Natural flood management benefits estimation method

FCERM Research & Development Programme

Research report

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Executive summary

The Environment Agency commissioned this study to develop a practical and repeatable method for estimating the benefits of natural flood management (NFM) interventions, reducing the need to develop resource-intensive hydrological modelling or monitoring. The method addresses a critical barrier to the wider uptake of NFM, providing a consistent approach to cost-benefit appraisal that includes both flood risk reduction and wider environmental benefits. The method draws directly on the best available evidence and latest scientific understanding, incorporating new insights from the recently updated Working with natural processes (WWNP) evidence directory and findings from the Natural Environment Research Council's (NERC) NFM programme.

NFM comprises a range of nature-based solutions (NBS) aimed at restoring natural hydrological processes to manage flood and erosion risk. These measures include:

- woodland planting
- leaky barriers
- floodplain reconnection
- run-off attenuation
- peatland restoration

While many of these schemes are low-cost and community-led, they often struggle to access mainstream funding due to the cost and challenge of demonstrating effective economic returns using conventional modelling approaches. This new approach is a way of overcoming that challenge.

The method integrates the Environment Agency's latest National Flood Risk Assessment (NaFRA), which provides information on flood risk and associated flood damages, and the Environment and Historic Environment Outcomes Valuation tool (EHOV-Lite) to estimate environmental benefits.

Flood benefits are estimated by converting the design storage volumes of NFM measures into effective storage using multipliers derived from over 2,000 NFM scenarios drawn from the NERC NFM programme. These values are then linked to downstream property damages avoided, applying a spatial decay function that considers catchment characteristics and distance from the intervention.

In parallel, the method quantifies wider environmental benefits by using a natural capital approach, assessing carbon sequestration, biodiversity, air quality and water quality. A rapid review of tools identified EHOV-Lite as the most appropriate due to its ability to quantify and monetise multiple ecosystem services. NFM measures were converted into corresponding land use changes to enable valuation within the tool. Other NFM-specific assumptions and limitations were also incorporated, for example, the impact of NFM measures on Water Framework Directive (WFD) classifications. While the tool has its limitations such as challenges in valuing NFM measures which do not result in significant habitat creation or restoration, and in valuing benefits such as recreation and amenity, there is opportunity for it to be refined in the future.

The approach makes generalisations about the effectiveness of NFM across varied catchment types and relies on the accuracy and completeness of scheme data, such as land use change, intervention type and watercourse length, provided by those developing the schemes. Therefore, while the approach is grounded in reliable evidence, its ability to reflect the nuances of individual catchments is limited. Even with further refinement, it is not intended to replace detailed, site-specific hydrological modelling where this is justified, and the outputs should not be interpreted as detailed, precise results.

However, the method offers a consistent, practical and scalable means of estimating both flood and environmental benefits across a wide range of NFM interventions. By providing a proportionate approach, it supports early-stage decision-making, screening and prioritisation, particularly in cases where bespoke modelling would be resource intensive or disproportionate. As such, the method can help guide investment and resource allocation for NFM, supporting the Environment Agency’s strategic objective of mainstreaming nature-based solutions. This is set out in the National Flood and Coastal Erosion Risk Management Strategy for England and its roadmap, which recognises the role of NFM in providing flood and climate resilience. Importantly, it allows for future refinement as new data and monitoring evidence become available.

1 Introduction

1.1 Natural flood management

Natural flood management (NFM) is a type of nature-based solution (NBS) that aims to protect, restore and emulate the natural functions of catchments, floodplains, rivers and the coast to reduce flood risk (Environment Agency, 2024).

It can also be referred to as working with natural processes (WWNP), engineering with nature, natural water retention measures and catchment-based flood management. However, for the purpose of this project, NFM has been chosen as the defining term.

NFM can comprise a wide range of different measures, applicable to different parts of a river catchment, from source to sea, as shown in Figure 1. While NFM applies in estuarine and coastal environments, this project has focused solely on inland, freshwater NFM measures.

When designed effectively, NFM measures have the potential to realise wider environmental, biodiversity and societal benefits, including improved water quality, habitat creation and health and wellbeing enhancements.

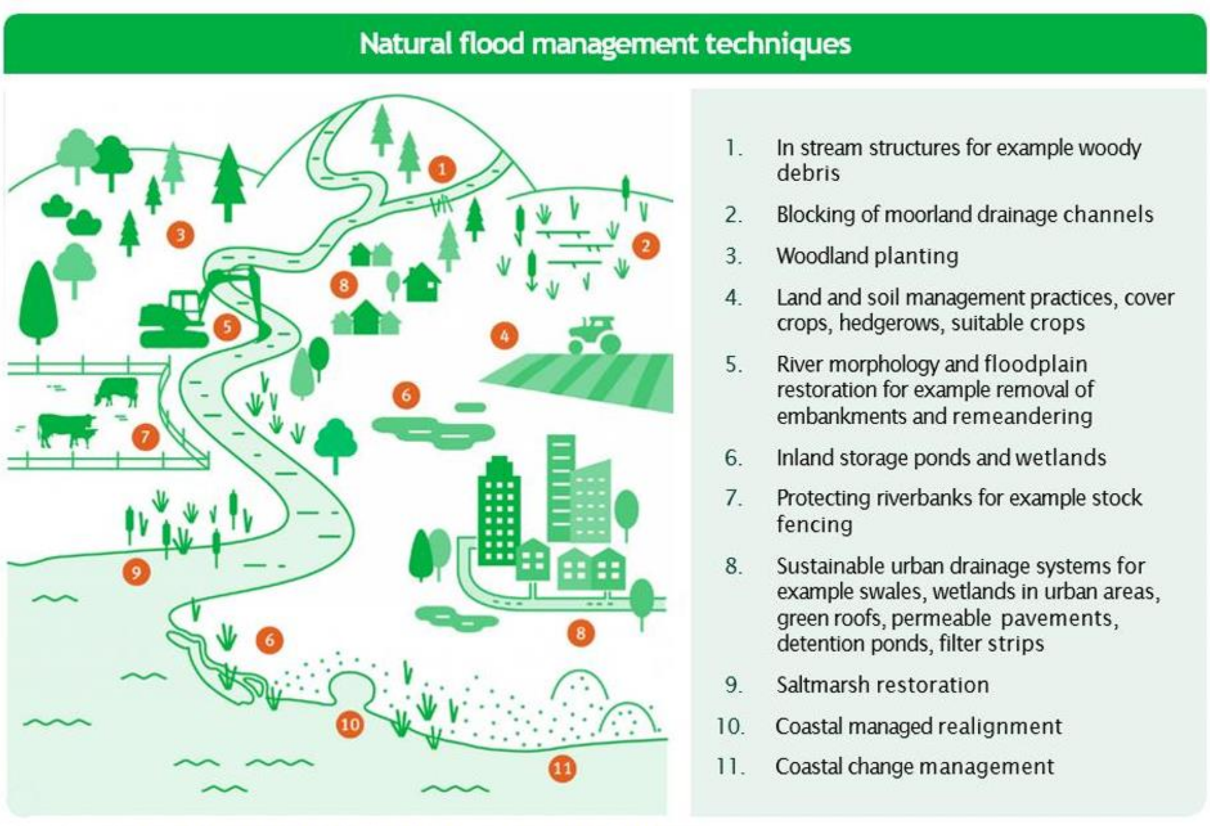

Figure 1: Examples of natural flood management measures

1.2 Background

Many NFM projects in England are small scale, use natural materials, involve minimal engineering, and involve communities and landowners, making them low cost to deliver. However, to access flood risk management funding like Flood Defence Grant-in-Aid (FDGiA), detailed modelling or economic assessments are often required to quantify the cost-effectiveness of the scheme. For smaller NFM initiatives, the cost of modelling can be disproportionate and may even exceed the design and construction costs. This can make projects financially unfeasible, creating a barrier to accessing funding sources.

The Environment Agency has sought to address this barrier by commissioning this study, which provides a method for estimating the benefits of NFM schemes without the need for new modelling and/or monitoring. The approach aims to use up-to-date academic research and novel approaches to:

- provide a repeatable and efficient method to quantify the benefits of NFM, including:
    - woodland planting
    - leaky barriers
    - river and floodplain restoration
    - floodplain reconnection
    - run-off attenuation/management
    - offline storage areas
    - soil and land use management
    - peatland restoration
- be applicable for a range of geographical contexts and landscape types across England
- avoid the need for new modelling and/or monitoring by using existing available data
- be adaptable in the future and designed in such a way that it can be refined, accommodating new data and evidence as it becomes available
- reduce barriers to the uptake of NFM and encourage mainstreaming of its use (as recommended in the National Flood and Coastal Erosion Risk Management Strategy for England)

1.3 Method overview

The method described in this report requires an understanding of the size and spatial scale of the NFM scheme being proposed. The method has been developed in a modular way as shown in the diagram below (Figure 2). This report describes each module separately in subsequent sections. These are:

- estimate design storage (section 2 Design storage)
- effective storage of NFM measures (section 3 Effective flood storage)
- reduction in flood risk benefits moving downstream (section 4 Downstream flood risk benefits)
- environmental benefits (section 5 Environmental benefits)

The report concludes (section 6) with a summary of findings and recommendations for the method's future development and refinement.

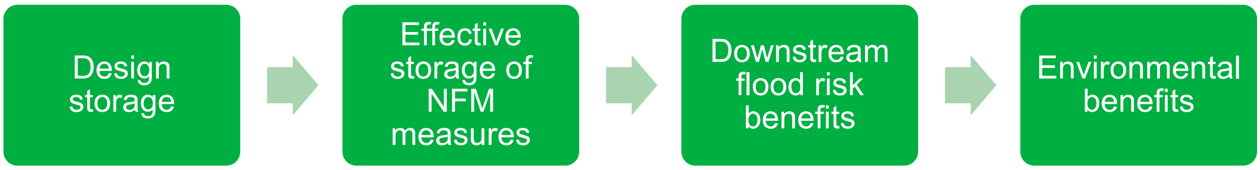

Figure 2: Overview of method process

2 Design storage

Design storage refers to the estimated volume of water that an NFM feature is physically capable of holding or storing, based on its planned or actual dimensions and configuration.

It represents the maximum theoretical capacity of the feature to retain or temporarily hold water, before accounting for real-world factors such as inflow timing, soil infiltration, partial filling or hydraulic inefficiencies.

Design storage is typically calculated using geometric dimensions such as area and average depth for surface features (for example, ponds, floodplains) or length, width and structure height for linear features (for example, leaky barriers). It is expressed in cubic metres (m^3).

The approach to develop the flood storage (see Figure 3) takes 4 steps.

1. Identifying the type of NFM measure(s) being implemented.
2. Defining the scale at which each NFM measure is being implemented.
3. Estimating the design storage of the NFM measure(s) (before adjusting for how effective the storage is during a flood event).
4. Estimating the effective storage of the NFM measure(s) - see section 4 below.

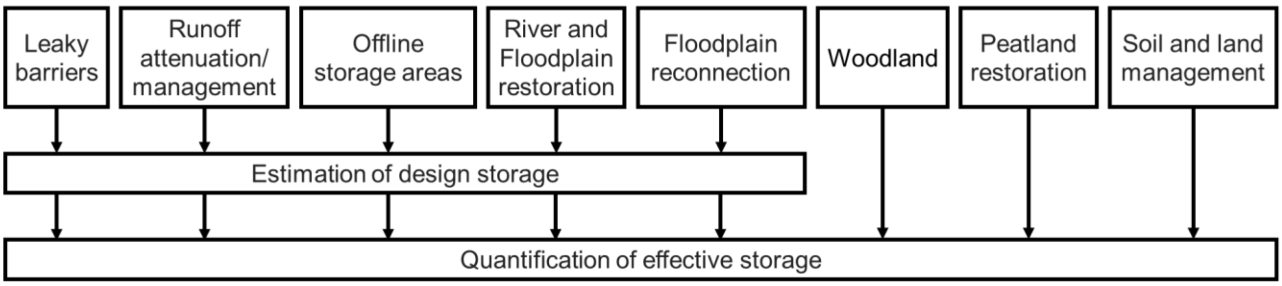

Figure 3: Process overview of identifying effective storage for each NFM measure

In this method, calculating NFM measure size begins with determining the area or extent of the intervention. For most measures, this is initially expressed in hectares, except for leaky barriers and river restoration which are calculated in kilometres or metres. The method then converts this area into an estimated storage volume in cubic metres (m^3) by applying a representative average depth specific to the type of measure.

The following section describes how design storage is calculated for the individual NFM measures.

2.1 Leaky barriers

For leaky barriers, design storage is estimated by calculating the length and width of the channel within which they are proposed. This assessment also includes information on the number and height of leaky barriers, and the length of watercourse affected by installing them (backwater length).

A high-level estimate of backwater length can be derived as 10 times the channel width. The number of leaky barriers can be derived from the length of watercourse considered and backwater length based on findings by Uttley and others, 2019 and Wren, 2022. Leaky barrier height can be assumed to be on average 1m (Wren and others, 2022). The design storage for leaky barriers can, therefore, be simplified with assumptions to a calculation multiplying the length of watercourse (in metres) by the channel width (in metres), divided by 2.

2.1.1 Run-off attenuation features

For run-off attenuation features, the design storage volume is estimated by first converting the NFM measure from hectares to m^2 and then multiplying by an assumed average depth of 0.5m (Wren and others, 2022).

2.1.2 Offline storage areas

For offline storage areas, the design storage volume is estimated by first converting the NFM measure from hectares to m^2 and then multiplying by an assumed average depth of 0.75m (Wren and others, 2022).

2.1.3 River and floodplain restoration/reconnection

For river and floodplain restoration, the design storage volume is estimated by first converting the NFM measure from hectares to m^2 and then multiplying by an assumed average depth of 1m. In the absence of data to draw from academic literature, a higher average flood depth is assumed compared to offline storage areas on account of river and floodplain restoration or floodplain reconnection measures being more effectively designed. This is typically due to the need for detailed planning and regulatory approvals when working in or near a watercourse, such as bespoke hydraulic modelling and environmental design to meet permitting requirements. It is assumed that this results in more optimised and targeted interventions that can accommodate greater flood depths and associated volumes.

3 Effective flood storage

The effectiveness of NFM depends on how measures are designed. For example, ponds may not provide the full range of storage if they are already partially filled or if they lack controlled outflows. To assess performance, the effective flood volume is defined as the flood volume avoided within a 4-hour window around the peak flow (Figure 4).

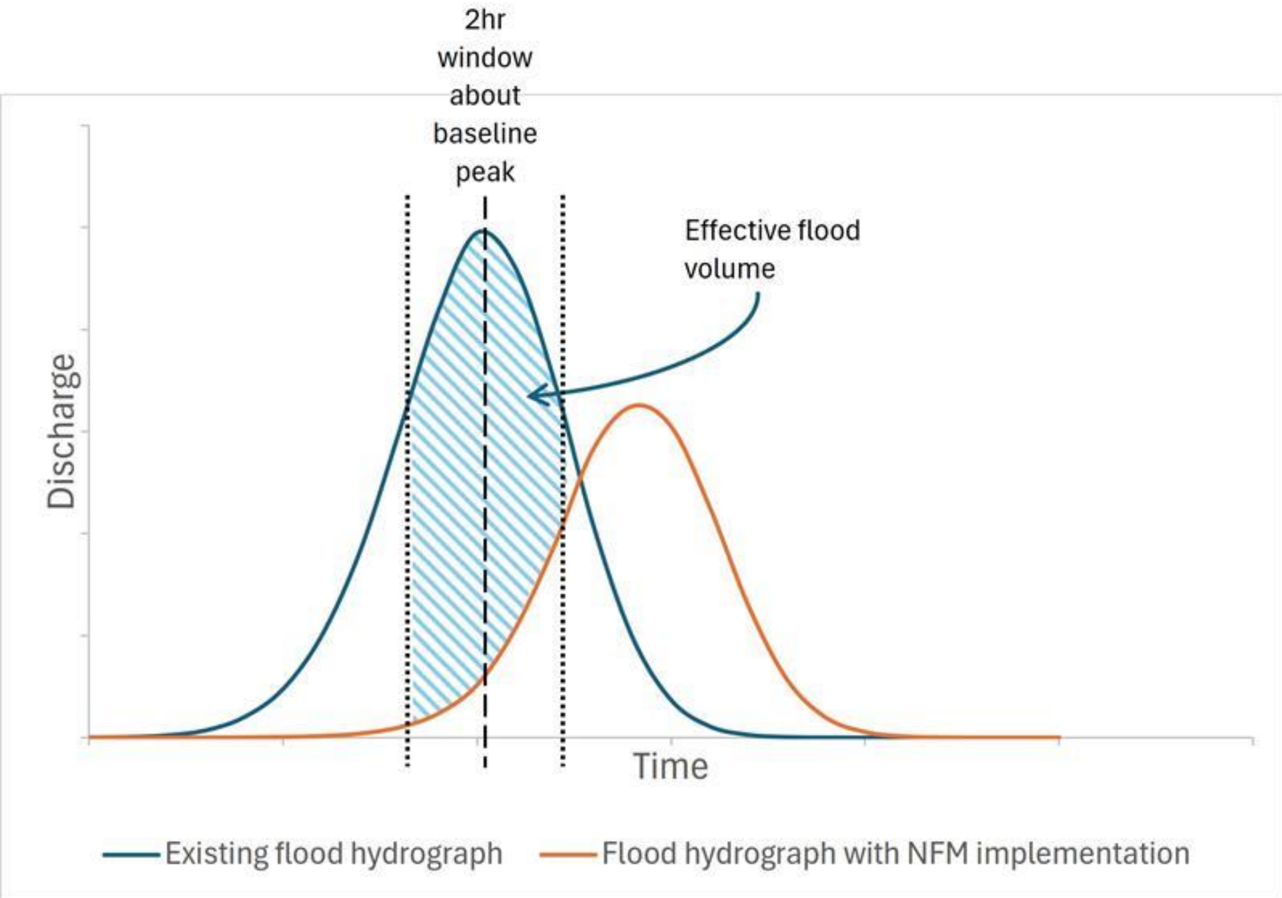

Figure 4: Illustrative example of effective flood storage in a hydrograph

The method estimates average effectiveness by translating the design storage volume of NFM measures into effective storage volume factors, based on evidence from over 2,000 modelled scenarios in the NERC NFM programme (Chappell and others, 2023). These scenarios span small to medium catchments (1 to 25km²) and a range of flood return periods (5 to 1,000 years).

Hydrographs with and without NFM were analysed to calculate the effective flood volume (EFV) during peak flow. A 4-hour window (±2 hours around the peak) is used to isolate the effective flood volume.

For each event, a storage efficiency factor (SEF) is calculated as a proportion of either the design storage (DS) or area of enhancement (AoE) dependent on the NFM measure.

$$SEF = \frac{EFV}{DS} \quad or \quad SEF = \frac{EFV}{AoE}$$

These SEFs were averaged and weighted by annual exceedance probability (AEP) to produce a single flood storage multiplier per NFM measure.

Table 1 presents area-based NFM measures along with their respective multipliers, which are applied to the AoE to estimate the effective storage volume per hectare. For example, 2ha of woodland planting would be estimated to provide 64.7m³ of effective storage.

Table 1: Effective flood storage multipliers for area-based NFM measures

NFM measure	Effective storage volume per ha multiplier
Woodland planting	32.35m³/ha
Soil and land management	4.04m³/ha
Peatland restoration	36.56m³/ha

Table 2 presents volume-based NFM measures with multipliers applied to the DS to calculate the corresponding effective storage volume. For example, 2m³ of run-off attenuation/management DS would be estimated to provide 0.12m³ of effective storage.

Table 2: Effective flood storage multipliers for volume-based NFM measures

NFM measure	Effective storage volume per m³ design storage multiplier
Leaky barriers/in-channel	0.23m³/m³
River and floodplain restoration	0.24m³/m³
Floodplain reconnection	0.24m³/m³
Run-off attenuation/management	0.06m³/m³
Offline storage areas	0.06m³/m³

These multipliers reflect average effectiveness across a range of events. They can be refined with site-specific modelling or monitoring data.

4 Downstream flood risk benefits

The flood risk benefits of inland, freshwater NFM measures become proportionately less significant and more localised the further downstream they are located within a catchment. Progressing downstream, the cumulative volume of water increases and the relative influence of upstream interventions becomes more diluted, particularly during larger storm events.

Additionally, as rivers converge downstream, the benefits of ‘desynchronisation’ - where NFM measures are used to delay the timing of peak flows from different parts of the catchment - can be reduced, unless interventions are coordinated across the entire catchment (Metcalfe and others, 2018).

Research from the NFM community, recently collated by the Environment Agency in its updated WWNP evidence directory (2024) and from the NERC NFM programme (Chappell and others, 2023) supports this. It shows that while NFM can significantly reduce peak flows in small to medium catchments, its effectiveness can be less significant when applied at a larger catchment scale.

4.1 Conceptualisation

Figure 5 provides an illustration of the approach summarised in this report, depicting the NFM benefits that could be expected across a catchment. It identifies locations for proposed NFM measures (for example, A or B), showing potential flow pathways along the river network. Flood risk benefits are then assessed along this network, based on a defined downstream distance that varies according to catchment size and flow magnitude. These benefits are calculated by identifying property receptors at risk of flooding and estimating the proportion of potential damages that may be avoided by implementing NFM.

As distance from the NFM measure increases or as the catchment area and flow volumes grow, the potential benefits are proportionally reduced. Flood damages and catchment characteristics are summarised using 1km² grid units, with benefits derived through a connected downstream flow pathway through these units.

This approach allows the potential downstream flood benefits from NFM measures to be estimated at a national scale. Each 1km² grid square accounts for local catchment size, downstream flow pathways and the cumulative flood risk damages.

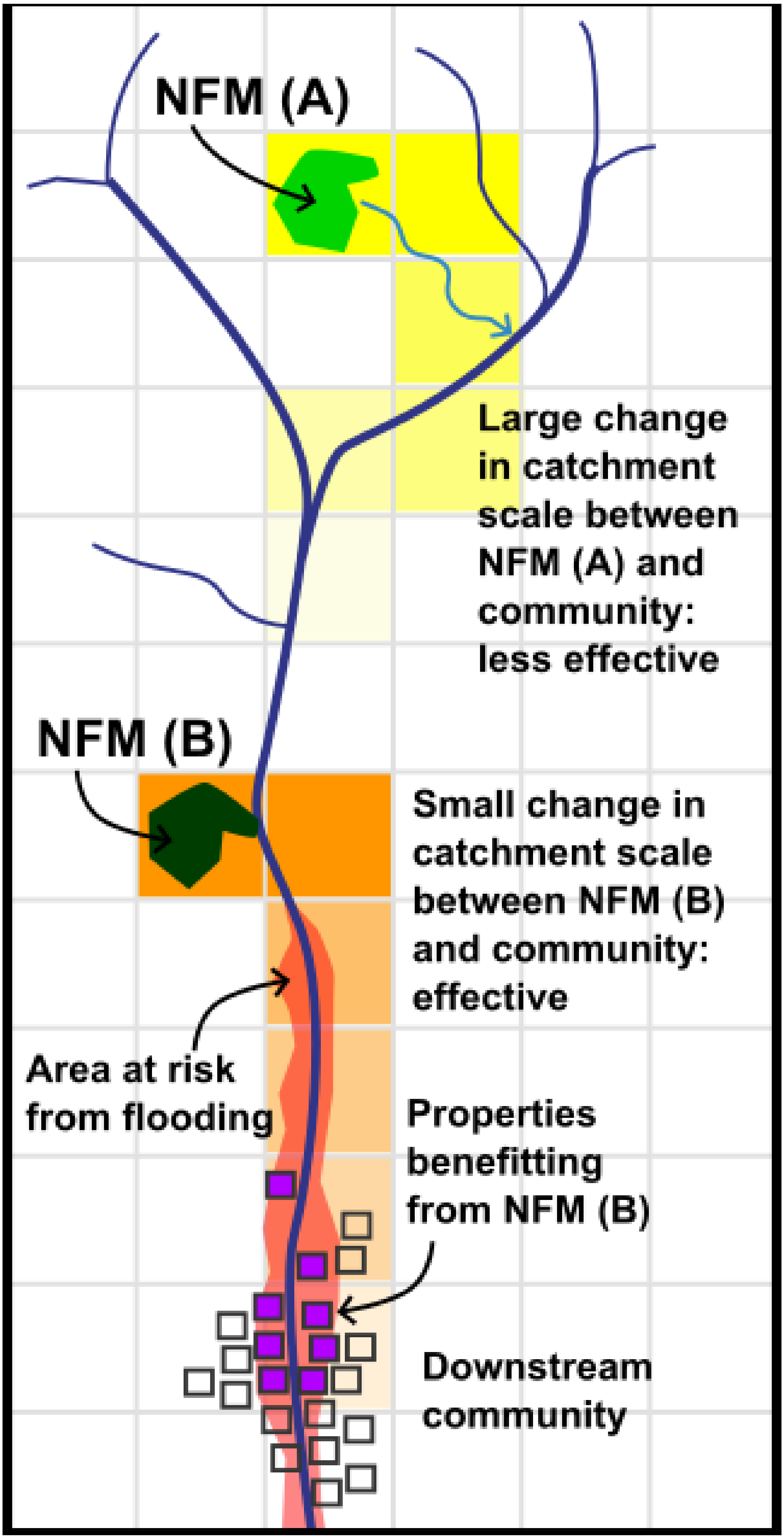

Figure 5: NFM flood benefits conceptual approach for 2 NFM example locations, A and B upstream from a community of property receptors

4.2 Predicting existing local flood risk damages

Flood risk and associated property damages are predicted within each 1km^2 grid square based on the latest national-scale Environment Agency flood risk modelling and mapping, the latest National Flood Risk Assessment (NaFRA). The outputs, which use the best available data from the Environment Agency and local authorities, have been used to provide a consistent and national-scale assessment of flood risk.

Using flood risk predictions from the risk of flooding from rivers and sea (RoFRS) and risk of flooding from surface water (RoFSW) products, the frequency and consequences of flooding to property have been assessed. These products separate the source of flood risk between surface water (RoFSW) and rivers and sea (RoFRS) to avoid any potential double counting.

Flood damage estimates derived from NaFRA2 are based on a consistent set of assumptions and methodologies. Property receptors are defined using the Environment Agency's National Receptor Database 2023 (NRD2023). NRD2023 is a spatial data set that identifies and maps significant receptors that may be at risk of flooding (for example, residential properties, infrastructure and environmental sites). Flood depths at each property are determined by their location relative to modelled flood depth outputs.

To estimate the economic impact, standard depth-damage curves from the Multi-Coloured Manual (MCM) are applied, tailored to both property type and the source of flooding. The assessment encompasses a comprehensive range of damage categories, including vehicle losses, evacuation costs, mental health impacts, business disruption for non-residential properties and emergency response costs. All damages are expressed as annual average damages (AAD), which represent the expected average loss per year, accounting for both the likelihood and severity of flooding.

The analysis assumes that:

- a uniform threshold of 0.2 metres is applied, meaning floodwater must exceed this depth above ground level to be considered damaging
- no cap is applied to the total damages per property
- properties predicted to flood in a 1-in-3-year event (33.3% annual exceedance probability) are assumed to be written off

Finally, damages derived from the RoFRS and RoFSW data set are combined to provide a comprehensive estimate of flood risk per 1km^2 grid square across the national data set.

4.2.1 Defining anticipated downstream network

The flood benefits approach requires the downstream connectivity between 1km^2 grid squares to be established to identify areas that may benefit downstream from NFM measures located upstream.

A downstream benefit network is generated by analysing ground topography at a 250m unit spatial resolution. This allows the general downstream flow direction for any given location to be determined based on the ground elevation across each neighbouring grid square. This spatial resolution balances the need to assess NFM benefits at the $1km^2$ scale with maintaining a logical representation of river network connectivity.

Each $1km^2$ grid square of flood risk damages contains 16 smaller grid squares that define potential downstream flow direction. Where different flow directions emerge from these 16 sub-units (for example, across a watershed), the downstream benefit network selects the flow path associated with the greatest predicted flood damages.

4.2.2 Scaling economic damages based on NFM location

After deriving the downstream flow path, the method scales the economic damages to account for their location within the specific catchment and its downstream benefit network. This establishes a decay function to limit the economic benefits based on the relative change in catchment scale and the distance of the benefitting site relative to the location of NFM.

The total AADs (*T*), assumed to represent the annualised benefit, are calculated as the sum of the damages within each new downstream 1km grid square (*Ai*) multiplied by a decay term (*d*) and a scaling based on the base flow index (BFIHOST), moderated by a constant (k) as shown in Equation 1. The total annualised benefit (*T*) is further scaled by catchment size for use in any onward application of the method.

Equation 1

$$T = \sum_{i=1}^{n} A_i . d . (1 - k * sBFI_i)$$

The decay term (*d*) is a function of the cumulative flow accumulation change from the starting grid square (ΔQ) as shown in Equation 2.

Equation 2

$$d = \mathrm{e}^{-\frac{\Delta Q}{f}}$$

The flow accumulation value is indicative of the catchment area upstream of a given location.

The function of the cumulative flow accumulation change from the starting grid square Q_0 and a given grid square Q_i is shown in Equation 3.

Equation 3

$$\Delta Q = \sum_{i=1}^{n} Q_i - Q_0$$

This produces a decay term that scales from a maximum value of 1 closest to the starting location on the benefit network to a value of 0 further away from the starting grid square, such that the accumulated AADs and resulting economic benefits are effectively 0 when ΔQ is large.

A constant of f=1,000 was agreed with the Environment Agency based on initial sensitivity tests of a range of values (for example, f=20 and f=100.). The lower values resulted in rapid benefit decay, limiting the recognition of downstream impacts. In contrast, f = 1,000 provided a more gradual and realistic attenuation, better capturing the influence of upstream interventions over a 20km flowpath. This follows the empirical evidence, which shows only minor effectiveness of NFM in catchments larger than 25km^2 (McIntyre and Thorne, 2013; Black and others, 2021).

Figure 6 illustrates the influence of this and the other tested f constants on distance for a uniform catchment shape along the benefit network against increasing catchment area or flow accumulation. Higher f constants lead to a more gradual decay and increased distance of accumulated benefits along the benefit network compared to smaller f constants. The choice of f=1,000 reflects a pragmatic balance between minimising the overstatement of benefits and avoiding the underrepresentation of connected, cumulative effects.

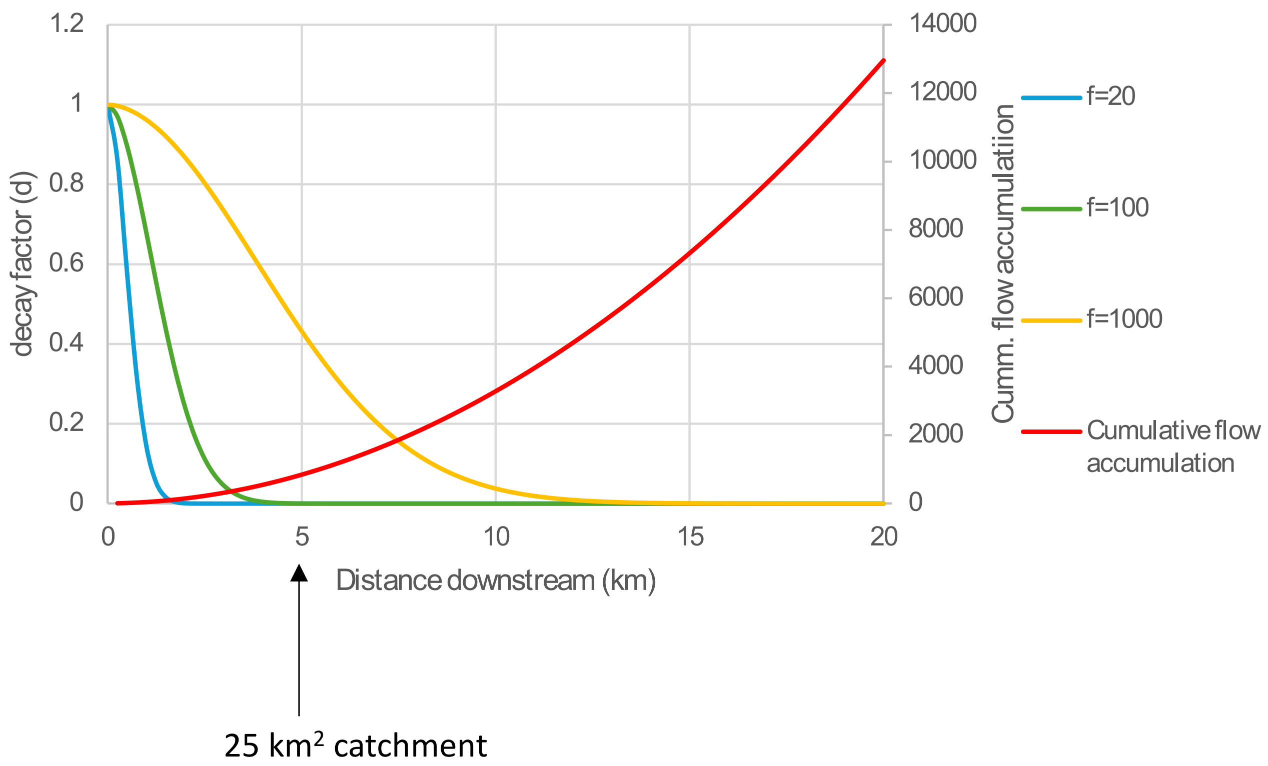

Figure 6: Graph showing how decay term varies downstream, such that communities that are more distant from the NFM measure contribute less to the accumulated AADs.

For a perfectly square catchment of 25km^2, the decay term, d is equal to 0.42.

As research has found NFM is generally less effective within groundwater dominated catchments (Acreman and others, 2011; Barnsley and others, 2021), the method scales the accumulated AADs by a factor that reflects the complement of a scaled BFIHOST (sBFI). BFIHOST serves as a catchment parameter for the baseflow index, where higher BFIHOST values typically indicate a greater baseflow contribution to observed flows, often due to more permeable underlying geology.

The method resamples BFIHOST to 1km from a 5km grid using the nearest neighbour and is scaled by the national maximum and minimum value as shown in Equation 4.

Equation 4

$$sBFI_i = \frac{BFI_i - BFI_{min}}{BFI_{max} - BFI_{min}}$$

The proportion by which BFIHOST influences each cell is moderated by the constant k. When k=0, BFIHOST has no effect on the downstream AADs. When k=1, the downstream AADs are scaled directly by the complement of BFI. Given that the average BFIHOST value is 0.52, this is equivalent to a *sBFI* of 0.42. The method uses a value of k=0.5 to apply a weak scaling of AADs by BFIHOST, relative to other contributing factors already incorporated into the earlier stages of the scaling process.

4.2.3 Scaling economic damages to benefits based on NFM measures

The NFM flood benefits approach scales the maximum downstream damages to an anticipated economic benefit, drawing from a filtered selection of 155 model runs from the Eddleston Water Project, the NERC NFM Programme and the Ousewem (York) Flood and Coastal Resilience Innovation Programme (FCRIP) project. This is important given that NFM measures are not expected to mitigate all flood risk damages.

The approach converts the maximum downstream annual average damages (AADs) to an economic benefit by using a percentage economic benefit factor as applied in Equation 5.

Equation 5

$$Economic\ \ benefit\ (£) = Percentage\ economic\ \ benefit \times Max\ downstream\ AADs\ (£)$$

Using a filtered list of 155 simulated NFM measure scenarios, drawing on studies from the WWNP evidence base (Environment Agency, 2024), the percentage economic benefit factor is derived from a multiple regression.

The multiple regression is created from the statistical relationship between each NFM measure scenario’s effective volume, catchment area and predicted economic benefit. The resultant regression is shown in Equation 6, where ESV is the effective storage volume in m^3 and A is the catchment area in km^2.

Equation 6

$$\text{Percentage } economic\ \ benefit = \beta_1 . ESV + \beta_2 . \log(A) + \beta_3 . (ESV . \log(A))$$

$$\text{Percentage } economic\ benefit = \begin{cases} 1 & econ. ben. < 1 \\ \%\ econ. ben. & 0 < econ. ben. < 100 \\ 100 & econ. ben. > 100 \end{cases}$$

To better reflect the underlying relationship between catchment size and NFM effectiveness, the regression uses a logarithmic transformation of catchment area, log(A). This approach captures the nonlinear, diminishing effect of increasing catchment size on predicted benefit. It acknowledges that the same volume of storage will generally deliver greater proportional benefit in smaller catchments than in larger ones. The transformation also helps to reduce skew caused by large catchments. Table 3 shows the multiple regression's coefficients and their standard error.

Table 3: Coefficients of percentage economic benefit multiple regression

Coefficient	Value	Standard error
β_1	5.52e-4	2.09e-5
β_2	1.15e-1	5.10e-2
β_3	-1.18e-4	5.66e-6

While the coefficients shown above are used to derive the average percentage economic benefit, minimum and maximum percentage economic benefits can also be derived to account for the range of standard errors for each coefficient. The minimum benefits account for each coefficient minus its respective standard error, while the maximum benefits account for each coefficient plus its respective standard error.

The percentage economic benefit factor is limited to values between 1 and 100%.

The R^2 of the multiple regression is 0.8996. This suggests a good fit to the data when comparing the predicted percentage economic benefit derived from the multiple regression and the 'actual' values predicted within the original studies. This is shown by the positive correlation between predicted and 'actual' economic benefits shown in Figure 7. The p-value of the multiple regression is 2.2e-16. This indicates a statistically significant relationship which is unlikely due to random chance.

Figure 7 illustrates how well the multiple regression reproduces the original modelled economic benefits from the NFM scenario data. Each point represents a scenario for which both an 'actual' benefit (from the original modelling) and a 'predicted' benefit (from applying the regression equation to that scenario's input values) are known. The red 1:1 line shows where predictions perfectly match the actual modelled values.

For example, the point at the top right of the graph corresponds to a scenario with a maximum economic benefit of 38% when the same inputs are used in the regression, it returns a predicted benefit of 38% indicating a perfect match. Similarly, the point just to the left represents a scenario with an actual benefit of 36%, for which the regression predicts a slightly higher value of around 42%. This demonstrates an over prediction of 17% in absolute terms.

For scenarios with benefits between 5% and 35%, the model is effective at predicting the overall magnitude of benefits though tends to produce underestimates, some of which are large in proportionate terms.

For scenarios with benefits less than 5%, the model is effective at predicting the overall magnitude and with no clear pattern of under or over estimation.

Therefore, the model is effective at predicting the overall magnitude of benefits, though results at an individual project level may be affected by other factors not included in the model. Discussion on how this regression could be further developed is in Section 6.

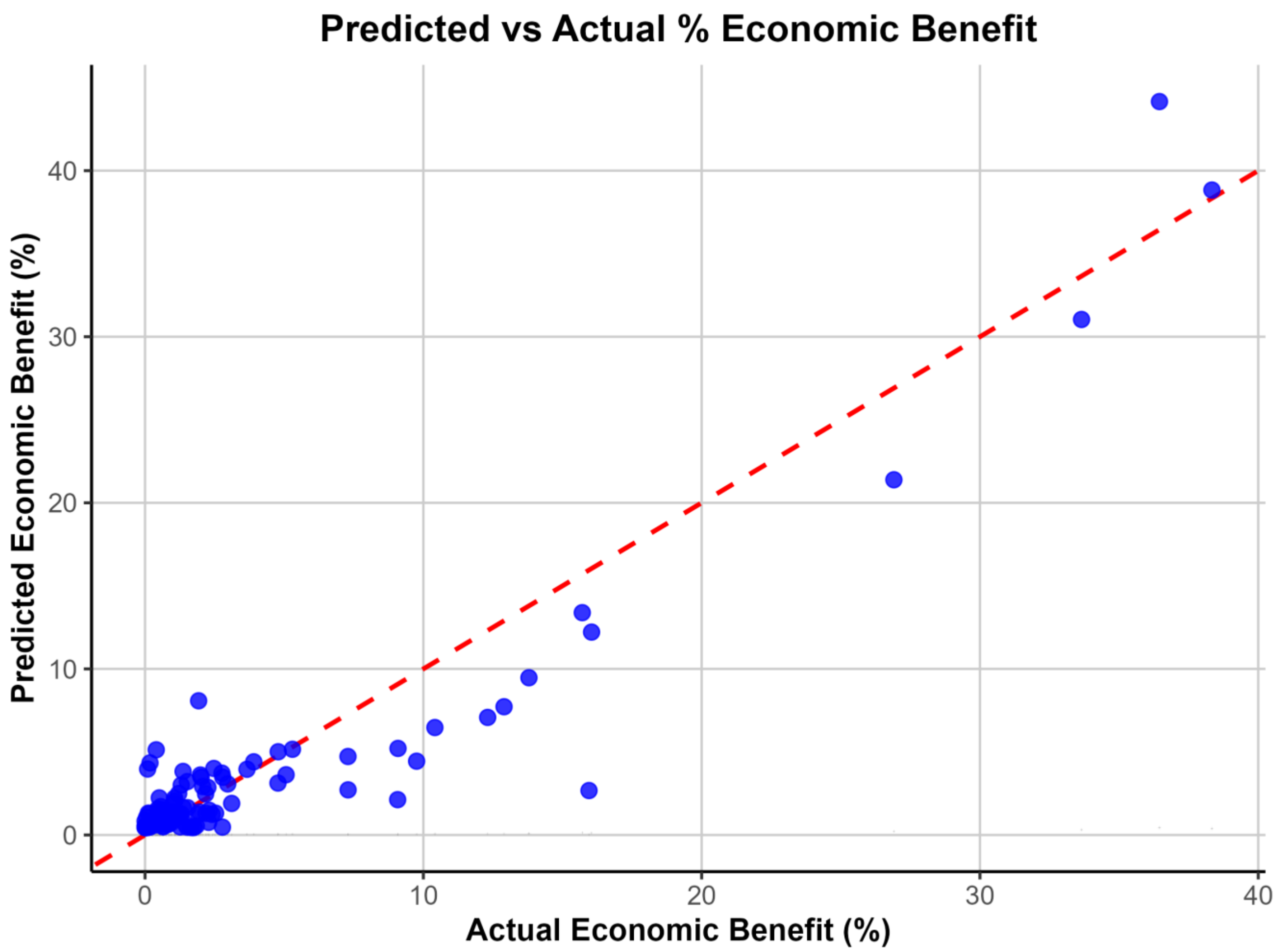

Figure 7: Scatterplot of predicted percentage economic benefit relative to 'actual' (original) percentage economic benefit. Red line shows the target 1:1 correlation

5 Environmental benefits

The primary role of NFM is to attenuate flood peaks within catchments to manage flood risk. However, NFM has the potential to provide additional benefits to people and nature, benefitting local communities and their natural environment.

Over the past 5 years, evidence demonstrating the wider benefits of NFM has expanded (Environment Agency, 2024). Actions such as planting woodland, restoring wetlands, managing soil and reconnecting floodplains have been shown to increase biodiversity, improve water quality, store carbon and offer recreational and amenity benefits.

Incorporating these wider benefits into cost-benefit analyses is vital. It should be noted that some NFM measures have a stronger evidence base than others, which makes it easier to quantify their natural capital benefits.

5.1 Estimating environmental benefits using natural capital

To understand the wider benefits associated with NFM it is necessary to take a natural capital approach. The UK government's 25-Year Environment Plan defines natural capital as 'the elements of nature that either directly or indirectly provide value to people' (HM Government, 2018). Natural capital can be thought of as the stocks of renewable and non-renewable assets in the environment, while the flows of benefits from these are referred to as ecosystem services. An assessment of ecosystem services can help to quantify and monetise the environmental and societal benefits of NFM schemes.

Monetising ecosystem services is typically carried out by either packaging a series of ecosystem services together to estimate a total economic value provided by broad habitat types or by quantifying and monetising specific ecosystem services. Defra's Enabling a Natural Capital Approach (ENCA) provides a set of data, guidance and tools to help assess the natural capital benefits of different types of intervention.

The method, therefore, adopts an approach based on pre-existing, open-access natural capital tools to help estimate the wider environmental benefits associated with NFM. These tools offer a practical and consistent means of valuing ecosystem services without needing to develop bespoke approaches for each scheme.

To identify the most appropriate tool, a rapid review of available natural capital valuation tools was carried out. This review applied a series of screening criteria, including:

- whether the tool is open access and freely available for use
- whether the tool's calculations are transparent and visible (not a 'black box')
- whether the tool provides quantitative and monetary valuation, rather than qualitative outputs only

- the number and type of ecosystem services the tool can assess quantitatively and as a monetary valuation

This process helped to identify a tool that can provide consistent and reliable results to practitioners, and is capable of supporting consistent and defensible valuation of the multiple environmental benefits that NFM schemes can provide.

EHOV-Lite was selected from the review based on its ability to provide both quantitative and monetary valuations for the greatest number of relevant ecosystem services. In addition, EHOV-Lite is an open-access tool that is already available for use in FCERM appraisal. It draws on Defra's Enabling a Natural Capital Approach (ENCA) guidance, ensuring consistency with national standards for ecosystem services assessment and valuation. The Environment Agency also uses the tool as part of the appraisal process for FCERM projects to describe and quantify the impacts of options on the natural and historic environment (Environment Agency, 2023). Many of the other tools reviewed had software dependencies, focused on a narrower set of services, lacked the ability to monetise benefits or were not transparent in how final benefits figures were derived.

5.2 Environmental benefits method

EHOV-lite is an Excel-based tool that provides indicative values for a defined set of ecosystem services. It is designed to assess the change in service delivery resulting from changes in land use or habitat extent, based on user-supplied data.

The primary input into the tool is land-use change (for example, hectares of new woodland or altered farmland). However, EHOV-Lite does not account for changes in habitat condition, which limits its ability to value NFM interventions that do not involve a measurable change in habitat area, such as leaky barriers or small-scale run-off attenuation features.

Recognising this limitation, a series of modifications were made to the tool to enable it to better capture the types of interventions typically associated with NFM.

5.2.1 Ecosystem services valued by EHOV-Lite

The rapid review identified that EHOV-Lite can provide quantitative and monetary valuations for the following ecosystem services. These were:

- food production - based on average farmland rent (Defra, 2023), used as a proxy for land's potential for cropping or livestock
- timber - valued using coniferous timber prices (Forest Research, 2023) and average yields per hectare (Forest Research, 2022)
- air pollutant removal - calculated from avoided health costs due to reduced respiratory and cardiovascular illness (Jones and others, 2017)

- carbon sequestration - based on carbon values from the Department for Energy Security and Net Zero (DESNZ) and the Department for Business, Energy & Industrial Strategy (BEIS) (2023), using sequestration rates from:
    - Office for National Statistics’ (2020) UK natural capital accounts
    - Natural England’s (2021) report on carbon storage and sequestration by habitat
- Biodiversity - a non-use value derived from people’s stated willingness to pay for different habitat types (Christie and others, 2011)

Although recreational benefits are included within EHOV-Lite, they were excluded from this method on the assumption that most NFM measures, particularly those on private land, are unlikely to provide significant public access or amenity improvements.

5.2.2 Rationalisation and adaptation of EHOV-Lite

EHOV-Lite estimates changes in ecosystem services primarily based on habitat extent. Provisioning services such as food and timber are calculated from the area of specific land types affected by NFM interventions, including:

- enclosed farmland – arable
- enclosed farmland – livestock
- enclosed farmland – dairying
- woodland (used for timber harvesting)

As this structure already aligns well with area-based interventions, no changes were required for the valuation of provisioning services.

In contrast, regulating services (such as air quality, carbon storage and biodiversity) are linked to broader land-use changes, using the following habitat categories:

- enclosed farmland (all types)
- semi-natural grassland
- woodland
- mountains, moors, and heath
- coastal margin

However, many NFM measures, for example, river restoration, leaky barriers, floodplain reconnection or soil management, do not fit neatly into habitat change categories. To address this, the method includes additional measure types within EHOV-Lite, allowing users to assign values to interventions that were previously unsupported.

The following NFM interventions were added:

- river restoration
- leaky barriers
- floodplain reconnection
- offline and run-off storage areas

- soil and land management
- upland peatland management – degraded
- upland peatland management – restored

Where EHOV-Lite did not originally include calculations for air pollutant removal, carbon sequestration or biodiversity for these added measures, values were introduced using habitat creation assumptions (see Appendix A).

A summary of the changes made to EHOV-Lite in relation to NFM measures and ecosystem services is presented in Table 4.

Table 4: Links between ecosystem services and NFM measures

NFM measure	Food	Timber	Air pollutant removal	Carbon sequestration	Biodiversity (habitat provision)
River restoration	Included	Included	Added	Added	Added
Leaky barriers	N/A	N/A	N/A	N/A	Added
Floodplain reconnection	Included	Included	Added	Added	Added
Floodplain reconnection	Included	Included	Added	Added	Added
Woodland management	Included	Included	Included	Included	Included
Soil and land management	N/A	N/A	N/A	N/A	Added
Peat management	Included	N/A	Added	Added	Added

5.3 Water quality benefits

Estimating water quality benefits within the method is based on values taken from the EHOV-Lite tool and its associated guidance lookup tables. However, given the current level of uncertainty in the evidence linking NFM explicitly to Water Framework Directive

(WFD) status improvements, several adjustments were made to reflect a more conservative and realistic interpretation of potential benefits.

EHOV-Lite provides a monetary valuation for improvements in WFD status of rivers or streams. For instance, the value assigned to an improvement of 1km of watercourse from 'bad' to 'moderate' status is £20,886. This figure is derived from the National Water Environment Benefits Survey (NWEBS), which estimates willingness to pay for improved water quality based on a set of 6 main components that influence ecological condition and public perception.

The 6 components are:

- fish – the presence and diversity of fish species as indicators of ecological health
- invertebrates – populations of aquatic invertebrates, which reflect water quality and biological richness
- plants – aquatic vegetation, used to assess nutrient status and habitat quality
- clarity – the visual clarity of the water, which affects amenity, ecology and perception of cleanliness
- flow – the naturalness of flow regime, important for ecological function and hydrological health
- safety – factors such as bacterial pollution that influence the safety of water for public contact or recreation

Each of these components contributes equally to the total valuation. EHOV guidance recommends adjusting the total value to avoid double counting, specifically subtracting one-sixth of the total (£3,481) if the component has already been accounted for elsewhere. This results in a revised baseline value of £17,405 for a full-status improvement.

5.3.1 Review of evidence of NFM and water quality impacts

A rapid review of available evidence was carried out to assess NFM interventions that have led to measurable improvements in WFD status. The findings indicate that, while there are a handful of cases where NFM measures may have contributed to observed status improvement, such as the Belford Burn, the Eddleston Water project and restoration works in the River Glave, these instances are relatively rare and often influenced by other catchment-scale activities or simultaneous interventions. In most of the cases reviewed, no direct evidence was available linking specific NFM measures to verified changes in WFD status.

Of the NFM measures reviewed, river restoration, floodplain wetland restoration and riparian woodland creation appear most frequently in association with improved WFD outcomes, although the causal link to NFM remains uncertain in many instances. Conversely, measures such as leaky barriers, soil and land management and offline storage lack sufficient consistent evidence of water quality improvements to change WFD classification.

Even where positive change has been observed, the evidence often does not isolate NFM as the sole driver, and in several cases, monitoring timelines coincided with or closely followed implementation, making attribution uncertain. The review supports a precautionary approach to valuing water quality benefits, reinforcing the need for conservative estimates within the method, and highlighting the importance of further research to strengthen the evidence base.

Furthermore, the baseline figure of £17,405 per km is relatively high compared to other benefits valued in the EHOV-Lite and, in some cases, could exceed the highest possible value for residential flood damages and the other highly valued environmental benefits in the tool (for example, woodland creation which is valued at £1,979 per ha per year). This raised concerns about potential overestimation of water quality benefits in the absence of strong supporting evidence.

5.3.2 Approach adopted in the method

To address these concerns and reflect the low confidence in the direct WFD status improvements provided by NFM, the method takes a conservative approach by:

- using the lowest available value for a WFD status improvement (from 'bad' to 'moderate')
- applying the value for WFD status improvement as a flat rate per kilometre of watercourse predicted to experience improvement
- as with EHOV-Lite, using the 2021 NWEBS data set for willingness to pay values, which are differentiated by catchment
- adjusting the monetary value to reflect the assumption that an NFM measure is likely to affect only 3 of the 6 NWEBS components, rather than all 6
- using a further scaling factor of 30% to reflect low confidence in empirical links between NFM and verified WFD outcomes, account for variation in performance across catchments and types of NFM and ensure water quality benefit estimates remain proportionate to other benefits

The calculation used is:

$$Total\ water\ quality\ benefits = (2021\ NWEBS\ low\ value\ at\ catchment\ level\ x\ length\ of\ watercourse\ improved\ (km) \times 3) \times 0.3$$

6 Conclusion

6.1 Limitations and recommendations

While this method draws on the latest available evidence and scientific understanding, including the updated WWNP evidence directory and findings from the NERC NFM programme, certain limitations remain. Many of these stem from inherent uncertainties and gaps in observed data, and could be addressed through further development, refinement and validation of the underlying assumptions as the evidence base continues to grow. This section summarises the limitations identified for each component of the method, and a recommended approach to resolving them in the future.

6.1.1 Design storage

Limitation: While the design storage estimates provide a practical and consistent means of quantifying NFM feature capacity, they are based on simplified assumptions (for example, average depths and geometries) that may not fully reflect the diversity of feature design and site-specific characteristics.

Recommendation: Future updates could refine these assumptions using observed data from built NFM schemes, enabling more accurate volumetric estimates based on typical design profiles and performance monitoring.

6.1.2 Effective storage

Limitation: The method does not currently account for the degradation or improvement of NFM performance due to factors such as sediment accumulation, vegetation change, land management shifts or maintenance. Similarly, it does not consider the temporal change, such as changes in performance associated with woodland establishment and maturation over time. This means that long-term effectiveness, particularly in relation to flood attenuation, may be over or underestimated, depending on site conditions and scheme longevity.

Recommendation: Using observed data or through further research, introduce dynamic performance factors or lifecycle adjustments (for example, decay curves or maturity multipliers) to better capture changes in effective storage over time, enhancing long-term benefit estimation.

6.1.3 Downstream flood risk benefits

Limitation: The method incorporates a decay function to scale flood risk benefits as distance increases downstream from an intervention along with a regression equation, drawing on outputs from simulated NFM scenarios. While this approach provides a useful, national-scale framework, it assumes a level of uniformity across different catchments that may not accurately reflect the hydrological and ecological variability observed on the ground. Factors such as underlying geology, land cover, antecedent moisture conditions and hydrological response types are not explicitly accounted for, which may affect the applicability of the outputs in more complex catchments.

Recommendation: Enable optional regionalisation of parameters or integrate additional spatial data sets (for example, soil moisture, slope gradient) to better reflect variability in catchments.

6.1.4 Environmental benefits – refining estimation benefits

Limitation: The environmental valuation method incorporates a wide range of ecosystem service benefits, including carbon sequestration, biodiversity and air quality improvements. However, its outputs can appear disproportionately high when compared to flood risk benefits, from some previous business cases. This reflects the use of benefit values per hectare derived from EHOV-Lite, a tool not developed specifically for NFM. As a result, there is uncertainty in how some NFM features, particularly linear features such as leaky barriers are translated into habitat categories for valuation. These conversions may either overstate benefits or fail to reflect local variation, highlighting uncertainties related to ecological and economic benefit estimates.

Recommendation: Future refinement should focus on improving the representation of NFM-specific interventions within EHOV-Lite by enhancing assumptions about land use change, better capturing the outcomes of linear features, and incorporating co-benefits such as avoided carbon emissions and social or amenity value. The method has been intentionally designed to allow integration of new evidence as it emerges.

6.1.5 Environmental benefits - water quality

Limitation: There is uncertainty in estimating water quality benefits due to limited empirical evidence linking NFM interventions to measurable improvements in WFD status. The method applies monetary values derived from NWEBS to user-defined estimates of watercourse length improved, moderated by a uniform 30% confidence factor. However, this flat rate approach simplifies what is, in practice, a highly variable and spatially dependent outcome.

Recommendation: While a precautionary approach has been adopted to reflect the low confidence in current evidence, further research is needed to improve understanding of the links between NFM and WFD outcomes. Strengthening the evidence base would support more reliable valuation methods and reduce uncertainty in future versions of the method. In the meantime, water quality outputs should be interpreted with appropriate caution.

6.1.6 Measure coverage and scope

Limitation: The current method is limited to inland, freshwater NFM measures and does not extend to interventions in estuarine, coastal or urban environments. As the demand for multi-functional land use and climate adaptation grows, there is an increasing need to incorporate these other settings. The exclusion of certain benefits, such as avoided carbon emissions from traditional grey infrastructure or reduced flood-related property damage emissions, also constrains the full accounting of NFM's climate mitigation potential.

Recommendation: The method could be expanded to include interventions from source-to-sea, such as estuarine and coastal measures. Sustainable drainage systems (SuDS) are also important nature-based solutions (NBS) measures for flooding. However, it is recognised that there are already established methods and tools available to estimate the benefits of these measures, such as CIRIA's B£ST Benefits Estimation Tool. Additionally, flow paths in urban environments are typically much more complex due to factors such as impermeable surfaces, underground drainage networks and highly modified topography, which may necessitate bespoke modelling approaches.

6.1.7 User input and data dependence

Limitation: The method requires the input of several important assumptions, such as the area of intervention, habitat type conversion and estimated water quality improvement length, which introduces a degree of subjectivity. The accuracy of the output, therefore, depends on the users' knowledge, data availability and interpretation. Inconsistent inputs or misunderstanding of assumptions may skew results.

Recommendation: Provide worked examples and guidance to support a consistent approach to user inputs and reduce subjectivity.

6.1.8 Validation

Limitation: Although the method is grounded in current research, including the updated WWNP evidence directory and the NERC NFM programme, there is currently no systematic validation of its outputs against observed, post-implementation outcomes. Without such validation, the method should be treated as indicative rather than predictive. However, the method has been sense checked using real project information and reviewed by subject matter experts to help verify, as far as reasonably practicable, that the outputs are reasonable and reflect plausible estimates of NFM performance under typical conditions.

Recommendation: A validation method that compares the method outputs with observed post-implementation outcomes across a variety of schemes and geographies could be developed and integrated into a feedback loop, allowing evidence and lessons learned to continually improve the approach. Monitoring and learning from the Environment Agency's £25 million NFM programme offers a valuable opportunity to strengthen the assumptions underpinning the method and improve its reliability over time.

6.2 Summary

This study has developed a novel, repeatable approach to estimate the potential flood risk reduction and environmental benefits of an NFM scheme. The method is designed to support the scaling-up and mainstreaming of NFM by enabling benefits to be estimated at a high-level without the need for bespoke modelling and assessment. The method uses Environment Agency data sets (NaFRA2 and EHOV-Lite), integrating them into a framework that can be applied nationally.

The method estimates flood benefits by converting design storage to effective storage and linking this to avoided damages through a spatially explicit benefit decay function. It also incorporates wider environmental benefits, including carbon sequestration, biodiversity enhancement, air quality and water quality improvements into a cost-benefit framework. The method draws directly on the latest scientific understanding, incorporating new insights from the recently updated WWNP evidence directory (Environment Agency, 2024) and findings from the NERC NFM research programme (Chappell and others, 2023). These sources have provided useful data related to effective flood storage multipliers and catchment-scale impacts, which have been used to underpin the method's technical assumptions and parameters.

6.2.1 Proportionate application

It is important to note that this method has not been developed to replace detailed modelling where it is required. In contexts where significant investment is being considered, such as large-scale capital schemes or catchment-scale programmes, bespoke hydrological or hydraulic assessments remain important to fully understand site-specific impacts and optimise design.

While the method provides a consistent, practical and scalable means of estimating benefits across a wide range of NFM interventions, there are inherent limitations to how accurately it can reflect specific local conditions. As such, even with further refinement, it is not expected to offer the precision of site-specific modelling. However, it can provide a useful tool to support screening, prioritisation, early-stage decision-making and investment in cases where more bespoke modelling could be disproportionate.

Appendix A: Input values and dimension assumptions made during adaptation of EHOV

As EHOV did not contain calculations for valuing the air pollutant removal, carbon sequestration and biodiversity benefits of certain NFM measures, the values were added to the benefits estimation method based on habitat creation assumptions.

The first 3 sections detail the input values added to the EHOV method to allow for valuation of air pollutant removal, carbon sequestration and biodiversity for certain NFM measures. The values were added based on habitat creation assumptions. For those NFM measures whose implementation cannot be quantified in hectares (leaky barriers or river restoration), assumptions were made to convert these values to hectares. The 'Habitat dimension assumptions for NFM options' section outlines these assumptions.

Where ‘ID’ is quoted in ‘Assumptions’, this refers to values taken from EHOV look-up worksheets.

Air pollutant removal input values and assumptions for NFM options

River restoration

Value (£/ha): 8
Assumption: average PM2.5 removal from freshwater (ID 3.25 and 3.26) multiplied by the average per tonne value of PM2.5 (ID 4.11 and 4.12). It is assumed that the flow and value of carbon reduction is constant over time.

Leaky barriers

Value (£/ha): N/A
Assumption: air pollutant removal value was assumed to have limited benefits.

Floodplain reconnection

Value (£/ha): 8
Assumption: average PM2.5 removal from freshwater (ID 3.25 and 3.26) multiplied by the average per tonne value of PM2.5 (ID 4.11 and 4.12). It is assumed that the flow and value of carbon reduction is constant over time.

Offline and run-off storage

Value (£/ha): 8
Assumption: average PM2.5 removal from freshwater (ID 3.25 and 3.26) multiplied by the average per tonne value of PM2.5 (ID 4.11 and 4.12). It is assumed that the flow and value of carbon reduction is constant over time.

Woodland management

Value (£/ha): 482
Assumption: average PM2.5 removal for all woodland types (ID 4.1, 4.2, 4.3, and 4.4). It is assumed that the flow and value of carbon reduction is constant over time.

Soil and land management

Value (£/ha): N/A
Assumption: air pollutant removal value was assumed to have limited benefits.

Peat management – Degraded

Value (£/ha): 7
Assumption: assume lower PM2.5 removal rate by mountains, moors and heaths (ID 3.18) for degraded peat and multiply by the average per tonne value of PM2.5 (EHOV ID 4.11 and 4.12). It is assumed that the flow and value of carbon reduction is constant over time.

Peat management – Restored

Value (£/ha): 11
Assumption: assume upper PM2.5 removal rate by mountains, moors and heaths (ID 3.17) for restored peat and multiply by the average per tonne value of PM2.5 (EHOV ID 4.11 and 4.12). It is assumed that the flow and value of carbon reduction is constant over time.

Carbon value input values and assumptions for NFM options

Emissions, values and assumptions for each NFM type are outlined below. Negative carbon emissions values (CO_2e/ha/yr) indicate sequestration from the atmosphere back into the vegetation or soil. Positive figures indicate emissions to the atmosphere.

River restoration

Carbon emissions (CO_2e/ha/yr): -3.37
Value (£/ha): 824
Assumption: assumed floodplain carbon accumulation rate (Natural England, 2021). It is assumed that flow and value of carbon reduction by habitats is constant over time.

Leaky barriers

Carbon emissions (CO_2e/ha/yr): N/A
Value (£/ha): N/A
Assumption: carbon reduction was assumed to have limited benefits.

Floodplain reconnection

Carbon emissions (CO_2e/ha/yr): -3.37
Value (£/ha): 824
Assumption: assumed floodplain carbon accumulation rate (Natural England, 2021). It is assumed that flow and value of carbon reduction by habitats is constant over time.

Offline and run-off storage

Carbon emissions (CO_2e/ha/yr): -7.10
Value (£/ha): 1,738
Assumption: assumed lake carbon accumulation rate (Natural England, 2021). It is assumed that flow and value of carbon reduction by habitats is constant over time.

Woodland management

Carbon emissions (CO_2e/ha/yr): -5.75
Value (£/ha): 1,408
Assumption: assumed average sequestration rate for all woodland (ID 3.51). It is assumed that the flow and value carbon reduction by habitats is constant over time.

Soil and land management

Carbon emissions (CO_2e/ha/yr): N/A
Value (£/ha): N/A
Assumption: carbon reduction was assumed to have limited benefits. While some research has shown links between land management practices, soil porosity and carbon content, additional evidence is needed before a carbon sequestration rate can be applied as standard to all soil and land management measures.

Peat management – Degraded

Carbon emissions (CO_2e/ha/yr): 23.80
Value (£/ha): -5,827
Assumption: eroding peat carbon emission values taken from EHOV look-up worksheet (ID 3.57). It is assumed that flow and value carbon reduction by habitats is constant over time.

Peat management – Restored

Carbon emissions (CO_2e/ha/yr): 1.10
Value (£/ha): -269
Assumption: natural condition peat carbon emission values taken from EHOV look-up worksheet (ID 3.60). It is assumed that the flow and value carbon reduction by habitats is constant over time.

Biodiversity input values and assumptions for NFM options

River restoration

Value (£/ha): 54.15
Assumption: average of 'semi-natural grassland' (ID 4.26) and blanket bog (ID 4.25) from EHOV look-up tables workbook.

Leaky barriers

Value (£/ha): 65.98
Assumption: assumed blanket bog (ID 4.25) as a proxy for leaky barriers features that may be created for this measure.

Floodplain reconnection

Value (£/ha): 54.15
Assumption: average of 'semi-natural grassland' (ID 4.26) and blanket bog (ID 4.25) from EHOV look-up tables workbook.

Offline and run-off storage

Value (£/ha): 65.98
Assumption: assumed blanket bog (ID 4.25) as a proxy for leaky barriers features that may be created for this measure.

Woodland management

Value (£/ha): 90.00
Assumption: taken from EHOV look-up tables workbook (ID 4.21).

Soil and land management

Value (£/ha): 7.47
Assumption: average of improved grassland and arable field margins from EHOV look-up tables workbook (ID 4.27 and 4.28).

Peat management – Degraded

Value (£/ha): 32.99
Assumption: biodiversity value taken from EHOV look-up tables workbook (ID 4.25). Assumed 50% of benefit value associated with blanket bog for degraded peat.

Peat management – Restored

Value (£/ha): 65.98
Assumption: biodiversity value taken from EHOV look-up tables workbook (ID 4.25).

Habitat dimension assumptions for NFM options

River restoration

River restoration was captured by determining a ‘corridor’ along the watercourse being restored to represent it in hectares rather than length.
Calculation: [(Average barrier width (m)/1,000)] x [Length of watercourse restored on (km)] = ha improved.

Leaky barriers

Leaky barrier features were captured by determining a ‘corridor’ along the watercourse throughout which features are applied.
Calculation: [(Average barrier width (m)/1,000)] x [Length of watercourse barriers applied on (km)] = ha improved.

Floodplain reconnection

Should be represented as hectares.
Assumption: represent as the area of floodplain reconnected.

Offline and run-off storage

Should be represented as hectares.
Assumption: represent the measures as the area they cover (rather than the volume stored).

Woodland management

Should be represented as hectares.
Assumption: record total area of implementation.

Soil and land management

Should be represented as hectares.
Assumption: record total area of implementation.

Peat management – Degraded

Should be represented as hectares.
Assumption: record total area of implementation.

Peat management – Restored

Should be represented as hectares.
Assumption: record total area of implementation.

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