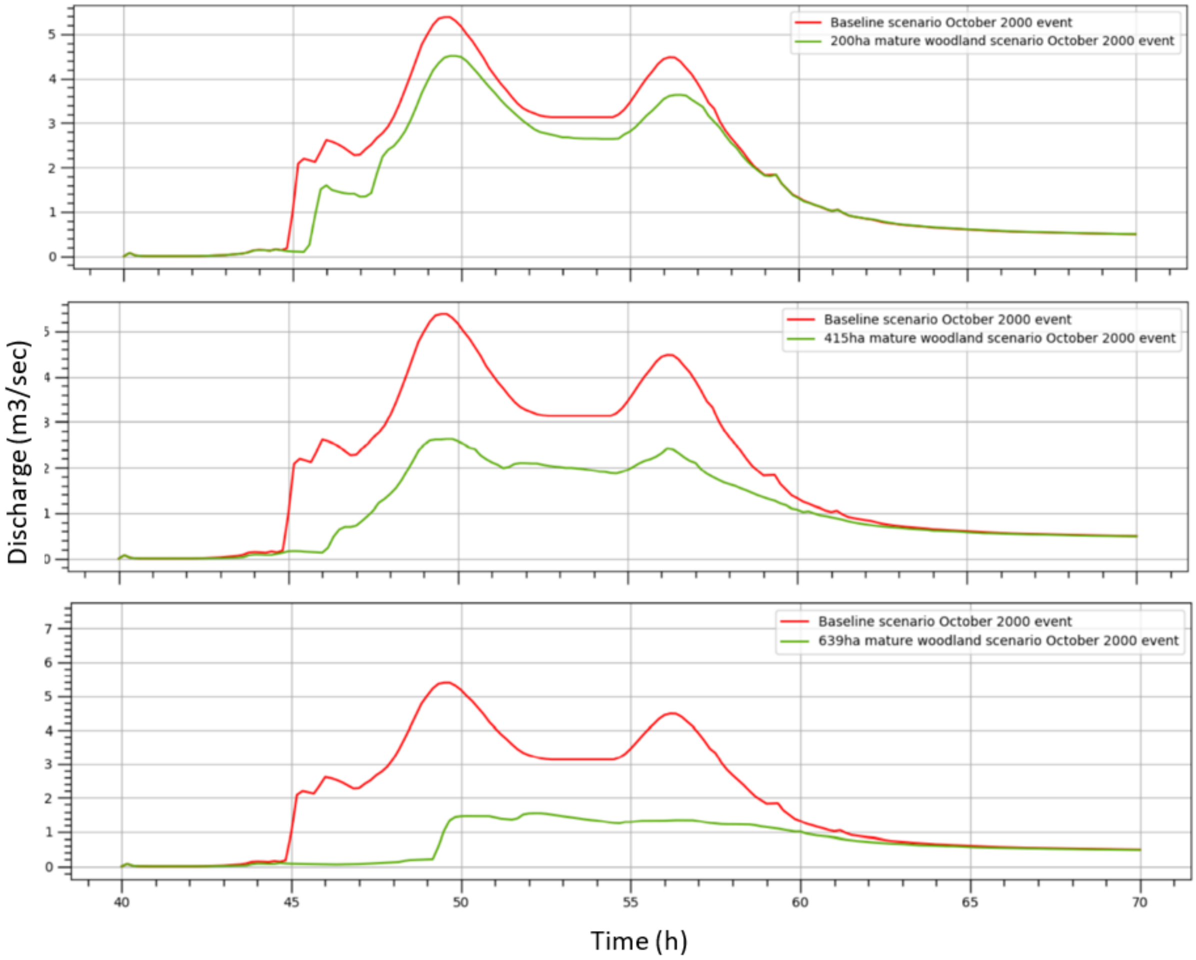

Figure 14: *Hydrographs of the impact of proposed mature woodland (green line) compared with the baseline scenario with no NFM (red line) for proposed mature woodland of 200ha (top), 415 ha (middle) and 639 ha (bottom) extent during the October 2000 event. Hydrographs sampled at the Salmons Brook and Leeching Beech Gutter confluence, south of Hadley Road Bridge (location 1, Figure 4).*

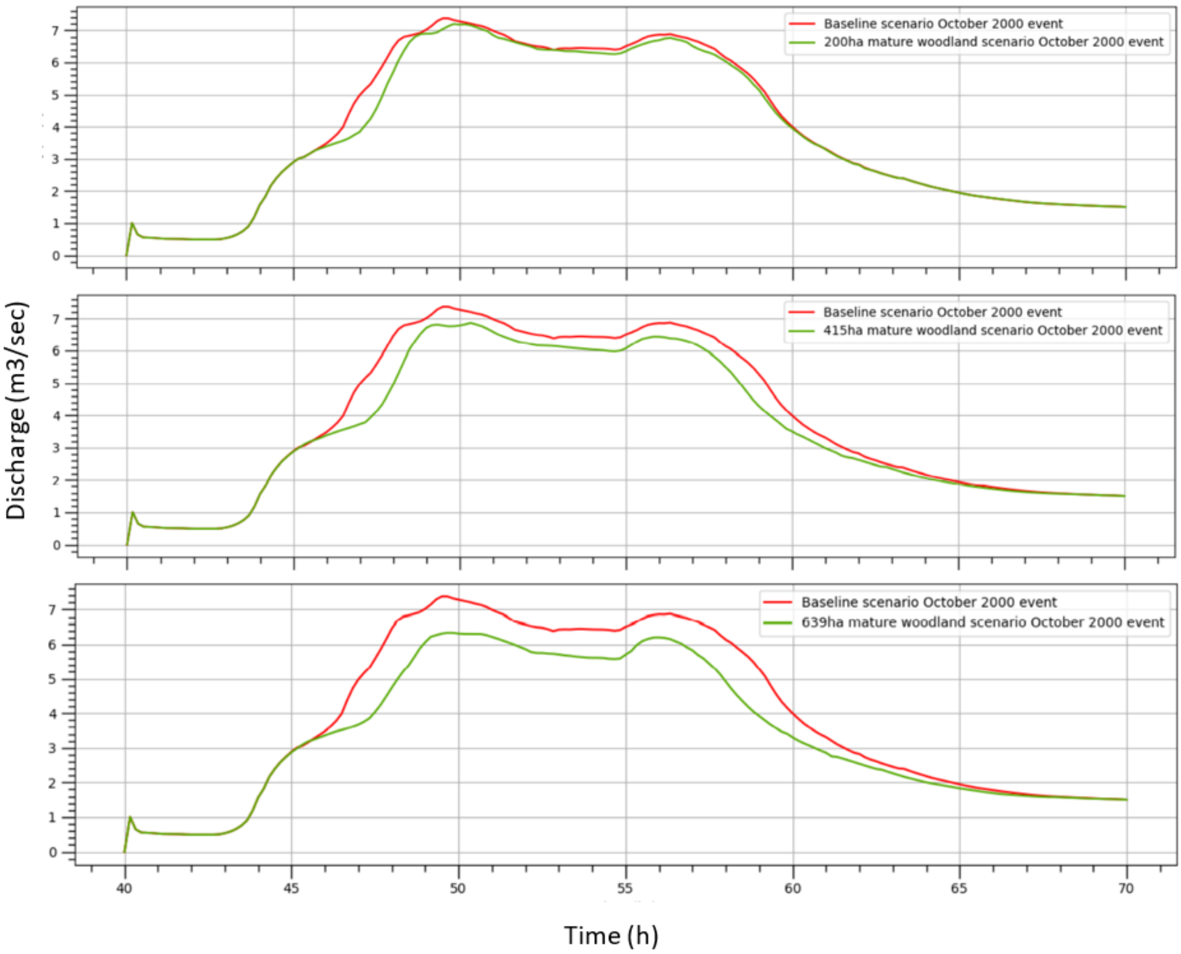

Figure 15: *Hydrographs of the impact of proposed mature woodland (green line) compared with the baseline scenario with no NFM (red line) for proposed mature woodland of 200ha (top), 415 ha (middle) and 639 ha (bottom) extent during the October 2000 event. Hydrographs sampled at the Clarendon Arch, Bush Hill (Figure 4).*

These reductions in peak flow correspond to peak water height differences of between 10 and 30 cm in the EA flood zones in the Bush Hill area of Enfield (Figures 16 - 18). Woodland planting therefore generates significant benefit to flood risk reduction through storage/attenuation/interception of overland flow resulting from rougher terrain and less saturated soils created by woodland. Hydrographs and peak water heights for the sapling scenarios are available in Appendix 1. However, note the small areas of disbenefit (deeper peak flood water levels)in the urban catchment in Figures 16 - 18. These may be spurious due to unknowns in water inputs and the surface water drainage network, but careful modelling of final wood planting locations will be required in order to fully investigate this.

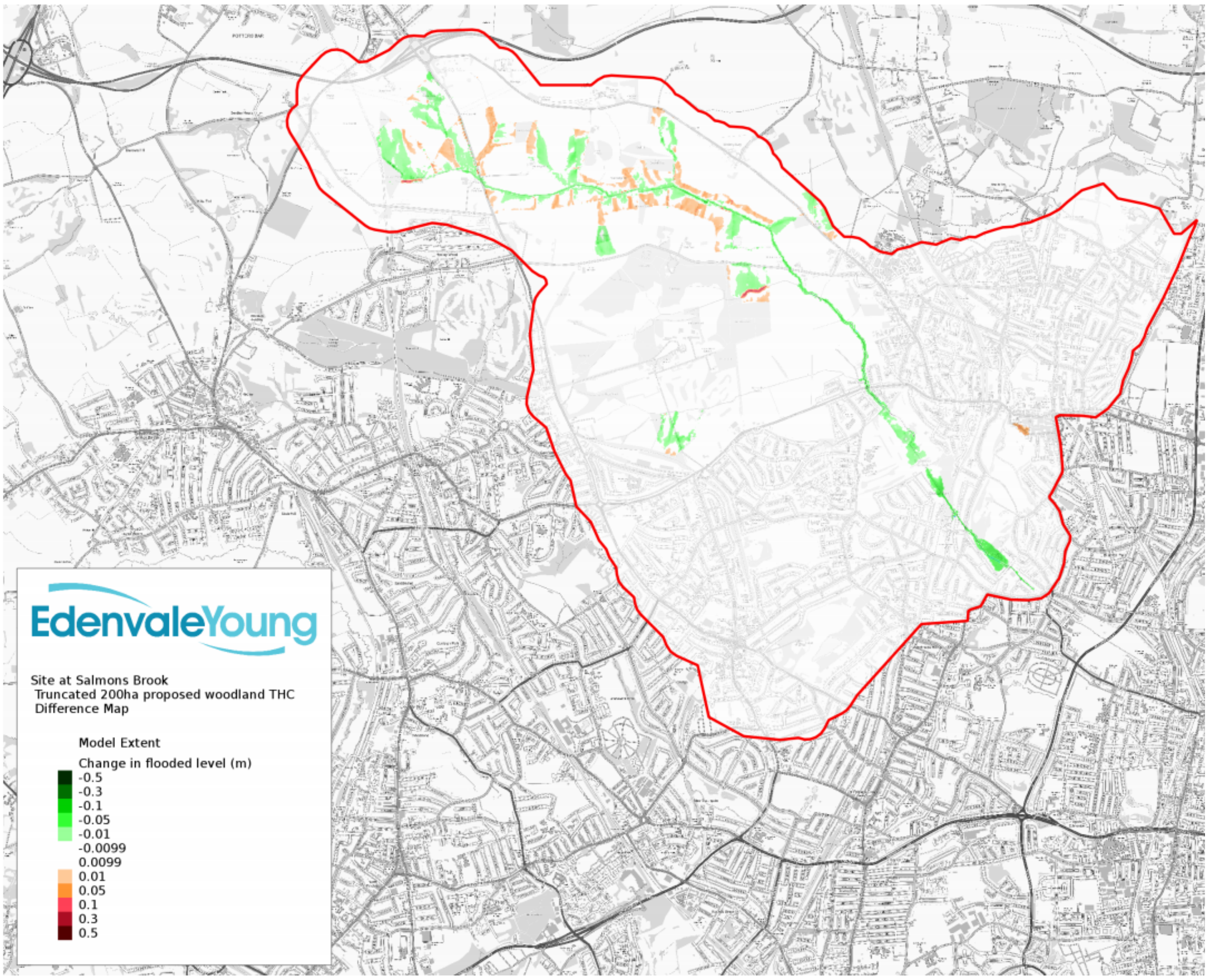

Figure 16: *Peak water level difference between the scenario with 200 ha of mature woodland and the baseline scenario with no NFM interventions for the October 2000 (approx. 1 : 25 return period) event.*

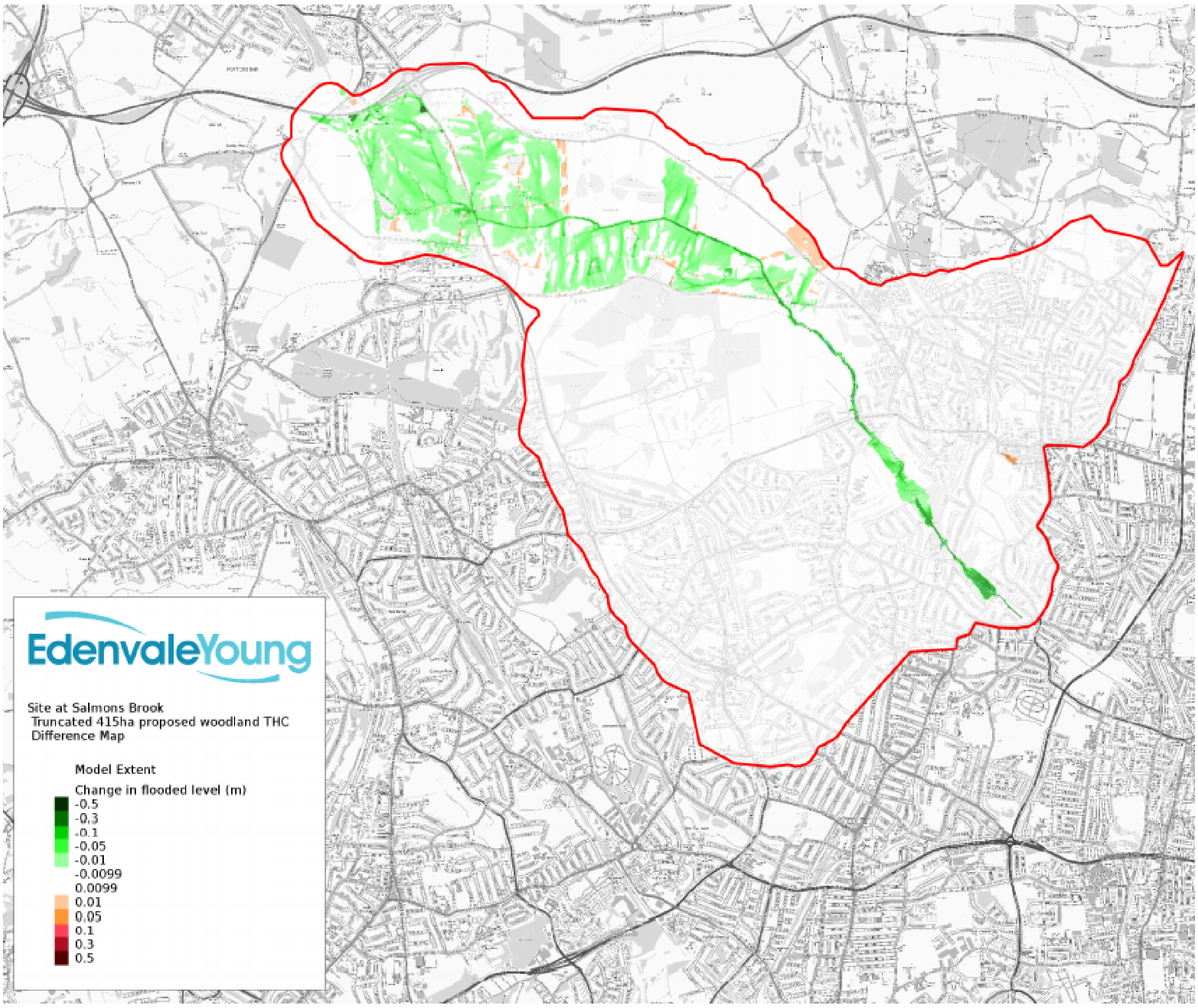

Figure 17: *Peak water level difference between the scenario with 415 ha of mature woodland and the baseline scenario with no NFM interventions for the October 2000 event.*

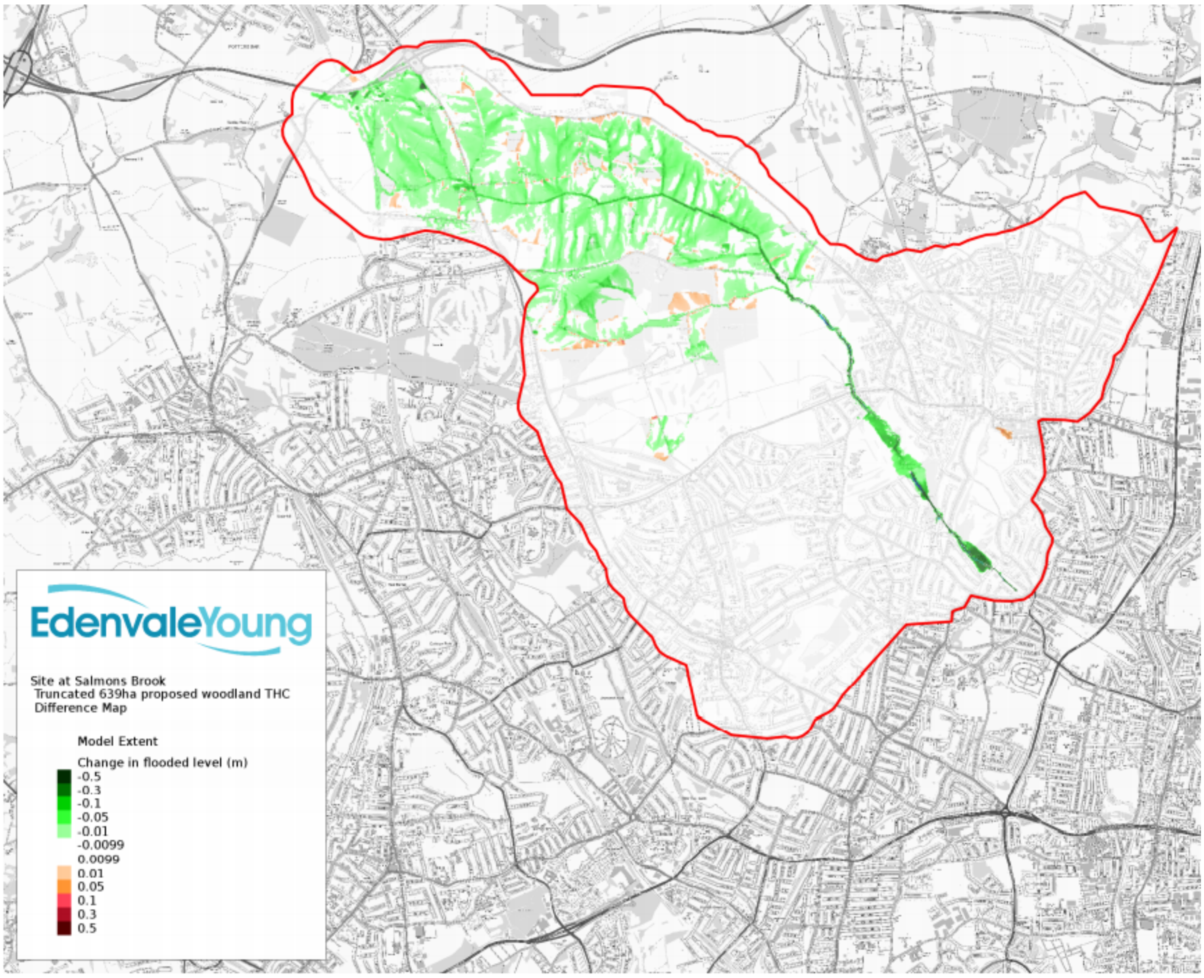

Figure 18: *Peak water level difference between the scenario with 639 ha of mature woodland and the baseline scenario with no NFM interventions for the October 2000 (approx. 1 : 25 return period) event.*

iii) The effectiveness of converting individual farms to woodland

In the tree planting scenarios above, locations of the woodland were selected at random within available rural areas, with woodland on higher ground generally having greater impact on overland flow reduction than riparian planting.To further refine understanding of where in the catchment woodland creation might be most beneficial from a flood risk reduction perspective, multiple proposed woodland scenarios were simulated.

Full results of sapling and mature woodland scenarios are found in Appendix 1 and key findings are summarised in Table 5. As can be seen, proposed woodland planting in Plumridge and Chase and Slopers Pond farms offer the highest reduction in peak flows of all the farms considered. There is no significant change to the timing of the flood peak for these farms (Figures 19 and 20) or any of those considered in Table 5. The impact of the NFM measures at the most downstream hydrograph reporting location (Clarendon Arch, location 2, Figure 4) are diluted by inputs into the main channel from tributaries and the surface water drainage network, also observed in the other NFM scenarios already discussed.

Table 5: *Peak flow reduction offered by proposed woodland planting scenarios on individual farms in the Salmons Brook catchment for the October 2000 (1 : 25 year return period) event.*

Farm name	Proposed woodland (ha)	Peak flow reduction (%)
Plumridge Farm	168	15
Chase and Slopers Pond Farm	119	10
Parkside Farm	128	8
Beech Barn Farm	85	6
Ferny Hill Farm	101	6
Botany Bay Farm	38	4

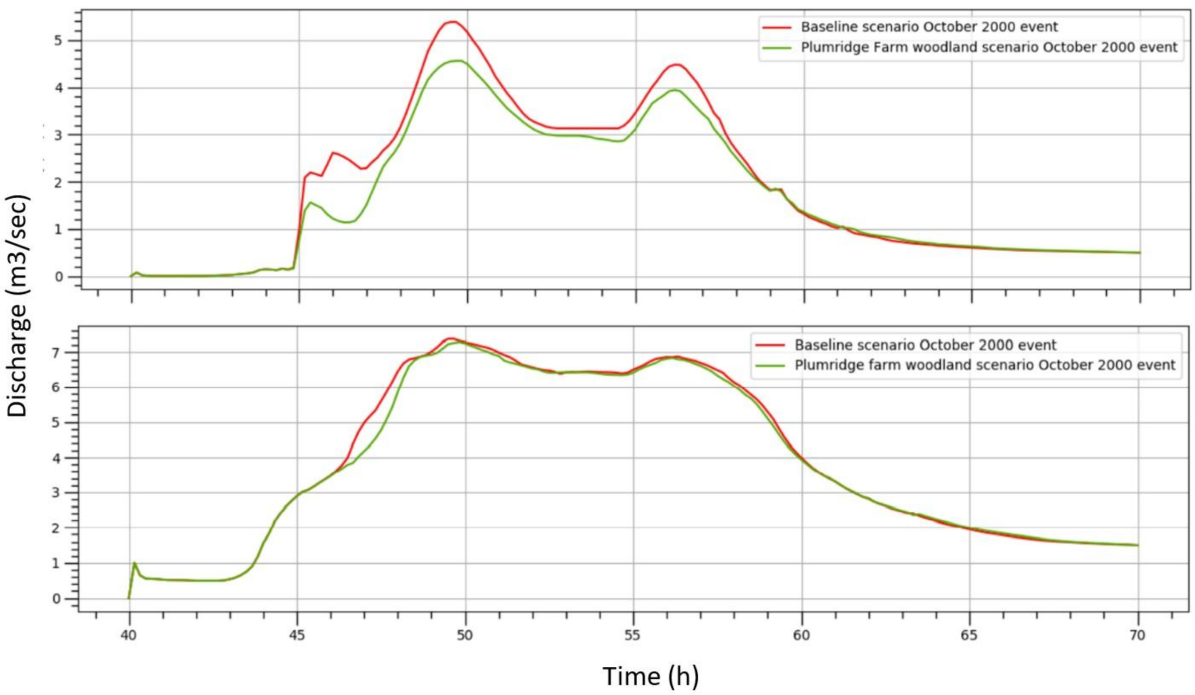

Figure 19: *The impact of proposed mature woodland 168ha at Plumridge Farm (green line) compared with the baseline scenario with no NFM (red line) during the October 2000 (1 : 25 year return period) event. Hydrographs sampled at the Hadley Road Bridge (top) and Clarendon Arch, Bush Hill (bottom) - locations Figure 4.*

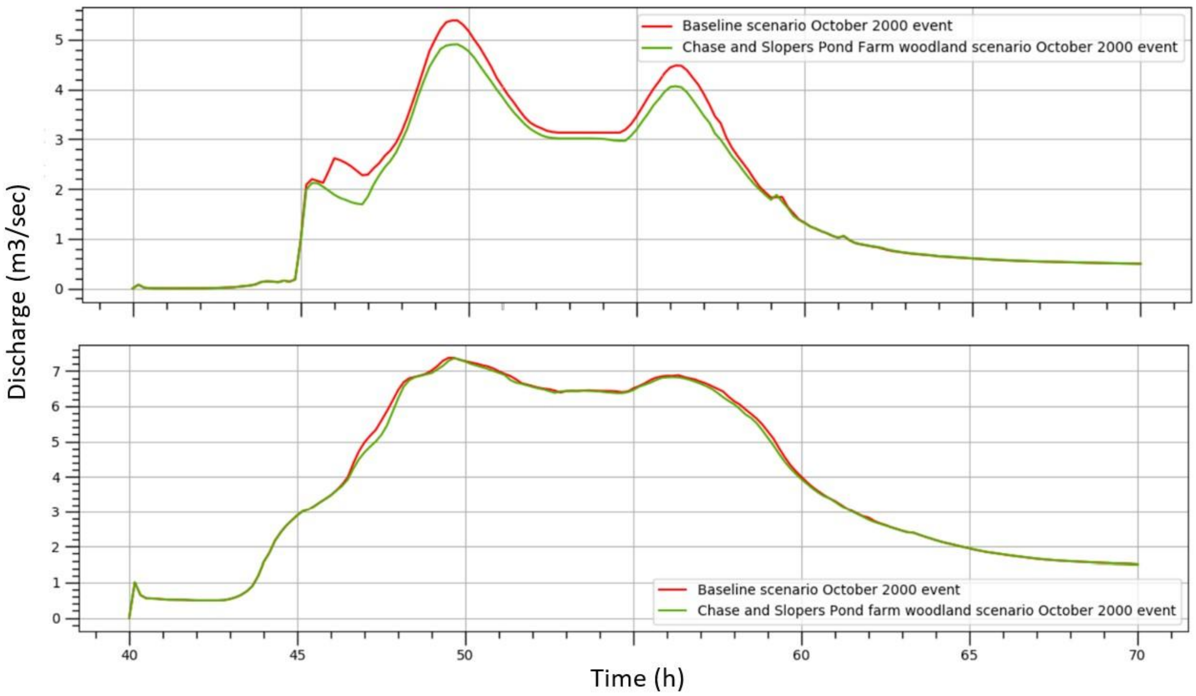

Figure 20: *The impact of proposed mature woodland 119ha at Chase and Slopers Pond Farm (green line) compared with the baseline scenario with no NFM (red line) during the October 2000 (1 : 25 year return period) event. Hydrographs sampled at the Hadley Road Bridge (top) and Clarendon Arch, Bush Hill (bottom) - locations Figure 7.*

These reductions in peak flow correspond to peak water height differences of up to 10 cm in the EA flood zones in the Bush Hill area of Enfield with no disbenefit detected in the urban area (Figures 21 and 22). Woodland planting therefore generates significant benefit to flood risk reduction through storage/attenuation/interception of overland flow in the rural catchment resulting from rougher terrain and less saturated soils created by woodland.

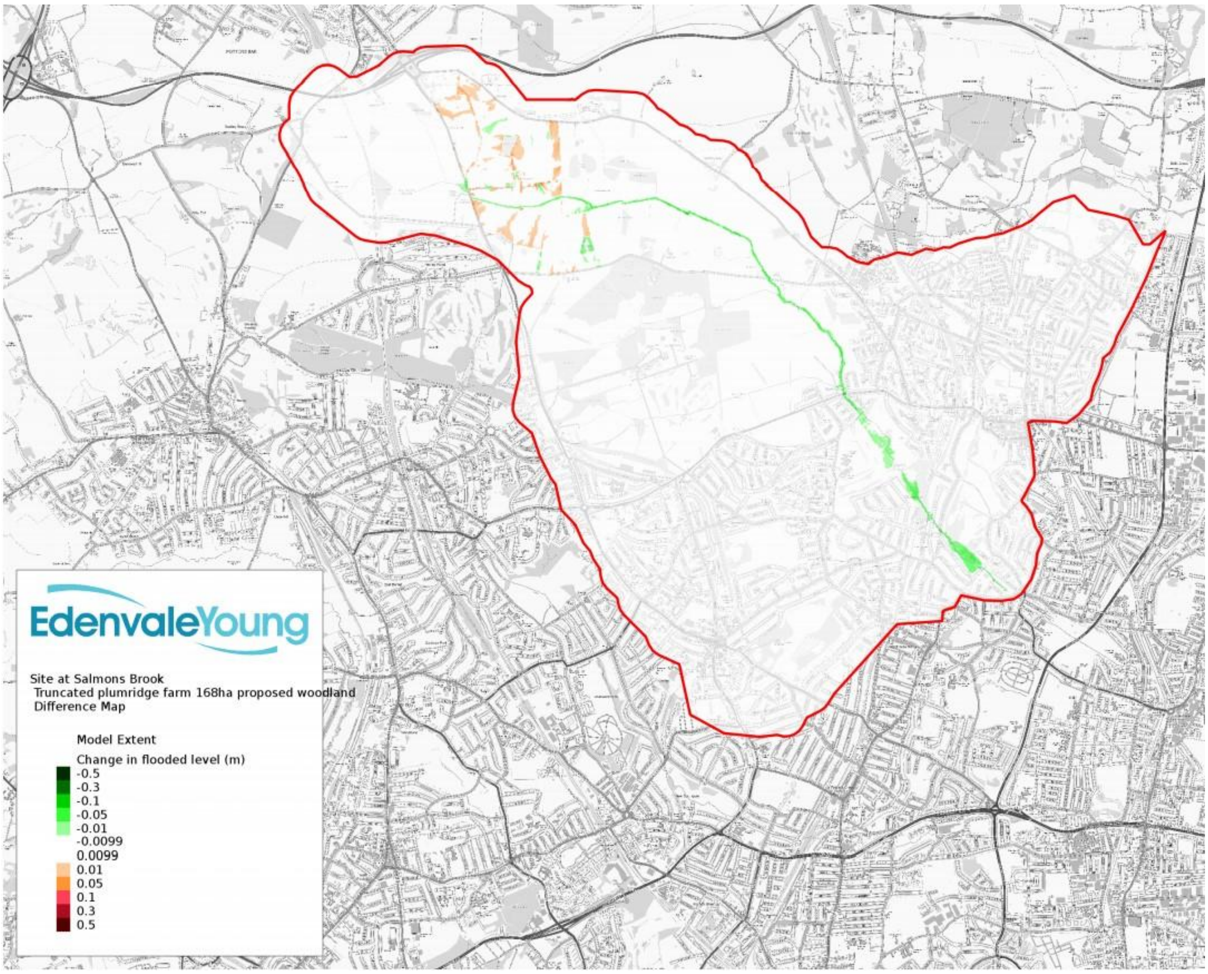

Figure 21: *Peak water level difference between the scenario of 168 ha of mature woodland at Plumridge Farm and the baseline scenario with no NFM interventions for the October 2000 (approx. 1 : 25 return period) event.*

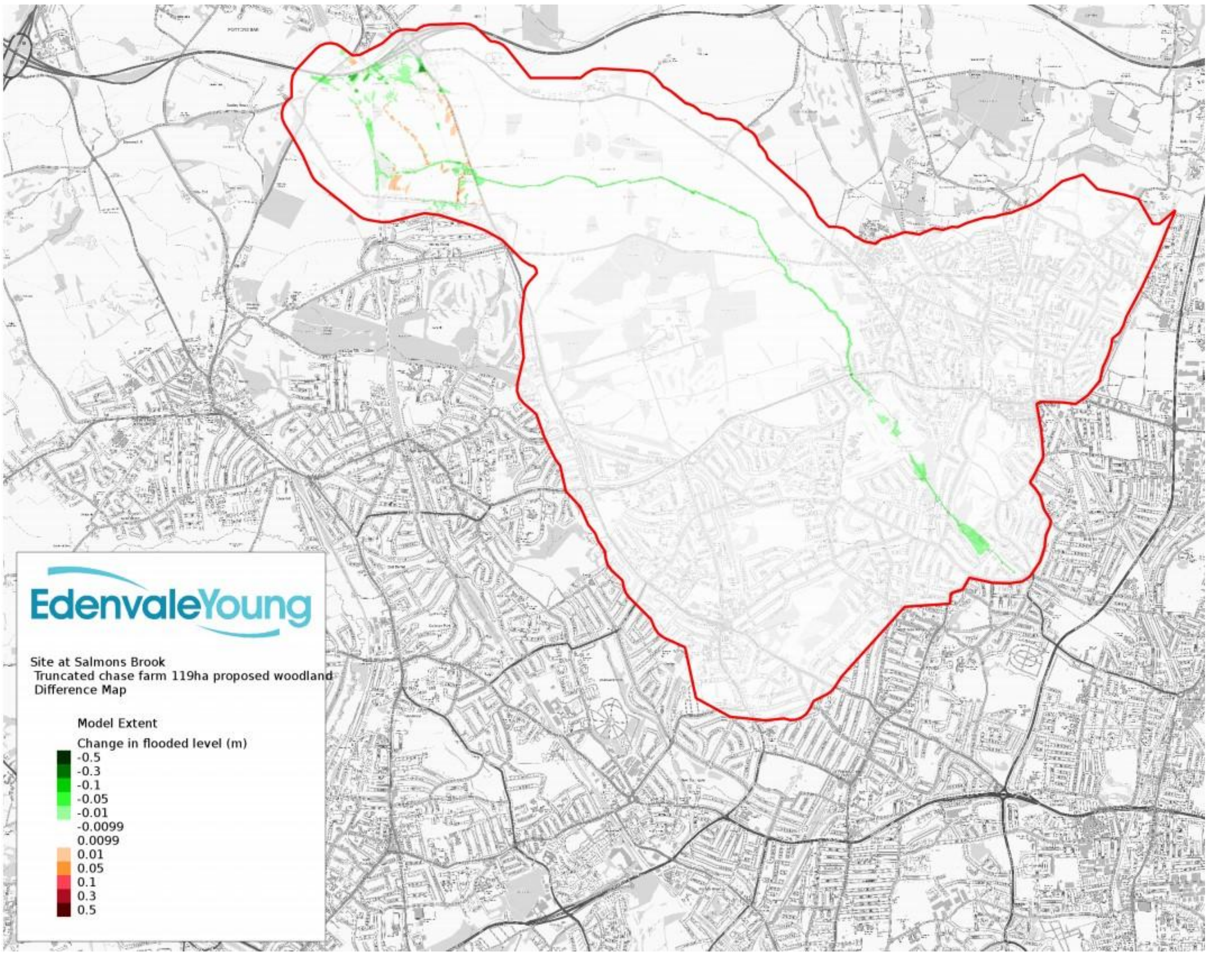

Figure 22: *Peak water level difference between the scenario of 119 ha of mature woodland at Chase Farm and Slopers Pond Farm and the baseline scenario with no NFM interventions for the October 2000 (approx. 1 : 25 return period) event.*

iv) The impact of permeable bunds (wetland ponds, 'rural SUDS') on reducing flood risk

The advantage of permeable bunds over leaky dams is their larger storage area. They can be engineered to store water at the required volume at the correct time, where as leaky dams continue to permit passage of water during all stages of the hydrograph. Results indicate that, had the 46 proposed permeable bunds (wetland ponds) been present during the October 2000 event, they would have reduced peak flow by up to 35% at the Hadley Road Bridge (Figure 23). Impact is reduced to 5% downstream in the urban catchment at the Clarendon Arch due to inflows from other tributaries and runoff from urban areas diluting the effects of measures in the rural catchment upstream.

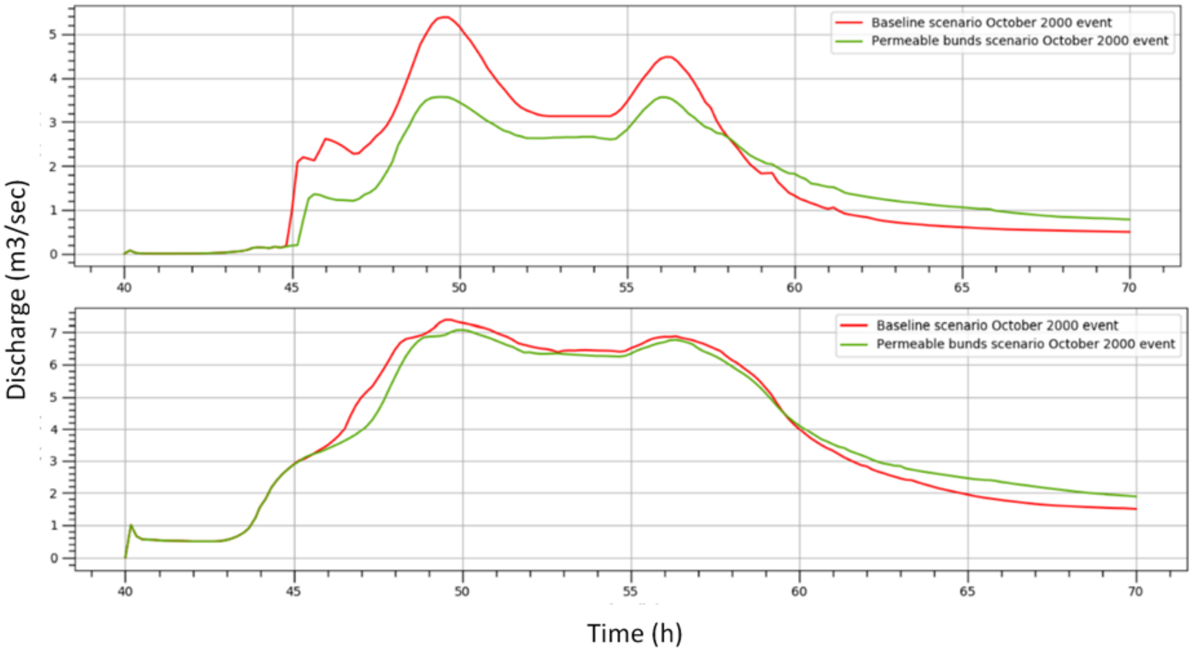

Figure 23*: Hydrograph at the Hadley Road Bridge (top) and Clarendon Arch (bottom) for the October 2000 (approx. 1 : 25 return period) event with (green) and without (red) 46 permeable bunds (wetland ponds) proposed in the rural catchment (see Figure 4 for hydrograph sampling locations).*

Peak water level difference mapping indicates distinct locations of storage and attenuation dispersed around significant flow routes in the rural catchment associated with the bunds and additionally downstream in urban Bush Hill, within the EA flood zones, where there is a 10 cm reduction in peak flooded level (Figure 24). The permeable bunds therefore have a positive impact on flood risk reduction in the catchment, unlike the leaky dams.

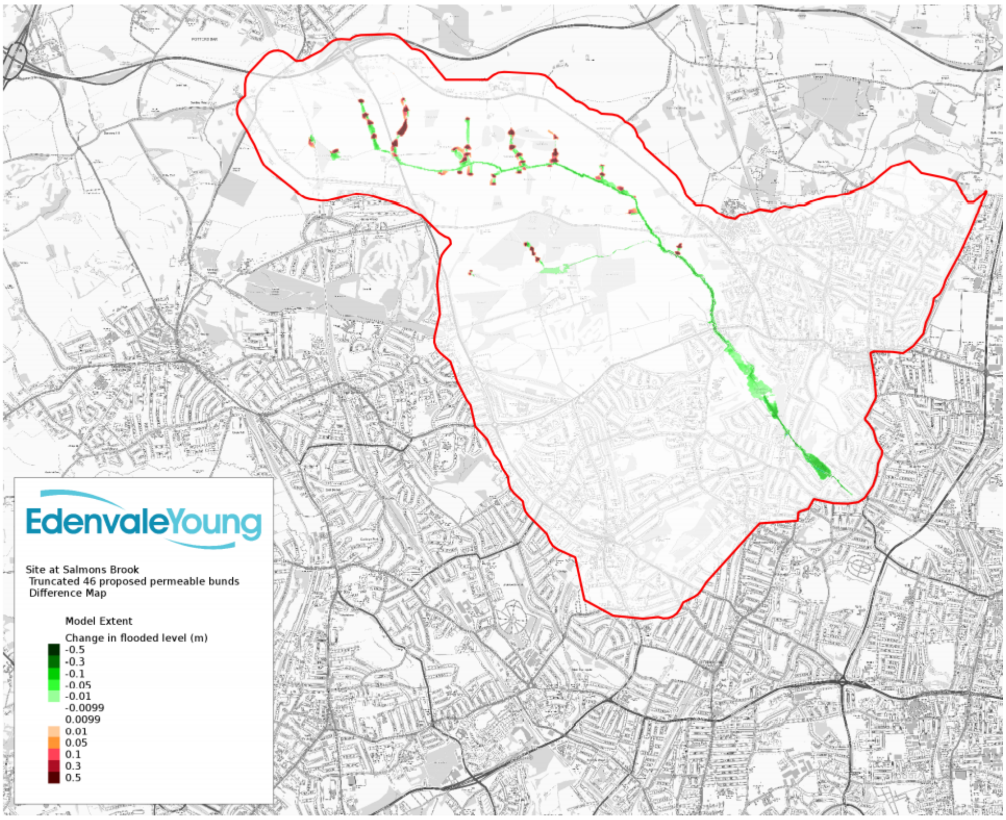

Figure 24: *Peak water level difference between the scenario with 46 proposed permeable bunds (wetland ponds) and the baseline scenario with no NFM interventions for the October 2000 (1 : 25 year return period) event.*

v) Effectiveness of rural channel restoration on downstream flood risk

Even in high flow events, the Salmons Brook in the rural catchment tends to stay largely in-channel. The scenarios in this section considered channel pinching by either a 75% or 90% width reduction to activate the rural floodplain as a mechanism for flood prevention in the urban catchment downstream. The result is reduction in the peak flow hydrograph by 15% under the 75% rural channel width reduction scenario and 23% under the 90% rural channel width reduction scenario, coupled with delay in the timing of the peak by up approx. 2 hours at the upstream sampling location of Hadley Road bridge (Figures 25 and 26). Peak flow reduction between the proposed and baseline scenarios dropped to 5% at the Clarendon Arch, Bush Hill due to the diluting influence of the intervening catchment, discussed above.

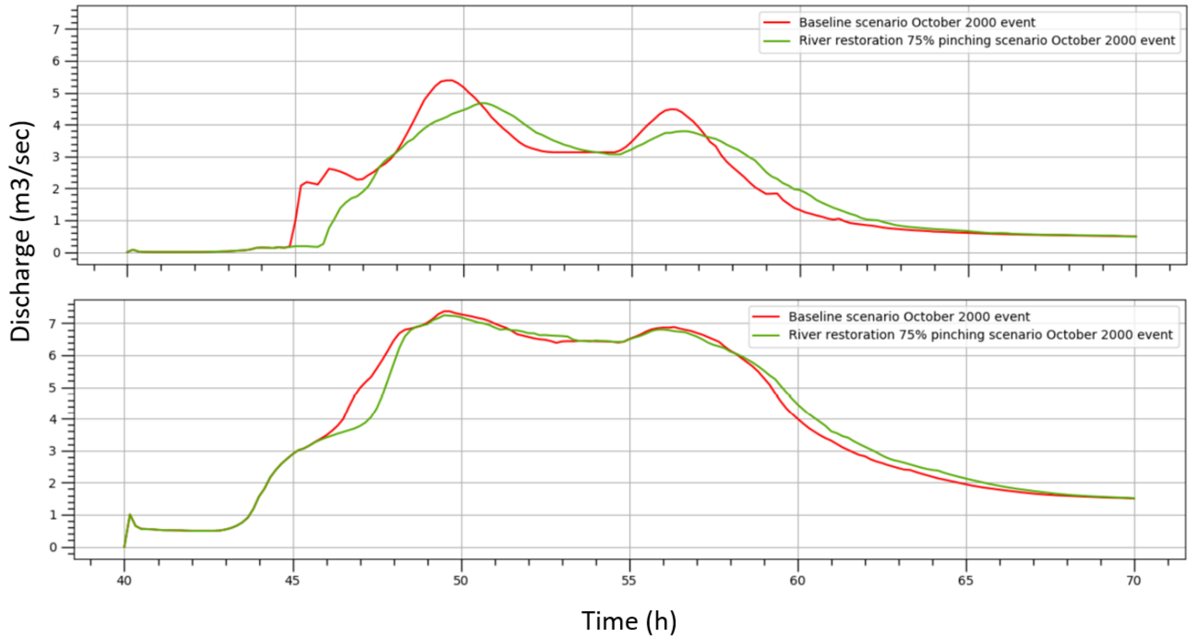

***Figure 25*: *Hydrograph at the Hadley Road Bridge (top) and Clarendon Arch (bottom) for the October 2000* (approx. 1 : 25 return period) *event with (green) and without (red) channel pinching of 75% proposed in the rural catchment (see Figure 4 for hydrograph sampling locations).*

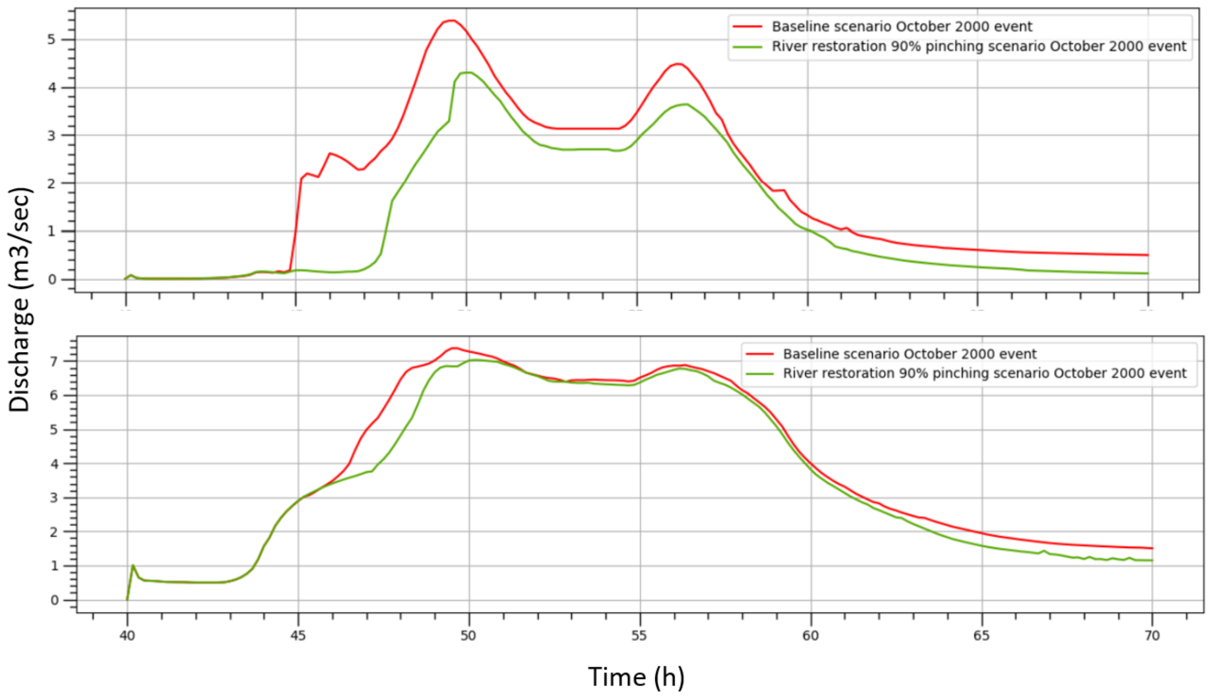

***Figure 26*: *Hydrograph at the Hadley Road Bridge (top) and Clarendon Arch (bottom) for the October 2000 event with (green) and without (red) channel pinching of 90% proposed in the rural catchment (see Figure 4 for hydrograph sampling locations).*

Water level difference mapping indicates these scenarios deliver between 10mm and 50mm reduction in peak flood level heights at properties at Bush Hill within the EA flood zones (Figures 27 and 28). In addition, there is clear attenuation of flows in the rural channel along the reach with reduced channel width. As discussed previously, the small zone of increased water level in the urban catchment resulting from this scenario may be spurious and caused by uncertainties in the surface drainage network. Further modelling and refining of this scenario is required to ensure there is no disbenefit.

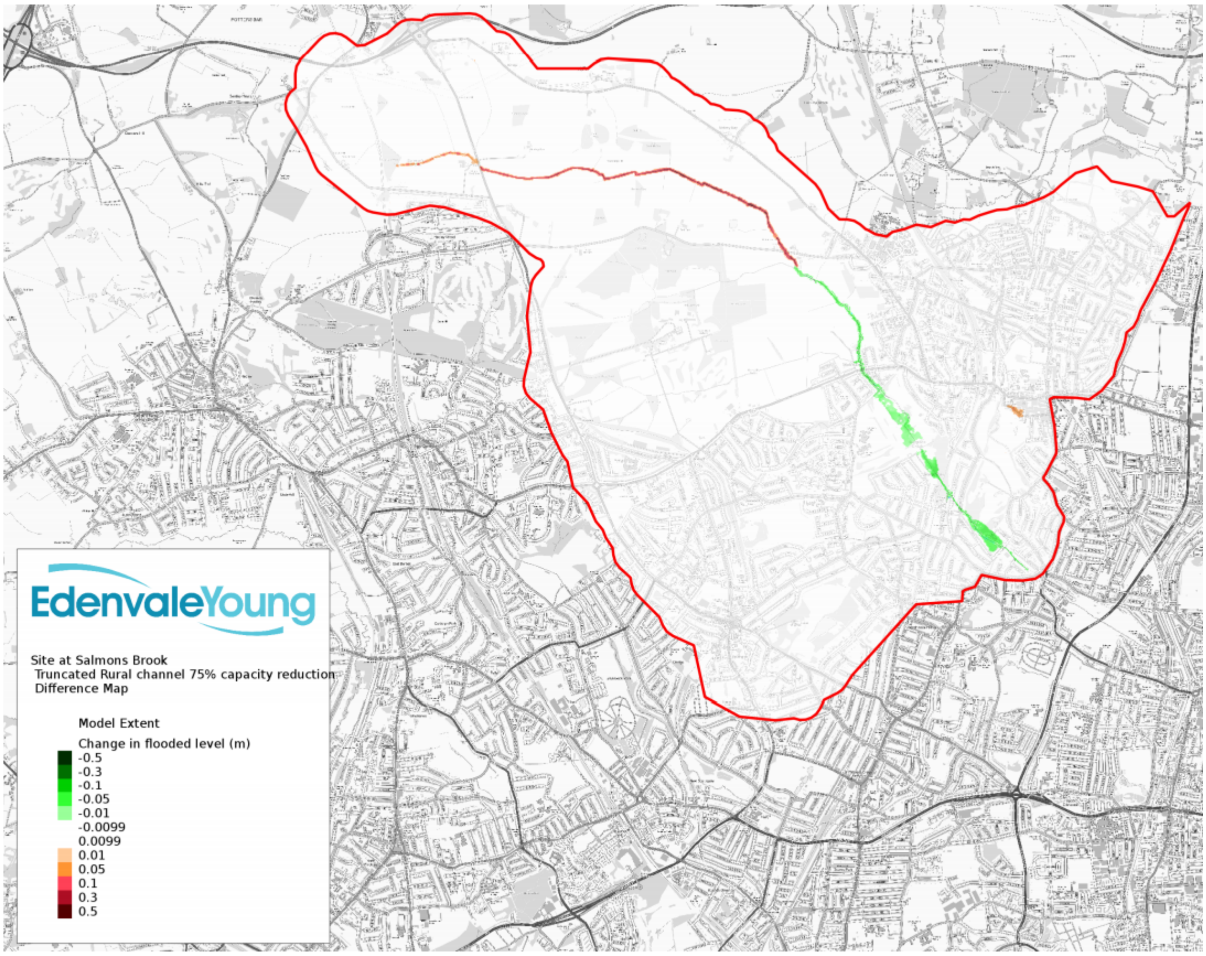

Figure 27: *Peak water level difference between the proposed rural river restoration of 75% channel width reduction compared to the baseline without NFM during the October 2000 (approx. 1 : 25 return period) event.*

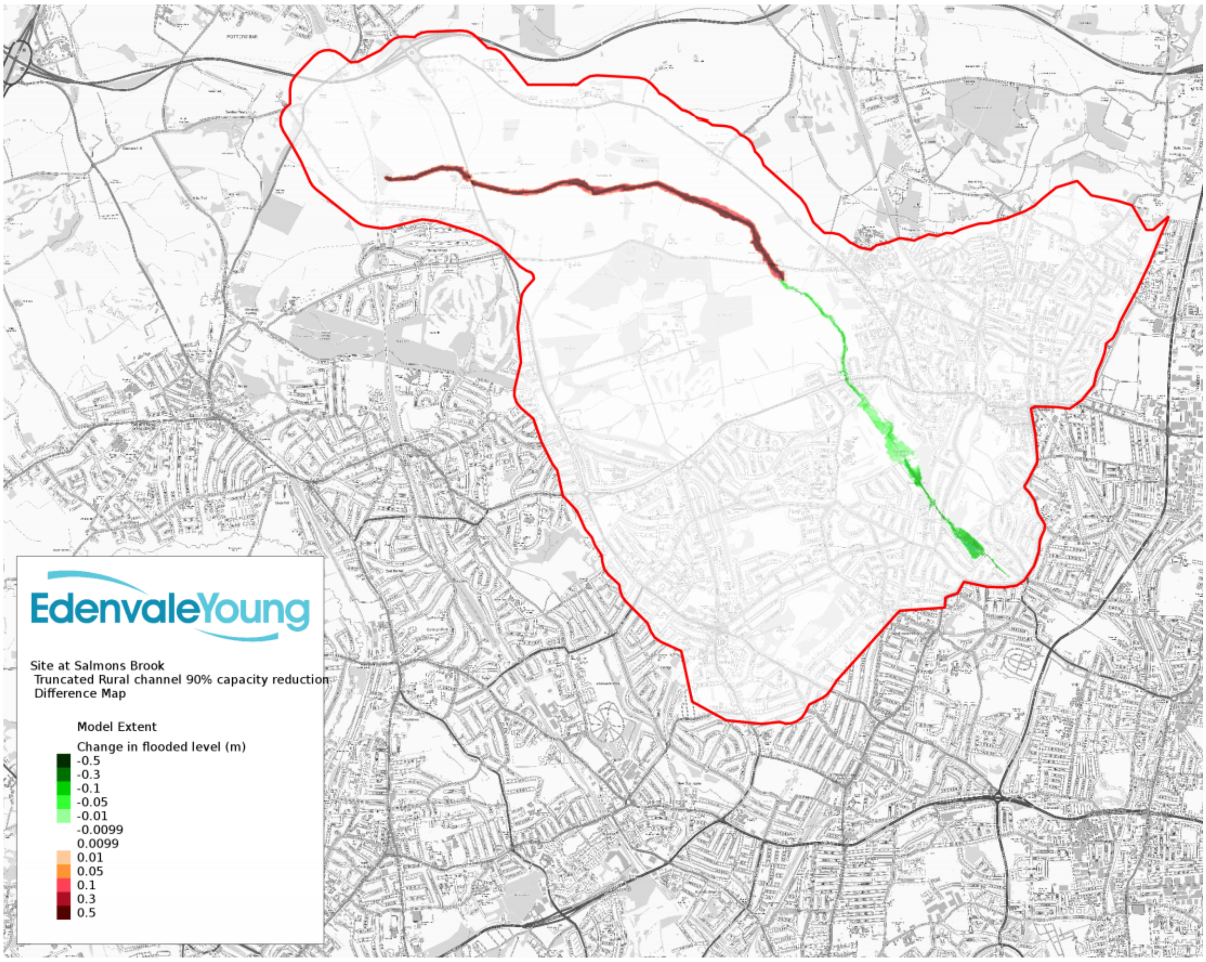

***Figure 28**: Peak water level difference between the proposed rural river restoration of 90% channel width reduction compared to the baseline without NFM during the October 2000 (approx. 1 : 25 return period) event.*

vi) Impact of combined NFM measures on downstream flood risk reduction

Current proposed NFM option

The effects of the current working proposal for NFM to alleviate flooding and provide other benefits in the Salmons Brook catchment have been summarised individually above and in Appendix 1. In this section they are assessed in combination. This comprised: 200ha of woodland (as saplings), 75% channel width reduction and 46 rural SUDS (permeable bunds) in the rural upper catchment. Scenarios were created for the October 2000 (1 : 25 year return period) event and also a much larger 1 : 100 year return period event.

During the October 2000 event, this combination of measures reduced peak flow by 50% at the Hadley Road Bridge and 15% at the Clarendon Arch hydrograph sampling locations, compared to the baseline scenario (Figure 29). For the 1 : 100 year event the peak flow reduction was approximately 35% and 21% respectively at the two reporting locations (Figure 30). This reduction is due to dilution of impacts by additional inflows between the rural catchment and the reporting area.

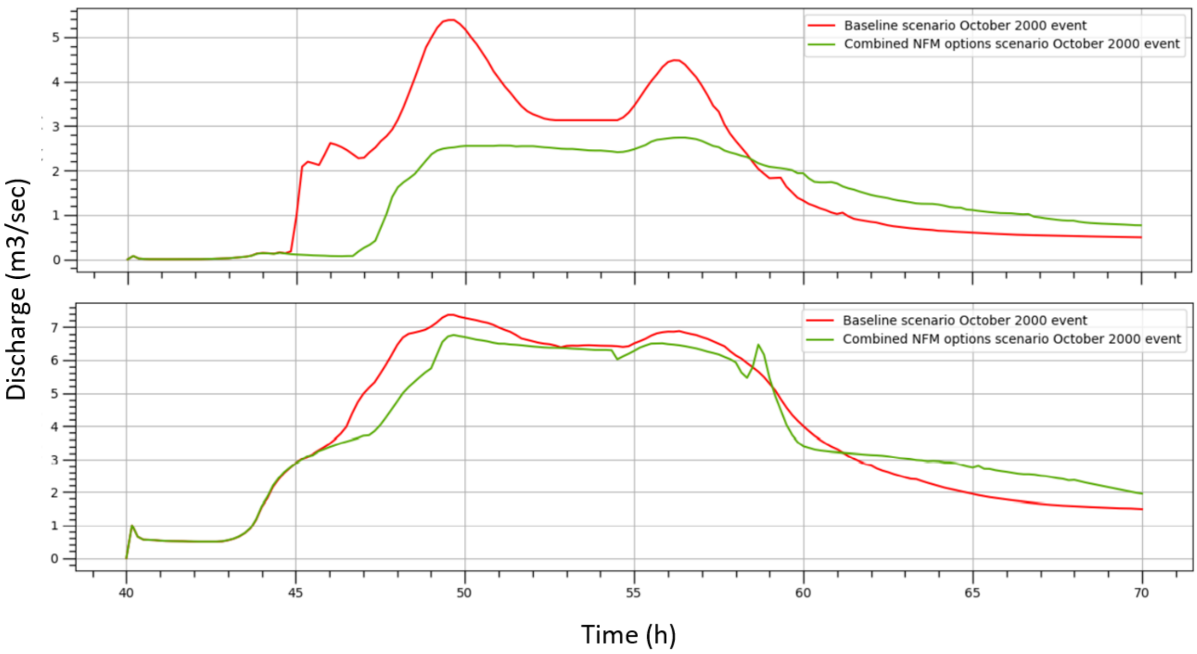

__Figure 29:__ Proposed combined NFM options (green line) compared to the baseline (red line) at Hadley Road bridge (top) and Clarendon Arch, Bush Hill (bottom) during the October 2000 (approx. 1 : 25 return period) event. The combined options comprised 200 ha woodland, 75% channel width reduction and 46 permeable bunds (wetland ponds).

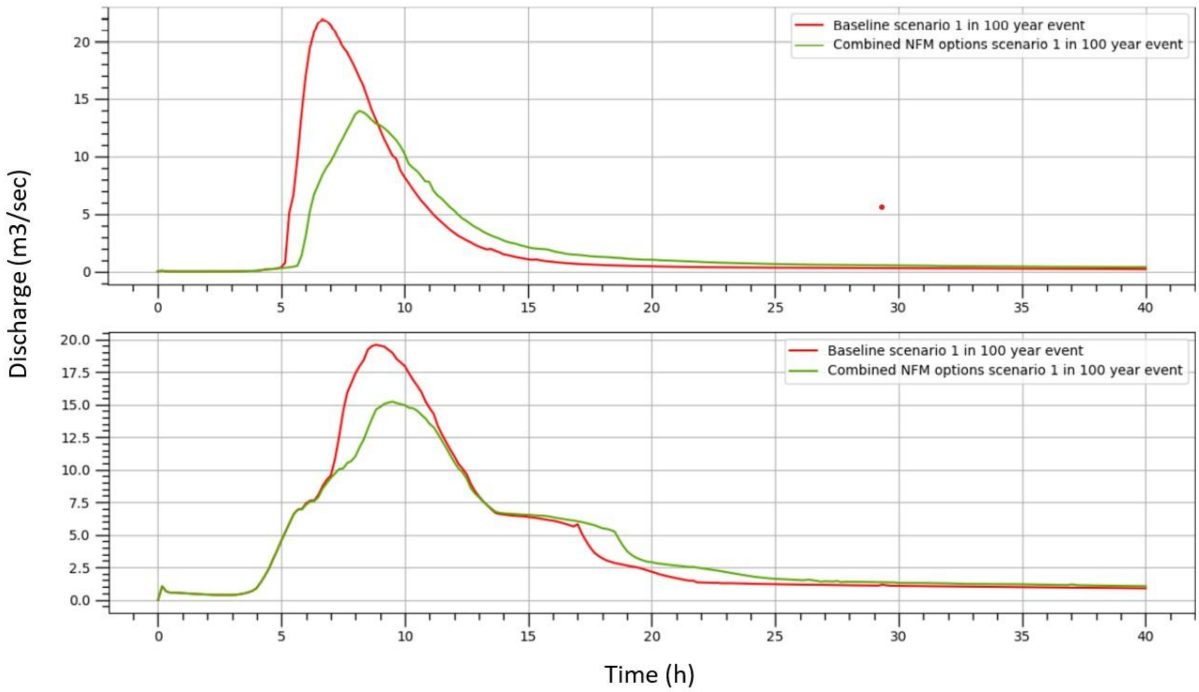

__Figure 30:__ Proposed combined NFM options (green line) compared to the baseline (red line) at Hadley Road bridge (top) and Clarendon Arch, Bush Hill (bottom) during the 1 : 100 year return period event. The combined options comprised 200 ha woodland, 75% channel width reduction and 46 permeable bunds (wetland ponds).

Peak flood water heights in the properties at Bush Hill, within the EA flood zones are reduced by 10 - 30 cm during the October 2000 scenario and by up to 50cm during the 1 : 100 year return period scenario (Figure 31 and 32). Meanwhile, the rural upper catchment experiences widespread increase in water levels as the floodplain activates and water is retained by bunds and in association with woodland canopies. This demonstrates the positive effect this combination of NFM measures can have on reducing flooding in this catchment. However, it should also be noted that there are some small zones within the urban area where flood water heights increase. Although likely spurious (see discussions above), further modelling would be required to ensure no disbenefit.

Note also that this scenario represents a conservative estimate, with larger impacts on peak flows and maximum water levels anticipated as the woodland matures.

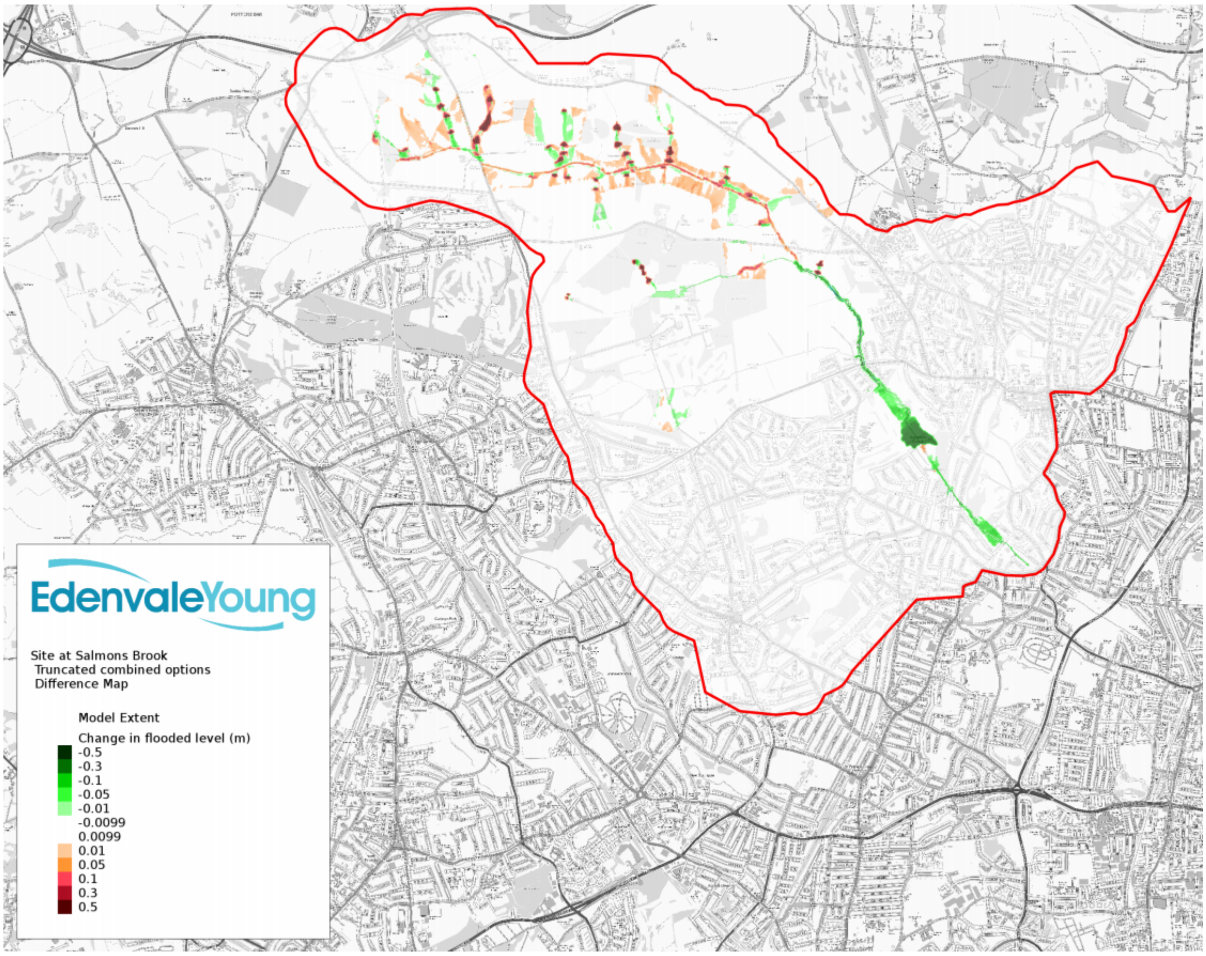

***Figure 31**: Peak water level difference between the proposed combined NFM options (200 ha sapling woodland, 75% channel width reduction and 46 permeable bunds (wetland ponds) compared to the baseline during the October 2000 (approx. 1 : 25 return period) event.*

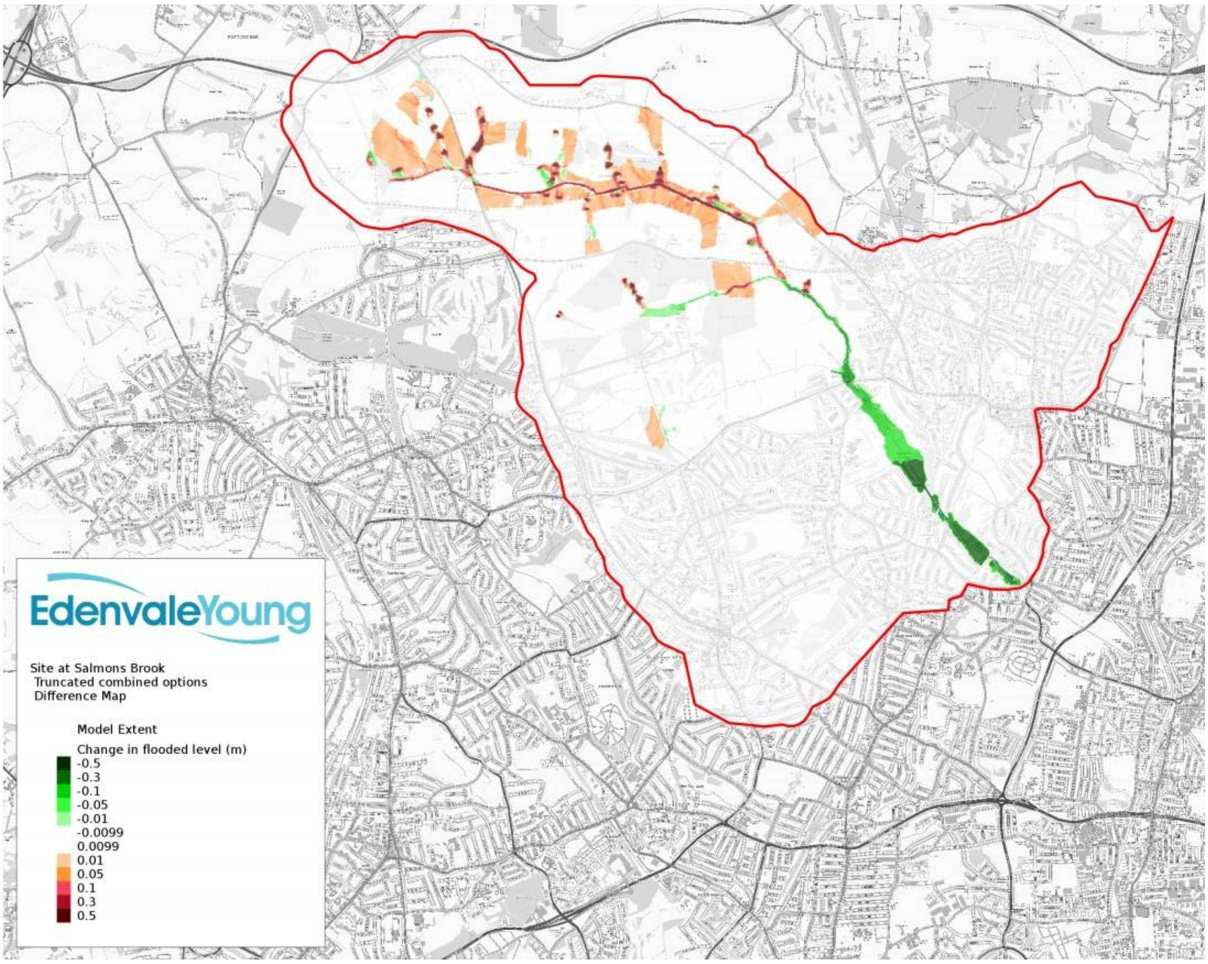

Figure 32: *Peak water level difference between the proposed combined NFM options (200 ha sapling woodland, 75% channel width reduction and 46 permeable bunds (wetland ponds) compared to the baseline during a 1 : 100 year return period event.*

Proposed NFM options for maximum benefit

The maximum benefit option to alleviate flooding in the Salmons Brook catchment comprised: 415 ha of woodland (as saplings), 90% channel width reduction and 46 rural SUDS (permeable bunds) in the rural upper catchment. Simulations were created for the October 2000 (approx. 1 : 25 return period) event and a larger 1 : 100 year return period event.

This option has potential to significantly reduce flood risk for larger events. Downstream of the proposed NFM measures, the peak flow for the October 2000 event is reduced by 78% with the peak of the event reduced from 5.2m3/s to 1.1m3/s at the upstream reporting location (Figure 33). At Clarendon Arch, Bush Hill, the downstream hydrograph reporting location, the peak flow reduction is 6%. Modelled peak flows for the 1 : 100 year return period event are reduced by 65% at the Hadley Road bridge, with the peak of the event reduced from 22m3/s to 8m3/s (Figure 34). The measures also delay the peak of the hydrograph by 3 hours at this upstream location. At Clarendon Arch, Bush Hill, the downstream hydrograph reporting location, the modelled peak flow is reduced by 31% with no significant change in peak timing. This once again highlights the influence of the intervening catchment between the two reporting locations, with flow from the Houndsden Gutter catchment and the urban area in north Enfield diluting the impact seen at the upstream hydrograph reporting location, located much closer to the interventions.

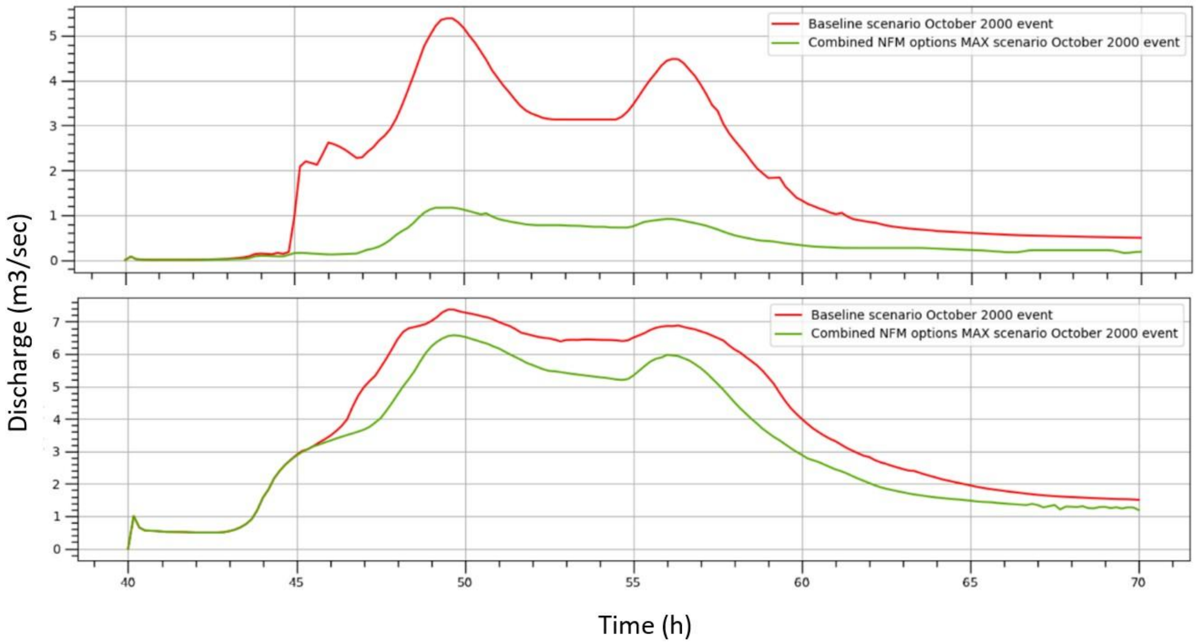

Figure 33: *Proposed maximum combined benefit NFM options (green line) compared to the baseline (red line) at Hadley Road bridge (top) and Clarendon Arch, Bush Hill (bottom) during the October 2000 (approx. 1 : 25 return period) event. The combined options comprised 415 ha woodland, 90% channel width reduction and 46 permeable bunds (wetland ponds).*

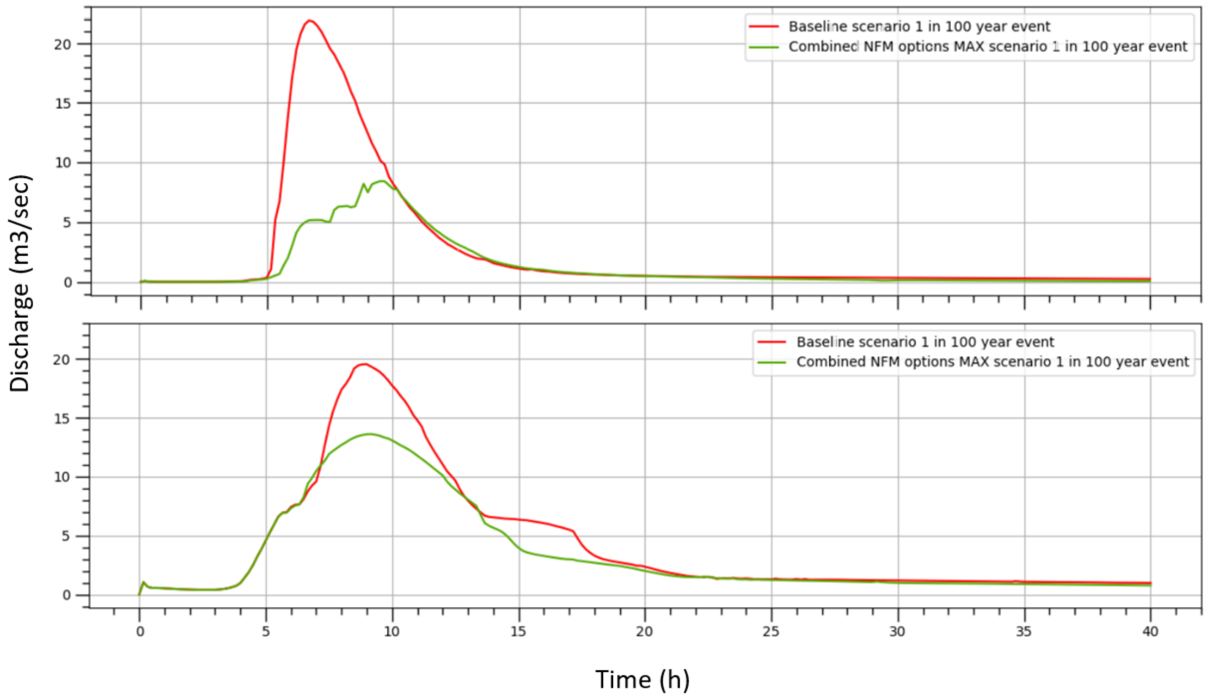

Figure 34: *Proposed maximum combined benefit NFM options (green line) compared to the baseline (red line) at Hadley Road bridge (top) and Clarendon Arch, Bush Hill (bottom) during a 1 : 100 return period event. The combined options comprised 415 ha woodland, 90% channel width reduction and 46 permeable bunds (wetland ponds).*

Peak flood level difference mapping for the October 2000 (1 : 25 year return period event) indicates reduction in water height of up to 30 cm at properties in Bush Hill (Figure 35). This is similar to the result from the NFM measures scenario currently under consideration (Figure 31). However, there are more notable differences in peak water level reductions provided by the maximum benefit NFM scenario in a 1 : 100 year return period event. Significant benefit is observed in urban Enfield with in excess of 50 cm peak water level reduction widespread along the entire modelled network downstream of the NFM measures and especially at properties in Bush Hill (Figure 36).

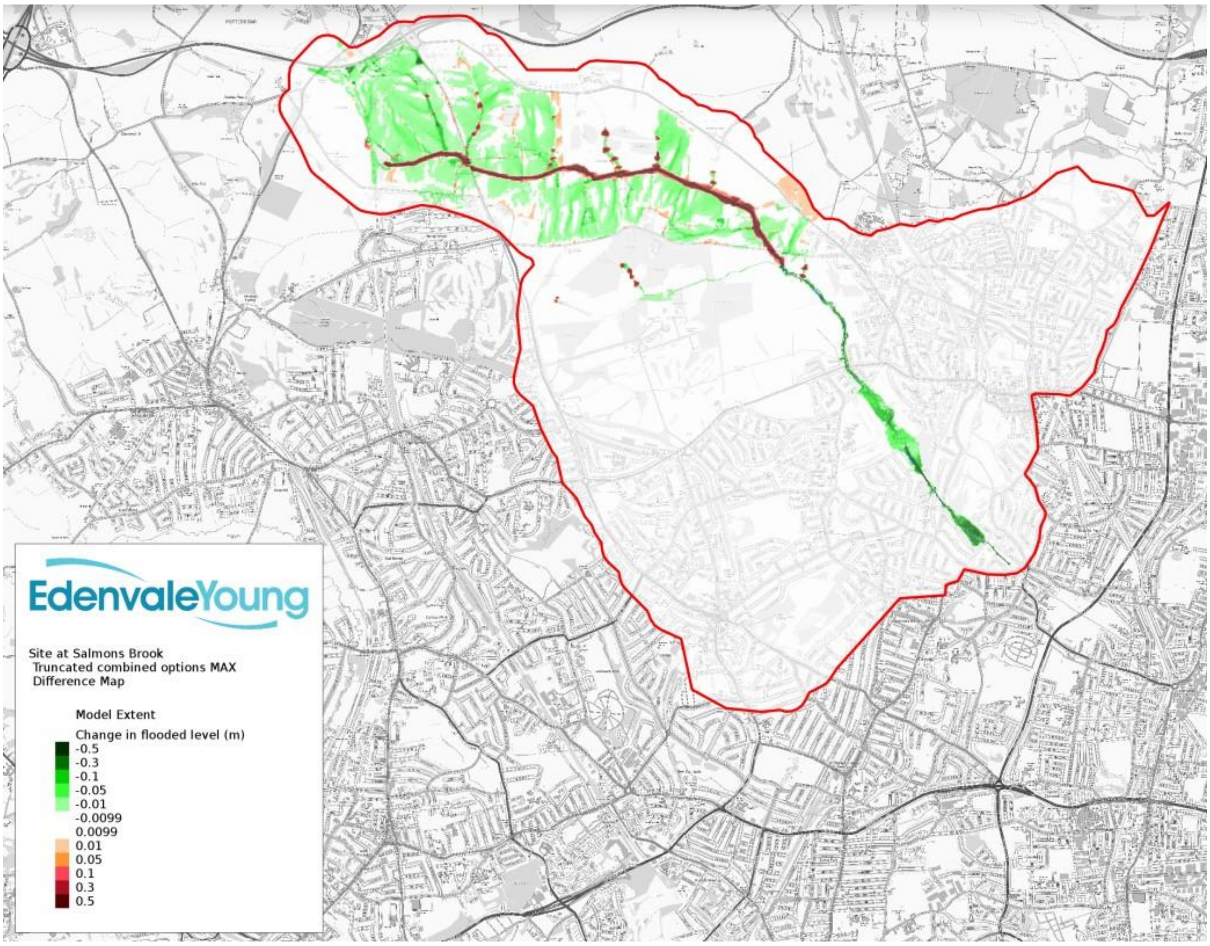

***Figure 35**: Peak water level difference between the maximum combined benefit NFM option (415 ha sapling woodland, 90% channel width reduction and 46 permeable bunds (wetland ponds) compared to the baseline scenario during the October 2000 (1 : 25 year return period) event.*

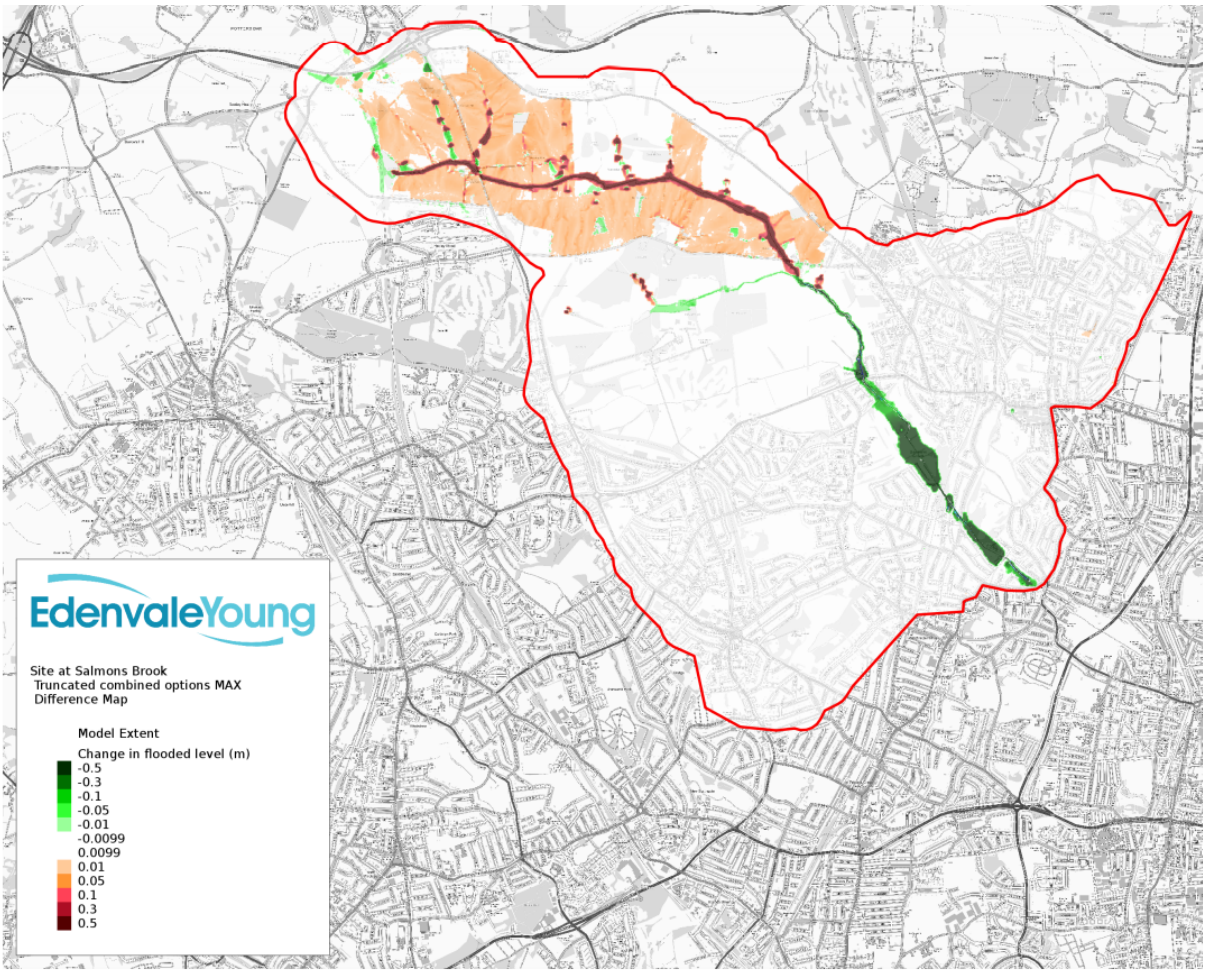

***Figure 36**: Peak water level difference between the maximum combined benefit NFM option (415 ha sapling woodland, 90% channel width reduction and 46 permeable bunds (wetland ponds) compared to the baseline scenario during a 1:100 year return event.*

As above, it should be noted that the combination of NFM for maximum benefit scenario is a reasonable, conservative estimate of flood risk reduction. Long term, as the woodland matures, further reductions in peak flow and peak water heights can be anticipated.

Note, in all scenarios, the October 2000 flood event occurred before construction of the flood storage area at Enfield Golf Course (constructed 2016). Modelling of impacts of the upstream NFM including the presence of the Enfield Golf Course flood storage area would reduce the impact at downstream locations. A recommendation for future implementation of NFM could be to focus measures to mitigate against smaller events whilst using the Flood Storage Area to control larger events.

Flows from the Houndsden Gutter and other tributaries entering the Salmons Brook closer to urban areas of Enfield are noticeably diluting the impacts of the NFM interventions upstream in all modelled scenarios. Further modelling could characterise and identify opportunities for flow attenuation using NFM in these sub catchments

Measured evidence of NFM performance

Water level Sensors

Figure 37 shows example telemetry data from three of the seven FreeStations deployed in the rural Salmons Brook catchment capturing changes in water level associated with three significant rainfall events. Edenvale Young Associates used FreeStation data from these events, in particular the 1:10 return period event, in model calibration. Level data from the rural catchment when NFM activities are taking place is particularly useful because the Environment Agency flow gauging stations are situated downstream in the urban catchment.

Water level sensors were placed on the main Salmons Brook channel at some distance from the leaky dams on the Leeging Beech Gutter (Figure 8) so were not anticipated to detect the impact of leaky dams on flow timings or peaks in the main water course. The effects of woodland creation are unlikely to be observed until the woodland matures.

The FreeStations were deployed before commencement of major NFM works with the purpose of establishing baselines from which to understand longer term changes in catchment hydrology resulting from installation of different NFM measures across the borough and to inform future floodplain activation (towards base-zero) restoration. Detecting the impacts of NFM from natural variability in catchment response to storm events (deriving, for example, from antecedent conditions and the characteristics of individual storm events), requires long term data sets therefore the FreeStations will be left in place beyond the timeframe of the DEFRA pilot.

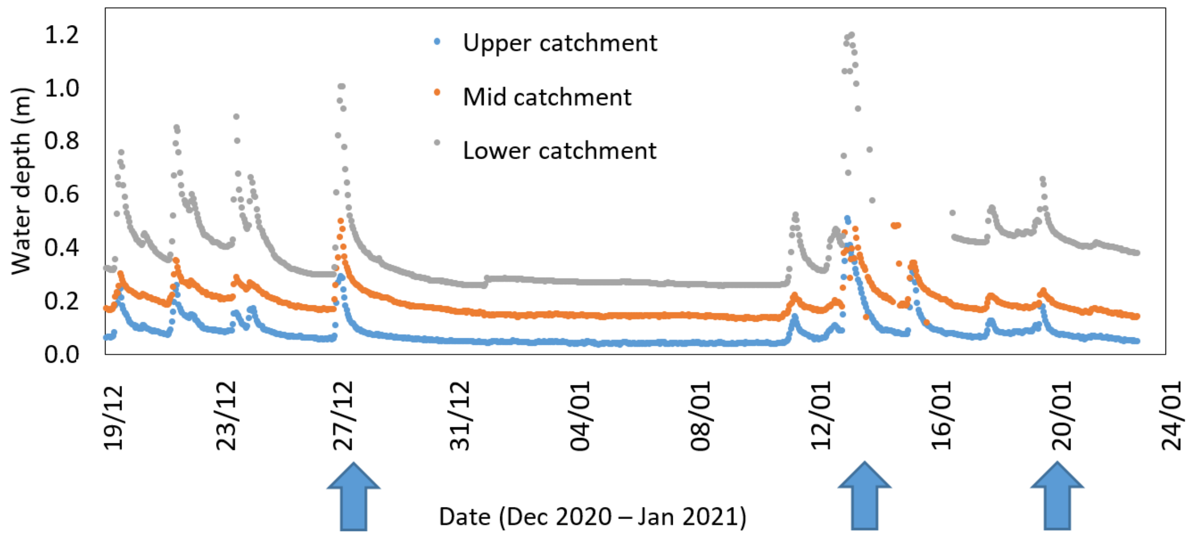

Figure 37: *Water depth (m) telemetry data for the period 19th December 2020 – 24th January 2021 from three FreeStations deployed in the headwaters of the Salmons Brook catchment. Freestations were located in the upper, mid and lower zones of the rural headwaters (Figure 8) and, in this period, recorded three storms: Storm Bella (26-27th December); a 1:10 year rain event (14-15th January) used in model calibration and Storm Christophe (20-21st January), indicated by arrows.*

Various learning outcomes relevant for future projects arose from use of low-cost level sensors:

Trial and demonstration of experimental technology contributes to the research and development objectives of the DEFRA pilot but inevitably requires higher investment of staff time to support them compared with 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 suffered a variety of additional, time consuming challenges after deployment, resulting in data gaps and successive maintenance visits. It is therefore likely that purchase of proven, commercially available sensors that are more robust but higher cost would have been more cost effective - though riskier in case of loss or damage when deployed in public spaces.

Challenges centred on poor signal for telemetry and adequate access to sunlight for charging of solar panels. These requirements – and the need to position sensors discretely to prevent vandalism or theft in public places - meant that, to some extent, sensor locations were chosen to meet these needs, rather than in optimal locations for data collection. Despite this, incised channels, seasonally tall riparian vegetation, tree cover or proximity to tall structures – even ideal deployment locations, such as bridges - 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, the FreeStation team at Kings College London modified the firmware to prevent stations continuously searching for signal. Instead they logged data on the on-board SD card until signal improved.

Another issue occurred during heavy rain events. Mobile signal cannot penetrate heavy cloud and rain resulting in data gaps in the telemetry and requirement to visit the station. In most cases, after the firmware updates, data were logged to the on-board SD card, but not always. This resulted in data loss for 24-48 hour periods at key times and with implications for project officer time requirements for ongoing management of FreeStations.

Soil Moisture Sensors

he six soil moisture sensors generally operated without significant issues after deployment. This is because they were deployed in more optimal conditions in terms of signal and sunlight (Figures 8 and 10). The intention is for these sensors to remain in situ to record long term changes in soil moisture in response to woodland planting and floodplain reactivation. Example data, shown in Figure 38, are therefore characterising baseline soil moisture in the early stages of the restoration activities and will be compared to future data as woodland canopy matures. A long data set will also allow inter-annual variability to be characterised so true trends in soil moisture resulting from land use changes to be revealed.

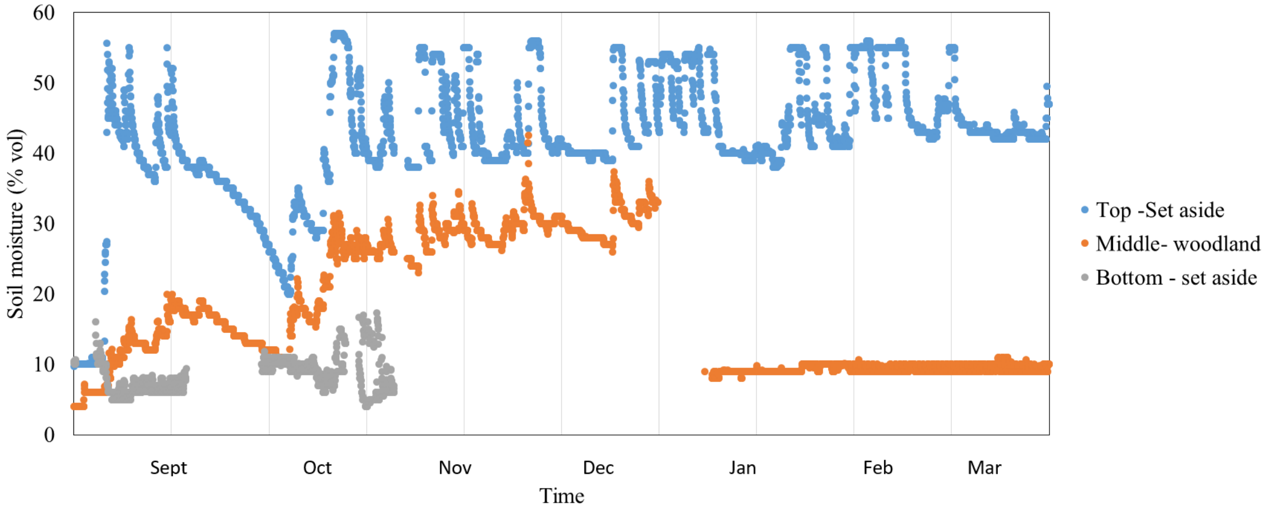

Figure 38: *Soil moisture (% vol) for the period 8th August 2020 – 15th March 2021 from three FreeStations deployed in a transect down a gradient of altitude and land use changes in the Salmons Brook catchment. From top to bottom of the valley: Arable field set aside for woodland planting; established woodland; arable field set aside for woodland planting.*

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 39 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 NFM features, in particular the leaky dams.

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.

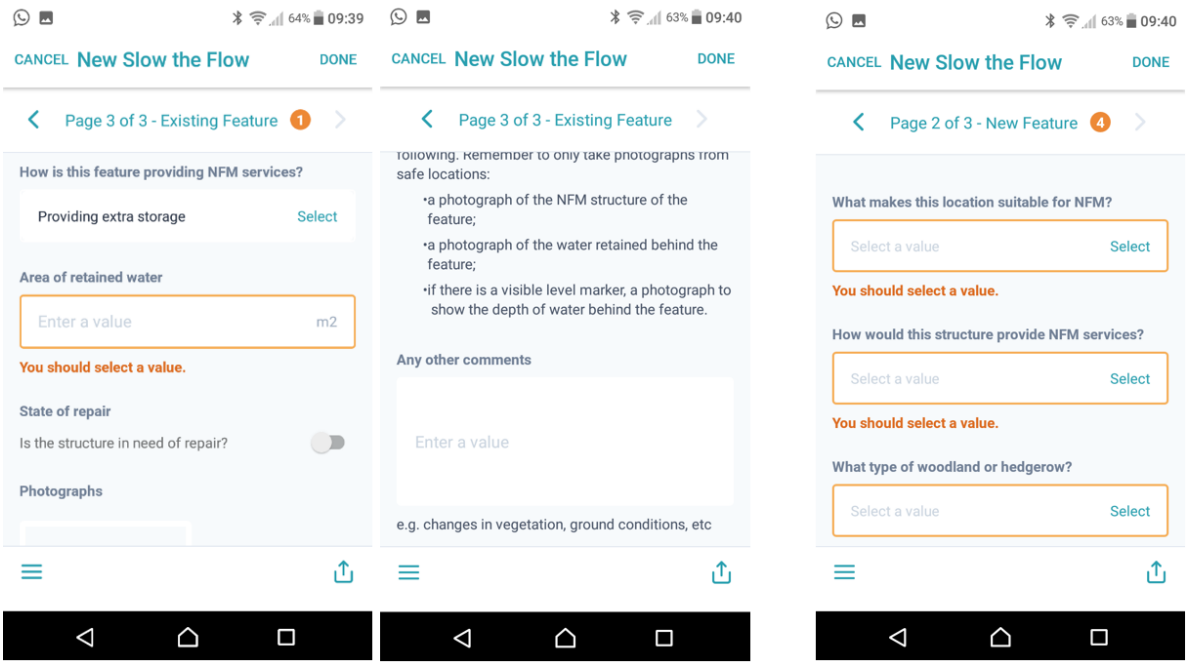

Figure 39*: Screenshots of the SlowFlowCapture App for collection of data about the NFM assets by the public and trained volunteers. Left and centre: recording data for existing features; right: recording suggestions for a new NFM feature.*

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

iii) Lack of immediate results to sustain volunteer interest. Dam building and training events took place when flows were low and the ephemeral channels either side of the obelisk in Trent Park (Figure 8) were dry. Unless you are in the woods after heavy rain when the leaky dams are holding water there is little to survey and photograph around a newly built dam. This means there is no immediate result, unlike, for example with riverfly monitoring where you achieve reliable, informative data instantly. It also means it is hard to sustain volunteer interest in monitoring.

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

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

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

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

3.3 Additional benefits from the NFM

Geomorphological changes

Two branches of the Leeging Beech Gutter (named Obelisk left and Obelisk right in Figure 4) were surveyed for baseline (as built) and post-project monitoring. During the baseline survey the channels were dry, but flowing during the repeat surveys.

The dams on the channels are numerous and spaced so close together, that almost all the modules contained at least one dam. For this reason, analysing downstream scouring and upstream siltation is difficult using the data calculated by MoRPh summary indices, as all modules are expected to have both these processes and the calculations average out.

Comparing the single MoRPh indices of the repeat surveys to the baseline surveys, Index 4 (coarsest present/extensive bed material type) shows that gravels have started to appear in both channels suggesting bed scouring in the vicinity of some dams and increasing in-channel habitat complexity. This was more apparent in the left-hand channel. Index 7 (extent of superficial bed siltation) indicated increasing siltation on the right-hand-side channel, an example is shown in Figure 40.

This suggests that the dams are functioning to trap sediment that may otherwise end up in water courses downstream of the project area and which may contribute to flooding. However, a repeat survey once the dams have become more established would hopefully demonstrate this change more robustly.

Figure 40: Increased channel siltation observed in association with leaky dams in Trent Park

The other indicators were difficult to interpret, therefore inconclusive. The majority of summary indices revealed no trend and deeper evaluation of the individual components of these indices also revealed no clear trends. Furthermore, the survey methodology did not adequately capture debris accumulation behind dams.

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 Trent Park 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 surveys in Trent Park were conducted in different seasons (autumn, and early spring 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.)

- Indices referring to silt and clay were confused at times by surveyors resulting in different surveyors reporting different materials. More staff training to ensure consistency is required.
- 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). Whilst anecdotal notes were recorded, these were too small to be incorporated into the calculation of the indices.

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 survey 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.

Additional benefits

Project funding and time were insufficient to quantify the diverse potential benefits that NFM can deliver in addition to flood risk reduction. However, Figure 41 estimates ongoing and future benefits offered by leaky dams, woodland and wetland (permeable bund) creation in the Salmons Brook catchment.

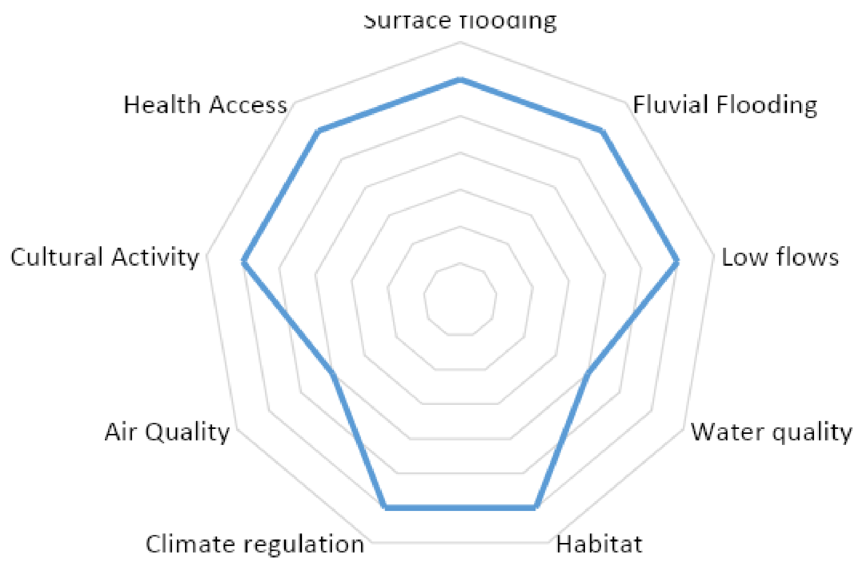

***Figure 41**: Potential multiple benefits of all NFM measures underway in the Salmons Brook catchment, after they are more established.*

Potential impacts on flows and hydrogeomorphology have already been discussed above, but other advantages are expected or anecdotally observed in the following areas:

Ecology

Conversion of arable farmland to wetland ponds and pasture-woodland at the catchment scale will increase habitat complexity and connectivity between Local Wildlife Sites, helping the borough to meet targets set out in its Biodiversity Action Plan. Once established, these areas have potential to support various BAP species of London and National priority already recorded in the borough.

Water quality

Evidence of sediment and debris washing off bare arable fields has been documented in the borough (Figure 42) and can contribute to flood risk through obstructing culverts and water courses. Woodland intercepts water on the canopy and stabilises soils, reducing overland flow, whilst, bunds and leaky dams temporarily impound water, trapping and settling sediment out and catching large and small woody debris before it enters the rivers. Sediment and debris build up behind leaky dams has been observed during MoRPh surveys in Trent Park, Figure 40, discussed above.

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

Figure 42: *Gullying and overland flow in arable farmland in the Salmons Brook catchment*

Health and wellbeing

The NFM installed in Enfield borough has potential to enhance physical and mental health and wellbeing through three main aspects:

1- *Stress and anxiety relief*. Installation of flood risk reduction measures and understanding their impact on downstream flood risk may contribute to relief of stress and anxiety of homeowners whose properties are at risk through observing that 'something is being done' and through being informed of the level of protection these measures may provide. It is therefore recommended that the modelling findings of this report are shared with owners of at risk properties downstream who have not already been engaged with the projects.

2- *Access to high quality greenspace*. Creation of extensive areas of publically accessible woodland and grazing land, including wetland ponds and enhancements to the London Loop walking route footpath, will create a legacy of high quality public greenspace in a borough containing areas of deficiency in access to nature. Research has shown that exercise and recreation in areas of rich biodiversity improves both physical and mental health.

3- *Volunteering opportunities*. Additional physical and mental health benefits were provided during the project through volunteering events to plant trees and build leaky dams (discussed below). Ongoing NFM activities in the catchment may provide additional opportunities to foster community cohesion – for example, volunteering events focused on ongoing dam maintenance or planting of wetland ponds. NFM installation funded in future should consider wider community engagement and involvement in building and management of NFM assets, including creation of education opportunities in schools and colleges, also community visits to learn about natural flood management techniques. This has been achieved very successfully elsewhere in Enfield borough, for example associated with the award winning constructed wetlands for water pollution treatment at Firs Farm.

4. PARTNERSHIP WORKING

Benefits of partnership working

The project was delivered by a partnership of Enfield Council (the local council, lead local flood authority and land owner), and rivers trust Thames21 working closely with local farmers, businesses (e.g. Enfield Golf club) and community groups (e.g. Friends of Trent Park, Enfield Society) in areas under consideration for installation of NFM.

A new engagement approach for both Enfield Council and Thames21 was taken in the creation of the Farmers Forum. The purpose of the group is to facilitate consultation and address any concerns about the scope for NFM works across the catchment, any opportunities, barriers and also the scale and nature of land acquisition for any works that may have consequences for the farmers. It was considered that as long as Enfield Council and their representative land agent were kept informed they did not necessarily need to be present. This was to enable the group to focus on relevant topics and not transgress onto other matters or concerns.

Since its creation, the group managed to meet once in person and, during Covid-19 restrictions, have been communicating via email but have to schedule organised site visits. The intention is that the group will continue beyond this pilot study and will aid a collaborative approach to NFM and rewilding. With additional funding available through Natural England, Thames21 hopes to draw in more landowners and farmers across the Turkey Brook (East), and into the Lea Valley (North), linking established Nature Recovery Networks on a landscape scale.

Farmers facilitated collection of level and soil moisture telemetry data through hosting 7 of the 12 FreeStations on private land. This had the significant benefit of minimising the likelihood of vandalism and theft. Of the three NFM Pilot catchments where FreeStations were deployed, the Salmons Brook was the only one that did not experience issues with members of the public interfering with monitoring equipment. Links to view data in real time were shared as a method of increasing the involvement and by-in of landowners and other stakeholders in the project.

In comparison to project delivery by the Environment Agency local teams, 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 - 100,000. Although the London Borough of Enfield did not initially commit to any measure of in-kind contribution, as a dedicated partner to the project their efforts have been considerable across a range of teams (Watercourse and Structures, Parks, Arboriculture, Heritage, Public Health, Commercial, Planning, and Property Services). This covers a number of site visits and meetings, detailed design work, steering group meetings, consultations, assistance with funding grants, felling and transporting timber for leaky dams, attendance of NFM training sessions, and more. This does not include valuable foundation work undertaken by the London Borough of Enfield prior to project commencement.

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.

An opportunity was offered to all the tenant farmers for a Natural England stewardship style payment agreement where they would get paid an initial £1000/ha followed by £375/ha/yr for 10 yrs as compensation as well as to ensure the trees survive as per the Forestry Commission requirements. Initial interest was high but due to the requirements for funding from the Greater London Authority (GLA) for large scale woodland creation and the councils wider vision to provide more publicly accessible green space, agreements for land surrender with compensation was considered the most appropriate solution. The 10yr payment system may be reviewed in the future to use on areas of land not connected to those that are now publicly accessible.

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. In this project, 5 members of Enfield Council's Parks team completed a Thames21 led training course in building and maintenance of leaky dams.

Community engagement, training and volunteering

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

i) Farmers Forum (discussed above)

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 (discussed below).

iii) Leaky dam building events involving volunteers, led by a project officer (discussed below).

iv) Awareness raising about NFM and the project via our website, the Farmers Forum, volunteers and talks to local community and resident groups including Church, Rotary and resident groups and societies.

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 under estimated by DEFRA in future projects. Public engagement activities in the Salmons Brook catchment include: recruiting and training volunteers for leaky dam building, woodland planting and collection of NFM monitoring data; sustaining momentum and supporting volunteers. However, the process of consultation and engagement of tenant farmers during land requisition for woodland planting as part of the wider NFM works in the catchment include aspects relevant for national scale learning, so shall also be discussed.

There was limited public input into the selection of sites for leaky dams within Trent Park. However, The Friends of Trent Park had previously been in contact with another environmental charity who were progressing with a project to create two additional wildlife habitat ponds in the park. Ecology surveys had indicated the presence of species considered at risk and as their outputs could be aligned to those of this NFM pilot a partnership was found.

Varying levels of engagement were observed from tenant farmers for locating possible wetlands/ponds and trees on current agricultural land. These started with informal site visits and conversations but progressed formally with the help of a woodland creation consultant who was commissioned to assist with Forestry Commission applications and project partners from Enfield Council. Improvements in farmer engagement and their response were noted as working relationships and trust improved with a larger physical presence in the area. One farm in particular went as far as allowing the project delivery team to be based in their farmyard and accommodating the needs such as material and tool storage, receiving regular deliveries, and allowing volunteers to park on site.

Beyond the project lifetime, ongoing monitoring and maintenance of the leaky dams by the public and parks team within Trent Park will be of enormous benefit to the London Borough of Enfield, including in reporting vandalism and assistance with annual repair and maintenance.

Volunteer engagement and training opportunities

Thames21 initially developed a two day accredited training course to support public learning about flood risk, NFM and the project activities taking place in the Salmons Brook catchment and the other three NFM Pilot projects. Completing this course equipped participants with the necessary skills to lead their own dam building events with volunteers (dam locations guided and agreed by project plans), fully protected by Thames21 liability insurance. This course was run once in Trent Park in July 2019 and completed by 4 participants, one of whom completed the full accreditation.

After running the two-day course across three of the 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 combined day of theory and practical experience building leaky dams. It was intended to widen the appeal to local users of Trent Park and an endeavour to recruit citizen scientists to participate in monitoring of dams with the Slow the Flow app. Due to the impacts of Covid, the course became an online element (run on three occasions: October 2020, February 2021 and March 2021) attended by 55 trainees in total and a practical dam building event in Trent Park that took place in October 2020. A further training event was delivered in order to upskill 5 employees of Enfield Council Parks team in leaky dam management and included practical experience in dam maintenance.

In addition to the training course, volunteers were recruited to assist with leaky dam building. In total 8 leaky dam building events were run in Trent Park by project officers between December 2018 and November 2020, involving over 40 volunteers building 26 of dams. Monitoring and the Slow Flow app were also introduced at these events.

In addition, 17 volunteer tree planting events were delivered by project officers between December 2018 and December 2020, involving over 400 volunteers planting ~30 hectares of trees. Figure 43 shows photos taken on volunteer dam and tree planting events.

Figure 43*: Tree planting and leaky dam building in Trent Park with the assistance of volunteers.*

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 and WaterEnvironment, a private consultant. However, the interest was mainly in woodland planting and dam construction and less in long term volunteering through identifying new sites and monitoring via the Slow Flow App.

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 or will take place;
ii) events tailored towards participating in NFM (woodland planting, leaky dam building) and monitoring of assets;
iii) a more thorough series of linked training sessions leading to accreditation upon completion of all the steps. This would be aimed at upskilling local authority staff and established volunteer groups in various aspects of NFM creation and maintenance - including follow-up sessions for those leading their own NFM creation events.
iv) support of the above with a short video and online resources.

Comparing volunteer participation in the four NFM Pilots delivered by Thames21, recruiting and sustaining volunteer interest in long term monitoring of NFM flood reduction measures was most challenging in Enfield. Outside of difficulty in sustaining momentum due to Covid, the primary reasons for this are interrelated and comprise:

- *Insufficient resources for large scale public engagement*. NFM creation in Enfield covered multiple sites and multiple activities, therefore was on a much larger scale than the other three pilots, which focused on a single site. With limited budget, it is not possible for large scale public engagement and recruitment initiatives so efforts were focused on locations where NFM was being installed.

- *Disconnect between NFM installation sites and properties at risk of flooding*. NFM measures focused on the rural headwaters of the catchment whilst the properties at risk of flooding were down stream in urban Bush Hill and Edmonton, therefore creating a disconnect between measures and risk. In contrast, in the NFM Pilot sites where NFM measures were installed in the immediate area of flood risk (in particular at Park Wood), volunteers had more vested interest and were therefore much more likely to fully engage with the project and participate in long term data collection than people attending course and NFM creation events purely for curiosity and learning.

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, rather than being developed in parallel with delivery of training events. This facilitates public interaction with it and standardizes data recording and reporting. The app is now fully functioning and available for use by similar future projects and by Enfield Council and the other partners involved in the four NFM pilot projects to assist with ongoing NFM asset maintenance and management, in combination with QR codes which will remain permanently on the dams.

Securing Additional Funding

The award of funding from DEFRA initially helped to secure further funding from the Thames RFCC that enabled a project officer to be full time on this project. This in turn gave capacity to secure a further £30k from the GLA's Greener City Fund towards delivering tree planting and NFM interventions in Trent Park. On top of this, sufficient time was available to progress in the wider Enfield Chase Restoration project that includes over £1.5m of funding for 100,000 trees, wetlands and improved public access, a feasibility study into stage zero river restoration, and more recently a DEFRA and HLF grant to help restore Enfield's rivers where £200k has been set aside for additional rural SuDS.

Ongoing maintenance of NFM features beyond the project

This section focuses in particular on the leaky dams built as part of the DEFRA funded pilot, but also touches on aspects relevant for DEFRA regarding management of created woodland.

Vandalism of dams

As an urban greenspace, Trent Park 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 several dams at a time was reported on at least 3 occasions and required at least 3 project days to repair them. Types of activity recorded included:

i) Vandalism and complete destruction of dams
ii) Alteration of formal dams by adding or removing timbers.
iii) 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 water and wetting the local woodland; others are more ephemeral with risk of creating debris blockages upon breakdown.

The importance of an engaged, invested local community and Borough Council are once again highlighted. Enfield Council Parks team need to adopt the dams and trees into their maintenance regime otherwise the level of effectiveness could rapidly decrease. 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. Learning indicates that, in very public spaces, dams need to look formal and include anti-tamper measures Figure 44.

Figure 44: Wiring as a measure to deter vandalism and timber removal of leaky dams.

Vandalism of trees

Planting trees and shrubs in public places always has its caveats, over 100 trees were stolen from Trent Park the day after they were planted. The guards were left so it can be assumed these were taken for a private garden (Figure 45). Since then it was observed that those trees with bamboo supporting canes and spiral guards suffered the most when the canes were removed, this is because the tree wasn't strong enough to support the guard by itself. Replacement canes didn't last long either. The trees with wooden stakes and Tubex guards fared the best but we estimate a loss of over 25-30%, much higher than expected or observed in areas with no public access.

During the past 12 months many public green spaces have been put under intense pressures due to Covid-19 and Trent Park is no different. Increased footfall and social distancing resulted in many footpaths being informally widened, especially through areas of newly planted trees.

Figure 45*: Theft of trees in Trent Park, leaving the guards and stakes behind.*

Catchment plan for ongoing maintenance of NFM assets

The following focuses on the plan agreed with project partners for ongoing management and maintenance of the leaky dams in Trent Park after the DEFRA Pilot.

Leaky dams and other NFM assets will be added to Enfield's local Flood Risk Management Asset Register to ensure that a record of their condition is maintained and future remedial action taken when considered necessary. Five members of Enfield Council's Parks team have attended the training course to enable ongoing dam maintenance.

A detailed woodland management plan is currently being drafted and includes a management guide for tenant farmers, the Friends of Enfield Chase and other volunteers to adopt.

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.
- Future NFM funding should seek to repeat MoRPh surveys in order to track geomorphological changes associated with the leaky dams.

5. SUMMARY OF LESSONS LEARNED

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

i. Performance of NFM assets

- According to the modelling, leaky dams do not offer significant reduction in flow peak or timing of heavy rainfall events. However, anecdotally, restoring natural processes by installing leaky dams may increase catchment resilience and flood risk reduction by providing benefits such as reducing debris and sediment entering water courses, as well as providing biodiversity benefits. It may therefore still be relevant to install them, in particular where other options have been exhausted or where sediment contributes significantly to flood risk through clogging of culverts or rapid siltation of flood storage ponds.
- Based on the modelling undertaken to assess the wider scheme of works underway in Enfield borough, other forms of NFM have much greater impact on downstream flood risk than leaky dams, namely woodland creation and installation of permeable bunds. This was also the conclusion at Bedfords Park and Bentley Priory, where flood storage ponds were also evaluated. In combination, these other measures have been demonstrated in Enfield to have the potential to reduce peak flows by up to 50% and peak flood water levels by up to 50 cm.
- It is important to model the contribution of different forms of NFM to flood risk reduction (both immediately and as they mature) to ensure that, through changes in timing and volume of flood peaks, they do not coincide to result in negative impact.
- A 1:25 return period event (used by the model to test scenarios) has not been experienced during the lifetime of the project, so the NFM measures have yet to be ‘tested’ in similar conditions.
- It is too early to quantify the impact of NFM assets on ecology or hydrogeomorphology. Instead, survey methodologies and monitoring baselines have been established against which future surveys can compare.

- Vandalism (of young trees and leaky dams) is an issue in heavily used urban settings and all four NFM Pilot sites suffered from vandalism of NFM assets. Metal wires to secure timbers in place can be a deterrent to tampering with leaky dams. In public areas dams may decline at faster rates than on private land due to public 'fixing' or vandalising them, and this must be taken in to account in maintenance schedules. Similarly tree planting and subsequent management should assume higher levels of loss.
- Incidence of public vandalism of dams and the trampling and theft of trees could be due to the unusual circumstances created by Covid restrictions and people staying local, but longer term data would be required to confirm this.
- -Public education campaigns around the NFM assets, and an engaged local community could potentially reduce issues around vandalism, but require adequate budgeting.

ii. Monitoring tools

- *Freestations*. Higher cost commercially available loggers generated more reliable data and required less officer time to manage and maintain, therefore are likely more cost effective overall to the project than trial and demonstration of low cost monitoring devices in partnership with research institutions. However, low cost stations carry less risk when deployed in public spaces where theft or vandalism is more likely. Suitable deployment locations that are discrete but with adequate telemetry and sunlight for data transmission and charging of solar panels are surprisingly hard to find in peri-urban environments – even at the catchment scale. Loggers rather than telemetry may be more suitable for some projects but recognising that data live streams can be a hugely valuable public engagement tool.
- *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).
- *Hydraulic modelling*. Modelling has been a useful exercise in contributing to the body of evidence for NFM and has enabled the testing of future scenarios and identification of optimal locations for installation of measures.
- *Geomorphology surveys (MoRPh)*– The current survey method is designed as a tool to assess river restoration projects pre- and post-delivery. It has potential as a tool for monitoring of leaky dams and other features but requires refinement.

iii. Community engagement and partnership working

- Community engagement is key and is rewarded with contributions of considerable local knowledge and willingness to react to rainfall events and be 'eyes on the ground' above and beyond what can be achieved using project officers.
- Whilst building relationships with invested community groups is essential, a balance must be struck between time invested in collaborative working with the community and

effective project delivery. Roles and expectations of all partners must be clearly defined at the outset, including responsibility for management decisions.

- £50 K is not sufficient for LLFAs and NGOs to commit sufficient officer time for wider engagement of the community, so, by necessity, focus in this project was training and support for NFM creation but it did help to secure additional match funding.
- 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 creating NFM (woodland planting, leak dam building) rather than monitoring of NFM. This is likely because, unless you live locally or have a house at risk of flooding, there is not much in it for the volunteer and not much to monitor except during heavy rainfall, and with no immediate results. The volunteer journey therefore needs careful planning, tools need to be ready before training and training needs to be targeted at the community in the immediate vicinity of the NFM or zones at risk of flooding, rather than the wider public.
- Monitoring of NFM may be better integrated with other volunteering programmes happening in the park, for example habitat management.

iv. Other learning from the Salmons Brook catchment

- Project duration not long enough to create strong working relationships and partnerships, install features and measure quantifiable outcomes
- Reporting in March during the peak of the wet season means loss of a complete final season on which to report
- Reservations surrounding uptake of NFM among the farming community are common and therefore evidence and additional support from specialist advisors i.e. Farm and Wildlife Advisory Group (FWAG) or Natural England could benefit project progression.

6. APPENDIX

Appendix 1

Salmons Brook Catchment Hydraulic Modelling report, Revision B EdenVale Young 2021

With appendices:

A Hydraulic simulation;

B Salmons Brook Catchment Delineation Technical Memorandum;

C Salmons Brook, Harrow Headwaters, Rise Park Stream and Pymmes Brook NFM Modelling Calibration Report

Appendix 2

Slow Flow App questions