Feasibility Assessment of a Watershed Investment Program in the Warwickshire Avon, UK.

Aug 2025

Warwickshire Avon, United Kingdom

The Partners Consortium

Warwickshire Wildlife Trust:
WWT is a local conservation charity dedicated to protecting and enhancing wildlife and wild places across Warwickshire, Coventry, and Solihull. It combines scientific expertise with strong community engagement, delivering nature-based solutions through habitat restoration, biodiversity enhancement, and education. With extensive experience in catchment-based work and practical delivery of nature-based solutions, WWT plays a key role in driving local environmental initiatives and partnerships.

Severn Trent:
Severn Trent is one of the UK’s largest water companies, providing water and wastewater services across the Midlands. The company has made significant commitments to environmental sustainability, including large-scale investment in green infrastructure, water quality improvements, and natural flood management. It is a key player in water catchment management, supporting nature-based interventions and community-driven water stewardship.

Warwickshire County Council:
WCC is the local authority responsible for strategic planning, environmental policy, and public services in Warwickshire. The Council is a key enabler of place-based climate and nature action, leading on initiatives that promote resilience, biodiversity, and sustainable development. WCC plays a central role in aligning environmental goals with wider regional development strategies and facilitating cross-sector partnerships.

Environment Agency:
The EA is a non-departmental public body under Defra, responsible for protecting and enhancing the environment in England. It plays a leading role in managing water resources, flood risk, and climate resilience, as well as regulating environmental impacts. The EA supports and funds innovative nature-based approaches through strategic programmes like WINEP (Water Industry National Environment Programme) and partnership delivery models.

Nature for Water
The Nature for Water (N4W) Facility is a global technical assistance programme co-led by ***The Nature Conservancy (TNC)*** and ***Pegasys Consulting***. Its mission is to support local champions in designing and launching large-scale watershed investment programmes that deploy Nature-based Solutions (NbS) for water security, biodiversity, and climate resilience. The Facility offers hands-on, tailored support across hydrology, ecology, GIS, governance, finance, and stakeholder engagement – delivered through pro-bono, fee-based services. TNC is one of the world’s largest conservation organisations, working in over 70 countries to create science-based, collaborative solutions to the world’s most pressing environmental challenges. Pegasys is a mission-driven consultancy with deep expertise in policy, sustainability, and nature finance, operating across Africa, Europe, and globally. Together, TNC and Pegasys have supported over 35 watershed investment programmes worldwide, catalysing investment in healthy ecosystems and resilient communities.

Acknowledgements

This assessment was conducted by the Nature for Water Facility for the partner consortium. The Warwickshire Wildlife Trust, the Environment Agency, Severn Trent, and the Warwickshire County Council have provided critical input throughout this process.

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Report Highlights

- **A Shared Vision for a Resilient Future.**
  We envision a thriving Warwickshire Avon catchment where NbS secures water resilience, restore biodiversity, support sustainable economic growth and empower communities through long-term collaboration, investment and stewardship.

- **A Unique Partnership.**
  Warwickshire Wildlife Trust, Warwickshire County Council, Severn Trent, and the Environment Agency have formed a pioneering partnership to scale NbS across the catchment.

- **Critical Challenges across the Catchment.**
  The region faces growing flood risk, poor water quality, and biodiversity loss driven by land use pressures, ageing infrastructure, and climate change. While flooding is the immediate concern, future climate-driven drought and water shortages could threaten food security and economic growth. These impacts hinder sustainable development, harm public health, and degrade quality of life and natural habitats.

- **Working with Nature. Our Holistic Solution.**
  NbS offer a cost-effective alternative to traditional grey infrastructure – reducing flooding, improving water quality, and enhancing groundwater recharge – though their benefits extend well beyond this. When implemented catchment-wide, NbS provide a regenerative, long-term approach, delivering water and food security, biodiversity, carbon capture, and community wellbeing. They also enhance existing infrastructure by extending its lifespan, easing pressures, and enabling adaptation to climate change and shocks.

- **A New Model for Delivery.**
  The proposed solution represents a shift in how water is valued and delivered. A new delivery model is needed – collaborative, cross-sectoral, and designed to deliver multiple benefits. The core partners are committed to formalising collaboration, with decision-making protocols and delivery structures to be defined and iterated upon in the next phase. Options are being explored to balance broad stakeholder participation with prioritising optimal NbS for catchment health.

- **Science and Technical Analysis.**
  Our specialist team applied best-practice NbS optimisation – GIS mapping, advanced hydrological modelling, and spatial analysis – to propose a robust, catchment-wide approach. The models show that at-scale NbS can significantly reduce flooding, improve water quality and availability, and deliver major benefits to people and nature.

- **What will this cost, and what will it return?**
  We undertook a rigorous analysis of costs and benefits to implement the proposed catchment-wide NbS approach through a partner-led investment programme (the "Programme"). The full Programme could require up to GBP 700 million over 30 years and is expected to generate around GBP 2 billion in economic benefits – a benefit-to-cost ratio of approximately 2.7 to 1. Crucially, this level of investment is not needed upfront: early funding can already deliver meaningful outcomes such as reduced flooding, while building momentum for wider-scale implementation.

- **What shall we do next? Urgent Call to Action.**
  Over the next three years, the partners aim to establish a Water Hub – a coordinated collective to manage investment and track benefits for at-scale NbS. For this start-up phase, the partners will expand their network and seek to raise GBP 4.4 million to fund initial projects, including technical assistance, programme management, and monitoring. Importantly, the core partners have already committed GBP 300,000 in support of this effort. A roadmap defines key steps to establish governance, delivery models, and stakeholder participation to ensure long-term viability.

Executive Summary

INTRODUCTION

The Warwickshire Avon catchment, covering 2,800 km² in Central England, faces increasing pressures from climate change, urban development, and agricultural intensification. These pressures have contributed to more frequent flooding, declining water quality, and growing competition for water resources.

Nature-based Solutions (NbS) offer a promising response. By protecting, managing, and restoring ecosystems, NbS can address societal challenges such as flooding and pollution while also delivering biodiversity gains, climate and community co-benefits. They hold particular potential in the context of the Warwickshire Avon for small and dispersed communities, where traditional grey infrastructure flood defences are often prohibitively expensive or technically unfeasible.

Recognising the need for more integrated, cost-effective, and collaborative approaches, Warwickshire Wildlife Trust, Warwickshire County Council, Severn Trent, and the Environment Agency have come together to explore a holistic, catchment-wide NbS strategy. While each has implemented NbS in isolation, their ambition is to scale up impact through a collaborative partnership model.

Over the past year, the Nature for Water Facility (N4W) has supported this coalition by conducting a feasibility study into the potential for a large-scale NbS programme ("the Programme"). The study assessed anticipated impacts, costs, governance options, and funding strategies to determine the conditions for successful implementation.

- By 2080, over 18,000 homes across the catchment are projected to be at risk of flooding.
- 98% of water bodies in the catchment continuously fail to meet good ecological status under the Water Framework Directive (WFD).

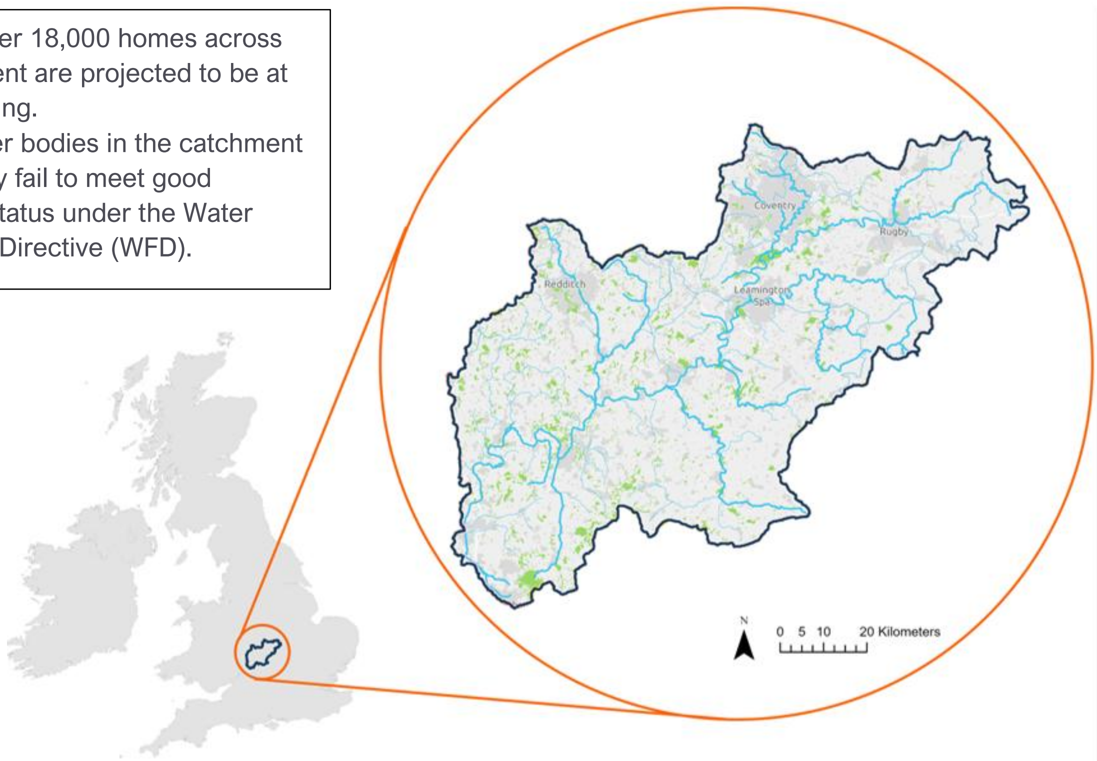


Figure 1: Map of the Warwickshire Avon catchment.

PROGRAMME VISION

N4W supported the partners to refine the vision for the Programme. The partnership envisions a collaborative model for securing long-term water resilience through scaled implementation of NbS. Building on individual partners' experience, the vision is to co-develop a programme capable of achieving catchment-wide outcomes through shared governance, joint financing, and coordinated delivery. The Programme would integrate a portfolio of tailored NbS interventions informed by scientific, stakeholder, and financial analyses.

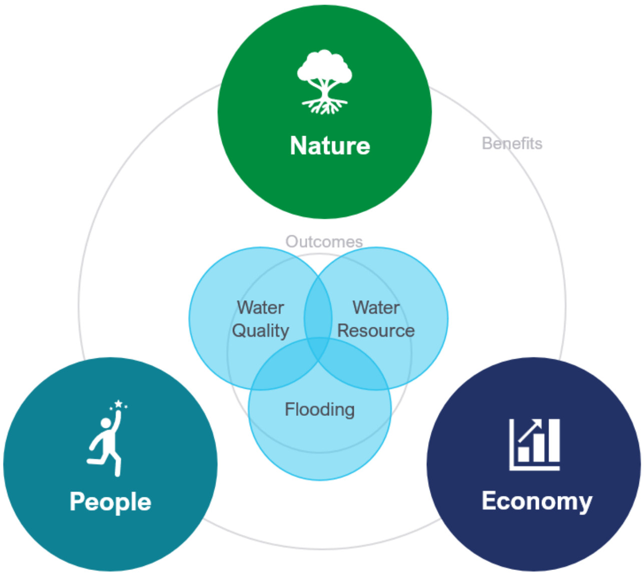


Figure 2: Programme vision.

*The aim of this Programme is to pioneer a **collaborative partnership model** in the Warwickshire Avon to **scale up funding for Nature-based Solutions** that secure a **resilient water future**.*
*The Programme's vision is to deliver a catchment that is **resilient to climate and nature-related water risks** delivering tangible benefits for **Nature, People, and the Economy.***
*It will identify sustainable and **holistic** land and water management interventions which tackle water security challenges **including flooding, water quality, and water availability** across the catchment.*

NATURE-BASED SOLUTIONS TO BUILD A WATER RESILIENT FUTURE

A rigorous technical assessment was undertaken to identify the most suitable types and locations of NbS, as well as to estimate their potential impacts. All spatial mapping was carried out at the catchment scale, while hydrological modelling was undertaken in a targeted sub-catchment of the Warwickshire Avon. The results from this modelled area were then extrapolated to the wider catchment in a second step. The assessment included:

- **Sub-Catchment Prioritisation**: Mapping identified areas with the highest need and feasibility for NbS delivery based on partners' existing strategies and priorities, flood risk, water quality, and water resources.
- **NbS Opportunity Mapping**: GIS-based analysis identified suitable
- , at the catchment scale, for specific interventions such as bunds, ponds, leaky barriers, and riparian restoration (see Figure 4).
- **Hydrological Flood Modelling**: Using a hydrological flood model (HEC-HMS) in a targeted sub-catchment of the Warwickshire Avon revealed that NbS implementation could reduce peak flood flows by up to 25% in key areas, delay flood peaks, and enhance emergency preparedness.
- **Co-benefit Modelling**: NbS could significantly reduce nutrient export and increase biodiversity, while also delivering carbon and groundwater recharge benefits.

A final portfolio of interventions covering 5.5% of the catchment area was selected, balancing impact, cost-efficiency, and deliverability. The portfolio prioritised bunds, ponds, and leaky barriers for their cost-effectiveness and combined them with riparian buffers, floodplain reconnection and woodland planting for broader co-benefits (see Figure 3).

The analysis demonstrated that, with minimal land take from productive agricultural areas, NbS can be implemented at scale to deliver significant improvements in flood risk management, water quality, and water resources, while also generating co-benefits for climate resilience and biodiversity.

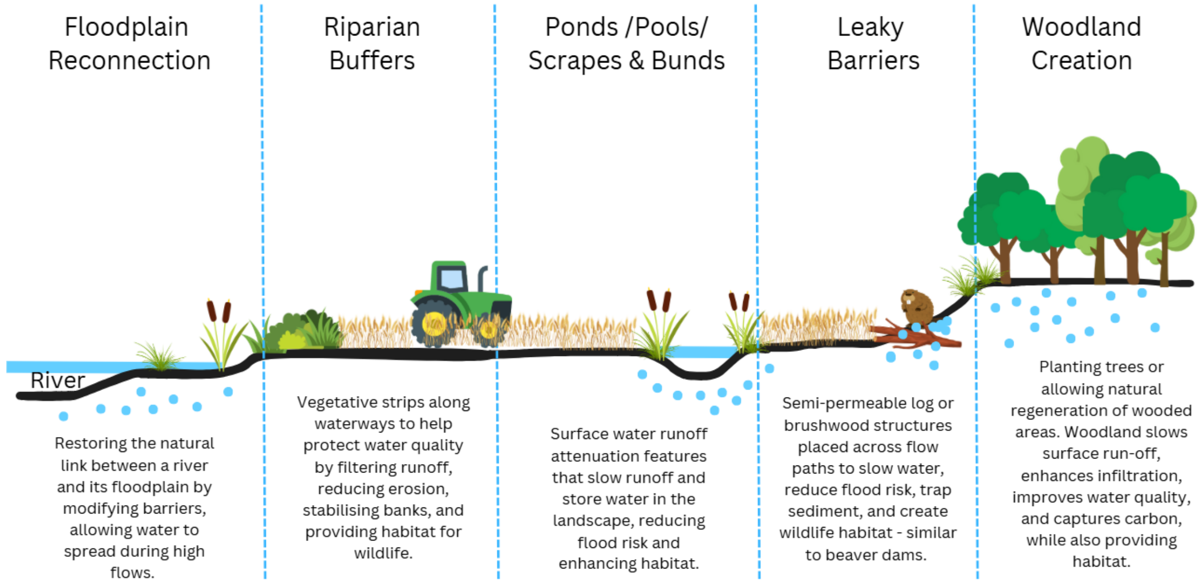


Figure 3: Shortlist of priority NbS.

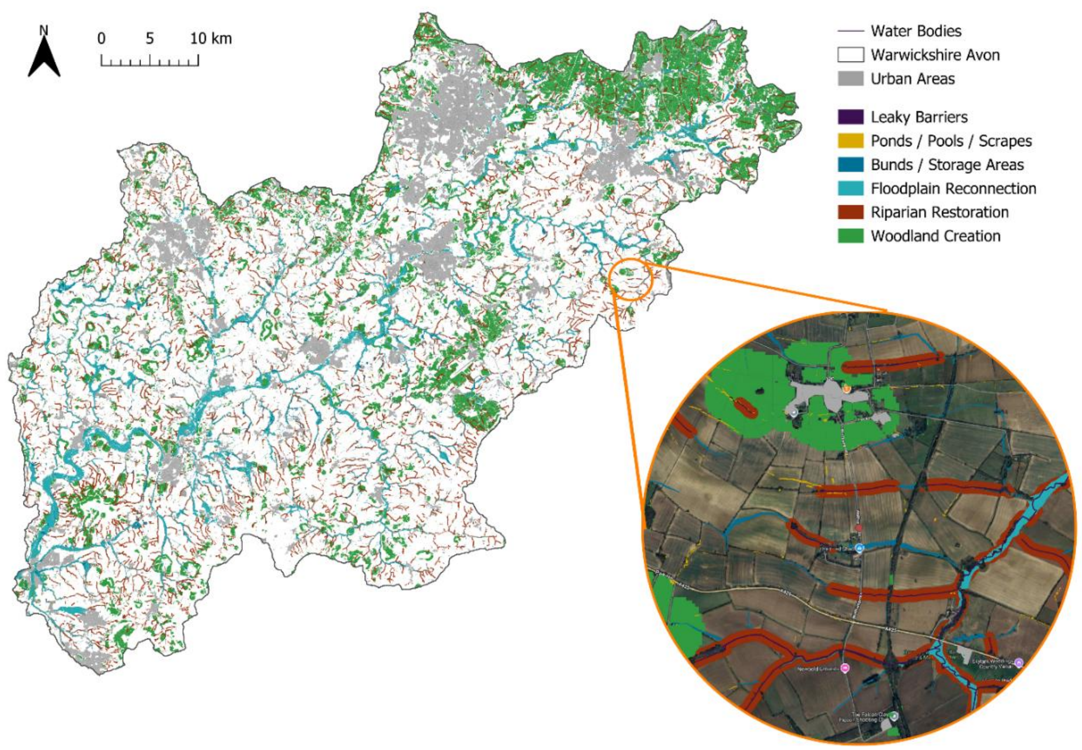


Figure 4: Opportunity mapping for the Warwickshire Avon

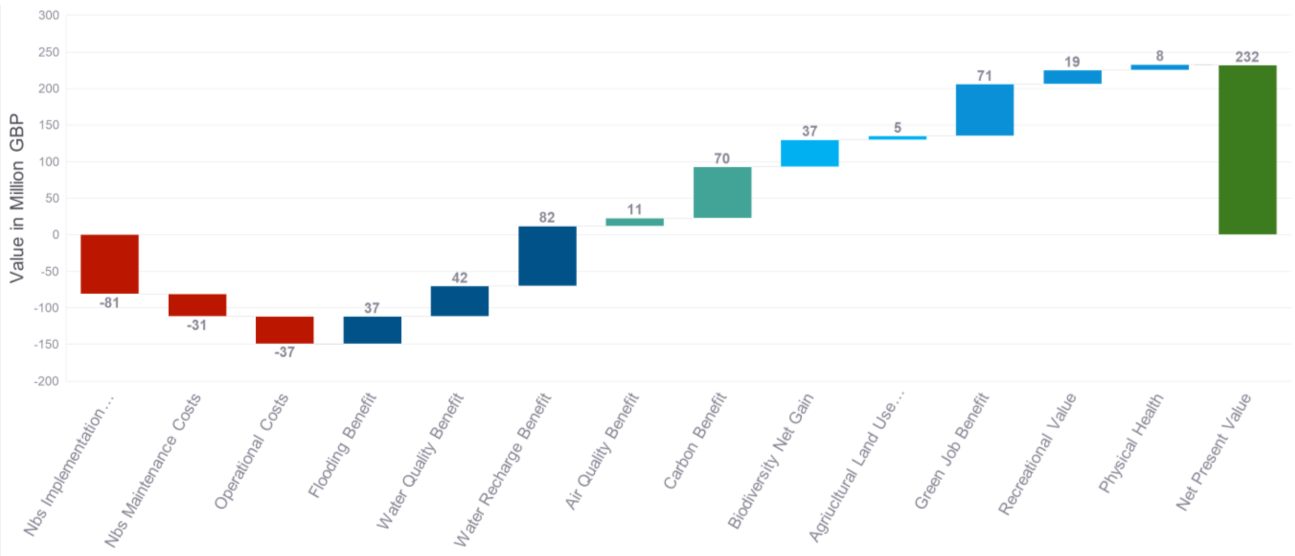
ECONOMIC AND FINANCIAL ANALYSIS

A 30-year cost–benefit analysis (CBA) was undertaken to evaluate the Programme's economic case. The assessment compared total costs (estimated at GBP 149 million for the modelled area) with monetised benefits across water, climate, biodiversity, and community domains (estimated at GBP 382 million). Consistent with the technical and scientific analysis, the CBA focused on the targeted modelling area, with results subsequently extrapolated to the wider catchment. Key findings include:

- **Benefit-Cost Ratio (BCR)**: 2.5 for the modelled area and 2.7 when scaled to the entire catchment, indicating a positive economic case (with values > 1).
- **Net Present Value (NPV)**: GBP 230 million.
- **Internal Rate of Return (IRR)**: 14%, well above the UK social discount rate.

Benefits were conservatively estimated, relying on gold standard methodologies such as the HM Treasury's Green Book (HM Treasury, 2022) or the Multi-Coloured Manual for flood damage assessment. The analysis focused on measurable outcomes such as avoided flood damage, improved water quality, carbon sequestration, health and recreation gains, and green job creation. Other benefits – such as reduced insurance costs, enhanced resilience to climate stressors, and water treatment cost savings – were not quantified due to the absence of sufficiently rigorous methodologies or data at the required level of granularity.

In summary, the analysis demonstrates a strong economic case for at-scale NbS: for every GBP 1 invested in the Programme, an estimated GBP 2.70 of benefits would be generated across flood resilience, water quality, water resources, climate, biodiversity, and community domains.



[1]

Figure 5: Waterfall diagram of costs and benefits of NbS implementation across the targeted modelling area.

[1] As each cost and benefit has been rounded to the nearest whole number, the aggregated NPV on this chart may appear as GBP 233M. In reality, the precise value is GBP 232.3M, which has been rounded to GBP 232M.

FUNDING STRATEGY AND NEXT STEPS

The Programme will adopt a blended finance model combining public, philanthropic, and private capital. Near-term funding will rely on public and philanthropic support to de-risk initial projects. Over time, investment will be scaled through biodiversity, carbon, and water markets. Warwickshire County Council's pioneering role in Biodiversity Net Gain and nature market development creates a strong platform for this approach.

Next steps include:

- Formalising the partnership and governance structure.
- Implementing initial pilot projects.
- Develop a Monitoring and Evaluation Framework.
- Developing a 5-year implementation plan.
- Launching a targeted stakeholder engagement strategy.
- Define the governance structure.
- Securing GBP 4.4 million in start-up funding (with GBP 300,000 already committed by the partners).
- Develop a long-term and sustainable funding strategy.

CONCLUSION

The feasibility assessment demonstrates that large-scale NbS implementation in the Warwickshire Avon catchment is technically feasible, economically viable, and socially beneficial. The Programme offers a compelling investment case with strong returns across water, climate, biodiversity, and community outcomes. The evidence supports immediate action to launch a start-up phase, formalise governance, and secure early-stage funding.

With coordinated effort, the partners can unlock a scalable, nature-based solutions Programme that addresses the region's water challenges while delivering wider environmental and societal benefits. Beyond the robust cost-benefit rationale, this Programme represents a paradigm shift in how water security and environmental resilience are approached. Rather than relying solely on engineered solutions, the initiative seeks to restore the natural systems that once provided these services, aligning ecological function with economic logic. This integrative approach is not only more adaptive in the face of climate change, but it also presents opportunities for job creation, improved public health, and enhanced community well-being.

The groundwork laid by the feasibility study positions the partnership to move confidently into implementation. Importantly, early-phase activities will provide critical proof-of-concept, showcasing the efficacy of NbS and building trust with funders, landowners, and local communities. With a long-term vision and a commitment to inclusive, evidence-based planning, the Warwickshire Avon NbS Programme can become a national exemplar for systemic catchment-scale restoration.

To realise this vision, decisive action and committed investment are now required. Mobilising the proposed start-up funding will catalyse progress and unlock broader co-financing opportunities. As such, this moment presents a timely and strategic window to act – delivering measurable outcomes for people, nature, and the economy in Warwickshire and beyond.

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List of Acronyms

Meaning	Abbreviation
Agricultural Best Management Practices	AgBMPs
Annual Maximum Series	AMS
Biodiversity Net Gain	BNG
Business as Usual	BaU
Environment Agency	EA
Catchment Based Approach	CaBA
Combined Sewer Overflows	CSO
Community Interest Company	CIC
Cost-Benefit Analysis	CBA
Curve Number	CN
Department for Environment, Food & Rural Affairs	DEFRA
Environmental Land Management	ELM
Environmental, Social and Governance	ESG
Geographic Information System	GIS
Global Environment Facility	GEF
Great British Pounds	GBP
Ground Outcomes	GO
Hydrologic Engineering Center's Hydrologic Modeling System	HEC-HMS
Hectare	Ha
Hydrological Response Units	HRUs
Integrated Water Resources Management	IWRM
Internal Rate of Return	IRR
Jaguar Land Rover	JLR
Land use/land cover	LULC
Light Detection and Ranging	LiDAR
Land Cover Map 2023	LCM2023
Local Nature Recovery Strategy	LNRS
Measurement, Reporting, and Verification	MRV
Memorandum of Understanding	MoU
Metropolitan, Municipal and District Assemblies	MMDAs
Million Cubic Meters	MCM
Nash-Sutcliffe Efficiency	NSE
National Water Environment Benefit Survey	NWEBS
Natural Capital Register and Account Tool	NCRAT
Nature for Water	N4W
Net Present Value	NPV
Non-Governmental Organizations	NGOs
Percent Bias	PBIAS
Public Utilities Regulatory Commission	PURC
Quality-Adjusted Life Year	QALY
Reasons for Not Achieving Good	RNAGs
Representative Concentration Pathways	RCP
Return on Investment	ROI
Riparian Restoration and Protection	RPR
Severn Trent	ST
Taskforce on Nature-related Financial Disclosures	TNFD
The Nature Conservancy	TNC

To be confirmed	TBC
United Kingdom	UK
UK Climate Projections	UKCP
United Kingdom Soil Observatory	UKSO
Warwickshire County Council	WCC
Warwickshire Wildlife Trust	WWT
Water Framework Directive	WFD
Water Industry National Environment Programme	WINEP
World Health Organisation	WHO

1. Introduction

The Warwickshire Avon, a **headwater catchment** spanning 2,800 km² in Central England, is under increasing pressure from **agricultural degradation, diffuse pollution, population growth, and climate change**. These drivers are contributing to more frequent flooding, ongoing water quality decline, and growing concerns over the long-term sustainability of water resources.

Traditional grey infrastructure is increasingly failing to provide effective, long-term solutions – especially for flood protection in small, dispersed communities – due to high costs and, in some cases, technical infeasibility. As such, **NbS** can present a promising opportunity to address those water-related challenges, while also delivering benefits for nature, people, and the economy. NbS are actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham, Walters, Janzen, & Maginnis, Nature-Based Solutions to Address Societal Challenges, 2016).

The **Warwickshire Wildlife Trust (WWT), Warwickshire County Council (WCC), Severn Trent (ST), and the Environment Agency (EA)** have partnered to explore ways to collaboratively address the water-related challenges in the Warwickshire Avon catchment, leveraging NbS. The partners all have a track record of implementing NbS on their own. However, more collaboration is needed, along with a strategy to attract the long-term public and private funding required, to meaningfully scale up NbS across the catchment.

Over the past year, the **Nature for Water Facility** has been supporting this partnership in assessing the feasibility of a large-scale NbS Programme in the catchment, which included estimating its potential impact, costs, and benefits, as well as understanding the stakeholder and governance landscape. N4W explored how NbS could mitigate riverine flooding, improve water quality, and enhance water resource management, while delivering co-benefits such as biodiversity gains and carbon sequestration. To achieve this, N4W have conducted a stakeholder analysis, a scientific analysis including detailed GIS mapping and hydrological flood modelling, as well as an economic and financial analysis to understand the costs and benefits associated with the Programme. The findings contribute to making the case to attract sustainable and long-term funding sources for the catchment's restoration. The findings from this assessment are presented in this document.

1.1. Purpose and Objectives

A feasibility assessment is one of the first reviews conducted along a typical programme development process. If its results are favourable, it is typically followed by a design phase and subsequent pilot implementation. The overarching objectives of this feasibility assessment were twofold:

1. Quantify the potential impacts, costs and benefits of large-scale NbS implementation in the Warwickshire Avon.
2. Assess the overall feasibility of a Programme considering scientific, economic and financial factors, as well as stakeholder dynamics.

1.2. Scope of Work and Approach

The feasibility assessment followed three key workstreams to develop a Business Case and recommendations for implementation (Figure 6).

1. The first was **Stakeholder Engagement**, designed to
   a) better understand the water and nature-related challenges in the Warwickshire Avon catchment,
   b) learn from similar initiatives across the UK, and
   c) explore stakeholder interests, economic incentives, potential roles, and potential barriers to participation.

This engagement was also critical in identifying the benefits and metrics stakeholders value most, as well as the level of evidence they require to support investment. These insights directly informed the design of the subsequent scientific and economic analyses, shaping both the focus and metrics of those workstreams.

2. The **Scientific & Technical Analysis** was designed to:
   a.) identify priority waterbodies where most synergies between partners exist,
   b.) identify areas of opportunity for NbS implementation across the catchment, and
   c.) estimate the potential impact large-scale NbS implementation could have on water-related outcomes as well as co-benefits for nature, people and the economy.

3. Lastly, the **Economic and Financial Appraisal** was conducted to:
   a.) estimate the costs and benefits of a large-scale NbS Programme,
   b.) assess its economic and financial viability, and
   c.) determine investment needs, staffing requirements, and other key resources.

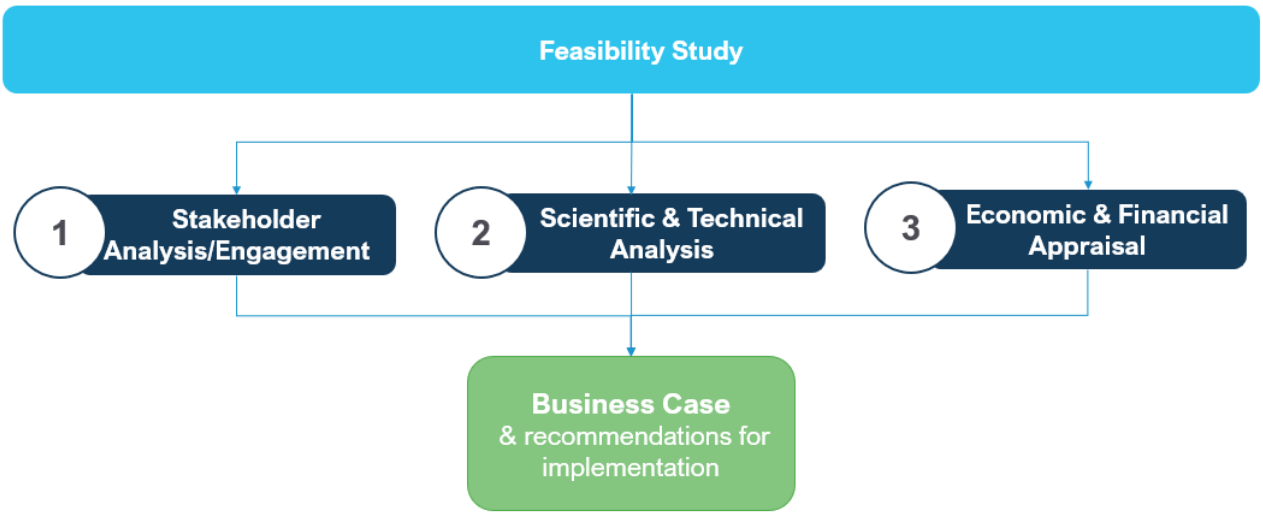

Figure 6: Scope of work.

The outputs of the feasibility study formed the basis for the **Business Case**, a document targeted to package the findings of this study for potential funders and investors.

The project team applied a multi-disciplinary approach combining qualitative and quantitative methodologies, including:

- Literature Review
- Stakeholder Mapping and Stakeholder Engagement
- GIS mapping
- Hydrological modelling (event-based flood modelling using HEC-HMS)
- Various co-benefit modelling (water quality, water resources, carbon, biodiversity, etc.)
- Economic Valuation and Cost-Benefit Analysis

The analytical steps and applied methodologies are further detailed in the respective sections below.

1.3. Other initiatives and how this work fits in

Catchment-based approaches (CaBA) have become increasingly prominent in the UK as frameworks for integrated water and land management. Operating at the river catchment scale, they aim to improve water quality, manage flood risk, enhance biodiversity, and promote sustainable land use through collaboration.

Launched by **Defra in 2011**, the CaBA brings together a wide range of stakeholders – including local authorities, farmers, environmental NGOs, water companies, and regulators such as the Environment Agency – to plan and deliver joined-up action. The principle is simple: "Water doesn't follow administrative boundaries, so why should management?"

This **Programme in the Warwickshire Avon** supports the CaBA ethos by fostering collaboration and holistic responses to the region's interconnected water and nature-related challenges at the catchment scale. While CaBA has already delivered numerous successful projects, the partners involved in this initiative are working to raise the level of ambition and co-develop an innovative delivery model capable of achieving impact at scale. **Core partners**, including the Environment Agency and the County Council, are active members of the CaBA group and will ensure close alignment with that wider initiative.

The **Warwickshire Avon Programme** could operate as a standalone model or be integrated into a broader regional or national approach. It has the potential to serve as a **locally-led testing ground** that contributes to, and complements, other initiatives – helping to drive delivery against broader strategies such as the **Local Nature Recovery Strategy (LNRS)**. Similar programmes in other regions - such as those in **Wyre** and **Norfolk** – were explored during stakeholder engagement to facilitate **knowledge exchange and shared learning**. See Appendix 2 for a summary of comparable projects.

2. The Water Security Challenges

The **Warwickshire Avon** is a headwater catchment spanning approximately **2,800 km²** in central England, supporting the water needs of around **900,000 people**. It contains more than **60 protected areas** – including ancient woodlands, wetlands, and wildflower meadows – making it a landscape of high biodiversity value. However, decades of **climate change, intensive agriculture**, and **urban development** have significantly degraded the landscape, reducing the catchment's **natural capacity to manage water**. As a result, the area now faces increasing challenges related to **flooding, water quality**, **and water resources** (CaBA, 2023) (see Figure 7).

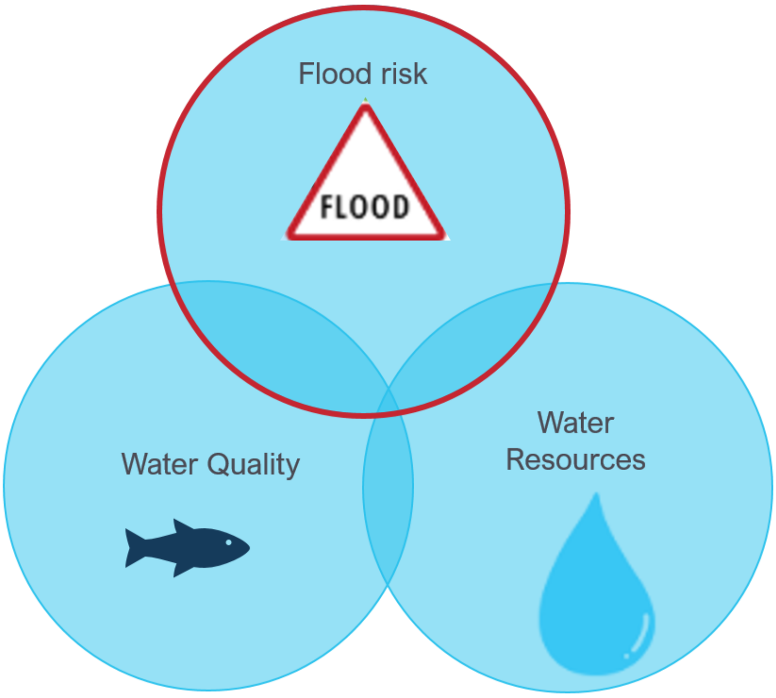

Figure 7: Schematic view of water security challenges.

Flooding is a particularly urgent concern – damaging homes, infrastructure, and livelihoods, while also restricting land available for **sustainable housing and economic investment** (River Severn Partnership, 2021). The impacts of **climate change** and **population growth** are compounding these issues, placing greater pressure on the river system's ability to absorb and convey increasingly **erratic rainfall**. This is driving more **frequent and severe flood events** that disrupt supply chains, affect transport, and undermine daily life across the region. As a consequence, **insurance premiums are rising to unsustainable levels**, placing additional financial strain on communities (Thomasson, 2025). By **2080**, more than **18,000 homes** across the catchment are projected to be at risk of flooding (Environment Agency, forthcoming).

Water quality is another major concern. Approximately **98% of water bodies** in the catchment fail to achieve **'good' ecological status** under the **Water Framework Directive**, largely due to elevated levels of **phosphorus and other nutrients** from agriculture and the water industry, as well as **pesticide runoff**. Decades of river channel modification and habitat degradation have further weakened the catchment's natural regulatory processes. This pollution harms wildlife, degrades aquatic ecosystems, and limits the **recreational and amenity value** of rivers and streams.

Finally, while the **current water supply** is not in deficit, demand is projected to rise, and **future pressures** are likely to grow (Severn Trent, 2025). Ensuring the **long-term security of water resources** – including promoting **groundwater recharge** and sustainable **infiltration** – is a key priority, particularly for **Severn Trent**, the local utility. See Figure 8 below for a systems map of the interlinked challenges in the catchment.

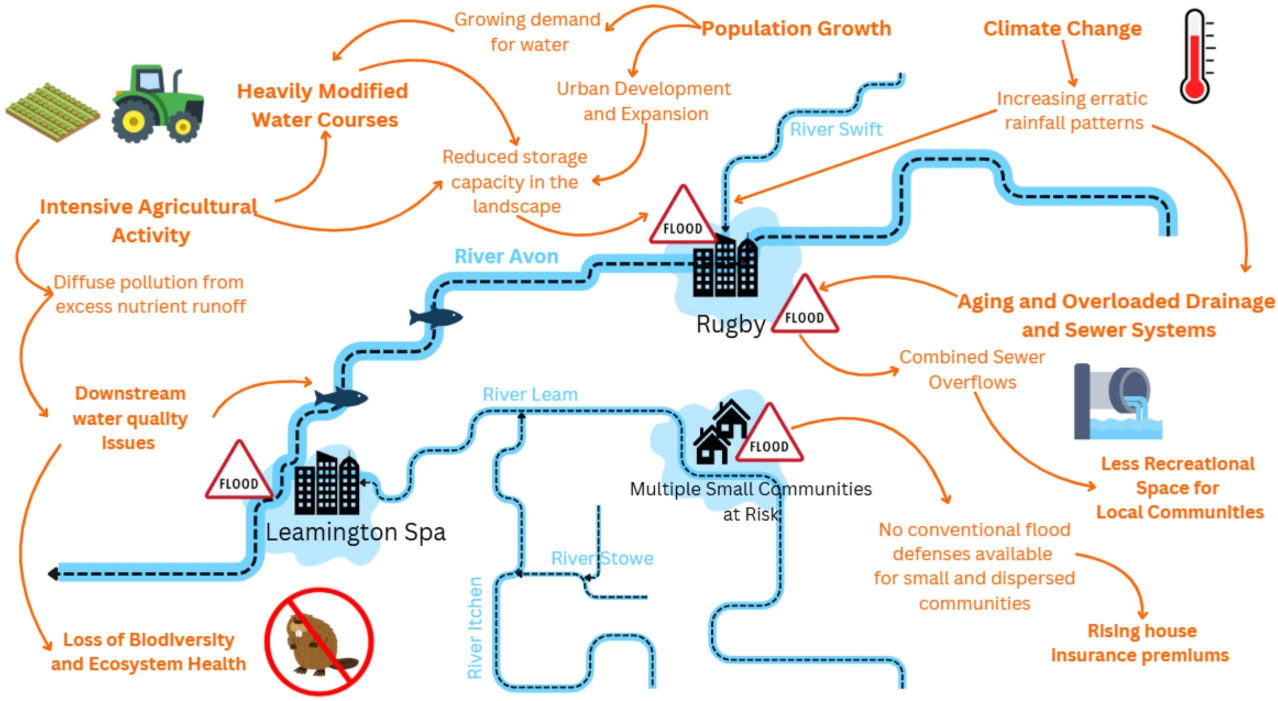

Figure 8: System map of water security challenges in the Warwickshire Avon

Despite **billions of pounds** invested each year in the catchment, evidence suggests that **grey infrastructure alone is failing** to address these complex challenges (Severn Trent, 2021). In many areas, traditional flood defences are either **technically unfeasible** or **prohibitively expensive**, particularly for **smaller and more dispersed communities**, which remain highly vulnerable to repeated flooding and rising insurance costs (Warwickshire County Council , 2025). Moreover, grey infrastructure typically fails to deliver **holistic benefits** for both communities and nature – highlighting the urgent need for more **integrated approaches**, such as **nature-based solutions (NbS)** that harness the power of **healthy ecosystems** to deliver multiple outcomes at scale.

3. Nature as a solution to the Warwickshire Avon's Water Security Challenges

Water security issues have traditionally been tackled through a mix of **demand-side measures and conventional engineered infrastructure** – such as dams, reservoirs, wastewater treatment plants, and inter-basin water transfers. However, there is growing recognition of the role that NbS can play in addressing these challenges. This approach takes a **broader, catchment-wide perspective**, factoring in land use patterns, the ecological functions of natural systems, and the social and economic forces that influence them.

NbS offer the ability to **manage freshwater** flow quantity, timing, and quality, while also delivering additional benefits. These include reduced flood risks and better regulation of water availability. Beyond hydrological benefits, **NbS can support biodiversity, reduce disaster risk, and improve public health and livelihoods**. They also contribute to climate change mitigation goals and provide a cost-effective way to enhance service delivery, all while making infrastructure systems more adaptable and resilient in the face of climate change.

3.1. The Partners Vision

Recognising the power of NbS**, Warwickshire Wildlife Trust (WWT), Warwickshire County Council, Severn Trent, and the Environment Agency** have partnered to explore ways to collaboratively address the water-related challenges in the Warwickshire Avon catchment, leveraging NbS.

The partners all have a track record of implementing NbS on their own, and recognise that more collaboration, combined with large-scale implementation, is needed to address the catchment's challenges holistically. Therefore, the partners' vision is to **pioneer a collaborative partnership model** for a resilient water future. Over the past year, the Nature for Water Facility (N4W) has supported the partnership in refining its vision and assessing the case for large-scale NbS implementation (see a summary diagram of the vision in Figure 9 below).

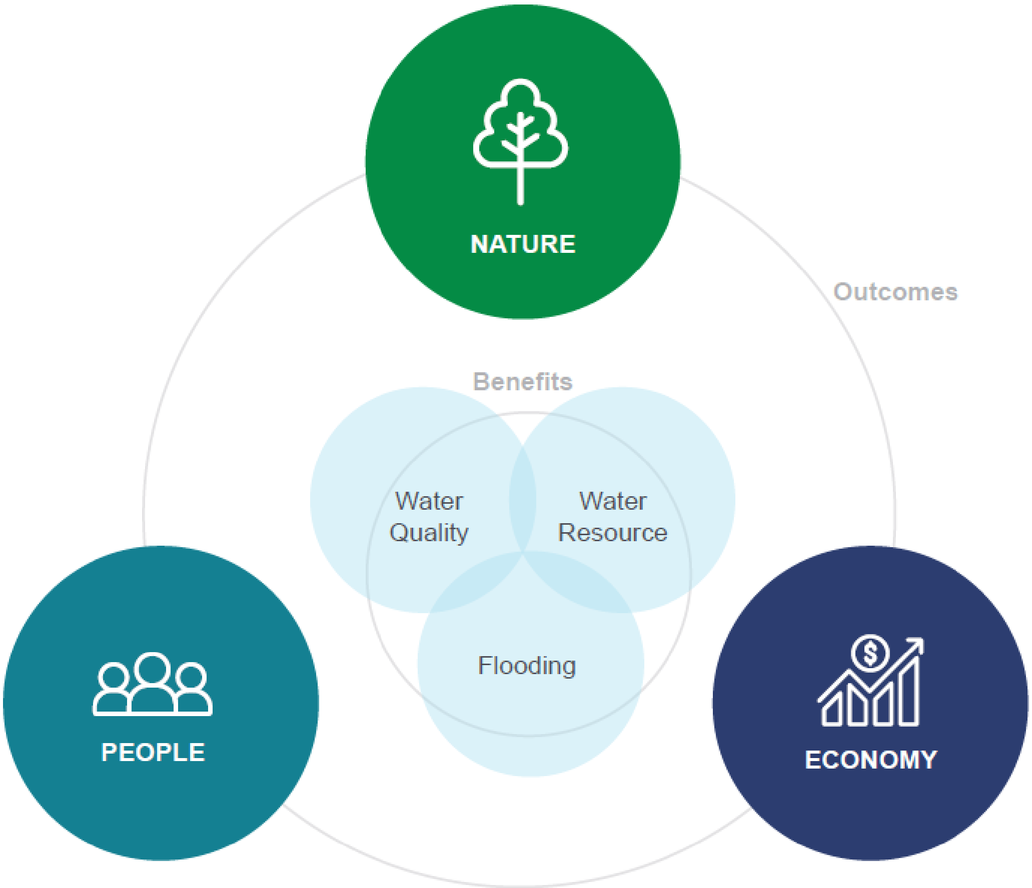

Figure 9: Programme vision.

The aim of this Programme is to pioneer a collaborative partnership model in the Warwickshire Avon to scale up funding for Nature-based Solutions that secure a resilient water future.

The Programme's vision is to deliver a catchment that is resilient to climate and nature related water risks delivering tangible benefits for Nature, People, and the Economy. It will identify sustainable and holistic land and water management interventions which tackle water security challenges including flooding, water quality and water availability across the catchment.

N4W and the core partners have identified a shortlist of NbS approaches tailored to the Warwickshire Avon, as detailed in Section 5 Science Analysis: Approach & Results.

4. Relevant Stakeholders

Recognising the need to **expand the partnership** and build broader support for the Programme, N4W and the core partners undertook a comprehensive stakeholder engagement process. This aimed to develop a deeper **understanding of the challenges** facing the catchment, **stakeholder interests** and economic incentives, **potential roles in programme delivery**, and the **barriers** that may limit participation.

As part of this process, stakeholders were identified and grouped from an operational perspective – that is, based on their relevance to programme implementation, whether as funders, landowners, regulators, delivery partners, or beneficiaries. This mapping exercise also informed early thinking on governance and collaboration models (see
Figure 10).

Figure 10: Relevant stakeholders from an operational perspective.

The engagement surfaced several promising insights on potential new funding partners. Notable stakeholders are listed below:

Table 1: Notable stakeholders

Stakeholder	Relevance / Potential Funding Interest
Jaguar Land Rover (JLR)	Major industrial actor in the catchment. Potential strategic partner. Environmental risk management through TNFD offers a valuable entry point. Aligning the Programme with JLR's ESG and risk priorities could unlock long-term partnership opportunities.
Insurance Sector	While not directly financially affected by increased floods (due to competitive price adjustments based on changes in risk), insurers are motivated by ESG objectives to support climate resilience projects.
→ *Flood Re*	The UK's national reinsurance scheme, Flood Re, has a strong interest in reducing systemic flood risk and maintaining insurability. Potential partner for scaling NbS flood mitigation.
→ *Insure for Nature*	Innovative insurance model redirecting marketing spend toward nature-based climate adaptation. Limited by reach but aligned in mission – potential funder as they scale.
Nature Finance Platforms & Intermediaries	Connects corporate carbon buyers with high-integrity projects or supports the development of nature credits through a profit share model. Strong alignment with the Warwickshire Avon Programme. A pilot collaboration could provide funding and increase programme visibility in the sustainability space. Examples include TreeApp, Credit Nature, or Rebalance Earth (See Annex A for a full list of identified actors).
Nature Investors and Funders	Institutional investors, ethical banks focusing on nature-finance, and local authority pension funds all have long-term investment interests with environmental and social outcomes that could potentially provide funding to the Warwickshire Avon Programme. Examples include Tridos Bank, Nettergal, and Foresight (See Annex A for a full list of identified players).
Golf Courses	Large land managers and water users. May benefit from and contribute land for NbS implementation. Represent a niche but valuable partner group for private sector engagement and water stewardship.
Agri-Food & Beverage Sector (Supply Chain Actors)	Companies sourcing agricultural inputs locally have strong incentives to invest in NbS for water quality, climate resilience, and soil health. Early outreach indicates growing corporate interest in supporting catchment-based restoration to de-risk supply chains and meet sustainability goals.

Planning ahead, the team has outlined a stakeholder engagement strategy as detailed below in Figure 11.

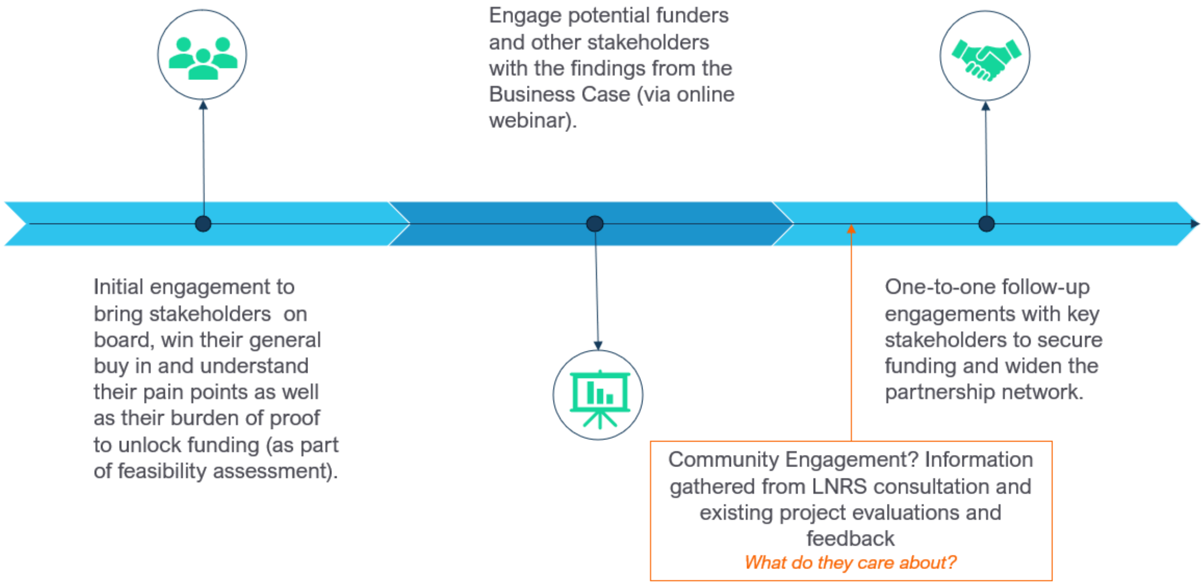

Figure 11: Stakeholder engagement strategy.

This stakeholder engagement process has been instrumental in **validating the Programme's relevance**, identifying strategic **entry points**, and **shaping a vision** for inclusive, multi-sectoral governance that can support delivery at scale. It was also instrumental in identifying the **metrics** that the Science and Economic Analysis, outlined in the following sections, should focus on.

5. Science Analysis: Approach & Results

5.1. Overview

This section outlines the scientific and technical analyses undertaken by N4W to inform a robust Business Case for long-term NbS investment in the Warwickshire Avon. This brings together geospatial analyses and hydrological modelling approaches. The overarching aim was to assess where and how NbS can deliver impact across critical water-related outcomes and co-benefits, including:

- Flood mitigation
- Water quality enhancement
- Water resource sustainability
- Biodiversity uplifts

To support this goal, N4W led a comprehensive set of scientific analyses. This work provides an evidence base for designing a catchment-scale NbS Programme. It supports both immediate and long-term planning objectives and informs the development of a Business Case for attracting public and private investment. Scientific analyses are comprised of the following elements (also detailed in Figure 12):

1. **Sub-catchment prioritisation** using geospatial and biophysical datasets to identify areas most in need of intervention.
2. **NbS Identification** to determine the most impactful and widely accepted types of NbS to deliver in Warwickshire Avon.
3. **Opportunity mapping** to locate feasible and impactful sites for NbS deployment.
4. **NbS portfolio development and optimisation** to model different combinations and scales of interventions.
5. **Biophysical modelling** to quantify the potential impacts of NbS on water outcomes under different scenarios.

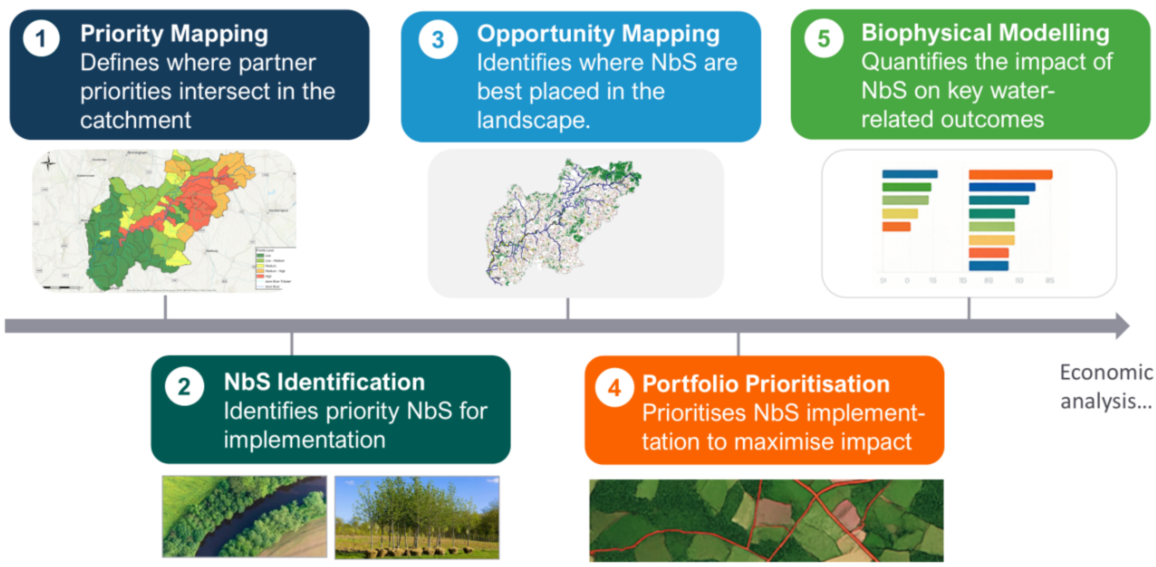

Figure 12: Science analysis overview.

5.2. Where are NbS most needed? Sub-Catchment Priority Mapping

5.2.1. Objectives and Purpose

Sub-Catchment Priority Mapping aimed to identify the most strategic locations across the Warwickshire Avon for the implementation of NbS. The approach sought to align environmental need with organisational priorities and practical feasibility to maximise the impact of NbS interventions. This process served not only to guide modelling and investment planning but also to help identify areas where project partners could most effectively collaborate.

Priority areas were identified based on three main criteria:

1. **Water Security Priorities** – High priority areas relating to flood risk, water quality, and water resources.
2. **Partner Priorities** – Evidence of existing priorities from consortium partners, based on local plans, environmental programmes, or regulatory frameworks.
3. **Opportunity to deliver NbS –** Areas in which a significant opportunity exists for the delivery of NbS, considering landscape suitability, land use, ecological condition, and strategic potential for co-benefits.

5.2.2. Methodology

To produce mapping outputs, raw spatial datasets (further detailed in Annex B) were first processed through data averaging, where indicators such as total area at risk of flooding, Water Framework Directive (WFD) ecological status, and abstraction pressure were normalised across consistent spatial units – namely WFD water bodies. Averaged indicators were then aggregated into thematic layers, including Water Security Priorities, Partner Priorities, and Opportunity to Deliver NbS. Each theme combines multiple datasets to produce composite scores per catchment. A total priority score was calculated for each sub-catchment by averaging the thematic scores, producing a map which identifies high, medium, and low priority water bodies for NbS delivery.

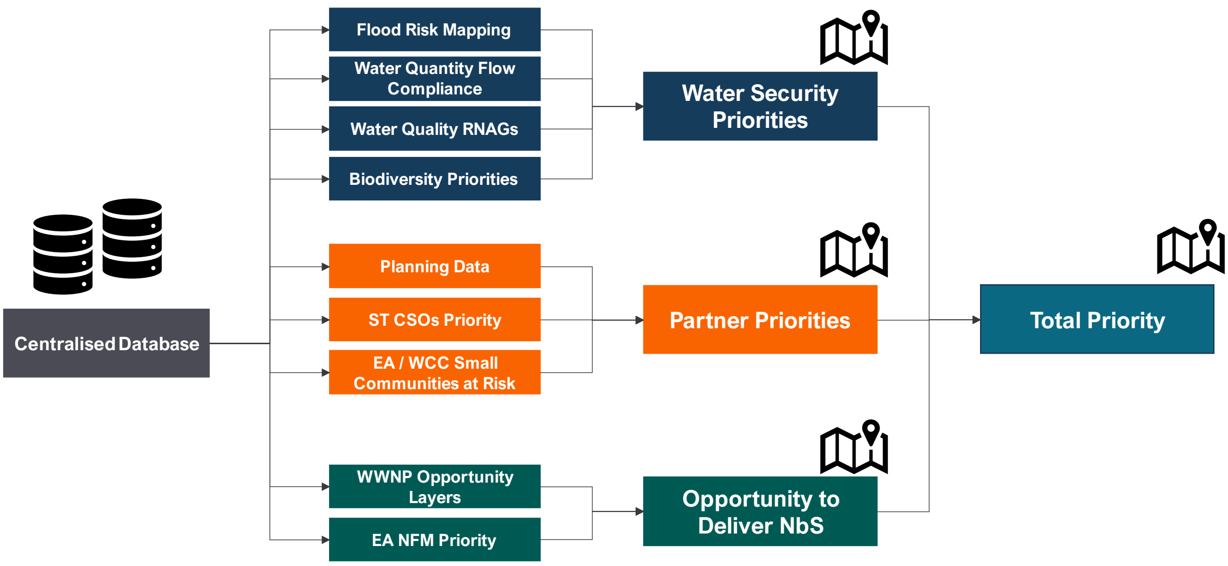

Figure 13: Sub-catchment priority mapping methodological overview.

5.2.3. Results

Priority mapping was key in identifying that flood risk was a major challenge in the Warwickshire Avon, with this representing a major water security priority and driving a significant amount of investment and attention from partners.

This work identified high-priority areas for NbS delivery in water bodies along the main Avon – likely corresponding to areas in which flood risk and larger populations are concentrated. The mapping also picks out areas in the Northeast of the catchment as high priority – notably in the Leam and Upper Avon. This suggested that these should be taken forward as priority areas for the delivery of NbS and the targeting of further modelling in this project. It should also be noted that, as headwater sub-catchments, delivery in these areas will also produce benefits for downstream areas along the main Avon. The outputs of this process, and a full methodology, are provided in Annex B.

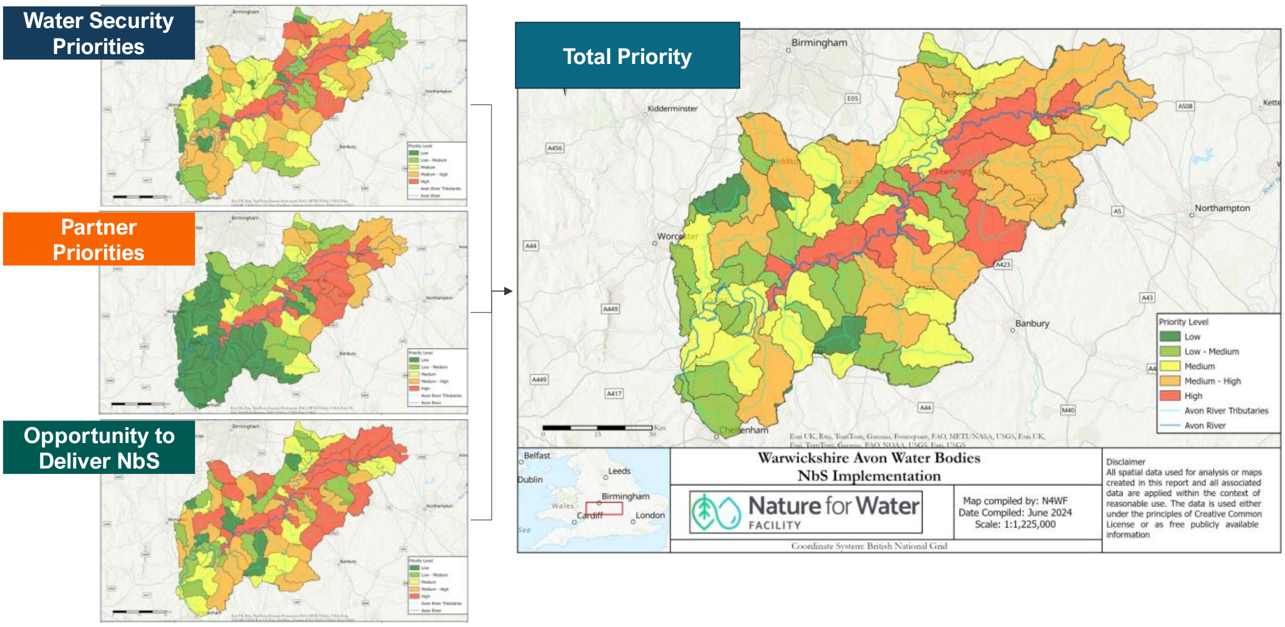

Figure 14: Outputs of sub-catchment priority mapping in the Warwickshire Avon

5.3. NbS Identification

NbS identification aimed to determine which NbS would fit best in the hydrological and environmental context of the Warwickshire Avon. The shortlist of NbS was developed through close collaboration between the Nature for Water (N4W) Facility and core project partners. Selection was grounded in practical delivery experience, focusing on interventions that partners were already delivering or had the capacity to implement. This ensured that the portfolio would align with existing skills, resources, and strategic goals.

In parallel, the selection process considered the potential of each NbS to deliver multiple co-benefits, including carbon sequestration, biodiversity gain, and improved landscape resilience. Only those interventions that could provide both strong hydrological outcomes (e.g. slowing flow, increasing infiltration) and wider ecosystem services were shortlisted for inclusion in the modelling and business case.

The final shortlist of NbS was developed through a series of workshops with Warwickshire Wildlife Trust in Winter 2024. These are shown in Figure 15 with definitions provided in Table 2 below. These options were taken forward to be integrated into a business case.

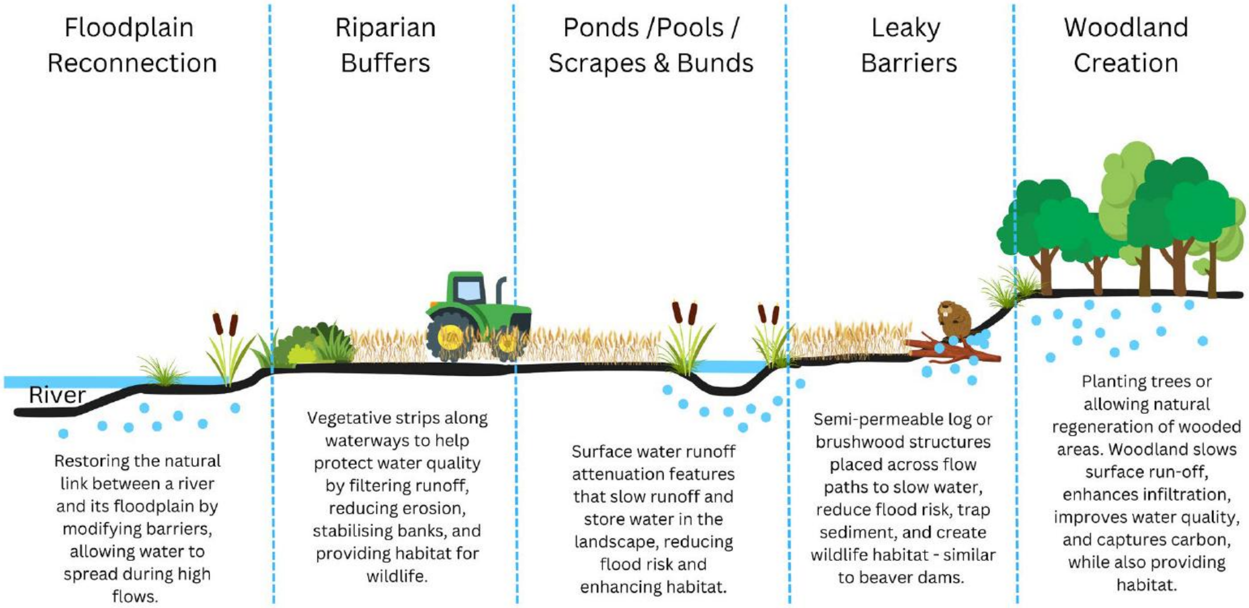

Figure 15: Final NbS prioritised for the Warwickshire Avon project.

Table 2: NbS Types and definitions

NbS	Definition
Floodplain Reconnection	Floodplain reconnection involves restoring the natural link between rivers and their adjacent floodplains. This allows excess water to spill into the floodplain during high-flow events, reducing downstream flood peaks, storing water in the landscape, and creating valuable wetland habitat.
Woodland Creation	Planting individual trees or blocks of woodland helps intercept rainfall through the canopy and enhances soil infiltration through root systems. When strategically placed, woodland can significantly reduce surface runoff, improve soil stability, and support wider ecosystem services.
Leaky Barriers	Leaky barriers are timber structures installed across small watercourses to slow down high flows. Logs or branches are placed just above the normal water level to back up and temporarily store water during storm events, while still allowing low flows and fish passage through gaps. Materials may be sourced locally (“chop and drop”) or brought in.
Ponds, Pools and Scrapes	These are shallow features excavated to store water during heavy rainfall. Some may hold water permanently, while others (scrapes) are designed to dry out seasonally. They reduce downstream runoff by capturing overland flow or intercepting ditch water, while also supporting biodiversity.
Bunds	Bunds are low earthen banks or embankments constructed along contours or across slopes to hold back surface runoff. Often paired with ponds or ditches, they temporarily store water, promote infiltration, and reduce the velocity and volume of flow moving downslope during rainfall events.

5.4. Where are the opportunities to deliver NbS? NbS Opportunity Mapping

5.4.1. Objectives and Purpose

The goal of the opportunity mapping was to identify where, across the Warwickshire Avon catchment, NbS could most feasibly and effectively be delivered. Building on sub-catchment priority mapping, this workstream focused on the spatial potential for implementing specific NbS types – namely ponds, riparian buffers, leaky barriers, and floodplain reconnection. The mapping aimed to target these interventions in areas where they would intercept flow pathways, restore hydrological function, and deliver water-related benefits.

5.4.1. Methodology

The mapping followed a standardised process for each NbS type, applying a GIS workflow built around three core elements: opportunity layers, constraint layers, and supplementary data (see Figure 16). These were used as such:

- **Opportunity** layers were developed from hydrological and topographical datasets, such as flow pathways and slope. These were used to pinpoint the biophysical settings in which each NbS type would function best – for example, bunds along flow pathways, or leaky barriers within small watercourses in flood-prone areas.
- **Constraint** layers were then used to exclude areas unsuitable for NbS, such as urban zones, existing infrastructure and protected drinking water zones (SPZ1).
- **Supplementary** data (e.g. land use, ownership proxies, biodiversity zones) were then attached to the layer to give additional context and prioritisation potential for each opportunity feature.

Each of the NbS described in Section 5.3 were mapped using a different combination of opportunity, constraint and priority layers. For a full description of the data layers used in this mapping and all output products, refer to Annex C.

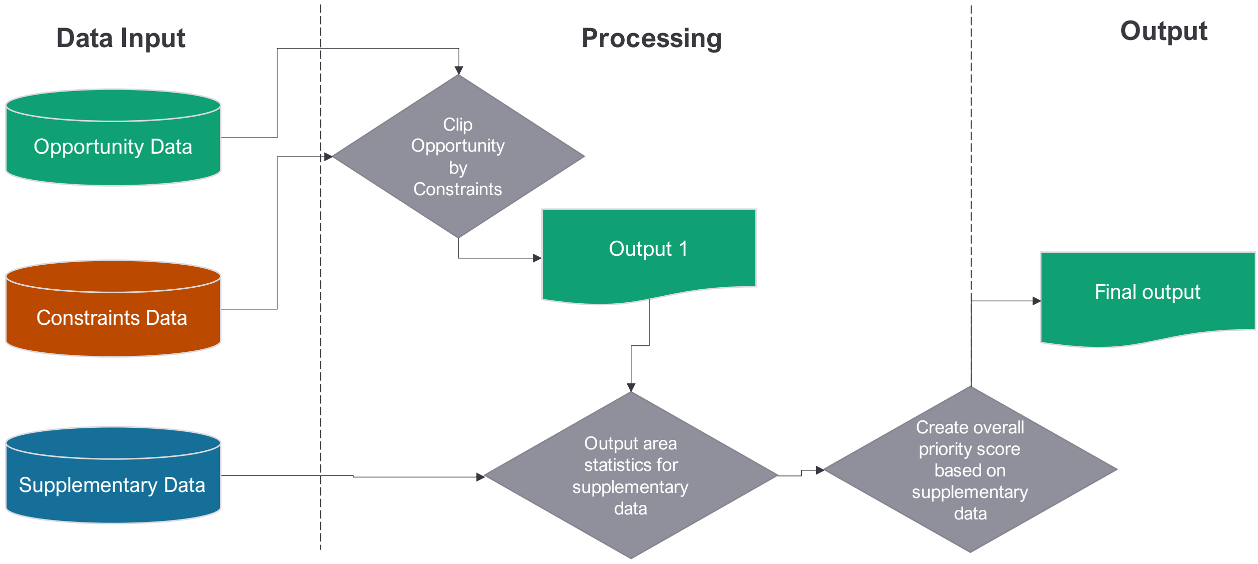

Figure 16: Overview of NbS opportunity mapping methodology.

5.4.2. Results

Opportunity mapping revealed significant potential to deliver NbS across the Warwickshire Avon. In particular, the analysis identified extensive areas where low-productivity land – often located in seasonally wet arable field margins, near ditches, or alongside rivers – could be repurposed to intercept flow, enhance infiltration, and store water. These features represent high-impact, low-conflict opportunities for NbS delivery. The mapping also identified significant areas for NbS delivery adjacent to existing natural features, suggesting opportunities to extend or connect fragmented habitat corridors while delivering hydrological benefits. The outputs of this process, and a full methodology, are provided in Annex C.

Overall, the results confirmed the feasibility of developing a scalable NbS portfolio across the catchment, with numerous high-potential sites distributed across multiple sub-basins. These outputs were used to define and cost NbS intervention scenarios for modelling and business case development. These results were also used to support mapping exercises needed to produce the Local Nature Recovery Strategy (LNRS) for Warwickshire, meaning that delivery of the features identified here will be incentivised through local planning mechanisms.

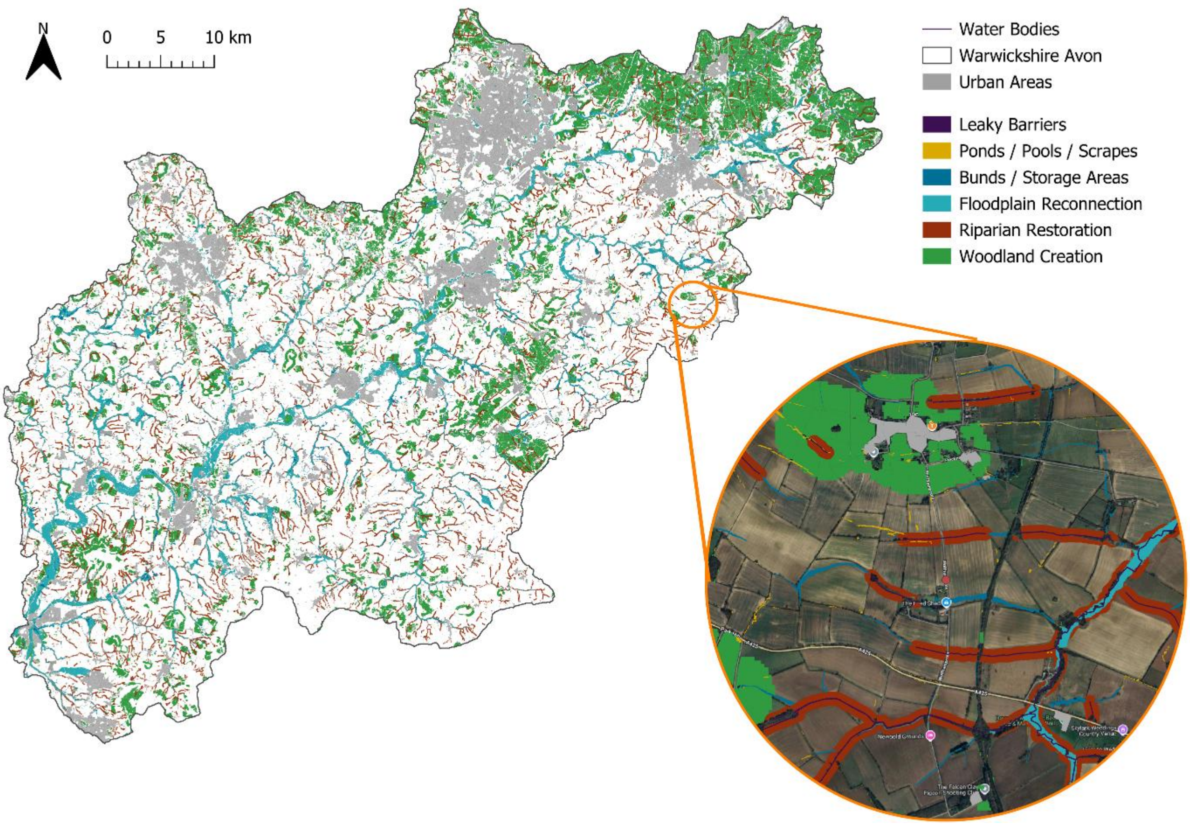

Figure 17: Results of NbS opportunity mapping

5.5. What is the impact of NbS delivery? Hydrological and Co-Benefit Modelling

5.5.1. Overview

Hydrological and environmental modelling was conducted to evaluate the potential benefits that Nature-based Solutions (NbS) could deliver across the Warwickshire Avon catchment. This analysis centred on four core value propositions: namely that NbS can reduce flood risk, improve water quality, enhance water resource availability, and increase biodiversity. Each of these was assessed through a tailored modelling or calculation approach, summarised in Table 3.

Outputs were used to estimate both direct hydrological benefits and wider co-benefits across the catchment, forming the technical foundation for the investment case and cost-benefit analysis described in Section 6.

Table 3: Modelling methodologies and outputs

Value Proposition	Analysis	Key Output Metric
Flood Risk	Event-Based Hydrological Analyses in HEC-HMS	Peak Flow (m^3/s)
Water Quality	Unit and area-based calculations based on nutrient export for different land use types	Total Nutrient (phosphorus, nitrogen) export (m^3/s)
Water Resources	Unit and area-based calculations based on simplified 1-dimensional rainfall-runoff-recharge modelling	Infiltration Enhancement (m^3/yr)
Biodiversity	Unit and area-based calculations based on the statutory BNG tool	BNG Units

5.5.2. Creating a Targeted Modelling Extent

To maximise modelling efficiency, the project team opted to define a targeted modelling area, allowing for a more focused assessment of NbS performance. The selected region, located upstream of Rugby and Leamington Spa (Figure 18), was chosen based on the priority mapping described in Section 5.2. By focusing analysis on this priority sub-region, the team was able to carry out detailed hydraulic modelling, co-benefits modelling, and cost-benefit evaluation with greater precision.

All further analyses described in the Science Analysis section use this target area as the spatial extent for modelling. This was decided with the knowledge that results from modelling in this area can then be used to generate catchment-wide inferences based on sub-catchment characteristics and relative levels of opportunity to achieve NbS implementation.

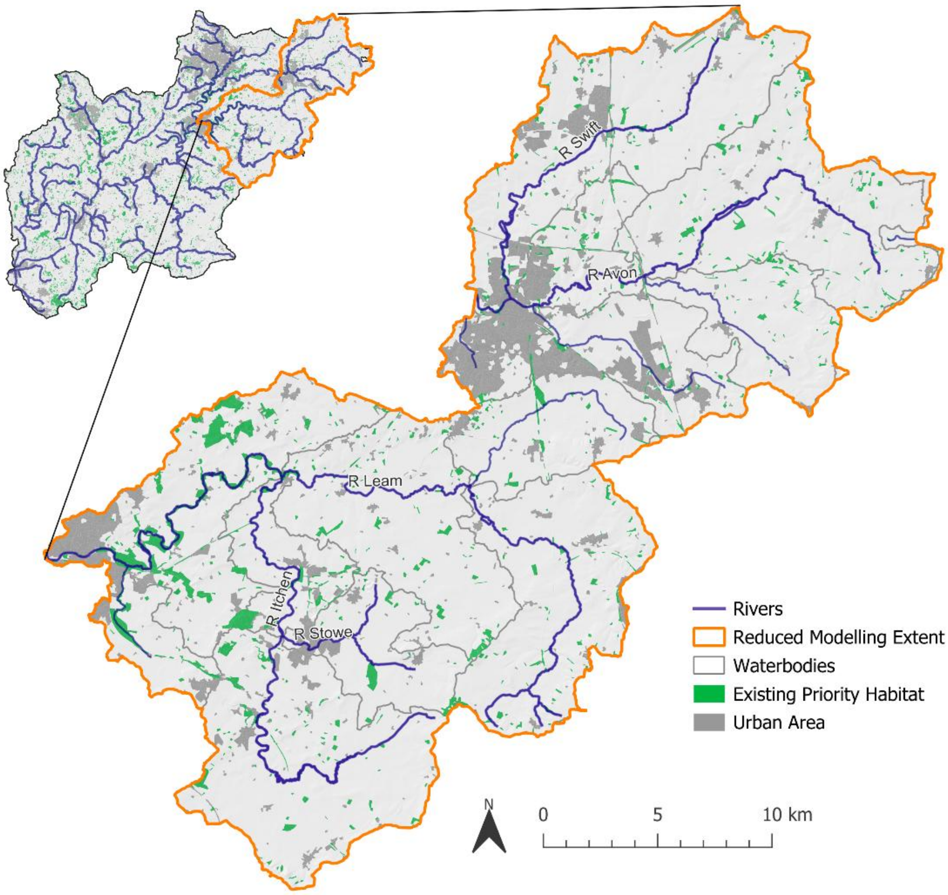

Figure 18: Targeted modelling extent in the Warwickshire Avon

5.5.3. Peak Flow Modelling

Peak flow modelling was conducted to better understand the impact of NbS on flood risk. This was the most extensive modelling exercise conducted within the science analysis, as flooding was found to be the most important and challenging water-related issue to characterise. The results of this exercise, therefore, informed portfolio prioritisation by helping to understand where the most significant efficiencies could be achieved in terms of flood risk reduction through NbS delivery.

5.5.3.1. Model Setup

To assess the impact of NbS on flood risk, event-based hydrological modelling was undertaken using HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System). This was selected due to its ability to represent peak flows at given delineated points in the modelled area, and due to the fact that it is a widely used and robust model. It was configured for two key sub-catchments, the Upper Avon and Leam, which together make up the area highlighted in Figure 18.

NbS features were incorporated in the modelling approach by adjusting rainfall-runoff parameters for land use-based NbS (riparian restoration and woodland planting), and by introducing aggregate storage reservoirs for storage-based NbS (ponds, floodplain reconnection and leaky barriers). Calibration and validation were conducted using observed flow data, with the model achieving good performance in terms of simulating peak flows. For a full description of the model setup, refer to Annex D.

5.5.3.2. Sensitivity Testing

A key objective of the modelling was to understand the range of possible outcomes NbS could achieve under different conditions of scale, climate, and configuration. The modelling explored variations across four key dimensions: flood return period, NbS implementation level, intervention configuration, and climate change. By running more than 50 scenarios across this matrix, the project was able to build a detailed picture of how NbS perform individually and in combination – and where thresholds of cost-effectiveness or diminishing returns begin to emerge. Table 4 summarises the structure of the scenarios tested.

At the core of this testing was a baseline "business-as-usual" scenario, representing current land use and hydrology with no additional NbS intervention, but with climate change represented through an RCP 8.5 scenario. This served as the counterfactual against which all NbS scenarios were assessed, allowing for reductions in peak flows to be determined against a baseline.

Table 4: Scenarios modelled in HEC-HMS for sensitivity testing.

Dimension	Options Modelled	Purpose
Flood Return Period	• 1 in 20 years • 1 in 50 years • 1 in 100 years	Represent different magnitudes of flood events
NbS Implementation Level	• 25% of available opportunity • 50% • 75% • 100%	Assess how the benefit scales with the extent of NbS delivery
NbS Configuration	• All NbS types combined • Single NbS type runs (e.g. ponds only, woodland only) • Feasible mixes	Identify the individual and combined contributions of different NbS
Climate Scenario	• Present day baseline • RCP 8.5 (90th percentile, medium-term)	Evaluate performance under future climate stress conditions

This analysis revealed that different NbS implemented at differing levels of delivery offer varying degrees of flood reduction potential, and that these benefits are closely tied to both the hydrological function of the intervention and the available opportunity for implementation across the landscape.

Storage-based interventions, particularly floodplain reconnection, bunds and ponds, and leaky barriers, were the most effective at reducing peak flows (see Figure 19). However, total reductions were largely determined by how much storage volume could be realistically delivered based on the catchment's geography and land use. At full implementation, floodplain reconnection achieved a peak flow reduction of around 63%, making it the most impactful intervention due to the greater area and volume available for reconnection in the catchment (this being informed by opportunity mapping). In comparison, leaky barriers delivered only around a 0.7% peak flow reduction at 100% implementation. This reflects their limited total storage capacity, particularly when compared to large floodplain systems.

The analysis also showed evidence of diminishing returns for several NbS types. For instance, most of the gains from floodplain reconnection occurred below 25% implementation, with diminishing additional benefits thereafter. A similar pattern was seen with leaky barriers, where overlapping catchments and reduced incremental gain meant that scaling up beyond a certain point added little extra benefit.

Woodland planting and riparian zone restoration showed smaller flood reductions (e.g. around 5% for woodland at full delivery), but were only modelled at 100% implementation due to time and resource constraints. While these are less impactful for peak flow, they offer strong co-benefits for water quality, biodiversity, and carbon, supporting their inclusion in a balanced portfolio.

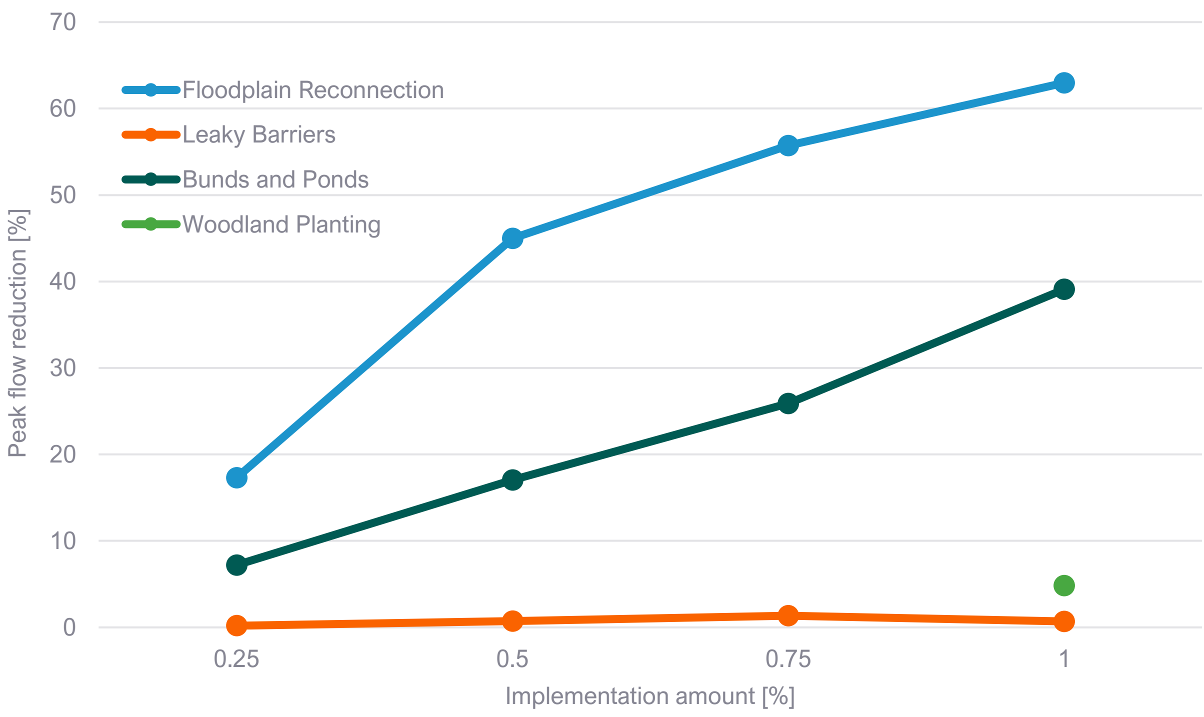

Figure 19: Average peak flow reduction across all output nodes (generally situated at the outflow of WFD water bodies) in the HEC-HMS model domain.

5.5.4. Water Resources, Nutrient Export and Biodiversity Modelling

Alongside flooding and peak flows, the project also aimed to consider the wider water-related and environmental outcomes which could be achieved by Nature-based Solutions (NbS) implementation. To do so, a modelling approach developed previously by N4W for the Norfolk Water Fund Business Case was used. This method uses a land-use change-based approach, applying per-hectare coefficients to estimate changes in key ecosystem outcomes when land is converted to Nature-based Solution (NbS) interventions. These outcomes include:

1. Water Resources: via improvements in infiltration and groundwater recharge.
2. Water Quality: via reductions in nitrogen and phosphorus export.
3. Biodiversity: via net gains in habitat quality and diversity using Defra's statutory Biodiversity Net Gain (BNG) metric.

For each NbS intervention, the model calculates both baseline values (reflecting existing land use) and post-intervention values (reflecting the NbS land cover). The uplift is then the difference between these values across all hectares of intervention. This allowed the project team to estimate the cumulative benefit of the final portfolio and to make comparative assessments of NbS types based on their unit benefit per cost. For a full description of this methodology and the model used in this process, see Annex E.

5.5.4.1. Results

The modelling revealed that different NbS types deliver very different levels of benefit per hectare (Table 5). For instance, leaky barriers demonstrated high per-hectare reductions in nutrient export and infiltration. In contrast, floodplain reconnection delivers important ecological benefits but offers lower per-hectare impact in hydrological terms. An important consideration here is the cost-effectiveness of NbS; some high-performing interventions in terms of per-hectare benefit (e.g. leaky barriers) are also relatively low-cost, making them attractive for widespread application. Others – for example, floodplain reconnection – are more capital-intensive but essential for meeting biodiversity-related goals.

Modelling also highlighted important trade-offs. Interventions like woodland creation and riparian restoration provided good biodiversity and runoff reduction benefits, but in some cases were associated with reductions in infiltration due to increases in evapotranspiration from the change in land use. Similarly, leaky barriers performed highly against water-related objectives but offer very little in terms of biodiversity uplifts. These trade-offs highlight the importance of delivering balanced portfolios that optimise multiple objectives–since no single intervention performs best across all outcomes.

Table 5: Average per-hectare delivery calculated for each NbS based on model outputs.

NbS	**Nitrogen Reduction** [kg/yr/ha]	**Phosphorus Reduction** [kg/yr/ha]	**Infiltration Enhancement** [m³/yr/ha]	**Runoff Reduction** [m³/yr/ha]	**BNG Units** [units/ha]
Woodland Creation	8.8	0.1	-435	753	2.7
Riparian Zone Restoration	7.6	0.1	-435	753	1.9
Floodplain Work	7.7	0.1	0	0	0.8
Leaky Barriers	744	17.0	28,547	107,543	0
Bunds	20.5	0.5	11,098	58,032	4.7
Ponds Scrapes	14.0	0.3	785	4,542	4.7

5.6. How much NbS should we implement and where? NbS Portfolio Prioritisation

5.6.1. Objectives and Purpose

To develop a compelling and investment-ready Business Case for Nature-based Solutions (NbS) in the Warwickshire Avon, it was essential to define a single, spatially explicit portfolio of interventions. This would act as the foundation for all further analyses, including economic valuation and cost-benefit assessment (see Section 6). The overarching aim here was to construct a final NbS portfolio that was grounded in reality in terms of cost and deliverability.

The project focused on developing one final, high-impact portfolio. This balances ambition with realism and serves as the core scenario tested throughout the remainder of the modelling and financial appraisal workstreams.

This process involved three key steps:

1. Determining the **overall scale of implementation** based on realistic cost and impact thresholds (“sizing the ask”).
2. Defining the **optimal combination of NbS** types based on effectiveness and feasibility.
3. **Spatially prioritising interventions** implementation based on where the greatest benefits could be achieved.

For a further description of this process please refer to Annex F.

5.6.2. “Sizing the ask”: Prioritising an NbS Portfolio

The total size and cost of the final NbS portfolio were determined through a combination of scientific analysis and stakeholder engagement. Discussions were held with project partners to establish a realistic investment envelope for investment in NbS in the catchment. This involved benchmarking against existing and planned spending commitments, such as those under the Water Industry National Environment Programme (WINEP), as well as other public and private funding streams. This aimed to ensure that the proposed portfolio remained rooted in reality regarding cost.

Insights from the peak flow modelling detailed in Section 5.5.3 also helped define where maximum cost efficiencies could be achieved through NbS implementation. This work showed that maximum benefits in terms of peak flow reduction occurred in the first 25% of NbS delivery, hence delivering the greatest hydrological benefits per pound spent in this increment. Beyond this threshold, diminishing returns set in, meaning additional investment would yield lower efficiency in terms of peak flow reduction. This informed the decision to limit the scale of the final portfolio to a level that maximised cost-benefit performance, balancing ambition with pragmatic resource constraints.

The final envelope in terms of NbS delivery was determined to sit at around GBP 200 million for the targeted area described in Section 5.5.2. This was used as a ceiling in terms of final portfolio size.

5.6.3. Prioritising Combinations of NbS

Within the overall portfolio envelope, it was still necessary to define the optimal mix of NbS types. This required determining how much of each intervention should be implemented relative to its total opportunity across the catchment. To do this, a multi-criteria analysis was carried out using outputs from the hydrological modelling described in Section 5.5. Specifically, each NbS type was evaluated based on its unit benefit per cost, normalised by hectare, across different hydrological outcomes.

This approach enabled a like-for-like comparison between different NbS types by evaluating the environmental benefit per unit cost, normalised per hectare. For example, the nutrient reduction potential of woodland creation was assessed relative to its implementation cost, allowing it to be directly compared with other interventions such as bunds or ponds. By standardising benefits and costs across all interventions, each NbS could be ranked and proportionally weighted in the final portfolio to maximise environmental returns for every pound invested.

The resulting analysis informed the mix of interventions selected for implementation. While some NbS types were more cost-effective than others, a balanced mix was favoured over dominance by any single intervention type. As such, implementation levels for each NbS were set between 10% and 25%

of their total mapped opportunity. These bounds were established to keep the portfolio within the total delivery budget of GBP 200 million, while also reflecting modelling insights that showed maximum efficiency occurred below 25% implementation. Table 6 shows the final NbS combination resulting from this exercise.

Table 6: Final combinations of NbS for delivery in the modelled area

NbS	Rank based on unit benefit per cost	Percentage Implementation vs. Total Opportunity
Woodland Creation	4	13%
Riparian Zone Restoration	5	10%
River Restoration	6	10%
Leaky Barriers	2	23%
Bunds	1	25%
Ponds Scrapes	3	20%

5.6.4. Spatial Prioritisation of NbS

Spatial prioritisation was undertaken to determine exactly where in the landscape NbS features should be implemented to achieve the greatest impact. The prioritisation process was built on the outputs from earlier sub-catchment and opportunity mapping exercises and focused on areas where interventions could maximise hydrological and ecological returns.

Using GIS-based analysis, each NbS opportunity was assigned a priority score (0–1) based on criteria such as agricultural land grade, proximity to flood risk receptors and potential to improve connectivity. Using this prioritisation, the highest-scoring features were selected until the final area of NbS delivery determined in previous sections was reached. This ensured that the final portfolio was composed of interventions in the most effective and deliverable parts of the landscape.

5.6.5. Final NbS Portfolio

Through the combined process of sizing the portfolio, prioritising by unit benefit per cost, and applying spatial filters to identify high-impact areas, a single, optimised NbS portfolio was developed. This includes a diverse suite of NbS types, ranging from large-scale woodland creation to smaller-scale but strategically impactful interventions such as bunds and ponds. The prioritisation process ensured that each intervention contributes meaningfully to hydrological and ecological outcomes, while collectively staying within the defined budget and implementation thresholds.

Crucially, the total portfolio covers just over 5.5% of the modelled area, reflecting a targeted, efficient approach to delivery. Table 7 summarises the final portfolio composition.

Table 7: NbS portfolio prioritised within the modelled areas of interest

NbS	Delivery Area [ha]	Percent of total modelled area [%]
Woodland Creation	2,430	3.4%
Riparian Zone Restoration	736	1%
Floodplain Work	375	0.5%
Leaky Barriers	6	0.01%
Bunds	363	0.5%
Ponds Scrapes	66	0.1%

Totals	3,975	5.51%

5.6.1. Portfolio Modelled Results

The impact of this portfolio was assessed using the hydrological and ecological modelling described in Section 5.5. This demonstrated clear benefits across all targeted water-related outcomes: flood mitigation, water quality improvement, water resource enhancement, and biodiversity gain.

Together, these results highlight that Nature-based Solutions are not a trade-off, but a strategic investment capable of delivering multi-functional, catchment-wide benefits. The final portfolio demonstrates how these interventions can contribute meaningfully to regional policy goals in flood risk management, water quality improvement, biodiversity enhancement, and climate adaptation.

5.6.1.1. Flooding

Peak flow modelling using HEC-HMS revealed that the portfolio could deliver peak flow reductions across modelled areas. Importantly, this showed a ~20% reduction in peak flood flows in Leamington Spa and a ~10% reduction in Rugby (see Figure 20 and Table 8). These reductions represent a meaningful decrease in the severity and frequency of flood events, and as such, fewer properties are flooded, less damage to infrastructure, and reduced economic disruption during storm events.

Equally important, the modelling revealed that smaller, dispersed rural communities – often lacking viable options for grey infrastructure defences – would also receive notable benefits. In some sub-catchments, such as Clifton Brook, peak flows were reduced by over 25% for more frequent storm events (Table 8). In villages in this area at risk of flooding, NbS could provide the only feasible and scalable intervention, offering critical protection for people, agriculture, and infrastructure while enhancing natural systems.

Modelling also showed that NbS interventions could not only reduce the volume of peak flows but also delay the timing of those peaks, by around 6 hours in Rugby, for example (see Figure 20). This delay in peak flow is critical as it increases the window of response for emergency services, reduces the likelihood of flood peak synchronisation from multiple tributaries, and provides additional time for drainage systems to manage stormwater.

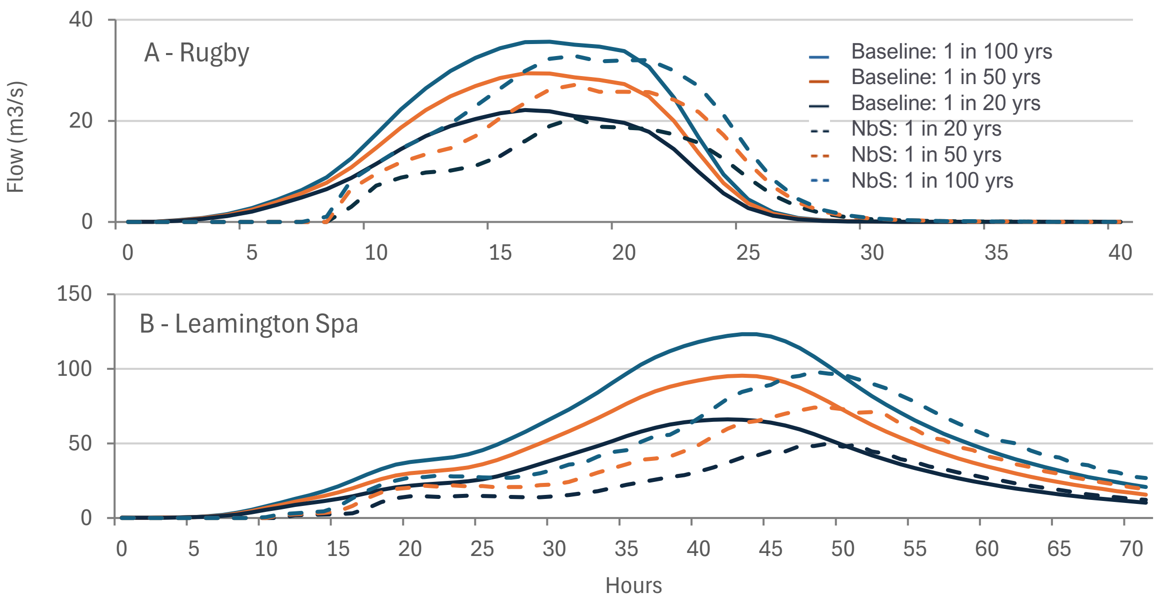

Figure 20: Modelled changes in peak flow for storm events in Rugby and Leamington Spa resulting from NbS portfolio implementation.

Table 8: Modelled changes in peak flows for different return periods resulting from NbS implementation.

		Peak Flow Reduction (%) per Return Period		
Location	**Catchment**	**20**	**50**	**100**
Clay Cotton Brook	Upper Avon	-6	-6	-6
Clifton Brook	Upper Avon	-28	-24	-18
Itchen at Itchington	Leam	-30	-26	-22
Leam at Leamington Spa	Leam	-24	-22	-20
Avon at Rugby	Upper Avon	-26	-21	-18
Swift at Rugby	Upper Avon	-14	-8	-5

5.6.1.1. Water Quality

The modelling also projected substantial improvements in water quality relating to nutrient export. This showed that the implementation of this portfolio of NbS would significantly lower levels of phosphorus exported from water bodies. In total, around 39,714 kilogrammes per year of Nitrogen Export Reduction and 704 kilogrammes per year of Phosphorus Export Reduction could be achieved through the implementation of this portfolio across the model domain.

Model results were output per EA Water Body to give an impression of how this portfolio could deliver against targets for the Water Framework Directive (WFD), more specifically those relating to phosphorus – a key limiting factor for river health in this region – set via source apportionment modelling using the SAGIS tool. These targets were compared with modelled phosphorus export reduction per waterbody to better understand how this portfolio could help meet regulatory targets in the Warwickshire Avon. The analysis indicates that 9 out of 14 modelled water bodies could meet their diffuse pollution targets for “good” status for phosphate. This shift has major implications not only for ecosystem health but also for compliance with statutory obligations and the long-term sustainability of land and water use in the region.

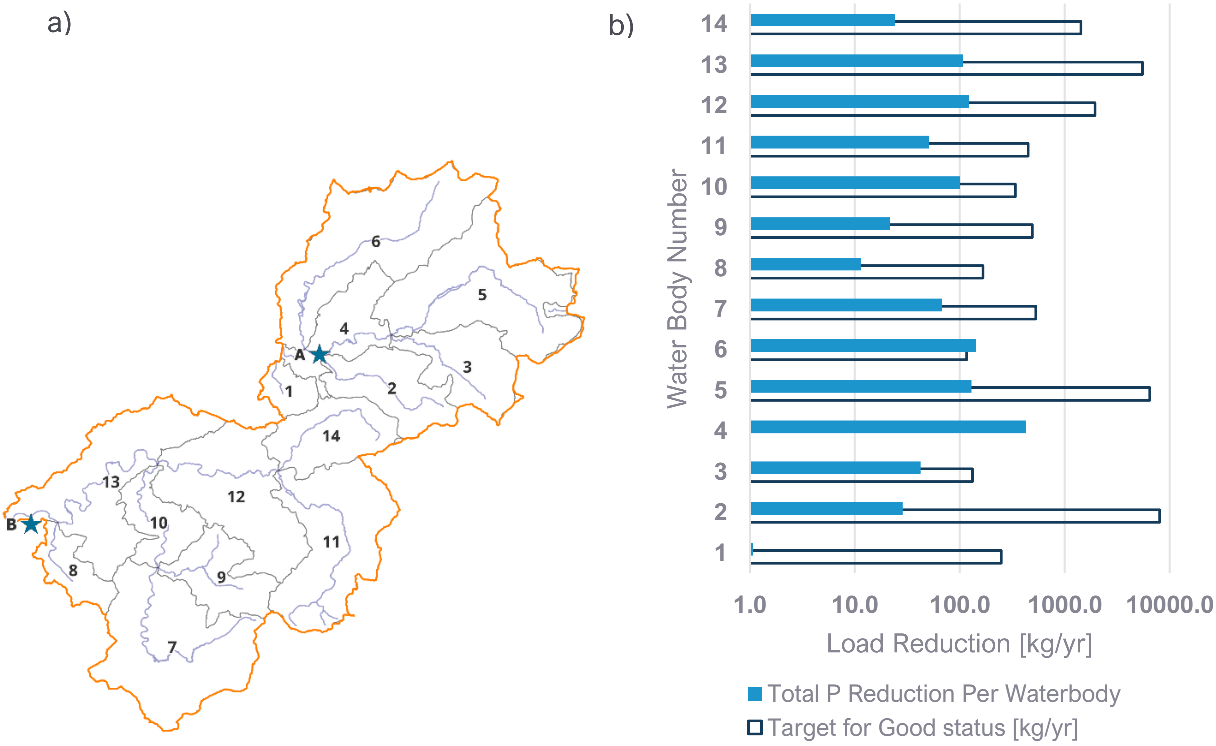

Figure 21: Results of portfolio modelling showing: a) Water bodies at which results were output; b) Modelled phosphorus load reductions per waterbody compared to WFD targets.

5.6.1.1. Water Resources

Modelling indicates that the final NbS portfolio could enhance infiltration by approximately 3 million cubic metres per year across the targeted Warwickshire Avon sub-catchments. This uplift supports improved groundwater recharge, sustained baseflows, and long-term water security, particularly important in the face of increased drought risk under climate change. To put this figure in perspective, this figure translates to around 8 megalitres per day (Ml/d) of additional infiltration – a notable figure given that the total deployable groundwater output for Warwickshire is estimated at around 30 Ml/d. This suggests that NbS could make a substantial contribution to regional water resilience, especially when combined with demand-side interventions and more sustainable abstraction regimes.

The majority of infiltration gains were delivered by bunds (see Figure 22), interventions designed specifically to retain runoff and enhance soil infiltration. However, the modelling also revealed important trade-offs: interventions like woodland creation and riparian buffer restoration were associated with slight decreases in infiltration due to increased evapotranspiration and changes in soil structure. While these NbS deliver valuable biodiversity and water quality benefits, the findings highlight the importance of designing balanced portfolios that consider multi-benefit trade-offs and target each intervention to the locations where they will perform best.

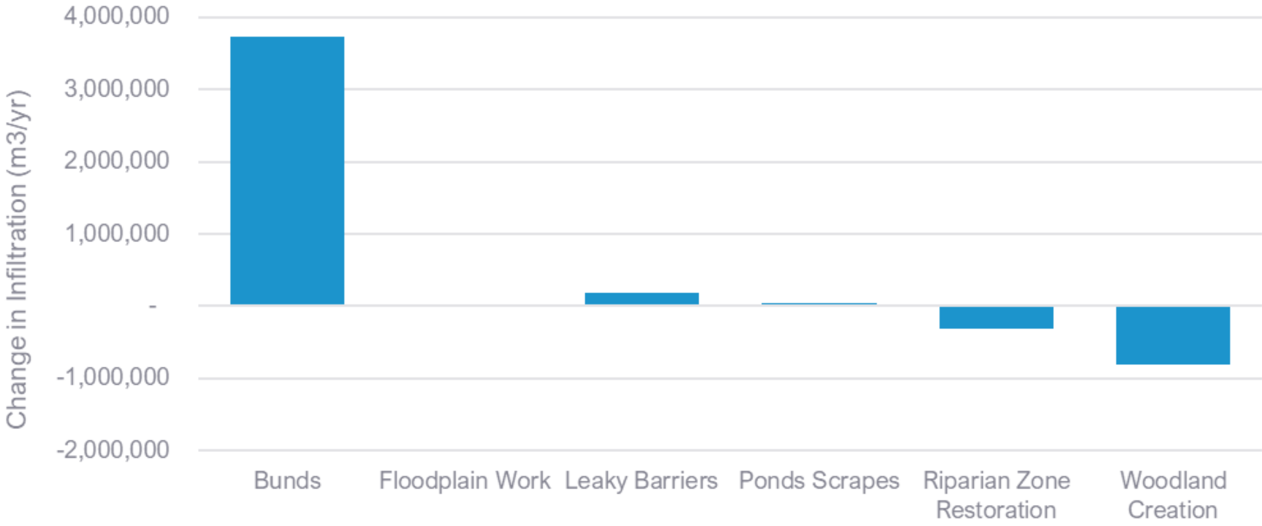

Figure 22: Infiltration changes resulting from portfolio implementation.

6. Economic and Financial Analysis

A Cost-Benefit Analysis (CBA) was conducted to assess the financial and economic feasibility of a catchment-scale NbS Programme across the Warwickshire Avon.

The analysis evaluated the financial costs of the Programme against the expected economic benefits, focusing on water-related benefits (flooding, water quality and groundwater recharge), climate benefits (carbon and air quality), biodiversity benefits (Biodiversity Net Gain Units and Agricultural Land Use change), as well as community benefits (green jobs, recreational value and physical health).

This CBA had two main objectives. Firstly, it aimed to inform the consortium of partners on the economic viability of the proposed NbS interventions in line with their vision of improving water resilience across the catchment. Secondly, the analysis aimed to provide a basis for substantive engagement with stakeholders and funders by demonstrating the potential value of a Programme.

Given that the Programme was expected to deliver a variety of different benefits to people, the economy, and nature, an economic CBA was deemed the most suitable evaluation framework. Unlike a financial return-on-investment (ROI) approach, which assesses financial returns to investors, the economic CBA captures both the economic values of environmental and societal benefits, making it a more appropriate tool for informed decision-making in this context.

This section begins with an overview of the approach, structure, and key assumptions underpinning the CBA. It then details the model inputs and results, first presenting the costs and then the benefits. Finally, it offers a comparative discussion of costs versus benefits, interpreting the results within the context of NbS implementation and outlining the next steps.

6.1. Analytical Framework and Key Assumptions

6.1.1. Analytical Framework

The analysis was conducted over a 30-year time horizon from 2025 to 2055 and adhered to the following analytical steps:

- **Step 1:** Estimating the costs of the Programme over 30 years broken down per NbS type for the targeted modelling extent.
- **Step 2**: Valuing the benefits of the interventions.
- **Step 3:** Building a discounted cash flow model.
- **Step 4:** Evaluating the net benefits of the Programme (incl. decision metrics BCR, NPV, IRR).
- **Step 5:** Extrapolating the values from the targeted modelling extent to the entire Warwickshire Avon catchment.

Figure 23 illustrates how the costs and benefits were organised within the analysis to calculate the benefit-cost ratio, grouping benefits by type and aligning them against programme implementation, maintenance, and management costs:

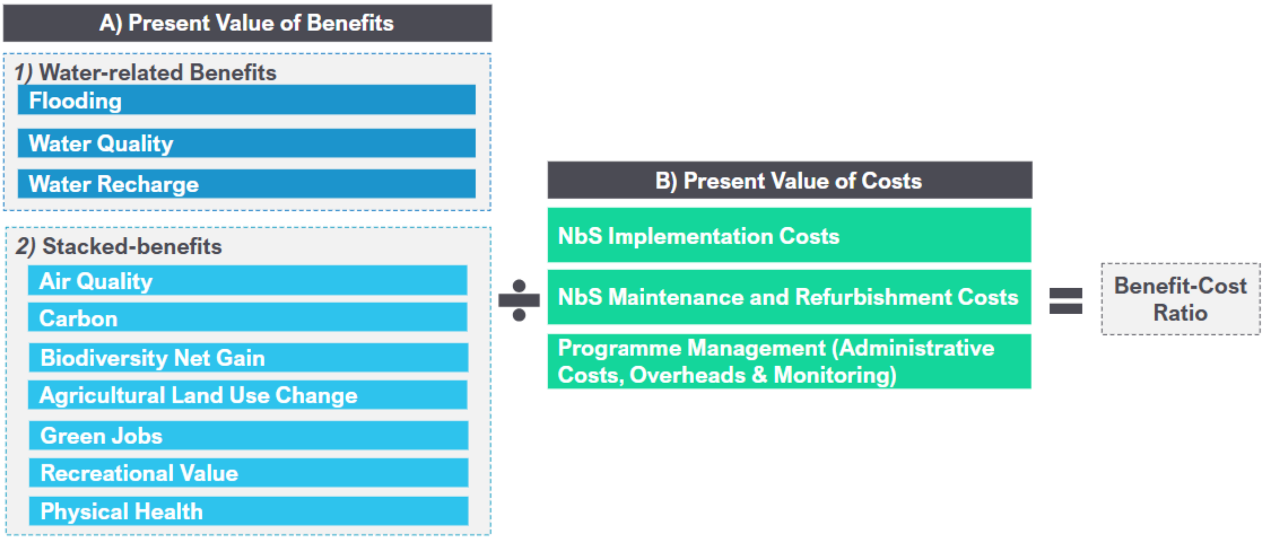

Figure 23: Structure of the Cost-Benefit Analysis

6.1.2. Key assumptions

For the purpose of the analysis, a few general assumptions about the economy and the planned Programme had to be made, which are listed below:

- **Inflation:** The analysis was conducted in real terms, meaning it does not adjust future costs for inflation, as recommended by HM Treasury's Green Book (HM Treasury, 2022). This decision was made to allow decision makers to focus on evaluating the real social costs and benefits of a project, without the complexity of predicting inflation rates over long time horizons.

- **Discount Rates:** The analysis used the UK's social discount rate of 3.5% for over 30 years of the Programme, also recommended by HM Treasury's Green Book (HM Treasury, 2022). This rate was used to evaluate the present value of future costs and benefits. This rate is used in similar analyses.

- **Currency:** The CBA was modelled in Great Britain Pounds (GBP).

- **Phased implementation:** The CBA assumed a phased implementation over 5 years. However, incorporating this assumption directly into the science models (e.g., HEC-HMS) would have introduced significant complexity. Therefore, the science models assume that all implementation happens in year 1. The implementation and related benefits were then postponed in the Cost-Benefit Analysis to generate more realistic cost curves and cost-benefit calculations by applying a 5-year ramp-up profile to both costs and benefits.

6.2. Estimating the Costs of the Programme

6.2.1. Overview and Approach

To estimate the costs associated with the Programme and each NbS intervention, the Warwickshire Wildlife Trust provided costs from previous NbS projects it had implemented, and those were validated by the other partners. Costs were therefore based on real-life, on-the-ground data, relevant to the local context, as the projects were implemented within the catchment. An iterative process was followed, including sense-checking with consortium partners and relevant external stakeholders.

These costs were categorised as follows:

- **Implementation costs:** These include all costs directly related to the execution of the interventions, such as equipment and labour. The costs were determined by listing all the expenses required for the implementation of the NbS, establishing a unit cost for each, and then multiplying these by the corresponding quantities to obtain a total cost per hectare. This per-hectare costing approach facilitates comparisons between different NbS interventions.
- **Maintenance costs:** These encompass all costs required for the long-term upkeep of the interventions, including labour and equipment needed for regular maintenance activities. They were calculated by determining the different maintenance requirements for each NbS, assigning a unit cost to every item, and aggregating these based on the quantities needed in one hectare. Expressing these costs on a per-hectare basis allows for comparability across the different NbS interventions.
- **Operational costs:** These refer to operational costs not directly tied to implementation and/or maintenance, and include:
    - **Overheads and Administrative costs:** These are critical costs to making the entire Programme function smoothly over the 30-year period, such as programme management, office supplies, and IT and communications infrastructure. These costs were defined to represent 20% of the total implementation and maintenance costs (Shiteng Kang, 2023).
    - **Monitoring costs:** These are essential to track the effectiveness and impact of interventions over the 30-year period, such as ecological surveys, water quality testing, and remote sensing analysis. These costs were defined to represent 5% of the total implementation and maintenance costs (Shiteng Kang, 2023).

To project costs with different implementation sizes and best reflect reality, the following two approaches were used:

- **Linear costs (scaled by hectare):** These costs increase proportionally with the area of NbS implementation. For example, vegetation costs scale directly with the number of hectares, as more area requires more planting.
- **Non-linear costs (scaled by number of projects):** These costs do not increase with each hectare but rather per project. A standard project size of 50 hectares was defined. Certain costs, such as permitting and licensing, occur once per project rather than per hectare. These were therefore scaled by the number of projects, calculated as the total implementation area divided by the project size.

This approach enabled the cost framework to be adaptable to different implementation scales, ensuring accurate budgeting and resource allocation. Notably, some costs, particularly some maintenance costs, are time-bound and occur in a periodic fashion. It is important to note that the costing exercise was based on several key assumptions, including the use of a delivery model in which WWT is responsible for a significant portion of implementation activities. The framework also incorporates anticipated cost efficiencies, recognising that as the Programme progresses, delivery becomes more streamlined, and economies of scale are achieved. It is acknowledged that NbS costs can vary considerably depending on the specific project context. A full list of assumptions is provided in the Annex B.

This approach resulted in the following total 30-year costs for implementation and maintenance of the NbS.

Table 9: NbS Implementation and Maintenance Costs per Hectare

Intervention Type	Category	Area type	30-Year Cost (GBP)
Buffer Strips	Implementation	Per hectare	9,075/ha
	Maintenance	Per hectare	30,000/ha
Attenuation Ponds	Implementation	Per hectare	122,700/ha
	Maintenance	Per hectare	90,000/ha
Leaky Barriers	Implementation	Per hectare	32,190/ha
	Maintenance	Per hectare	14,000/ha
Woodland Creation	Implementation	Per hectare	11,725/ha
	Maintenance	Per hectare	7,000/ha
Floodplain reconnection	Implementation	Per hectare	40,875/ha
	Maintenance	Per hectare	12,000/ha
Bunds	Implementation	Per hectare	122,700/ha
	Maintenance	Per hectare	90,000/ha

6.2.2. Summary and Results of NbS Costing

The areas defined under the prioritised NbS portfolio (Section 5.6.5) were then applied to the corresponding unit costs per hectare for implementation and maintenance of the NbS measures outlined in Table 9. Once these costs were established, overheads and administrative expenses, as well as monitoring costs, were computed based on the percentage allocations described in Section 6.2.1.

Table 10 below presents the resulting discounted costs of the Programme over 30 years in real terms for the targeted modelling area, and the prioritised NbS portfolio described in the Science Analysis section.

Table 10: Summary of discounted Programme costs

Implementation	Maintenance	Operational	Total Programme
GBP 81 million	GBP 31 million	Overheads and Administrative costs: GBP 30 million Monitoring: GBP 7 million **Total: GBP 37 million**	GBP 149 million

Figure 24 below illustrates the distribution of undiscounted costs over time for the targeted modelling area. Most costs occur within the first 5 years during the scaling of implementation, amounting to GBP 121 million, which represents over 50% of total Programme costs. After this period, costs drop significantly, leaving only operational costs and maintenance expenses. The concentration of costs early in the project weighs more heavily on the cost-benefit ratio compared to if they were to occur later, when expenses are subject to greater discounting. This results in a more conservative benefit-cost ratio, because the benefits, which occur in later years, are more significantly discounted.

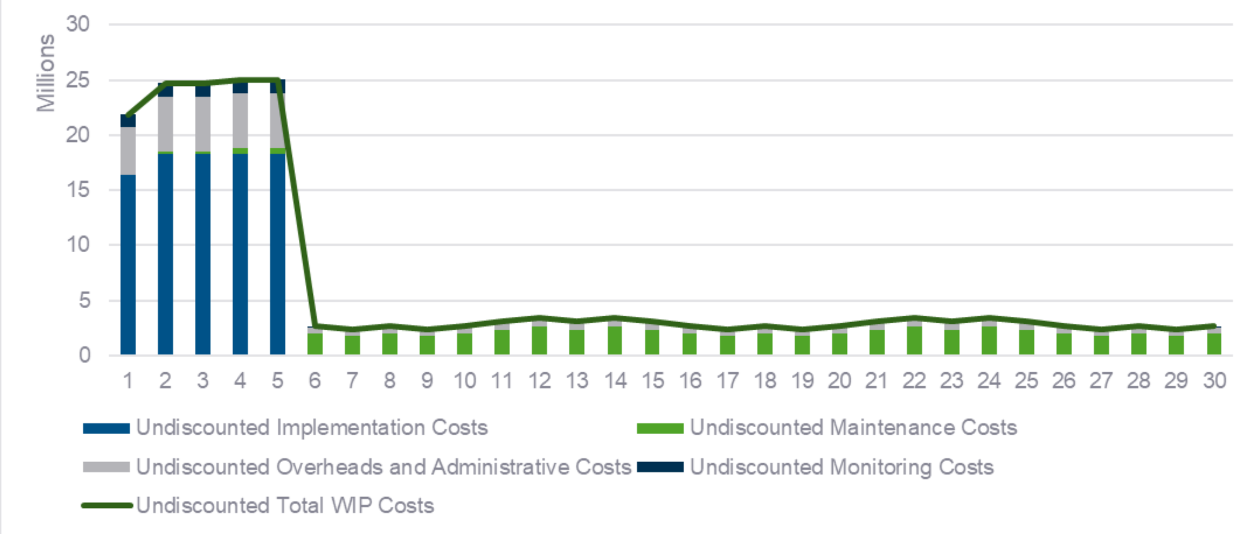

Figure 24: Cash flows of undiscounted costs of the Programme (over 30 years)

6.3. Valuing the Benefits

6.3.1. Overview and Approach

The CBA focused on quantifying the direct benefits to stakeholders, considering the impacts of the Programme on the Warwickshire Avon catchment as a whole. The analysis has taken an integrated approach valuing all water-related benefits (across quality, resources, and flooding) as well as co-benefits to demonstrate the true value of NbS in creating ecosystem services, which makes them distinct from grey infrastructure solutions. The rationale behind every benefit is explained in Table 11 below.

Unlike grey infrastructure for water supply and treatment, which typically targets a single issue such as flood protection or water supply, the NbS approach delivers a broad spectrum of interconnected benefits. By capturing environmental, social, and economic value across multiple domains, this analysis highlights the multi-functional nature of NbS and their capacity to deliver systemic improvements rather than isolated outcomes.

All benefits were estimated by comparing a business-as-usual scenario (which reflects a continuation of current land use and management practices, assuming no additional interventions are made) with one that includes large-scale NbS implementation across the catchment. This counterfactual approach enables a clear assessment of the additional value generated by the Programme. The benefits are stated and described in Table 11 below:

Table 11: Benefits of the Programme

Benefit Category	Rationale	Benefit and Description
Water Benefits		
Flooding	The Warwickshire Avon catchment has a history of surface water and riverine flooding, affecting both residential and commercial areas, particularly with one in ten residential	Through peak flow reduction, NbS will reduce flood damage to residential and commercial properties, vehicles and mental health, and reduce evacuation costs. Additionally, Woodlands will

	properties and one in seven commercial properties at risk, as reported by the Warwickshire Local Flood Risk Management Strategy.	contribute to run-off reduction, ultimately helping avoid flood reservoir construction costs.
Water Quality	98% water bodies in the Warwickshire Avon catchment fail to meet 'good' ecological status under the Water Framework Directive due to high levels of nutrient and sediment runoff.	NbS will improve the overall quality of numerous water bodies in the catchment by reducing sediment and nutrient runoff, enhancing natural filtration, and restoring riparian and wetland habitats that help regulate water quality.
Groundwater Recharge	The catchment is increasingly experiencing seasonal water stress, with abstraction pressures from agriculture and urban demand. The Environment Agency also stated that if no action is taken between 2025 and 2050, there will be a shortfall of around 4,000 million extra litres of water per day in the public water supply.	NbS will enhance groundwater recharge in the catchment by increasing infiltration through soil restoration, reforestation, and the rehabilitation of wetlands and riparian zones, which slow runoff and promote groundwater replenishment.
Climate Benefits		
Air Quality	While overall air quality in the region is moderate, areas within the catchment - especially near urban centres and major roads – report concentrations of pollutants like SO_2 and NO_2 that periodically exceed WHO and UK guideline levels.	NbS will capture various harmful pollutants such as SO_2, NO_2, PM2.5 and O_3.
Carbon	Given the UK's legally binding net zero targets by 2050, capturing carbon benefits illustrates how the Programme aligns with national priorities. Large-scale NbS interventions can contribute meaningful sequestration at the local level, supporting both regional climate adaptation and mitigation objectives.	NbS will capture carbon, contributing to addressing the climate crisis.
Biodiversity Benefits		
Biodiversity Net Gain (BNG)	BNG is now a legal requirement under the Environment Act 2021 for most development projects in England. Measuring the creation and sale of BNG units in this context reflects both regulatory alignment and the potential for landowners and local authorities to generate income from biodiversity enhancements.	The Programme will enable the creation and sale of BNG units, standardised credits that represent measurable biodiversity enhancements and can be sold on a market.
Agricultural Land Use Change	Farmers and landowners want to understand the economic implications of shifting from low-productivity farming to NbS.	By targeting only unproductive land for NbS implementation, the Programme will create opportunities for more sustainable and beneficial land use.

Community Benefits		
Green Jobs	The transition to a greener economy is a government priority, meaning stakeholders, particularly local authorities, are interested in the Programme's impacts in terms of local income and employment opportunities	The Programme will create new jobs linked to the design, implementation and maintenance of NbS.
Recreational Value	There is growing demand for accessible green spaces, particularly from local residents and families in both urban and peri-urban areas of the catchment. This reflects broader national trends around mental well-being, outdoor activity, and the need for nature access close to where people live.	The Programme will create various new recreational sites in the catchment.
Physical Health	The West Midlands reports lower-than-average physical activity levels, contributing to higher rates of lifestyle-related illnesses, highlighting the need to create physical health improvement opportunities.	Through the creation of recreational sites, the Programme will create opportunities for exercise and activity, improving users' life expectancy.

6.3.2. Quantified Benefits for the Targeted Modelling Area

Water Benefits

Flooding benefits were calculated in conjunction with the flood modelling process described in Section 5.5.3. Flood damages were initially assessed under the Business-As-Usual scenario, which reflects current land use and hydrological conditions without any additional NbS interventions. The assessment encompassed multiple categories of damage (residential and non-residential properties, vehicles, evacuation costs, and mental health impacts) using the methodology outlined in the Multi-Coloured Manual (MCM), widely regarded as the gold standard for flood benefit evaluation in the UK (Flood Hazard Research Centre, 2022). These figures represented baseline damages and were associated with a specific peak flow as modelled under the Business-As-Usual scenario by the science model. The reduced peak flow, resulting from the hydrological modelling, was then linked to corresponding damage levels, showing a decrease in damage as a direct consequence of reduced peak flow. This ultimately led to a reduction in total damages, which can be interpreted as avoided flood damages attributable to NbS implementation. The analysis revealed a substantial avoided damage value of GBP 25 million, with over 800 property assets (across both residential and non-residential property classes) safer from flooding. Additionally, the analysis also included the avoided costs of building a flood capture reservoir linked to the run-off reduction resulting from woodlands, which act as a natural flood storage system. The valuation was based on the volume of flood storage captured by woodlands in m^3/year (from the biophysical modelling), and monetised using the monetary value of 0.47 GBP/m^3 representing the flooding reservoir construction cost (The Research Agency of the Forestry Commission, 2023), contributing a total value of GBP 12 million. Both flood valuation methodologies combined created a substantial discounted flooding benefit of GBP 37 million.

Water quality benefits were assessed at the water body level using business-as-usual data from the Water Framework Directive. These were linked to the Environment Agency's key water quality indicators (fish, invertebrates, macrophytes, clarity, and river channel condition), with recreational safety excluded to prevent overlap with recreational benefits. Values associated with improvements from one quality band to another were drawn from the National Water Environment Benefit Survey (NWEBS). Central values of each water quality improvement band were considered: GBP 20,200 from Bad to Poor, GBP 23,400 from Poor to Moderate, GBP 27,400 from Moderate to High (2012 values, which were then adjusted for inflation to 2025 values). By using the science modelling outputs described in Section 5.6.1.1 the analysis linked the reductions in phosphorus and nitrogen loads from NbS interventions to each water body's Reasons for Not Achieving Good (RNAGs), identifying quality improvements across components. Each component was then given an equal value: $1/5^{th}$ of the total band quality improvement value. In total, 11 out of 14 water bodies saw at least one component improve, resulting in a discounted benefit of GBP 42 million.

Groundwater recharge benefits were evaluated at the NbS intervention level, with each solution contributing differently to groundwater recharge. As highlighted in Section 5.6.1.1 each NbS has a groundwater recharge output in m^3/yr, culminating in a total enhanced infiltration volume of 40 million cubic meters over 30 years. This result was then monetised using unit values for water abstraction for public supply (GBP 0.46/m^3, 2020 value, adjusted for inflation to 2025 value), as defined by the Office for National Statistics (Office for National Statistics, 2020). This generated a discounted benefit valued at GBP 82 million.

Climate Benefits

Climate benefits were assessed through both air quality improvement and carbon sequestration, based on land use changes between a business-as-usual scenario, as well as one with NbS implementation, using sequestration rates defined by the Water Industry National Environment Programme (WINEP) regulatory framework.

For **air quality**, the analysis focused on four key pollutants: PM2.5, Sulphur Dioxide (SO_2), Ozone (O_3), and Nitrogen Dioxide (NO_2). By converting existing land covers into types that capture more pollutants, and multiplying them by the value of each pollutant removal in GBP/tonne/year, which represents an avoided health damage cost (Centre for Ecology and Hydrology, 2017), as highlighted by WINEP. NbS interventions are estimated to remove 1,100 tonnes of pollutants over 30 years, generating discounted benefits of GBP 11 million.

For **carbon sequestration**, the analysis compared business-as-usual and NbS-enhanced land covers, applying the central range of UK government carbon prices. This represents the 'social cost of carbon', which is the monetary value of cost that UK society places on one tonne of carbon dioxide equivalent, as per the WINEP guidelines. This resulted in the removal of over 400,000 tonnes of CO_2 over the total 30-year timeframe of the targeted modelling area, amounting to a total present value of GBP 70 million.

Together, these climate benefits bring substantial added value to the Programme, highlighting the potential of NbS to help address the climate crisis.

Biodiversity Benefits

Biodiversity and agricultural benefits were also evaluated in monetary terms as part of the CBA to capture the broader value of NbS implementation.

Biodiversity benefits were assessed through the creation of **Biodiversity Net Gain** (BNG) units, calculated by comparing business-as-usual land cover with NbS-enhanced land cover. The total number of BNG units was limited by local demand, as identified through stakeholder consultations and on-the-ground assessments by Warwickshire County Council (annual demand of 47 BNG units in the catchment). Unit pricing was based on previous experience from the Council to reflect local market conditions (GBP 21,000 unit price), resulting in a discounted total 30-year benefit of GBP 37 million.

For **agricultural land use change,** the same comparative land cover approach was used. As NbS were implemented only on low-productivity land, baseline agricultural activities were limited to those suited to degraded conditions - primarily beef and sheep grazing, with wheat considered unfeasible. Under the NbS scenario, land cover changes enabled alternative uses such as increased sheep grazing and some timber production, in line with recommendations from the Natural Capital Register and Account Tool (NCRAT) and data from the UK Forest Market Report, generating an additional discounted GBP 5 million benefit, representing agricultural revenues resulting from increased productivity.

These benefits highlight the added ecological and economic value of the Programme, reinforcing the relevance of NbS in supporting biodiversity and enabling more sustainable land use practices.

Community Benefits

Finally, the CBA assessed the direct benefits that the Programme would generate for local communities and residents of the catchment. While categories such as water and climate already provide indirect local benefits, this section focused specifically on well-being and employment outcomes, which directly affect peoples' livelihoods.

The first component examined was the creation of "**green jobs**" associated with the implementation and maintenance of NbS over the 30-year period. Job estimates were based on staff and contractor costs developed during the costing exercise, converted into full-time equivalents (FTE)[2], and monetised using local salary data from Warwickshire Wildlife Trust (GBP 29,000/year on average). This analysis yielded an estimated discounted employment benefit valued at GBP 71 million.

For the **recreational value**, the team developed four new recreational sites of varying sizes, distributed across the targeted modelling area. Using the Outdoor Recreation Valuation (OrVAL) tool, the four sites were translated into the number of annual visits and related economic value for recreation. The OrVAL tool assigns a yearly welfare value to each site based on the public's use of these areas for activities such as walking, playing, or enjoying nature. The total discounted recreational benefit was estimated at GBP 19 million, which includes 303,727 visits.

Additionally, the OrVAL tool provided estimates of annual visitor numbers per site. Using the NCRAT methodology, the number of **physically active visits** was identified and converted into a health benefit using the Quality-Adjusted Life Year (QALY) metric, a standard measure in health economics. This resulted in a discounted health-related benefit of GBP 9 million.

These community-focused benefits highlight the potential for, and important role of, NbS in enhancing local quality of life and supporting sustainable livelihoods.

Discounted costs and benefits of the targeted modelling area for the modelled NbS Portfolio are highlighted in Figure 25 below in the form of a waterfall chart.

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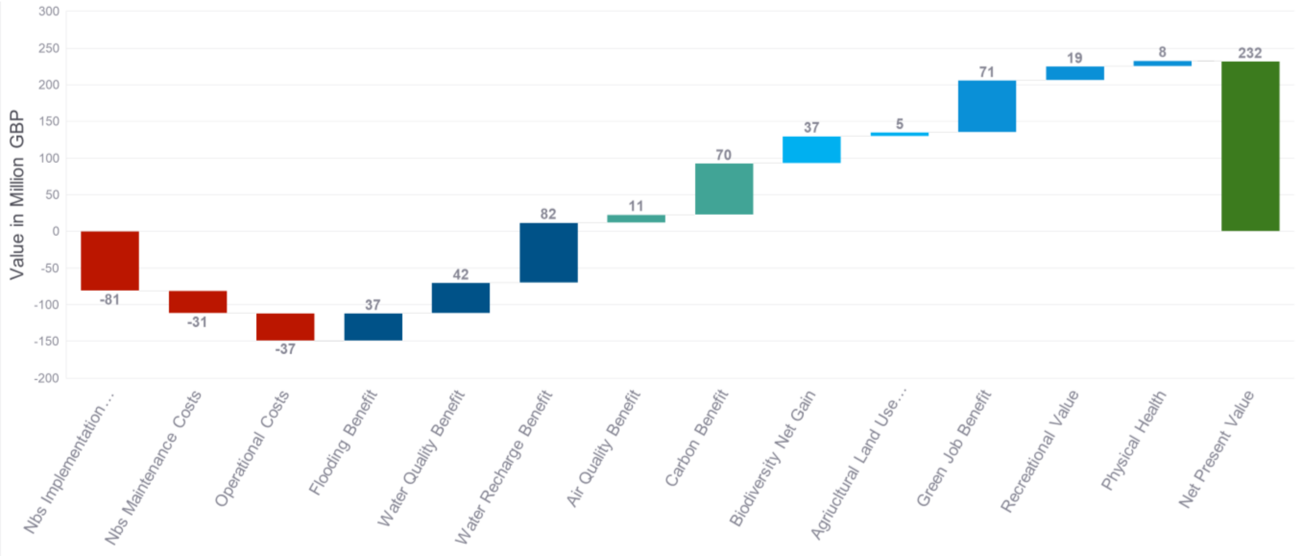
[2] Full-time equivalent (FTE) expresses an employee's workload as a fraction of a full-time schedule, defined here as 5 days of 8 hours (40 hours) per week.



[3]

Figure 25: Waterfall chart of the Programme's costs and benefits.

By leveraging the ability of NbS to **provide a variety of different ecosystem services**, the Programme is able to reach a wide range of beneficiaries in the catchment area. For water companies, it provides a practical, nature-based program to achieving **regulatory** and **environmental** targets whilst also complementing grey infrastructure investments. Local authorities are able to progress their climate, biodiversity, and wellbeing **agendas**. Businesses manage **nature and water-related risks** while advancing ESG **commitments**. Landowners and farmers benefit from greater **resilience** and new **income opportunities** through nature-based approaches, while communities enjoy **reduced flooding, cleaner rivers, and better access to green space.** A detailed outline of Programme beneficiaries is included in Annex G.

6.3.3. Unquantified Benefits

Our analysis has shown that at-scale NbS implementation would provide considerable benefits despite taking a conservative approach. In reality, benefits would exceed what was measured as part of this scope of work, as they could **extend to a broader range of environmental, social, and economic outcomes**. These additional benefits could be further explored depending on interest from stakeholders and funders:

- **Additional flood-related benefits**, such as reductions in Combined Sewer Overflows (CSOs), lower insurance premiums, avoided repair costs, and avoided flood damage to major infrastructure and agricultural land. As an order of magnitude, CSOs are a major issue in the UK, with estimated annual costs of £212–£257 million in England alone (DEFRA, 2023). NbS, could potentially meaningfully help addressing this issue, when implemented in the right areas where they keep rainwater away from the sewer systems.
- **Wider economic benefits**, including knock-on effects like increased ecotourism and the unlocking of land for housing development due to reduced flood risk.
- **Fewer restrictions on water abstraction licences** in the future, enabled by improved groundwater recharge and a more reliable water supply.

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[3] As each cost and benefit has been rounded to the nearest whole number, the aggregated NPV on this chart may appear as GBP 233M. In reality, the precise value is GBP 232.3M, which has been rounded to GBP 232M.

- **Water treatment cost savings** resulting from improved water quality, reduced diffuse pollution, and lower levels of nutrient-rich agricultural run-off. This was measured by Severn Trent as part of its 2025-2030 business plan, which highlighted treatment cost savings of GBP 2 for each GBP 1 spent on reducing pesticide, nitrate and cryptosporidium concentrations from agricultural activity, an approach that includes NbS use.

6.4. Comparing Costs and Benefits

This section will first provide an overview and the approach taken for the comparative analysis of costs and benefits, and then outline the results.

6.4.1. Overview and Approach

In order to systematically compare and analyse the costs and benefits, the following metrics were calculated to support decision-making:

- **Benefit-Cost Ratio (BCR):** Represents the ratio of the present value of total benefits (discounted over 30 years) to the present value of total costs (discounted over 30 years).
- **Net Present Value (NPV):** Represents the total value of an investment opportunity (discounted over 30 years).
- **Internal Rate of Return (IRR):** Represents the rate at which the NPV of the Programme's costs and benefits equals zero.

6.4.2. Results of the CBA

Based on the above outlined formulas, the three 'decision metrics' were calculated. The results can be found in Table 1 below.

Table 12: CBA Decision Metrics

Metric	Result
Benefit-Cost Ratio (BCR)	Targeted modelling area: 2.5 Entire Warwickshire Avon catchment: 2.7
Net Present Value (NPV)	GBP 232 million (for targeted modelling area, only)
Internal Rate of Return (IRR)	14% (for targeted modelling area, only)

Table 12 highlights that the BCR exceeds 1, indicating that the benefits of the Programme outweigh its costs and confirming it as an **economically favourable investment**. The analysis in the target area shows that for every GBP 1 invested, the Programme would generate GBP 2.5 in benefits. Scaled to the entire catchment, the benefits would grow to GBP 2.7. This is because costs are likely to decrease at a greater rate than benefits, due to efficiencies, while some benefits are likely to increase further due to cumulative system improvements.

The NPV is also positive, meaning that the Programme is expected to **generate greater benefits than the costs incurred**, indicating an economic case for investment. The magnitude of the NPV (GBP 232 million) also indicates that the scale of the value added is significant, further supporting the economic case for the Programme.

The IRR of 14%, which shows the expected annual growth rate of an investment in the Programme, **further supports the overall economic case of investment** for the Programme, showcasing strong economic viability.

Comparing the annual cash flows (undiscounted costs and benefits) of the Programme (see Figure 26) reveals that the investment **costs occur earlier in the 30-year timeframe**, whereas benefits are realised later in the project.

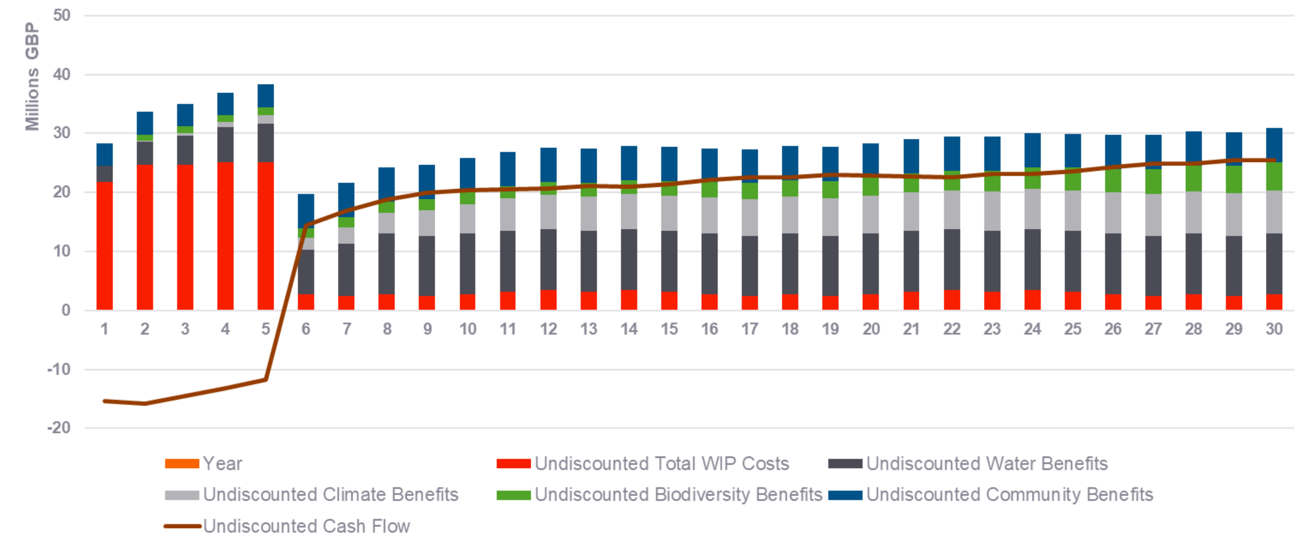

Figure 26: Cash flows (undiscounted costs and benefits) of the Programme (over 30 years)

This is typical of NbS projects, as their **benefits take longer to accrue** compared to grey infrastructure projects. This risks low cost-effectiveness of NbS programmes when investment decisions are made over shorter time periods, such as 5 years. Over decades, however, benefits start to significantly exceed costs, which emphasises the **need for long-term, investment decision-making and planning, sustainable funding and effective governance arrangements**. These are components of a successful investment programme across the entire catchment.

6.5. Summary and Conclusions from CBA

An investable proposition

By comparing the monetary costs against the expected financial and economic benefits, the Cost-Benefit Analysis highlights that a Programme could deliver **substantial net benefits** for **water**, **climate**, **biodiversity**, **community well-being** and **economic growth**.

The assessment shows that while watershed restoration requires significant investment, **its long-term positive returns outweigh its costs**. The Benefit-Cost Ratio (BCR) exceeds 1, indicating that for **every GBP 1 invested**, **GBP 2.7 of benefits are realised across the Warwickshire Avon catchment**. Additionally, the Net Present Value (NPV) is positive, reinforcing the Programme's ability to generate economic value. The Internal Rate of Return (IRR) also remains well above the social discount rate of 3.5%, confirming that the Programme’s investment would generate strong economic value.

These findings support the use of NbS to achieve the partner’s vision of securing a **resilient water future.** The Programme would generate substantial water-related benefits across flooding, water quality, and groundwater recharge, amounting to **GBP 161 million** in present day value**.** These alone surpass the total Programme cost of **GBP 149 million** for the targeted modelling area, demonstrating that **even a narrow focus on water outcomes** justifies the investment.

In addition, the Programme would deliver further co-benefits related to climate, biodiversity, and community well-being. These stacked benefits represent an **additional GBP 221 million of value**, significantly strengthening the case for NbS and highlighting their ability to **deliver multiple outcomes** across sectors and stakeholders, through collective action.

Altogether, this makes a compelling economic case for scaling NbS implementation, across the Warwickshire Avon catchment. Beyond generating a strong economic return on investment (E.ROI), the Programme would build meaningful climate and water resilience in across the catchment. This creates a robust, investable proposition for stakeholders and funders committed to long-term, system-wide improvements in catchment health and sustainability.

The required scale of investment and resource allocation

The CBA not only highlights the overall economic value of the Programme but also provides valuable insights for **public sector funders, investors, and policymakers** to support strategic planning and informed resource allocation.

When results from the targeted modelling area were **scaled up to the full Warwickshire Avon catchment**, the **BCR increased from 2.5 to 2.7.** This improvement reflects both **cost efficiencies** linked to economies of scale in the implementation of NbS as well as the **cumulative impact of wider, system-level benefits**. It demonstrates that expanding implementation across the entire catchment would generate even greater returns.

However, achieving this scale would require a proportionally larger investment. A catchment-wide Programme requires an **estimated investment of around GBP 700 million over 30 years**, yielding approximately **GBP 2 billion in economic benefits**, expressed in present-day terms. Importantly, this level of investment remains relatively modest when compared to the capital sums typically allocated to **large-scale grey infrastructure** projects.

Crucially, this level of investment is **not all required upfront,** as early funding can already **unlock meaningful outcomes** such as reduced flood risk and improved water quality, while **building momentum and confidence for broader implementation over time**. In fact, only a fraction of the total investment is needed to begin delivering measurable results (as highlighted in Section 6.3) laying the groundwork by achieving early wins, demonstrating proof of concept, and piloting delivery mechanisms with landowners. This **phased approach** enables **adaptive learning** and strengthens the foundation for scaling up over the longer term.

Limitations and Looking Ahead

This analysis has taken a conservative approach, and the Programme's true benefits **are likely greater than those quantified.** As mentioned in Section 6.3.3, a **range of valuable outcomes** were not monetised (such as reductions in Combined Sewer Overflows, avoided infrastructure damage, and water treatment cost savings) due to the unavailability of standardised methodologies and/or reliable data. Additionally, broader economic gains, such as the potential for **increased housing development** or **more secure abstraction licensing**, were also excluded. As a result, the analysis intentionally presents a conservative estimate of the E.ROI, with actual net benefits expected to meaningfully exceed the reported values.

Given the substantial costs of the Programme and the long-term nature of its benefits, it is crucial to **establish sustainable, multi-generational governance and funding mechanisms** that can attract and sustain both **public** and **private** investment. Ensuring long-term financial and institutional support will be key to the Programme's establishment, success and resilience.

7. Implementation & Delivery

7.1. Governance Considerations

The partners are committed to formalising their collaboration and expanding participation to include a broader group of stakeholders. Looking ahead, they envision establishing a "Water Hub" – a coordinated platform that oversees investment, supports delivery, and tracks outcomes over the long term. Currently, they are considering several typical models of governance, including:

i. **Umbrella Agreement / Unincorporated Joint Venture:** A loose framework, typically via Memorandum of Understanding (MoU) or charter, where partners coordinate on shared goals while implementing activities independently. While this model allows for flexibility, it often proves ineffective in the long-term for several reasons, such as limited accountability, a lack of operational integration, and unsustainable funding flows. This could however be an effective short-term option to provide formality around the partnership, with its vision and objectives.
ii. **Hosted Programme:** One lead organisation hosts the Programme, overseeing delivery, coordination, financial flows and secretarial services. Strategic decisions are made by a multi-partner steering group, and responsibilities are formalised through MoUs. This model balances efficiency and shared ownership. But, hosting a programme for decades is uncommon, due to the lobsided operational and financial burden that it may place on a single partner. Therefore, this may also be a useful short- to medium-term option to ensure the proper establishment of the Programme.
iii. **New Dedicated Institution / Independent, Incorporated Entity:** Establishing a new legally incorporated entity, such as a Community Interest Company (CIC). This would create a separate legal personality, that employs its own staff, governance, and operations. This model offers greater autonomy, clarity of purpose, and legitimacy. But, it can take long to setup (i.e. 6–18 months), and the partnership modality and liability associated with the existing partners (and future collaborators) may be unclear or unfavourably aligned. There are many examples where a new dedicated institution has been successfully used in programmes with some similarities to the prospective Programme in the Warwickshire Avon (e.g. Wyre NFM).

The partners are currently assessing these options, with the **Hosted Programme or Dedicated Institution** emerging as the most suitable pathways, at this early stage. They could also choose to go ahead with two or three models, where for example, they start with a hosted programme for the first 5 years, which intentionally evolves into a new dedicated institution. This would underpin their shared ambition to scale the Programme and formalise stakeholder participation.

This is a critical assessment, which should be undertaken in the next phase of work (Design Phase). Operational and governance models that are used in Norfolk and Wyre will be reviewed for relevance.

7.2. Delivery Model

Importantly, the selected governance structure must enable the at-scale delivery of Nature-based Solutions (NbS). All core partners have successfully implemented NbS in isolation. However, the next step requires a more inclusive, coordinated, and strategic model that reflects the complexity of water resilience challenges across the Warwickshire Avon.

To be effective, the delivery model for the selected structure must move from high-level commitment to operational readiness. The model should (operational examples provided within):

i. **Be Implementation-Orientated:** A functional delivery mechanism must move beyond strategy and into execution. This includes:
    a. Dedicated Programme Management Unit (PMU) or “Water Hub” with clear mandates to: oversee day-to-day operations, manage implementation pipelines, and support contracting, procurement, and compliance.
    b. Implementation / deployment teams working regionally or thematically (e.g. upstream, mid-catchment, urban/rural interface).
    c. Delivery Framework Agreements to enable rapid contracting of delivery / executing partners (e.g. landowners, NGOs, contractors, etc.).
    d. Tools for Execution: Standardised templates for: landowner agreements, environmental monitoring, and payment-for-results contracts.
    e. Immediate action (example): Recruit an interim programme director, seconded from a core partner or hired externally, to lead setup of PMU / Water Hub.

ii. **Be Catchment-Wide:** To address water resilience at the right scale, with:
    a. Geographic Coverage: Subdivide the catchment into operational zones with lead coordinators (e.g. north catchment, south catchment).
    b. Sectoral Integration: Involve not only environmental and water partners, but also agriculture (via farmers’ unions and supply chain actors), urban development (through councils and housing developers), and even possibly health and insurance (to align with climate adaptation and risk reduction goals).
    c. Coordination mechanism: A quarterly Catchment Delivery Forum chaired by the Water Hub to align regional plans, resolve issues, and share lessons.

iii. **Be Outcomes-Driven:** The delivery model must attract and retain investment by transparently showing results, through:
    a. Defining a Common Outcomes Framework (COF) covering: flood risk reduction, water quality and recharge, Biodiversity Net Gain, climate mitigation and adaptation, community benefits (e.g. access, wellbeing).
    b. **Embedding Results-Based Financing (future prospect)**: Linking funding tranches to verified outcomes.
    c. **Establishing an Integrated Monitoring, Reporting and Verification (MRV) System**: use satellite and in-field sensing data, engage third-party verifiers, publish annual report cards / impact reports.

WWT brings **deep expertise** and a **strong track record** in **delivering NbS in a cost-effective manner**. Due to its organisational setup, operational flexibility, and the absence of some regulatory constraints faced by utilities such as Severn Trent, WWT is often able to implement projects more efficiently. In the near-term, this positions WWT as a **strong candidate** to act as a key delivery partner for on-the-ground implementation. Over the medium-to long-term, delivery should be undertaken by **a range of organisations**, and the operational roles, responsibilities, and delivery mechanisms will need to be defined more clearly in the next phase of work (Design Phase).

8. Funding Approach & Next Steps

8.1. Long-term Funding

The Programme is expected to adopt a **blended finance approach**, combining **public** and **private** capital. In the short term, as the Programme progresses through the Design Phase and formalises an early governance structure, funding may need to be arranged on a **case-by-case basis** for each pilot project. However, the partners ultimately aspire to establish **a coordinated, centralised funding mechanism** that ensures continuous capital flows, which would avoid the inefficiencies of stop-start fundraising and implementation cycles. **Public grants and philanthropic support will be critical in the early phases**, as they can absorb risks that private investors typically avoid. Over time, the Programme seeks to attract private capital by aligning with **existing investments** (e.g. WINEP) and leveraging emerging nature markets.

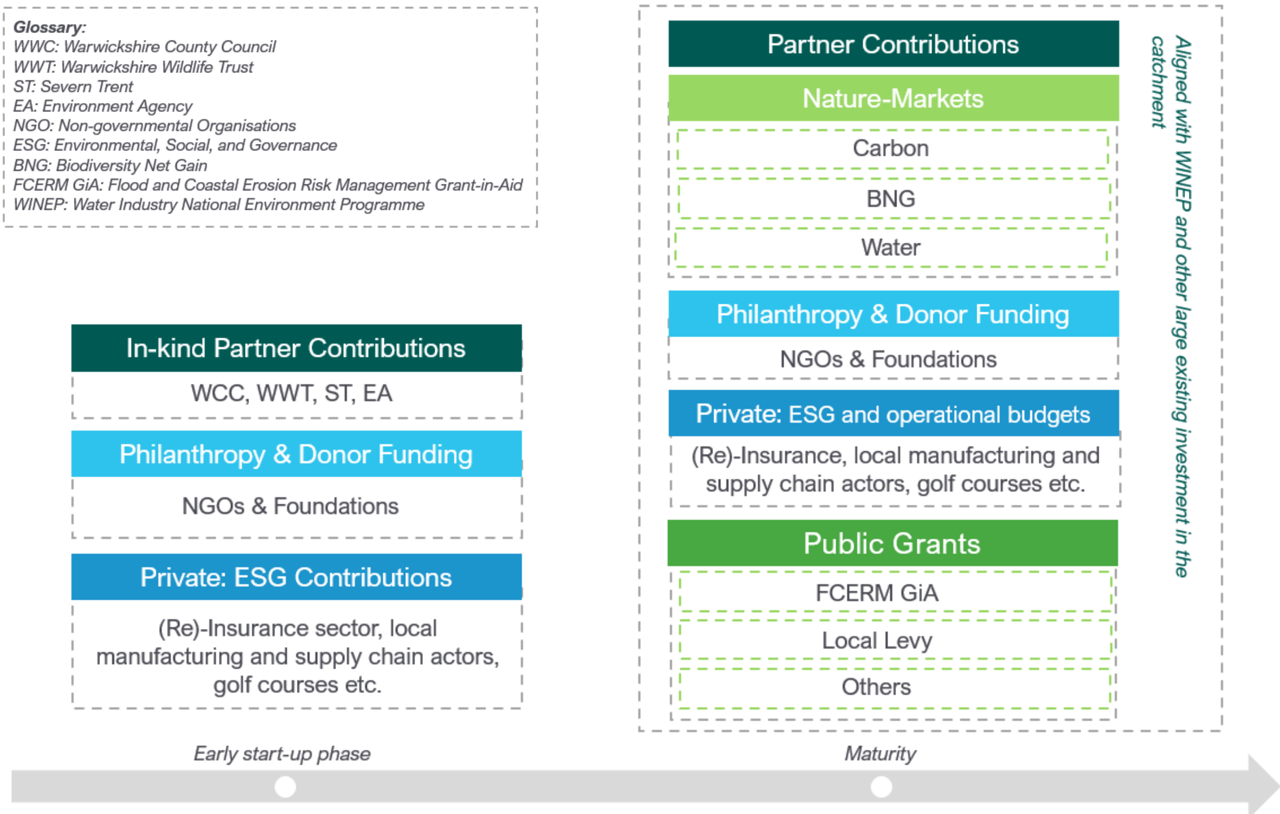

Figure 27: Vision for the blend finance vehicle's evolution from early phase to maturity

The UK policy landscape is **increasingly supportive of NbS**, particularly through **regulatory reforms** and **market-based mechanisms** designed to incentivise environmental outcomes. Notably, agricultural subsidies have undergone a significant transformation under the **Environmental Land Management schemes (ELMs)**, moving away from area-based payments to a system that rewards the delivery of public goods such as improved soil health, water quality, biodiversity, and climate resilience. This shift provides a **critical policy foundation** for scaling up NbS at the catchment level, providing confidence to the partners as they collectively seek other sources.

In parallel, new regulatory requirements on developers, such as **mandatory Biodiversity Net Gain** and the upcoming **carbon and nutrient neutrality obligations**, are accelerating the growth of nature markets. These markets create **structured opportunities for private investment** in environmental improvements, enabling landowners and developers to meet compliance targets and fund the creation and/or restoration of natural assets. These are necessary force-factors to cause these parties to better understand their direct and downstream impact on the environment, and the important role of NbS.

Warwickshire has been a national frontrunner in developing and implementing these mechanisms. Long before BNG became a statutory requirement in England, the Warwickshire Avon catchment was home to **one of the UK's earliest operational BNG markets**, established and managed under local authority leadership. This pioneering work not only demonstrated the technical feasibility of biodiversity offsetting but also helped shape national policy discussions.

Now, Warwickshire County Council is advancing its ambition to be at the forefront of the next evolution in this space, by expanding from biodiversity-only credits to **multi-metric nature markets that integrate carbon, biodiversity, and water outcomes**. This includes exploring the introduction of a **'water metric'** to capture the hydrological benefits of interventions like wetland restoration, soil infiltration improvements, and natural flood management. This progressive and **enabling policy environment**, combined with Warwickshire's proven track record, provides a strong platform for developing a scalable, locally-led NbS delivery model that aligns ecological, social, and economic benefits across the catchment.

Numerous **potential investors** and **funding models** have been identified across the UK (Annex A), which will need to be engaged and explored further. A detailed funding strategy will be developed as part of the next phase of work (Design Phase).

8.2. Next Steps & Fundraising Target

The Programme will follow a phased approach, beginning with a **start-up phase** that lays the groundwork for a future **NbS scale-up phase**, during which NbS will be implemented at scale (see **Error! Reference source not found.**).

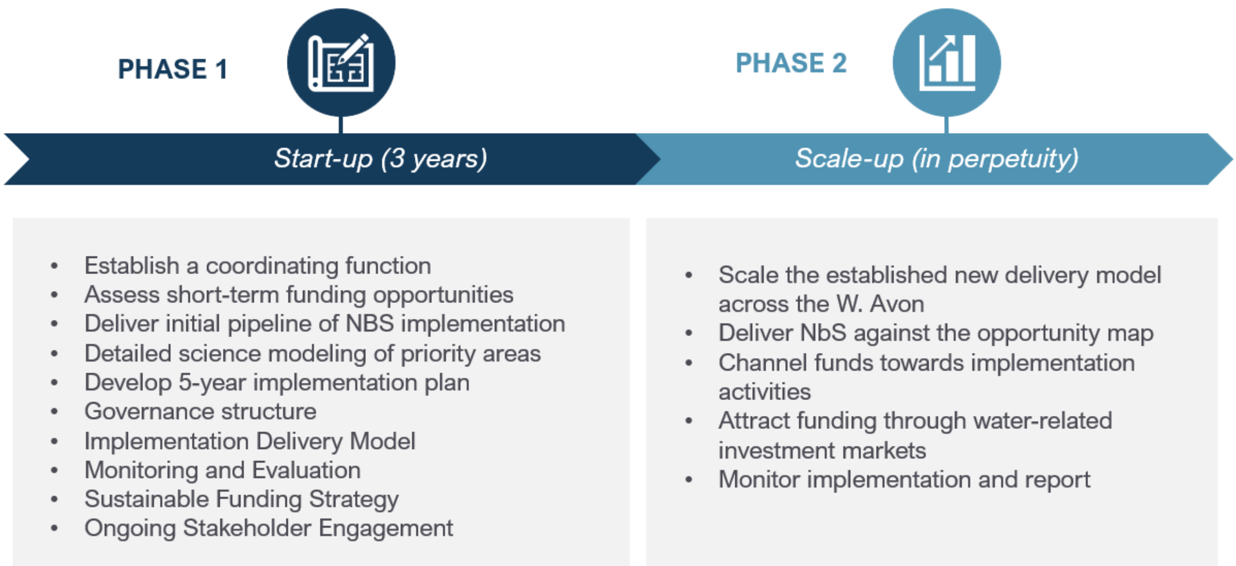

Figure 28: Phased approach to programme development.

The start-up phase – including the Design Phase work – is crucial for bridging the gap between feasibility and implementation, and usually takes 3 years at least. It will serve to operationalise key insights from the feasibility assessment, establish early governance structures, identify initial funding mechanisms, and prepare the enabling conditions necessary for more significant implementation. This phase will consist of the following core workstreams, which are delivered in parallel, but tend to have the following sequential flow:

1. **Establish a Coordinating Function** – Formalise the partnership structure.
2. **Identify and Assess Short-Term Funding Opportunities** – Identify and support the securing of initial financial resources to cover initial implementation.
3. **Engage Stakeholders** – Continuous alignment with key actors, to raise funding, get pilot projects off the ground, and solidify stakeholder's roles and governance arrangements.
4. **Prioritise Initial Interventions for Implementation** – Analyse priority areas based on the existing opportunity mapping and stakeholder input.
5. **Develop a 5-Year Implementation Plan** – Outline strategic actions and milestones, with a strong rationale for moving from establishment to scale.
6. **Design the Delivery Model and Capacity** – Establish how the Programme will be executed in practice and build readiness and capacity for delivery.
7. **Define the Governance Structure** – Clarify decision-making processes and roles, building on the formalised partnership arrangement.
8. **Formulate a Sustainable Funding Strategy** – Ensure long-term financial viability.
9. **Develop an Impact Measurement and Monitoring (MM) Framework** – Track progress and measure impact using bespoke tools and program intelligence.
10. **Implement Initial Partnership Projects** – Launch demonstration initiatives to test and refine approaches.

To support this next phase, the Programme will require GBP 4.4 million over the first 3 years, with GBP 300,000 already committed by core partners. The majority of this funding (+70%), will be dedicated to the implementation and maintenance of initial partnership projects, laying the foundation for large-scale NbS deployment. The remaining funds will support the technical assistance, programme management, and monitoring needed to ensure the Programme is implementation-ready and backed by strong evidence. The proposed Programme costs for start-up are listed as follows:

Table 13: Funding requirement for Start-up Phase

Amount ('000 GBP)	Status	Description
300	Committed	In-kind contributions from core partners
200	Required	Technical Assistance (Design Phase)
750	Required	Programme Management (3 years)
190	Required	Monitoring (over 3 years)
3,000	Required	Implementation and maintenance of initial partnership projects
4,440		**Total Start-up Fundraising Target**

This Table 13 represents the funding required for the start-up phase, supporting the transition toward readiness for scaling up NbS implementation across the catchment. Beyond this initial transition phase, the fundraising target is expected to be significantly higher. Precise figures will be established during the next phase of work.

9. Concluding Remarks

This assessment, undertaken by N4W in collaboration with the partners, evaluated the feasibility of a long-term NbS investment Programme for the Warwickshire Avon catchment. The Programme seeks to address the **catchment's urgent and interconnected water security challenges.**

Drawing on stakeholder engagement, scientific/technical modelling, and economic appraisal, the feasibility findings make a **compelling case** for the Programme, demonstrating that NbS can deliver significant, measurable benefits in terms of flood mitigation, water quality improvement, and water resources, while also delivering numerous co-benefits for climate, biodiversity, and long-term community resilience. With a benefit-cost ratio of 2.7 to 1, **early-stage investment in the Programme is justified and economically viable.**

The Programme proposes a **coordinated and collaborative approach** that establishes sustainable funding and governance mechanisms that are arranged in a **'Water Hub'** to drive focus, coordinated intention, and investment into at-scale NbS. While some of the **operational details** around **decision-making and delivery model** still need to be determined in the next phase of work (Design Phase), the feasibility has highlighted the impact and value this Programme could deliver. The key findings and recommendations from this work are summarised in the table below:

Workstream	Key findings and recommendations for further work
Stakeholder Analysis	• Stakeholders across all sectors (private and public) underscored **the need for such a Programme** and showed **willingness to engage and contribute** in principle. However, further engagement is needed to articulate the value and clarify roles and capacity to contribute, particularly with the private sector. • **Stakeholder Engagement is a continuous process** that will continue in the next phases (Design Phase). The feasibility results should be leveraged for this purpose, throughout the next phase and thereafter. • **Re-insurance (Flood-Re)** has a strong interest in minimising environmental/flood risk and could be a great partner to this Programme. Further engagement is needed to realise that potential. • **Local businesses in the manufacturing sector** and **corporates with Agricultural Supply Chain** interest in the region have been identified as a stakeholder group with a strong interest in water resilience. • **Landowners/farmers** and the public are essential stakeholder groups that require further, targeted engagement in the next phase of work (Design Phase) to ensure the Programme serves their interests and takes their perspectives and challenges into consideration. This engagement will be the cornerstone to identify pilot sites with the greatest buy-in and impact potential.
Governance	• A **phased approach** should be applied to the structuring of governance for the Programme, to ensure both: (i) proper establishment in the start-up phase, and (ii) maturity to grow and scale NbS implementation. • An **Umbrella Agreement**, where partners collaborate under a shared vision outlined in a MoU (for example), may be a good way to formalise the partnership initially. But, this may soon be **too informal to provide**

	effective governance when the partners aim to co-finance and disburse meaningful sources of funding. A more structured and formal entity would likely be better suited to meet these objectives. • Detailed assessment during the Design Phase should **focus on determining whether a Hosted Programme and/or New Dedicated Vehicle** would be suitable legal and governance options to best support the delivery model.
Science Workstream	• There is a **significant opportunity across the Warwickshire Avon catchment to deliver Nature-based Solutions (NbS)**, particularly in low-productivity and riparian zones where implementation is both feasible and impactful. • **NbS can deliver measurable, multi-benefit outcomes –** including reductions in flood risk, improvements in water quality, enhanced water resource recharge, and biodiversity gains. • **Hydrological modelling reveals meaningful reductions in peak flood flows**, with up to 20% reductions observed in urban centres such as Leamington Spa, under realistic implementation scenarios. • **Strategic spatial targeting and smart NbS combinations are essential.** Modelling shows that the right mix of interventions in the right places can amplify benefits compared to ad hoc, unilateral or isolated delivery.
Cost-Benefit Analysis (CBA)	• NbS can deliver **meaningful net economic benefits** in the Warwickshire Avon catchment across **water, climate, biodiversity and livelihoods**. • The benefit-cost ratio (BCR) highlights a strong economic case for the Programme, demonstrating that for **every GBP 1 invested**, there is a **GBP 2.7 economic return** in benefits. • **Water Benefits** alone outweigh the costs to implement the Programme, in line with the Partners' vision of creating long-term **water resilience** in the catchment. • In reality, the Programme would deliver **greater net benefits**, as many potential outcomes were **not monetised** by the CBA (such as potential reductions in Combined Sewer Outflows, additional flooding benefits, wider economic benefits, fewer water abstraction licenses and water treatment cost savings). • **Early funding** can already unlock meaningful economic benefits such as reduced flood risk and improved water quality, while building **momentum** and confidence for **broader implementation** over time.
Funding	• The Programme aims to establish a coordinated, **long-term blended finance mechanism** combining public and private capital. Early-phase funding will rely on public and philanthropic sources to build a track record and de-risk medium-to long-term investments. • Evolving UK regulations, including Environmental Land Management schemes, Biodiversity Net Gain (BNG), and **nature markets**, create strong incentives for **private investment** in Nature-based Solutions (NbS). This

	is especially true in Warwickshire, which is considered a **national frontrunner** in this space. • Warwickshire has demonstrated early leadership in biodiversity offsetting and is now exploring multi-metric markets that integrate carbon, biodiversity, and water. • The Programme will begin with a start-up phase (first 3 years) to build governance, prioritise interventions, launch pilot projects, and develop a five-year implementation plan, paving the way for catchment-wide NbS rollout, which requires clarity of ownership, mature decision-making structures and implementation processes. • GBP 4.44 million is required now for the start-up phase, with GBP 300,000 already committed by the partners, through in-kind contributions. Over 70% of this funding will go towards implementing and maintaining initial projects, while the rest will support technical assistance, governance, and monitoring.

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Annex A. Stakeholders

1. Potential Funders

Other relevant nature finance actors that could be engaged moving forward:

Table 14: Potential funding sources

Organisation	Description
Investors and Funders	
Aviva	Large insurer and asset manager, active in nature-positive investing and a supporter of biodiversity finance innovation.
Defra	UK government department that funds environmental and nature-based projects through grants and policy tools.
Environment Agency Pension Fund	Leading public pension fund integrating ESG factors and a UK pioneer in natural capital investment.
Foresight	Investor in sustainable infrastructure and natural capital, including forestry and regenerative land use.
Gresham House	Specialist alternative asset manager investing in forestry, biodiversity net gain, and sustainable land use.
Royal London Asset Management	Institutional investor integrating natural capital and long-term environmental value into asset management.
M&G	Major UK investment manager with a growing interest in sustainable and impact investing, including natural capital.
Nettergal	Nature investment firm restoring degraded UK land for carbon, biodiversity, and water outcomes.
Triodos Bank	Ethical bank financing nature-based, regenerative, and social-impact projects.
UK Nature Impact Fund / Finance Earth	Investor in high-quality projects directed at the recovery of biodiversity across the UK.
Warwickshire Pension Fund	Local authority pension fund serving Warwickshire, with increasing interest in ESG-aligned and local nature recovery investments.
Nature Finance Models, Platforms, Intermediaries	
CreditNature	Platform developing nature credits based on ecological uplift, resilience, and habitat quality metrics.
Environment Bank	Delivers biodiversity net gain through habitat banking and the sale of biodiversity units.
Ent Trade	Digital marketplace for nature credits, supporting transactions in carbon, biodiversity, and nutrient neutrality.
Rebalance Earth	Platform connecting buyers with verified UK nature restoration projects for biodiversity and ecosystem service outcomes.
Regenerate Outcomes	Outcome-based financing structure supporting investment in measurable environmental and social results.
Tree App	Platform connecting nature credit buyers with sellers.

Wider Carbon	UK-based developer of woodland and peatland carbon projects, focused on high-integrity credits.
(Re)Insurance Sector	
Flood Re	National Re-insurer for flood risk in the UK.
Aviva	Large insurer and asset manager, active in nature-positive investing and a supporter of biodiversity finance innovation.
RSA Insurance	Insurance company with history of supporting water resilience initiatives.
Golf Courses	
Stoneleigh Deer Park GC	Stoneleigh, Next to River Avon
Warwickshire Golf Club (The)	Leek Wootton, Warwick
Leamington & County GC	Leamington Spa
Bidford Grange Hotel & GC	Bidford-on-Avon
Stratford Oaks GC	Near Stratford-upon-Avon
Welcombe Hotel & Golf Club	Stratford-upon-Avon
Feldon Valley GC	Banbury area
Atherstone Golf Club	North Warwickshire
Manufacturers	
Dennis Eagle	Based in **Warwick**, Dennis Eagle is a world-leader in the design and manufacture of refuse collection vehicles, producing over 1,000 units annually and holding a dominant UK market share.
Godiva Fire Pumps	Based near Coventry and Warwick, Godiva (with automotive heritage tied to Coventry Climax) manufactures fire pumps for emergency services. Their products are critical tools in flood response and rescue efforts.
Thwaites / Mecalac UK	Located in **Bedworth**, Thwaites manufactures site dumpers and construction equipment. Mecalac UK, its successor, has developed innovations such as the Revotruck, and operates from a highly sustainable, modern manufacturing facility in the Avon catchment area.
Bluecode / BPC / Leeson etc.	Engineering, chemical, and materials technology based out of Rugby, Welford, and Warwick.
Supply Chain Actors	
Britvic	Operates a major soft drinks factory in Rugby and has been growing the local site capacity recently which already employs 330 staff.
Pepsi-co - Walkers Snack Foods	Walkers is a producer of crisps and other snacks, owned by Pepsi-co. It has a factory in Coventry and several farms across Warwickshire.
Sainsbury's	Major UK Supermarket with supply chain interest in Warwickshire Avon.

Premier Foods – Manor Bakeries (Cadbury)	Large-scale food production within the Avon catchment.
Warwickshire Farming Clusters	Farm clusters are agricultural communities with an interest in catchment management.
Purity Brewing Company	Local independent brewery, with supply chain interest, based in Spernall.
Other small-scale breweries	Church Farm Brewery, Fosse Way Brewing Co., Fizzy Moon, are all small-scale breweries based around Lemington Spa.

2. List of Relevant Projects

Table 15: List of relevant projects

Location Catchment	Lead / Key Partner(s)	Project / Focus Area	Link / Source
Gloucestershire	Gloucestershire Wildlife Trust, RSA Insurance Group	Climate-resilient communities; insurance sector involvement	RSA – Climate Resilience
National / Various	Highways England	National NFM fund linked to infrastructure & roads	Highways England NFM Fund
River Soar	WWF, Aviva Insurance, Trent Rivers Trust	Natural Flood Management (NFM) initiatives	Natural Flood Management in the Soar
River Aire	Aire Resilience Company	Privately funded catchment resilience project	Aire Resilience Company
Wyre Catchment	Wyre Rivers Trust, Multiple Partners	NbS, NFM, blended finance model	Wyre NFM Project
Norfolk	Water Resources East (WRE)	Norfolk Water Strategy – long-term resilience and funding models	Norfolk Water Strategy

Annex B. Priority Mapping

3. Partner Priorities

Background | **Partners and Priorities**

Who are the partners we are mapping for?

Partner	Description	Key Priorities / Responsibilities
Severn Trent	Privatised water utility for the midlands region (Severn and Trent are rivers)	• Supply water to customers • Treat wastewater • Drainage in urban areas
Warwickshire Wildlife Trust	Charity delivering habitat improvement projects and campaigning for nature	• Deliver nature-based projects • Improve the state of nature through partnership and community work
Environment Agency	Regulator around water and the natural environment	• Monitor, investigate and regulate on waste, water quality and water quantity issues • Reduce flood risk on the regional level
Warwickshire County Council	Local government body, specifically the planning and nature recovery teams	• Ensure that development does not impact significantly on nature • Creating regional strategies for improving the state of local wildlife
Warwickshire County Council (LLFA)	Local government body, specifically the flood risk team	• Reduce flood risk on the local level • Provide protection for homes

Priority Mapping | **Flooding**

Background

What represents a priority area for working on WQ?

- “Small Communities at risk” – these are small communities which currently do not qualify for flood protection due to their size and the fact that limited amounts of houses or assets are exposed to flood risk. Interventions here are ofte deemed not cost beneficial, but if NbS could also provide WQ benefits, these may become cost beneficial through partnership funding.
- Areas with existing flood protection assets – delivery of NbS could help ensure the lifetime and function of existing infrastructure in these areas. If more water is stored upstream through NbS, this may improve asset functioning.

Partner priorities:

- Environment Agecy (EA) are responsible for managing flood risk originating from so-called “main rivers”. They invest in flood risk reduction projects that can mitigate the risk of flooding to communities at risk in these areas.
- Warwickshire County Council are the Lead Local Flood Authority (LLFA). This means that they are responsible for managing flood risk to properties generated by smaller water bodies or surface water flooding. As such, they are interested in protecting small communities at risk through a variety of schemes.

Priority Mapping | **Water Quality**

Background

What represents a priority area for working on WQ?

- Areas which are failing under Water Framework Directive (WFD) water body classifications, with the Reason for Not Achieving Good being related to WQ (Overall Pressure = Phosphate, Ammonia) and– these are based on monitoring data and show the overall health of the river. They are split into Bad/Poor/Medium/Good/Excellent, with everything below Good classified as “Failing”. This is the major driver for enforcement and the development of projects around WQ in most catchments.
- Areas with Combined Sewage Overflows problems– these are a big issue in the news in the UK. This happens because of sewerage and surface water drains being in the same system, with heavy rainfall leading to the discharge of raw sewage into rivers.

Partner priorities:

- Severn Trent priority = reducing the impact of their Wastewater Treatment works on the environment and stopping Combined Sewer Overflows discharging, this is achieved through their Water Industry and the Natural Environment Programme (WINEP) programme, which targets spending to address key issues
- EA priority = getting all WFD Water Bodies to “Good” status
- Several partners are aiming for bathing water status in some rivers. This requires a certain, consistent level of water quality to be maintained.

Priority Mapping | **Water Quantity**

Background

What represents a priority area for working on water quantity?

- Areas in which water resources are stressed due to over-abstraction from groundwater for public water supply or farming, leading to impacts on low-flows and breaches in environmental flow requirements (this is especially important in priority river habitats and their aquatic ecology)
- Water supply infrastructure which may be strained by environmental challenges or changes in water supply in the future

Partner priorities:

- Severn Trent priority = reducing the impact of their abstractions on water resources availability and the natural environment
- Environment Agency = maintaining environmental flow in rivers through regulating on abstractions from groundwater and surface water (for example reducing or revoking licences to abstract water, which are a necessity for all abstractions in the UK)

Priority Mapping | **Biodiversity and Ecosystems**

Background

What represents a priority area for biodiversity and ecosystems?

- Areas adjacent to or upstream of existing protected areas or Special Sites of Scientific Interest (SSSIs), with an aim of reducing impacts of pollution and water resources challenges on these sites. This is especially important for priority aquatic habitats.
- Priority areas for habitat expansion – areas close to existing habitats to improve the extent and connectivity of priority habitat sites.

Partner priorities:

- Warwickshire County Council are very interested in Biodiversity Net Game schemes –
- Severn Trent are interested in Nutrient balancing schemes – this relates to offsetting the impacts of development through creating interventions in the upstream catchment which reduce nutrient levels in runoff

Priority Mapping | **Planning and Economic Activity**

Background

What represents a priority area in a planning context?

- Development through the building of houses will lead to increased stress on the environment and water resources. A growing market is emerging in the UK to offset the impacts of development through providing improvements elsewhere. Example = Biodiversity Net Gain (BNG) mandates that a reduction in biodiversity from building on one site should be offset by improving biodiversity elsewhere (e.g. by creating forest or grassland from farmland).
- Catchments with high levels of planned development therefore represent an opportunity to deliver NbS which can help offset the impacts of this development upstream

Partner priorities:

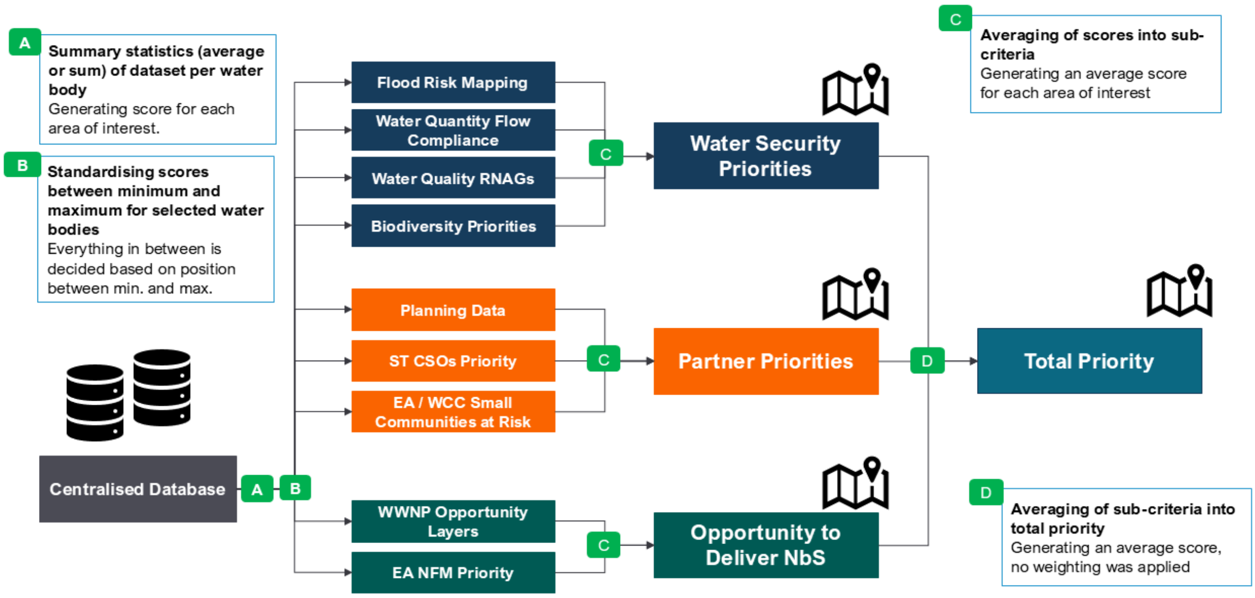
- Warwickshire County Council are very interested in Water Neutrality schemes – these look at offsetting extra water requirements ofnew housing or economic activity through creating nature-based schemes to encourage infiltration and increase water availability
- Severn Trent are interested in Nutrient balancing schemes – this relates to offsetting the impacts of development through creating interventions in the upstream catchment which reduce nutrient levels in runoff

4. Methodology and Datasets

Priority Mapping | **Datasets**

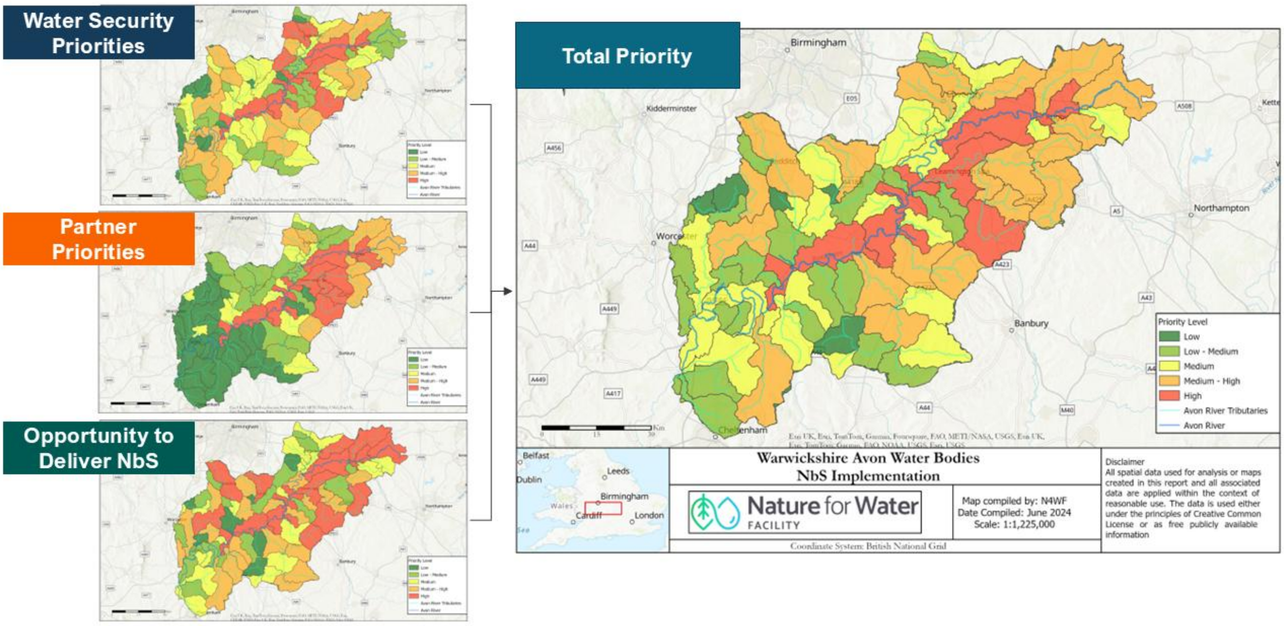
Major Categories	Minor Categories	Dataset	Link
Context	Catchment Area	EA River Water Body catchments	https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3007/shapefile.zip
1. Water Security Priorities	Flood Risk	%age of catchment under 1 in 100 year SW hazard	https://environment.data.gov.uk/dataset/b5aaa28d-6eb9-460e-8d6f-43caa71fbe0e
		%age of catchment under 1 in 100 year river flooding hazard	https://environment.data.gov.uk/dataset/96ab4342-82c1-4095-87f1-0082e8d84ef1
		Flood reports	Provided by partners
	Water Resources	EA Flow compliance	https://environment.data.gov.uk/dataset/071276a7-b067-449b-97b0-7654553aaaef
	Water Quality	Nitrates / Eutrophic rivers	https://environment.data.gov.uk/dataset/6f14d861-d465-11e4-b5b7-f0def148f590
		RNAGs for Phosphates	https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3007/classifications
	Ecosystems	Priority Ecosystems	https://environment.data.gov.uk/dataset/626d5050-7f3e-48ed-a68f-8b8e90d02a3e
2. Partner Priorites	Communities at risk	EA C@R dataset	Provided by partners
	Severn Trent infrastructure investment	ST dataset	Provided by partners
	Severn Trent priority CSOs	ST CSO dataset	Provided by partners
	ST Catchment Nutrient Balancing	ST CNB dataset	Provided by partners
	Planned development	Planning datasets (MERGE ALL)	Provided by partners
3. Opportunity to deliver NbS	Land management	WWNP Datasets	https://environment.data.gov.uk/dataset/38946802-13a2-4d80-8486-742eccff191d
	Woodland creation	WWNP Dataset	https://environment.data.gov.uk/dataset/7b6c23f0-200e-453d-b3f9-1ace36974bce

Priority Mapping | **Methodology Overview**

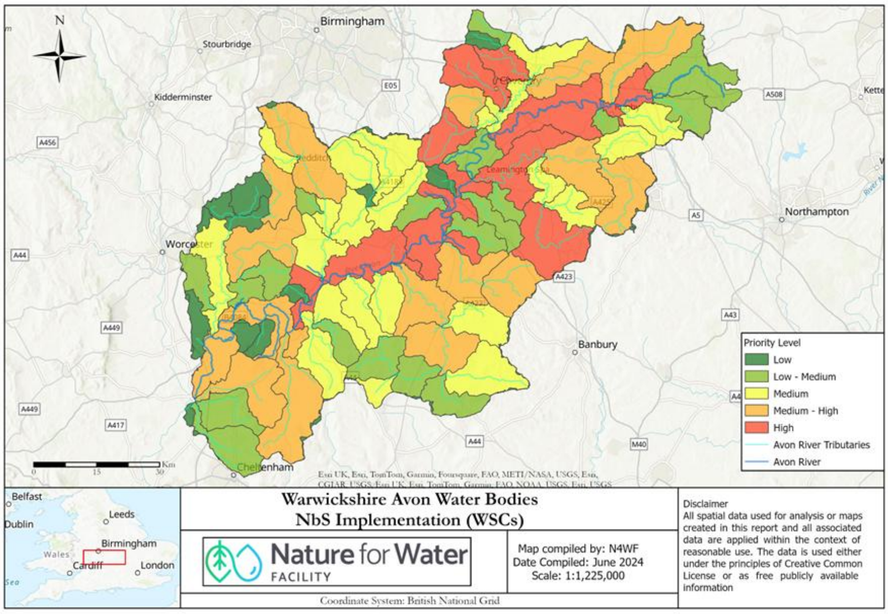


5. Results

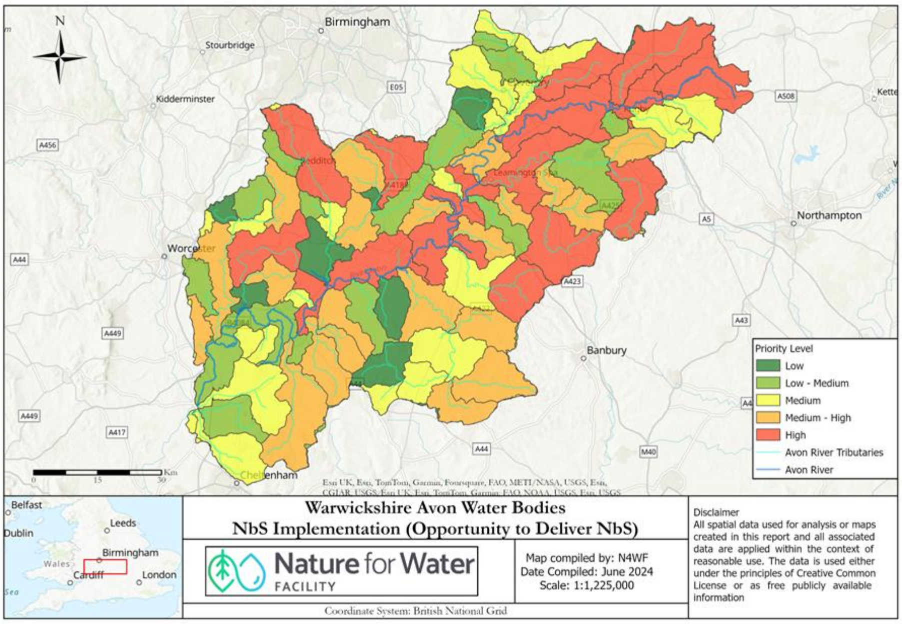
Priority Mapping | **Results**



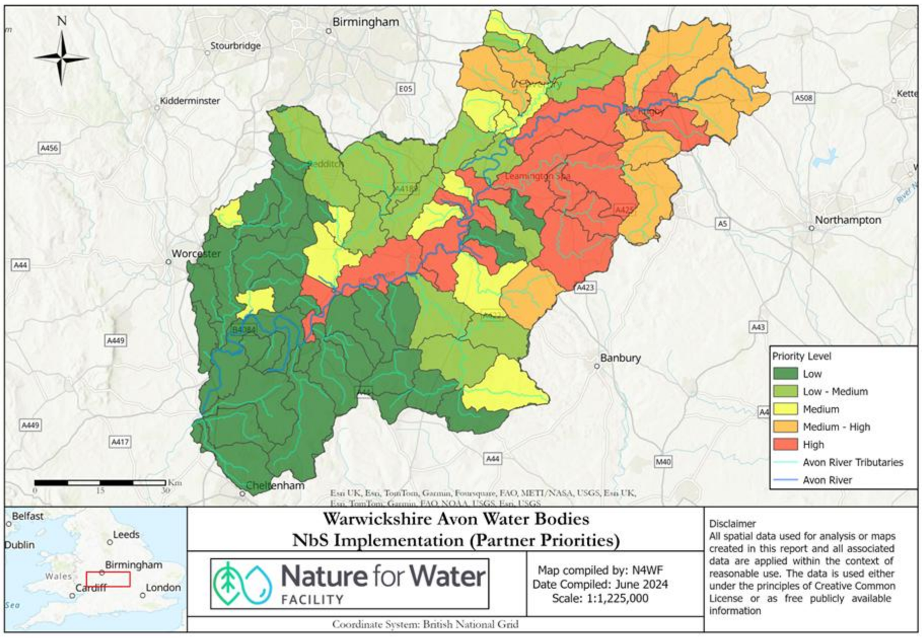
Priority Mapping | **Water Security Challenges**



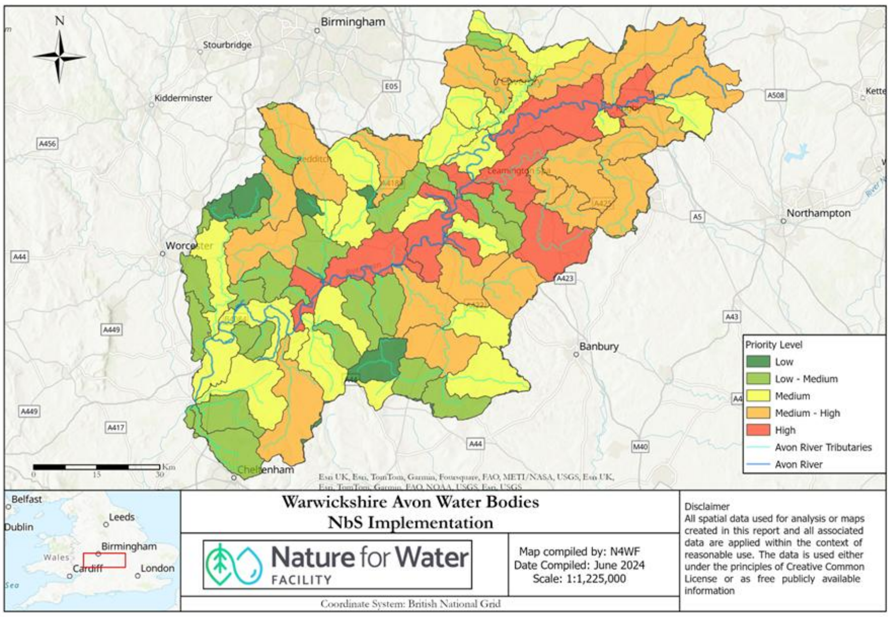
Priority Mapping | **Opportunity to Deliver NbS**



Priority Mapping | **Partner Priorities**



Priority Mapping | **Total Priority**



Annex C. Opportunity Mapping

6. NbS Options

NbS Mapping | **NbS Definition**

What are most suitable NbS options to deliver maximum impact at a catchment scale

Pond/Pool/Scrape Creation:

- Water retention features of different sizes that store water (typically about 5m x 10m)
- Ponds retain water all year round, whilst pools and scrapes can dry out.
- 10-20m buffer zone around ponds/scrapes to protect from agricultural inputs.
- May require fencing if on agricultural land.
- ***Maintenance:*** Every 5 years, to remove excess vegetation.

Leaky Barriers:

- Constructed timber features designed to intercept and attenuate overland flows and in channel flows. 5 leaky barriers cover around 500 sqm of land.
- Can be designed to store water for irrigation purposes and habitat creation.
- ***Maintenance:*** Occasional, whenever there is insufficient natural wood supply, if sedimentation occurs upstream of the barrier or after high flows.

Floodplain Reconnection:

- Establishing pathways between watercourses and floodplains to increase water storage capacity, while providing additional habitat, reduced soil erosion and improved water quality.
- ***Maintenance:*** Periodically for invasive species removal, renewed excavation or dredging of excess sediments, grazing management and inspection after heavy rains.

NbS Mapping | **NbS Definition**

What are most suitable NbS options to deliver maximum impact at a catchment scale

Riparian Buffer Strips:

- Integrated system of plantings and landscaping measures in riparian areas to better intercept agricultural pollution from atmospheric, surface and subsurface pathways. It also provides biodiversity benefits by creating habitats. One buffer strip covers around 600 sqm.
- ***Maintenance:*** 1-2 years (control of invasive species, and reuse or disposal, vegetation harvesting).

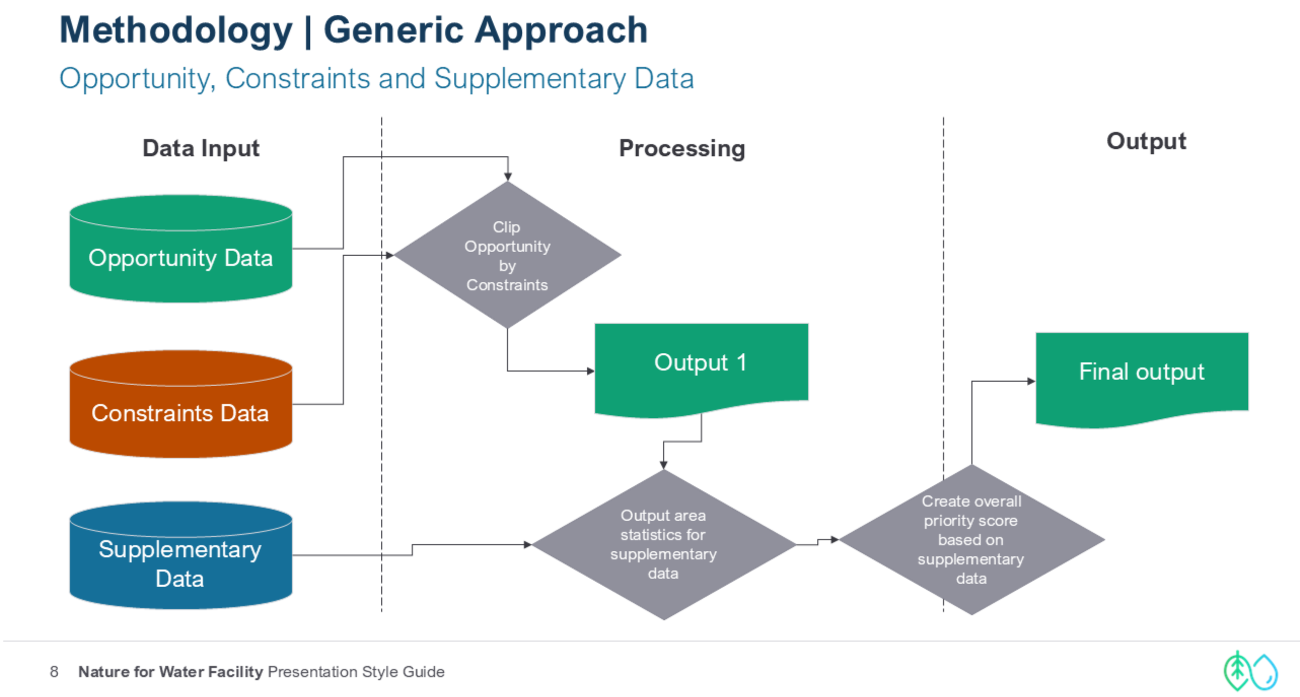
Woodland and Tree Planting:

- Increasing tree cover in an area (we consider 2500 trees/hectare) to reduce flood risk and surface runoff by promoting soil infiltration, intercepting water and increasing ground roughness.
- Trees can also enhance biodiversity and constitute carbon sinks.
- ***Maintenance***: Annually in first five years (watering, fertilizing, weed control).

Bunds:

- Small earth embankments typically constructed across slopes or flow pathways to **store and slow overland water**. Help **reduce peak runoff**, promote **infiltration**, and **trap sediment and nutrients**.. Particularly effective in **moderate to steep landscapes** with concentrated surface flows.
- *Maintenance:* Periodic inspection for erosion or blockages, especially after storms; vegetation management may be required annually.

7. Generic Approach



8. Creating a Constraints Layer

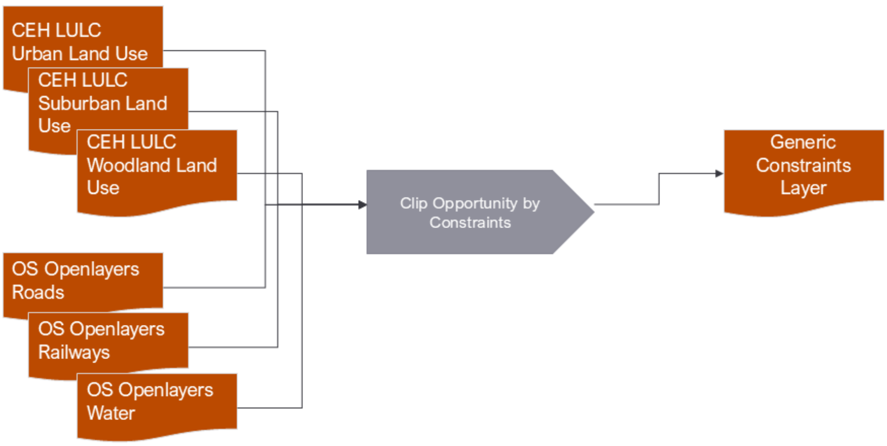
Constraints Data

Identifying areas where we shouldn't implement NbS

Dataset	Description	Link
Corine 2012 LULC Urban Land Use	Land use mapping of urban areas	https://land.copernicus.eu/en/products/corine-land-cover
Corine 2012 LULC Peat Land Use	Land use mapping of areas of peat	As above
Corine 2012 LULC Woodland Land Use	Land use mapping of areas of broadleaved woodland	As above
OS Openlayers Roads (10m buffer)	Roads	https://www.ordnancesurvey.co.uk/products/os-open-zoomstack
OS Openlayers Railways (20m buffer)	Railway lines	As above
Source Protection Zone 1 + 2 (No Infiltration Area)	Drinking water protection (can't change infiltration)	

Creating Generic Constraints Data

Methodology: Combining Datasets



9. NbS Mapping

NbS Mapping | **Pond/Pool/Scrape Creation**

Flow Pathways

What are opportunities and constraints?

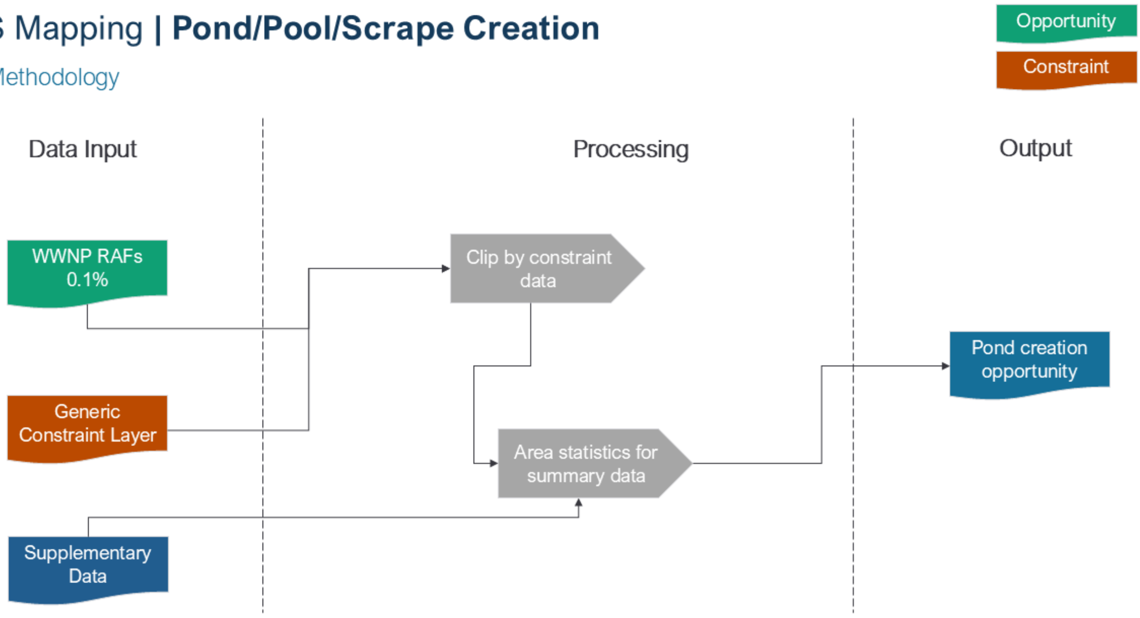
Description:
- Water retention features of different sizes that store water (typically about 5m x 10m)
- Ponds retain water all year round, whilst pools and scrapes can dry out.
- 10-20m buffer zone around ponds/scrapes to protect from agricultural inputs.
- May require fencing if on agricultural land.
- ***Maintenance:*** Every 5 years, to remove excess vegetation.

Opportunity Data:

Dataset	Description	Link / Folder
WWNP RAFs 0.1%	Working with Natural Processes layer identifying isolated areas of runoff accumulation	https://environment.data.gov.uk/dataset/fc69965f-684f-463d-b7c9-2471a5d49741

NbS Mapping | **Pond/Pool/Scrape Creation**

GIS Methodology



Flow Pathways

NbS Mapping | **Bunds / Catchment Storage Areas**

What are opportunities and constraints?

Description:

- Water retention features perpendicular to runoff pathways that store water (typically 0.5m depth)
- ***Maintenance:*** Every 5 years, to remove silt and vegetation

Opportunity Data:

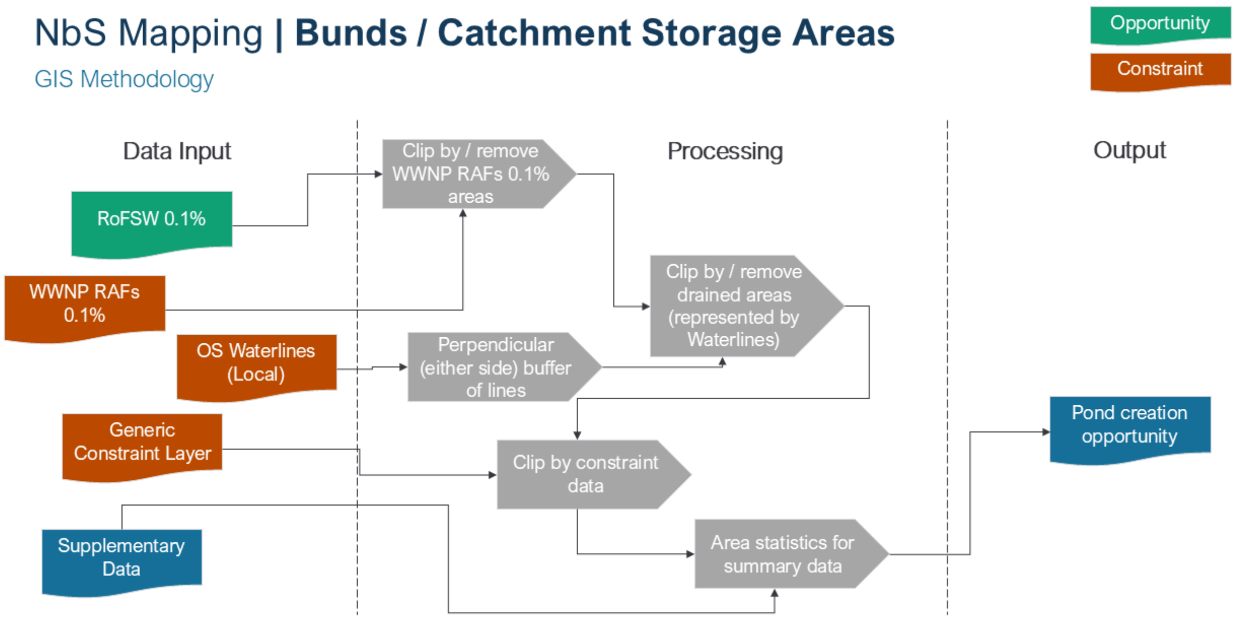
Dataset	Description	Link / Folder
RoFSW 0.1%	EA's mapping of Flooding from Surface Water Extent 1 in 100 yr (proxy for flow accumulation)	https://environment.data.gov.uk/dataset/b5aaa28d-6eb9-460e-8d6f-43caa71fbe0e

Constraint Data:

Dataset	Description	Link / Folder
WWNP RAFs 0.1%	Working with Natural Processes layer identifying isolated areas of runoff accumulation	https://environment.data.gov.uk/dataset/fc69965f-684f-463d-b7c9-2471a5d49741
OS Waterlines (Local)	Ordanance Survey mapping of waterways, specifically those features identified as "local" – these usually represent ditches and drainage features	https://environment.data.gov.uk/dataset/0608e0cf-803f-4e0e-b8ab-6f783aa05f33

NbS Mapping | **Bunds / Catchment Storage Areas**

GIS Methodology



In-Channel

NbS Mapping | **Leaky Barriers**

What are opportunities and constraints?

Description:

- Constructed timber features designed to intercept and attenuate overland flows and in channel flows. 5 leaky barriers cover around 500 sqm of land.
- Can be designed to store water for irrigation purposes and habitat creation.
- ***Maintenance:*** Occasional, whenever there is insufficient natural wood supply, if sedimentation occurs upstream of the barrier or after high flows.

✔ **Opportunity Data:**

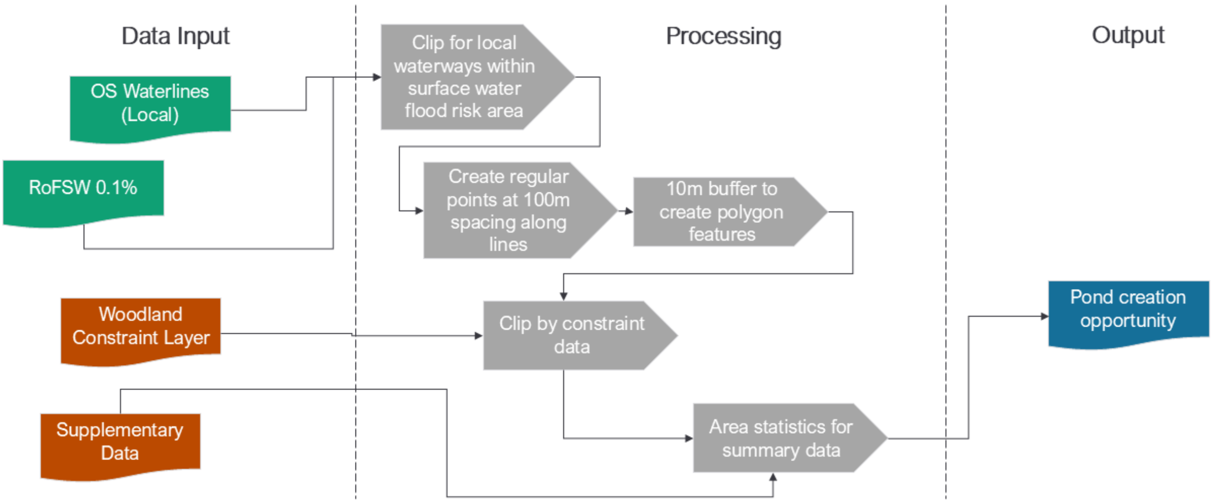
Dataset	Description	Link / Folder
OS Waterlines (Local)	Ordanance Survey mapping of waterways, specifically those features identified as "local" – these usually represent ditches and drainage features	https://environment.data.gov.uk/dataset/0608e0cf-803f-4e0e-b8ab-6f783aa05f33
RoFSW 0.1%	EA's mapping of Flooding from Surface Water Extent 1 in 100 yr (proxy for flow accumulation)	https://environment.data.gov.uk/dataset/b5aaa28d-6eb9-460e-8d6f-43caa71fbe0e

NbS Mapping | **Leaky Barriers**

GIS Methodology

Opportunity

Constraint



In-Channel

NbS Mapping | **Floodplain Reconnection and Restoration**

What are opportunities and constraints?

Description:

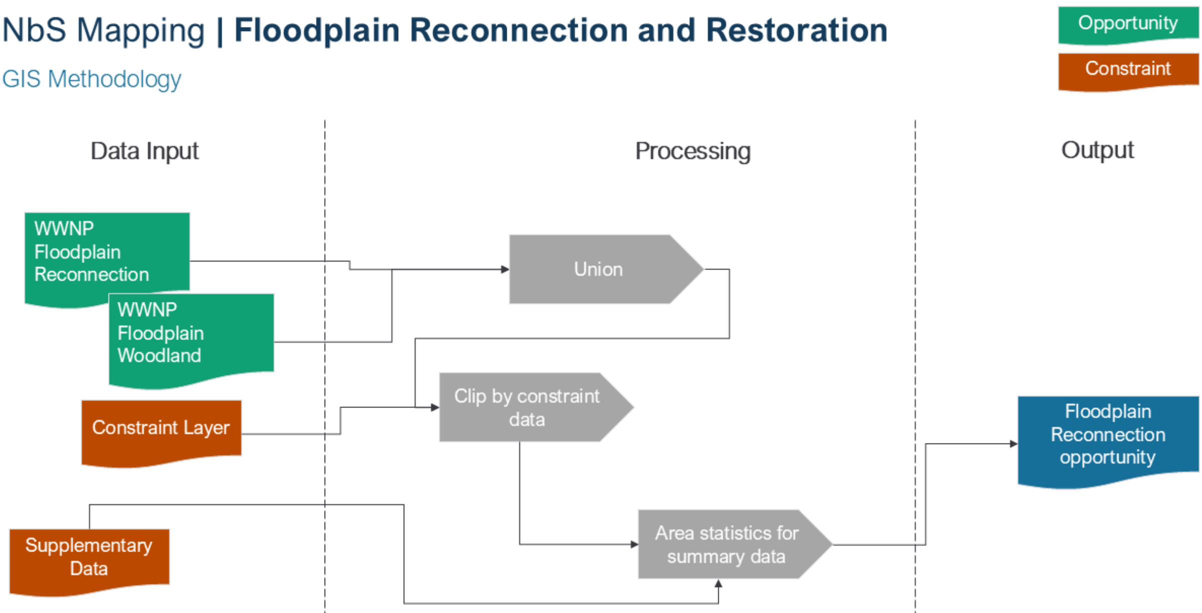
- Establishing pathways between watercourses and floodplains to increase water storage capacity, while providing additional habitat, reduced soil erosion and improved water quality.
- ***Maintenance:*** Periodically for invasive species removal, renewed excavation or dredging of excess sediments, grazing management and inspection after heavy rains.

Opportunity Data:

Dataset	Description	Link / Folder
WWNP Floodplain Woodland Potential	Working with Natural Processes layer identifying areas for planting trees in the floodplain	https://environment.data.gov.uk/dataset/d1b028b8-6090-4621-8645-034f01b32403
WWNP Floodplain Reconnection Potential	Working with Natural Processes layer identifying areas of opportunity for floodplain reconnection	https://environment.data.gov.uk/dataset/e92e50e6-d2c5-4ae7-b824-138e0da0b554

NbS Mapping | **Floodplain Reconnection and Restoration**

GIS Methodology



NbS Mapping | **Riparian Buffer Strips / Restoration**

Edge-of-Field

What are opportunities and constraints?

Description:

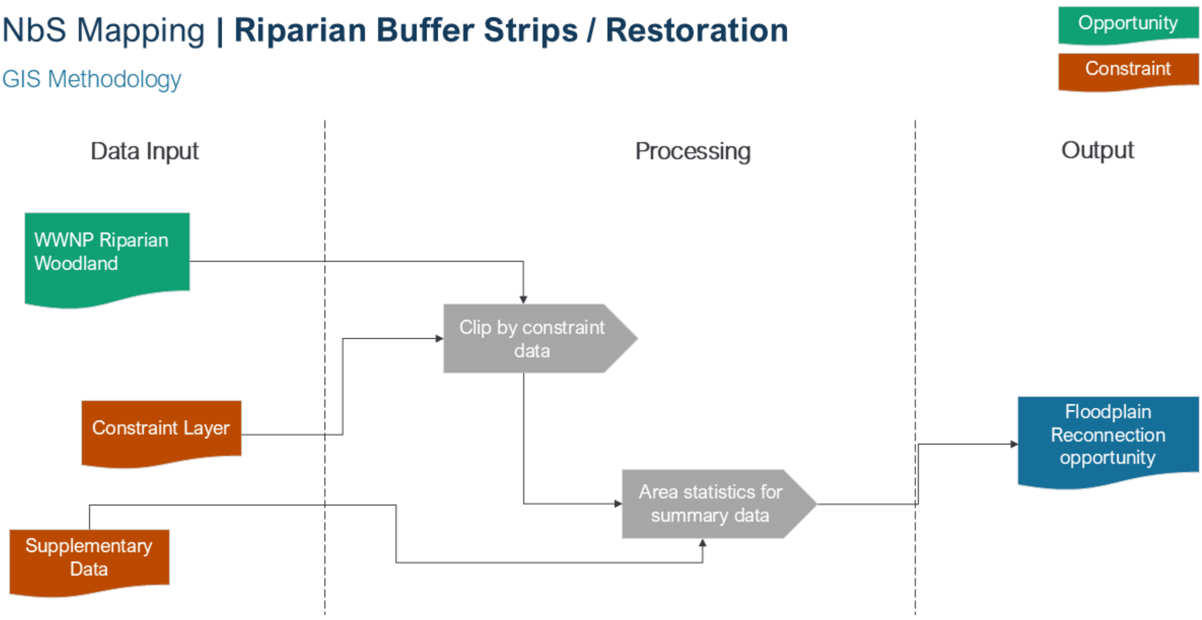
- Integrated system of plantings and landscaping measures in riparian areas to better intercept agricultural pollution from atmospheric, surface and subsurface pathways. It also provides biodiversity benefits by creating habitats. One buffer strip covers around 600 sqm.
- ***Maintenance:*** 1-2 years (control of invasive species, and reuse or disposal, vegetation harvesting).

Opportunity Data:

Dataset	Description	Link / Folder
WWNP Riparian Woodland Potential	Working with Natural Processes layer identifying areas of opportunity for riparian planting	https://environment.data.gov.uk/dataset/960926b5-84e7-45f0-a38f-8ef58004820e

NbS Mapping | **Riparian Buffer Strips / Restoration**

GIS Methodology



NbS Mapping | **Woodland and Tree Planting**

In-Field

What are opportunities and constraints?

Description:

- Establishing pathways between watercourses and floodplains to increase water storage capacity, while providing additional habitat, reduced soil erosion and improved water quality.
- ***Maintenance:*** Periodically for invasive species removal, renewed excavation or dredging of excess sediments, grazing management and inspection after heavy rains.

Opportunity Data:

Dataset	Description	Link / Folder
England Woodland Creation Sensitivity	Forestry commission maps of the relative sensitivity of woodland creation	https://environment.data.gov.uk/dataset/607b4b94-1e07-43ee-b79d-524010a848b1
WWNP Wider Catchment Woodland Potential	Working with Natural Processes layer identifying areas of opportunity for floodplain reconnection	https://environment.data.gov.uk/dataset/7b6c23f0-200e-453d-b3f9-1ace36974bce

10. Supplementary Data

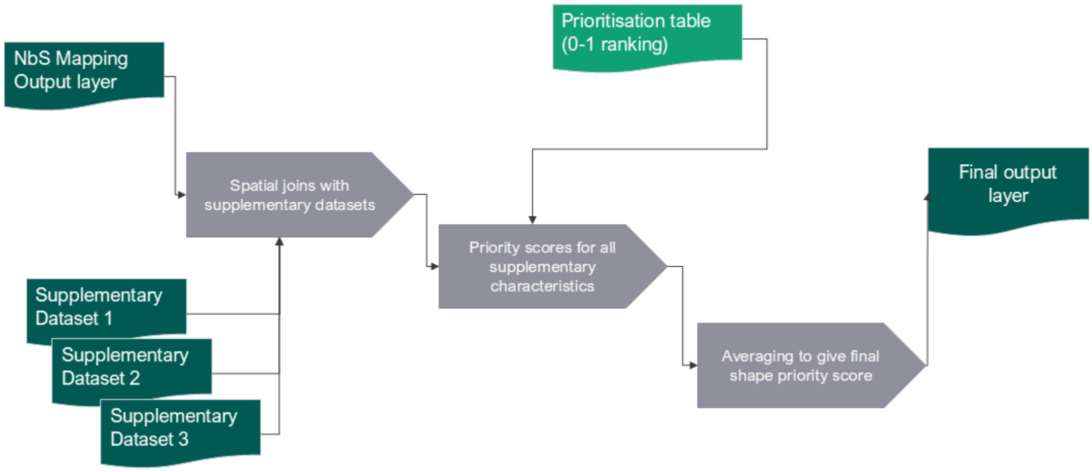
Supplementary Data

Data to attach to output shapefiles

Dataset	Description	Link
ALC Agricultural Grade	Priority agricultural land for food production	https://www.data.gov.uk/dataset/c002ceea-d650-4408-b302-939e9b88eb0b/agricultural-land-classification-alc-grades-post-1988-survey-polygons
EA NbS Infiltration Class	1-5 score of ability to infiltrate water from EA prioritisation tool	https://environment.maps.arcgis.com/apps/webappviewer/index.html?id=91202d8f6e3947689dc1c74b9fdd078f
Priority Habitat Area	Natural England Habitat Networks Combined – Subsetted for the following classes: Fragmentation Action, Habitat Restoration, Network Enhancement, Network Expansion, Restorable Habitat, SSSI	https://environment.data.gov.uk/dataset/626d5050-7f3e-48ed-a68f-8b8e90d02a3e
Soil Group	Soil texture / type listed ranked from heavy to light	https://www.bgs.ac.uk/datasets/soil-parent-material-model/
Baseline Landuse	CEH land use mapping, with existing arable / improved grassland taken as priority	https://environment.data.gov.uk/dataset/b4539897-c13f-4f14-b683-52654d5d8aec
Woodland Creation Sensitivity	Forestry commission maps of the relative sensitivity of woodland creation	https://environment.data.gov.uk/dataset/607b4b94-1e07-43ee-b79d-524010a848b1

Creating Generic Constraints Data

Methodology: Adding Supplementary Stats



Annex D. HEC-HMS Model Setup

Note: Although this annex describes setup of both a continuous and event-based model in HEC-HMS, only the event-based model was taken forward for creation of the business case due to a relatively low performance in calibration of the continuous simulation model. This model could be re-adopted in future iterations of this work given more time and resources, but for this phase it was deemed more appropriate to use a simpler conceptualistion to simulate water resources dynamics (as detailed in Annex E).

11. Background

D 1.1. Scientific Site Description

Opportunity mapping that was done above has highlighted that the Leam Itchen and UpperAvon Swift Water Bodies have the highest priorities in terms of needing interventions. The Leam Itchen Water Body is situated within the West Midlands and southeastern Warwickshire region. The catchment spans a largely rural area, characterized by a mix of agricultural lands, scattered urban centers, and natural woodlands (British Geological Survey, 2025; Environmental Agency, 2020). The water body displays mixed flow regimes, heavily influenced by precipitation patterns and the underlying geology.

Landcover

The landcover information utilized in the study was obtained from the Land Cover Map 2023 (LCM2023) is a comprehensive suite of geospatial datasets developed by the UK Centre for Ecology & Hydrology (UK CEH). It provides a detailed and accurate representation of the land surface across the United Kingdom for the year 2023. The dataset includes both raster and polygon formats, allowing for a range of applications in environmental monitoring, land-use planning, and ecological research.

The LCM2023 was produced by classifying satellite imagery captured during the year 2023. The primary sources of these satellite images are high-resolution sensors capable of capturing multi-spectral data across various bands of the electromagnetic spectrum. These images enable the differentiation of land cover types based on their spectral signatures. The satellite data were complemented by ground truthing and ancillary datasets to enhance the classification accuracy. The integration of remote sensing and ground-based data ensures that the final dataset reflects the actual land cover conditions on the ground. This landcover dataset is one of the most up-to-date representations of land cover in the UK. Its temporal relevance is critical for tracking recent changes in land use, such as urban expansion, deforestation, or agricultural shifts. The present day landcover that exists across both respective sub-water bodies is presented in Figure 29.

A summary of the present landcover classes across each sub-water body is presented in Table 16. It is evident that both catchments are dominated by agricultural land, with Improved Grassland and Arable Land making up the majority of the land cover. These classes highlight the significance of farming and grazing in the regional land-use patterns. The Leam Water Body has more natural vegetation and lower urban influence, while the UpperAvon Swift Water Body shows higher levels of urban and suburban development. Minor land cover classes, such as Woodlands, Freshwater, and Inland Rock, contribute minimally to the overall composition but may still hold ecological significance.

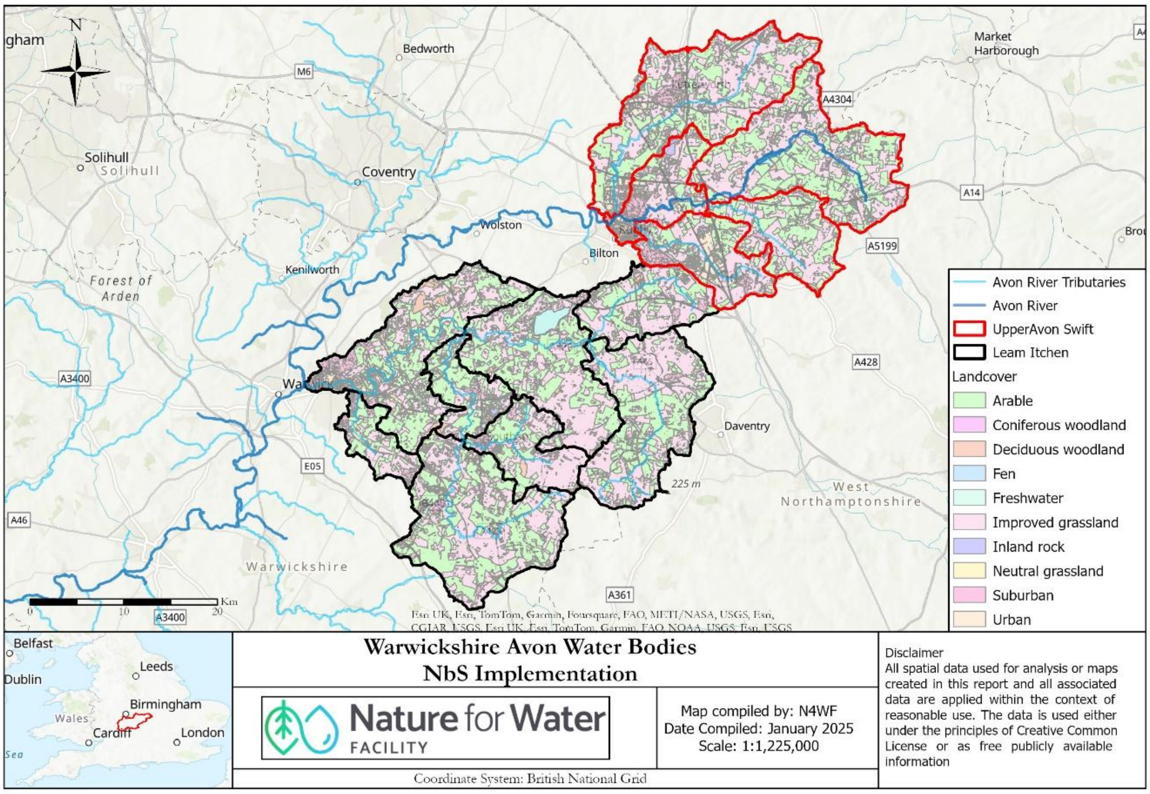


Figure 29: Landcover Classes Across both Water Bodies

Table 16: Area Weighted Landcover Classes

Land Cover Class	Leam Itchen Water Body		UpperAvon Swift Water Body	
	Area (km²)	**Weighted Area**	**Area (km²)**	**Weighted Area**
Deciduous woodland	15.0	4.1%	8.7	3.6%
Coniferous woodland	0.7	0.2%	0.4	0.1%
Arable	145.8	39.9%	90.3	36.8%
Improved grassland	166.2	45.5%	115.0	46.9%
Neutral grassland	5.4	1.5%	0.0	0.0%
Fen	0.0	0.0%	0.0	0.0%
Inland rock	0.5	0.1%	0.9	0.4%
Freshwater	3.9	1.1%	1.8	0.7%
Urban	6.6	1.8%	12.3	5.0%
Suburban	21.1	5.8%	16.1	6.5%
Total	**365.2**	**100%**	**245.5**	**100%**

Soils Information

The soils information for the respective sub water bodies was obtained from the UKSO (UK Soil Observatory) soils dataset which is a comprehensive resource that provides detailed information about the soils of the United Kingdom. It is designed to support environmental research, land-use planning, and agricultural decision-making by offering accessible and high-resolution data on soil properties. One of its key components is the 1:50,000 soil texture information, which provides spatially detailed information about the proportions of sand, silt, and clay in soils, which are critical factors influencing soil behaviour.

Soil texture affects a wide range of properties, such as water retention, permeability, fertility, and susceptibility to erosion. This makes the dataset invaluable for various applications, including agricultural planning, hydrological modeling, and climate adaptation strategies. The dominant soil textures identified across both the water bodies in study, includes clay loam to silty loam soils and clay to clayey loam soils. Sandy to sandy loam soils are also present across both water bodies, but to a lesser extent.

D 1.2. Science Analysis and Approach

Hydro-Climatic Information Gathering

The following sub-chapters provide details on the data collection process.

Streamflow Data

The main source of streamflow data for the study was from the Department for Environment, Food & Rural Affairs (DEFRA) Hydrology Data Explorer in the UK, which provides detailed and high-quality hydrological data. The streamflow data is primarily collected from a network of gauging stations managed by the Environment Agency (EA) in England. The streamflow gauges used in this study were selected based on their reliability in terms of record length and limited missing data. Streamflow gauges that had more than 15% of missing data and less than 25 years of record length were not considered for the analysis. As presented in Table 17, the catchment areas pertaining to the respective gauges vary greatly, ranging from 110 km^2 to 362 km^2. The location of the streamflow gauges used in this assignment are presented in Figure 5 1. These gauges provided hydrological data for a wide range of catchment areas, which was beneficial for the hydrological analysis undertaken.

Table 17: Streamflow Gauge Data Obtained from the EA

Station ID	Station Name	Record Period	Record Length (Hydrological Years)	Catchment Area (km^2)
Leam Itchen Water Body				
2049	Leamington	1979 - 2024	45	362
UpperAvon Swift Water Body				
2088	Lilbourne	1998 -2024	26	110
2090	Rugby	1988 - 2024	35	246

Meteorological Data Availability Assessment

In order to apply deterministic methods of design flood estimation and for continuous simulations, design rainfall is required as an input variable and historical rainfall is required for model calibration. Design rainfall attributes a particular rainfall depth with a calculated recurrence interval, and is based on statistical analysis of recorded daily or hourly rainfall values. The availability of detailed rainfall data for extended record periods is, therefore, imperative for the estimation of design rainfall values. Based on an assessment of the available rainfall data from the EA, two rainfall stations were identified across both water bodies in study.

A summary of the rainfall stations and a description of the details of the respective stations is presented in Table 18. The stations' summary shows variations of their elevations, period of record, years of data and locations. The respective locations of these rainfall stations can be cross-referenced to the map presented in Figure 30.

Table 18: Rainfall Station Information

Station ID	Name	Elevation	Record Period	Years Data	Latitude (°)	Longitude (°)
450263	Braunston	96	1981 - 2024	43	52.2810964°N	1.2253757°W
1155	Stanford	112	1982 – 2024	42	52.4161688°N	1.1243132°W

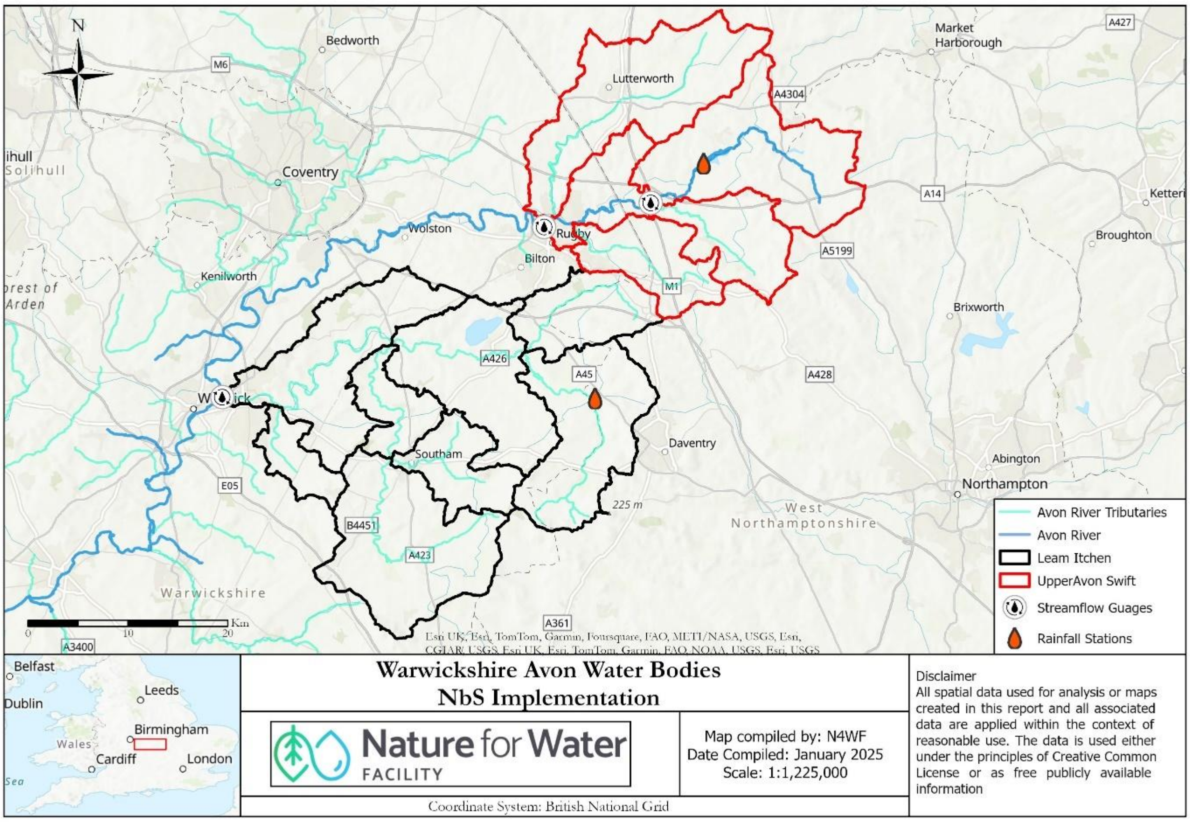


Figure 30: Location of Meteorological Stations Assessed in the Study

Design Rainfall Estimation

As mentioned above, number of design flood estimation methods require design rainfall as an input variable. Therefore, in order to facilitate application of a range of methods for design flood analysis, design rainfall depths were estimated for the two stations presented in Table 19 and Figure 30. For design rainfall analysis, the Annual Maximum Series (AMS), which is the maximum recorded rainfall depth across a hydrological year, was extracted from the historical rainfall timeseries at each station. Thereafter, a number of probability distributions were fitted to the AMS using L-moments (Hosking, 1990), including the following distributions:

- log-Normal (LN)
- 3-parameter LN (LN3)
- log-Pearson Type 3 (LP3)
- log Gumbel (L-EV1)
- Gumbel (EV1)
- Extreme Value Type 3 (EV3)
- General Extreme Value (GEV)

- Generalised Pareto (GPA)
- Pearson Type 3 (PE3)
- Wakeby (WAK)

Based on the goodness of fit analysis, the GEV distribution was selected as the best distribution of AMS for each of the respective stations, and was therefore used to estimate design rainfall for 1 to 7 day durations, for return periods from 2 to 100 years (shown by different colours) as presented in Table 19.

Table 19: Design Rainfall Estimates for the 1-Day Rainfall Event

Duration (days)	Rainfall (mm)								
	2	5	10	20	50	100	200	500	1000
Braunston Station									
1	30	41	50	59	73	85	98	117	134
Stanford Station									
1	28	37	43	50	59	66	74	85	93

Observed Design Peak Discharge Estimation

Observed flood data provides a reliable baseline for understanding the frequency and magnitude of extreme events, which is crucial for calibration and validation of hydrological models (Peel, 2011). Observed design flood estimates rely on historical streamflow data, specifically the peak flow values recorded during significant flood events (Peel, 2011). Many flood estimation methods, such as rainfall-runoff modeling or regional flood frequency analysis, require accurate estimates of peak flows to ensure the design is resilient against extreme hydrological events. These estimates are derived using statistical analysis of the Annual Maximum Series (AMS), which consists of the highest recorded discharge for each hydrological year at a given gauging station. To analyze the AMS, a range of probability distributions is fitted to the data to model the statistical behavior of extreme events.

The probability distribution fitting process typically follows the same process as mentioned in Section 5.1. Based on goodness of fit the analysis, the GEV distribution was selected as the best distribution of AMS for each of the respective stations, and was therefore used to estimate design rainfall for 1 to 7 day durations, for return periods from 2 to 100 years (shown by different colours) as presented in Table 5 3, as shown in Figure 5 2.

Table 20: Observed Design Peak Discharge Estimates for the Streamflow Gauging Stations in Study

Station ID	Name	Peak Discharge ($m^3.s^{-1}$)								
		2	5	10	20	50	100	200	500	1000
Leam Itchen Water Body										
2049	Leamington	27	41	52	65	85	104	125	160	191
UpperAvon Swift Water Body										
2088	Lilbourne	10	14	16	19	22	24	26	30	32
2090	Rugby	24	38	49	60	75	88	101	121	137

Climate Change Analysis

Climate change is expected to increase the frequency and intensity of extreme rainfall events, leading to more frequent and severe flooding. Consequently, design flood estimates must consider potential increases in flood peak discharge rates and volumes driven by these changes in rainfall extremes. The anticipated rise in storm intensity and magnitude is likely to result in elevated runoff and higher flood peaks, necessitating more robust design standards. This underscores the importance of integrating climate projections into the design of Nature-based Solutions (NbS). By considering the projected changes in rainfall and flood behavior due to climate change, NbS can be effectively designed to complement traditional engineering solutions, ensuring sustainable and adaptive flood management in the face of uncertain future conditions.

The UK Climate Projections (UKCP) was used to source information on projections of climate change across the project areas. Projections of future climate scenarios are based on climate data from multiple reputable sources, this includes global climate models (GCMs), regional climate models (RCMs), and specific greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC). The IPCC's Fifth Assessment Report (AR5) introduced four Representative Concentration Pathways (RCPs) which provide a framework for understand how human activities, particularly green house gas emissions and land-use changes, might influence the climate system over the 21st century and beyond. For this assignment RCP 8.5, representing a high emissions "business as usual" scenario with no significant mitigation measures, resulting in rapid and continuous growth in greenhouse gas concentrations, was used. Only the 90th percentile 1-day total precipitation was considered for modelling purposes.

A subset of daily rainfall time series data is was obtained as absolute values from local (5 km grid) projections for the required RCP 8.5 for the medium-term period of 2025-2050. Only the 90th percentile time series was considered, which was applied for the continuous simulations. Probabilistic projections of climate extremes for rainfall depth was also utilized from the UKCP, this data is available as absolute future values for a given emissions scenario, return period (20, 50 and 100-year), specific season, time range and grid cell. The absolute extreme rainfall values are only available at 25 km grid squares, the summer season was selected for medium-term period of 2025-2050. The extreme rainfall values for the available respective return periods is presented in Table 21.

Table 21: Climate Change Projected Design Rainfall Estimates

Duration (days)	Rainfall (mm)		
	20	**50**	**100**
Braunston Station			
1	60.56	74.40	85.56
Stanford Station			
1	51.35	60.58	67.93

12. Modelling Approach

This section provides a comprehensive overview of the hydrological modelling approach employed in the study, detailing the selection of the hydraulic model, its underlying requirements, and the configuration process, including specific considerations for Nature-based Solutions (NbS). The hydraulic model serves as a critical tool in simulating hydrological processes, enabling a robust understanding of flow dynamics, flood risk, and the impact of various management interventions.

The configuration process is outlined to ensure that the model accurately represents the study area's physical and hydrological characteristics. Special emphasis is given to the integration of NbS, which aims to leverage natural processes to mitigate environmental hazards, improve water management, and enhance ecosystem resilience. A description of the model's performance is provided, including the performance assessment metrics used to evaluate its predictive accuracy. The calibration and validation processes are discussed in detail, highlighting the methods and data sources employed to optimize the model's parameters and ensure its reliability in representing real-world conditions. Calibration involves adjusting model parameters to minimize discrepancies between simulated results and observed data, while validation further tests the model’s predictive capability against independent datasets.

Finally, the report presents the model's application across different scenarios, including baseline or present-day conditions, projected climate change impacts, and the incorporation of NbS strategies. These scenarios allow for an assessment of future hydrological dynamics, providing valuable insights into the effectiveness of NbS in addressing climate variability and fostering sustainable water management solutions. Through these processes, the model serves as an essential tool for informed decision-making and planning in the context of climate resilience and environmental protection.

D 1.3. HEC-HMS Model Selection

The Hydrologic Engineering Center – Hydrological Modeling System (HEC-HMS), created by the US Army Corps of Engineers, is a renowned hydrological semi-distributed tool for simulating rainfall-runoff processes. It stands out in hydrological modelling due to its relatively minimal input requirements compared to other physically based models, making it adaptable for diverse case studies globally (Choudhari et al., 2014; Sahu et al., 2023). This study utilizes HEC-HMS primarily because it is well-documented and has proven effective for assessing runoff, infiltration, and peak discharge dynamics (Agarwal et al., 2024; Halwatura and Najim, 2013). Adjustments to parameters such as the curve number (CN) and percentage of impervious surfaces, alongside the integration of elements such as reservoirs, allow it to simulate the influence of NbS like ponds and leaky barriers.

Moreover, the HEC-HMS model represents each sub-basin as a lumped model and uses separate components that compute runoff volume, component of direct runoff, and component of baseflow (Guido et al., 2023). It has nine different loss methods; some of it is designed for event simulations, whereas others are for continuous simulation. It also has seven different transformation methods, six baseflow methods, and eight routing methods. Figure 31 illustrates the different components of the model that was also mentioned above. The simplification of the hydrological cycle in HEC-HMS has led to its division into four components in the program, with each component modelled separately.

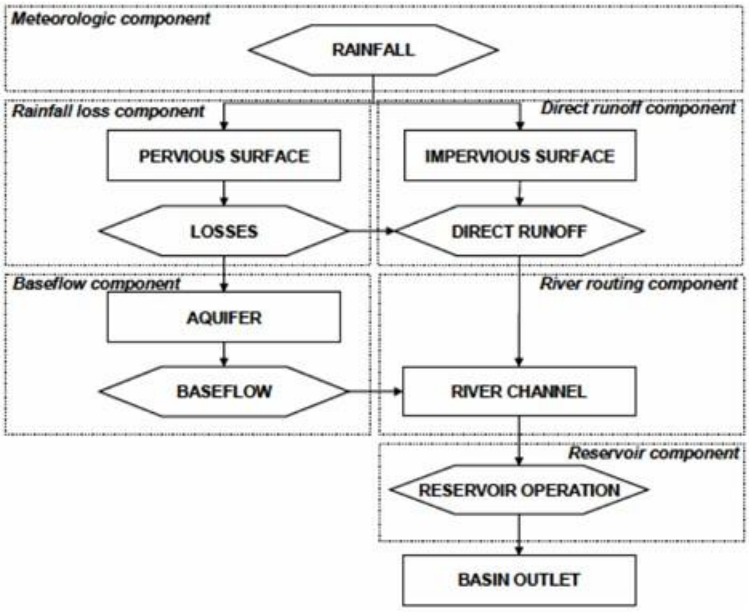


Figure 31: Schematic of rainfall-runoff process in HEC-HMS (Ismail et al., 2022)

D 1.4. Site Topography and Survey

The level of detail in topographical surveys and Digital Elevation Model (DEM) data is crucial in hydraulic modelling, as it directly influences the accuracy and reliability of model predictions and flow path determination. The importance of topographical information is demonstrated in the accompanying figure below (Figure 5 14). This diagram shows that coarse spatial data (red line) can result in significant loss of detail in cross-sectional representations. In contrast, detailed spatial data (pink line) closely aligns with the actual cross-sectional topography (blue line), ensuring greater accuracy and reliability in the modelling outputs.

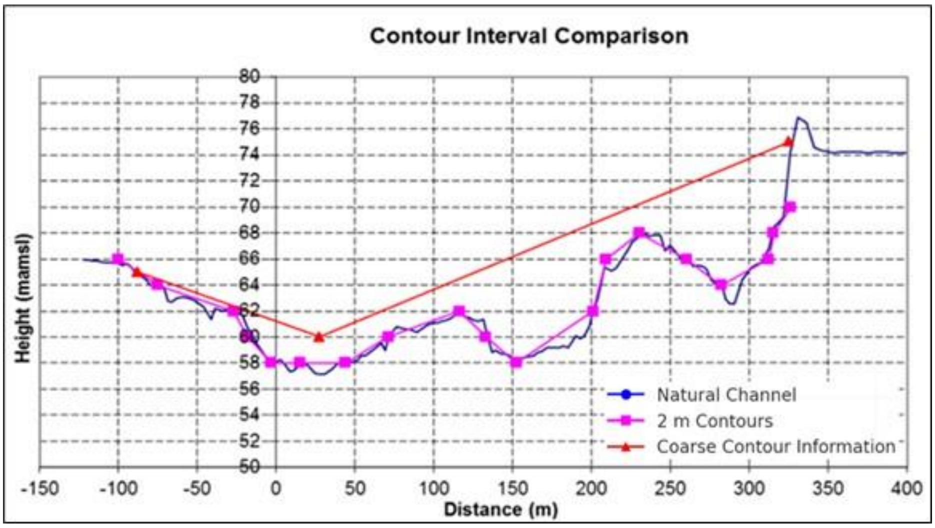


Figure 32: Illustration of Contour Information Representation (example)

Detailed survey information is currently available at this stage of the study. The LiDAR Composite Digital Terrain Model (DTM) is a raster elevation model covering approximately 99% of England at 2m resolution which was produced by the Environment Agency (EA) in the UK. The 2m DTM is a high-quality, high-resolution dataset designed for detailed analysis of the Earth's surface. This model represents the bare-earth surface, with natural and artificial objects such as vegetation and buildings removed, providing a precise depiction of ground elevations across the surveyed areas.

The 2m spatial resolution means that each pixel in the dataset represents a 2m x 2m area on the ground. This fine resolution enables detailed mapping of surface features, making it suitable for applications requiring high precision. The vertical accuracy of the model typically ranges from ±15 cm to ±30 cm, depending on factors such as terrain complexity, survey method, and the LiDAR system used. This level of accuracy ensures the reliability of the model for both scientific and practical applications.

The accuracy of hydraulic simulations provided through this study can only be as accurate as the DEM data applied. A more detailed topographical survey not only refines the DEM but also enhances the overall reliability of hydraulic outputs. By capturing finer nuances of terrain elevation and features, such as channels and embankments, detailed survey information provides crucial inputs that improve the reliability and predictive capability of hydraulic models. This ensures that the simulated hydraulic behavior more accurately mirrors real-world conditions, thus enabling more informed decision-making when considering flooding impacts on communities at risk.

D 1.5. Model Configuration

The model was set up with sixteen sub-basins for the UpperAvon Swift Water Body, and 43 sub-basins for the Leam Itchen Water Body. Each sub-basin in the HEC-HMS model is represented as a lumped model. With version 4.9 of the model iteration, the sub-basins and river reaches were automatically delineated, using 2 m x 2 m DEM data, and points of interest such as communities at risk. Using the GIS tool in HEC-HMS Model other variables such as slope, length of longest flow path, and the time of concentration were estimated. The Modeling methods for all sub-basins are unified (i.e. the Loss Model, Transform Model, Baseflow Model, and Routing Model adopt the same methods for all the subbasins). The following sub-chapters describe the selection process of the modelling methods and parameters adopted in this study.

Canopy Method

For the canopy method, a simple canopy is chosen for both the event based and continuous simulation set up. This approach offers a simplified conceptualization of a plant canopy's interaction with precipitation. All incoming precipitation is intercepted by the canopy until its maximum storage capacity is reached. Once this threshold is surpassed, the excess precipitation bypasses the canopy and falls either onto the surface or directly into the soil, provided no surface representation is incorporated in the model. The initial state of the canopy is defined by specifying the percentage of its water storage capacity that is occupied at the onset of the simulation. Canopy storage is quantified as the maximum water volume that can be retained on foliage before excess water transitions into throughfall. This storage capacity is commonly expressed as an effective water depth. Additionally, the crop coefficient, which serves as a scaling factor, is applied to the potential evapotranspiration calculated from the meteorological model to determine the actual water extraction from the soil (Roy et al., 2013).

Linking canopy storage and crop coefficient to land cover classes enables hydrological models to capture the interplay between vegetation, water balance, and land management. For example, changes in land cover (e.g., deforestation or conversion to agricultural fields) alter canopy storage and crop coefficient values, thereby influencing water interception, runoff, and evapotranspiration patterns. This linkage supports accurate simulation of water balance components and informs land use planning and ecosystem management.

Surface Method

The surface method is employed to represent the ground surface, particularly in areas where water can accumulate within depression storage zones. Net precipitation collects in these depressions and infiltrates into the soil when its capacity to absorb water allows, thereby diminishing the volume of precipitation available for direct runoff. Surface interception storage comprises precipitation that is neither retained by canopy interception nor absorbed into the soil due to infiltration constraints. This method was only employed to the continuous simulation set up. Depression zones exhibit storage capacities that are strongly influenced by land cover classes. Land cover classes serve as a foundational input for estimating depression storage capacities because they encapsulate key surface properties and hydrological processes (National Research Council, 2009).

Infiltration Loss Method

This method is utilized to calculate runoff volumes by estimating water losses due to infiltration and evapotranspiration during rainfall events. The loss technique quantifies the proportion of precipitation that contributes to surface runoff in a river system for each time step within the modeling cycle. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) provides eleven distinct methodologies for modeling these processes (USACE-HEC, 2016b).

For the event-based model set up the gridded soil conservation service (SCS) curve number (CN) loss method was utilized. The SCS-CN method is widely regarded as one of the most reliable and extensively applied techniques for estimating runoff. Its widespread acceptance is attributed to its simplicity, predictability, and stability, as well as its reliance on a single, well-defined parameter (Abushandi & Merkel, 2013; USACE, 2016). This method subdivides the catchment into grid cells, computes the precipitation loss for each cell independently and finally routes the excess to the outlet of the catchment. The SCS curve numbers used to develop the gridded SCS-CN were determined from the landcover and soil texture information available for the respective water bodies in study. Based on the overlapping soil texture and landcover class, inference was made to the hydrological soil grouping which enabled the appropriate curve number to be determined for each landcover class per grid cell.

For the continuous simulation set up the soil moisture accounting method was utilized as recommended by the user manual of the HEC-HMS model. The Soil Moisture Accounting (SMA) loss method models water movement dynamics above and within the soil using five distinct storage layers: canopy interception, surface depression storage, soil, upper groundwater, and lower groundwater (Singh & Jain, 2015). These layers reflect key hydrological processes, with initial conditions for each layer represented as the percentage of water in the respective storages at the onset of the simulation. The maximum canopy storage quantifies the highest volume of water that can be held by vegetation before throughfall to the surface occurs. Surface storage denotes the maximum water volume that can accumulate on the soil surface before initiating surface runoff. Surface runoff is triggered when the surface storage reaches full capacity, leading to overflow due to excess precipitation.

The model specifies the maximum infiltration rate as the upper limit for water transfer from surface storage into the soil profile. Urbanization is incorporated into the model by specifying the percentage of impervious areas within each sub-basin. The soil storage layer accounts for the total available water storage capacity within the soil profile, while the tension storage, a component of the upper soil layer, represents water held against gravity at field capacity. Tension storage values are derived from the soil's field capacity, which varies based on soil texture (Singh & Jain, 2015). The above-mentioned parameters for the respective water bodies were determined using the available landcover and soil texture information detailed in Section 5.2.

Transform/Runoff Method

The Transform Method is also referred to as the Direct Runoff Method as the approach facilitates the conversion of excess precipitation across a watershed into a hydrograph at its outlet, integrating considerations of surface roughness and watershed geometry to ensure accurate representation. Within the HEC-HMS modeling framework, seven transformation methods are available: the Soil Conservation Service (SCS) Unit Hydrograph, the Clark Unit Hydrograph, the Snyder Unit

Hydrograph, the kinematic wave method, the Modified Clark (ModClark) method, the user-defined unit hydrograph, and the user-defined S-Graph method (USACE-HEC, 2016).

The Clark Unit Hydrograph (UH) transformation method was adopted for both the event-based and continuous simulation set up, as it is a widely utilized technique for estimating direct runoff and requires two key parameters: the time of concentration (Tc) and a storage coefficient (R). This method explicitly models the processes involved in runoff generation within a watershed. The time of concentration, Tc, is a fundamental parameter in this method and is defined as the time required for a water droplet falling at the most distant point of the drainage basin to travel to the basin's outlet. Accurate estimation of Tc is crucial, as it directly influences the shape and timing of the resulting hydrograph (Singh, 1988; Maidment, 1993). The storage coefficient, R, is a parameter used to represent the temporary storage effects of water within a watershed during the transformation of excess precipitation into runoff. It characterizes the attenuation of the hydrograph, accounting for delays caused by the retention of water in various storage elements, such as surface depressions, soil, and channel systems (USACE-HEC, 2016).

Base Flow Method

The simulation of groundwater contributions to runoff is a critical component of hydrological modeling, particularly in understanding baseflow dynamics. In HEC-HMS, five distinct methods are available for simulating baseflow: the bounded recession method, constant monthly method, linear reservoir method, nonlinear Boussinesq method, and recession method (USACE-HEC, 2016). Among these, the recession method is the most commonly employed for modeling baseflow contributions within a catchment due to its simplicity and effectiveness in capturing the gradual decline of flow after a precipitation event (Ali et al., 2011; Oleyiblo & Li, 2010).

In this study, the linear reservoir baseflow method was adopted for both the event-based and continuous simulation set up. This method simulates subsurface flow by conceptualizing it as the storage and movement of water through linear reservoirs. The linear behaviour of the reservoir implies that, during each time step of the simulation, the outflow is directly proportional to the average storage within the reservoir over the same period. This mathematical approach mirrors the structure of the Clark Unit Hydrograph model in its representation of watershed runoff (USACE-HEC, 2008).

Routing Method

Flow routing techniques are essential for simulating the movement of water through sub-basins and channels, ultimately delivering flow from upstream watersheds to downstream outlets. In HEC-HMS, six routing methods are available to model these processes: the Muskingum method, the kinematic wave method, the Lag method, the Modified Puls method, the Muskingum-Cunge method, and the Straddle-Stagger method (USACE-HEC, 2016). Each routing technique is designed to represent specific hydraulic and hydrological conditions.

The Lag Method is a simplistic and effective flow routing approach used in hydrological modeling to simulate the movement of water through a channel or watershed. This method assumes that the outflow hydrograph at a downstream point is a delayed version of the inflow hydrograph from an upstream location, with no change in shape or volume. The delay, referred to as the lag time, represents the travel time required for water to traverse from the upstream to the downstream point (USACE-HEC, 2016). In this study, the lag routing method was adopted for both the event-based an continuous simulation set up, as it is ideal for event-based simulations due to its straightforward implementation and minimal data requirements. In continuous simulations, the lag method effectively captures flow delays across varying hydrological conditions over extended periods.

D 1.6. Model Calibration & Validation

Model calibration is a systematic process and is performed to obtain the best fit between model calculations and observed data by adjusting or changing the selected parameters in the model. A model is considered plausible only when it can reliably estimate stream flow as compared to observed stream flow. A long period of observed flow is preferred for model calibration and validation to check the consistency of the model performance in continuous runoff simulation.

Model Performance Criteria

Evaluating the performance of the HEC-HMS model is critical to ensure that it adequately represents the hydrological process under study. Performance metrics provide quantitative and qualitative means to measure how well simulated results align with the observed data. Statistical metrics are vital for quantifying the discrepancies between the observed and simulated results. These metrics provide objective, numerical insights into the model's predictive accuracy. HEC-HMS model in this study will be assessed using various standard statistical tests of error functions such as Nash-Sutcliff efficiency (NSE), Percent Bias (PBIAS) and Root Mean Square Error (RMSE)-observation standard deviation ratio (RSR). The different statistical tests of error function are expanded on in detail in the following sub-chapters. **Error! Reference source not found.** is used to determine the range of performance evaluation of the HEC-HMS model based on Singh et al. (2005) and Chung et al. (2002).

Table 22: Range of Performance Evaluation

No.	Performance Rating	NSE	RSR	PBIAS (%)
1	Very Good	0.75 – 1	0 – 0.5	< 10
2	Good	0.65 – 0.75	0.5 – 0.6	10 – 15
3	Satisfactory	0.50 – 0.65	0.6 – 0.7	15 – 25
4	Unsatisfactory	< 0.50	> 0.7	> 25

Nash-Sutcliff Efficiency (NSE)

The NSE is one of the most widely used metrics in hydrology (Nash and Sutcliff, 1990). It measures the proportion of the variance in the observed data explained by the model. A NSE value of 1 indicates that there is a perfect match between the observed and simulated data, while values closer to 0 suggest poor performance of the model. Negative values highlight significant issues in the model calibration or setup. The NSE formula is represented as:

$$NSE = 1 - \frac{\sum(Qo - Qs)^2}{\sum(Qo - \bar{Q}o)^2}$$

where:

- Q_o is the observed discharge, Q_s is simulated discharge, and $\bar{Q}_o$ is the mean observed discharge

Percent Bias (PBIAS)

PBIAS assesses the average tendency of the model to overestimate or underestimate the observed values (Gupta et al., 1999). It is expressed as a percentage, with 0% indicating that there is a perfect agreement between the observed and simulated values. Positive values indicate underestimation, while negative values suggest overestimation. The PBIAS formula is represented as:

$$PBIAS = 100 \times \frac{\sum Qo - Qs)}{\sum Qo}$$

Ratio of RMSE to Standard Deviation (RSR)

The RSR is a performance metric used to assess the accuracy of hydrological models, especially in relation to the variability of observed data. The ratio normalizes the RMSE by the standard deviation of observed data, providing a relative measure of the model's error in relation to the inherent variability in the data. Lower RSR values are desirable and indicate better model performance (Moriasi et al., 2007). The RSR is calculated using the following equation:

$$RSR = \frac{\mathrm{RMSE}}{\sigma_o}$$

where:

- RMSE is the Root Mean Square Error between the observed (Q_o) and simulated (Q_s) values:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Qo(i) - Qs(i)\right)^2}$$

where:

- Q_o(i) is the observed value at time step I, Q_s(i) is the simulated value at the time step, and n is the total number of observations
- $\boldsymbol{\sigma_o}$ is the standard deviation of the observed vales, representing the variability in the observed data.

HEC-HMS Model Performance

The Predictive ability of HEC-HMS model is dependent on the spatial and temporal variation of morphological and hydrological characteristics of the watershed. Therefore, both the calibration and validation periods were divided into two phases to check the temporal variation of the optimum value of sensitive parameters. The calibration of the model was performed for both the event-based and continuous simulation set up. The event-based simulation set up was calibrated using manual calibration where the storage coefficient parameter of the Modified Clark Unit Hydrograph Transform method was changed iteratively for all the sub-basins until the best fit between model results and observations is achieved.

Streamflow data from gauging stations for both catchments in the study area was obtained and the Annual Maximum Series (AMS) from both flow gauging station was extracted for hydrological years and various probability distributions were fitted to the AMS using L-moments (Hosking, 1990). The fitted distributions are shown in **Figure 5 and Figure 6**, respectfully, including the following:

- Log-Normal (LN)
- Log-Pearson Type 3 (LP3)
- Log Gumbel (L-EV1)
- Gumbel (EV1)
- Extreme Value Type 3 (EV3)
- General Extreme Value (GEV)
- General Pareto Distribution (GP)

The AMS of the observed record length was associated with a return period using the Weibull and Cunnane plotting positions to enable the comparison with the estimates from the fitted probability distributions. According to Pegram and Parak (2004) the Weibull plotting position is more conservative than the Cunnane Plotting Position, and for this reason the Weibull plotting position was adopted to determine the return period associated with the respective AMS. The manual calibration results for the Leam Catchment are presented in **Table 7** and **Figure 5**, the calibration results for the UpperAvon Swift Catchment are presented in Table 8 and Figure 6. An NSE of 0.86 and RMSE of 0.37 indicate good model performance according to the criteria stated above. Similar conclusions can be drawn for the Upperavon Swift Catchment.

Table 23: Design Peak Discharge Estimates for the Leam Catchment

	Peak Discharge (m^3/s)					
	2	5	10	20	50	100
Observed	27	41	52	65	85	104
Hec-Hms	20	34	49	66	95	123
% Difference	-25%	-16%	-6%	1%	11%	18%
NSE	0.86					
RMSE	0.37					

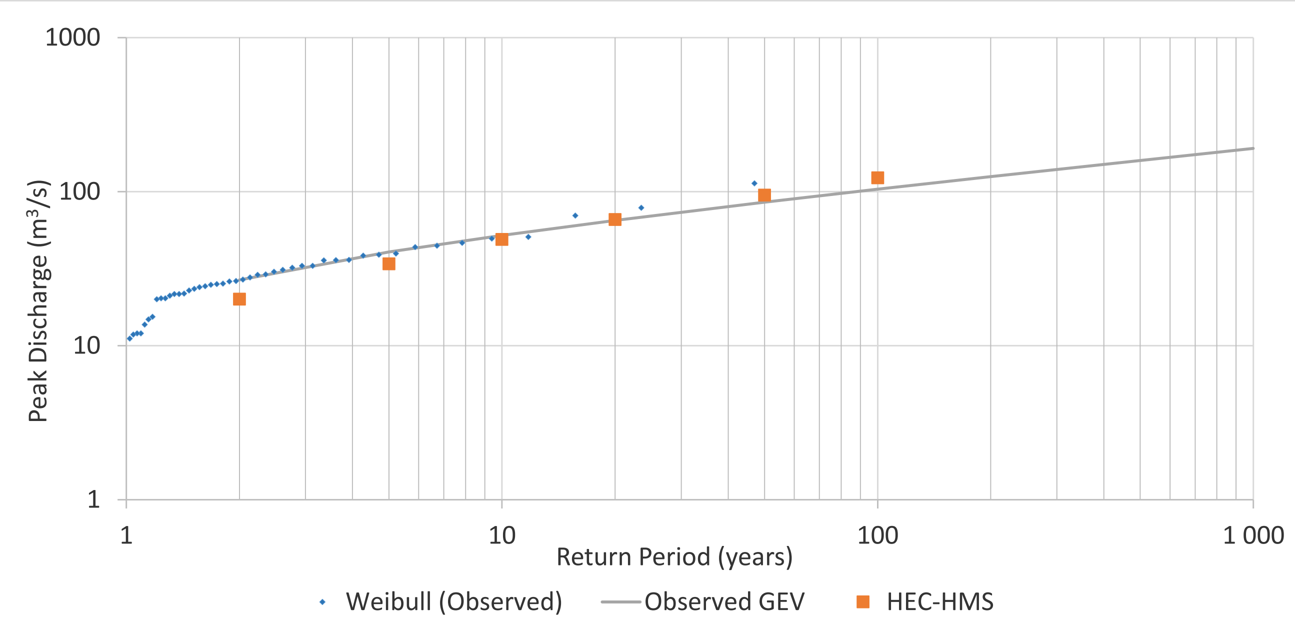


Figure 33: HEC-HMS Event-based Peak Discharge Estimates Relative to the Observed Design Peak Discharge Estimates for the Leam Catchment

Table 24: Design Peak Discharge Estimates for the UpperAvon Swift Catchment

	Peak Discharge (m^3/s)					
	2	5	10	20	50	100
Observed	24	38	49	60	75	88
Hec-Hms	20	33	44	59	80	99
% Difference	-16%	-14%	-10%	-1%	7%	13%
NSE	0.92					
RMSE	0.28					

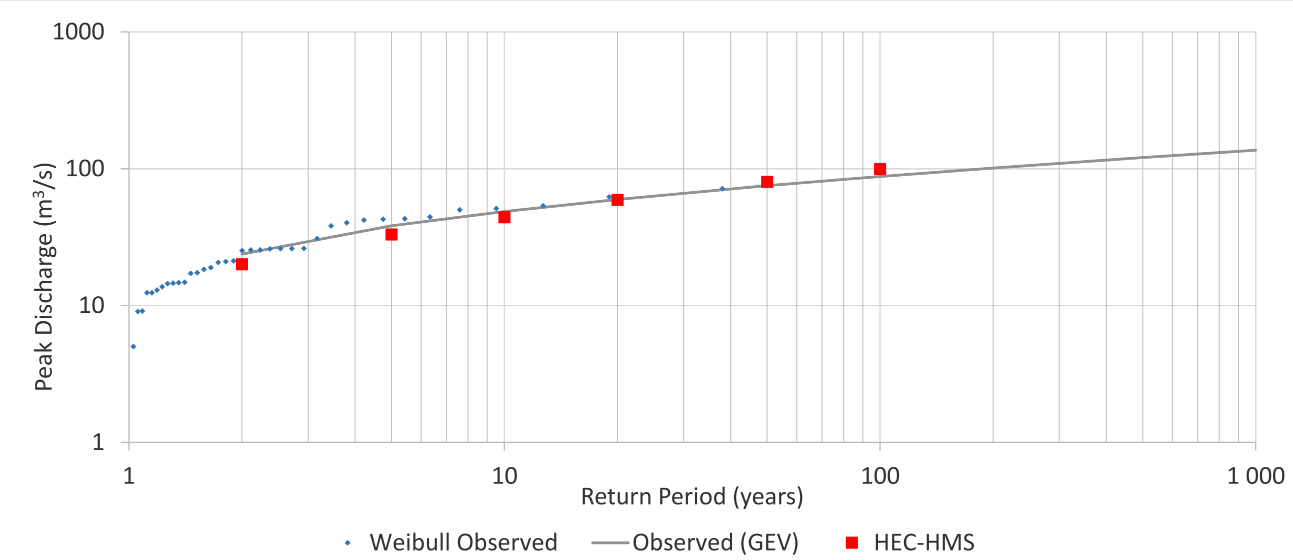


Figure 34: HEC-HMS Event-based Peak Discharge Estimates Relative to the Observed Design Peak Discharge Estimates for the UpperAvon Swift Catchment

The continuous simulation set up was calibrated using both manual and automatic calibration. The automatic calibration of HEC-HMS uses the Univariate Gradient optimization algorithm, and the Peak-Weighted RMS Error objective function is minimized. The calibration was focused on the most sensitive parameters, including those from the Soil Moisture Accounting (SMA) loss method such as soil storage, soil percolation, maximum infiltration, and tension storage. Optimization trials available in HEC-HMS model have been used for optimizing the initial estimates of the sensitive model parameters. The next step after the model setup and calibration is the validation of the model. The process of comparing the model to the real system is validation. Validation is achieved without any additional adjustment to the model parameters by running the model using data covering an alternative period. parameters. Moreover, the splitting of the calibration and validation period is important to check the consistency of the trend of the relationship between simulated and observed flow.

13. Modelling Nature-based Solutions

D 1.7. NbS Model Configuration

Five Nature-based Solution (NbS) types were selected for implementation within the HEC-HMS model to assess their potential impact on flood mitigation across the Warwickshire Avon study area. These interventions were modelled under the medium-term 90th percentile RCP 8.5 climate scenario, reflecting a precautionary approach to future rainfall intensities.

NbS were represented in the model using two principal methods, aligned with best practice and model functionality.

Storage-Based NbS – Reservoir Representation

NbS interventions designed to store water (e.g. bunds, ponds, leaky barriers, and floodplain reconnection) were modelled using the reservoir element in HEC-HMS. These reservoirs were inserted into each lumped sub-basin to reflect the total aggregate storage capacity of the specific NbS implemented within that catchment.

Bunds and ponds were modelled as reservoirs with moderate detention characteristics, allowing water to accumulate and slowly release over time. Leaky barriers were represented as reservoirs with limited storage and short residence time, achieved through faster release parameters to simulate partial obstruction of flow without full retention. Floodplain reconnection was represented as a large-scale reservoir with both storage and overflow pathways, allowing water to be diverted and attenuated before rejoining the main channel.

Land Use-Based NbS – Curve Number Modification

Land use-based NbS such as woodland creation and riparian zone restoration were implemented by modifying the SCS Curve Number (CN) parameter in the lumped loss method applied to each sub-basin.

Curve numbers were adjusted based on expected changes in infiltration and runoff characteristics associated with the proposed land-use change (e.g. converting grassland or arable land to woodland or riparian buffer). Weighted average CN values for each sub-basin were recalculated based on the area of NbS implemented at each scenario level. This approach allowed for representation of increased infiltration and reduced runoff resulting from NbS interventions, without the need for spatially distributed (gridded) modelling.

Table 25: NbS Representation in HEC-HMS.

NbS Type	HEC-HMS Representation
Bunds / Ponds	Reservoir (aggregate storage)
Leaky Barriers	Reservoir (short residence storage)
Floodplain Reconnection	Reservoir (detention with overflow)
Woodland Creation	Curve Number adjustment (lumped CN method)
Riparian Zone Restoration	Curve Number adjustment (lumped CN method)

NbS Simulations

To test the sensitivity of the hydrological response to NbS implementation, multiple levels of NbS application (25%, 50%, 75%, 100%) were tested for each intervention. This allowed for the exploration of the non-linear relationship between extent of implementation and hydrological benefit an the identification of potential inflection points in performance, where diminishing returns or optimal levels of delivery became evident.

Each scenario varied the volume and number of these reservoirs according to different levels of NbS implementation (25%, 50%, 75%, and 100%) based on opportunity mapping and physical feasibility.

Table 26: Range of Performance Evaluation

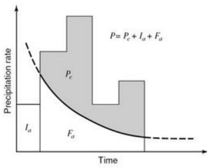
NbS Type	Climate Scenario	Application Levels
Bunds / Ponds	RCP 8.5 (90th percentile)	25%, 50%, 75%, 100%
Leaky Barriers		25%, 50%, 75%, 100%
Floodplain Reconnection		25%, 50%, 75%, 100%
Woodland Creation		100%
Riparian Zone Restoration		100%

Annex E. Co-Benefits Modelling

14. Overview: Generic Calculation Methodologies

Modelling Overview and Aims | **Generic Approaches**

Analyses are based on the following tools…

Value Proposition	Water Resources Uplifts	Water Quality Uplifts	Biodiversity Uplifts
Tool / Method			
Anaysis	Unit and area-based calculations based on simplified 1D hydrological model	Unit and area-based calculations based on farmscoper estimates	Unit and area-based calculations based on BNG tool
Output Metric	Total Recharge m^3 / yr	Nutrient Export Kg / yr	BNG units

5 **Nature for Water Facility** Co-benefits Modelling

Modelling Overview and Aims | **Generic Approaches**

Two approaches are used for different NbS types…

In general, two approaches are used in these assessments, depending on how different types of Nature-based Solutions (NbS) function:

- Point-based NbS features (e.g. bunds, leaky barriers) are evaluated using simplified hydrological modelling. This method relates their upstream contributing area to the volume of water expected to pass through the structure, providing estimates of flow attenuation or infiltration enhancement.
- Land-use-based NbS (e.g. woodland creation, riparian restoration) are assessed using area-based uplift calculations. This involves applying per-hectare coefficients to estimate changes in ecosystem services (e.g. nutrient export, infiltration) based on the extent of land converted.

Approach	Assessment	NbS	Brief Description
Land-use based assessment	Water Resources, Nutrient Export, BNG	• Woodland Creation • Floodplain Reconnection • Riparian Restoration • Bunds (only BNG) • Leaky Barriers (only BNG) • Ponds/Pools/Scrapes (only BNG)	Area-based calculations based on coefficients for 1) baseline and 2) NbS land use
Feature-level calculations	Water Resources, Nutrient Export	• Bunds • Leaky Barriers • Ponds/Pools/Scrapes	Point-based calculations based on upstream catchment of feature using curve-number methodology

6 **Nature for Water Facility** Co-benefits Modelling

Modelling Overview and Aims | **Land Use Assessments**

Core concept

The method relies on applying **uplift coefficients** to land areas **based on a change in land use type**. These coefficients represent the **per-hectare** impact of a land use change on a particular environmental outcome.

For example:

- Nitrogen reduction (e.g. kg N/ha/year)
- Phosphorus reduction (kg P/ha/year)
- Infiltration enhancement (m^3/ha/year)
- Biodiversity uplift (BNG units/ha), etc.

These **coefficients are derived from empirical studies**, monitoring data, or published literature, and are intended to represent average values under typical implementation conditions.

This approach can be practically implemented through either a **lumped approach** that looks at total areas of NbS being delivered and assuming an underlying land use, or through a **raster approach** using two rasters (a baseline and NbS implementation).

Modelling Overview and Aims | **Land Use Assessments**

Calculating uplifts through baseline and NbS coefficients

1. Calculate Baseline Units (before NbS implementation):

$$Baseline\ Units = \sum_{i=1}^{n} Coefficient_{existing\_landuse_i} \times Area_{existing\_landuse_i}$$

Where: Coefficient $_{existing\_landuse\ i}$ = unit impact (e.g., nutrient export rate per ha) for each existing land use type; Area $_{existing\_landuse\ i}$ = area of each land use type (hectares or m²); n = number of existing land use types considered

2. Calculate NbS Units (after land use change):

$$NbS\ Units = \sum_{j=1}^{m} Coefficient_{new\_landuse_j} \times Area_{new\_landuse_j}$$

Where: Coefficient $_{new\_landuse\ j}$ = unit impact for each new (NbS) land use type; Area $_{new\_landuse\ j}$ = area of each new land use type; m = number of new land use types (both pre-existing and created through NbS implementation)

3. Calculate Uplift:

Uplift=NbS Units−Baseline Units

$$Uplift = NbS\ Units - Baseline\ Units$$

Modelling Overview and Aims | **Land Use Assessments**

Worked Example using lumped areas

Baseline units = $(\text{Coeff.}^{\text{existing landuse1}} \times \text{Area}^{\text{existing landuse1}}) + (\text{Coeff.}^{\text{existing landuse2}} \times \text{Area}^{\text{existing landuse2}}) + \ldots$

NbS units = $(\text{Coeff.}^{\text{new landuse1}} \times \text{Area}^{\text{new landuse1}}) + (\text{Coeff.}^{\text{new landuse2}} \times \text{Area}^{\text{new landuse2}}) + \ldots$

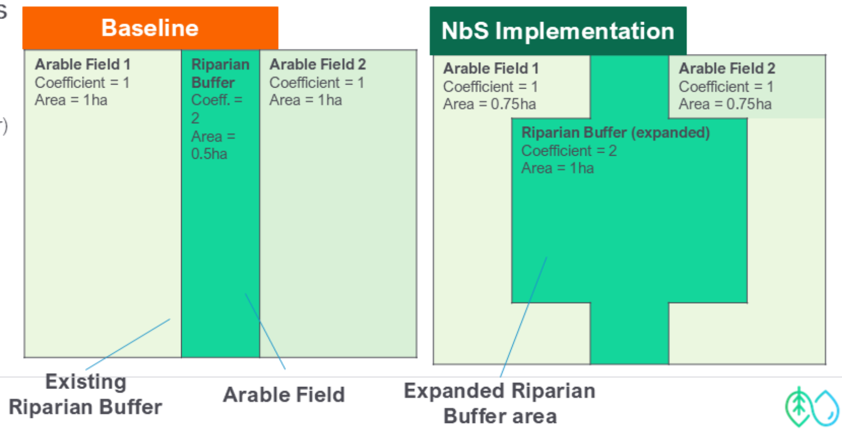
Uplift = NbS units = Baseline units

In this example:

Baseline units = 1*2 (arable) + 2*0.5 (Rip. Buffer)

NbS units = 1*1.5 (arable) + 2*1 (Rip. Buffer)

Uplift = 3.5 – 3 = **0.5**



Modelling Overview and Aims | **Feature-Level Assessments**

Calculating uplifts through rainfall-runoff methodology at point-level

These feature-level assessments **rely on work completed for the** [Norfolk Water Strategy Business Case] **by Nature for Water and JBA**. A key output of this work was a 1-dimensional rainfall-runoff-recharge model in excel which models storm runoff from a defined upstream catchment area and estimates volumes stored and infiltrated by NbS features. *Further reporting describing this tool is available on request.*

The tool accounts for:

- Event-based rainfall (e.g. design storms or local rainfall data)
- Soil permeability (via hydrological soil group)
- Feature design dimensions (e.g. bund crest height, pond volume)
- Flow routing and overflow assumptions

This tool was **used to generate outputs (runoff stored, recharge etc.) for Leaky Dams, Bunds and Ponds / Scrapes** by **applying specific parameterisations** of the model based on best judgement of how to represent these features.

Modelling Overview and Aims | **Feature-Level Assessments**

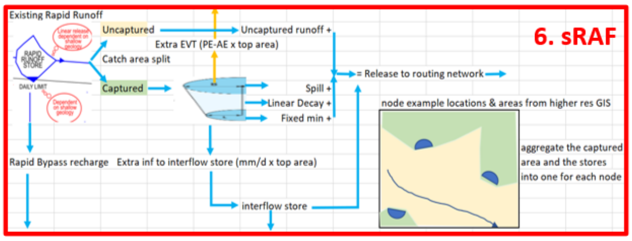
Process representation in Runoff Attenuation Features

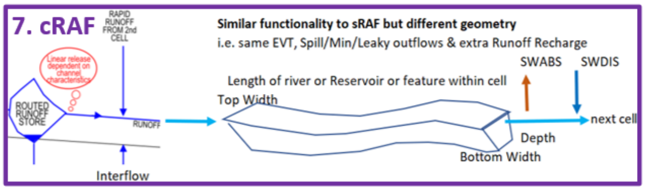
The tool is specifically designed for "**Runoff Attenuation Features**", and can model the following:

- **sRAFs** (surface water runoff attenuation features): These are conceived as upland storage areas, storing water prior to any significant flow pathways or drainage channels
- **cRAFs** (in-channel / on flow pathway runoff attenuation features): These are conceived of features within the mid catchment on drainage channels or flow pathways

These both have different calculation methodologies and

For the work in Warwickshire, **ponds are represented as sRAFs** and **leaky barriers, bunds are represented as cRAFs**





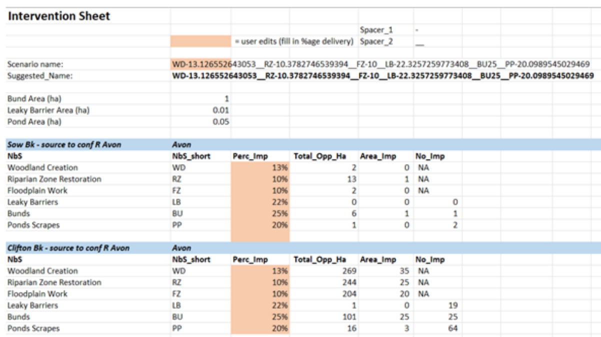
15. Implementation: Spreadsheet Description

Modelling Overview and Aims | **Architecture**

These approaches are brought together in a spreadsheet format

These generic approaches are brought together in **a single spreadsheet approach**, which uses lookups based on deeper analysis and best-practice guidelines.

This represents a **lumped approach at EA Water Body level**, where a user can enter different levels of NbS implementation and generate rapid results.



Intervention Sheet

				Spacer_1	-
		= user edits (fill in %age delivery)		Spacer_2	__
Scenario name:	WD-13.126552643053__RZ-10.3782746539394__FZ-10__LB-22.3257259773408__BU25__PP-20.0989545029469				
Suggested_Name:	**WD-13.126552643053__RZ-10.3782746539394__FZ-10__LB-22.3257259773408__BU25__PP-20.0989545029469**				
Bund Area (ha)	1				
Leaky Barrier Area (ha)	0.01				
Pond Area (ha)	0.05				
Sow Bk - source to conf R Avon	***Avon***				
NbS	**NbS_short**	**Perc_Imp**	**Total_Opp_Ha**	**Area_Imp**	**No_Imp**
Woodland Creation	WD	13%	2	0	NA
Riparian Zone Restoration	RZ	10%	13	1	NA
Floodplain Work	FZ	10%	2	0	NA
Leaky Barriers	LB	22%	0	0	0
Bunds	BU	25%	6	1	1
Ponds Scrapes	PP	20%	1	0	2
Clifton Bk - source to conf R Avon	***Avon***				
NbS	**NbS_short**	**Perc_Imp**	**Total_Opp_Ha**	**Area_Imp**	**No_Imp**
Woodland Creation	WD	13%	269	35	NA
Riparian Zone Restoration	RZ	10%	244	25	NA
Floodplain Work	FZ	10%	204	20	NA
Leaky Barriers	LB	22%	1	0	19
Bunds	BU	25%	101	25	25
Ponds Scrapes	PP	20%	16	3	64

Modelling Overview and Aims | **Architecture**

Spreadsheet calculation methodology…

1. Land-Use Based Assessments

Estimate ecosystem service uplifts by applying per-hectare coefficients for a set baseline (typically grassland) versus a Nature-based Solution (NbS) intervention. Each intervention has an associated uplift value (e.g. nutrient reduction, runoff decrease, biodiversity gain), derived from literature or modelled outputs. This is implemented as such:

- Area of implementation is input.
- Lookup tables provide the relevant coefficients (e.g. BNG units, kg N reduced per ha/year).
- Total uplift is calculated as: Uplift = Area × Uplift per ha
- This method is used for interventions such as woodland creation, riparian restoration, and floodplain reconnection.

2. Feature-Level Assessments

Used for point-based interventions, where performance depends on site-specific factors like upstream catchment size, design specifications, and soil permeability.

- Number of interventions are input.
- Lookup tables derived from a bespoke hydrological model (4R tool referred to earlier) relate interventions to upstream area and predefined performance outputs (e.g. m^3 of runoff intercepted per bund).
- This method is used for interventions such as leaky barriers, bunds, and ponds/scrapes.

16. Detail on Water Resources Assessments

Water Resources Modelling | **Land-Use Assessments**

Coefficients used in Land-use based assessments

Coefficients for rainfall and runoff in the landuse approach are derived from previous modelling from the 4R spreadsheet, updated to represent best estimates for the area.

This is a simplified methodology in which only three typologies are used: Arable, Deciduous and Grass land use types. NbS are represented using these typologies.

Landuse Type	Runoff (m3/yr/ha)	Recharge (m3/yr/ha)
Arable	1341	669
Deciduous	496	191
Grass	1249	627
Woodland Creation	496	191
Riparian Restoration	496	191
Floodplain Reconnection	1249	627

Water Resources Modelling | **Approach**

Developing feature-level lookup table

These are the coefficients used in the 4R spreadsheet to develop lookups which are used in the final assessment tool.

Average upstream areas were based on GIS analysis of averages for leaky barriers and bunds based on opportunity and flow accumulation mapping.

Note that bunds are represented as 1ha in area. **This is representative of the delivery of multiple bunds on a single flow pathway**. Analysis showed that 1ha was a representative size for flow pathways based on opportunity mapping.

Parameter (cRAF type calculation)	Leaky Barriers	Bunds
Lumped catchment area u/s of cRAF (km2)	0.16	0.44
Routed order of cell with cRAF	4	4
Routed runoff store release for each order	0.99	0.99
% of cells with nat runoff recharge	1	1
nat runoff recharge cell limit	10	10
% of cells with sRAFs (step 6)	0%	0%
length	50	200
bot width	2	50
top spill width	2	50
Max spill depth	1	1
Floodplain cRAF Sy	100%	100%
cRAF leaky outflow release factor	100	0
cRAF extra runoff recharge limit	100	100

Parameter (sRAF type calculation)	Ponds/Scrapes
CAPTURED proportion of cell rapid runoff	0.1
Aggregated open water area when spilling	500
Aggregated minimum water area before dry	300
Max aggregated spill water depth	0.4
Min fixed outflow	1
Linear sRAF leaky outflow release factor	0
sRAF extra bypass infiltration limit	0.5

Water Resources Modelling | **Approach**

Lookups used for feature-level modelling

The analysis using the 4R model produced the following values which are used as lookups in the final tool developed for water resources modelling. This can be multiplied by the number of features to give a total value.

As such:

Total Recharge from bunds = No. bunds delivered x Recharge from lookup table

NbS Type	Inflow [m3/yr/feature]	Stored [m3/yr/feature]	Recharge [m3/yr/feature]	Spill [m3/yr/feature]
Leaky Barriers	4285	1075	285	3217
Bunds	11784	58032	11098	513
Ponds Scrapes	402	1978	39	0

17. Detail on Water Quality Assessments

Water Quality Modelling | **Land-Use Assessments**

Lookups used for landuse based modelling

Coefficients for rainfall and runoff in the landuse approach are derived from Farmscoper - a free to use decision support tool developed by ADAS. This is widely used in the UK for land-use and farm planning. It uses land-use based coefficients for nutrient (and sediment) export.

Coefficients for the baseline are defined based on catchment, land use type and drainage.

Coefficients for NbS implementation are based on Farmscoper's "natural" land use type – e.g. no input from fertiliser etc.

Baseline

Catchment	Land Use Type	Drainage	Nitrogen export [kg/yr/ha]	Phosphorous export [kg/yr/ha]
Leam	Arable	FreeDrain	31.6	0.07
Leam	Arable	DrainedAr	23.2	0.42
Leam	Arable	DrainedArGr	23.2	0.42
Leam	Grass	FreeDrain	12.3	0.10
Leam	Grass	DrainedAr	8.8	0.13
Leam	Grass	DrainedArGr	8.8	0.13
Avon	Arable	FreeDrain	30.8	0.06
Avon	Arable	DrainedAr	22.8	0.40
Avon	Arable	DrainedArGr	22.8	0.40
Avon	Grass	FreeDrain	17.8	0.13
Avon	Grass	DrainedAr	12.5	0.18
Avon	Grass	DrainedArGr	12.5	0.18

NbS Implementation

NbS	Nitrogen export [kg/yr/ha]	Phosphorous export [kg/yr/ha]
Woodland Creation, Riparian Zone Restoration, Floodplain Reconnection	3	0.02

Water Quality Modelling | **Feature-level Assessments**

Approach used for feature-level modelling

To work out the nutrient export reduction derived from bunds, leaky dams and ponds, **an efficacy-based approach based on literature and regulatory guidance was used**. This uses total inflow to the feature and relates this to a treatment efficacy per pollutant.

Total inflow is taken from the 4R water resources modelling, with the runoff captured value being used as the inflow to the feature. The below pollutant concentration and NbS efficacy lookups were created using Natural England's NbS for Nutrient Neutrality evidence base and expert judgement during the Norfolk project.

The calculation methodology is then:

Total export reduction = Flow through feature * Pollutant Concentration * (1 - Removal Efficacy)

Pollutant conc. lookup

Parameter	Concentration [mg/l]	Concentration [kg/m3]
Total Nitrogen	6.95	0.00695
Total Phosphorous	0.11	0.00011

NbS Efficacy Lookup

NbS	N Removal Efficacy	P Removal Efficacy
Bunds	0.25	0.36
Leaky Dams	0.25	0.36
Ponds / Scrapes	0.25	0.36

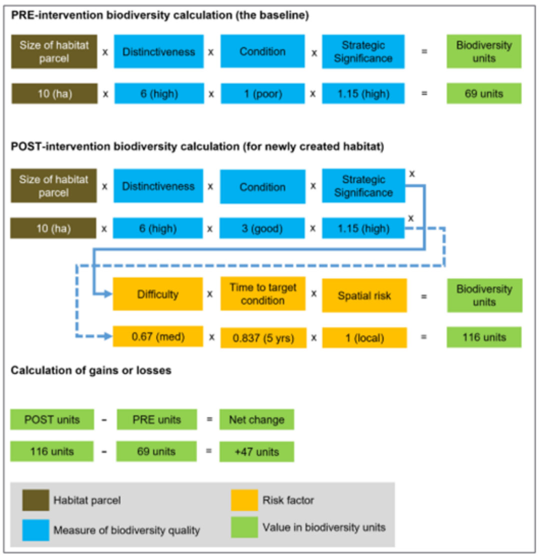
18. Detail on Biodiversity Assessments

Biodiversity Modelling | **Land-Use Assessments**

BNG Background

Coefficients for Biodiversity units in the landuse approach are derived from the [Statutory Biodiversity Metric Tool] - a government developed tool to assess mitigation requirements and offsets arising from development or the delivery of NbS. Units relate to the distinctiveness, condition and strategic significance of the habitat delivered or removed.

This methodology is developed via the same kinds of unit-area calculations which are deployed here, so it is used as a framework for assessing biodiversity uplifts resulting from NbS delivery.



Biodiversity Modelling | **Land-Use Assessments**

Lookups used for landuse based modelling

Coefficients are derived based on applicable land-use types for the NbS selected. Leaky barriers are considered as having no biodiversity uplift in the methodology as they do not result in a change in land use type.

Note that for the baseline, it is generally considered that NbS are delivered on existing grassland or arable areas.

Baseline

Land Use	Habitat Type used	Condition	BNG Units / ha
Arable	Cropland - Non-cereal crops	NA	2
Pasture	Grassland - Modified grassland	NA	2

NbS Implementation

Land Use	Habitat Type used	Condition	BNG Units / ha
Woodland Creation	Woodland and forest - Other woodland; broadleaved	Moderate	4.7
Riparian Zone Restoration	Grassland - Floodplain Wetland Mosaic (CFGM)	Moderate	3.9
Floodplain Work	Grassland - Floodplain Wetland Mosaic (CFGM)	Moderate	2.8
Leaky Barriers	Grassland - Modified grassland	NA	2
Bunds	Lakes - Temporary lakes, ponds and pools	Moderate	6.7
Ponds Scrapes	Lakes - Temporary lakes, ponds and pools	Moderate	6.7

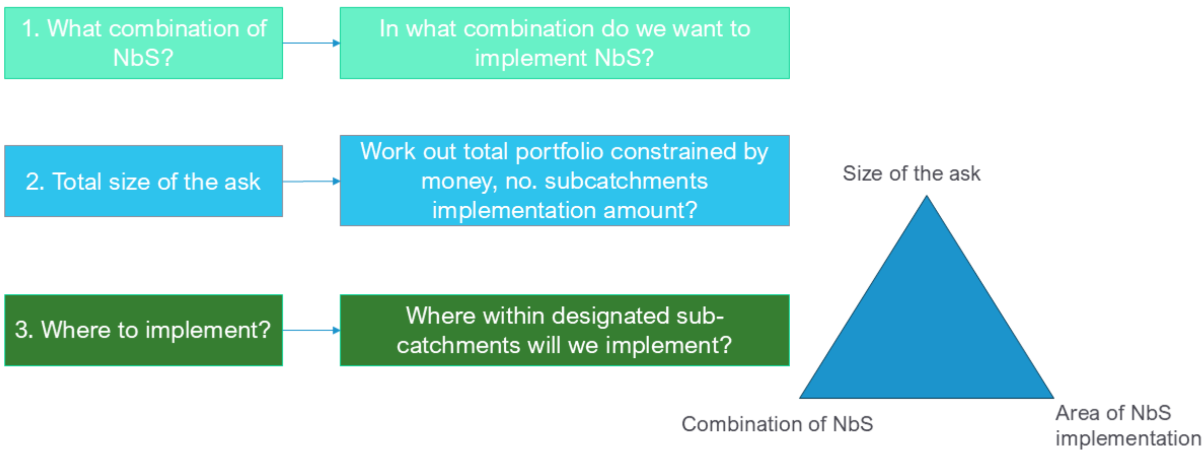
Annex F. NbS Portfolio Prioritisation

19. Prioritisation Overview

Portfolio Prioritisation | **Prioritisation Overview**

Determining appropriate portfolios for the Business Case

Overarching aim = work out a single priority portfolio to be modelled for the business case



Portfolio Prioritisation | **Prioritisation Overview**

Determining appropriate portfolios for the Business Case

Overarching aim = work out several priority portfolios to be modelled for the business case

Prioritisation Aspect	Aim	Informed by
1. Total size of the ask	Work out what the total portfolio will be constrained by – money, implementation amount?	• "Size of the pot" – realistic estimates of ceiling in terms of total spend • Science-led understanding of levels of implementation required to achieve impact
2. What combination of NbS?	How do we want to implement NbS in combination?	• Science-led understanding of specific efficacy of differing NbS in terms of achieving water-related outcomes
3. Where to implement?	Which specific opportunities in which areas will the NbS be implemented?	• Prioritisation of specific NbS spatial features for implementation • GIS prioritisation exercise

Portfolio Prioritisation | **Prioritisation Overview**

Determining appropriate portfolios for the Business Case

	1. Work out constraining conditions	2. Define combination of NbS	3. Create map of NbS
Aim to work out:	• Total spend • Number of sub-catchments	• Distribution of NbS (%age based) • Trade-offs and optimisation	• Specific locations for NbS implementation
Tools:	• "Sizing the ask" excel	• Model outputs	Priority shape scores (0-1)
Example Outputs:	• 600k GBP • 4 sub-catchments	• 25% implementation of all NbS	• Map of specific NbS implementation locations

20. Sizing the Ask

Portfolio Prioritisation | **Sizing the Ask**

1. Work out constraining conditions

Determining appropriate portfolios for the Business Case

Considerations:

- Ask partners to define a realistic total spend for implementation
- Lead with impact demonstrated by science modelling (what represents a realistic impact?)

Aim to work out:

- Maximum monetary spend for finalised portfolios
- Maximum implementation area deemed realistic

Methodology:

1. **Calculations of total price of different %age implementation for NbS (e.g. 100% implementation in all target areas = £X million)**
2. **Science-based understanding of nick points in implementation where increased implementation doesn't increase benefits**

Portfolio Prioritisation | **Sizing the Ask**

Determining appropriate portfolios for the Business Case

Calculations of total price of different %age implementation for NbS (e.g. 100% implementation in all target areas = £X million)

Example calculations (from portfolio sizing excel):

Average size of sub-catchment (hectares)	5000
Average density of NbS (%)	
Leaky Barriers	1%
Catchment storage areas (bunds and ponds)	2%
Floodplain reconnection	2%
Tree planting	50%
Riparian zone restoration	10%
Cost per hectare of NbS	
Leaky Barriers	£1,000,000.00
Catchment storage areas (bunds and ponds)	£1,000,000.00
Floodplain reconnection	£500,000.00
Tree planting	£100,000.00
Riparian zone restoration	£100,000.00

NbS	Implementation Percentage	Sub-catchments implemented	Implementation area (ha)	Cost of implementation (million GBP)
Leaky Barriers	25%	4	50	50
Catchment storage areas (bunds and ponds)	25%	4	100	100
Floodplain reconnection	25%	4	100	50
Tree planting	25%	4	2500	250
Riparian zone restoration	25%	4	500	50

Total area of portfolio (ha) =	**3250**
Total cost of portfolio (million GBP) =	**500**

Portfolio Prioritisation | **Sizing the Ask**

Determining appropriate portfolios for the Business Case

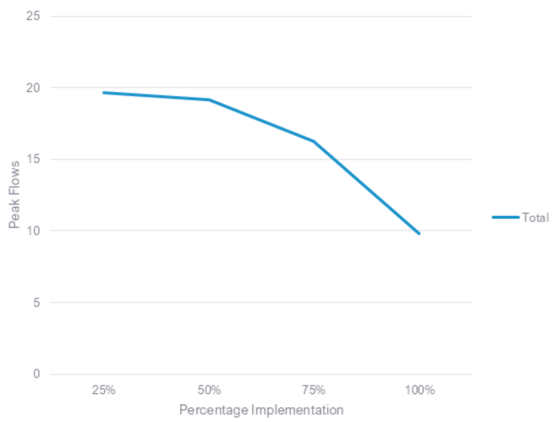
1. Work out constraining conditions

Science-based understanding of nick points in implementation where increased implementation doesn't increase benefits

Findings from hydraulic modelling:

- Implementation vs. impact is a non-linear relationship
- These effects vary per NbS
- For ponds and floodplain reconnection, increased implementation has an increasingly positive effect on peak flows for certain NbS

Delivery below 25% of total potential implementation achieves the greatest degree of benefit.



Percentage implementation vs. peak flows – average for ponds implementation across all sub-catchments

21. Combinations of NbS

Portfolio Prioritisation | **Defining Combinations of NbS**

2. Define combination of NbS

Determining appropriate portfolios for the Business Case

Considerations:

- We want to minimise trade-offs in delivery and maximise multiple benefits

Aim to work out:

- Global split between NbS delivery
- Percentages of NbS to be taken forward into delivery

Methodology:

1. **Calculations of unit delivery of NbS based on modelling outputs**
2. **Benefit per cost calculations per-NbS based on costing data (per hectare)**

Portfolio Prioritisation | **Defining Combinations of NbS**

2. Define combination of NbS

Determining appropriate portfolios for the Business Case

Calculations of unit delivery per area and per GBP for all of the NbS listed.

Example calculations (for a full description of this see the accompanying portfolio sizing excel):

NbS	Unit Delivery (FR/WQ…) / ha (output from model)	Cost of delivery	Benefit / cost / area
Leaky Barriers	1	10000	0.0001
Catchment storage areas (bunds and ponds)	2	10000	0.0002
Floodplain reconnection	3	10000	0.0003
Tree planting	45	10000	0.0045

22. Mapping Implementation

Portfolio Prioritisation | **Mapping Implementation**

3. Create map of NbS

Determining appropriate portfolios for the Business Case

Considerations:

- We need a specific implementation area for modelling
- NbS delivered in specific areas will have greater impact than others due to geology, soil type etc.

Aim to work out:

- Exactly where NbS will be implemented based on constraining area (e.g. 1500 ha of tree planting)
- Which exact NbS features should be implemented within the priority modelling area

Proposed methodology:

1. **GIS prioritisation of specific features from opportunity mapping (this has already been completed in opportunity mapping step)**
2. **Priority ranking of NbS shapefiles based on supplementary data**

Portfolio Prioritisation | **Mapping Implementation**

3. Create map of NbS

Determining appropriate portfolios for the Business Case

For a full description of the GIS priority mapping exercise, which assigns scores from 0-1 to features created in the opportunity mapping, can be found in Technical Annex D.

Example data which informs final 0-1 score per-shape:

Dataset	Approach
EA NbS Infiltration Class	Map 0-1 on 1-5 classes
Priority Habitat Area	0 = not a priority 1 = priority area for habitat delivery
ALC Agricultural Grade	0 = prime agricultural land 1 = low productivity

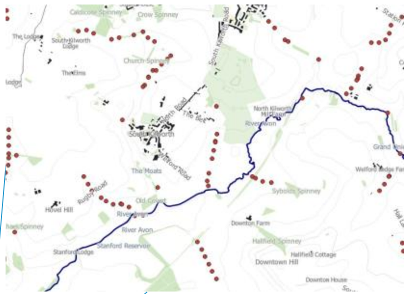
Portfolio Prioritisation | **Mapping Implementation**

3. Create map of NbS

Determining appropriate portfolios for the Business Case

When we have calculated priority, we can select top X shapes to meet the total constraining area informed by steps 1 and 2 described in this methodology. **The output of this step is a spatially explicit portfolio of interventions.**

Final outputs from this process are available upon request



Constraint: Deliver 0.4 ha of leaky barriers

NbS	Area	Priority Score
Leaky Barrier 1	0.1 ha	0.6
Leaky Barrier 2	0.2 ha	0.55
Leaky Barrier 3	0.1 ha	0.4
Leaky Barrier 4	0.3 ha	0.3
Leaky Barrier 5	0.15 ha	0.3

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Annex G. Cost-Benefit Analysis

23. Cost Assumptions

Implementation: It was assumed that the implementation of the NbS would be spread over a 5-year period, with an equal yearly implementation of 20% of the NbS portfolio.

Maintenance: Maintenance costs were defined for each NbS depending on their maintenance rationale. Each NbS has a different maintenance period and requirements (labour and equipment), resulting in different costs.

Operational costs: It was assumed that overheads and administrative costs would amount to 20% of yearly implementation and maintenance costs, while monitoring would amount to 5% of yearly implementation and maintenance costs. This distribution reflects the rationale that higher implementation and maintenance in a given year requires greater administrative costs, therefore greater overheads, along with greater monitoring efforts, while lower activity levels reduce those needs accordingly.

Table 27: NbS Maintenance Assumptions

NbS Type	Maintenance Period	Maintenance Description	Maintenance requirements (per Ha)
Buffer Strips (Riparian Zone Restoration)	Bi-Annually	Cutting vegetation, reseeding as appropriate	4 contractor days + reseeding
Attenuation Ponds	Every 5 years	Ongoing management to ensure the overall functionality of the pond and sediment removal	30 contractor days
Leaky Barriers	Every 5 years	Cutting and flailing of vegetation, replacement when required	13 contractor days + reseeding
Woodland Creation	Years 2-5	Replacement of lost trees, canes and guards	250 trees + 3 contractor days
	Years 10 and 20	Thinning of woodlands	3 contractor days
Floodplain Reconnection	Every 5 years	Ongoing management to ensure the overall functionality of the reconnected river	4 contractor days
Bunds	Every 5 years	Ongoing management to ensure the overall functionality of the bund and sediment removal	30 contractor days

24. Beneficiaries of the Programme

Table 28: Full list of beneficiaries

Benefit Category	Beneficiaries
Water Benefits	**Flooding** • Public and private landowners (reduced damage to residential and commercial properties) • Local authorities (reduced evacuation costs) • Insurance companies (reduced disbursements)
	Water Quality • Local populations (healthier conditions) • Water companies (regulatory targets) • Local and national authorities (regulatory targets)
	Groundwater Recharge • Water companies • Local populations (drinking water) • Private sector (ESG and water replenishment targets) • Farmers (irrigation)
Climate Benefits	**Air Quality** • Local populations (healthier conditions) • Local and national authorities (regulatory targets) • Private sector (ESG targets)
	Carbon • Local populations (healthier conditions) • Local and national authorities (regulatory targets) • Private sector (ESG targets) • Farmers and landowners (extra revenue sources through carbon credits)
Biodiversity Benefits	**Biodiversity Net Gain** • Farmers and landowners (extra revenue sources through BNG Units)
	Agricultural Land Use Change • Farmers and landowners (extra revenue sources through new land uses)
Community Benefits	**Green Jobs** • Local populations (additional job opportunities and resulting economic prosperity)
	Recreational Value • Local populations (healthier conditions) • Local and national authorities (regulatory targets)
	Physical Health

	• Local populations (healthier living conditions) • Local and national authorities (regulatory targets)

25. CBA Decision Metrics

Benefit-Cost Ratio (BCR)
The BCR is a decision metric commonly used in Cost-Benefit-Analysis to assess the economic feasibility of projects. It represents the ratio of the present value of total benefits (discounted) to the present value of total costs (discounted), as follows:

$$BCR = \text{Present Value of Benefits} / \text{Present Value of Costs}$$

A BCR greater than 1 means that the benefits of a project outweigh its costs. In economic terms, for every unit of cost, the project generates more than one unit of benefit, indicating that the project is economically worthwhile and creates net value. Contrarily, if the BCR is smaller than 1 indicates an inefficient investment and negative value creation.

Net Present Value (NPV)
The NPV is a financial metric to estimate the total value of an investment opportunity, and is calculated using the following formula:

$$NPV = Rt/(1+i)^t$$

Where:
NPV = net present value
Rt = net cash flow at time t
i = discount rate
t = time of the cash flow

Economic theory states that a project with a positive NPV creates net value, as the present value of future cash flows exceeds the present value of necessary investments. This indicates the project is profitable and/or contributes to economic welfare and is economically justified.

Internal Rate of Return (IRR)
The IRR is a key decision-making metric used to evaluate economic viability. It represents the discount rate at which the NPV of the Programme's costs and benefits equals zero – in other words, the rate at which the Programme breaks even in present value terms. Unlike NPV, which expresses net benefits as a monetary value, the IRR identifies the rate of return that the Programme is expected to generate over its lifetime. If the IRR is greater than the cost of capital or the required rate of return (such as the risk-free rate or an investor's target), the project is considered economically justified. A higher IRR indicates that the project is expected to generate returns that exceed the cost of financing or investment, making it an attractive option.

26. Benefit Calculation Methodologies and Information Sources

This Annex describes the various steps taken to value each benefit, including data sources and inputs. It does not aim to duplicate the methodologies described in Section 6, but rather complement them but adding another layer of detail.

Flooding

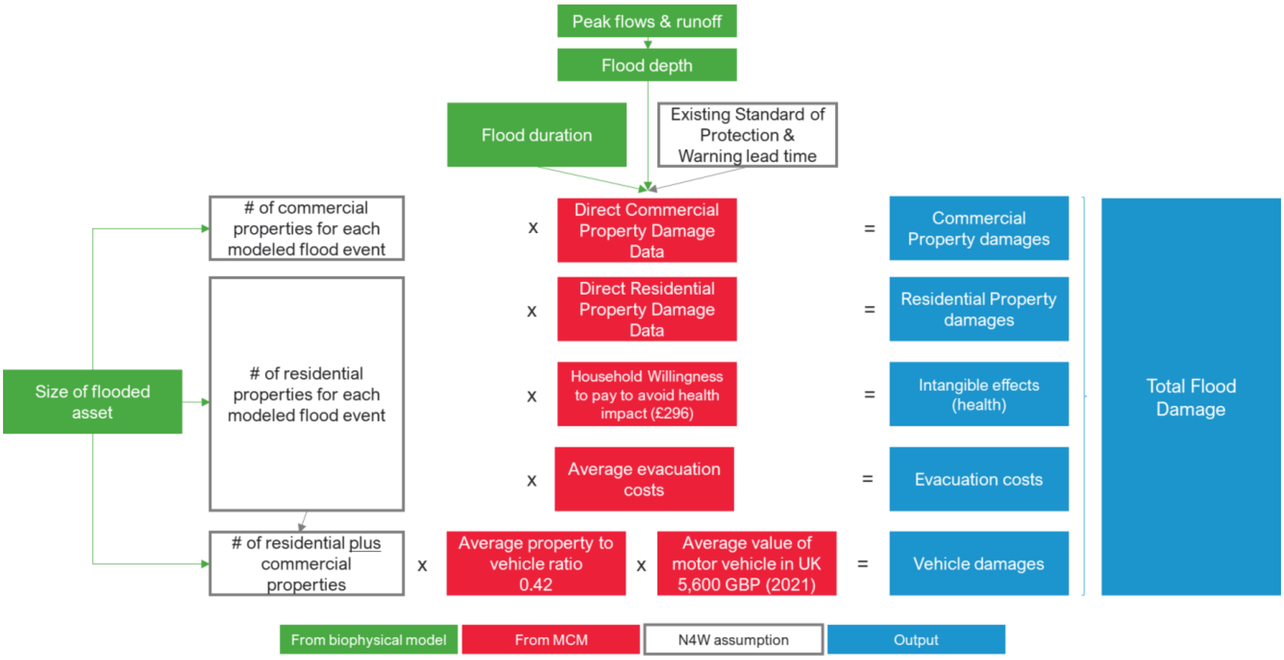

Figure 35: Schematic diagram of flood benefits estimation

Definitions

- MCM: Multi-Coloured Manual (Flood Hazard Research Centre, 2022).

Process

- This process shows the various damages/costs that were calculated as part of the flood risk reduction benefit. The following damages/costs were measured and stacked up, resulting in a total flood damage:
    - Damage to commercial property
    - Damage to residential property
    - Willingness to pay to avoid health impact
    - Evacuation costs
    - Vehicle damage costs
- This methodology relied on key outputs from the biophysical model: size of flooded assets, peak flows, flood depths and flood durations.
- The N4W team then assumed the number of properties based on outputs from the biophysical model.

Water Quality

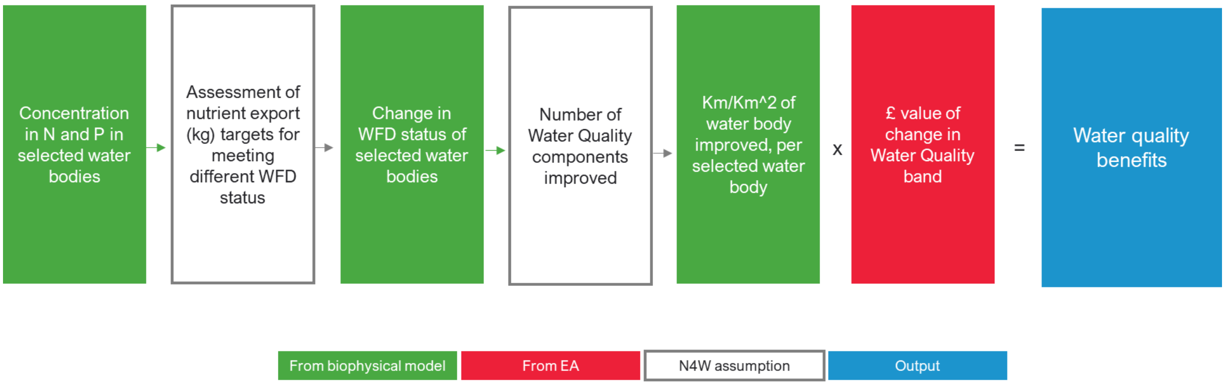

Figure 36: Schematic diagram of water quality benefits estimation

Definitions

- EA: Environment Agency (£ NWEBS values for change in Water Quality Band).
- WFD: Water Framework Directive (WFD targets and regulations).

Process

- This benefit correlates the impact of the NbS Portfolio on WFD status and the NWEBS values defined by the EA for changes in water quality bands.
- Based on the change in WFD statuses as a result of Nitrogen (N) and Phosphorus (P) reduction, and based on the Reasons for Not Achieving Good (RNAGs) of each water body, N4W assumed which of the 5 water quality components (fish, invertebrates, macrophytes, clarity, and river channel condition, with recreational safety excluded to prevent overlap with recreational benefits) were impacted and improved by the NbS Portfolio, if any.
- Each water quality component has 1/5th of the total water quality band improvement value.
- Multiplied by the length of each water body, this results in a total water quality improvement benefit.

Water Resources

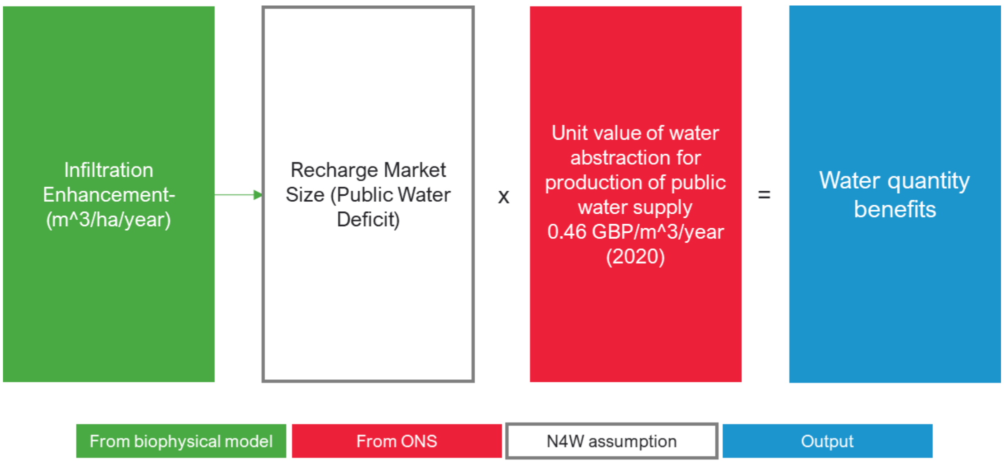

Figure 37: Schematic diagram of water resources benefits estimation

Definitions

- ONS: Office of National Statistics (Office for National Statistics, 2020): UK Natural Capital Accounts.

- m³/ha/year: Cubic meter per Hectare per Year.

Process

- This process values the infiltration enhancement output from the biophysical model (resulting from the NbS portfolio implementation) using the ONS unit value of water abstraction for production of public water supply, resulting in a total groundwater recharge benefit.
- The recharge market size, corresponding to the public water deficit in the UK, symbolises the total potential demand for public water.

Air Quality

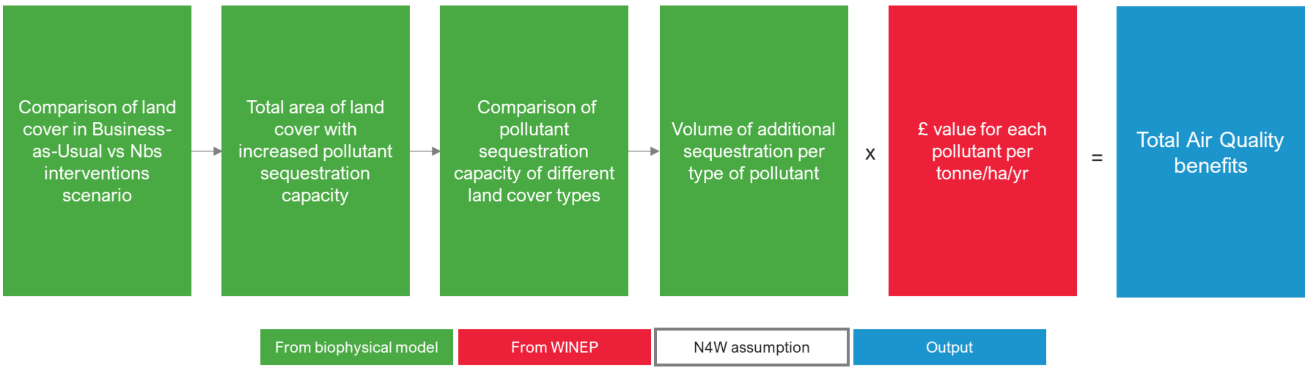

Figure 38: Schematic diagram of air quality benefits estimation

Definitions

- WINEP: Water Industry National Environment Programme. [WINEP Methodology](#).

Process

- This process compares a baseline "business-as-usual" scenario vs an "NbS" scenario in terms of land cover, with attached air pollutant sequestration rates.
- The value for the capture each pollutant is expressed in £/tonne/hectare/year, as highlighted in the WINEP methodology, which is based on a paper: "Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts" (Centre for Ecology and Hydrology, 2017).
- This methodology results in a total air quality benefit, representing the total value linked to increased pollutant capture related to modified land cover.

Carbon Sequestration

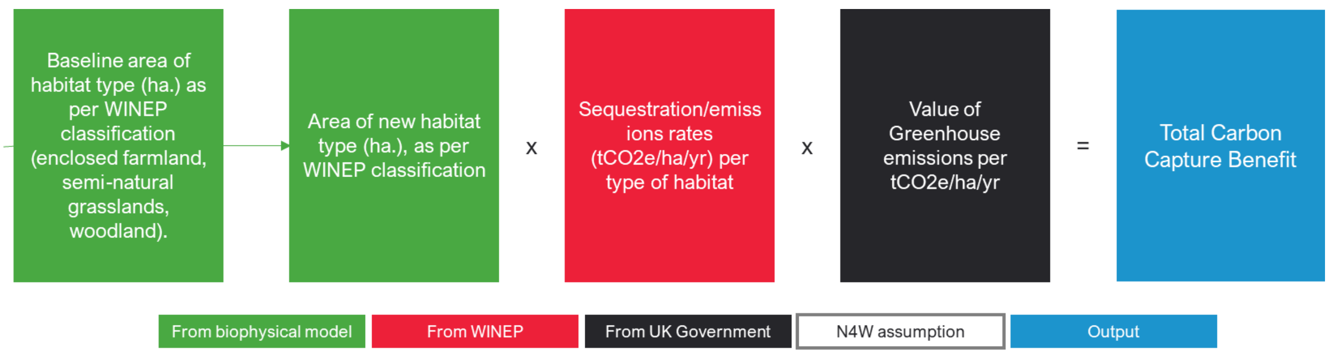

Figure 39: Schematic view of carbon sequestration benefits estimation

Definitions

- WINEP: Water Industry National Environment Programme. [WINEP Methodology].

Process

- This process follows a similar approach than the Air Quality one, comparing different sequestration rates of CO_2 linked to different land covers under the business-as-usual scenario vs the NbS scenario.
- Values for CO_2 carbon capture are given by the UK Government, as per its valuation methodology.
- This process resulted in a total carbon benefit, representing the total value linked to increased CO_2 capture related to modified land cover.

Biodiversity Net Gain

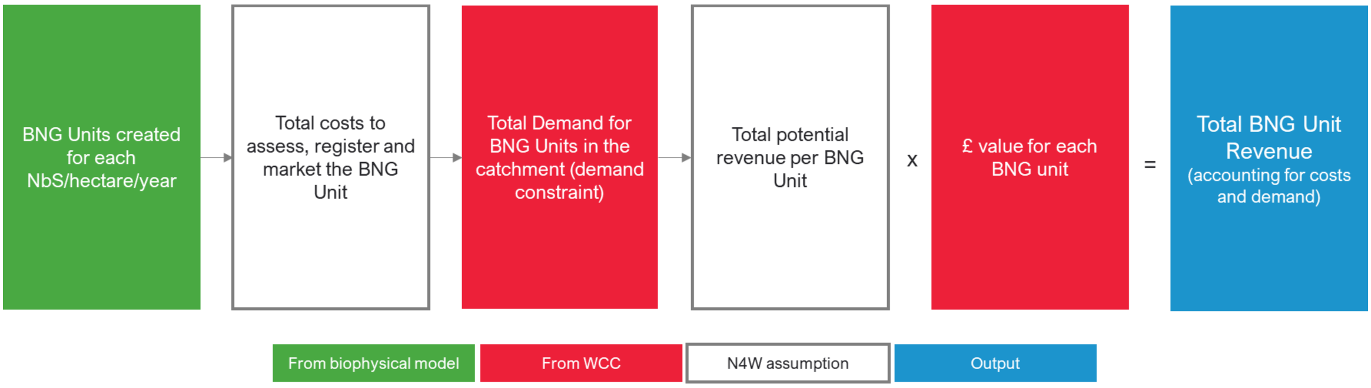

Figure 40: Schematic view of biodiversity benefits estimation

Definitions

- WCC: Warwickshire County Council.

Process

- This process placed a value on the BNG units created as a result of the NbS portfolio, an output from the biophysical model.
- N4W assumed the total costs to assess, register and market the BNG unit, based on stakeholder consultations and desktop research.
- Total demand for BNG units in the Warwickshire Avon, as well as the £ value of each BNG unit, were provided by the WCC, who has experience handling BNG units in the Warwickshire Avon.
- This process resulted in a total revenue linked to the sale of BNG units, which is grounded in local data (demand, costs and price).

Agricultural Land Use Change

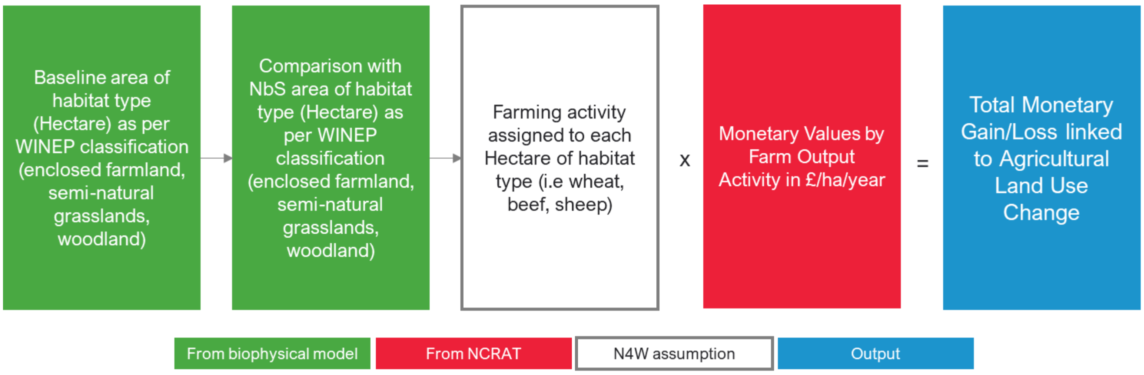

Figure 41: Schematic view of agricultural land use change benefits estimation

Definitions

- WINEP: Water Industry National Environment Programme. WINEP Methodology.
- NCRAT: Natural Capital Register and Account Tool. NCRAT.

Process

- This process compares the land covers under the business-as-usual and the NbS scenario.
- The N4W team assumed which farming activities would take place on each land cover, based on current practices – and considering that only unproductive land was taken out for NbS implementation, meaning that some activities (such as wheat) were not suitable.
- Each defined farming activity was then given an economic value based on the NCRAT methodology, assigning a monetary value by £/hectare/year.
- This resulted in a total monetary value linked to the change in land covers (and sub-sequent land uses). A positive value means a gain, a negative value means a loss. In the case of this Programme, the process resulted in a gain.

Green Job Creation

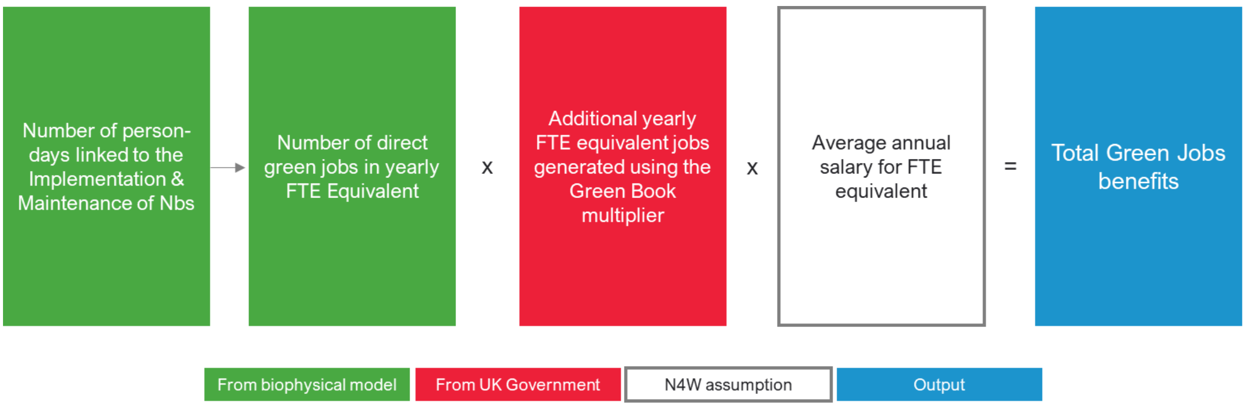

Figure 42: Schematic diagram of green job creation benefits estimation

Definitions

- FTE: Full-time Equivalent.

Process

- This process involved the assessment of the total number of days required for the implementation and maintenance of each NbS.

- This total effort was then converted to a total number of direct green jobs expressed in FTE.
- This number FTE was multiplied by the Green Book Multiplier (Green Book), to obtain the additional yearly FTE jobs generated.
- The yearly average salary per FTE was assumed by N4W, in coordination with the Warwickshire Wildlife Trust – the same that was used for the costings exercise (GBP 29,000/year).
- This resulted in a total monetary value of salaries paid as a result of green job creation (both direct and indirect).

Recreational Value

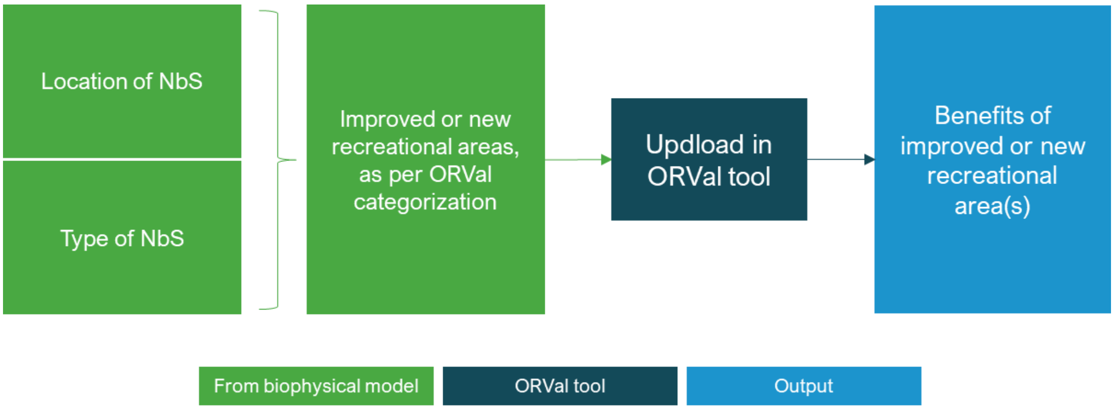

Figure 43: Schematic view of recreational benefits estimation

Definitions

- ORVal: Outdoor Recreation Valuation tool ORVal tool.

Process

- By looking at the distribution of NbS in the targeted modelling area, the N4W team was able to identify various areas that could be considered as recreational sites in the targeted modelling area (4 different sites).
- These sites were then uploaded to the ORVal tool, by defining their size, their location, and their land cover (based on the combination NbS for each site).
- This resulted in a total monetary benefit linked to the creation of these 4 recreational sites.

Physical Health

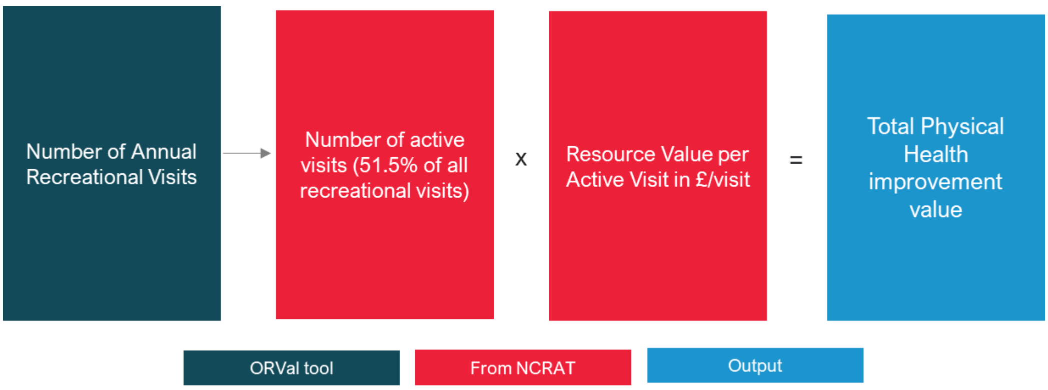

Figure 44: Schematic view of physical health benefits estimation

Definitions

- ORVal: Outdoor Recreation Valuation tool ORVal tool.
- NCRAT: Natural Capital Register and Account Tool NCRAT.

Process

- Another output from the ORVal tool (based on the created recreational sites) is the annual number of visits per year.
- The NCRAT tool determines that 51.5% of all recreational visits are active, and assigns a monetary value to these visits, corresponding to the avoided public health costs linked to improved physical health because of these active visits, which have a positive impact on people's life expectancies.
- This resulted in a total physical health improvement value.

The Nature Conservancy

Nature for Water
Local solutions. Global impact.

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