

# Bristol Avon Flood Strategy

## Natural Flood Management Assessment

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# Executive Summary

Bristol and its neighbouring communities on the banks of the River Avon are facing an increasing risk of flooding. An increase in storm frequency and intensity, as projected by climate change, could increase peak flows or may force tidal water to surge up the Severn Estuary. The predominant flood risk and potential for the most severe damage to much of the city centre is from high tides combining with storm surges.

As part of the Bristol Avon Flood Strategy and as agreed at the Strategic Outline Case, Natural Flood Management (NFM) measures to reduce peak river flows have been explored, in particular on smaller tributaries of the River Avon. Benefits of NFM include the potential to mitigate localised flood risk from pluvial and fluvial flooding within the study area, and wider benefits including enhancing habitat and sequestering carbon. Moreover, implementation of NFM aligns with the objectives outlined in the Bristol City Climate Change Strategy to achieve by 2030.

This report outlines the high-level assessment that has been undertaken to identify NFM opportunities throughout the River Avon catchment and estimate the storage and peak flow mitigation potential within its sub-catchments. As part of the assessment high-level cost and carbon sequestration calculations have been carried out for two sub-catchments of focus within the River Avon, the Brislington Brook and the Malago. A site visit validated the mapping through ground truthing of the identified NFM features, as well as identifying potential additional opportunities. This study demonstrates that delivery of NFM within sub-catchments of the River Avon reduces local watercourse peak flows in a 1% annual exceedance probability (AEP) (1 in 100-year) event.

The storage modelling results show that Brislington Brook could store 20,500m<sup>3</sup> within the catchment, with a downstream mitigated impact of 12.3% during a 1 in 100-year return period fluvial flood event. From the opportunity mapping, the Malago catchment was indicated to be able to store 6,000m<sup>3</sup>, with a downstream mitigation impact of 3.7% during a 1 in 100-year return period fluvial flood event. The site visit indicated that there may be potential for more ambitious NFM interventions within these catchments than those detailed by the opportunity mapping, which is underpinned by conservative assumptions.

High level cost and carbon sequestration calculations have been completed for the identified NFM opportunities for a 100-year scheme life, as part of the Bristol Avon Flood Strategy. The Malago and Brislington Brook NFM interventions PV costs are estimated at £476k and £823k respectively; and over a 100-year design life could be estimated to sequester 160.28 TCO<sub>2</sub>e/year and 305.43 TCO<sub>2</sub>e/year respectively.

This study has demonstrated that there is potential for NFM measures to be feasible within the Bristol City boundary. These could have impact on the watercourses within Brislington Brook and Malago catchments, reducing localised flood risk within the catchments. Further work is recommended to quantify the potential benefits to property and infrastructure in terms of flow reduction on the Brislington Brook and Malago. This can be done using existing hydraulic models for the two sub-catchments. Once it is confirmed that benefits can be achieved, it is recommended that high-level conceptual designs are developed alongside geospatial analysis for the areas identified in the site visits and used to produce updated storage volume potential and provide an understanding of viability in terms of site constraints. These volumes can then be tested using the ASM to determine any resulting reduction in peak flows.

Moreover, consideration should be given to changing the design storm return period for which the NFM is designed. For example, an NFM scheme could be designed to be optimal during for a lower return period event (e.g. 1 in 50 years), thus adding resilience to the catchment generally by being more effective for more frequent design storm events. It is recommended that other potential benefits such as biodiversity net gain and potential water dependent habitat delivery as part of implementing NFM should be quantified in line with the Bristol City Climate Change Strategies objectives, which will help with the business case development of any proposed schemes.

# 1. Introduction

Bristol City Council is working with the Environment Agency and other partners to create a vital long-term strategy for managing the flood threat from the River Avon, supported by The Capital Strategic Partner (consisting of Arcadis, Arup and Mott Macdonald). The strategy will outline action to be taken in phases to reduce the chance and impact of flooding from the River Avon, and how each phase will be funded. The Strategic Outline Case (SOC) for the Bristol Avon Flood Strategy was consulted on in 2020 prior to adoption by Bristol City Council and adoption by the Environment Agency.

Following consultation on the adopted Strategy, BCC agreed to explore opportunities for NFM within the Avon catchment and their impact on the wider Strategy.

## 1.1 Study Objectives

The aim of this study is to produce a high-level assessment of NFM, including the production of Opportunity Maps and a Hydrological Assessment of identified features to provide some degree of flood risk reduction in specific areas.

This study will provide clarity on the potential feasibility of NFM within the Bristol City Boundary. In particular, NFM has been considered within the Brislington Brook and The Malago sub-catchments within the Bristol City boundary.

## 1.2 Context of Study

### 1.2.1 Study Area

The River Avon flows through the major cities of Bristol and Bath to its confluence into the Severn Estuary at Avonmouth. The river drains parts of Gloucestershire, Wiltshire and Somerset. The River Avon catchment (Figure 1) is large, spanning approximately 2,230 km<sup>2</sup>. Within the Avon catchment there are numerous sub-catchments and smaller river tributaries and water courses, for example the Malago, Brislington Brook, and Frome.

The Bristol Avon is a tidal river, and as such the flood risk in Bristol is affected by rising sea levels and increased storm frequency and severity due to climate change, from increased flows in the river or tidal water surging up the Severn Estuary.

Text from the Strategic Outline Case for the Bristol Avon Flood Strategy (2020) regarding the predominant flood risk in the city is below:

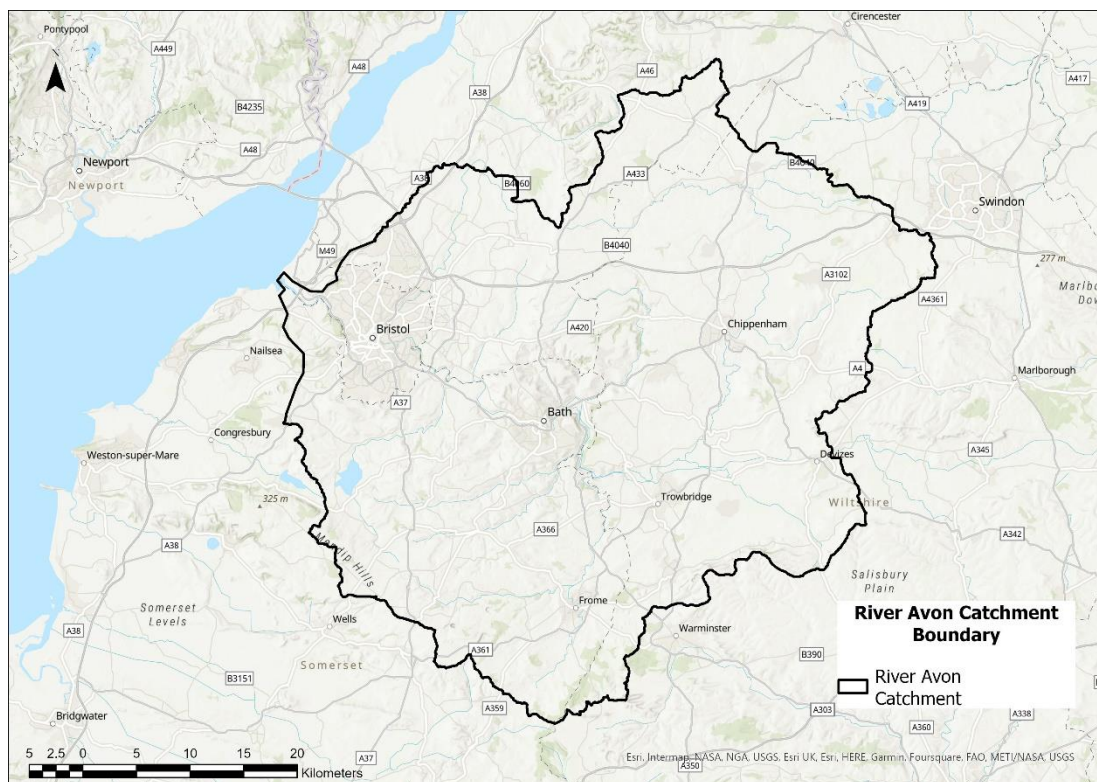
*'The predominant flood risk and potential for the most severe damage to much of the city centre is from high tides combining with storm surges. This forces water up the river, overtopping many low spots around the harbour and causing the Floating Harbour to flood properties.'*

The Bristol Central Area Flood Risk Assessment describes the tidal influence within the River Avon catchment:

*'The flow regime of the River Avon is tidally influenced as far upstream as Keynsham. Along this reach tidal water can cause tide-locking on tributaries draining to the Avon, including all of the study catchments.'*

The study catchments include Brislington Brook and the Malago. Brislington Brook and the Malago are Water Framework Directive (WFD) waterbodies, both from source to confluence with the River Avon water body. Both catchments score 'Moderate' on Ecological Classification, and both fail on the 'Chemical Classification'. Both of the catchments have land adjacent to the water courses located in Flood Zone 2 (land having between a 1 in 100 (1%) and 1 in 1,000 (0.1%) chance of flooding each year from rivers) and Flood Zone 3 (land with a 1 in 100 (1%) or greater chance of flooding each year from rivers).

The Bristol Avon catchment spans a large area and has numerous land use types within it. Bristol City is located to the west of the catchment, and is predominantly urban land cover, with other significant areas of urban land cover in Bath, Trowbridge, Chippenham, Corsham, Frome, Midsomer Norton and Devizes. The majority of the catchment, aside from the urban areas, is non-irrigated and permanently irrigated agricultural land, with small areas of forest towards the north and south of the catchment.



**Figure 1: Bristol River Avon Catchment Boundary**

### 1.2.2 Bristol Avon Flood Strategy

The key objectives for the Strategy were defined in the SOC as follows:

- To support safe living, working and travelling in and around central Bristol by ensuring flood threat is reduced and measures address residual risks.
- To facilitate the sustainable growth of Bristol and the West of England by supporting opportunities for employment and residential land, and infrastructure.
- To maintain natural, historic, visual and built environments within the waterfront corridor and where possible deliver enhanced recreational, heritage and wildlife spaces.
- To ensure navigation of river and marine activities continues.
- To ensure the strategy is technically feasible and deliverable.

As part of the option development for the SOC, measures that slow the flow upstream of Bristol to reduce peak flows were discounted due to the required scale of measures needed, and the fact that they would not address tidal flood risk.

BCC support NFM measures in upstream areas and work closely with the Avon Catchment Partnership to take a catchment wide approach. However, these techniques would not reduce tidal flood risk and the large size of the upstream river catchment makes this impractical for the Bristol Avon. Recognising that this is a long-term strategy, it was agreed at SOC stage that NFM measures that reduce peak river flows will be explored, in particular on smaller tributaries of the River Avon.

While NFM is not viable in addressing the risk from tidal flooding for the River Avon, it will be explored in the context of sub-catchments of the Bristol Avon, reducing localised catchment flood risk, and aiming to reduce peak flows of smaller water courses within the River Avon catchment. As well as considering potential additional benefits of NFM, such as carbon sequestration, and increasing resilience to climate change, in line with the City's Strategy, see Section 1.2.4. Brislington Brook and Malago are tributaries to the Bristol River Avon that are further assessed.

### 1.2.3 Consultation on the Bristol Avon Flood Strategy

In the development of the Bristol Avon Flood Strategy there was feedback sought from the local community and stakeholder groups from October to December of 2020. A consultation result report, Bristol Avon Flood Strategy Consultation Report<sup>1</sup>, was released in the January of 2021, summarising the views of community responses to the draft strategy, further information can be found about the consultation results in this report. There were 576 responses received, with overall strong support for the proposals in the draft, with positive support for the strategy regarding the aim to future proof the city and neighbouring communities, and strong support for the aim to enable a greener, more active city. The feedback also considered the integration of flood defences, with the responses showing support for integration, most strongly for combining flood defences with opportunities for green spaces and increased biodiversity, with a general consensus that protecting/enhancing the environment to benefit wildlife is important when considering the strategy and implementation of flood defences.

As part of the feedback, respondents were asked to consider any other suggestions for improvements that they thought should be considered. Of these responses, the most cited suggestion in the replies was Natural Flood Management, with over 40 respondents citing this. This highlights the communities' interest in seeing that NFM is considered as part of the Bristol Avon Flood Strategy.

A response to the consultation was issued in January of 2021, in the Responses to Consultation Analysis<sup>2</sup> report outlining what will be done in response to the feedback. Of particular relevance to this NFM assessment is the recognition that NFM will not reduce the tidal flood risk to central Bristol, however that the strategy will seek opportunities to implement NFM and funding to deliver them, citing a 2021 bid focused on NFM and green infrastructure schemes in the Frome catchment (a tributary to the Avon).

As well as the Bristol Avon Flood Strategy Consultation Report<sup>1</sup>, there was consultation of the voluntary Strategic Environment Assessment (SEA). The responses from this were reported on in February 2021, more detail of which can be found in the SEA Consultation Report<sup>3</sup>. There were 24 respondents to the SEA consultation, alongside the statutory consultees, who were Natural England, Environment Agency, Bristol City Council – Nature Conservation Officer (Planning), Wessex Water, and Historic England. In regards to NFM the Environment Agency have strongly encouraged the implementation of NFM techniques as part of the strategy, with Natural England also recommending to allow for flexibility in considering upstream NFM measures, with it being noted that an approach considering NFM could potentially significantly support the objectives of the Government's 25 Year Environment Plan.

### 1.2.4 Bristol City Climate Change Strategy

Bristol City have developed a Climate Strategy, Bristol One City, which outlines how Bristol plan to be carbon neutral and climate resilient by 2030. Bristol City have recognised within their climate strategy that the city is facing a climate emergency, and that there is a need to act now to reduce direct and indirect carbon

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<sup>1</sup> Bristol City Council and the Environment Agency (2021) *Bristol Avon Flood Strategy Consultation Report*. Available at: [434b20c02d31b41f2a1fa778e4b9697f\\_Bristol\\_Avon\\_Flood\\_Strategy\\_consultation\\_report.pdf \(amazonaws.com\)](https://www.amazonaws.com/434b20c02d31b41f2a1fa778e4b9697f_Bristol_Avon_Flood_Strategy_consultation_report.pdf) (Accessed: 13 January 2023).

<sup>2</sup> Bristol City Council (2021) *Bristol Avon Flood Strategy Responses to consultation analysis*. Available at: [3a219a679ff349541195ffe28ea04b58\\_You\\_Said\\_We\\_Did\\_-\\_Consultation\\_responses\\_and\\_outcomes.pdf \(amazonaws.com\)](https://www.amazonaws.com/3a219a679ff349541195ffe28ea04b58_You_Said_We_Did_-_Consultation_responses_and_outcomes.pdf) (Accessed: 13 January 2023).

<sup>3</sup> Bristol City Council (2021) *River Avon Flood Risk Management Strategy SEA Consultation Report*. Available at: [Report \(amazonaws.com\)](https://www.amazonaws.com/Report) (Accessed: 13 January 2023).

emissions to net zero. Bristol's climate vision is as follows, 'In 2030, Bristol is carbon neutral and climate resilient. We have collectively achieved a fair and inclusive transition; capturing the opportunities of new jobs and investment, improved health, wellbeing and education, and a better environment for local people. We have helped lead the way to a safer global climate.'

The Climate Strategy has natural environment themes, with two specific goals within it:

*'2030 goal: The natural environment in Bristol will be restored, protected, and enhanced to deliver climate change benefits'*

*'2030 goal: As the climate changes, we will adapt to limit damage to wildlife, whilst supporting opportunities for recovery and protection of species'*

Within these goals there are objectives that have been set to help reach the goals:

- **2030 Objective (i)** - All new developments use appropriate blue and green infrastructure to protect from future climate events whilst also providing ecological net gain and enhancing the sequestration potential of all developments.
- **2030 Objective (ii)** - The city's natural environment (including canopy cover and biodiversity) has been restored, preserved, and enhanced to maximise carbon sequestration in carbon sinks, climate resilience and health and wellbeing.
- **2030 Objective (iii)** - Everyone lives and works within a 10-minute walk of a quality green space with sufficient tree canopy cover to provide refuge for citizens during climate change induced extreme heat conditions.
- **2030 Objective (iv)** - Bristol businesses and organisations are wildlife friendly by providing habitats, birdboxes or sponsoring the development of green infrastructure in an effort to recover wildlife lost as a direct result of climate change or urbanisation.

The implementation of NFM within Bristol would help to contribute towards these objectives while also helping to reduce flood risk within the city. In particular, NFM has the ability to contribute to carbon sequestration and improve local habitats to help provide ecological net gain. NFM will be a key element in Objective (i) as new developments will need to use appropriate blue and green infrastructure, which NFM could play a key role in. Implementing NFM and Nature Based Solutions to reduce flood risk will contribute to Bristol's goals within the city's Climate Strategy and its aim to be carbon neutral and climate resilient by 2030.

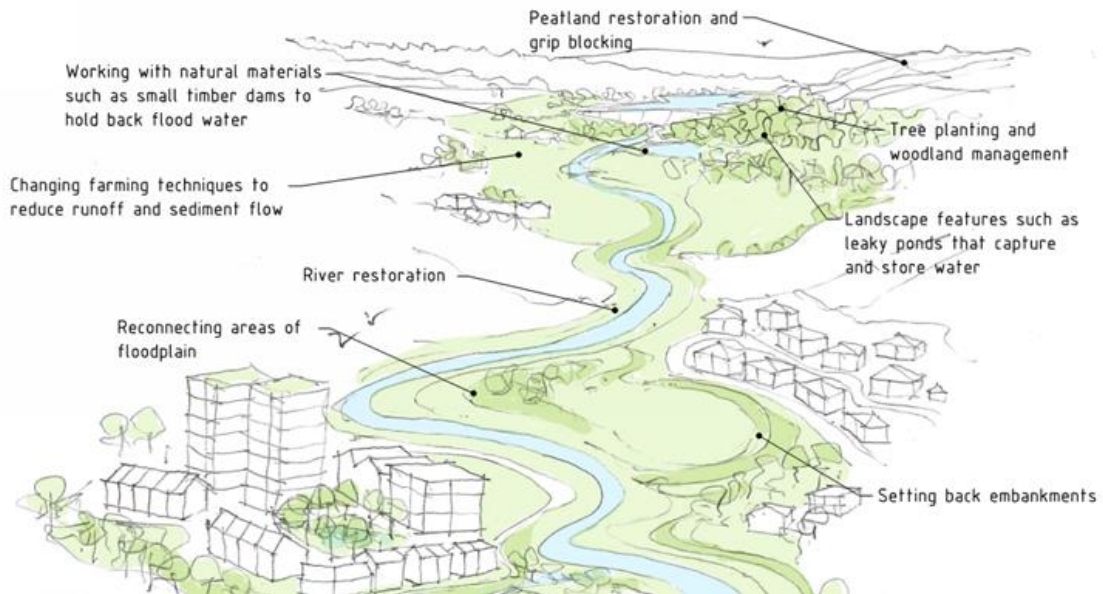
### 1.2.5 Natural Flood Management

NFM is the alteration, restoration, or use of landscape features to reduce flood risk<sup>4</sup>. Working with Natural Processes (WWNP) and NFM is a form of flood risk management that can be adopted throughout a catchment, being implemented on hillslopes, rivers, floodplains, estuaries and coasts as show in Figure 2<sup>5</sup>.

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<sup>4</sup> POST. (2011). Natural Flood Management POSTNOTE 396. London, England: Parliamentary Offices of Science and Technology.

<sup>5</sup> Environment Agency (2018) Working with Natural Processes – Evidence Directory.  
[https://assets.publishing.service.gov.uk/media/6036c5468fa8f5480a5386e9/Working\\_with\\_natural\\_processes\\_evidence\\_directory.pdf](https://assets.publishing.service.gov.uk/media/6036c5468fa8f5480a5386e9/Working_with_natural_processes_evidence_directory.pdf)



**Figure 2 – NbS Measures (Arup, 2016)**

There are arguments that support the restoration of catchments through ‘Rewilding’, allowing natural processes and native species to reclaim their position in large areas of land. NFM can take a more ‘engineered’ approach to deliver many small landscape interventions that intercept and attenuate hydrological flow pathways to emulate natural processes and provide multiple benefits, including flood management and improving water quality. The design philosophy is to create features that ‘slow, store and filter’ runoff and peak flow in the landscape<sup>6</sup>. Figure 3 shows an idealised storm hydrograph, which has had its shape altered through attenuation from NFM.

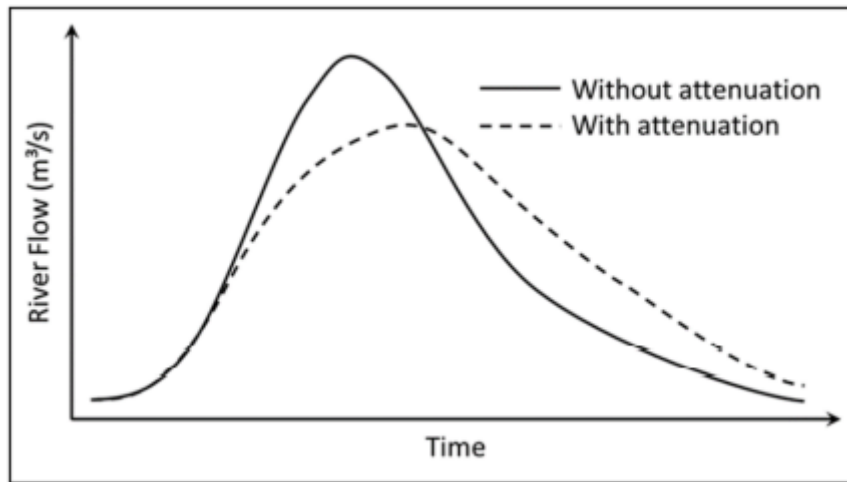
NFM has limitations that should be understood by catchment stakeholders. Choosing locations for features, developing landowner engagement, and providing maintenance of numerous assets is not always straightforward. As a result, NFM should be considered as a wider catchment-based approach to work alongside traditional forms of flood defence.

NFM has the potential to increase resilience of other proposed measures by attenuating flood flow, capturing sediment before it enters the watercourse<sup>7</sup>, creating habitat, carbon sequestration, and increasing climate change resilience. Examples include better land use management and catchment-wide water storage (for example, the runoff attenuation approach in Belford, Northumberland<sup>8</sup>).

<sup>6</sup> Nicholson, A. R., Wilkinson, M. E., O'Donnell, G. M. & Quinn, P. F., 2012. Runoff Attenuation Features: A sustainable flood mitigation strategy in the Belford Catchment, UK. *Area*, 44(4), pp. 463-469.

<sup>7</sup> Barber, N. J., & Quinn, P. F. (2012). Mitigating diffuse water pollution from agriculture using soft-engineered runoff attenuation features. *Area*, 44(4), 454-462.

<sup>8</sup> Quinn, P. et al., 2013. Potential use of Runoff Attenuation Features in small rural catchments for flood mitigation: Evidence from Belford, Powburn and Hepscott, s.l.: Joint Newcastle University, Royal Haskoning and Environment Agency Report



**Figure 3: Attenuating flow in a hydrograph**

Numerous NFM solutions were considered within the Bristol Avon catchment; including:

- Runoff Attenuation Features (RAFs)
- Floodplain reconnection
- Gully Stuffing
- Large Woody Debris (LWD)
- Soil Management
- Buffer Strips
- Tree Planting
- Wet Woodland

Peat Management and Grip Blocking were also considered but upon investigation were not appropriate interventions due to the lack of peatland in the Bristol Avon catchment.

More detail on these measures, including examples, can be found in Appendix A.

### **1.3 Previous Studies**

There have been previous studies assessing the potential for NFM within the Bristol Avon catchment. Bristol Avon Rivers Trust (BART) have carried out a detailed survey of potential NFM opportunities within Brislington Brook, and Atkins have produced opportunity maps and hydrographs for the Frome catchment for a number of scenarios.

#### **1.3.1 Bristol Avon Rivers Trust (BART)**

BART carried out a walkover survey on the 18<sup>th</sup> December 2019 of the Brislington Brook, from its headwaters to its confluence with the River Avon. The Brislington Brook catchment is located south of the River Avon, with its headwaters originating near Whitechurch and Hengrove, which join near to Brislington before its confluence with the Avon. The survey split the Brook into a series of Reach Maps, with specific NFM features identified and recommended for each area. The study considered a range of features at specific site relevant scale such as:

- Storage features such as ponds and bunded areas
- Planting up buffer zones
- Leaky dams in parts where the brook is narrower
- Bunds in fields near to the Whitechurch headwater

- Re-profiling areas of the bank along the Brook
- Tree planting in corners of nearby fields
- Re-diverting the watercourse into the channel if it is disconnected
- Offline storage ponds
- Reconnect the floodplain with leaky dams
- Re-profile the banks to connect to the floodplain
- Address issues of golf course management where the Brook runs alongside
- Swales at the bottom of sloped pitches
- Sky lighting of bank vegetation
- Installing woody debris structures
- Tree planting along areas of the bank
- Community engagement to promote care for the brook
- Re-meandering the channel

Different features were recommended for the various reaches, reflecting the changes in condition of the Brook throughout the catchment. Figure 4 shows part of the Brislington Brook watercourse. The study examines both the potential impact to improve flood risk within the catchment, with a focus on the flood zones, as well as measures to improve water quality in the Brook, considering the bodies WFD class. The study is qualitative with specific flow or quality improvements not quantified.

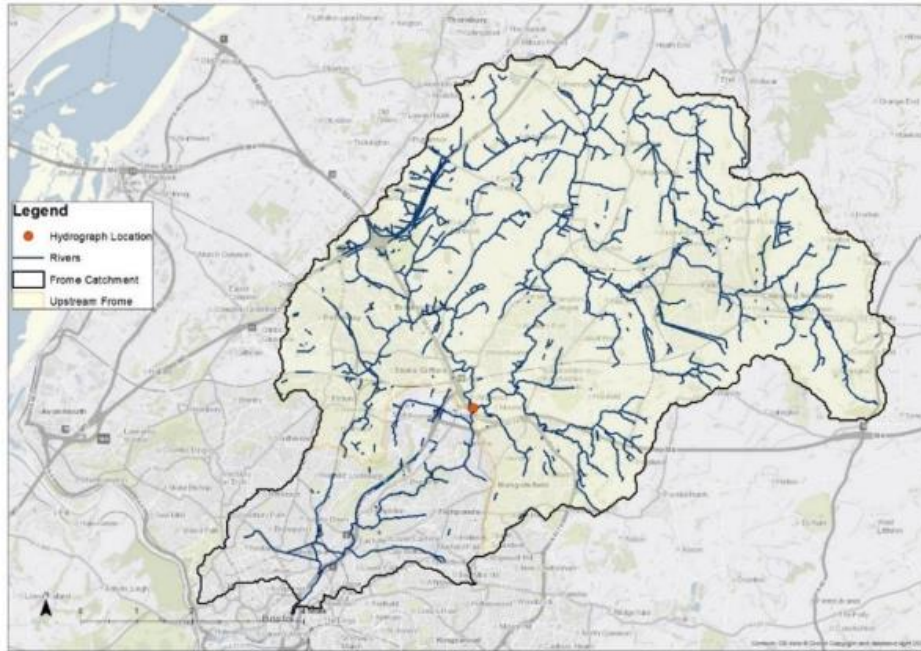
The storage potential has not been quantified for these measures, with BART recommending developing a programme of work to identify natural processes that occur within the catchment for both frequent and extreme storm events and to identify potential NBS for their management.



**Figure 4: Brislington Brook watercourse section**

### 1.3.2 Atkins River Frome Catchment Report

Atkins carried out an analysis of potential NFM opportunities in the Frome catchment. The Frome catchment, see Figure 5, is a large catchment, with an estimated extent of 145km<sup>2</sup>. The catchment is north of the River Avon, extending north to just south of Wickwar, east to near Dodington by the M4, west to near Catbrain, with the outfall of the catchment at Castle Park. The study's aim was to estimate the benefits that NFM could provide across the Frome catchment. The method of analysing the catchment had three distinct stages, opportunity mapping, hydrological assessment, and looking at the nature capital and multiple benefits NFM could bring.



**Figure 5: Frome catchment map from the Atkins River Frome Catchment Report (with Revitalised Flood Hydrograph (RefH) Model information)**

Opportunity mapping was carried out for the catchment, with a map produced for each of the NFM intervention types, which were Land Use Change, Flow Pathways, and In Channel and Floodplain opportunities. From these maps, a combined opportunity map considering all three of the intervention types was produced. A hydrological assessment of NFM Scenarios was carried out using a Daily Based Morgan-Morgan-Finney (DMMF) model, for the scenarios identified and for four different return period events. The scenarios considered were in the three categories of land use change, flow pathway measures, and in-channel and floodplain attenuation measures, with specific measures considered within each category of NFM measures.

#### The three categories of NFM Intervention Types

- 1) Land use (and management) change
  - a) Scenario 1 – Land-use change
  - b) Scenario 2 – Woodland Creation
  - c) Scenario 3 – Soil Recovery
- 2) Flow pathway interventions
  - a) Minimum bunds within the catchment
  - b) Maximum bunds within the catchment
- 3) In-channel and floodplain attenuation

Example measure of this type is woody features in a watercourse, with interest surrounding this measure alongside the potential of a Stage 0 river restoration in the Frome catchment.

Total runoff reduction for a 1 in 100-year return period for each of the scenarios was calculated, and overall minimum and maximum storage volumes calculated for the combinations of these. A series of hydrographs were produced for the scenarios and return periods considered.

An assessment of the potential Natural Capital and Multiple other benefits that NFM could deliver are quantified within the report, with the method for this consistent with Defra’s Enabling a Natural Capital Approach (ENCA) guidance, however, it is not a formal account and the assets have not been explicitly measured. The assessment considered Air Quality, Biodiversity, Carbon, Flood, Food, Recreation, and Water Quality. This gave monetary values for each of the scenarios in terms of potential benefits.

The majority of the available opportunities identified for NFM in the catchment are in the North, centre and east of the catchment, which is largely of the land types of pastures and non-irrigated arable land.

### 1.3.3 Summary

Both the BART and Atkins reports indicate that there are feasible NFM opportunities within the River Avon catchment. The Atkins report considers wider opportunities within the whole Avon catchment; however, the Frome sub-catchment is not a focus of this report. The BART report is a detailed survey of Brislington Brook, which is a catchment further assessed within this report.

### 1.3.4 Ongoing Work in the Frome

While the Bristol Frome catchment is not being assessed within this report there is ongoing project development within the catchment. The Resilient Frome<sup>9</sup> project has six overarching aims, one of which is to install natural flood management in the Frome headwaters. The project is currently investigating the feasibility of NFM solutions, with the aim to then prepare a Full NFM Business Case, with the long-term project aim of showing and quantifying the benefits of NFM measures. NFM is being considered in wider areas of the Bristol Avon catchment.

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<sup>9</sup> Environment Agency (2022) *Resilient Frome*. Available at: <https://engageenvironmentagency.uk.engagemthq.com/bri001-frome> (Accessed: 13 January 2023).

## 2. Methodology Overview

This section provides a high-level overview of the methodology followed for this study. More detail is provided for each section in the Appendices.

It was agreed at SOC stage that NFM measures that reduce peak river flows will be explored, in particular on smaller tributaries of the River Avon. This study focusses on flow reduction with Brislington Brook and the Malago catchments within the River Avon catchment. The study methodology followed this structure:

1. Understanding catchment context and previous studies – A high-level catchment study was undertaken and a review of previous studies within the Avon and specific catchments within the River Avon catchment.
2. Opportunity Mapping – Assessing NFM feasibility through an ArcGIS Toolbox and an Arup developed Feasibility Assessment Tool (FAT)
3. Site Visit – A site visit of the Brislington Brook and Malago catchments was undertaken to ground truth the identified NFM opportunities and undertake an opportunity survey.
4. Aggregate Storage Model – Assessing the storage capacity and impact on catchment flows within the Aggregate Storage Model (ASM), in this study the decrease in catchment peak flows is of interest.
5. High-level cost and carbon sequestration calculations – high-level calculations for both of the catchments and sub-catchments within them.

For this study the proposed Standard of Protection is 1 in 100-year for fluvial flows for the Outline Business Case. The methodology outlined above allows assessment of NFM impacts within Brislington Brook and the Malago catchments.

## 3. Opportunity Mapping

### 3.1 Methodology

ArcGIS software has been used to spatially analyse the entire Bristol Avon catchment in order to undertake coarse NFM Opportunity Mapping. The GIS analysis is based on a variety of data sources and analytical tools. A more detailed methodology can also be found in Appendix B.

The Opportunity Mapping process is a methodology to ‘score’ each NFM intervention within a catchment. This is first done by an ArcGIS Toolbox, that spatially analyses the catchment. Identifying slope and runoff potential within the catchment, from a range of data sources, including land cover, flood risk and LiDAR DTM data. A 250m by 250m (6.25ha) fishnet grid is then applied to the catchment, where each grid is then assigned values for a range of aspects, such as slope, runoff route length, flood zone percentage, land use percentages, based on the spatial analyse from the ArcGIS Toolbox.

The geospatial analyses from the ArcGIS Toolbox are then exported into an Arup developed Feasibility Assessment Tool, where the feasibility of the range of NFM features is scored per grid. From this analysis, the highest scoring NFM intervention for each grid cell is shown on the map, where a ‘threshold’ score is then applied, to avoid overestimating NFM potential. The range of NFM measures considered for the Bristol Avon catchment is detailed in Appendix A. The output opportunity map then shows the NFM opportunities that have been identified across the catchment, with a score above the threshold. Any grid square where the threshold score is not exceeded is then left blank, with no measure identified.

From this output map insights can be gathered relating to proposed opportunities and baseline conditions. The insights that can be gathered are:

- Potential new storage
- High-level net change in carbon sequestration potential (compared to baseline)
- High-level net change in habitat areas (compared to baseline)
- Scheme construction costs
- Data that feeds into the Aggregate Storage Model (ASM) tool, which is an Arup-developed hydrological routing model designed to help understand potential flow reduction during design events from NFM interventions. In this case the ASM will be applied to The Malago and Brislington Brook sub-catchments.

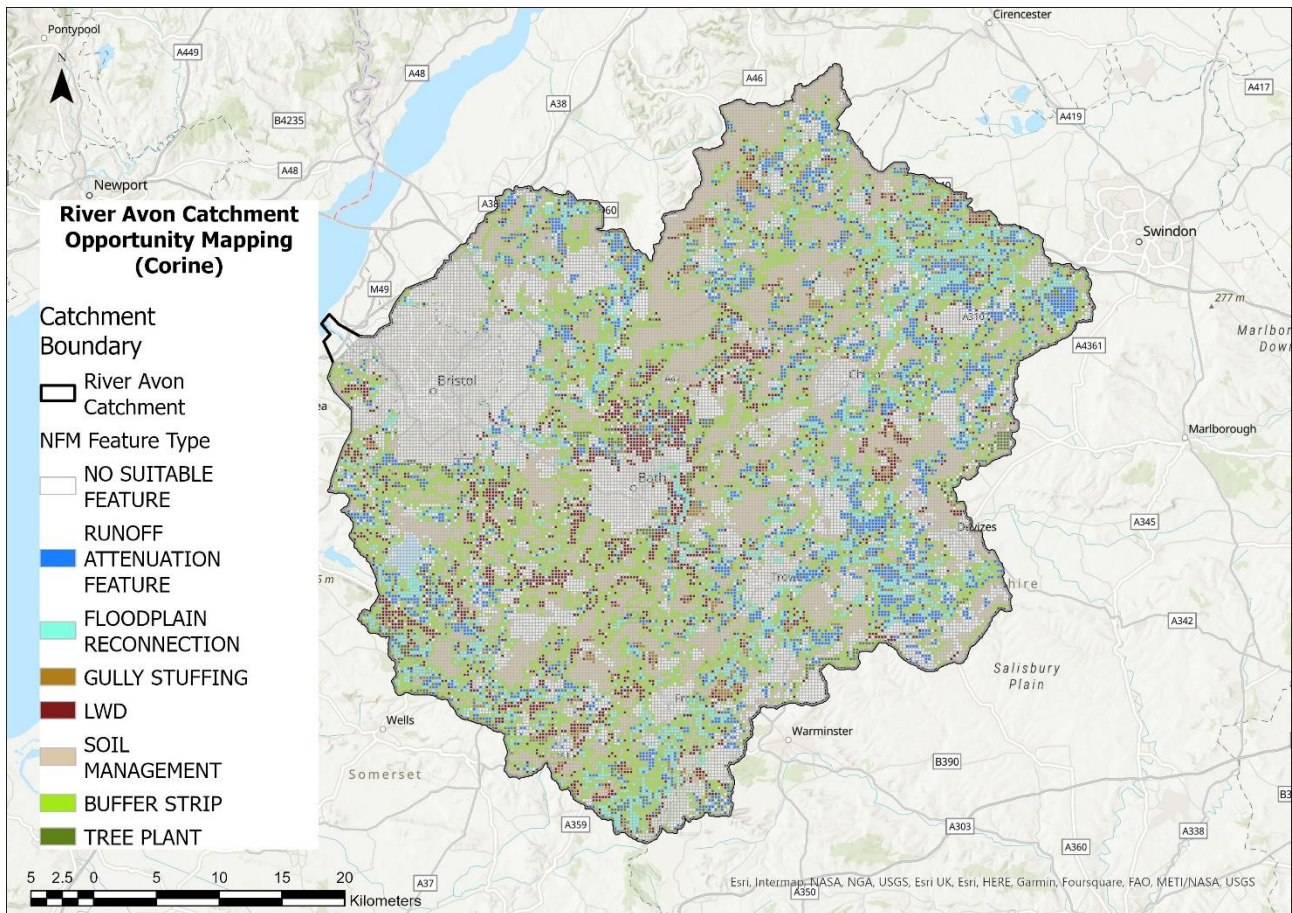
Refer to Appendix B for further details of the Opportunity Mapping methodology.

## 3.2 Results

The outcome of the GIS analysis and the Feasibility Assessment Tool is the production of opportunity maps for the catchment, showing the most suitable intervention-type for each fishnet grid square based on a number of scenarios e.g., thresholds applied to the NFM intervention score produced by the analysis.

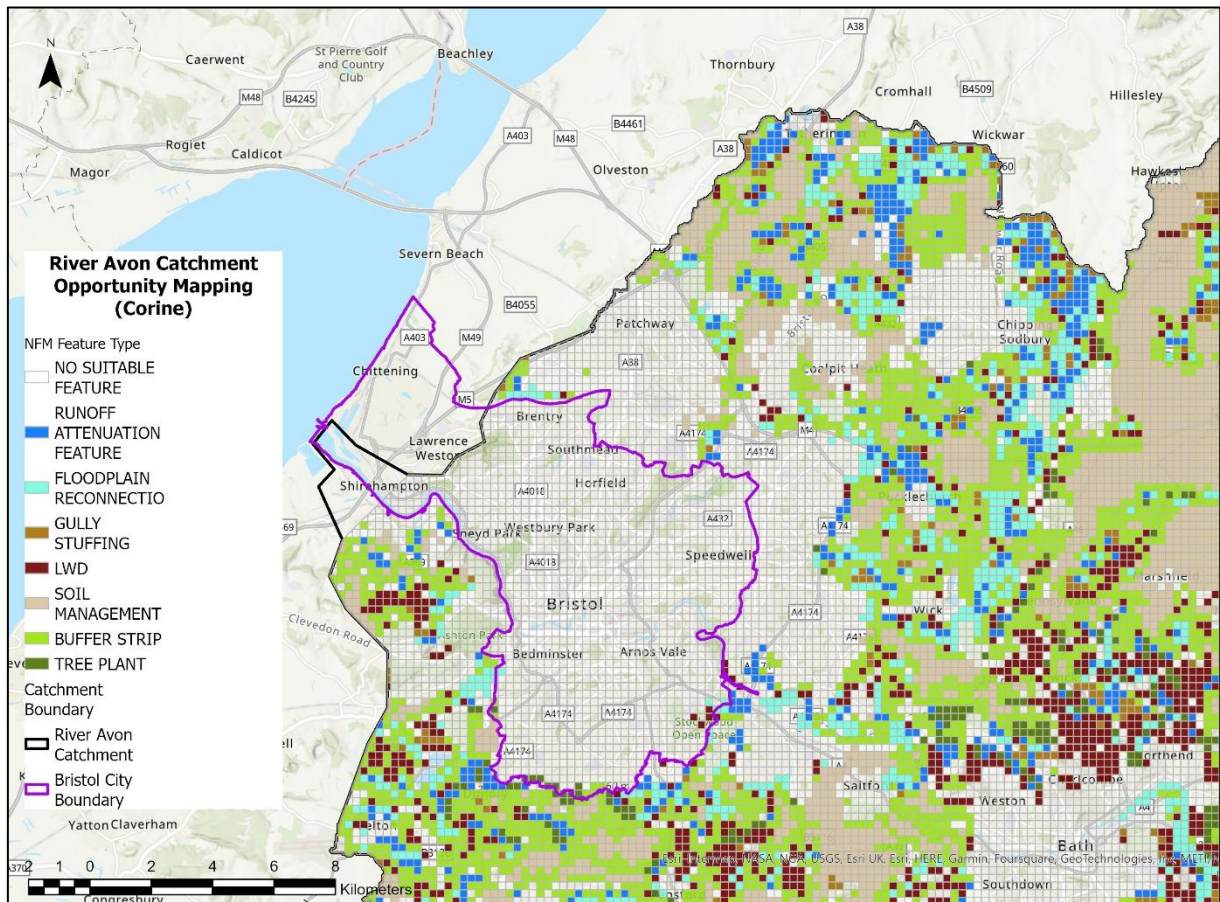
For the ten types of NFM considered (2 of which do not apply to the context of the Bristol Avon catchment as mentioned in 1.2.5), the highest scoring ‘NFM-type’ was selected for each grid square. To prioritise the areas within the catchment with the highest NFM potential, a threshold was applied to the fishnet (out of 5). The score for each grid had to be reached or exceeded for a NFM intervention to be selected in that grid square.

A whole catchment Opportunity Map, using the Corine 2018 Land Cover dataset, was produced for the Bristol Avon catchment (Figure 6), and the Bristol City Boundary overlayed onto the output map, in pink, see Figure 7. There were limited NFM opportunities identified in Bristol when using the default weightings and score thresholds.



**Figure 6: Opportunity Mapping of the Bristol River Avon Catchment using Corine Land Cover Maps with a threshold above 3.4**

Across the Bristol Avon catchment, seven of the eight NFM feature types have been identified as suitable, as seen in Figure 6. Large areas of soil management have been identified, as well as significant areas of Buffer Strips and Floodplain Reconnection. There are also clusters of RAFs towards the edges of the catchment, and a number of LWD also identified. There are limited options for Tree Planting and Buffer Strips.



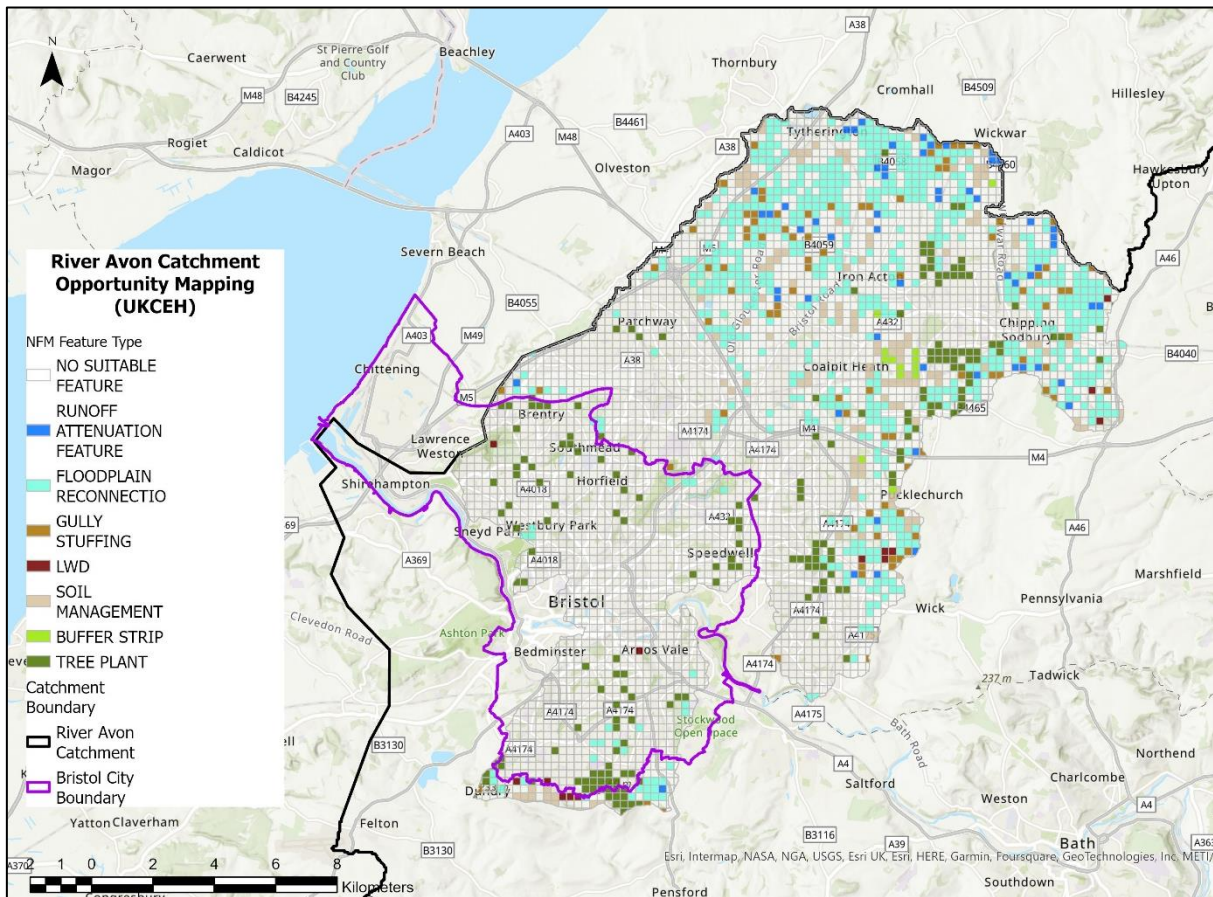
**Figure 7: Bristol City Boundary Overlaid on the Corine Opportunity map**

Figure 7 overlays the Bristol City Boundary over the opportunity mapping when the spatial analysis has used Corine as the Land Cover dataset. There are limited opportunities identified within the city boundary, with several grid squares prioritised for tree planting, LWD and floodplain reconnection. This small number of features identified would not achieve the intended outcome for the Bristol Avon Flood Strategy. It is useful to investigate the potential of NFM installed outside of the city boundary.

It was decided to rerun the opportunity mapping analysis using a higher resolution land cover dataset. The UK Centre for Ecology and Hydrology (UKCEH) Land Cover Map 2019 was used in replacement of Corine 2018. The UKCEH Land Cover Map (2019) has fewer land cover classes but has a higher resolution output; UKCEH 2019 data has a 20m resolution compared to Corine 2018 which has a resolution of 100m. As well as changing the land cover dataset, the weightings for the NFM scores were also altered. See Appendix B for more detail.

The weighting of the Agricultural Land Classification (ALC) data was reduced from 20% to 5% in the multi-criteria analysis, due to the land inside the Bristol City Boundary almost solely being classified as ‘Urban’ or ‘Non-Agricultural’ and therefore giving limited NFM opportunities in these categories. The changes in the analysis identified more NFM opportunities within the Bristol City Boundary. Figure 8 shows the Opportunity Map for the Bristol Avon Catchment using the UKCEH land cover data and updated matrix weightings. The area that this opportunity map was produced for does not cover the whole Avon catchment, it has focused on the WFD sub-catchment areas surrounding the Bristol City Boundary.

Tree planting has been identified in more areas throughout, and a cluster of measures have been identified towards the south of the city boundary, in particular tree planting and floodplain reconnection.



**Figure 8: Opportunity Map for part of the Bristol Avon Catchment using UKCEH Land Cover map, above a threshold of 3.6**

It is important to note that although the opportunity maps show the most suitable (highest scoring) intervention for each grid square in the Avon catchment, this does not mean that other interventions are not also suitable in each grid cell. This also applies to the areas marked as ‘no suitable feature’ within the Avon catchment. It does not mean NFM interventions are unfeasible in these areas, only they are not the preferred locations for the selected NFM interventions due to underlying catchment characteristics and the threshold score used to produce the map.

Due to the large scale of measures that would be required to target peak flows on the Avon, and the fact they would not address tidal flood risk, smaller catchments within the River Avon catchment are the focus of this assessment. Brislington Brook and the Malago catchments are assessed within this report, with the aim to explore reducing local flows of the watercourses within these catchments. The location of the catchments can be seen in Figure 9, with Figure 10 showing a closer image.

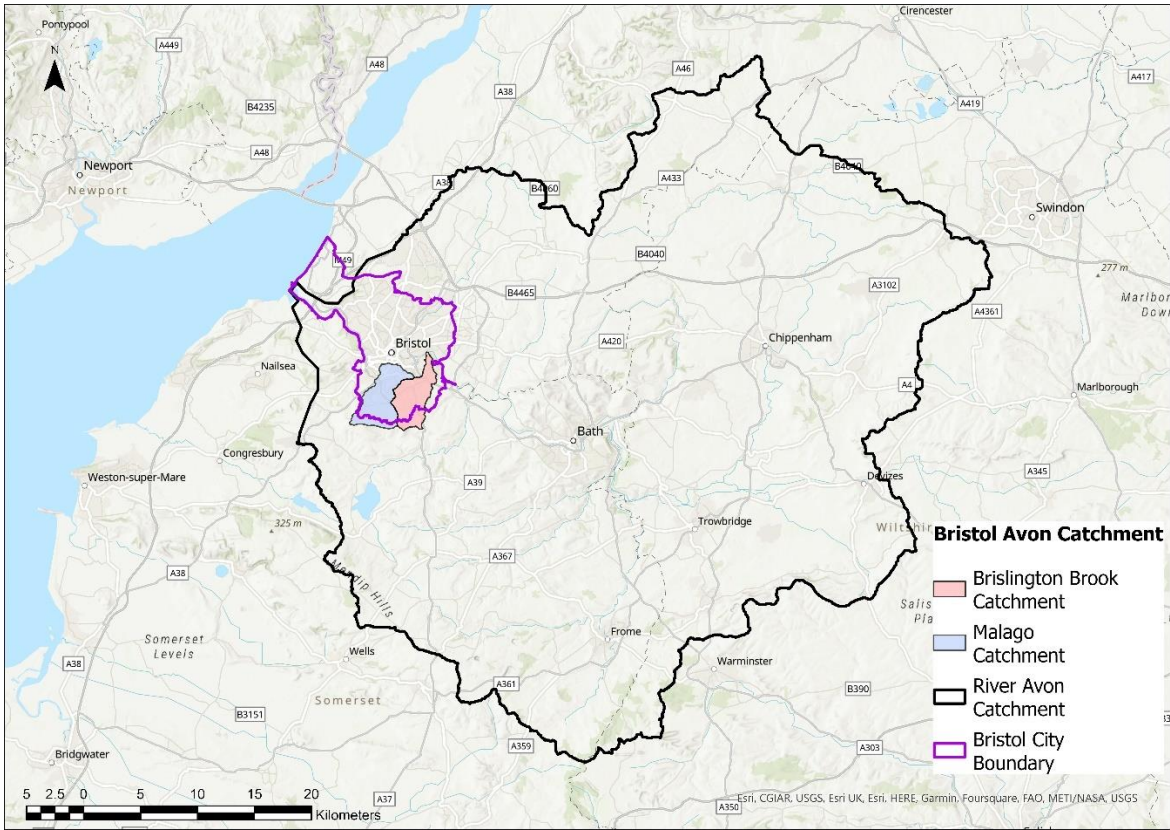


Figure 9: Location of Bristol City Boundary and catchments

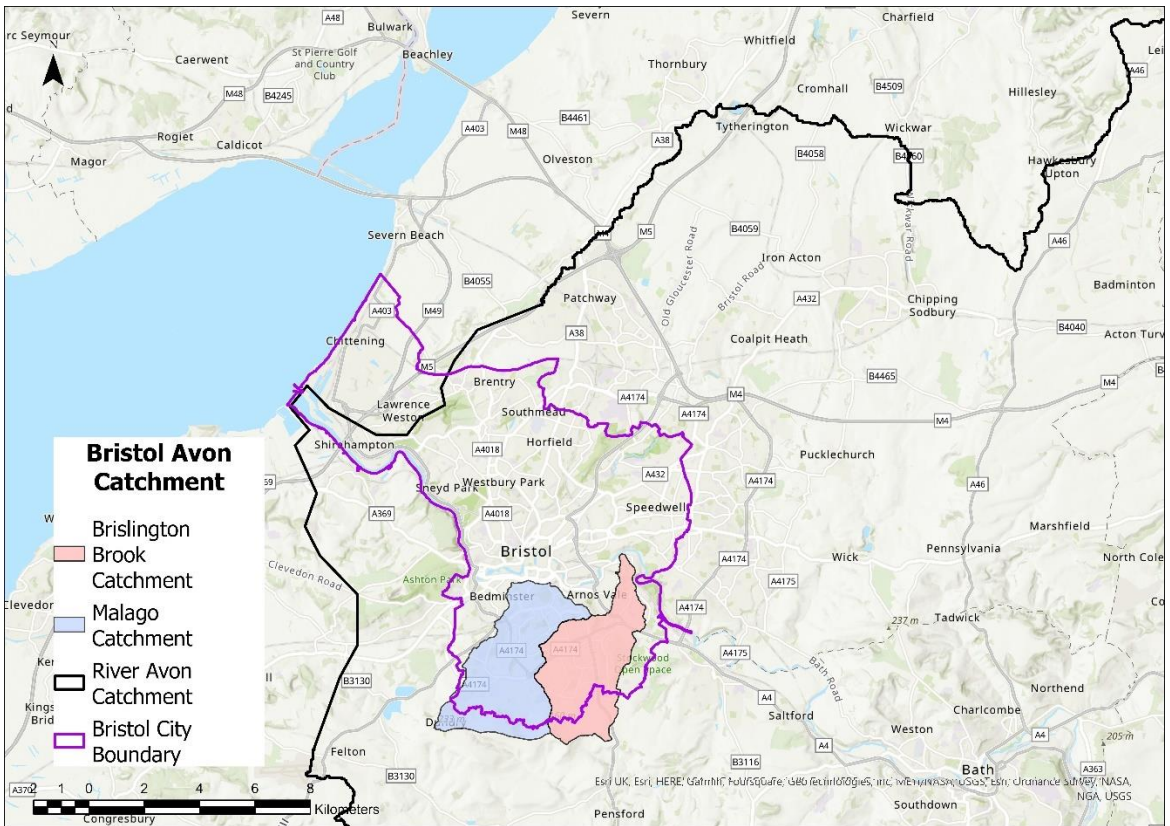


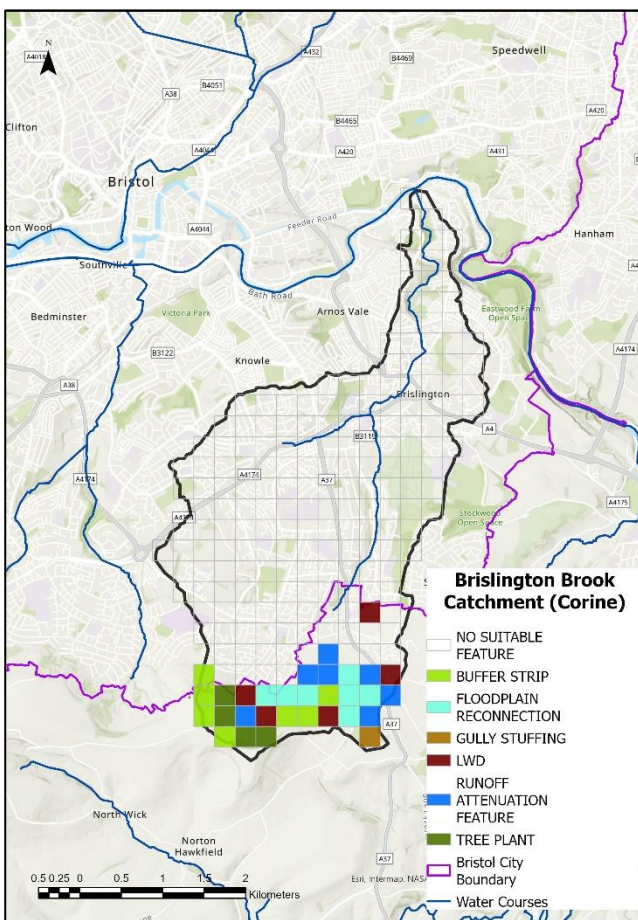
Figure 10: Location of Brislington Brook and Malago within the Bristol River Avon catchment

### 3.3 Brislington Brook and The Malago

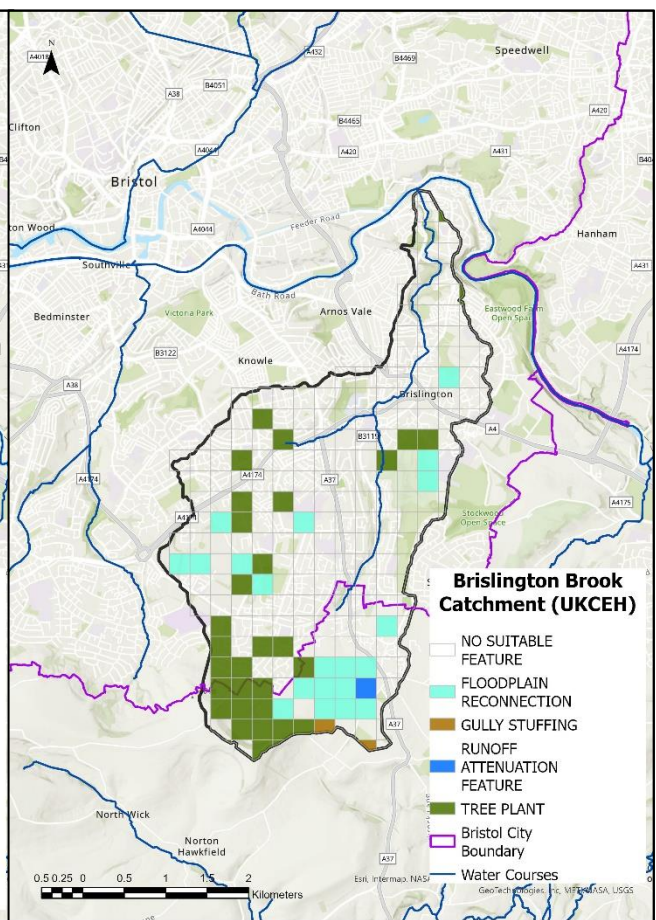
#### 3.3.1 Brislington Brook

The Brislington Brook catchment is located towards the south of the Bristol City Boundary, adjacent to The Malago sub-catchment, see Figure 10. The catchment has an area of 13.7 km<sup>2</sup>. Brislington Brook is formed of two tributaries that confluence within Brislington, before discharging into the Avon. Brislington Brook has been artificially modified, with sections culverted, artificially straightened, and banks incised.

Figure 11 shows the results of the opportunity mapping when using Corine 2018 as the land cover map. A threshold score of 3.4 has been used for the Corine opportunity map. The identified NFM measures are clustered almost completely at the south of the catchment, with the measures identified largely buffer strips, LWD, RAFs and floodplain reconnection. There are no measures identified in the downstream of the catchment, and the majority of measures fall outside of the Bristol City Boundary.



**Figure 11: Opportunity Mapping for Brislington Brook using Corine Land Cover Mapping, over a threshold of 3.4**

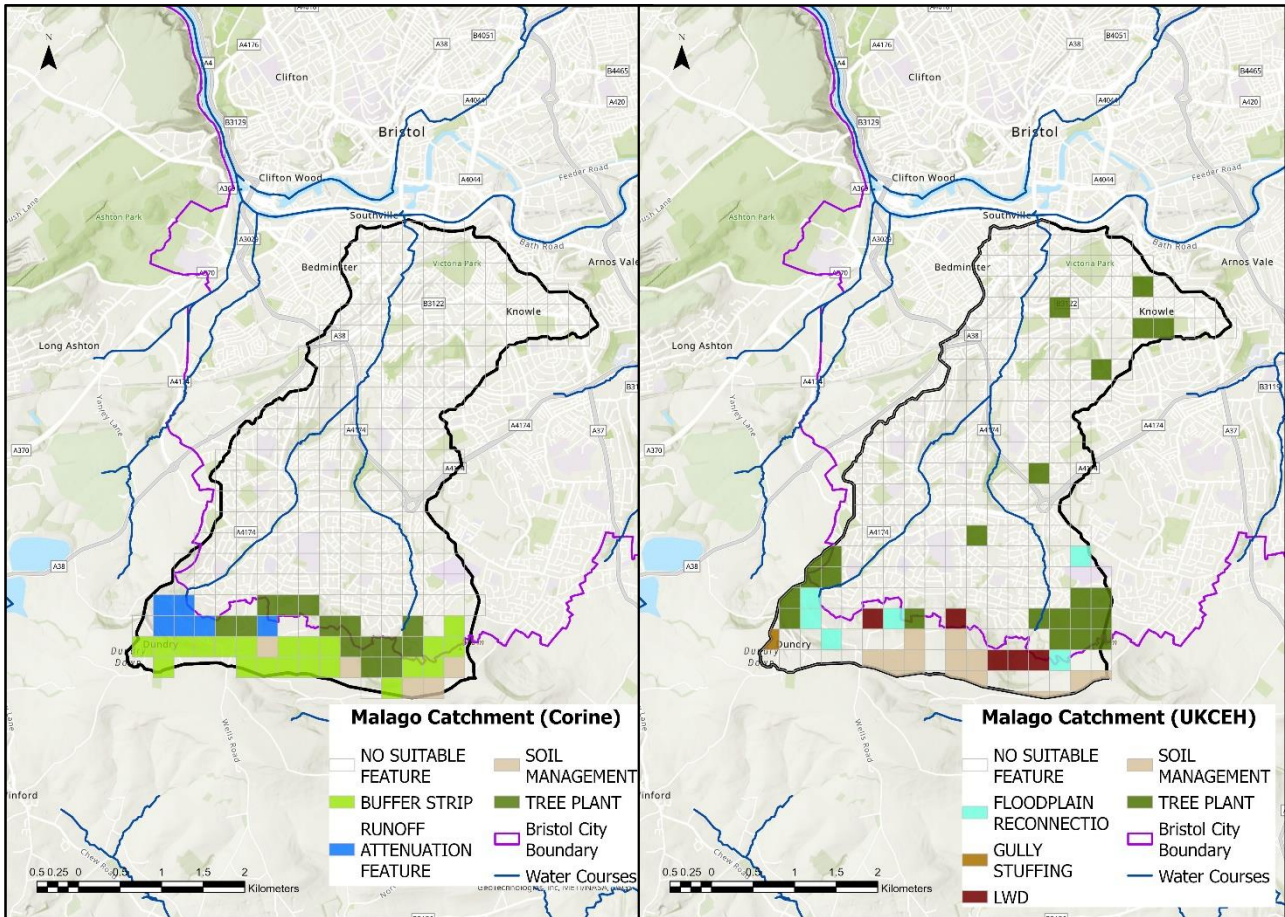


**Figure 12: Opportunity Mapping for Brislington Brook using UKCEH Land Cover Mapping, over a threshold of 3.6**

shows the results of the opportunity mapping when using UKCEH Land Cover Map as the land cover map and a threshold score of 3.6 has been used. Of the types of NFM considered, four have been identified as suitable within the Brislington Brook catchment when using the UKCEH Land Cover Map. A threshold score of 3.6 has been used for the UKCEH opportunity map, rather than a threshold of 3.4 as a result of the high resolution data. Tree planting is the most common measure identified, with floodplain reconnection also being identified as a suitable intervention throughout the catchment. One RAF feature has been identified, with two Gully Stuffing features at the south of the catchment. There are more NFM measures identified within the city boundary, largely towards the south and west of the catchment. Figure 12 is the opportunity map that has been used as the main basis for further hydrological analysis within the sub-catchment.

### 3.3.2 The Malago

The Malago sub-catchment is located towards the south of the Bristol City Boundary, adjacent and to the west of Brislington Brook sub-catchment, see Figure 10. The catchment has an area of 15.63 km<sup>2</sup>, and has three smaller sub-catchments within it, Upper Malago, Lower Malago, and Pigeonhouse. These sub-catchments are shown more clearly in Figure 26 in Section 5.1. The Malago is a tributary to the Avon, with the main tributary being the Pigeonhouse watercourse. Much of the watercourse has been modified as it flows towards the city.



**Figure 13: Opportunity Mapping for Malago using Corine Land Cover, above a threshold of 3.4**

**Figure 14: Opportunity Mapping for Malago using UKCEH Land Cover Mapping, above a threshold of 3.6**

Figure 13 shows the results of the opportunity mapping when using Corine 2018 as the land cover map. A threshold score of 3.4 has been used for the Corine opportunity map. The identified NFM measures are clustered at the south of the catchment, with buffer strips being the predominantly identified NFM measure, with tree planting the second most prioritised. RAFs have been identified in the southwest of the catchment, as well as soil management. There are no measures identified in the downstream of the catchment, and very few identified within the Bristol City Boundary.

Of the types of NFM considered, five have been identified as suitable within The Malago catchment when using the UKCEH Land Cover Map, see Figure 14. A threshold score of 3.6 has been used for the UKCEH opportunity map. Tree planting is the most common measure identified, with measures identified throughout the catchment, and soil management also being identified as a suitable intervention, particularly in the south of the catchment. Floodplain reconnection and LWD have also been identified in the south of the catchment. There are more NFM measures identified within the city boundary, largely towards the south and east areas of the catchment. This is the opportunity map that has been used as the main basis for further hydrological analysis within the sub-catchment.

### 3.4 Outputs

The outputs from the opportunity maps have been used to inform the next phase of the assessment, estimating the impact of storage based NFM interventions on flood risk. A conservative approach has been adopted, assuming that only floodplain reconnection and RAFs contribute storage potential within the sub-catchment areas. The analysis is based on the assumption that for every 6.25ha (250 m x 250m) grid cell in which an NFM storage feature is identified, one such intervention is implemented based on the assumed storage volumes outlined in Table 1. These comprise a high-level assessment of potential storage volumes based on literature<sup>10</sup> and experience for similar NFM assessments for catchments within the British Isles. The number of RAFs and floodplain reconnection grid cells are carried through to the ASM tool on the condition that the cell for which the interventions have been identified is equal to or greater than 25,000m<sup>2</sup> (40% of the total cell area). This is a conservative assumption to ensure the cell is large enough to hold the identified feature.

**Table 1: The potential storage volumes of individual NFM interventions**

Intervention	Storage Capacity (m <sup>3</sup> )
Runoff Attenuation Feature (1m high)	500
Floodplain Reconnection	1,000

**Note** - within each grid square it has been assumed that it is possible to place only one storage intervention. In reality, it may be possible to place more, or none. This is considered a conservative estimate. Moreover, an assumption has been made that if any portion of a grid square which falls within the catchment boundary and has been highlighted to be suitable for a RAF or Floodplain Reconnection feature, then the full storage value in the above table has been included in the assessment of storage potential.

**These storage volumes are designed to be rough estimates, suitable only for a high-level assessment. Particular catchment-specific characteristics and localised constraints are not possible to be accurately assessed at this level without more detailed analysis.**

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<sup>10</sup> Nicholson AR, O'Donnell GM, Wilkinson ME, Quinn PF. The potential of runoff attenuation features as a Natural Flood Management approach. J Flood Risk Management. 2019:e12565. <https://doi.org/10.1111/jfr3.12565>

## 4. Site Visit

A ground truthing and opportunity survey was undertaken in the Brislington Brook and the Malago catchments. The purpose of this site visit was to ensure that the opportunities proposed by the mapping exercise in Section 3 were appropriate and to detail any further opportunities that may have been omitted as a result of the threshold scoring.

Through the undertaking of the surveys and understanding the dynamics of the catchment, it has been possible to identify and consider some additional opportunities within the catchment area, shown in Figure 15.

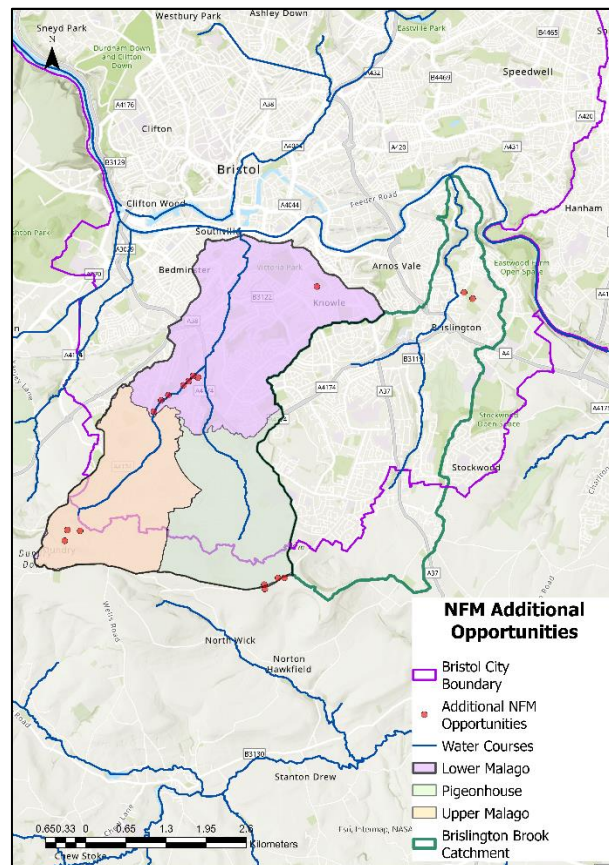


Figure 15 - Additional NFM Opportunities

### 4.1 The Malago Catchment

Along the Malago, there are opportunities to enhance biodiversity, create habitat and improve river geomorphology by implementing a range of different river restoration measures, whilst also providing flood risk benefits.

Manor Woods Valley is contained within Malago Valley SNCI (Site of Nature Conservation Interest) and Bishopsworth and Malago Conservation Area. The majority of the area is contained within Manor Woods LNR (Local Nature Reserve). The LNR excludes Manor Woods Orchard, The Quarries and Rabbit Field at the northern end of Manor Woods Valley. Within the Valley there is a large area which could deliver multiple benefits. As well as reducing flood risk by slowing flow and attenuating peak levels; there are many other benefits which could be exploited within this area, such as biodiversity net gain and habitat improvements.

Arup attended site with BART to assess the Malago catchment. BART work closely with the community stakeholders in this area and any future works should be considered working alongside or in partnership with them to maintain relationships and engagement of the community in this area.

Within Manor Woods Valley, there is potential to increase the sinuosity of the river channel, encouraging the river to spill into the floodplain. Whilst the left bank of this river is utilised for access, the right bank looks to have low utilisation and therefore potential to use for floodplain reconnection as shown in Figure 16 and Figure 17.



**Figure 16 - Right bank of the Malago through Manor Woods Valley.**



**Figure 17 - Left bank of the Malago through Manor Woods Valley.**

Throughout much of the reach within the Manor Valley Woods, geomorphological and biodiversity enhancements could be achieved through targeted introduction of gravels and coarse woody debris within the river. Whilst there are areas where some debris has fallen into the channel (shown within Figure 18), formalising this would be beneficial for peak flows.



**Figure 18 - Debris within the Malago in Manor Valley Woods**

The Malago at the downstream end of the Manor Valley Woods enters a culverted system. However, there is space to daylight this brook and attenuate and create a wetland in the natural depressions of the landscape (see Figure 19), improving the local biodiversity and creating a place of interest for those using the existing green space.



**Figure 19 - Potential area for daylighting and wetland creation**

Within Manor Woods Valley at this downstream end, there is a significant structure and culvert system for the flood relief scheme with the City of Bristol and Wessex Water Authority in 1976, see Figure 20. To ensure this daylighting opportunity would be suitable consultation is recommended with Wessex Water to understand the full design.



**Figure 20 - The Malago Flood Relief Scheme**

In addition to the Manor Woods Valley, there are opportunities within the upper Malago Catchment, surrounding Dundry. There are opportunities to develop RAFs and utilise storage in fields with runoff pathways and natural depressions (see Figure 21). There is potential to create some areas that could be used for attenuating and slowing the flow whilst maintaining productive land for the livestock present, and providing access to water for the cattle.



**Figure 21 - Field in Dundry area, identified for potential runoff interception.**

Within Knowle Perret Park, there is an opportunity to intercept the flow pathway and create a buffer strip or RAF around the play park and entrance (see Figure 22). Landowner engagement would have to be sought as it would likely result in flooding of the park during flood events.



**Figure 22 - Opportunity for interception of flow route**

## **4.2 The Brislington Brook Catchment**

In addition to the opportunity mapping in the upper catchment of Brislington Brook, adjacent to Mannings Wood, there are opportunities for soil management in surrounding fields, see Figure 24. In this area, there are also good opportunities to implement buffer strips in fields with a natural slope to slow the flow. In many cases this would be ‘filling in’ the existing gaps in the existing hedgerows, see Figure 23.



**Figure 24 - Opportunity for soil management**



**Figure 23 - Opportunity for buffer strips**

Upstream of School Road adjacent to the Brislington Cemetery, the brook was dry, however was surrounded by a steep catchment. There is an opportunity to improve connectivity from the brook into the floodplain as well as large wood debris across the watercourse to slow the flow through the watercourse.



**Figure 25 - Opportunity for Floodplain Reconnection and large woody debris.**

In addition to the opportunities discussed above, it is important to note that there may be other opportunities that exist within the catchment. This is because it was not practicable at the time to survey all elements of the watercourses. Elements were prioritised based on review of available literature, hydrological importance in the context of the FAS/NFM geospatial mapping analysis.



The hydrographs at each of the catchment/sub-catchment outlet are then used within the Aggregate Storage Model (ASM). The ASM assesses the synchronicity of flows from each of the sub-catchments in a wider catchment area and allows the user to allocate a total (or aggregate) storage volume to each of the sub-catchments, which has been obtained from the Opportunity Mapping of the sub-catchments. For the Brislington Brook and The Malago, the hydrological analysis is determining the difference in peak flows within each sub-catchment, assessing the impact on peak flows due to the NFM storage identified within the Opportunity Mapping.

For more detail on the ASM tool refer to Appendix C.

## 5.2 Results

### 5.2.1 NFM Impact on Peak Flows

Results for each sub-catchment are presented in the section below. These results show the local, nested, and downstream impact within each sub-catchment, with three values presented for each one of these: unmitigated flow, mitigated flow and percentage mitigation. The definitions of each of these are below.

- **Local flows** are those occurring at the outlet of a sub-catchment which include only the runoff generated from within that sub-catchment boundary i.e. they do not include flows from any upstream sub-catchments.
- **Nested flows** are those which include both the local runoff generated from within the sub-catchment and also flows from any sub-catchments located upstream. If there are no sub-catchments located upstream, for example sub-catchment 1 or 2 of The Malago, then the local flows will be the same as the nested flows.
- **The downstream flow** is that occurring at the outlet of the whole catchment, including all nested flows from any upstream sub-catchments.
- **Unmitigated peak flow (Qp)** is the maximum flow which normally flows through the point of interest (i.e. local, nested or downstream) if no storage-based NFM interventions were installed.
- **Mitigated peak flow (Qp)** is the maximum flow at the point of interest (i.e. local, nested or downstream) after it has been attenuated by NFM storage-based interventions.
- **Percentage mitigation** is the ratio of mitigated and unmitigated flows, represented as a percentage.

### 5.2.2 Brislington Brook

Table 2 summarises the size of the sub-catchment and the interventions and storage information that has been extracted from Figure 12 the UKCEH Opportunity Mapping, based on the storage assumptions set out in Table 1 of Section C.4. The results for local, nested, and downstream impacts are also set out in Table 2.

**Table 2: Intervention types and storage types for each sub-catchment, and the projected impact of that storage on peak flows within Brislington Brook**

	Catchment	Brislington Brook
	Catchment Size (km <sup>2</sup> )	13.7
Features and Storage	No. of RAFs	1
	No. of Floodplain Reconnection Features	20
	Total Features	21
	Total Storage (m <sup>3</sup> )	20,500
Local Impact	Qp Unmitigated (m <sup>3</sup> /s)	28.502
	Qp Mitigated (m <sup>3</sup> /s)	28.502
	Percentage Mitigation (%)	0%
Nested Impact	Qp Unmitigated (m <sup>3</sup> /s)	31.062
	Qp Mitigated (m <sup>3</sup> /s)	27.250
	Percentage Mitigation (%)	12.3%
Downstream Impact	Qp Unmitigated (m <sup>3</sup> /s)	31.062
	Qp Mitigated (m <sup>3</sup> /s)	27.250
	Percentage Mitigation (%)	12.3%

### 5.2.3 The Malago

Table 3 summarises the size of the sub-catchment and the interventions and storage information that has been extracted from Figure 14, the UKCEH Opportunity Mapping, based on the storage assumptions set out in Table 1 of Section C.4. The results for local, nested, and downstream impacts are also set out in Table 3.

**Table 3: Intervention types and storage types for each sub-catchment, and the projected impact of that storage on peak flows at different strategic locations within The Malago**

	Catchment	The Malago			
	Sub-Catchment	Upper Malago	Pigeonhouse	Lower Malago	Total
Features and Storage	Catchment Size (km <sup>2</sup> )	4.6	5.08	5.95	15.63
	No. of RAFs	0	0	0	0
	No. of Floodplain Reconnection Features	4	2	0	6
	Total Features	4	2	0	6
Local Impact	Total Storage (m <sup>3</sup> )	4000	2000	0	6000
	Qp Unmitigated (m <sup>3</sup> /s)	16.153	18.079	10.319	
	Qp Mitigated (m <sup>3</sup> /s)	16.153	18.079	10.319	
Nested Impact	Percentage Mitigation (%)	0%	0%	0%	
	Qp Unmitigated (m <sup>3</sup> /s)	17.514	19.508	42.673	
	Qp Mitigated (m <sup>3</sup> /s)	16.039	18.658	42.061	
Downstream Impact	Percentage Mitigation (%)	8.4%	4.4%	3.7%	
	Qp Unmitigated (m <sup>3</sup> /s)		42.673		
	Qp Mitigated (m <sup>3</sup> /s)		42.061		
	Percentage Mitigation (%)		3.7%		

## 5.3 ASM Discussion and Recommendations

Timings of peak flows occurring within the sub-catchments are a critical component of determining the overall peak flows. In some cases, mitigating and delaying peak flows in one sub-catchment can cause a coincidence in peak flows with another sub-catchment, resulting in increased peak flows at the downstream point of interest. This phenomenon is referred to as the synchronicity of sub-catchments.

### 5.3.1 Brislington Brook

In the Brislington Brook catchment, NFM opportunity mapping indicates that storage can be located throughout the catchment, namely floodplain reconnection features. The RAF feature providing 500m<sup>3</sup> of storage within the catchment has no effect on the local, nested or downstream flows in the catchment. The 20,000m<sup>3</sup> of storage provided from the Floodplain Reconnection features yields a nested and downstream benefit of 12.3%, which for a catchment of 13.7km<sup>2</sup> is a significant reduction and should be further explored.

A key factor when considering NFM within Brislington Brook is that the interventions in this assessment have been optimised for a 1 in 100-year return period and may not be as effective for smaller return period storms. Implementing RAFs has little effect on a 1 in 100-year return period event, even when considering further RAF interventions as the Corine Opportunity map suggests in Figure 11, which was confirmed during a sensitivity test. However, implementing RAFs or further NFM opportunities if identified, could have an effect on smaller magnitude return periods, as opposed to in a 1 in 100-year return storm, and therefore could be effective at reducing flood risk under smaller storm events, which could be explored further.

### 5.3.2 The Malago

In the Malago catchment, NFM opportunity mapping indicates that storage can be located in two of the three sub-catchments, Upper Malago and Pigeonhouse, in the form of Floodplain Reconnection (FPR) features. Four FPR features were identified in Upper Malago, giving 4,000m<sup>3</sup> of storage, and a nested impact of 8.4% mitigated flows within the sub-catchment. Pigeonhouse contains two FPR features, giving 2,000m<sup>3</sup> of storage, and a nested impact of 4.4% mitigated flows within the sub-catchment. This totals to 6,000m<sup>3</sup> of storage within the whole Malago catchment, and a total downstream impact of 3.7% in Lower Malago. Lower Malago did not have any storage features identified, and as such any reduction results from storage within Upper Malago and Pigeonhouse.

A sensitivity test of sub-catchments within the Malago indicated that if measures were isolated to the Upper Malago sub-catchment that the downstream impact in Lower Malago would be 3.3% as opposed to 3.7%. Whereas isolating a scheme just in Pigeonhouse would reduce the impact in Lower Malago to 0.9%. This shows that the primary flood risk benefits for this scenario derive from the Lower Malago sub-catchment. However, it is always important to consider wider benefits such as carbon sequestration potential, which is detailed in Section 6.1

A key factor when considering NFM within The Malago is that the measures have been optimised for 1 in 100-year return period and may not be as effective for smaller return period storms. A sensitivity assessment of implementing RAFs in Upper Malago, as the Corine Opportunity map suggests, had little impact on mitigating peak flows within the catchment. However, implementing RAFs, or further NFM opportunities if identified, could have an effect on smaller magnitude return periods, as opposed to in a 1 in 100-year return storm, and therefore could be effective at reducing flood risk under smaller storm events.

The storage volumes identified from the opportunity mapping assessment were relatively low, totalling only 6,000m<sup>3</sup> across the 15.6km<sup>2</sup> catchment. It is worth noting that if more storage volume could be located within this catchment, it is likely that the peak flow mitigation could be improved. Moreover, the site visit indicated that there could be more storage potential within the Malago catchment.

## 6. Cost and Carbon Sequestration Calculations

High level cost and carbon sequestration calculations are outlined in this Section for identified NFM opportunities as part of the Bristol Avon Flood Strategy. Associated assumptions behind both sets of calculations can be found in Appendix D. The calculations are for all the identified NFM within the sub-catchments and not solely focused on the storage-based interventions that were assessed in the ASM. However the calculations are split by NFM type, so can give an indication of specific information for these and wider benefits of NFM within the sub-catchment.

**The calculations in this Section are for the NFM opportunities identified during the Opportunity Mapping using the UKCEH as the Land Cover for the sub-catchments.**

### 6.1 Carbon Sequestration

Table 4 shows the high-level carbon sequestration estimates when a threshold of 3.6 is applied in the sub-catchments from the UKCEH land use Opportunity Mapping. Associated assumptions behind these carbon estimates are found in Appendix D. This table can be used to calculate the sequestration of any combination of sub-catchments being implemented with NFM and/or land cover change.

**Table 4: High-level carbon sequestration estimates for each sub-catchment (based on UKCEH Opportunity Mapping with a threshold of 3.6)**

Catchment	Sub-catchment	Number of features					Storage (m <sup>3</sup> )						Carbon Sequestered (TCO <sub>2</sub> e/yr, increase compared to baseline)			
		RAFs	FPR	LWD	Gully Stuffing	Land Cover Change	RAFs	FPR	LWD	Gully Stuffing	Land Cover Change	Total	RAFs	FPR	Land Cover Change	Total
The Malago	Upper Malago	0	4	1	1	15	0	4000	100	10	613.75	4723.75	0	14.44	71.61	86.05
	Pigeonhouse	0	2	4	0	20	0	2000	400	0	898.88	3296.88	0	6.86	65.99	72.85
	Lower Malago	0	0	0	0	6	0	0	0	0	3.75	3.75	0	0	1.37	1.37
	<b>Total</b>	0	6	5	1	41	0	6000	500	10	1514.38	8024.38	0	21.30	138.98	160.28
<b>Brislington Brook</b>		1	20	0	2	36	500	20,000	0	20	347.5	20,867.5	1.19	102.15	202.09	305.43

Note:

- FPR – Floodplain Reconnection
- RAFs – Runoff Attenuation Features
- LWD – Large Woody Debris
- Land Cover Change – Defined in Table 10

## 6.2 Costing

Table 6 shows the high-level cost estimates when a threshold of 3.6 is applied in the sub-catchments from the UKCEH land use Opportunity Mapping.

Associated assumptions behind these cost estimates are found in Appendix D. This table can be used to calculate the costs of any combination of sub-catchments being implemented with NFM and/or land cover change. An example total cost is estimated for the Upper Malago catchment below.

### 6.2.1 Cost Assumptions

For maintenance of NFM features it has been assumed that the RAFs will need to be refurbished every 30-35 years, assuming half are made of soil and half are made of timber. For this, the same SPONs values used for the original Capex construction of RAFs are used alongside 30% mobilisation and 44% Optimism Bias. A present-day value is then determined using discount factors from HM Treasury guidance at the time of writing. For floodplains it is assumed the total maintenance is 5% of the capital cost, with an annual maintenance equivalent to 1% of this value (over 100-years). A general rate of £250/km<sup>2</sup> per year is applied on top of these as an additional maintenance rate. This value is applied every year of the scheme for 100-years and a present-day value is determined as before

### 6.2.2 Using the Cost and Carbon Estimates

The cost estimates shown in Table 6 provide a breakdown of estimated costs per sub-catchment if all the mapped opportunities in section 3 are implemented. This can be used to explore alternative scheme options which may be necessary following landowner engagement. For example, considering an NFM scheme isolated to the Upper Malago catchment could achieve a nested percentage mitigation of 8.4%, at a total scheme cost of £190,652, as seen in Table 5.

**Table 5: Example total costs if Upper Malago is taken forward in isolation**

Item	Cost (£)
Construction	£71,750
Mobilisation (30% of construction costs)	£21,525
Optimism Bias (44%)	£41,041
Land Cover Change	£30,125
Maintenance and refurbishment (assuming 100-year life span)	£26,211
<b>Total</b>	<b>£190,652</b>

Additionally, the Carbon Sequestration rate of the catchment has the potential to increase by approximately 86.05 TCO<sub>2e</sub>/yr (if all measures are implemented). Over 100 years (the assumed life of the NFM scheme in the calculations), this equates to 8,605 TCO<sub>2e</sub> sequestered. According to the Woodland Carbon Code, companies are paying between £7 to £20 per TCO<sub>2e</sub>, which would value the carbon sequestered by the scheme between £60,235 and £172,100.

**Table 6: High-level cost estimates for each sub-catchment (based on UKCEH Opportunity Mapping above threshold 3.6)**

Catchment	Sub-catchment	Sub-catchment area (km2)	Construction Costs					Mobilisation (30% of Construction Costs)	Optimism Bias (44%)	Land Cover	Maintenance and refurbishment costs (PV) based on 100-yr design life	Total
			RAFs	FPR	LWD	Gully Stuffing	Total					
The Malago	Upper Malago	4.60	£0	£66,000	£5750	£250	£71,750	£21,525	£41,041	£30,125	£26,211	£190,652
	Pigeonhouse	5.08	£0	£33,000	£23000	£0	£56,000	£16,800	£32,032	£53,238	£78,001	£236,070
	Lower Malago	5.95	£0	£0	£0	£0	£0	£0	£0	£46,875	£2,623	£49,498
	<b>Total</b>	15.30	£0	£99,000	£28,750	£250	£127,750	£38,325	£73,073	£130,238	£106,834	£476,220
<b>Brislington Brook</b>		13.7	£6500	£330,000	£0	£0	£336,500	£100,950	£192,478	£159,250	£33,590	£822,768

Note:

- FPR – Floodplain Reconnection
- RAFs – Runoff Attenuation Features
- LWD – Large Woody Debris
- Land Cover Change – Defined in Table 10

## 7. Conclusions and Recommendations

A high-level assessment has been undertaken to identify NFM opportunities across the Bristol River Avon catchment using an Arup-developed opportunity mapping technique. This focuses on two catchments largely within the Bristol City Boundary, the Brislington Brook and the Malago. A site visit was undertaken to validate the mapping and identify further opportunities. High level modelling was undertaken in these two catchments using the Aggregate Storage Model to estimate the peak flow reductions achievable through implementing NFM. The cost and carbon sequestration potential for the mapped NFM interventions were estimated within these catchments.

Through delivery of NFM in Brislington Brook and the Malago, the 1 in 100-year peak flows can be reduced within the local catchment watercourses. Implementing NFM could also deliver wider benefits such as carbon sequestration, improved amenity space and biodiversity, which aligns with Bristol City Climate Change Strategy and its objectives for 2030.

A good reduction of 12.3% can be achieved with 20,000m<sup>3</sup> of storage in the 13.7km<sup>2</sup> Brislington catchment. A relatively low percentage flow reduction of 3.7% can be achieved in the 15.3km<sup>2</sup> Malago catchment. However, this is because of the low volume of storage identified by the relatively opportunity mapping, only 6,000m<sup>3</sup>. The site visit showed that there could be potential for this volume to increase, which could significantly increase the estimated reduction in flows within the Malago catchment.

Sensitivity testing was undertaken for the synchronicity of the three sub-catchments comprising the Malago. It was determined that the Upper Malago sub-catchment had the greatest potential impact both at the local sub-catchment outlet and at the downstream outlet of the Lower Malago. A scheme isolated within the Upper Malago would be estimated to cost £190,652 and over a 100-year design life could be estimated to sequester 8,605 TCO<sub>2e</sub>.

Further opportunities within the Brislington Brook and Malago sub-catchments have been identified through a site visit. The Lower Malago opportunities are those highlighted within Section 4.1, within Manor Woods Valley, however these opportunities need to be discussed with Wessex Water to understand the implication on the existing flood relief scheme. Other opportunities within this catchment that have been highlighted could be implemented to ascertain wider benefits.

It is recommended that NFM interventions identified within the Upper Malago, Brislington Brook, and Lower Malago (during the site visit) catchments are prioritised schemes as they have shown to have a greater localised flood risk within the Aggregated Storage Modelling. Additionally, wider NFM opportunity mapping across the entire Bristol Avon Catchment has identified the huge potential for further study. It is acknowledged that, due to the predominantly tidal mechanisms driving flood risk in the River Avon throughout Bristol City, implementation of NFM in other sub-catchment areas could likely be achieved as a 'no regrets' strategy. This would be provided the interventions reduced flood risk to upstream areas and deliver multiple benefits to the environment and society.

Further work is recommended to quantify the potential benefits to property and infrastructure in terms of flow reduction on the Brislington Brook and Malago. This can be done using existing hydraulic models for the two sub-catchments. Once it is confirmed that benefits can be achieved, it is recommended that high-level conceptual designs are developed alongside geospatial analysis for the areas identified in the site visits and used to produce updated storage volume potential and provide an understanding of viability in terms of site constraints. These volumes can then be tested using the ASM to determine any resulting reduction in peak flows.

Moreover, consideration should be given to changing the design storm return period for which the NFM is designed. For example, an NFM scheme could be designed to be optimal during for a lower return period event (e.g. 1 in 50 years), thus adding resilience to the catchment generally by being more effective for more frequent design storm events. It is recommended that other potential benefits such as biodiversity net gain and potential water dependent habitat delivery as part of implementing NFM should be quantified in line

with the Bristol City Climate Change Strategies objectives, which will help with the business case development of any proposed schemes.

Alongside this it is recommended that landowners are engaged to determine the feasibility of the identified locations of NFM within the catchments.

# Appendix A

## Natural Flood Management Measures


# A.1 NFM Measures




## A.1.1 Outline



For the Bristol Avon catchment a range of NFM measures were analysed. Examples and descriptions of the full range of considered measures is in e.




Table 7, with pictures to indicate what these measures could look like.



**Table 7: Description of the Natural Flood Management measures considered for implementation in the Bristol Avon catchment**



Intervention Type	Description	Images
<p>Buffer Strips</p>	<p>Buffer strips are areas adjacent to rivers, which are also referred to as ditches, dykes, becks, watercourses, where woody planting or grass buffers can be created to increase roughness and slow runoff. Due to their permanent vegetation, buffer strips promote effective water infiltration and slow surface flow.</p> <p>They can comprise a variety of vegetation including long grasses, trees and shrubs.</p> <p>Buffer strips are suitable in rural regions of the catchment with riparian buffer strips being located adjacent to watercourses (between 4-12 m from the bank). In-field buffer strips can also be used across fields and field boundaries in both pasture and arable fields.</p> <p>They can also contribute to sediment and nutrient management.</p>	<p>©Justen Wilkens (Unsplash)</p> 


Intervention Type	Description	Images
Soil Management	<p>The way rural land is managed affects the pathways and speed at which rainfall enters watercourses. This is controlled by both soil health and vegetation cover. By better managing our soils, such as avoiding bare soils (including the use of over-winter stubble) or using no or low tillage cultivation methods, the macro-structure and organic matter content of soils can be improved. This results in increased infiltration and therefore reduced runoff, which may also mobilise sediments. Even simple practices such as contour ploughing, which involves ploughing and/or planting across a slope following its natural contour lines, can make a difference to runoff volumes and flow rates.</p> <p>These practices are generally suited to arable agricultural land but are applicable to any area of open landscape within a catchment.</p>	<p>(© Blair Seitz)</p>  <p>(© Visual Services-East Moline)</p> 
Tree Planting	<p>Increasing tree cover has the potential to reduce flood risk by promoting soil infiltration, intercepting water on the canopy and increasing soil roughness, thus, slowing down the flow of surface runoff. The degree of benefit provided by tree planting can vary depending on the woodland, with coniferous being generally more efficient compared to broadleaved woodland. However, a mixed native woodland would provide the greatest benefits for biodiversity, providing a variety of food sources all-year-round.</p> <p>The most suitable areas within a catchment is on existing pasture, where the density of planting can be between 1,100 and 2,250 trees per ha. Existing woodland and non-irrigated arable land can also be suitable as well as at a small scale or density in green urban spaces. In particular, tree planting is best suited to the upper catchment and linking with existing woodland and hedgerows (to promote wildlife corridors) wherever possible.</p>	<p>(© Trevor Pye-Kyao Unsplash)</p> 

Intervention Type	Description	Images
<p>Peat Restoration</p>	<p>Restoring degraded peatlands to reverse the carbon emissions associated with their historic drainage. A wide variety of peat management measures can help to restore peatlands including, converting grassland to blanket bog, converting grassland to heath, improving existing peat condition, restoration burning and cutting to reduce heather dominance, rewetting of peat, the reintroduction of blanket bog species, as well as careful management of livestock grazing, to name but a few. This also includes Grip Blocking – restoring ecological, hydrological function and the peatland carbon sink function by damming and infilling old gripping ditches.</p> <p>This intervention is suitable in upland and lowland areas of the catchment, in areas of heath and peat.</p>	<p>(© K Brembo Unsplash)</p> 
<p>Wet Woodland</p>	<p>Wet woodland is woodland located in the floodplain subject to intermittent, regular planned or natural flooding regimes. It has the capacity to slow down and hold back flood flows within the floodplain and enhances sediment deposition and thereby reduces downstream siltation. Common tree species include alder, willows and birch with sedges, ferns and mosses dominating on the ground.</p> <p>It typically comprises broadleaved woodland and can range from productive woodland on drier, intermittently flooded areas to unmanaged, native, mixed wet woodland in wetter areas and is therefore located in areas of the catchment within the fluvial floodplain or subject to surface water or groundwater flooding.</p>	<p>(© Kat Closon Unsplash)</p> 

Intervention Type	Description	Images	
<p>Grip Blocking</p>	<p>Historically, areas of heath and blanket bog have been drained through the digging of ditches with the practice known as gripping. The ecological and hydrological function, as well as the peatland's carbon-sink function, can be restored by damming and infilling old gripping ditches. This enables the storage of water in the headwaters and re-wets the moorland.</p> <p>Grips can be blocked by creating a series of dams made from timber planks, peat, bales of heather or plastic piling. The best place for grip blocking is in the upper headwaters of a catchment, preferably along grips running in parallel to the natural slope.</p>	<p>(©RSPB)</p> 	<p>(©Moors for the Future)</p> 
		<p>(©Environment Agency)</p> 	

Intervention Type	Description	Images
<p>Gully Stuffing</p>	<p>Erosion gullies and ravines are filled with brash (term used to describe thin upper branches) and logs to impede erosion and flow and increase infiltration. These water bodies are largely seasonal and the brash and logs reduce the impact of surface runoff and slow the flow. By positioning the brash longitudinally, sediment and debris is also captured as well as slowing the flow.</p> <p>This intervention is particularly useful in a steep catchment where wood extraction might be difficult as it provides some justification for management activity in areas where none might previously have been undertaken. Therefore, gully stuffing is traditionally undertaken in ditches draining woodland.</p>	<p>© Catherine Wright (Twitter)</p> 
<p>Runoff Attenuation Features (RAFs)</p>	<p>Runoff attenuation features (RAFs) are man-made structures that intercept and attenuate a hydrological flow (runoff) pathway (e.g. an earth bund or machined timber 'leaky barrier'). By capturing and storing overland flow, a temporary pond or pool is formed behind the feature which then drains at a slower rate altering the peak and timing of the flood hydrograph. Low bunds or other ground reprofiling can slow or divert flow to disconnect the pathways and divert them into low points, ponds, buffer zones or woodlands. Further, overland flow over bare soil or heavily poached fields can also intercept sediment and debris in the flow.</p> <p>RAFs are best located in largely rural settings where the tailback of water, when full, will not affect any infrastructure. In particular, they are best suited to pasture to avoid any potential loss of crop.</p>	<p>©Newcastle University</p>  <p>©Environment Agency</p>

Intervention Type	Description	Images
		
<p>Large Woody Debris (LWD)</p>	<p>Placement of natural, large wood across/within the channel to slow the flow, leading to greater flow diversity and connectivity with floodplains. LWD are pieces of wood, occasionally combined with some living vegetation, that accumulate in river channels as well as on riverbanks and floodplains. LWD can occur naturally along rivers as a result of trees falling locally into watercourses through snagging of natural wood or occasionally due to beaver activity. Similar structures can also be engineered by humans to restore rivers and floodplains to slow and store flood waters. They are therefore best placed in the upper catchment, particularly through wooded areas where features such as these would more naturally occur.</p>	<p>(©Newcastle University)</p> <p>(© Arup)</p> 

Intervention Type	Description	Images
<p>Floodplain Reconnection (Offline Flood Storage)</p>	<p>Offline flood storage is an approach which aims to establish a pathway between a watercourse and its natural floodplain, especially during high flows, where flood waters were previously constrained to the channel and storing additional water on the floodplain than would naturally occur.</p> <p>Engineered to ensure timing of the floodplain of the intervention to benefit downstream flood impact - this could include removal/set back/breaching of embankments and excavation on the floodplain to create greater/new areas of flood storage. These features are therefore best located in or adjacent to the floodplain and modelled Flood Zones, in the mid-lower catchment.</p>	<p>(©Environment Agency)</p> 

# Appendix B

## Opportunity Mapping Methodology

# B.1 NFM Opportunity Mapping Methodology

## B.1.1 Outline

ArcGIS software has been used to spatially analyse the Bristol Avon catchment in order to undertake coarse opportunity mapping. The GIS analysis is based on a variety of data sources and analytical tools.

## B.1.2 Data Sources

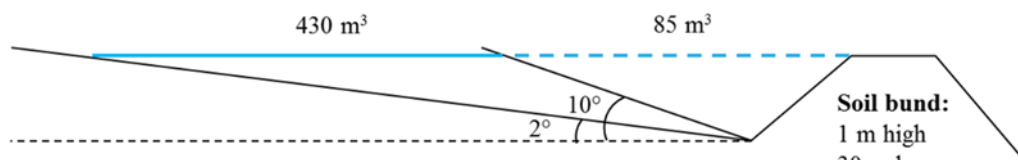
Data from publicly available sources that have been used for analysis, include:

- Corine Landcover Maps (2018);
- Agricultural Land Classification Maps (ALC);
- UK Centre for Ecology and Hydrology Land Cover Maps (2019);
- Background Mapping;
- Topographic data, called LiDAR DTM, at 2m resolution;
- Flood Zone EA data for Flood zone 2 and Flood zone 3 (2022);
- Hydrological Flow Data from the Bristol Central Area Flood Risk Assessment.

## B.1.3 Topographic and Flow Analysis

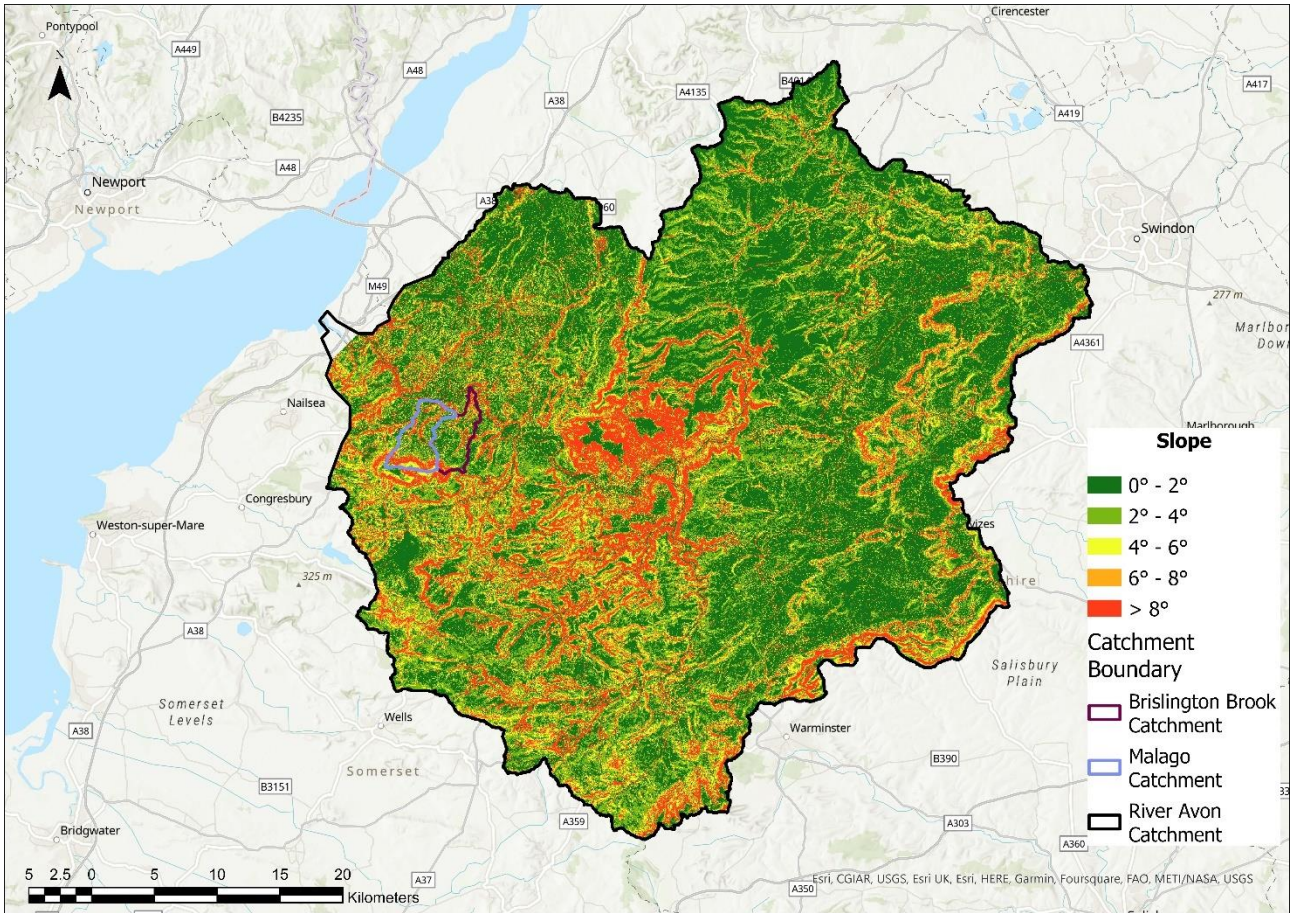
A GIS analysis of the topographic data (LiDAR) identified areas with the potential for surface runoff generation and slope across the catchment using a series of analytic ‘Hydro-Tools’ within ArcGIS.

The LiDAR data is used to generate a layer representing slope across the catchment. Slope is an important component to consider as it not only dictates where runoff will occur, but where high levels of storage can be positioned to capture that runoff. Figure 27 shows how the angle of slope can affect the storage potential of an NFM feature of a certain size.



**Figure 27: Example cross section of an NFM intervention and its potential storage volume when located on slopes of different angles**

The slope layer was generated at a 50m resolution and then categorised into steepness between 0°-2°, 2°-4°, 4°-6°, 6°-8° and >8°, as these angles are considered suitable and preferable for NFM interventions. Figure 28 indicates the steepness across the Avon catchment.



**Figure 28: The angle of slope throughout the catchment at a 50m-by-50m scale**

The Strahler (1957) stream order method was utilised to establish the relative size of streams within the river network of the Bristol Avon catchment, with three thresholds set as follows:

- 50ha drainage area for first order streams
- 5-50ha contributing drainage area for primary runoff route
- 1-5ha of contributing drainage area for secondary runoff routes

The thresholds represent the area of contributing drainage that is required before the streams are drawn. The 5-50 ha threshold are runoff routes considered to be active in low to medium magnitude storm events and are therefore more established runoff routes. The 1-5 ha threshold is to assess secondary runoff routes. These may take longer to generate during rainfall events, but intercepting water from these ephemeral flow paths is more likely to target peak flow in high magnitude rainfall events.

The output from the ArcGIS analysis was combined with background mapping, fluvial flood risk layers, land use data, and satellite imagery to determine feasible locations for NFM interventions.

## B.1.4 Estimating NFM Potential

### B.1.4.1 Corine

In order to assess the character of the catchment, a 250m x 250m (6.25ha) fishnet grid is applied to the Avon catchment to quantify the characteristics (e.g., land use type, slope area category, flood extent area and total length of runoff pathways) and their presence in terms of percentage in each grid square. This includes the percentage area of different land cover defined by the Corine Landcover dataset (generated in 2018), the percentage area of Agricultural Land Classification (ALC) Map, the percentage area of each slope category, area within the 1 in 100-year flood extent and, the total length of runoff pathways within each grid square.

Figure 29 shows the distribution of different land cover in the Bristol Avon catchment defined by the Corine Landcover dataset<sup>11</sup>.

The catchment is largely pasture and non-irrigated arable land. There are areas of continuous and discontinuous urban fabric, concentrated around the towns and cities within the catchment. The remaining land use types in the catchment are largely types of forests, industrial units, green urban areas, and sports and leisure facilities.

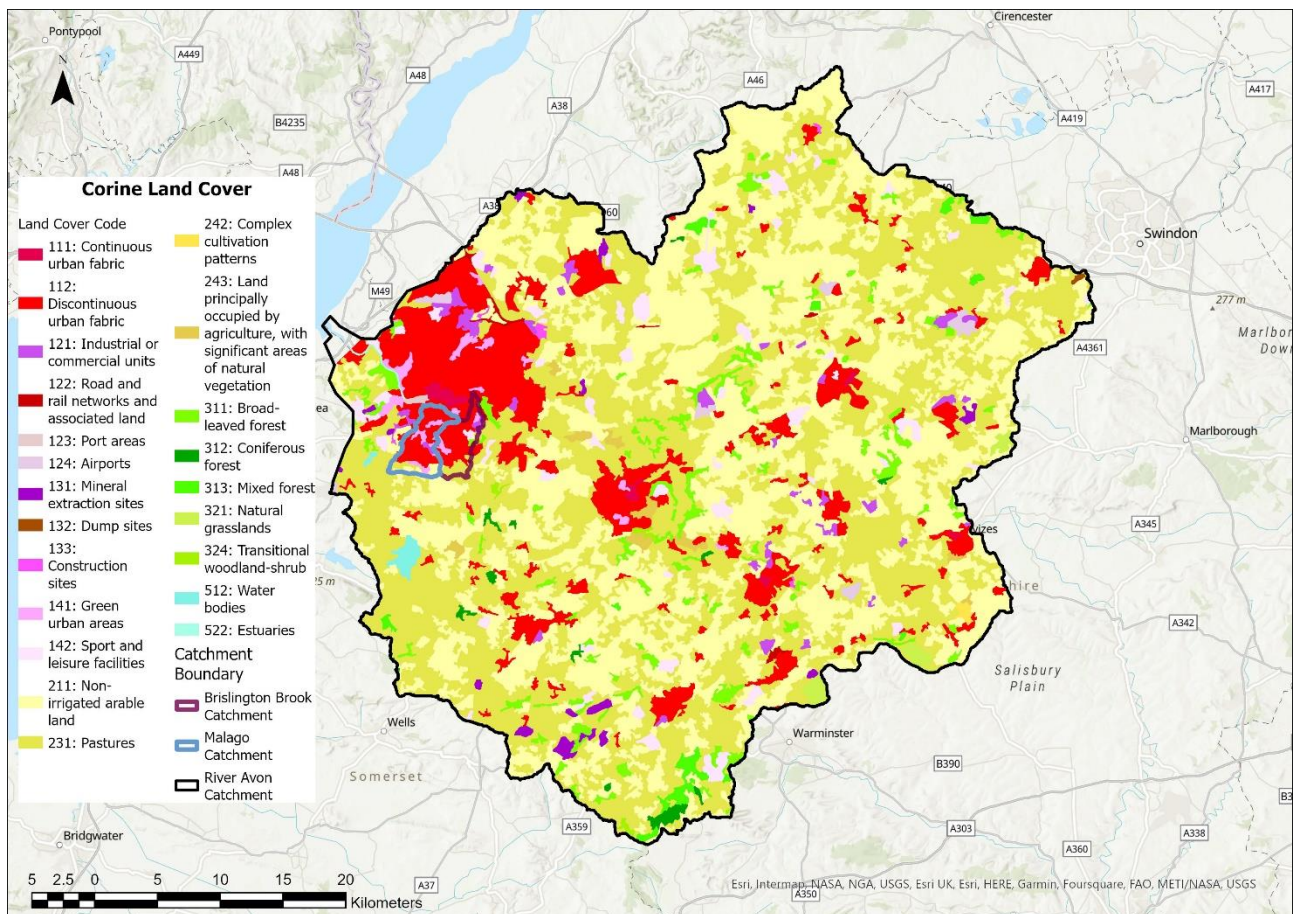
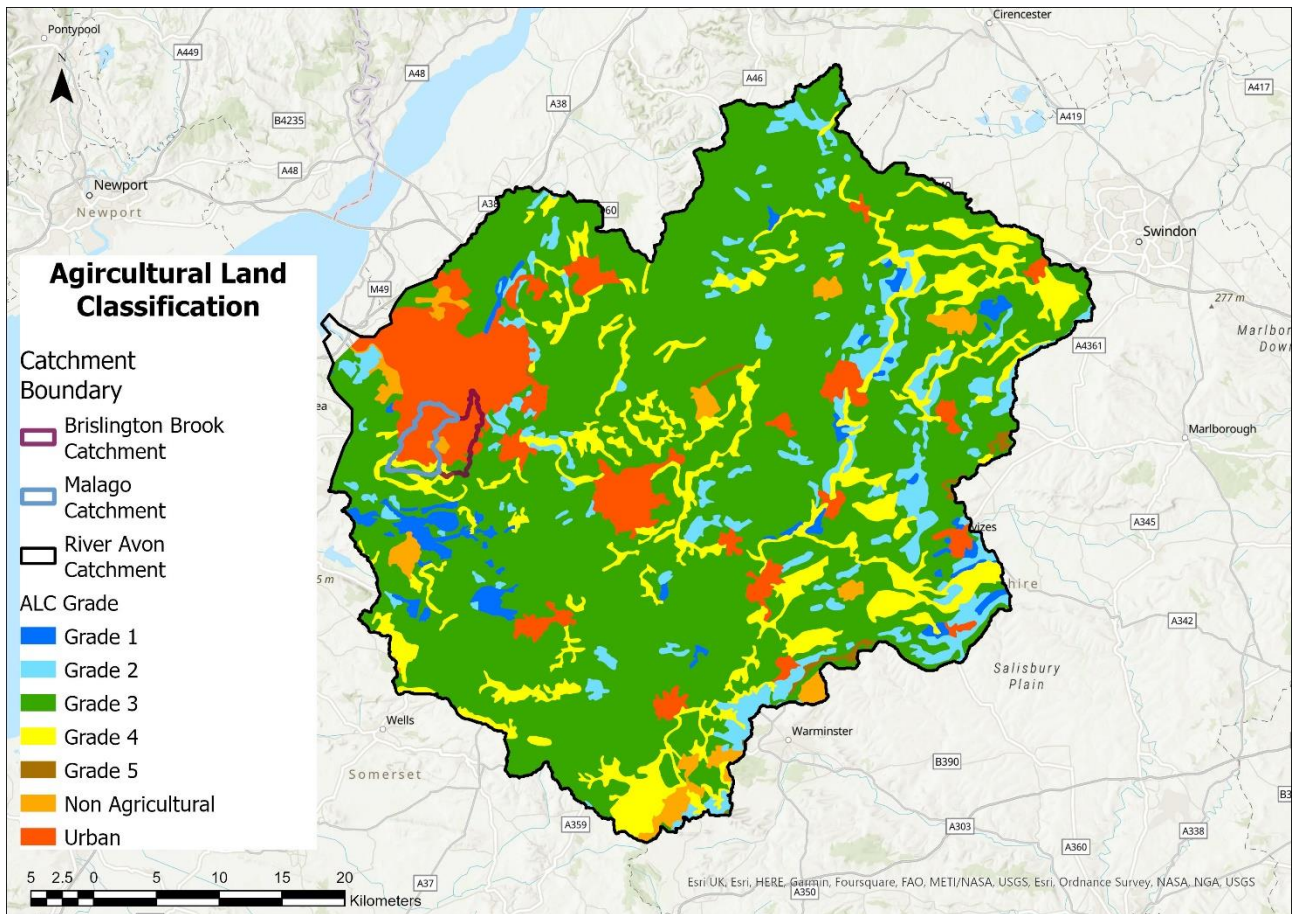


Figure 29: Corine Land Classification across the Bristol River Avon catchment

Figure 30 shows the different agricultural land classifications in the Bristol Avon catchment, defined by the Agricultural Land Classification (ALC).

The Avon catchment is predominantly Grade 3 agricultural land, with Grade one being the best quality and Grade 5 being the worst. There are urban areas, largely similar to the Corine land cover, with smaller areas of Grade 2 and Grade 4. There is very little Grade 1 or Grade 5 classification within the catchment.

<sup>11</sup> Copernicus Land Monitoring Service (2018). Corine Landcover 2018. European Environment Agency.



**Figure 30: Agricultural Land Classification across the Bristol River Avon catchment**

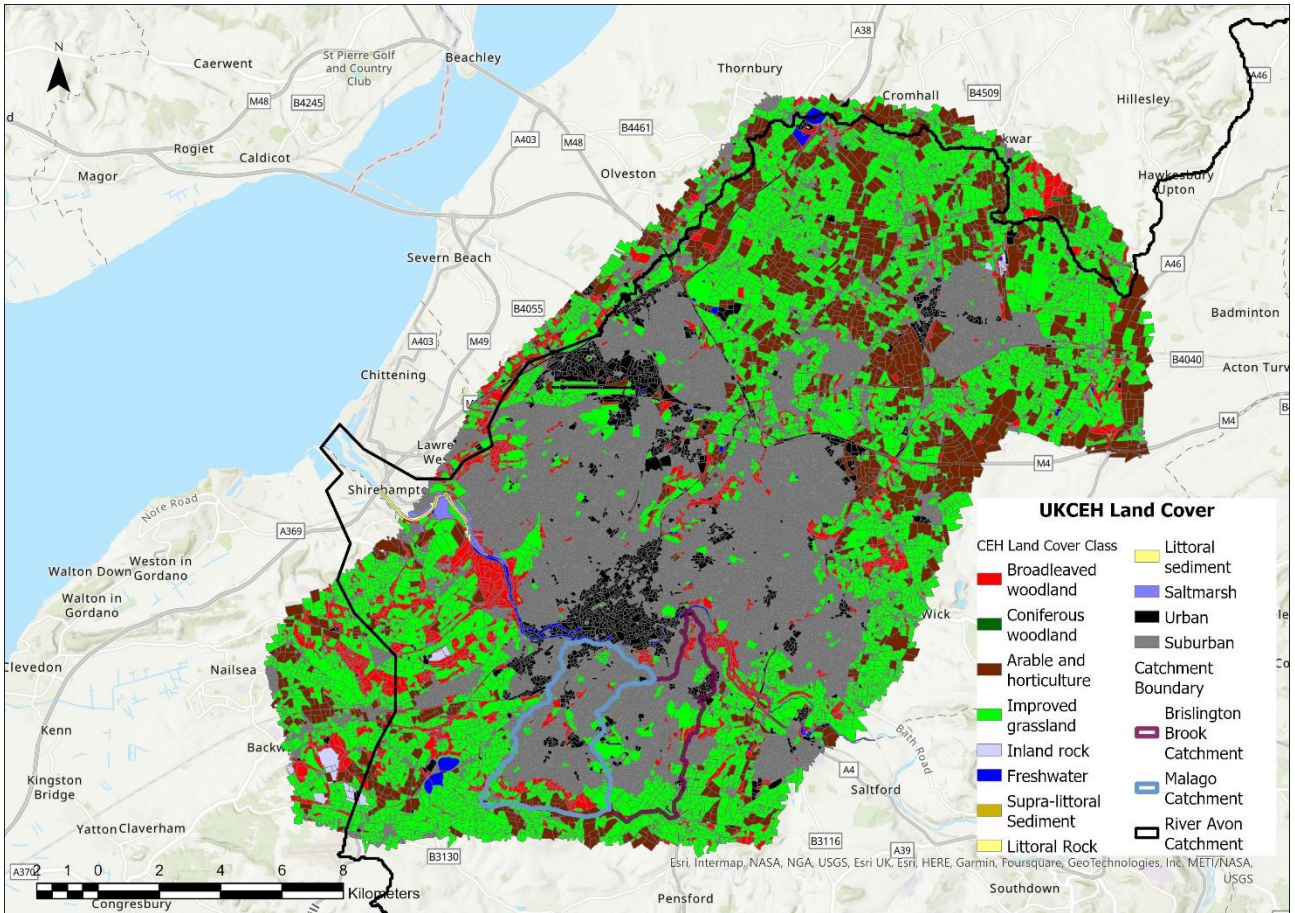
#### B.1.4.2 UKCEH

Due to limited opportunities identified within the Bristol City Boundary, the analysis in Section B.1.4.1 with the UKCEH Land Cover Map (2019)<sup>12</sup> instead of Corine Land Cover Maps, more detail in Section 3.2. Figure 31<sup>13</sup> shows the land cover types in the Bristol Avon catchment according to the UKCEH Land Cover Maps.

The UKCEH Land Cover for the area within and surrounding the Bristol City Boundary is predominantly urban land, with significant Improved grassland and Arable and horticulture coverage. There are also patches of Broadleaved woodland throughout the catchment. The land use is largely similar to the Corine data set, however the resolution is higher, so where Corine has some areas under Urban classification, UKCEH has this as woodland or grassland.

<sup>12</sup> DOI for Land Cover Map 2019 (20m classified pixels, GB): Morton, R. D.; Marston, C. G.; O’Neil, A. W.; Rowland, C. S. (2020). Land Cover Map 2019 (20m classified pixels, GB). NERC Environmental Information Data Centre. <https://doi.org/10.5285/643eb5a9-9707-4fbb-ae76-e8e53271d1a0>

<sup>13</sup> Based upon Land Cover Map 2019 © UKCEH 2020. Contains Ordnance Survey data © Crown Copyright 2007, Licence number 100017572.



**Figure 31: UKCEH Land Classification across the Bristol River Avon catchment**

## B.1.5 NFM Feasibility Analysis

The geospatial analyses from the ArcGIS Toolbox were then exported into an Arup developed NFM Feasibility Assessment Tool, to assess the feasibility of a range of NFM types.

The method utilises a series of look ups which determine the feasibility of numerous different NFM intervention types, scored between 0 and 5 based on their suitability (5 being most suitable) for each individual factor. Note, these scores are estimates, based on in-depth technical understanding, expert judgement, and previous project outcomes, and can be amended where appropriate during any more detailed mapping analysis.

Different NFM intervention types were assessed for their suitability in the Bristol Avon catchment, with the Peatland Management measures quickly being discounted due to a lack of peat. More detailed description and examples can be found in Appendix A. The interventions assessed are as follows:

### Runoff Reduction:

- Runoff Attenuation Feature (RAF) – a man-made structure that intercepts and attenuates a hydrological flow (runoff) pathway (e.g., and earth bund or ‘leaky barrier’);
- Large Woody Debris (LWD) – placement of wood across/within the channel to act as a dam and slow the flow; and
- Tree Planting – planting trees can intercept rainfall, reduce runoff by increasing infiltration and stabilise soils.

### Floodplain Storage:

- Floodplain Reconnection – establishing a pathway between a watercourse and its natural floodplain, especially during high flows, where flood waters were previously constrained to the channel; and
- Wet Woodland – wooded areas that experience waterlogged conditions for at least part of the year to manage flood waters, erosion, and water quality.

### Sediment and Nutrient Management:

- Buffer Strip – area of long grasses, trees and shrubs along field boundaries or across fields;
- Soil Management – managing soil health and vegetation cover to reduce the speed rainfall enters watercourses, even using simple practices such as contour ploughing to reduce runoff volume and flow rates.; and
- Gully Stuffing – blocking erosion gullies and ravines with brash (thin upper branches) and logs to impede erosion and flow, and increase infiltration.

### Peatland Management:

- Peatland Restoration – A wide variety of management measures possible including, converting grassland to blanket bog, converting grassland to heath, improving existing peat condition, restoration burning and cutting to reduce heather dominance, rewetting of peat, the reintroduction of blanket bog species, as well as careful management of livestock grazing, to name but a few.
- Grip Blocking – Restoring ecological, hydrological function and the peatland carbon-sink function by damming and infilling old gripping ditches.

Examples of the NFM features considered are in Appendix A.

The criteria on which the NFM interventions were scored were assessed in an evaluation matrix to weight modelling results, spatial factors, costs, maintenance responsibilities and numerous ecosystem services. For

the Bristol Avon catchment, two weighting matrices were used, as the weightings were amended when using the UKCEH Land Cover Map for analysis.

Table 8 explains the full list of factors included in the matrix for analysis using the Corine Land Cover dataset.

**Table 8: NFM weighting criteria and weightings for the Bristol Avon catchment using Corine**

Sub-Criteria	Criteria Weighting	Sub-criteria Weighting
Reduction in peak flows	10%	0%
Time delay		0%
Slope		10%
Flood Zone 3	30%	0%
Flood Zone 2		10%
Runoff		10%
Risk of flooding from surface water flooding		10%
Cost	5%	1.25%
Funding		1.25%
Maintenance		1.25%
Life expectancy		1.25%
Land use code	40%	20%
Agricultural Land Classification		20%
Flood (Fluvial)	15%	1.5%
Flood (surface water or ground water)		1.5%
Air quality		1.5%
Health access		1.5%
Low flows		1.5%
Climate regulation		1.5%
Habitat		1.5%
Water quality		1.5%
Cultural activity		1.5%
Aesthetic quality		1.5%

Table 9 explains the full list of factors included in the matrix for analysis using the UKCEH Land Cover Map dataset. Note the main differences in criteria weighting for UKCEH is that Land Cover percentage now refers to UKCEH as opposed to Corine, and that the impact of the Agricultural Land Classification (ALC) data was reduced in the weightings of the opportunity mapping multi-criteria analysis from 20% to 5%. This was altered because the land inside the Bristol City Boundary is almost solely classified as ‘Urban’ or ‘Non-Agricultural’.

**Table 9: NFM weighting criteria and weightings for the Bristol Avon catchment using UKCEH**

Sub-Criteria	Criteria Weighting	Sub-criteria Weighting
Reduction in peak flows	10%	0%
Time delay		0%
Slope		10%
Flood Zone 3	30%	0%
Flood Zone 2		10%
Runoff		10%
Risk of flooding from surface water flooding		10%
Cost	5%	1.25%
Funding		1.25%
Maintenance		1.25%
Life expectancy		1.25%
Land use code	40%	35%
Agricultural Land Classification		5%
Flood (Fluvial)	15%	1.5%
Flood (surface water or ground water)		1.5%
Air quality		1.5%
Health access		1.5%
Low flows		1.5%
Climate regulation		1.5%
Habitat		1.5%
Water quality		1.5%
Cultural activity		1.5%
Aesthetic quality		1.5%

Considering other factors in the ranking of opportunities has the potential to reduce the impact of modelling uncertainty. It also allows for the inclusion of other important factors into the analysis.

The weightings were designed to cover the most influential factors of successful NFM projects. The purpose of the criteria is to identify the highest ranking NFM opportunities with, theoretically, the greatest potential to yield success in an NFM project and identify relevant funding sources based on the biggest benefits likely to be achieved. The default weightings are intended to cover schemes with a good balance of criteria supporting NFM. A general balance of criteria has been used for the Bristol Avon opportunity mapping.

For the UKCEH Land Cover, a variety of weighting controls were trialled for the catchment but, ultimately, the highest weightings 40% and 30% were attributed to land use and flood zones respectively, given their strong influence on the potential and type of NFM intervention.

Ecosystem services represent the direct and indirect contributions of ecosystems to quality of life and well-being. This includes the provision of services such as food and water, regulating services such as climate regulation and water purification, and habitat services and cultural services such as recreation and aesthetic value. The ecosystem services have been assigned a weighting of 15%. The following ecosystem services were incorporated into the analysis to meet objectives for flood risk management and additional benefits:

- Flood risk management (fluvial & surface water or groundwater) (positive impact on fluvial flood risk reduction, surface and/or groundwater flood risk reduction);
- Air Quality (interventions leading to improvements in air quality such as tree planting);
- Health Access (creation of greater amenity for the public, thus generating improvements in terms of physical and mental health of the local population);
- Low Flows (regulation of low flows through capture and infiltration of water);
- Climate Regulation (contribution to regulation of climate change);
- Habitat (creation and enhancement of habitat such as wetlands and woodlands that support locally important species);
- Water Quality (potential to capture and/or filter out excess nutrients and sediments from farmland or other sources);
- Cultural Activities (potential to provide direct recreational benefit to the public such as facilitating angling by improving fish habitat); and
- Aesthetic Quality (interventions providing improvements to the local landscape).

Financial considerations (including cost, maintenance and life expectancy) were assigned a weighting of 5%, with the angle of slope within the catchment assigned a weighting of 10%.

Using scores awarded to the variables, the weighting of each criterion and percentage / presence of each variable, the most suitable NFM intervention was selected for each grid cell. Selected interventions could then be visualised using ArcGIS cartography.

Note, the scores awarded to the NFM intervention types are an index and therefore the scoring is comparative and not related to absolute performance or a measure of absolute suitability. The suitability scores are comparative within the catchment and sub-catchments, but not against other study catchments as weightings and parameters will differ.

# Appendix C

## Hydraulic Modelling

# C.1 Hydraulic Modelling

## C.1.1 Aggregate Storage Model (ASM)

The ASM was developed to assess the synchronicity of flows from each of the sub-catchments in a wider catchment area and is based the Pond Network Model<sup>14</sup>. The tool allows the user to allocate a total (or aggregate) storage volume to each of the sub-catchments to assess the impact of storage on both the selected sub-catchment and the total downstream flow at the point of interest. The total storage may be made up of a number of feasibly-sized ‘ponds’ (or pond objects). The ponds are an essential component of the storage unit as the number of attenuation features dictates how rapidly the storage unit can drain. Mass-balance is conserved with the tool. Figure 32 shows a conceptual schematic, similar to a linear storage (bucket) model<sup>15</sup>, which demonstrates the role of storage units within the tool.

The tool assesses the aggregate effects of new storage being added to sub-catchments in the form of attenuation. The tool simulates the effect of the total feasible storage quantities in a given sub-catchment (based on the mapped interventions) and calculates the peak volume of water discharging from each sub-catchment with the proposed storage features ( $Q_p$  mitigated) and without the storage features ( $Q_p$  unmitigated) based on a user-defined ‘Threshold Flow’. The threshold flow is a level that assesses the impact of NFM storage on each sub-catchment, that, once exceeded, will allow flow to enter the storage unit. A graph within the analysis tool shows the performance of the storage unit in the current configuration and allows the user to change the threshold flow and the number of ponds until they are satisfied that the storage unit is performing correctly within the sub-catchment.

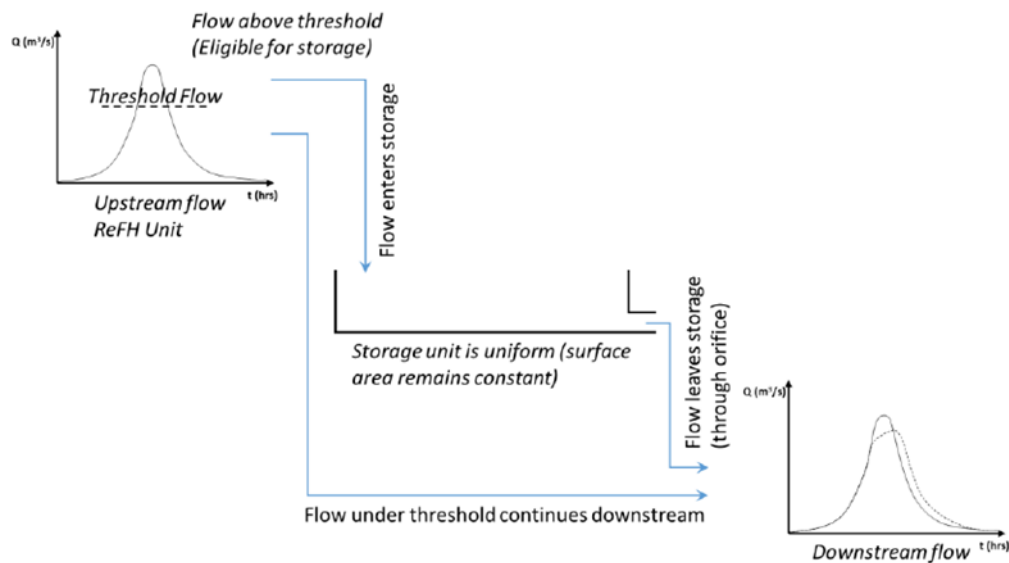


Figure 32: Conceptual model schematic of storage units

<sup>14</sup> Nicholson AR, O'Donnell GM, Wilkinson ME, Quinn PF. The potential of runoff attenuation features as a Natural Flood Management approach. J Flood Risk Management. 2019:e12565. <https://doi.org/10.1111/jfr3.12565>

<sup>15</sup> Nash, J. E. (1957). "The form of instantaneous unit hydrograph." Int. Assn. Sci. Hydro. Publ.No. 51, 546-557, IAHS, Gentbrugge, Belgium.

### **C.1.2 Return Periods**

The return period event of the 1 in 100-year event was used to optimise the storage achieved through NFM interventions for both sub-catchments. Therefore, the NFM assessment has been designed so as to target design flows for the 1 in 100-year storm event. For each sub-catchment, the 'new' storage created by NFM should almost completely fill with water, but not overtop and not be left with additional capacity that could have been used if there was greater flow. This means that under other design conditions (i.e. smaller or larger storm events) the NFM scheme will be less effective because it has been optimised for the 1 in 100 year flows.

# Appendix D

## Cost and Carbon Sequestration Calculations

High-level costing and carbon sequestration calculations have been carried out for the NFM opportunities identified within Brislington Brook and The Malago catchments. These calculations are broken down further into sub-catchments were relevant.

## D.1 Cost Assumptions

### D.1.1 Wider Assumptions

For NFM interventions, cost estimates have been developed based on Environment Agency’s ‘Cost estimation for land use and run-off – summary of evidence’ and Spon’s ‘Civil Engineering and Highways Pricing Book’. For interventions such as tree planting and soil management, cost and carbon estimations are based on the baseline (existing) land cover. The calculations in this assessment use the opportunities identified in the UKCEH land cover Opportunity Mapping. There were 8 UKCEH land cover types within the catchments (Brislington Brook and The Malago) areas, which have been associated with Corine land cover types and grouped into reclassified land codes for assessment. This is illustrated in Table 10.

**Table 10: Nature Based Solutions Land Cover Reclassification**

UKCEH Land Cover	Associated Corine Land Cover	Reclassified Land Code
Urban	Continuous urban fabric	Discontinuous Urban Fabric
Suburban	Discontinuous urban fabric	
Arable and Horticulture	Non-irrigated arable land	Non-irrigated arable land
Broadleaved woodland	Broad-leaved forest	Woodland
Coniferous woodland	Coniferous forest	
Improved grassland	Natural grasslands	Natural Grassland
Inland rock	Bare rocks	Bare rock
Freshwater	Water courses	Water courses

For consideration the NFM features have been reclassified into groups. This is summarised in Table 11.

**Table 11: Natural Flood Management Reclassification**

NFM Feature Type	Classification
Runoff Attenuation Feature	Runoff Attenuation Feature
Floodplain Reconnection	Floodplain Reconnection
LWD	LWD
Gully Stuffing	Gully Stuffing
Tree Planting	Land Cover Change
Soil Management	

### D.1.2 Cost Assumptions

A number of assumptions were applied to ensure a realistic and achievable output, when considering Land Use Change interventions. These assumptions are covered, per grid cell, in Table 12. These assumptions allow allocation storage quantities per intervention and allow a standard cost to be applied. The storage for the interventions is aggregated in a data science model allowing an estimate of the flow reduction to be determined. Holding these assumptions also enables translation into carbon sequestration potential.

**Table 12: Land Use Change suitability mapping - key assumptions per grid square**

Intervention type	Coverage rationale within each grid square
Tree Planting	Variable. Depends on existing land cover. Assume variable relative soil storage depending on existing land cover and assuming that soil store is provided with a density of tree planting equivalent to 1,000 trees per ha. For example, tree planting on pasture (25% of the grid at a density of 1,500 trees per ha) has the potential to provide approx. 47m <sup>3</sup> per grid. (15,625 x 0.002) x (1,500 / 1,000)
Soil Management	Variable. Depends on existing land cover. Assume variable relative soil storage depending on existing land cover

For certain interventions within the land cover change category, see Table 11, there is a variability on the proposed coverage within a grid cell; this is based on the existing (baseline) land cover. A number of variables can change depending on the baseline land cover, including the area of the proposed intervention, the density of planting (in this case trees) and the associated cost of implementing the intervention, which might be a function of the maturity of the vegetation or the difficulty of implementation. This variability allows interventions such as land cover change to be considered in more locations, rather than being simply included or excluded. An example of these nuances is set out for tree planting and soil management.

### Tree Planting

**Table 13: Land Use Change suitability mapping - example of variable coverage for the Tree Planting Intervention**

Existing land cover (re-classified)	Percentage of grid square adopted by intervention	Area of intervention (m2)	Density of planting (no of trees/ha)	COST (£/ha)	m effective soil storage
Discontinuous Urban Fabric	5	3125	50	£25,000	0.004
Non-irrigated arable land	10	6250	500	£1,000	0.003
Woodland	50	31,250	500	£1,000	0.001
Natural grassland	10	6250	1500	£3,000	0.002
Bare rock	-	-	-	-	-
Water courses	-	-	-	-	-

### Soil Management

**Table 14: Land Use Change suitability mapping - example of variable coverage for Soil Management**

Existing land cover (re-classified)	Percentage of grid square adopted by intervention	Area of intervention (m2)	COST (£/ha)	m effective soil storage
Discontinuous Urban Fabric	-	-	-	-
Non-irrigated arable land	80	50,000	£120	0.002
Woodland	-	-	-	-
Natural grassland	-	-	-	-
Bare rock	-	-	-	-
Water courses	-	-	-	-

The NFM interventions identified by the UKCEH Opportunity Mapping methodology also carry with them several assumptions. None of the mapped interventions would involve filling the entire grid square with, for example, offline flood storage on a floodplain. These assumptions are shown, per grid cell, in Table 15.

**Table 15: NFM suitability mapping - key assumptions per grid square**

Intervention type	Coverage rationale within each grid square
<b>RAF</b>	1 feature per grid square. 50m x 50m = 2,500m <sup>2</sup> i.e., 1 RAF is 4% of a grid square. (Average depth of 0.2m for 500m <sup>3</sup> per RAF).
<b>Floodplain Reconnection</b>	1 feature per grid square. Assuming 100m-200m of river impacted (depending on floodplain width). Assuming 1 ha (10,000m <sup>2</sup> ) of land take. Assume a single feature stores 1,000m <sup>3</sup> . Assume 100m-200m of watercourse is improved (depending on catchment) – as long as the watercourse is identified in the DRN.
<b>LWD</b>	Assume LWD have impact over area of 10m by 10m, and each dam ‘stores’ 10m <sup>3</sup> water. 100m <sup>2</sup> is 1% of a hectare. Assume 10 dams per grid square - so 1000m <sup>2</sup> total area benefiting (10% of a hectare), and 100m <sup>3</sup> of storage per grid. Also assumed that 0.2km of watercourse is improved – as long as the watercourse is identified in the DRN.
<b>Gully Stuffing</b>	Assume Gully Stuffing has impact over a 500m <sup>2</sup> area, however per grid this equates to 125m <sup>2</sup> , as this is assuming 0.25 features per grid square. Assume Gully Stuffing ‘stores’ 10m <sup>3</sup> per grid square. (Relative depth of Gully Stuffing is 0.3m).

Costs for the NFM were based on unit costs, built up to determine the cost per grid, based on the expected number of features and expected area of each intervention. This is summarised in Table 16.

**Table 16: Indicative construction cost per grid square (£) for NFM**

Intervention	Area of intervention (m <sup>2</sup> )	No of features per grid	COST (£) (per feature)	Per	COST per grid (£)
<b>Floodplain reconnection</b>	10,000	1	£16,500	feature	£16,500
<b>LWD</b>	1,000	10	£575	feature	£5,750
<b>RAF</b>	2,500	1	£6,500	feature	£6,500
<b>Gully Stuffing</b>	500	0.25	£1000	km	£250

For the majority of NFM interventions, the baseline land cover makes no difference to the assumed average cost per grid using the EA and Spon’s estimation guidance. Note the variability in costs for Tree Planting, and Soil Management is present due to the different baseline land covers they can be applied on, and the planting density/maturity adopted in these classifications.

## D.2 Carbon Sequestration Assumptions

Baseline carbon sequestration was considered for the existing land cover across the catchment to establish the impact potential interventions would have on carbon sequestration for each grid square. The UKCEH Land Cover Map (2019) types were associated to the Corine Land Cover Map (2018) and values were matched to the land cover classes in Brislington Brook and The Malago using a series of values obtained from literature.

Proposed Carbon sequestration and stock for the NFM interventions used the same unit values as the baseline, built up to determine the carbon sequestration per grid based on the expected number of features and expected area of each intervention. The baseline sequestration within each grid adopted by NFM was then subtracted proportionately to the area of proposed intervention(s). The rates shown are measured in tonnes of carbon dioxide equivalent per hectare per year (TCO<sub>2e</sub>/ha/yr), see Table 17.

**Table 17: Indicative Baseline Carbon Sequestration for different land covers in Brislington Brook and The Malago**

UKCEH Land Cover	Corine Land Cover	Baseline Carbon Sequestration (TCO <sub>2e</sub> /ha/yr)	Assumptions/references
Urban	Continuous urban fabric	0	Assumed
Suburban	Discontinuous urban fabric	0	Assumed
Arable and Horticulture	Non-irrigated arable land	0.335	Franko & Ruehlmann (201)
Broadleaved woodland	Broad-leaved forest	11	Alonso et al. (2012)
Coniferous woodland	Coniferous forest	2	Alonso et al. (2012)
Improved grassland	Natural grasslands	6.95	De Deyn et al. (2010)
Inland rock	Bare rocks	0	Assumed
Freshwater	Water courses	1.63	Alonso et al. (2012)

### References

The following material was used to inform the carbon sequestration assessments detailed above:

1. Franko & Ruehlmann (2018). SOC sequestration as affected by historic and present management, *Geoderma*, Volume 321, Pages 15-21, ISSN 0016-7061
2. ALONSO, I., WESTON, K., GREGG, R. & MORECROFT, M. 2012. Carbon storage by habitat - Review of the evidence of the impacts of management decisions and condition on carbon stores and sources. *Natural England Research Reports*, Number NERR043
3. De Deyn et al. (2010). Additional carbon sequestration benefits of grassland diversity restoration. *Journal of Applied Ecology*. Vol 48. Issue 3. P 600-608

The proposed carbon sequestration rate is calculated based on the baseline rates, the baseline land cover and the identified NFM or land cover change intervention, see Table 18. In each case, the area changed by the intervention is proportionally subtracted from the baseline sequestration and the altered sequestration rate is added to the grid – so the proposed replaces some of the existing in most cases. In the case of new woodland planting proposed in areas of existing woodland, however, the baseline sequestration rate is simply added to

by the proposed rate. For new tree planting on existing woodland, it is assumed that within a c. 3ha plot, thinning activities would take place to enable additional low-density planting of young trees.

**Table 18: Potential carbon sequestration rates by intervention (TCO<sub>2</sub>e/grid/yr) (sum needed to account for baseline sequestration using Table 13, Table 14 and Table 17)**

Existing UKCEH land cover	Associated Corine Land Cover	Runoff Attenuation Features	Floodplain Reconnection	Gully Stuffing	LWD	Tree Planting	Buffer Strip	Improved Arable Practices
Urban	Continuous urban fabric	2.925	11.7	-	-	0.25	3.65625	-
Suburban	Discontinuous urban fabric	2.925	11.7	-	-	0.25	3.65625	-
Arable and Horticulture	Non-irrigated arable land	2.925	11.7	-	-	5	10.9688	1.6
Broadleaved woodland	Broad-leaved forest	2.925	11.7	-	-	25	-	-
Coniferous woodland	Coniferous forest	2.925	11.7	-	-	25	-	-
Improved grassland	Natural Grassland	2.925	11.7	-	-	15	3.65625	-
Inland rock	Bare rocks	-	-	-	-	-	-	-
Freshwater	Water courses	-	-	-	-	-	-	-