Natural Capital and River Basin Management Planning

Protecting and Improving Scotland's Water Environment

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CENTRE OF EXPERTISE FOR WATERS

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Glossary

Common International Classification of Ecosystem Services	A detailed and standardised classification system for ecosystem services, distinguishing between provisioning, regulating, and cultural services.
Condition	The relative ecological status, health, or quality of an ecosystem reflecting the capacity of an ecosystem to maintain its structure and function over time.
Corporate Sustainability Reporting Directive	Legally binding EU directive that requires large companies to disclose standardised information on environmental, social and governance sustainability issues to increase reporting transparency.
Ecosystem services	The benefits humans receive from healthy ecosystems, including provisioning, regulating and maintenance and cultural services.
Ecosystem disservices	Negative impacts that ecosystems can have on human health or economy such as spreading disease, or pests.
Enabling a Natural Capital Approach	UK Government tool and guidance framework for valuing ecosystem services and integrating natural capital into decision-making.
Environmental, Social and Governance	Reporting relating to the sustainability and ethical goals of an organisation building its reputation and driving consumer demand. ESG reporting is increasingly looked at by financial institutes.
Functions	The physical, chemical and biological processes that occur within ecosystems and support the delivery of ecosystem services.
Functional linkages	The dependencies and interactions between the functions delivered by one ecosystem or natural capital asset and another ecosystem or asset, e.g., how land management interventions in terrestrial ecosystems may affect water environment outcomes.
Invasive Non-Native Species	Species introduced outside their native range that are invasive in nature causing ecological or economic harm.
Monitoring, Reporting and Verification	Monitoring, reporting and verification processes used to ensure transparency and accountability in ecosystem restoration and natural capital markets.
Nature-based solutions	Actions to protect, sustainably manage and restore managed and natural ecosystems targeted to address societal challenges whilst providing well-being and biodiversity benefits (IUCN definition)
Natural Capital	The stock of natural assets (e.g. soil, air, water, habitats, species) that provide ecosystem services supporting human wellbeing and economy.
Public goods	Goods or services that are freely available and openly accessible to all members of society with their use by one person not impacting availability to others (e.g. clean water, biodiversity and street lighting).
Payment for Ecosystem Services	Financial incentivise land managers to undertake practices intended to support or ensure ecosystem service.
River Basin Management Planning	A strategic framework under the EU Water Framework Directive for managing water resources at the catchment scale to improve water quality, ecological status, and resilience.
System of Environmental-Economic Accounting	Framework that integrates environmental data with economic accounts, used to classify ecosystem services into policy-relevant categories.
Water Framework Directive	European legislation targeted to protect the water environment and achieve “good status” through integrated catchment management.
Willingness to pay	The amount of money people are prepared to spend to obtain a good, service, or benefit providing a perception of value for that benefit.

Acronyms

AGWA	Automated Geospatial Watershed Assessment
BNG	Biodiversity Net Gain
BSI	British Standards Institution
CICES	Common International Classification of Ecosystem Services
CIEEM	Chartered Institute of Ecology and Environmental Management
CSRD	Corporate Sustainability Reporting Directive
DESNZ	Department for Energy Security and Net Zero
ENCA	Enabling a Natural Capital Approach
ERC	Ecosystem Restoration Code
ESG	Environmental, Social and Governance
ESVD	Ecosystem Services Valuation Database
FAS	Farm Advisory Service
FIRNS	Facility for Investment Ready Nature in Scotland
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
INNS	Invasive Non-Native Species
MRV	Monitoring, Reporting and Verification
NARIA	Natural Asset Recovery Investment Analytics
NIS	Nature Investment Standards
ONS	Office for National Statistics
PES	Payment for Ecosystem Services
PRAGMO	Practical River Restoration Appraisal Guidelines for Monitoring Options
RBD	River Basin District
RBMP	River Basin Management Planning
SEEA	System of Environmental-Economic Accounting
SEPA	Scottish Environmental Protection Agency
SG	Scottish Government
SPEN	Scottish Power Energy Networks
SSEM	Scottish Society for Ecological Modelling
SuDS	Sustainable Drainage Systems
SWMM	Storm Water Management Model
TNFD	Taskforce on Nature-related Financial Disclosures
WCC	Woodland Carbon Code
WFD	Water Framework Directive
WTP	Willingness to Pay

Executive Summary

Purpose of research

Natural capital offers a powerful mechanism to foster alignment across policy areas and should be at the heart of decision-making to meet the Scottish Government's ambitions for water, biodiversity, climate resilience, public health, net zero and sustainable land use. Adopting a natural capital approach to River Basin Management Planning (RBMP) will help prioritise landscape-scale actions that improve ecosystem functions which in turn support greater resilience and delivery of multiple benefits that transcend policy areas. To achieve this, we need to improve our understanding of the dependencies and interactions between the catchment's natural assets and the water environment. To inform the fourth RBMP cycle (2027–2033) this project aims to answer the following questions:

- What benefits (or ecosystem services) does the water environment in Scotland provide to nature, climate adaptation, public health, net zero and agriculture?
- What natural assets have the most significant influence on the condition of the water environment, as measured through the RBMP?
- How does the implementation of actions to protect, restore and enhance these assets (i.e. nature-based solutions – NbS), individually or in combination, affect the condition of the water environment and what are the wider impacts to nature, climate adaptation, public health, net zero and agriculture?
- What are the costs and potential benefits of investing in the protection and improvement of these natural assets? To what extent do current natural capital investment opportunities take account of the benefits to the water environment?
- What data and tools are currently available on the extent, condition, and opportunities for improvement of relevant natural assets? What is the status of those tools and data in terms of access, cost of use, licensing constraints etc.?

Background

RBMP is a catchment-based framework to identify key pressures (e.g. including pollution, physical modifications to waterbodies, loss and degradation of habitats) impacting the water environment and implement actions to address these pressures. The first three RBMP cycles have made significant progress. However, looking ahead there is a clear need to accelerate progress through adopting a more holistic catchment-wide natural capital approach. Such an approach will help prioritise and spatially target NbS to protect, enhance and restore natural capital and enhance the water environment whilst supporting a wide range of ecosystem services. Adopting such an approach will increase the relevance of RBMP to all society.

Key findings

- Ecosystem functions within the water environment underpin a wide variety of ecosystem services, demonstrating the strategic role that the water environment plays in supporting human wellbeing, the environment and economy.
- Key sectors in Scotland including forestry, agriculture, spirits/malting, tourism, water and sewage, electricity and aquaculture strongly rely on the water environment to provide crucial ecosystem services (e.g. water supply, flood protection, recreation, water flow maintenance and climate resilience).
- Our evidence indicates that natural assets differ in their capacity to deliver ecosystem services depending on their design, condition, management and location. Heathy, well-functioning ecosystems typically offer benefits rather than disbenefits and provide a wider array of ecosystem services.
- We found well-documented linkages between functions delivered by natural assets and the water environment. This demonstrates the importance of NbS that protect, enhance and restore these assets including river restoration, protecting soil health, wetland and woodland creation, riparian buffers and sustainable urban drainage systems.
- NbS that retain sediments, purify and store water and reduce runoff support the delivery of key water-related services, including water supply, water purification, flood mitigation and baseline flow regulation. Many NbS were multi-functional offering benefits extending beyond the water environment and building resilience to climate change.

- Some trade-offs were identified between NbS and 'business as usual' actions, particularly for agricultural production. For example, while some NbS may reduce agricultural outputs in the short-term, they can improve soil health, stabilise yields, improve profit margins and build resilience to climate change. Research is needed to properly evaluate these trade-offs.
- Catchments are complex with interacting factors (e.g. hydrology, the quantity and quality of natural assets, soils and weather) and this can make it difficult to directly evidence the impact of implementing NbS in the wider landscape (e.g. grazing management or hedgerow creation) on water-related ecosystem services.
- There are estimated economic values for several of key ecosystem services (provisioning of food and timber; regulating water and mass flows, water and air quality, and climate regulation; and cultural services including amenity, recreation and biodiversity) but gaps remain for some regulating services (e.g. pest and disease control, pollination and maintenance of biodiversity).
- Economic values are often context specific. For example, socio-economic factors such as population density may mean that values in an English context may overstate benefits for more rural areas of Scotland. There may also be important biophysical or spatial relationships that are not replicated when transferring values. Despite limitations, providing economic valuations for wider public goods helps build the business case for NbS.
- Blending public and private finance will be crucial in meeting the funding gap for ecosystem restoration. While market-based mechanisms are emerging in Scotland, without regulatory or compliance drivers in place, investment remains limited with market demand driven primarily by ecosystem service users (beneficiaries).
- Catchment-based approaches enable a holistic source-to-sea perspective of ecosystem functions and processes for planning and project aggregation, while also providing a clear geographic nexus. Aligning water outcomes with climate resilience, land-use strategy, public health and nature priorities could support coordinated investment for catchment-based NbS that deliver multiple benefits, including for the water environment.
- Informed decisions require the right data and tools to assist in the scaling up of action from the site to catchment-scale. There are a few notable datasets and toolkits, however with no one-size-fits-all solution, individual projects will typically need to pull together a bespoke toolbox that addresses the specific project context.

Recommendations

Strategic priorities for embedding a natural capital approach within RBMP

Strategically align policy and funding decisions.
Ensure climate, nature, health and wellbeing, planning and sustainable land use policies recognise and account for natural assets and the benefits they provide for the water environment. Better alignment and integration across these areas will help deliver more targeted and effective outcomes.

Adopt a whole catchment-scale approach to RBMP.
Catchments provide an appropriate scale for decision-making both ecologically and for coordinating action across policy areas. Managing land and water at this scale enables cumulative pressures and interactions to be understood and strategically addressed.

Strengthen evidence and integrated modelling.
Improve understanding of how different NbS impact the water environment and wider ecosystem services. Modelling to account for trade-offs, synergies and climate change to inform more robust decisions, reduce unintended consequences and build climate resilience.

Develop an integrated monitoring framework.
Establish an integrated monitoring and evaluation framework that aligns metrics with RBMP priorities and reflects underlying ecosystem functions. Consistent, transparent and quantifiable metrics will build confidence among regulators, investors and delivery partners.

Unlock private investment.
Private investment is needed to close the funding gap for nature restoration. Credible blended finance models can attract investment where barriers to market participation are addressed and high-integrity mechanisms are developed to drive demand.

Support practical delivery.
Share learnings, develop clear guidance and build capability to translate strategy into effective catchment-scale action. To facilitate delivery, collate existing data and tools. Strengthening capacity on the ground is essential to embed a natural capital approach in catchment management.

1.0 Introduction

1.1 Background and scope

Natural capital is the renewable and non-renewable stocks of natural assets, including geology, soil, air, water and plants and animals that combine to yield a flow of benefits to people (Scotland's National Strategy for Economic Transformation). Scotland is renowned globally for its natural capital. Together with the direct economic benefits of high-quality waters, its rivers and lochs support salmon fisheries, while its iconic heather moorlands, clean bathing waters and ancient Atlantic rainforests attract tourists and provide recreational opportunities boosting the economy and the nation's health and wellbeing (Scottish Government 2025a). The UK's Natural Capital Accounts estimated that Scotland's natural assets are worth around £254.7 billion. These assets provide approximately £38.7 billion in ecosystem services annually (based on 2022 data: Office for National Statistics (ONS), 2024a), contribute around £40.1 billion to Scotland's total economic output and support around 261,000 jobs (Scottish Government 2024a).

Many of the benefits provided by nature lack a market value, as a result natural capital has historically not been adequately accounted for in decision-making. This has led to the global degradation of natural assets and the ecosystem services they underpin, with freshwater and river environments particularly under pressure (Dasgupta 2021). With the degradation of natural capital putting the economy and societal wellbeing at risk, protecting, enhancing and restoring natural capital must be embedded into decision-making.

Healthy, well-functioning ecosystems underpin Scotland's economy, communities, and overall well-being, while building resilience to environmental and climate change. Recognising this crucial role, investing in nature recovery and nature-based solutions (NbS) are increasingly embedded across policy areas. Adopting a natural capital approach will help the Scottish Government (SG) deliver outcomes outlined in The Scottish Biodiversity Strategy to 2045, National Planning Framework 4 (NPF4), Scottish National Adaptation Plan (SNAP3), Agricultural Reform Programme and Net Zero Nation Framework and support actions within River Basin Management Planning (RBMP).

In providing a common framework a natural capital approach has the potential to support more joined-up delivery across policy areas benefiting water, biodiversity, climate adaptation, public health, net zero and sustainable agriculture.

RBMP provides the strategic framework to protect and improve the water environment, integrating ecological, hydrological, and socio-economic considerations. Under the third RBMP cycle (2021–2027), key priorities included actions to create healthier and more resilient communities; water supply and wastewater; sustainable and resilient rural land use; and removing barriers to fish migration. There are two RBMPs, one for the Scotland river basin district (RBD) and one prepared jointly with the Environment Agency for the cross-border Solway Tweed RBD. RBMP aims to take a basin-wide perspective of key pressures affecting the condition of the water environment, identify actions to address these pressures, set targets and monitor progress towards these targets. As the third cycle comes to an end, there is an opportunity to reflect on progress made and look ahead to the fourth RBMP cycle (2027–2033).

RBMP in Scotland has historically focused on actions to protect and improve natural assets close to waterbodies (e.g. restoring rivers and wetlands) and/or to address point source and diffuse pollution. Such actions have successfully protected the water environment from further deterioration and improved the ecological status of many waterbodies.

Despite these successes, many of Scotland's watercourses remain in less than good condition and the focus on waterbodies means opportunities for broader, landscape-scale interventions that deliver multiple benefits may have been missed.

Scotland's water environment faces a range of anthropogenic pressures, including diffuse and point source pollution and physical modifications to waterbodies, alongside loss, fragmentation and degradation of habitats at the catchment scale (e.g. peatlands, woodlands, grasslands and wetlands). These stressors affect chemical, physical and ecological processes degrading the condition and classification of waterbodies. These impacts are further compounded by climate change, increasing pressure on both water and land and the introduction and spread of Invasive Non-Native Species (INNS) on land (along riparian margins) and in waterbodies. Collectively these stressors can have cascading effects on ecosystem structure and function (Gallardo *et al.* 2016, Van Vliet *et al.* 2023).

Water quality and flow are strongly influenced by the mosaic of habitats and land uses within a catchment (Aalipour *et al.* 2022). The condition of these natural assets directly affects not only the health of Scotland's water environment, but also the delivery of a wide range of public goods, including flood mitigation, water supply, and carbon sequestration. NbS are actions targeted to protect, sustainably manage and restore these nature assets to tackle societal challenges including health and wellbeing, water security, climate change and biodiversity loss (IUCN 2020).

The fourth RBMP cycle provides an opportunity to accelerate progress by adopting a more holistic, catchment-wide approach that considers the full range of natural assets, their condition and spatial arrangement within a catchment. SEPA and Scottish Water's *One Planet Choices* framework promotes such an approach to identify current and future pressures and develop solutions that deliver multiple benefits thereby driving innovation in catchment management (Melville *et al.* 2023).

Central to success, is to increase our understanding of how landscapes influence water quality, ecosystem health, and ecosystem service delivery. Embedding natural capital thinking within catchment planning is key to translate this understanding into actions that are tailored to local contexts and deliver co-benefits across water, biodiversity, climate, and community outcomes. A natural capital approach also helps to identify key stakeholders who benefit from, depend on, or can contribute to the management of these assets. This supports more sustainable and resilient business models alongside the growth of voluntary and regulatory natural capital markets.

With public funding alone insufficient to meet Scotland's climate, biodiversity, and water ambitions (GFI *et al.* 2021), blending public and private investment is essential to close the fund gap for nature restoration. Integrating ecosystem service and natural capital valuations into policy and on-the-ground delivery therefore has a crucial role to play going forward. Payment for ecosystem services (PES) mechanisms recognise the functional linkages between a catchment's natural assets and the water environment incentivising investment in these assets to benefit the water environment (often referred to as payment for watershed services). Payment for watershed services represent the most mature PES sector and continue to expand globally (Salzman *et al.* 2018).

Untangling the multiple linkages between the natural assets within a catchment and the water environment is complex, making it difficult to determine the impact of specific NbS on the wide range of ecosystem services a catchment provides (Adams *et al.* 2022; Adams *et al.* 2024).

Strengthening our understanding of how a catchment's natural capital influences the water environment and the benefits it provides to people, communities, and businesses, will be vital in supporting the SG's goals for nature restoration, climate adaptation, public health, net zero, and sustainable agriculture.

There is currently a policy window to embed a natural capital approach within the fourth RBMP cycle. By identifying key natural assets, their functional linkages to the water environment and the ecosystem services they provide, alongside NbS that protect, enhance and restore these assets, this project aims to inform future RBMP. This project combines desk-based research and economic evaluation to assess the impacts of NbS on key ecosystem functions, ecosystem services and societal wellbeing, while identifying potential uncertainties and risks and providing an example of how this works in practice. Finally, this project explores potential nature finance routes to fund conservation and restoration. This holistic, evidence-led approach aligns with the UK Government's Green Book and Enabling a Natural Capital Approach (ENCA) and provides a strong foundation for shaping RBMP and investment decisions that support Scotland's ambitions for nature restoration, climate adaptation, and societal wellbeing.

1.2 Project aims and key research questions

Project Aim: Conduct an evidence synthesis to assess the current state of knowledge of how investments in protecting and improving natural capital influence the state of the water environment. The synthesis also explores the wider benefits these investments provide for nature, climate adaptation, public health, net zero targets and agriculture. The research questions that the evidence synthesis addressed are outlined in Figure 1.

Key research questions

1. What benefits (or ecosystem services) does the water environment in Scotland provide to nature, climate adaptation, public health, net zero and agriculture?

2. What natural assets have the most significant influence on the condition of the water environment, as measured through the RBMP?

3. How does the implementation of nature-based solutions, individually or in combination, affect the condition of the water environment and what are the wider impacts to nature, climate adaptation, public health, net zero and agriculture?

4. a) What are the costs and potential benefits of investing in the protection and improvement of these natural assets?
   b) To what extent do current natural capital investment opportunities take account of the benefits to the water environment?

5. a) What data and tools are currently available on the extent, condition, and opportunities for improvement of relevant natural assets?
   b) What is the status of those tools and data in terms of access, cost of use, licensing constraints etc.?

Figure 1: Key research questions.

1.3 Report structure

This report is structured to address the project objectives methodically (Figure 2). Each component includes its own methodology and results section, starting with an assessment of the ecosystem services supported by Scotland's water environment (Section 2). This is followed by a semi-systematic literature review exploring the effectiveness of NbS on water-related outcomes (Section 3). Section 4 presents valuation data, quantifying the benefits of NbS through existing economic data. Section 5 reviews the landscape of natural capital markets and opportunities aligned with river basin management planning. Section 6 synthesises the evidence as logic models linking natural assets, NbS, and functional ecological and hydrological processes, while Section 7 provides an overview of the available tools and datasets that can be used to target NbS. The report concludes with key recommendations (Section 8) and overall conclusions (Section 9).

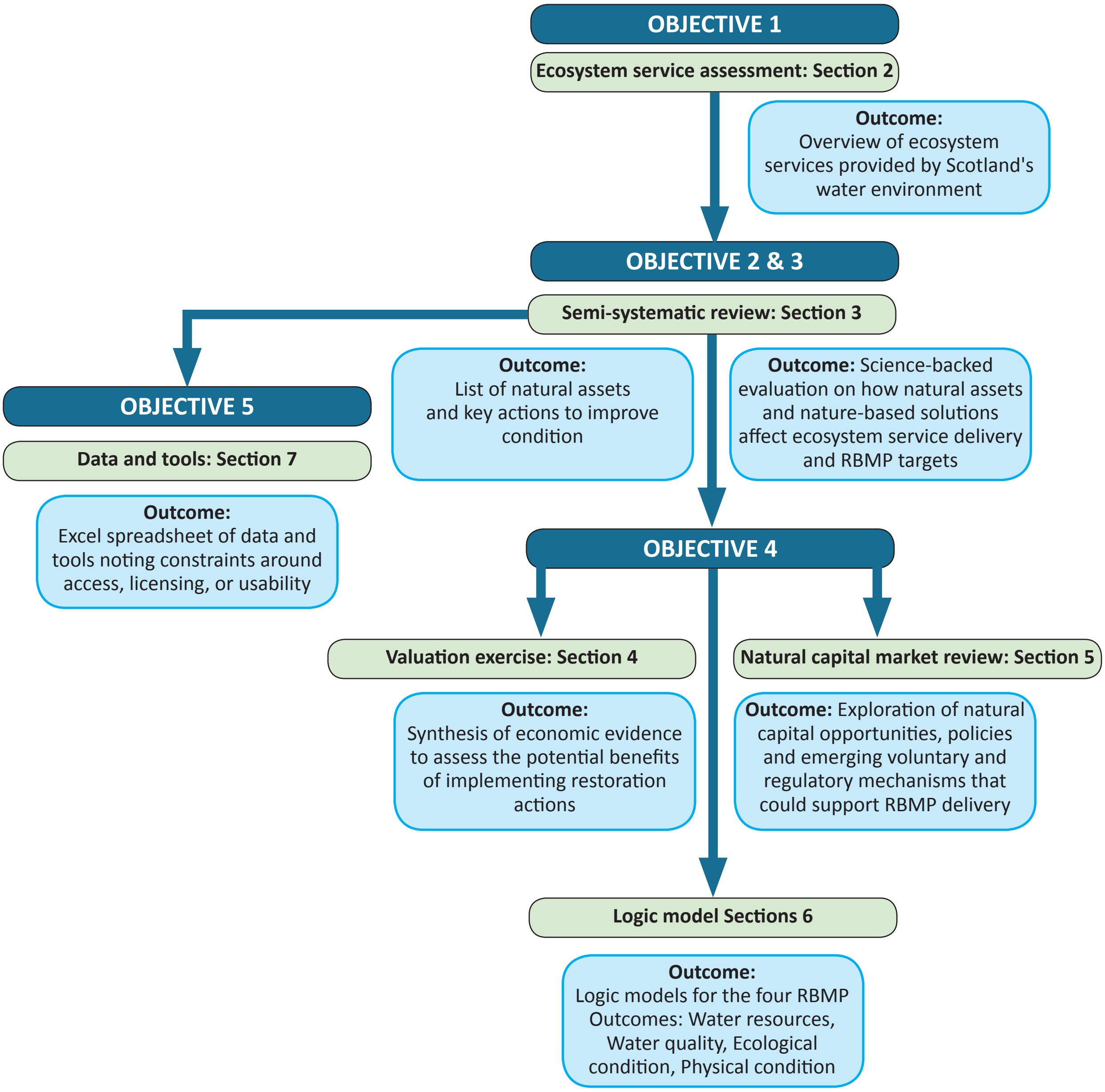


Figure 2: Overview of research objectives, steps and outcomes.

2.0 Ecosystem service assessment

2.1 Methodology: Ecosystem service assessment

A two-step process was used to identify the importance of the water environment in delivering ecosystem services.

Step 1: Identification using CICES

The Common International Classification of Ecosystem Services (CICES Version 5.2; Haines-Young, 2023) provided the starting framework for this exercise. CICES provides a detailed, comprehensive and standardised categorisation of ecosystem services and recognises three main categories:

- Provisioning services (e.g. food, water, raw materials)
- Regulating and maintenance services (e.g. regulation of water runoff, water purification, base flows and soil quality)
- Cultural services (e.g. recreational activities, aesthetic value, cultural identity)

CICES makes the distinction between benefits that are underpinned by living systems (e.g. plants, animals, microbes) termed ecosystem services, and those underpinned by non-living processes (e.g. hydrology, geology) termed geosystem processes. With considerable overlap between these groupings, we have used the terminology ecosystem services for both. For each ecosystem service listed in CICES, researchers identified whether it was underpinned by the water environment. Water for crop and livestock production are included separately (i.e. Water supply and Water flow regulation) and consequently to avoid double counting, provisioning services were only included when they related to aquatic produce. It is, however, important not to undervalue the role the water environment plays in terrestrial food and fibre production.

Step 2: Simplification using SEEA

CICES is highly detailed and consequently to ease interpretation the identified water-related ecosystem services were cross-referenced with the System of Environmental-Economic Accounting (SEEA) framework (United Nations 2021). SEEA classifies ecosystem services into broader, more policy-relevant categories and this framework was therefore used in the semi-systematic review and ecosystem service evaluation.

2.2 Results: Ecosystem service assessment

A total of 98 ecosystem services are identified by CICES[1]. Of these services, 70% (69 services) were considered as water-dependent including all cultural services (Table 1; Appendix 1 Table 15). Additionally, 64% of provisioning services and 59% of regulation and maintenance services were also strongly reliant on the water environment. Within the SEEA Framework, 73% (22 of 30 services) were deemed water-dependent, again including all cultural services together, with 50% of provisioning and 76% of regulating services (Table 1; Figure 3; Appendix 1 Figure 15 and Figure 16).

The prevalence of water-dependent services demonstrates the crucial role the water environment plays in sustaining and regulating ecosystem processes and providing economic and societal benefits. Many key sectors (e.g. agriculture, fishing and aquaculture, forestry, water and sewage, spirits and malting, tourism and electricity) are critically reliant on the water environment to provide important ecosystem services, including surface water, flood and storm protection and water flow maintenance (Scottish Government 2025a).

Freshwater provisioning plays a central role in supporting agriculture, food processing, manufacturing, drinking water and tourism. Fish provisioning alone (drawing on both freshwater and marine environments) was valued at approximately £166.5 million per year (ONS 2024a). In contrast, services such as pollination and natural pest control, while essential to agricultural productivity, are only partially linked to the water environment.

[1] Figures exclude seven ecosystem services labelled as 'Other' which provided a catch-all category.

Table 1: Ecosystem services and their dependency on the water environment.

Ecosystem service category	CICES		SEEA	
	Water dependent	Not water dependent	Water dependent	Not water dependent
Provisioning	25	14	4	4
Regulation & Maintenance	22	15	13	4
Cultural	22	0	5	0

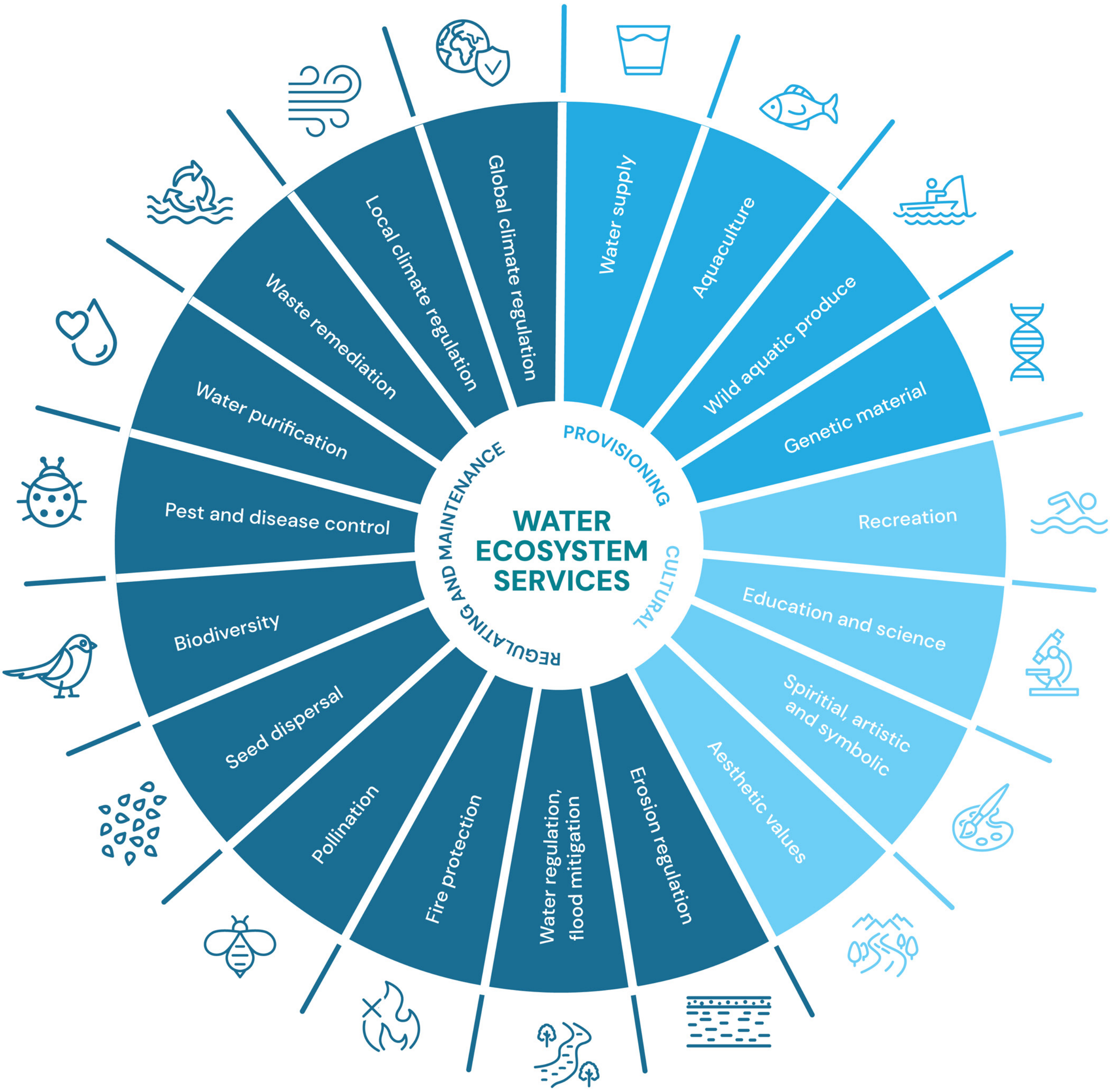


Figure 3: Diversity of ecosystem services provided by the water environment.

Different natural assets (e.g. arable land, woodland, floodplains) vary in their capacity to supply specific services. For instance, floodplains exhibit a high capacity for flood mitigation and water purification, while arable land primarily contributes to crop provisioning. The type and quantity of natural assets within a catchment therefore impacts on the portfolio of ecosystem services provided (Papacharalampou *et al.* 2015).

Ecosystem service delivery also strongly depends on the condition (i.e. quality) of natural assets and their spatial configuration within the landscape (Ogilvy *et al.* 2022; Debele *et al.* 2023). The same habitat type can provide contrasting outcomes depending on its ecological condition. For example, watercourses facilitate seed dispersal playing an important role in maintaining plant genetic diversity. However, when riparian zones support INNS, watercourses facilitate their spread. In such instances, the service of seed dispersal becomes a disservice. Similarly, healthy blanket bogs sequester and store carbon regulating the global climate, they provide natural flood management and support a range of specialist species (Strack *et al.* 2022). Degraded bogs, on the other hand, release carbon, can result in high water runoff, and have lower biodiversity value. **Healthy ecosystems, in good condition, are more likely to offer benefits rather than disbenefits whilst also providing a wider array of ecosystem services**.

Typically, when considering the condition of an asset we focus on ecological condition reflecting the asset's naturalness with respect to structure, composition, and ecosystem processes. However, the impact of an asset on ecosystem service delivery can vary depending on the services in question. For example, while core paths along a riverbank can increase recreational opportunities, their presence could adversely affect biodiversity due to increased disturbance by people and dogs. Such trade-offs in ecosystem service delivery often arise and consequently when assessing condition (i.e. what does good look like) it is important to consider the full diversity of ecosystem services (Fortier *et al.* 2016).

The spatial arrangement of habitats within a catchment also impacts their potential to deliver ecosystem services. Riparian woodlands, for example, provide shade which moderates stream temperatures, giving them greater capacity for local climate regulation than equivalent woodland located away from watercourses (Ogilvy *et al.* 2022). Hedgerows strategically placed along soil erosion pathways are more effective at intercepting sediment than those placed at random (Wolton *et al.* 2014). Catchment-scale planning must therefore consider the extent, quality and spatial arrangement of assets, when prioritising action to optimise ecosystem service provisioning.

Managing natural assets inevitably involves both synergies and trade-offs between ecosystem services which are important to consider, particularly with increasing pressures on land and water (Stosch *et al.* 2017). Land management practices designed to enhance crop and livestock production (e.g. field drainage, fertiliser application, or pesticide use) can adversely impact soil quality, water purification, and biodiversity. Such trade-offs can generate conflicts between stakeholders who have a vested interest in different ecosystem services. Effective stakeholder engagement is therefore essential when taking a natural capital approach to catchment management to ensure decision-making reflects both economic, societal and ecological priorities (Stosch *et al.* 2017).

3.0 Semi-systematic review

3.1 Methodology: Semi-systematic review

A semi-systematic review provided an unbiased approach to identify evidence regarding the effectiveness of different interventions across various catchment issues, which align to RBMP key outcomes (Table 2). Focus was on interventions to protect, restore and enhance natural assets (i.e. NbS) rather than on technical or engineering interventions, or those targeted to build social capacity such as training, education or farmer clusters. NbS included actions to prevent the degradation of natural assets (e.g. practices targeted to protect soils including cover crops and the reduction of grazing pressure in the uplands), actions to restore natural assets (e.g. reprofiling and rewetting of blanket bogs and actions to enhance natural assets (e.g. the creation of wetlands or expansion of riverwoods).

To avoid bias we did not pre-define NbS but instead adopted a broad approach (i.e. reviewing existing reviews/meta-analyses) that allowed the inclusion of a comprehensive range of NbS that improve natural capital asset condition/function and/or ecosystem services delivery and effectively address the catchment issues identified relevant to Scotland. Through this review we identified functional linkages that demonstrate how natural capital assets contribute to ecosystem function and ecosystem service delivery, with a focus on RBMP outcomes.

The four key stages of our systematic review process are outlined in Figure 4. The first stage clearly defined the scope of the review supporting the construction of search terms used to identify relevant evidence. Search terms were identified from the current project specifications, and RBMP current and future environmental outcomes as noted in the River Catchment Restoration Monitoring Framework. Through Web of Science we identified 2,132 primary literature publications, which were limited to those published between 2015 – 2025 resulting in 1,104 papers for review (search terms outline in Appendix 2). This was accompanied by an additional 90 publications identified through six searches using Elicit, an AI-powered research tool (search terms outline in Appendix 2).

Grey literature was collated through three Google searches (1) "meta-analysis of most effective catchment management for water quality", (2) "best management for water quality meta-analysis UK" and (3) "meta-analysis best management for water conservation UK". The first 30 'hits' were reviewed with the top 10 in each search being assessed in more detail.

Table 2: RBMP outcomes, pressures and issues informing the review.

RBMP outcome	Example issues
Water Quality	Diffuse and point source pollution from agriculture (fertiliser, pesticides, sewage sludge, machinery, erosion) and forestry (fertiliser, pesticides, machinery, erosion)
	Urban environments (toxins, chemicals, deposition of fumes, sediment, residential wastes, garden chemical use, sewage overflow)
	Organic matter and sedimentation from degraded soils
Water Resource	Sustainable/efficient use of water across sectors
(water flow and levels)	Water runoff and storage
Ecological Condition (aquatic biodiversity, fish migration, INNS)	Structural barriers (weirs, culverts, bridges) and infrastructure design
	Habitat fragmentation
	Invasive non-native species (in aquatic environments and along riverbanks)
Physical Condition	Risk of human intervention (straightening, embanking, damming, bank reinforcement) on hydrology, ecology, and health/wellbeing for people
	Climate change (fluctuations in temperatures)
	Bank stability (erosion risks)

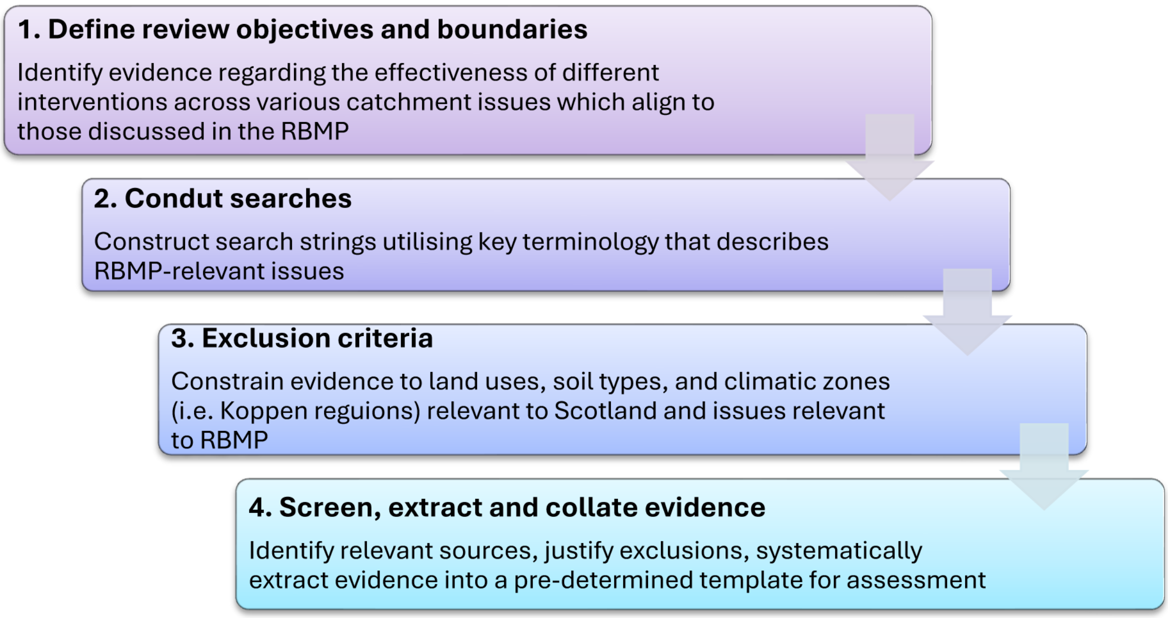


Figure 4: Semi-systematic review process.

Finally, a further 11 sources of evidence were included that were either highlighted in the tender or considered key sources by the research team. This identified a total of 1,235 sources of evidence which were screened to determine suitability for inclusion (1,104 via Web of Science, 90 via Elicit, 30 via Google and 11 via the tender/research team). Abstracts were scanned and justification for excluding sources was recorded. Exclusion criteria included sources not being relevant to Scotland (land use, habitats, soil, climate types), and sources not providing evidence on NbS, ecosystem services and RBMP priority issues/outcomes.

An initial scoping exercise identified 37 NbS with the potential for positive impacts on the water environment (Appendix 2). For each NbS, using a standardised spreadsheet, researchers extracted information for seven functional linkages to the water environment (Table 3) and 28 ecosystem services (as defined by SEEA: Appendix 2) (United Nations 2021).

Discussions were held early in the review process to ensure agreement in how the evidence should be represented in the extraction spreadsheet, e.g. data were only included when supported by evidence within the literature. This alongside the provision of detailed instructions provided a quality control measure to ensure consistency across the extraction of evidence. To ease interpretation, prior to summarising the data, the 37 NbS identified were grouped into 17 broad categories which aligned with RBMP priorities (Appendix 2). For completeness, summary heatmaps for the 37 NbS are also provided (Appendix 3).

Data was extracted for each NbS alongside the functional linkage/s that NbS had with the water environment. For example, noting evidence where peatland restoration (NbS) enhanced water storage and reduced runoff (functional linkage). To provide a measure of evidence strength we calculated the number of studies reporting each NbS-functional linkage pairing. Low evidence indicated that the NbS was only found to provide a specific linkage in 1–4 studies, medium 5 - 10 studies and high evidence being over 10 studies. Summary data was visualised as a heatmap (Figure 5).

Evidence on the impact of NbS on ecosystem service delivery was also extracted by noting the direction of impact in the data extraction spreadsheet. For each NbS and ecosystem service, the direction of impact was summarised to one of six categories: positive, positive to neutral, neutral, neutral to negative, negative, or negative to positive. For example, vegetated buffers having a positive impact on water purification, and a neutral to negative impact on crop production. The extraction template was left blank if the ecosystem service was not considered. With the literature search focussing on review papers and meta-analyses, mixed effects were common. Consequently, to avoid overgeneralising, only the main trend was extracted unless the evidence was genuinely mixed. Data were summarised by providing an overall count of studies reporting the impact of an NbS on ecosystem service delivery noting the effect direction. This allowed us to identify the dominant trend. Confidence was determined by considering the number of studies and the level of agreement among them: High confidence (more than 10

Table 3: List of functional linkages explored through the literature.			
Functional linkage	**Description**	**RBMP Outcome**	**Key ecosystem services impacted**
Water storage and reduced runoff	The NbS restored natural runoff and/or surface water storage and retention processes resulting in a reduction in water runoff and increased water storage.	Water resources (river flows, water levels and water use)	Flood mitigation Baseline flow maintenance Water supply
Retention and cycling of sediment and nutrients	The NbS increased the retention, recycling and bioremediation of sediments, nutrients, organic matter and/or other pollutants.	Water quality	Water supply Soil and sediment retention and nutrient cycling Solid waste remediation Water purification
Biological composition	The NbS helps to enhance the natural biological community of the watercourse restoring community interactions, and biogeochemical processes.	Ecological status (including fish migration, INNS)	Biodiversity (aquatic) Wild aquatic produce Aquaculture Genetic materials
Vertical connectivity	The NbS enhances vertical connectivity (i.e., surface/groundwater interaction, infiltration groundwater recharge and discharge).	Water resources	Flood mitigation Baseline flow maintenance Water supply
Lateral connectivity	The NbS enhances lateral connectivity (hydrologic and ecological) improving the natural movement of water and enhancing ecological connectivity between the watercourse and its adjacent floodplain or riparian zone.	Water resources Ecological status Physical condition	Biodiversity (aquatic) Wild aquatic produce Aquaculture Genetic materials
Longitudinal connectivity	The NbS enhances longitudinal connectivity (hydrologic and ecological) improving the continuous flow of water and enhancing ecological connectivity along the watercourse from headwaters to mouth.	Water resources Ecological status Physical condition	Biodiversity (aquatic) Wild aquatic produce Aquaculture Genetic materials
Thermal buffering and regulation	The NbS provides thermal buffering (e.g. through shade and shelter) which helps to stabilise and regulate waterbody temperatures, reducing the impact of extreme weather events.	Physical condition	Local climate regulation (aquatic)

studies and >90% agreement), Medium (5–10 studies and 70–90% agreement), and Low (fewer than 5 studies or <70% agreement). For example, if 8 out of 10 studies found peatland restoration had a positive impact on flood mitigation the effect would be positive, and the confidence would be medium (i.e. 10 studies with 80% agreement). Results are displayed as a heatmap, with colour indicating the effect direction and symbol size reflecting confidence (Figure 6).

3.2 Results: Semi-systematic review

Nature-based solutions and functional linkages

The strength of evidence for connections between our 17 NbS and seven functional linkages with the water environment is summarised in Figure 5. Strong evidence across all seven linkages was found for urban NbS, and riparian buffers (blue cells), with moderate to strong evidence for the restoration of wetlands (natural and constructed), rivers, floodplains and woodlands (both riparian and non-riparian). These findings indicate well-documented relationships between these NbS and the underlying hydrological and biogeochemical processes that support a healthy water environment.

Through these functional linkages, key water-related ecosystem services are supported including water supply, water purification, flood mitigation, and baseflow maintenance. It is important to note that the impact of enhancing these functional linkages on ecosystem service delivery can vary depending on the context and the ecosystem service in question. For example, while restoring ecological connectivity is typically deemed to be positive to aquatic biodiversity (e.g. maintenance of genetic flow and allowing species to migrate to different reaches to meet resource requirements: Amoros and Bornette 2002), in some instances negative impacts may arise including facilitating the spread of INNS (Dolan *et al.* 2025). Impacts of NbS on ecosystem service delivery are more fully explored in the next section

Evidence for peatland restoration was largely confined to water storage and reduced runoff, indicating the prevalence of research in this field. For soil management, evidence focussed on water storage/reduced runoff, vertical connectivity and the retention of sediments/recycling of nutrients. Evidence for ponds and agroforestry was mixed and while moderate evidence supported improved water storage/reduce runoff, retention of sediments/recycling of nutrients and enhancing vertical connectivity there was little evidence that these NbS supported other functional processes (i.e. longitudinal and lateral connectivity, thermal buffering and biological composition). Few studies demonstrated functional linkages with the water environment for the control of INNS, hedgerow creation, and lowland and upland grazing management.

It is important to note that a lack of evidence does not necessarily reflect a lack of impact on these functional linkages, but rather these connections were not demonstrated or quantified in the literature reviewed. For example, there is strong evidence that hedgerows trap and retain sediments (Bert *et al.* 2017, Xiong *et al.* 2018), and that overgrazing in the uplands results in soil erosion (McDowell *et al.* 2004; Sansom, 1999). Catchment scale processes, such as runoff and sediment or nutrient transport, often have an indirect influence on riverine functions affecting the physical integrity of the water environment which, then in turn, affects other riverine functions (Beechie *et al.* 2013). These indirect effects were, however, poorly captured in the review.

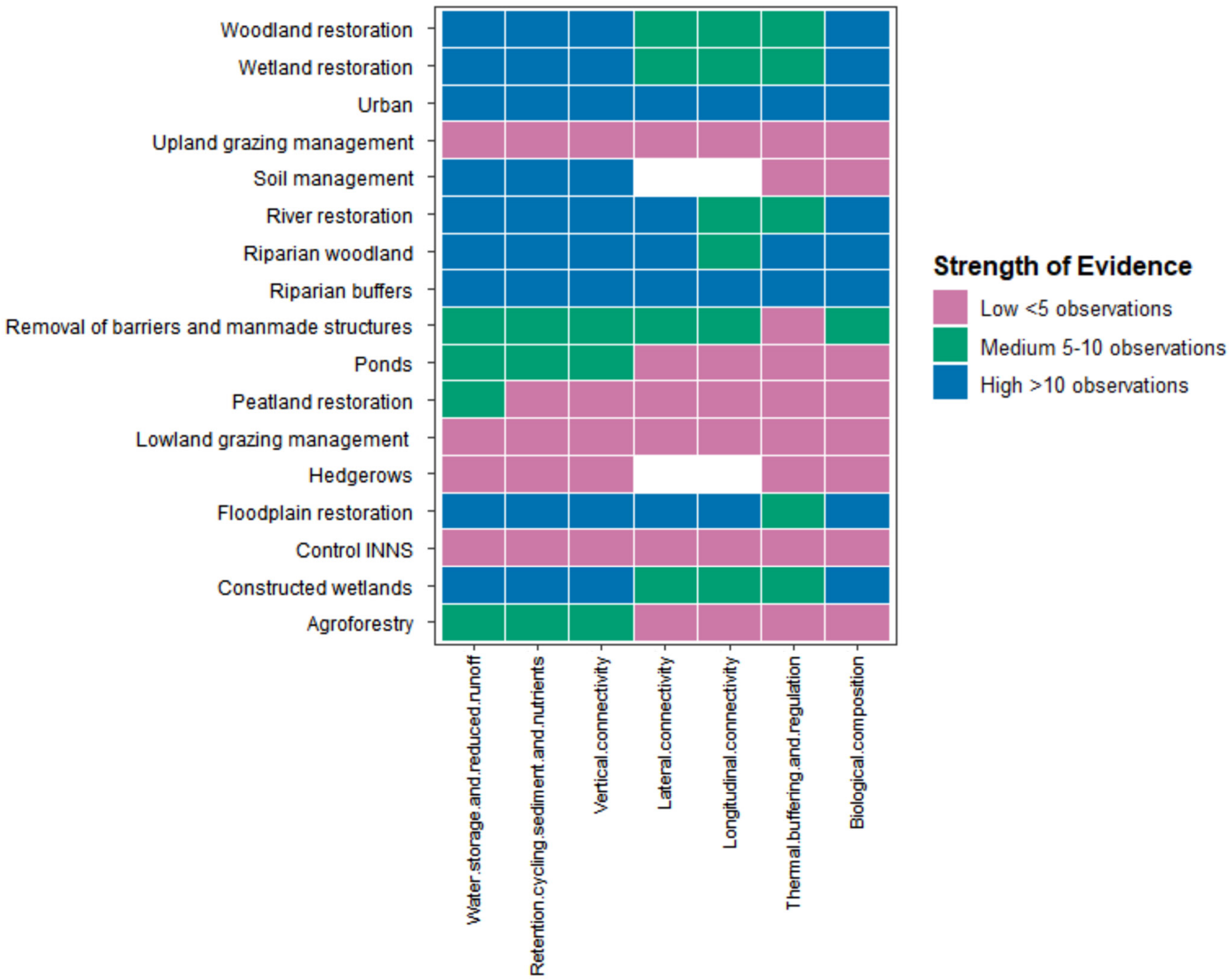


Figure 5: Functional linkages between NbS and the water environment. Colours represent the strength of evidence (i.e. the number of research papers that found a link between a specific NbS and the water environment). Blank cells indicate no evidence was found. Impacts on ecosystem service delivery are context specific, and consequently strength does not necessarily reflect a positive impact.

Nature-based solutions and ecosystem service delivery

The evidence collated for the impact of our 17 NbS on ecosystem service delivery is summarised in Figure 6. The literature review focussed on the key outcomes of RBMP; specifically, water quality, water resources (i.e. levels and flows), physical condition and ecological condition. Consequently, water-related ecosystem services were well represented in the evidence base. This was particularly evident for water supply, flood mitigation, baseline flow maintenance, aquatic biodiversity, soil and sediment retention, and water purification (Figure 6). For these key water-related ecosystem services, impacts were reported for between 14 and 16 NbS, with moderate to strong evidence available for between 7 and 13 NbS. The strongest evidence was found for soil and sediment retention (i.e. moderate to high confidence that 13 NbS provided this service) and water purification and flood mitigation (moderate to high confidence for 11 NbS). These findings reflect the robust functional linkages identified in Figure 5, specifically retention of sediments/recycling of nutrients, vertical connectivity and water storage/reduced runoff. Riparian buffers, soil management, urban measures, and wetland and floodplain restoration demonstrated strong evidence across these functional linkages, providing the mechanistic basis for the delivery of water purification, flood mitigation and baseline flow regulation.

Some water-related ecosystem services were less well evidenced. Evidence for NbS supporting aquatic climate regulation tended to be either lacking (11 NbS), or weakly positive (five NbS), although moderate evidence was found for riparian woodlands and riparian buffers due to their influence on buffering temperature extremes (see Figure 5). Similarly, only moderate evidence was found for NbS supporting wild aquatic produce provisioning (specifically river restoration and riparian buffers), and no NbS was found to have strong or moderate evidence on aquaculture provisioning services. Although strong evidence demonstrated benefits to water quality across a range of NbS, authors rarely articulated downstream benefits for the provisioning of aquatic produce (e.g. aquaculture, angling). This likely reflects a research focus on water supply and regulating services.

NbS such as riparian woodlands, urban NbS and riparian buffer strips not only supported water-related ecosystem services but also provided wider benefits (e.g. supporting terrestrial biodiversity and providing recreational opportunities) demonstrating strong multi-functionality (Cole *et al.* 2020; Ogilvy *et al.* 2022; Çeler and Serengil 2023).

The evidence reviewed **highlighted the importance of actions to protect natural assets from further deterioration.** In particular, inappropriate management can result in soils being lost through erosion with recovery taking hundreds of years. NbS that protect soils (e.g. reduced tillage and winter cover), not only reduced erosion risks, thereby protecting soils and watercourses, but also improved soil health and increased water infiltration and storage thus building resilience to climate change. It is therefore important to adequately value the role that NbS play in protecting asset condition and their contribution to building long-term resilience and safeguarding ecosystem service delivery.

Location, design, scale, management and condition of NbS were consistently identified as key factors influencing ecosystem service delivery (Debele *et al.*, 2023; Ogilvy *et al.* 2022; Cole *et al.* 2020; Zhu *et al.* 2025.). For example, targeting woodland planting along run-off/sediment pathways delivers greater benefits for water quality than untargeted planting (Ogilvy *et al.* 2022). Similarly, NbS targeted to protect soils (e.g. conservation tillage or reducing upland grazing pressure) will provide the greatest benefits to both soil health and water quality if implemented in steeply sloping ground where the risk of erosion is greatest.

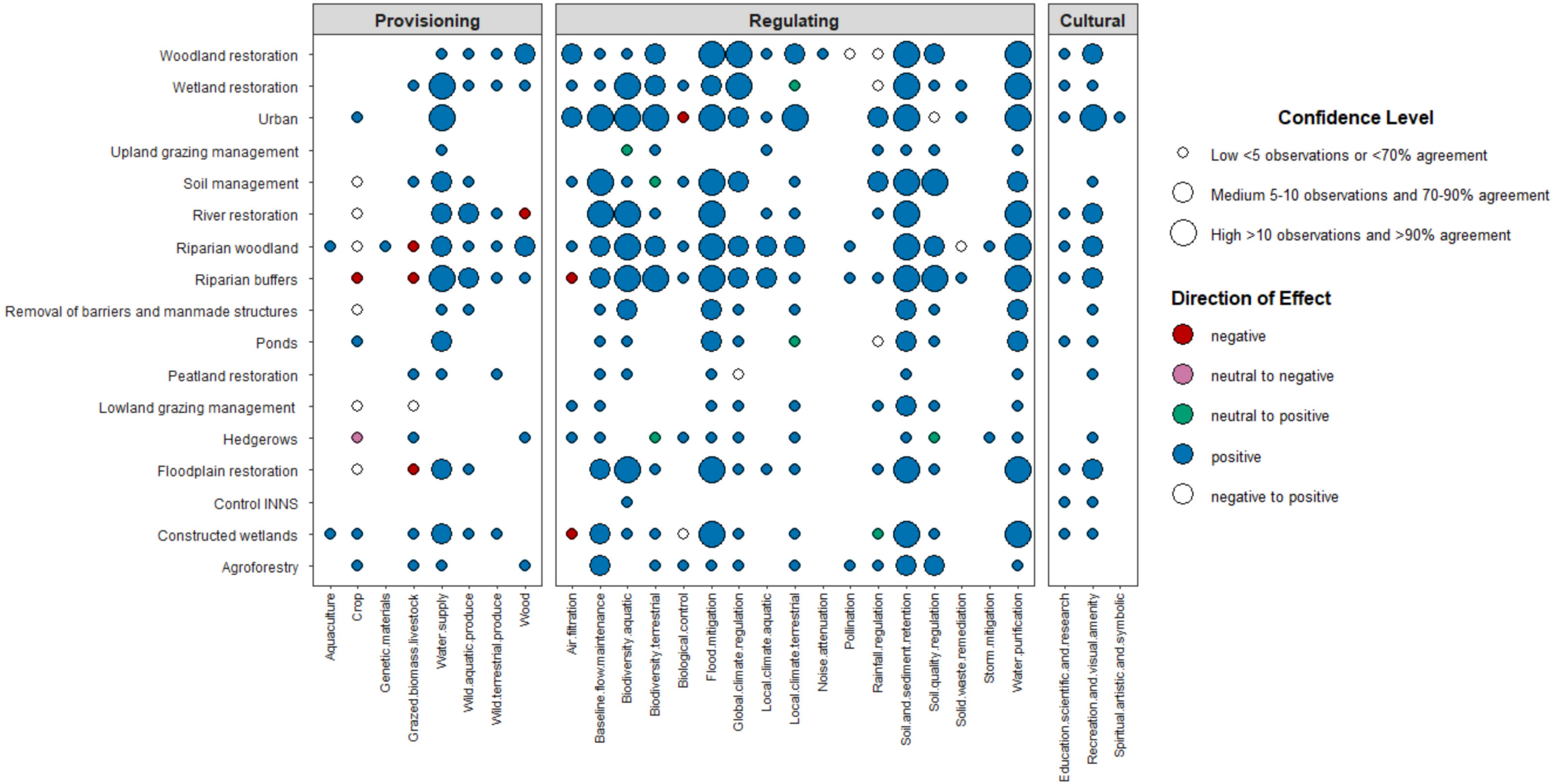


Figure 6: The impact of NbS on ecosystem service delivery. Colour indicates effect direction, and bubble size confidence level obtained from the number of studies and agreement between studies.

Management can also impact on the effectiveness of NbS. For example, while riparian buffers typically mitigate diffuse pollution, if inappropriately managed they can become nutrient saturated acting as a pollution source (Cole *et al.* 2020; Stutter *et al.* 2019; Stutter *et al.* 2025). Similarly, for urban ponds, the capacity to retain sediments and nutrients can decline with age, and under heavy rainfall such ponds can act as a pollution source (Kolath *et al.* 2021). This highlights the importance of continued management to ensure functionality and highlights the potential of integrating complementary measures to optimise outcomes (e.g. placing sediment traps adjacent to buffer strips will intercept sediments reducing the risk of nutrient saturation: Stutter *et al.* 2025).

While overall outcomes tended to be positive, some trade-offs were evident particularly for crop and livestock provisioning services. Trade-offs with provisioning services can arise when land is taken out of production (e.g. to create a buffer strips or floodplain), or when management is altered (e.g. soil management or livestock grazing densities) to provide wider environmental benefits (e.g. improved water quality or biodiversity). **While such trade-offs can impact on yield, evidence is building that NbS can restore soil health, improve farm resilience and/or profit margin (Kanter *et al.* 2018; Cole *et al.* 2021; Tscharntke et al 2024)**. Further research into the impact of NbS (particularly regenerative agricultural practices that target the reduction of pollution at source), on agricultural yield, profit-margin and resilience (e.g. stability of yield under climate extremes) would help build the business case for more widespread adoption (Mellander *et al.* 2025).

A holistic, catchment-based approach extends the focus of NbS beyond the waterbodies to consider the wider landscape processes that impact on the water environment. **Catchments are complex with interacting factors including hydrology, soils, local climatic conditions and asset quantity, quality and management, all impacting on the ecosystem services delivered. This can make it challenging to evidence the impact of landscape scale NbS on water-related ecosystem services.** This is further limited by the fact that NbS are frequently not implemented at the scale required to demonstrate clear impact (Ogilvy *et al.* 2022; Williams *et al.* 2024).

Evidence for the impacts of grazing management, control of INNS, and hedgerow establishment in the literature was typically weak, although positive impacts are often demonstrated at local scales (Bert *et al.* 2017, Xiong *et al.* 2018; McDowell *et al.* 2004; Sansom, 1999; Haapalehto *et al.* 2011). Strengthening the evidence base for these NbS will be crucial to quantify and value their full range of benefits, supporting the development of robust natural-capital approaches and emerging natural capital markets.

While the outcomes of NbS are context-dependent and at times uncertain, their role in restoring ecosystem health should not be undervalued. Healthier ecosystems not only provide a wider range of benefits (see above), but they are also more resistant and resilient to environmental stressors (Hernández-Blanco *et al.* 2022). NbS therefore can reduce risks, providing insurance and increasing the capacity of the ecosystem to buffer future pressures including environmental, land use change and climate change. The water environment, and the ecosystem services it underpins, are particularly vulnerable to climate change (Mellander *et al.* 2025; Schröter *et al.* 2005). Strategic catchment planning should therefore consider the avoidance of future environmental and economic costs through implementing NbS that safeguard and enhance the condition of the water environment.

3.3 Limitations: Semi-systematic review

A key limitation with this type of review is the risk of publication and confirmation bias. Projects that report clear benefits are more likely to be written up than those that find no impact or unintended negative impacts. Furthermore, as our review synthesises dominant trends in the published literature, mixed outcomes are likely to be under-estimated.

Rather than focusing in detail on a subset of NbS, the literature review aimed to capture a wide range of different NbS and consequently targeted searches for specific NbS were not conducted. Instead, the key search terms were designed to address catchment-scale pressures on the water environment (e.g. diffuse pollution, water abstraction and flow alterations, habitat loss and degradation, and climate change). This broad approach helps to explain why evidence for some NbS concentrates on a single well-established functional linkage (e.g. peatland restoration and water storage). It could also partly explain why some NbS that are important for RBMP, were not robustly captured in the literature (e.g. upland grazing management, hedgerow creation) suggesting that there remains a bias toward NbS located in or near waterbodies.

The complexity of NbS was clearly highlighted across research studies with NbS that are highly effective in one situation being less effective in another (Cole *et al.* 2020; Kolath *et al.* 2021; Lalonde *et al.* 2024). Effectiveness depends on a wide range of factors. For example, the effectiveness of SuDS ponds in mitigating diffuse pollution depends on pond dimensions, vegetation, age, frequency and spatial distribution with the catchment (Zhu *et al.* 2025, Kolath *et al.* 2021). The optimum design is therefore often context specific making generic guidelines difficult to formulate. Such nuances can make it difficult to predict the outcome of NbS and in some circumstances could even result in unintended consequences.

Research, local knowledge, and expert advice are therefore key to ensuring NbS are designed, implemented and managed to optimises the outcomes achieved.

Evidence gaps remained for several services, including noise attenuation, provisioning of genetic material, and spiritual, artistic, and symbolic cultural services. Such gaps likely reflect both the focus of our search terms on water-related outcomes, alongside research trends. Previous studies have also highlighted an underrepresentation of cultural and less tangible ecosystem services due to difficulties in measuring these services and this demonstrates the need for interdisciplinary research (e.g. Haines-Young 2023; Boerema *et al.* 2017; Fortier *et al.* 2016).

4.0 Valuation evidence

4.1 Methodology: Valuation evidence

Our approach to valuation of benefits follows the general principle of the ecosystem services cascade (Figure 7). Natural capital assets contribute to ecosystem functions producing ecosystem services which provide the benefits to people that we can value. This allows us to use values based on outcomes that can be applied, where appropriate, to different NbS.

Our primary source of valuation data was Defra's Enabling a Natural Capital Tool (ENCA) (Defra 2023). The ENCA Tool is a UK Government tool and guidance framework for valuing ecosystem services to assist with integrating natural capital into decision-making. ENCA has the advantages that the values included are UK relevant and it is consistent with the HM Treasury Green Book used in policy appraisals. However, although the values are generally applicable to Scotland, they may overestimate benefits where population size or density is an important element of the value calculation. Additionally, as ENCA is a compilation of values from different studies and sources, some of them can be fairly outdated from 10-20 years ago, which necessitates another layer of expert judgement in application as the natural environmental and valuation context might have changed since the original publication. Where necessary and possible, we will make appropriate adjustments to provide Scottish contexts. If data gaps exist, we identify appropriate secondary sources including the Ecosystem Services Valuation Database (ESVD) or literature searches.

The scope of ecosystem services benefits will include both the water environment and terrestrial outcomes (which may be the primary driver for measure implementation). Table 4 summarises where we have identified valuation evidence for each ecosystem service against broad categories of measures.

We used broad NbS categories, as due to the short project timeframe, the valuation evidence review and the semi-systematic review had to run concurrently and consequently there was not a finalised list of NbS. The valuation evidence is also related to final ecosystem services and may not be directly linked to specific NbS, but similar types of measures will have similar effects. There are gaps in the available valuation evidence, this reflects both an overall gap where a specific ecosystem service has not been valued, and gaps where links to impacts on the water environment are unclear. These include instances where service provision is very context specific and cannot be linked to general implementation of a measure. For example, pollination requires creation of suitable habitats for pollinators in proximity to pollinated crops, and noise attenuation requires suitable vegetation in proximity to both noise emitters and receptors. We discuss this further below with respect to the caveats for using estimated values for interception air pollutants. All values in the following section have been converted to 2024 prices unless otherwise stated using the latest UK GDP deflators available at the time of analyses (October 2025)[2].

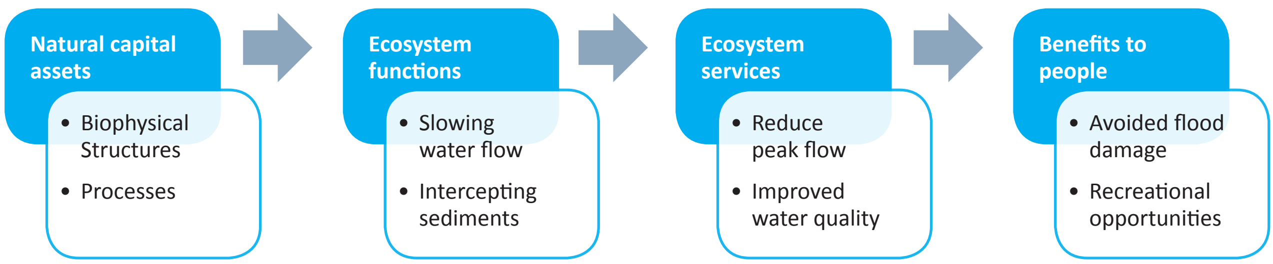


Figure 7: Ecosystem service cascade.

[2] https://www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-june-2025-quarterly-national-accounts

Table 4: Matrix of identified ecosystem service value estimates against broad categories of NbS.

	Provisioning services								Regulating services														Cultural services				
	Cultivated plants	Reared animals	Timber	Aquaculture	Wild plants	Wild animals	Genetic materials	Water supply	Erosion control	Hydrological cycle and water flow regulation	Hazard mitigation	Regulation of baseline flows and extreme events	Lifecycle maintenance, habitat/gene protection	Pest and disease control	Pollination	Water conditions	Solid waste remediation	Noise attenuation	Soil quality regulation	Air quality	Local climate regulation	Global climate regulation	Direct interactions, e.g. recreation	Indirect interactions, e.g. landscape & amenity	Physical and experiential interactions	Education, scientific and research	Spiritual, artistic and symbolic
River corridor restoration/interventions	■	■				■										■				■				■	■		
Floodplain restoration/interventions	■	■																		■		■		■	■		
Soil management and enhancement	■								■	■		■				■				■							
Restoration of on farm features (e.g. wetlands, hedgerows)																				■				■	■		
Moorland & peatland restoration/interventions							■	■				■				■				■		■	■	■	■		
Forestry and woodland restoration/interventions			■						■	■										■		■		■	■		
Urban interventions																				■	■			■	■		

4.2 Results: Valuation evidence

Provisioning services

Food production

ENCA provides a number of different value estimates for food production. The most relevant for our context are average annual farmland rent values for different agricultural activities. These are interpreted as an indicator of the contribution of land to agricultural output and the provisioning service provided by land. Land rental values have the advantage of reflecting the productive potential of land, i.e. its value as a natural capital asset, and are less prone to fluctuations in value due to variations in commodity prices and production costs. From the perspective of RBMP measures, these reflect the cost incurred in taking land out of agricultural use in terms of the natural capital value of the land, for example to allow riparian planting or floodplain restoration. ENCA uses Defra values for England, Scottish values are available from Farm Advisory Service (FAS, 2024) for the year 2024 and are summarised in Table 5. We recognise that annual rental values may underestimate actual income forgone (e.g. while the annual rental value for cereals is £160/ha the average gross margin for winter wheat is £1,280/ha: FAS 2024). However, land rental values better reflect the contribution of natural capital and are considered as best practice in natural capital accounting (NCAVES and MAIA, 2022). Gross margins will also include returns to man-made and human capital inputs.

Changing soil management to enhance soil health can reduce the damage and loss to soils due to erosion and compaction. ENCA includes estimates for these damage costs for England estimated in terms of production losses. The underlying study (Graves *et al.*, 2015) also produced estimates for the damages due to increased flood risk, water quality loss and diffuse contamination due to erosion and compaction. Subsequent Defra calculations have disaggregated these values to produce a range of per hectare values for the cost of soil erosion across these combined impacts.

The value for loss of agricultural production due to soil erosion ranges between £42 and £72 per ha and the loss due to soil compaction ranges between £257 and £314 per ha (Graves *et al.* 2015). Further analysis would be required to determine how transferrable these values are to Scotland reflecting the differences in production patterns and risks to soils. Baggaley *et al.* (2024) derive values for loss of production due to soil compaction for seven Scottish catchments based on the calculated levels of compaction, yield loss and the price of barley. Their estimates of yield losses suggest values that range from £1.10 to £10.81 per ha with a mean value of £5.37 per ha. More significant are the increased fuel costs due to compaction. These vary according to crop type and soil type, being lowest for sandy topsoils and highest for clay topsoils and range from £70/ha to £209 for potatoes, £15/ha to £56/ha for cereals, £20/ha to £60/ha for oilseed rape, and £18/ha to £55/ha for peas and beans (Baggaley *et al.*, 2024). These additional costs are summarised for each soil type in Table 6. The cost estimates from Baggaley *et al.* (2024) reflect private impacts on farmers due to yield loss and cultivation costs, the Graves *et al.* (2015) values reported in ENCA are higher as these also include external impacts such as the value of increased GHG emissions both from fuel use and emissions from fertiliser together with nutrient losses to the water environment (they assume that only 62% of N applications are fixed by compacted soils). Given their more comprehensive coverage of impacts we recommend the use of the Graves *et al.* (2015) values for soil compaction and erosion costs, although these should be considered as the upper limit of per hectare values within a range of uncertainty.

Table 5: Annual land rental values by farm type (source: FAS, 2024).

Farm type	Annual rental value (per ha, 2024 prices)
Cereals	£160
General cropping	£167
Mixed	£144
Dairy	£169
Cattle & sheep non-LFA	£149
Cattle & sheep LFA	£55
Pigs & poultry	£146

Table 6 Increase in fuel costs due to compaction by crop and soil type (source: Baggaley *et al.*, 2024).

Crop	Additional cost (£/ha)[a]		
	Sandy topsoils	Silty topsoils	Clay topsoils
Potatoes	70	144	209
Cereals	15 – 19	32 – 38	46 – 56
Oilseed rape	20	41	60
Peas and beans	18	38	55

[a] assumes a fuel cost of £0.98/litre

Timber production

Timber provisioning services may be relevant where woodland planting will eventually be used for harvesting. This would be applicable in contexts of general woodland expansion rather than applications such as riparian woodlands where native or broadleaved species are favoured without an intent for timber harvesting. ENCA estimates the aggregate value of UK timber provisioning using values for timber production and the Gross Value Added of the UK forestry sector. Unit values for timber sales are provided through the price per cubic metre overbark standing[3] for coniferous timber.

To provide a value for the timber potential of new woodland planting in Scotland we multiply the price £38/m^3 overbark standing (as given in ENCA and converted to 2024 prices) by the volume of timber per ha 304m^3/ha (Khan *et al.*, 2011) to get a value of £11,552/ha (with a range of £950 – £16,226/ha depending on age range).

Aquaculture

The improvement in ecological status due to the implementation of NbS may have indirect benefits for the provisioning services arising from the aquaculture sector. For example, ensuring sufficient water supplies or reducing water filtration or other treatment costs. However, directly attributing land use or management changes to the value of provisioning services from the aquaculture is problematic as we would need to match water quality and quantity changes with sites used for aquaculture. A case study rather than general valuation approach is suggested for this service in order to capture the contexts where it is provided.

Wild plants, fish and animals

The values for wild fish provisioning in ENCA relate to marine fisheries and are out of the scope of this study. Recreational fishing would be classified as a cultural service. However, values are provided in ENCA for these services when produced in wetlands.

A meta-analysis by Morris and Camino (2011) estimated the benefits and dis-benefits of a range of ecosystem services in UK wetlands. The value function was estimated in an original paper by Brander *et al.* (2008) who identified 215 global wetland valuation studies, 111 (52%) of these were from North America and 23 (11%) European. The meta-analysis estimated the effect of different characteristics on the observed values of wetlands, including reporting of ecosystem service type, wetland type, wetland area (within 50km), local population (within 50km) and GDP per capita. Morris and Camino identified spatial data for UK wetlands and populations and applied these to the Brander *et al.* value function. This then allowed them to estimate the impact of different ecosystem services in the value of wetland, i.e. if the service is provided how much will it affect the per ha value of a wetland. Morris and Camino defined ecosystem services as either 'Resource and environmental enhancement services'[4] or 'direct consumption and resource extractive services'[5]. The default value for all UK wetlands was estimated to be £436 per ha (2024 prices). Harvesting of natural materials and extracting materials for fuel are estimated to reduce this value by £186/ha and £329/ha respectively, noting that 'enhancement' ecosystem service, if provided, range in value from £2.88/ha (surface and groundwater supply) to £875/ha (flood control and storm buffering). It is, however, not clear that

[3]The volume of timber in standing trees including the bark.

[4]Flood control and storm buffering, surface and groundwater supply, water quality improvement, non-consumptive recreation, amenity and aesthetics, biodiversity

[5]Recreational fishing, commercial fishing and hunting, recreational hunting, harvesting or natural materials, material for fuel

negative impacts of extractive uses on overall wetland value can be interpreted as equivalent to the value of those provisioning services. Given that the underlying value function is from a global dataset and that the provisioning service values are effectively the impact on other ecosystem services we do not recommend the use of these values for an economic assessment of the RBMP.

Water supply

ENCA does not provide estimates of the value of water supply from particular land uses or NbS. The ONS Natural Capital Accounts do estimate a water supply value for Scotland, this is based on a resource rent approach that assumes that the residual value after removing production and capital costs represents the contribution of natural capital. However, this is not linked to land use or management so the value cannot be attributed to particular habitats. Morris and Camino (2011) estimated that provision of surface and groundwater adds £2.88/ha to the value of inland wetlands. However, water supply as a provisioning service is jointly provided through related regulating service such as base flow maintenance and water purification. We recommend that values for those services are considered as proxies for water supply benefits.

Table 7 provides a summary of the provisioning services values range including an assessment of the applicability of these values to Scotland.

Table 7: Summary of provisioning service value ranges (2024 prices).

Provisioning service	Measured by	Value range	Unit	Applicability
Food production (agriculture)	Opportunity cost of land removed from agriculture	£55–£169	£/ha/year	**High applicability; low uncertainty**. Scotland-specific rental data.
Food production (soil erosion)	Production losses due to erosion	£42–£72	£/ha/year	**Medium applicability; medium uncertainty**. Mix of England-derived and Scotland-specific evidence; site-dependent.
Food production (soil compaction)	Production losses due to compaction	£257–£314	£/ha/year	**Medium applicability; medium uncertainty**. Mix of England-derived and Scotland-specific evidence; site-dependent.
Food production (soil compaction – yield loss)	Yield loss from compaction	£1.10–£10.81 (mean £5.37)	£/ha/year	**Medium applicability; medium uncertainty**. Mix of England-derived and Scotland-specific evidence; site-dependent.
Food production (soil compaction – fuel costs)	Increased fuel use due to compaction; Varies by crop and soil type; private cost to farmers	£15–£209	£/ha/year	**Medium applicability; medium uncertainty**. Mix of England-derived and Scotland-specific evidence; site-dependent.
Timber production	Long-term potential from woodland planting; Depends on woodland age and management	£950–£16,226 (central £11,552)	£/ha (stock value)	**Medium applicability; high uncertainty**. Long time horizons; sensitive to species, age and management.
Aquaculture	Case-study approach recommended	—	—	**Low applicability; high uncertainty**. Attribution to land-use change unclear; case-study evidence required.
Wild plants, fish & animals (wetlands)	Composite wetland value (all services)	£436	£/ha/year	**Low applicability; high uncertainty**. Composite wetland values; reflects trade-offs, not provisioning outputs.
	Reduction in overall wetland value when harvesting natural materials or fuel	–£186 to –£329	£/ha/year	
Water supply (wetlands)	Incremental contribution of surface & groundwater provision; marginal contribution only	£2.88	£/ha/year	**Medium applicability; medium uncertainty**. Small marginal effect; not intervention-specific.

Regulating services

Soil and sediment retention and nutrient cycling

The economic value of soil and sediment retention and nutrient cycling as a regulating service is estimated based on the costs associated with soil erosion impacts, including flood risk, agricultural production loss, and water quality degradation. Using data from the ENCA database, the average cost of soil erosion is calculated to range from £149 to £241 per hectare (2024 prices)[6].

ENCA's estimate is based on a study by Cranfield University for Defra (2011) also reported in Graves *et al.* (2015), which uses a soilscape approach, dividing the land into 40 categories based on land use and soil type, then applying spatial data and expert judgement to assess degradation probabilities and impact intensities across England and Wales. Crop yields, land cover, and soil data are integrated with economic values from agricultural surveys to model the effects on provisioning and regulating ecosystem services. The Graves *et al.* (2015) study is applicable to arable farming, the per ha values could be transferred to Scotland with reference to the James Hutton Institute's soil erosion and compaction risk maps[7], which will identify relevant areas.

Baseline flow maintenance

The importance of trees in providing baseline flow maintenance, flood storage and water retention benefits is highlighted in our literature review. ENCA valuation data, based on research by Broadmeadow *et al.* (2023), estimates flood storage values in Scotland at between £1,544 and £8,534 per hectare (2024 prices) depending on whether trees are outside or within a woodland or on a floodplain respectively. This translates into annual values ranging from £52 to £280 per hectare per year.

More detailed replacement cost estimates, including annualised values over 100 years, from Fitch *et al.* (2022) quantify the ecosystem service values of canopy interception and soil water storage by vegetation type[8]. Canopy interception replacement costs per hectare range from £52 (£1.76 annualised) for shrubs to £1,094 (£36.73 annualised) for coniferous woodland, while soil water storage values range from £4,310 to £10,128 (£144 to £340 annualised) per hectare per year depending on vegetation cover, with broadleaf and coniferous woodland typically exhibiting the highest values. These services help to moderate hydrological flows by retaining rainfall in vegetation and soil, thereby reducing flood peaks and supporting water availability through regulated release. An important caveat in using these values is that they are estimated based on existing distributions of vegetation coverage and rainfall patterns[9], so may not fully reflect the benefits of changing land cover in a particular location.

Together, these values highlight the critical role of woodland and tree cover in supporting water cycle regulation and flood risk reduction, essential for maintaining ecosystem resilience and safeguarding downstream communities and infrastructure.

Peak flow mitigation

The value of mitigating peak flow through regulation of baseline flows and during extreme events is based on valuation of the regulating ecosystem service provided by inland wetlands and soil management. Based on data from ENCA, the average annual value of flood control and storm buffering by inland wetlands is estimated at £928 per hectare per year (2024 prices converted from 2007 prices). Additionally, the marginal value of an extra hectare of inland wetland flood control is estimated at £621 per hectare per year. These figures are based on research by Morris and Camino (2011), who use transfer function derived from a meta-analysis of European and North American studies which was then estimated using UK data which is standard practice with meta-analytic functions. However, there are a number of factors that might reduce the per hectare values in a Scottish context. In socio-economic terms these could include lower population densities and incomes per capita. In biophysical terms the size of the wetland site and the abundance of other wetlands in the surrounding area would also reduce per hectare values, noting that although this reflects diminishing marginal values the overall value produced by larger or more abundant wetland areas would still be higher.

[6]This estimate derives from aggregate erosion-related costs of £105 to £170 million in 2009 prices, inflated to 2024 values and averaged over approximately 1.022 million hectares.

[7]https://www.hutton.ac.uk/soil-maps/

[8]Estimated construction costs of a reservoir holding an equivalent volume of water. The volumes are calculated for each vegetation type compared to a counterfactual of bare soil.

[9]Water volumes and values were derived from rainfall and proportions of each vegetation type at 1km2 grid level within flood risk catchments which were then aggregated to national level.

The value of soil management in regulating water flow during extreme events can be estimated based on the economic costs of increased flood risk due to soil degradation (Graves *et al.*, 2015). Soil erosion in England and Wales is linked to an increased flood risk estimated to cost between £73 to £117 million, while soil compaction increases flood risk costs by approximately £175 to £292 million. Graves *et al.* (2015) provide an area undergoing erosion of 1.022 million ha and state that 3.859 million ha of England and Wales are liable to soil compaction. This suggests that the cost of increased flood risk due to erosion would be in the range of £71 to £114 per ha, and the cost of compaction would range between £45 and £76 per ha. Although this assumes that all areas of eroding or compacted soil contribute equally to flood risk.

These figures highlight the economic benefits of managing soil health and wetlands to moderate peak flows and reduce flood damage. However, they may require careful adaptation for Scotland's specific environmental conditions, given differences in land use, soil types, and hydrological regimes. For example, soil erosion and compaction risk maps produced by the James Hutton Institute[10] would identify the areas where values are likely to be higher, most likely in areas of more intensive arable production in the east and northeast regions.

Water purification

Water purification as a regulating service provides substantial economic and social benefits through river restoration, wetland management, and soil management techniques to support the reduction of nutrient and sediment pollution from agriculture. The ENCA database and national valuation studies (using National Water Environment Benefits Survey, Environment Agency, 2013) assign values to water quality improvements according to changes in ecological status. The estimated values are reflective of higher population densities in many English catchments. SEPA (2025a, 2025b) have produced revised estimates for Scottish catchments. For very high population density catchments with more than 10 people per ha, benefits of river restoration range from £21,200 per km to £28,800 per km where the resulting water quality status improves from bad to poor or moderate to good respectively. For low population density catchments with less than 0.3 people per ha these values range from £10,500 to £13,100 per km depending on the quality change. The values for each population density class and quality status change are presented in Table 7. Benefits of restoration for lochs, coastal and transitional water have also been estimated and range from £4,100 per km^2 for an improvement from bad to poor in a low population density catchment to £9,400 per km^2 for a change from moderate to good in a high population density catchment. The benefit estimates across population density and quality improvement classes are presented in Table 8. An important caveat is that these values reflect recreational, amenity and non-use values as the benefits obtained from improved water quality indicating that these services are jointly produced. Care is therefore advised when using these value estimates to avoid double counting.

Table 8: Value of river restoration benefit by population density and quality improvement class (source: SEPA, 2025b).

Population class	Population density range (per ha)	Benefit of river restoration, £'000/km/year (low and high)		
		Bad to poor	Poor to moderate	Moderate to good
Very high	>10	21.2 (17.4 – 25)	24.6 (20.2 – 29.1)	28.8 (23.4 – 34)
High	2.0 – 10.0	14.6 (12 – 17.3)	16.7 (13.7 – 19.7)	19.2 (15.8 – 22.7)
Medium	0.4 – 2.0	11.6 (9.5 – 13.6)	12.9 (10.6 – 15.3)	14.7 (12.1 – 17.4)
Low	<0.3	10.5 (8.6 – 12.3)	11.6 (9.5 – 13.7)	13.1 (10.7 – 15.4)

[10]https://www.hutton.ac.uk/soil-maps/

Table 9: Value of loch, coastal and transitional water body restoration benefit by population density and quality improvement class (source: SEPA, 2025b).				
Population class	**Population density range (per ha)**	**Benefit of loch, coastal and transitional water body restoration, £'000/km²/year (low and high)**		
		Bad to poor	**Poor to moderate**	**Moderate to good**
Very high	>10	7 (5.7 – 8.2)	8.1 (6.6 – 9.5)	9.4 (7.7 – 11.1)
High	2.0 – 10.0	5.8 (4.7 – 6.8)	6.6 (5.4 – 7.8)	7.6 (6.3 – 9)
Medium	0.4 – 2.0	5.1 (4.2 – 6)	5.7 (4.7 – 6.8)	6.6 (5.4 – 7.8)
Low	<0.3	4.1 (3.3 – 4.8)	4.5 (3.7 – 5.4)	5.1 (4.2 – 6.1)

In terms of avoided costs, source data (Cranfield University, 2011) attribute annual losses from water quality degradation due to soil erosion at £37–58 million, with a further £7–15 million stemming from soil compaction. The area of England and Wales undergoing erosion is estimated to be 1.022 million ha, implying that the average water quality losses values in the range £36–57 per ha. The area at risk of compaction is stated in Graves *et al.* (2015) (not in ENCA) as 3.859 million ha, indicating average water quality loss values of £1.81-3.89 per ha. Mitigation values include the annual cost per kilogram for removing nitrate (£1.37), phosphorus (£46.61), and sediment (£0.55) from agricultural runoff[11].

Moorland and wetland restoration also deliver significant water purification benefits, with average values for water quality improvements provided by inland wetlands estimated at £637 per hectare per year (Morris and Camino 2011). These figures emphasise the importance of investment in moorland and river restoration, as well as soil management techniques for protecting water quality, reducing treatment costs, and safeguarding aquatic life. For transferring these values to Scotland, adjustments would need to reflect population exposure, pollution pressures, and land cover to ensure representativeness.

Noise attenuation

Valuation of noise reduction (e.g. in ONS Natural Capital Accounts) is specifically based on mapping of urban noise receptors and vegetation to potentially reduce that noise. Robust transfer to other contexts would not be possible.

Soil quality regulation

Changing land use or management is an important step in protecting, halting and reversing soil degradation. Restoring soil health will provide multiple ecosystem services including reducing negative impacts. The values of these have been captured elsewhere in terms of the values for the losses in production and damage costs to soil retention, water quality and flood risk due to soil erosion and compaction as estimated by Graves *et al.* (2015). Graves *et al.* also estimated aggregate greenhouse gas emissions costs of £360-700 million due to loss of organic matter, and £80-120 million due to erosion and compaction in England based on 2009 carbon values of £51/tonne[12]. Using 2024 DESNZ[13] values (£260/t CO2e) suggests GHG emissions costs of £1,835-3,569m for organic matter loss and £408–612m for erosion and compaction assuming no change in erosion or compaction rates. These values were not broken

[11]These values are adjusted to 2024 prices from ENCA. The original estimates are based on the impacts of these pollutants on drinking water quality, fishing, bathing water quality, and eutrophication estimated by Chadwick et al (2006).

[12]The value of carbon is based on UK Government guidance on valuing greenhouse gas emissions for policy appraisal, these at expressed as value per tonne of CO_2 equivalent. The value is based on the estimated future social costs of climate change under an assumed stabilisation pathway (atmospheric CO_2 concentration of 550 parts per million). The carbon price is also consistent with the amount of GHG mitigation necessary for the UK to meet its emission reduction commitments. Further detail can be found here: https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation

[13]Department for Energy Security and Net Zero, formerly Department for Business, Energy and Industrial Strategy (BEIS)

down to per hectare values. However, using ENCA's modelled 1.022 million ha area of land undergoing soil erosion in any given year in England and Wales, suggests GHG losses from eroding and compacted soils have values of £399-599 per ha. We do not have an estimate for the area over which organic matter is lost. The level of emissions due to soil degradation are likely to vary according to soil types and initial soil carbon concentrations, but the range of estimated values are likely to be appropriate for application in Scotland.

The Graves *et al.* (2015) values relate to damage costs, so would reflect potential benefits from stopping damaging activities. McVittie and Glenk (2025) undertook a choice experiment valuation of the benefits of improving soil health through soil management NbS such as reduced tillage, winter cover and incorporation of organic matter. Members of the public were asked to choose different options with associated improvements in terms of reducing nutrient and soil loss (improving water quality), reducing runoff (increasing flood and drought risk resilience), increasing soil biodiversity, and increasing soil carbon. The values estimated from this study are summarised in Table 10. It should be noted that these values reflect the willingness to pay of the public to incentivise management changes that ensure these improvements occur. As such they do not reflect the benefit of reduced flood damage to property or the decrease in climate damages due to soil carbon sequestration. However, the per hectare values will likely underestimate the full benefits as some soils, due to their inherent properties such as texture, will already provide these ecosystem service benefits to some extent. McVittie and Glenk provide a spatial analysis of benefits based on soil properties that indicates where soil health enhancement could be targeted. These values can be used in a cost-benefit assessment of policy measures and incentives for improved soil management, for example through agri-environment schemes.

Baggaley *et al.* (2024) provide values for property damages due to flooding of between £56,776 and £76,035 per household covering insured buildings and contents loss and uninsured losses. However, there is no estimate for the number of flood events due to either soil compaction or soil sealing, or the numbers of properties these will impact.

Air filtration

The regulating service of air filtration provided by vegetation plays a critical role in improving air quality by intercepting pollutants. Valuations derived from the UK Natural Capital Accounts (ONS 2024a) quantify these benefits across different habitats found in Scottish local authorities, providing a measure of the economic value of pollutant removal services. The values are derived from modelling by UKCEH that takes into account the spatial distribution of emissions sources, the receiving population, and extent and effectiveness of different habitats in removing pollutants. This means that the value of pollutant removals will be lower in less populated regions even where there are either higher emissions (e.g. from dairy or poultry farms) or large extents of habitats that are effective at pollutant removal (e.g. coniferous forest). ONS

Table 10: Values for the benefits for enhancing soil health (source: McVittie and Glenk, 2025).

Attribute change		Implicit price (£/hh/yr)	Aggregate value (£m/yr)[a]	Value per ha (£/yr)[b]
Nutrients and soil being washed off the land	10% less	13.26	33.62	18.56
	30% less	25.81	65.44	36.12
	60% less	36.43	92.36	50.98
Water running off fields	10% less	18.27	46.32	25.57
	30% less	34.57	87.65	48.38
	60% less	40.99	103.92	57.37
Soil biodiversity	10% increase	16.68	42.29	23.34
	20% increase	23.85	60.47	33.38
	30% increase	27.31	69.24	38.22
Carbon storage in soils	5% increase	12.97	32.88	18.15
	10% increase	14.92	37.83	20.88
	20% increase	24.23	61.43	33.91

[a]aggregated over 2.54 million households in Scotland

[b]distributed across 1.81 million hectares in Land Capability for Agriculture classes 1 to 4.2 which are suitable for cropping

[14]PM2.5 refers to fine particulate matter of less than 2.5 micrometres diameter. Ammonia emissions from agriculture are an important precursor of PM2.5.

Table 11: Summary values for PM2.5 removal by habitat types in Scotland (derived from ONS 2024b).				
Natural asset	Annual value (£/ha, 2024 prices)			
	Mean	Median	Min	Max
Broadleaf woodland	29.8	15.0	0.2	317.1
Coastal margins	0.2	0.1	0.0	0.8
Coniferous woodland	24.6	13.1	0.4	86.4
Enclosed farmland	1.0	0.5	0.0	3.5
Freshwater, wetlands, and floodplains	1.0	0.2	0.0	6.5
Mountains, moorland, and heath	1.5	0.3	0.0	15.5
Semi-natural grassland	0.9	0.2	0.0	3.8
Urban grassland	2.5	0.7	0.0	22.3
Urban trees	97.1	22.8	0.2	481.8

(2024b) estimated values can be disaggregated by local authority, habitat and pollutant type. Table 11 summarises the annual per hectare values for Scotland for particulate matter PM2.5 across broad habitats[14]. A key observation is that there is considerable variation between minimum and maximum per ha values and the large differences between mean and median values indicates that the distributions are skewed. This indicates that appropriate local authority or regional values should be used accepting that even within local authority areas there may be considerable spatial variations in emissions, receptors, and removal benefits. Median rather than mean values would reduce the risk of over estimating benefits.

Local climate regulation

The ONS Natural Capital Accounts estimate values for the temperature reduction services provided by vegetation in urban areas. A threshold of hot days where the temperature exceeds 28°C is applied, with the value reflecting the loss in productivity. The only value estimated for Scotland is £10m in Edinburgh and relates to 5 hot days over 30 years.

Valuation of the benefits of local climate regulation in the context of the RBMP would require information on water quality changes (general status change), or other ecosystem services (e.g. recreational fishing), or additional context of implementation (e.g. measure also provides urban cooling effect). The value of reduced temperature of process water, e.g. for distilleries, would also be relevant. Relevant values were not available in ENCA and were not found during a literature search.

Salmonid species susceptible to increasing water temperature, with upper limit thresholds for Atlantic Salmon of 16°C for egg survival, 22.5°C feeding and growth, and 28°C for adult survival (Environment Agency, 2025). The Scotland River Temperature Monitoring Network provides mapping of river temperature, including the number days that salmonid vulnerabilities are exceed, and priority maps for riparian woodland planting to regulate water temperatures[15]. Attributing values to the benefit of water temperature regulation is difficult due to spatial variability, but for context the James Hutton Institute (no date) note that salmon and sea trout anglers contributed £73 million to the Scottish economy in 2004.

Global climate regulation

Different NbS such as floodplain restoration, peatland and moorland restoration, and forestry NbS can support the ecosystem service of global climate regulation through carbon sequestration and emissions reduction.

We can estimate the potential value of wetland restoration using emissions data from the ENCA database and values from Woodland Carbon Code Pending Issuance Unit (PIU) price of £26.85 per tonne (2024 prices)[16] or the DESNZ central policy appraisal value of £260 per tonne (2024 price). The choice of which carbon value to use depends on how emissions reductions might be achieved. The Woodland Carbon Code value reflects what a land manager might be able to obtain by selling verified carbon credits in a carbon market. This is indicative of the private benefit to the land

[15] https://www.gov.scot/publications/scotland-river-temperature-monitoring-network-srtmn/pages/outputs-and-tools/

[16] This value is the pending issuance unit (PIU) which is a promise to deliver a Woodland Carbon Unit in the future. There is insufficient information to provide an average carbon unit price, although these currently range from £25.04 for conifer to £27.84 for broadleaved woodland. Peatland Code PIUs are had a similar 2024 price of £25.04. https://www.woodlandcarboncode.org.uk/uk-carbon-prices

manager of emissions reduction. The DESNZ value is appropriate for policy appraisal and should be used by public sector agencies in assessments of emissions reduction policies. We use both here to illustrate the range of values between these private and public assessment values, and in the absence of certified carbon markets for most land uses, the DESNZ value is appropriate given the need for public sector support. The value of emission reductions from a rewetted fen habitat ranges from:

- £909 to £8,804 per ha compared to a drained cropland fen (saving 33.86 t/ha);
- £502 to £4,854 per ha compared to intensively drained and managed grassland (saving 18.69 t/ha); and
- £338 to £3,268 per ha compared to extensively drained and managed grassland (saving 12.57 t/ha).

These reflect avoided emissions when restoring degraded floodplain wetlands to near-natural, water-logged conditions and provide substantial climate mitigation benefits.

Moorlands have a high carbon storage and emission avoidance potential when properly managed. For moorland and peatland restoration NbS relative to 'rewetted modified bog', the following value ranges can be estimated using WCC and DESNZ values:

- £467 to £4,524 for 'actively eroding' or bare peat (saving 17.4 t/ha);
- £83 to £806 for 'revegetated' peat (saving 3.1 t/ha);
- £81 to £780 for 'drained' peat (saving 3 t/ha); and
- £59 to £569 for 'modified/degraded' peat (saving 2.19 t/ha).

Forestry and woodland restoration sequester carbon with estimated values between £180 and £1,742 per hectare for broadleaved woodland, based on a sequestration rate of 6.7 tonnes of CO_2 per hectare at the Woodland Carbon PIU price of £26.85 per tonne (2023 prices) and the central DESNZ non-traded sector value of £260 per tonne (2024 prices).

Carbon storage and flux estimates for a range of habitats provided by Gregg *et al.* (2021) could be used to estimate the potential values for different habitat types and conditions. The estimates in Gregg *et al.* (2021) are drawn from an evidence review relevant to the range of UK habitats. However, these are often point estimates without evidence of the range of storage and flux which may vary across UK conditions (e.g. climate). The authors provide an assessment of the confidence in these estimates, this is often 'low', with better studied habitats such as woodland and peatland considered as having 'medium' confidence. Caution is therefore advised in using these data for valuation, but the magnitude of values would still be informative.

Table 12 provides a summary of the provisioning services values range including an assessment of the applicability of these values to Scotland.

Table 12: Summary of regulating services values and their applicability to Scotland (2024 prices).				
Regulating service	**Measured by**	**Indicative value range**	**Unit**	**Applicability / significance / uncertainty**
Soil & sediment retention/nutrient cycling	Avoided damages from soil erosion and degradation	£149–£241	£/ha/year	**Medium applicability; high significance; medium uncertainty.** England-derived but transferable using Scottish soil risk mapping; integrates flood, production and water quality impacts.
Baseline flow maintenance (trees & woodland)	Flood storage and water retention	£52–£280	£/ha/year	**High applicability; high significance; medium uncertainty.** Scotland-specific evidence; sensitive to location (woodland floodplain).
	Rainfall intercepted by vegetation canopy	£1.76 - £36.70	£/ha/year	**High applicability; low-medium significance; medium uncertainty.** Replacement-cost based; sensitive to assumptions on canopy height, density, and management.
	Rainfall retained in soils and root zone	£144 - £340	£/ha/year	**High applicability; high significance; medium uncertainty.** Varies with soil type and vegetation cover.
Peak flow mitigation	Avoided flood damages via wetlands and soil management	£621–£928	£/ha/year	**Medium applicability; high significance; high uncertainty.** Strong evidence for benefit, but magnitude highly site- and event-dependent.
Water purification	Reduced nutrient and sediment loads via soil, moorland, river, and wetland restoration	£10.5k–£28.8k £4.1k to £9.4k	£/km restored river $£/km^2$ restored loch	**Medium applicability; high significance; medium uncertainty.** Values population-dependent. Values reflect cultural ecosystem service benefits
	Avoided damage costs	£0.55 - £46.61	£/kg removal	
	Restoration of moorland and wetland[1]	£637	£/ha/year	
Noise attenuation	Reduction in exposure to environmental noise	—	—	**Low applicability; high uncertainty.** Values are urban- and receptor-specific; not transferable to most RBMP contexts.
Soil quality regulation (GHGs & resilience)	Avoided emissions and improved soil functioning	£400–£600	£/ha (damage avoided)	**Medium applicability; high significance; high uncertainty.** per-ha estimates inferred from aggregates.
Air filtration	Removal of PM2.5 by vegetation	£0.20–£97	£/ha/ year	**Medium applicability; medium significance; high uncertainty.** Highly spatial; values vary strongly with population exposure. Indicative values are mean values across habitat types, minimum values are £0 and maximum £482.
Local climate regulation	Urban cooling/productivity effects	—	—	**Low applicability; low significance; high uncertainty.** Limited evidence for RBMP-relevant NbS in Scotland.
Global climate regulation	Carbon sequestration/ avoided emissions	£59–£8,800	£/ha (stock or flow)	**Medium applicability; high significance; medium uncertainty.** Strong evidence base; value sensitive to carbon price and habitat type and condition.

[1] Avoided water treatment costs and habitat-based purification values represent alternative expressions of the same regulating service and should not be summed.

Cultural services

Recreation-related, visual amenity

Visual amenity, as an ecosystem service, reflects the aesthetic value that natural and semi-natural habitats provide to communities.

This is often captured through changes in property prices associated with proximity to and presence of valued landscapes such as freshwater, floodplains, woodland, farmland, moorland, and urban green spaces. Valuation evidence from the ENCA database uses Gibbons *et al.* (2014) valuation study, which is based on an English dataset of housing transactions over a 13-year period and estimates the average England property uplift values from 1% increase in different land use types. This data indicates that each hectare increase in freshwater, floodplains, or wetlands within a 1 km grid square corresponds to a 0.36% increase in house prices, equivalent to approximately £1,033 per property (2024 prices). Enclosed farmland is estimated to contribute 0.06% to house prices per hectare increase or £171 per property (2024 prices), moors are estimated to add 0.08% to house prices per hectare increase or £240 per property, broadleaved woodland 0.19% or £560, and coniferous woodland 0.12% or £345. On the other hand, Morris and Camino's (2011) meta-analysis of European studies suggests amenity gains of £329 per hectare of wetland per year for UK inland wetlands, with an additional hectare adding £327 per year.

Urban NbS have particularly strong impacts on amenity. Based on ONS (2024) data, 1 ha increase in urban green or blue space correlates to a 1.1% increase (£2,626) in average house prices in Scotland.

These values should be taken as indicative of the potential amenity value benefits of different habitats or land cover types. Although based on English data, the Gibbons *et al.* (2014) values have the advantage of being national averages and cover a reasonably long period of time. This should smooth out regional variations in property markets and fluctuations in the contribution of amenity to property values. As such, the percentage values in particular are suitable for larger scale application in evaluating land cover change benefits in a Scottish context.

Physical and experiential interactions with natural environment

Estimates for the recreational, amenity and non-use value of the restoration of rivers and other water bodies are presented in Table 8 and Table 9 above. An element of recreation in natural environment are health benefits. ONS (2024b) provides estimates of the health benefits obtained by visits to the outdoors, with weekly visits that exceed a total of 120 minutes being associated with positive health benefits. The health benefits methodology is outlined in ONS (2022) and includes national survey data on visitors (e.g. NatureScot's Scotland's People and Nature Survey[17]) including visitor characteristics (e.g. demographics, self-reported health, deprivation etc.). The numbers of people visiting with the regularity to achieve health benefits and annual values provided by ONS (2024b) suggests that freshwater, wetlands and floodplains provided annual per visitor health benefits of £416 in 2022 (2024 prices). This compares to £347 for coastal and marine, £312 for enclosed farmland, £624 for mountains, moorland and heath, £404 for urban, and £338 for woodland. However, estimated benefits vary considerably from year to year, with freshwater benefits ranging between £312 and £624 per visitor between 2003 and 2022. The relative values between habitats are also not stable, changing from year-to-year presumably reflecting changing visitation patterns. This makes reliable comparisons of different habitats difficult, for example if trying to evaluate land use change from agriculture to riparian woodland. To put these values in context, ENCA provides per active visit (assuming one visit per week for 52 weeks) values of £3.73 per week saving in healthcare costs, and £15.94 per week perceived health and recreational benefits to the individual. The ONS value estimates are related to the lower savings in healthcare costs figure.

Biodiversity underpins several regulating ecosystem services and contributes to a number of cultural services. These include 'education, scientific and research', 'spiritual, artistic and symbolic' and 'physical and experiential interactions with natural environment'. The consultancy eftec (2022) undertook a valuation of the biodiversity benefits of nature restoration in England where biodiversity was defined as the improvement in the number of species[18]. The valuation scenario makes

[17] https://www.nature.scot/professional-advice/land-and-sea-management/managing-access-and-recreation/increasing-participation/measuring-participation

[18] This was described in general terms as either 'minimal', 'low', 'moderate' or 'full' – presumably allowing the same survey design to be applied across multiple habitats each with different potential numbers of species.

no reference to any ecosystem services provided by biodiversity, instead the values elicited can be interpreted as public values for biodiversity in general where species recovery "leads to a healthier overall environment that benefits everyone". There is also no mention of direct or indirect interactions with biodiversity or any non-use benefits such as existence values. Table 13 presents the results from eftec (2022) for different habitat types, these were reported in terms of the WTP per household per 1,000 ha of habitat restored and as transferable values per household per 100 ha of restored habitat. The transferable values have been scaled to allow application to smaller scale projects of up to 100 ha, eftec state that these values should not be aggregated to national level, instead they should be applied within the local context of a restoration project, e.g. the 'catchment' of the body undertaking the activity or the local authority area. Table 14 presents a summary of the range of cultural services values and an assessment of their applicability to Scotland (2024 prices).

Table 13: Benefits of species recovery by habitat (eftec, 2022, converted to 2024 prices).

Natural asset	Willingness to Pay (95% CI) for 5% of current habitat extent (per household per 1000 ha)	Transferable value (per household per 100 ha)[a]
Wood-pasture and parkland	£1.87 (± 0.42)	£0.19
Mixed deciduous woodland	£0.64 (± 0.21)	£0.06
Upland oakwood	£5.81 (± 1.68)	£0.58
Arable land	£0.62 (± 0.33)	£0.06
Lowland hay meadows	£8.75 (± 3.22)	£0.82
Semi-natural grassland	£0.82 (± 0.31)	£0.08
Heathland	£0.79 (± 0.28)	£0.08
Lowland fens	£8.83 (± 3.96)	£0.97
Blanket bog	£0.83 (± 0.32)	£0.09
Rivers	£6.98 (± 2.58)	£0.63
Coastal Sand Dunes	£8.36 (± 3.85)	£0.84

[a]The transferable values were scaled to make them applicable to smaller scale projects of up to 100 ha.

Table 14: Summary of cultural services values and an assessment of their applicability to Scotland (2024 prices).

Cultural service	Measured by	Indicative value range	Unit	Applicability/significance/uncertainty
Recreation & visual amenity (rural)	Increased amenity from rivers, wetlands, woodland	£171–£1,033	£/property	**Medium applicability; medium significance; medium uncertainty**. England-based hedonic pricing; population density sensitive.
Recreation & visual amenity (urban)	Increased green/blue space	~£2,600	£/property	**High applicability; high significance; medium uncertainty**. Strong evidence; highly relevant where RBMP measures affect urban areas.
Amenity (wetlands)	Landscape and amenity value	~£330	£/ha/year	**Medium applicability; medium significance; medium uncertainty**. Transfer values from European studies; not intervention specific.
Biodiversity (species recovery)	Public willingness to pay for habitat restoration	£0.06–£0.97	£/household /100 ha	**Medium applicability; medium significance; high uncertainty**. Sensitive to habitat type; Suitable for local-scale appraisal only.
Health benefits	Recreational visits to the outdoors	£208-£624	£/visitor/annum	**Low applicability; medium significance; high uncertainty**. Sensitive to visitation patterns and not stable across habitats.
Education, cultural, non-use values	Existence and bequest values	Included above	—	Implicitly captured within biodiversity stated-preference values; not separable by NbS.

4.3 Applying valuation evidence to measures

Here we provide a worked example identifying ecosystem service values to a specific NbS - vegetated buffer strips. The aim is to demonstrate how the figures above can help inform a more comprehensive valuation of a specific NbS. Furthermore, this worked example helps to highlight issues to consider when using values. The following approach could equally be applied to a more comprehensive riparian corridor restoration, for example where within the buffer area further actions are implemented such as re-meandering and partial reconnection to the floodplain (e.g. reducing bank heights to allow flooding of the buffer area). These would necessarily incur greater implementation costs and potential land use change to balance against the benefits.

Figure 8 illustrates the ecosystem services where values were identified in our review, there may be further services where valuation gaps exist. Grass buffer strips are assumed to remove land from agricultural production (as evidenced from our literature review). Using land rental values as a proxy for the value of production, installing buffer strips leads to a loss of provisioning services of between, £144 and £167 per hectare for cropping, or £149 to £169 for livestock (FAS, 2024 – values converted from 2020 to 2024 prices).

Values were identified for several regulating services. For air filtration we assume that grass buffer strips most closely match semi-natural grassland. Average values of £1/ha per annum for the habitat type enclosed farmland and £0.9/ha per annum for semi-natural grassland were estimated from Scotland specific estimates for this service (ONS, 2024b). This suggests a small reduction in the value for this service. However, care is required when applying these values as they are based on spatially explicit modelling of emissions sources and receptors together with the locations of different habitat types in that vicinity. Values for this service are estimated for different habitats at local authority level, and these should be used where possible to reflect differences such as local population densities. These are also based on the current habitat distributions, consequently applying the values to newly created habitats or land use change may under- or over-estimate the benefit. In this example it is assumed that although semi-natural grassland has a higher potential to provide air filtration than enclosed farmland (e.g. higher canopy interception), its existing distribution is further away from both emitters and receptors thus reducing the benefit provided. In addition to using estimates for the relevant local authority, it is recommended that the potential range of those values across Scotland is also noted.

Grass buffer strips	Provisioning services	Loss of productive land Land rental values Cropping: £144 - £167/ha Grazed biomass (livestock exc. LFA): £149 - £169/ha
	Regulating services	**Air filtration (PM2.5)** Enclosed farmland: £1/ha (range £0 - £3.5/ha) Semi-natural grassland: £0.9/ha (range £0 - £3.8/ha)
		Peak flow mitigation and baseline flow maintenance Canopy interception, Grass: £2.57/ha annualised (Crops £5.31/ha annualised) Soil water storage, Grass: £145/ha annualised (Crops £256/ha annualised)
		Global climate regulation Annual carbon flux for arable reversion to low input grassland (-1.59 tCO_2e/ha/yr): £43 - £413/ha
		Water purification Annual value of reducing 1kg from agricultural sources (avoided damage costs) Nitrate: £1.17 Phosphorus: £39.76 Sediment: £0.47
	Cultural services	**Biodiversity** Value of species recovery through nature restoration Semi-natural grassland: £0.08/household/100ha Rivers: £0.63/household/100ha
		River restoration Value of recreation, amenity and non-use values (low to very high catchment population density) Bad to poor: £10,500 - £21,200/km Moderate to good: £13,100 - £28,800/km

Figure 8: Example of applying ecosystem service values to vegetated buffer strips.

A similar issue arises with respect to peak flow mitigation and baseflow maintenance. These services are provided by similar mechanisms and may not be separable, particularly as the provided service depends on rainfall conditions. The values are based on the replacement cost of providing flood storage reservoir of equivalent volume to the water intercepted by vegetation canopies or stored in the soils (Fitch *et al.*, 2022). The volume of water available to be stored is based on regional rainfall data and calculated at catchment level. The higher value for this service for crops (£5.31/ha for canopy interception) relative to grass (£2.57/ha) likely reflects modelling assumptions about canopy height and leaf area index which are larger for crops on average[19]. However, it is assumed that grass is regularly grazed or mowed which is typically not the case for buffer strips. Differences in assumed root depth (with deeper roots increasing water infiltration) and underlying soil type likely impact on water infiltration and soil water storage capacity. By contrast the value of canopy interception and soil water storage by broadleaved woodland are £13.74 and £294 per hectare per annum respectively. An important caveat is that the values of canopy interception and soil water storage reflect current distributions of vegetation coverage and rainfall, and were not estimated for the evaluations of land use change.

The suggested value for global climate regulation is based on data from Gregg *et al.* (2021), with the reduction in carbon flux from arable land reverting to grassland considered most appropriate. The value of the emissions reduction ranges from £43 to £413/ha for the Woodland Carbon Code or DESNZ non-traded sector carbon prices respectively. The distinction is important depending on whether we wish to value the potential for this emissions reduction to be incentivised through private markets (assuming a high integrity grassland or soil market could be developed) or through public sector incentives.

Water purification benefits are related to reductions in nutrient and sediment inputs to the water environment (Gooday *et al.*, 2015). These values are per kilogram and would require this impact to the estimated for the specific context of the buffer strip installation.

Cultural services are represented by values for biodiversity enhancement (eftec, 2022) and the recreation, amenity and non-use values of river restoration. Enhanced biodiversity contributes to a wide range of ecosystem services including some important regulating services, but not all of these have been valued (e.g. relatively robust values for pollination services but values for pest and disease control services are less well evidenced). It is possible that those benefits have been included in valuation scenarios for stated preference valuations of biodiversity, but it would not be possible to isolate values for specific NbS and services (e.g. while relatively robust economic valuations exist for crop pollination services, values for the pollination of wild plants or values for the pollination uplift of specific NbS are not readily available: Hanley *et al.*, 2015). Instead, we suggest that biodiversity values that primarily reflect cultural services provide a 'catch-all' for all benefits provided by biodiversity. The values estimated by eftec (2022) are for 'species recovery' following 'nature restoration' in a range of habitat. The most appropriate value estimates are per household per 100ha of restoration and are intended to be applied at small-scale project rather than national level. Application to buffer strips would require both the area being created and data on the local population. Relevant estimates for buffer strips include £0.087/household/100ha for semi-natural grassland and £0.63/household/100ha for rivers.

The value for river restoration is based on updated values for the Environment Agency's National Water Environment Benefit Survey[20] which has been adjusted for Scotland by SEPA (2025a, 2025b). The original estimates are not publicly available, but 2022 values are available in ENCA. The value of river restoration ranges from £10,500/km to £28,800/km in 2024 prices depending on the change in water quality status and the population density of the river catchment. Application of these values to buffer strip installation would require assumptions about the impact on water quality status which will depend on baseline conditions.

In line with the findings of the literature, the valuation of vegetated buffers indicates economic benefits for water purification, global climate regulation, biodiversity, recreation services and negative economic impacts for food production. However, in some instances economic valuations contradicted the literature evidence. While the economic evaluation suggested buffer strips reduced the value of baseflow maintenance and peak flow mitigation, the literature review found

[19]These are annualised values derived by Fitch *et al* (2022) from total values estimated over 100 years. We present the annual values to allow comparison across ecosystem services.

[29]An update of the NWEBS was tendered in April 2024 and due to run until April 2026. A review of a previous update is available here: https://www.gov.uk/government/publications/updating-the-national-water-environment-benefit-survey-values-summary-of-the-peer-review

medium to strong evidence that buffer strips increased these services. The valuation evidence reflects the basis of these values in existing distributions of vegetation types (and rainfall), the underlying study (Filch *et al.*, 2022) did not intend to provide values to inform land use change. **Despite these challenges, the valuation clearly demonstrates that NbS can deliver a wide range of public goods compared to hard engineering solutions such as dams, flood gates and water treatment plants (Stosch *et al.*, 2017).** Recognising these broader benefits within RBMP would strengthen the business case for NbS and support more informed investment decisions.

This section has considered the application of existing value estimates to a specific measure. Values for multiple services are available, including the opportunity cost of lost production, but data gaps persist. Several values are also very context specific requiring information on the location of installation and the benefiting population. However, these values provide useful indicative estimates of the magnitude of potential benefits.

5.0 Natural capital market review

With public budgets under increasing pressure, leveraging private investment through natural capital markets is essential for SG to realise its ambitious targets for biodiversity, water quality, climate adaptation and NetZero. The Biodiversity Investment Plan (Scottish Government, 2025b) outlines the Government's commitment to blend private and public investment (e.g. Peatland Action, Agri-environment and Climate Schemes, SEPA Water Environment Fund) to maximise positive outcomes for nature and support the delivery of The Scottish Biodiversity Strategy to 2045, Scottish National Adaptation Plan (SNAP3) and Net Zero Nation Framework and RBMP. Under the 2021–2027 RBMP cycle these include action to create healthier and more resilient communities; water supply and wastewater; sustainable and resilient rural land use; and removing barriers to fish migration.

In their broadest sense, natural capital markets represent market-based finance mechanisms intended to deliver positive outcomes for nature through channelling private investment into ecosystem restoration providing public goods that benefit our wider society. There are a range of market-based mechanisms in place or emerging within Scotland, including environmental subsidies and tax incentives, payment for ecosystem service models and carbon and biodiversity markets. The SG's Natural Capital Market Framework (Scottish Government 2024b) aims to ensure emerging natural capital markets are high-integrity. To build trust in these markets, the SG have outlined six principles for responsible investment to attract responsible private investment and deliver measurable outcomes for biodiversity, climate and wider society (Figure 9).

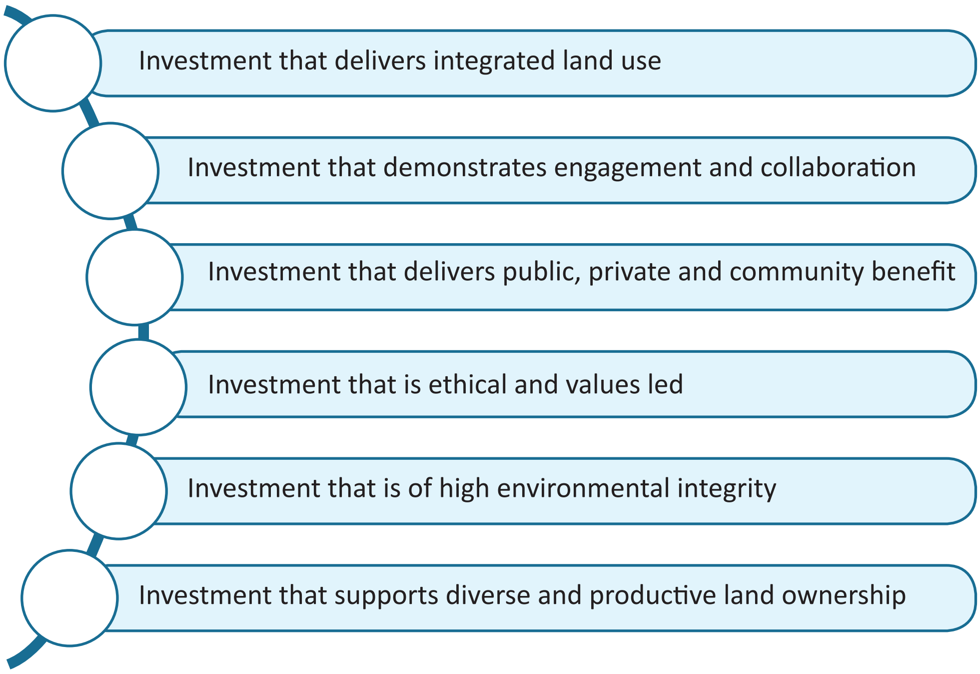


Figure 9: Scottish Government's six principles for responsible investment.

Systems thinking is needed to deliver strategic source to sea-outcomes, evaluate inter dependencies between different resources and design investible projects (Source to Sea: Kellock *et al.* 2023; One Planet Choices: Melville *et al.* 2023). Such thinking helps to articulate demand by linking the supply of projects to potential buyers or funders via the value alignment that drives demand and willingness to pay (Guillon and Bennet 2025). For example, logic models help us understand local natural capital assets, the pressures affecting their condition and how this could impact key functions within the water environment which underpin its delivery of ecosystem services. At a catchment scale, systems thinking is also required to understand the scale/combination of NbS required to enhance waterbody status/condition and, ultimately create confidence that NbS will deliver outcomes relevant to buyers (See Section 6: Logic Models). This type of strategic systems thinking can support incentives that both deliver outcomes for the water environment and align with corporate targets or otherwise reduce the costs and risks compared to the status quo.

Market-based approaches implemented at scale require both willing suppliers to provide a pipeline of potential projects as well as beneficiaries and buyers, who create demand for these NbS and the ecosystem services they provide. Within the water environment, a range of market-based initiatives are emerging which promote ecosystem restoration, NbS and integrated land management, where financing comes from users (beneficiaries), government or public funding, or via regulatory or compliance mechanisms (Salzman *et al.* 2018, Irving 2023).

Catchments provide a strategic scale for market-based approaches, enabling a holistic source-to-sea perspective of ecosystem processes for planning and project aggregation, while also providing a clear geographic focus. Water markets often create geographic-specific demand, operating within defined catchment areas that align with the location of impact or dependencies. Globally, payment for watershed services models reflect a growing mechanism to fund water conservation and restoration efforts and drive significant investment in integrated catchment-based initiatives (Salzman *et al.* 2018).

There are a range of natural capital markets and market-based mechanisms relevant to the Scottish context that have a potential nexus with the water environment; these are discussed below along with specific examples of water-related markets and catchment partnerships emerging in Scotland. The need to better incorporate water-based metrics and outcomes in emerging codes and standards within Scotland was highlighted in the recent engagement on the Ecosystem Restoration Code (ERC) (Scottish Government 2025c), as well as in Irving (2023). The SEPA-led Water Metrics and Standards working group, is engaged on these issues and provides an opportunity to create alignment amongst initiatives.

5.1 Types of natural capital markets

Voluntary carbon markets (Peatland Code and Woodland Carbon Code)

The Peatland Code and the Woodland Carbon Code are the only government backed voluntary natural capital codes in the UK. They produce high integrity, independently verified, carbon credits that businesses can purchase to support environmental claims. Limited demand for voluntary carbon credits means prices often fail to provide sufficient financial revenue to fully support project life cycles, with projects often requiring support from diversified revenue streams, including timber or agricultural production and the blending of private and public funding (e.g. Peatland Action). Natural capital accounting approaches that articulate wider benefits could support diversified revenue streams for project developers, further de-risking private investment into these markets.

The Peatland Code and Woodland Carbon Code are evolving to recognise and reward projects with additional biodiversity benefits, increasing credit value for projects that demonstrate biodiversity uplift. While this work has a terrestrial focus, our literature review demonstrates clear functional links between woodland creation, peatland restoration and the water environment. Efforts are underway to expand the Woodland Carbon Code to also include water benefits via the Woodland Water Code which would quantify how woodland creation contributes to outcomes within the water environment, primarily related to improved shading, stream temperatures and water quality. Furthermore, with functional linkages between peatland restoration and improved water storage/reduced runoff, there is also potential to integrate water-related outcomes within the Peatland Code. This would require the development of robust metrics, governance frameworks, and transparency mechanisms that allow the quantification of multiple functions and/or ecosystem service benefits (e.g. carbon, water, biodiversity) while ensuring additionality and avoiding double counting. Growing investor interest alongside the significant scope for woodland creation and peatland restoration in Scotland, highlights the potential for carbon markets to support source-to-sea action and deliver long-term commitments (Kellock *et al.* 2023).

Compliance markets

Government-led compliance markets, which may generate and sell credits for contribution and/or compensation (offsets) purposes, are well established in numerous jurisdictions globally, serving as the major demand driver for nature credit markets (International Advisory Panel on Biodiversity Credits *et al.* 2025). These markets can support a substantial restoration economy, with US wetland and stream compliance market transactions worth USD $3.6 billion annually, generating an additional USD $2.3 billion within supply chains and USD $3.8 billion spillover effects and supporting 53,000 jobs (BenDor *et al.* 2023). Within government-led compliance markets, public agencies will typically provide regulatory oversight and enforcement, along with some level of market administration. For example, some jurisdictions have opted to rely on private sector actors and intermediaries to manage some market functions, while others take on full responsibility for market implementation, including buying and selling credits (International Advisory Panel on Biodiversity Credits *et al.* 2025).

Through planning regulations, England has developed a compensation-driven compliance market for biodiversity (Biodiversity Net Gain; BNG) with new developments having to deliver 10% BNG under the Environment Act 2021. This market is underpinned by The Statutory Biodiversity Metric which provides a standardised way for developers to account for biodiversity. The metric is used to calculate biodiversity units pre-development and to estimate units post construction under a range of scenarios. Developers who can't meet the mandatory 10% BNG on site, must purchase biodiversity units generated from the creation or enhancement of habitats offsite. England's BNG approach considers three types of biodiversity units: area units, hedgerow units and watercourse units. Watercourse units are quantified using the River Condition Assessment, based on the Modular River Survey (MoRPh) framework, and apply to developments occurring within 10m of a watercourse. Outside these areas, impacts on rivers and water resources are not considered, and the limited characterisation of habitat condition within the metric fails to capture or account for functional linkages between terrestrial habitats such as woodlands and peatlands and the water environment.

Scotland's approach under the National Planning Framework 4 (NPF4) requires developers to demonstrate positive effects for biodiversity without a mandatory net-gain target. NatureScot are currently adapting England's Statutory Biodiversity Metric for use in Scotland to provide a standardised approach to biodiversity accounting. Additionally, some forward-thinking companies such as Southern Energy Networks (SSEN) and Scottish Power Energy Networks (SPEN) are already using adaptions of the Statutory Biodiversity Metric to demonstrate positive effects of developments. However, it is not clear how NatureScot will incorporate watercourses within a Scottish metric, or if planning regulations could drive the development of a compensation (offset)-driven compliance market in Scotland, similar to England.

Beyond the planning system, there are a range of regulated activities that impact the water environment which could underpin compliance markets in Scotland, including activities regulated under the Environmental Authorisations (Scotland) Regulations. For comparison, in the U.S., the Clean Water Act regulations require those impacting streams and wetlands to adhere to a set of tiered permitting requirements commensurate to the scale of impact and the mitigation hierarchy (i.e. avoidance, minimisation and finally compensation for unavoidable impacts to streams and wetlands) which serves as the foundation for stream and wetland compensatory mitigation (offset) markets. These types of 'polluter pays' approaches create economic incentives to avoid and minimise impacts, support deliver of policy objectives and drive funding towards ecosystem restoration.

Voluntary nature markets

In recent years, there has been a proliferation of natural capital schemes which differ on the element/s of natural capital they focus on, their maturity, their governance and their monitoring, reporting and verification (MRV) procedures (Reed *et al.*, 2025). These schemes offer potential investment streams for a wide range of ecosystems (e.g. rivers, fens, species-rich grasslands) and NbS (e.g. actions to enhance soil health, or to mitigate diffuse pollution). In Scotland, the primary emerging voluntary nature market is the government-led Ecosystem Restoration Code (see below), although other international voluntary biodiversity credit frameworks are emerging within Scotland, including rePLANET and CreditNature.

To build buyers' trust in these emerging markets, it is crucial that the credits generated represent real, transparent, measurable, long-lasting and additional environmental benefits through the development of robust standards and MRV processes. The BSI Nature Investment Standards (NIS) Programme outlines minimum requirements for high-integrity markets with respect to how uplift is quantified, governed, reported and verified, and considers aspects such as additionality, risk (leakage, double counting, unintended consequences) and permanence (e.g. BSI Flex 702 indicates biodiversity must last for at least 30 years).

A key challenge faced by emerging nature markets is the development of robust and transparent metrics to quantify biodiversity uplift. Unlike carbon which has a common currency (i.e. one carbon credit = one metric tonne of carbon dioxide equivalent), there is no common currency for biodiversity. Biodiversity impact varies depending on the NbS, species present, ecosystem/s, landscape context and geographical location making it difficult to standardise uplift across projects and locations. To tackle this, emerging nature-markets draw on multiple metrics that capture different aspects of biodiversity (e.g. PV Nature, rePLANET and CreditNature).

While compliance markets drive nature market demand globally, corporate disclosures and ESG also remain relevant drivers (International Advisory Panel on Biodiversity Credits *et al.* 2025). In Europe alone, approximately 50,000 companies are legally required to disclose their environmental and social impacts under the Corporate Sustainability Reporting Directive (CSRD). Additionally, many corporations are also signing up to voluntary initiatives to transparently disclose climate and nature-related risks and identify and set targets to mitigate these risks (e.g. Global Reporting Initiative (GRI) Standards, Science-Based Targets Initiative, Taskforce on Nature-related Financial Disclosures (TNFD) and The Taskforce on Climate-related Financial Disclosures). The SG has recognised the value in aligning their voluntary ERC with these emerging frameworks for nature-related disclosure, corporate ESG commitments, and supply-chain risk and resilience. However, without initiatives to incentivise or actively encourage participation, voluntary nature markets face uncertainty and competition with philanthropic opportunities and other market-based mechanisms.

Voluntary markets need to balance governance and MRV processes to ensure accessibility and economic viability from the suppliers' side, whilst retaining sufficient integrity to build confidence from the buyers' side. The multi-metric approach adopted by emerging voluntary markets results in high MRV costs. With market demand still unclear, there is a need to determine if credits generated from such markets will cover high MRV costs; particularly since the compliance BNG market in England focusses on a relatively simple metric based on habitat extent, type and quality.

Ecosystem Restoration Code

Government-backed voluntary markets are currently focussed on carbon, with actions limited to peatland restoration and woodland creation. To promote nature restoration across a wide range of habitats and ecosystems and provide greater flexibility for on the ground action, the SG is committed to develop an Ecosystem Restoration Code (ERC). This code aims to support high-integrity market mechanisms to lever private investment for projects that support the conservation and restoration of ecosystems at scale through a variety of NbS. In taking an ecosystem approach, the ERC is strongly relevant to RBMP. The SG recently sought stakeholder feedback on proposed metrics and measurement; durability of outcomes; additionality; and stacking and bundling, alongside input on overarching principles and governance, potential barriers with respect to both suppliers and buyers/investors.

While the ERC consultation response indicates that the code will aim to accommodate multiple metrics and use cases, the current proposal relies primarily on CreditNature's NARIA framework to quantify ecosystem uplift (Jepson *et al.* 2024). This approach draws from multiple metrics to robustly quantify ecosystem integrity and considers ecosystem condition, management and ecosystem services. The ecosystem condition index is designed for large scale applications (>200 hectares); which limits the utility of the NARIA framework to evaluate and forecast smaller scaled NbS (e.g. pond creation, implementation of arable margins), or soil management options, even when these smaller activities may be strategically aligned within nature networks or other landscape-scale planning.

The ecosystem condition index within the NARIA framework is currently only applicable within terrestrial ecosystems, although potential indicators to account for processes relating to the water environment are being explored, including considering man-made barriers (e.g. dams and weirs) when calculating landscape connectivity, measurements relating to the water retention capacity of vegetation, and a benthic macroinvertebrate trait diversity metric.

Currently, SG is reviewing the proposed ERC in response to comments received during the stakeholder engagement period (Scottish Government 2025c). This engagement raised concerns regarding solely relying on the NARIA framework, noting its limitations with respect to smaller projects, agricultural settings and projects focused on to the water environment. The response highlights the need for more flexibility to accommodate different metrics and market requirements, and alignment across different policy objectives to deliver a range of outcomes beyond biodiversity, including water, soil health and community benefits. In their response, SG specifically identified a key policy priority to *"consider and assess the extent to which the ERC has potential to support the delivery of water environment objectives and improvements in aquatic ecosystems, including in relation to the effectiveness of NARIA in this context."*

Other market-based mechanisms and how they are being implemented in Scotland

With businesses, corporations, and financial institutions increasingly recognising their dependencies and impacts on nature, these drivers are likely to play a key role in financing ecosystem restoration (Scottish Government, 2025c). A key lever in driving demand in the water environment is the inclusion of water-related metrics, e.g., for water quality and water utilisation, in voluntary initiatives to help organisations identify, manage and disclose nature-related risks (e.g. Taskforce on Nature-related Financial Disclosures and Science-Based Targets for Nature).

Water-related natural capital initiatives are already emerging across Scotland, although investment in these remains limited (Irving 2023). These mechanisms rely on a range of demand drivers, including strengthening community partnerships, reducing risks (e.g. related to flood and drought), operational costs (e.g. lower water treatment expenses) or impacts, creating greater supply chain resilience, or aligning with corporate ESG mandates, brand identity and disclosure requirements (e.g. CRSD).

Schemes that specifically target the agricultural supply chain include the Leven LENs. Here, LENs Scotland, 3Keel and the Forth Rivers Trust are bringing in private funding from organisations with a vested interest in protecting the natural assets in local landscapes to implement actions that protect and restore these assets. Actions include the adoption of more regenerative farming practices, buffer strips to protect watercourses, and woodland creation. These NbS provide benefits to soil health, water quality, biodiversity, local communities and farm and climate resilience. Other agricultural supply chain initiatives include Ecometric, which incentivises land managers to adopt more regenerative agricultural practices through monetising uplift in soil carbon. Similarly, the UK Carbon Code of Conduct aims to issue high integrity carbon credits for NbS and requires farms to meet net zero status before credits are issued. These mechanisms, which incentivise more sustainable agricultural practices (e.g., cover crops, reduced tillage), have the potential to provide the foundations for high integrity soil carbon accounting and could incentivise system or catchment-wide improvements to benefit the water environment.

Several emerging water-related initiatives have been supported by the SG, including via the Riverwoods initiative and the Facility for Investment Ready Nature in Scotland (FIRNS), to align on the ground action with investor interests. FIRNS projects include the Eddleston Water Project, led by the Tweed Forum, which is exploring private investment in flood management, and the Moray Farm Cluster and The Dreel Burn Investment Readiness Partnership which are exploring the use of farmer's cooperatives to build the economic (business) case to attract private investment to co-fund NbS. FIRNS has also funded development of the Scottish Rivers Fund, which is a voluntary contribution model aiming to align key environmental and social outcomes with funder needs. Some challenges faced by these pilot projects include complexities of monitoring and monetising uplift in water quality, lack of appropriate water codes, difficulties in finding investors, long-term contractual or management commitments and high-income forgone costs for arable landscapes limiting viability of markets.

Scottish Water provides one of the few examples of direct buyer engagement in market-based mechanisms. As a corporation with a statutory duty to serve the public interest and provide affordable essential services, their role extends beyond simply an ecosystem service user (beneficiary) and they have been active in a range of initiatives. For example, they are working in partnership with SEPA to address water availability in Fife via the One Planet Choices approach (Irving 2023; Adams *et al.* 2023). Recognising the important role that Scotland's natural assets has in protecting and enhancing the water environment, Scottish Water are taking a natural capital approach working from site to catchment scale. With climate change posing a major risk to the water environment, Scottish Water are investing in NbS to protect, restore and enhance ecosystem functions, thus building resilience into their business model, alleviating risk and safeguarding water quality and resources (Scottish Water 2024). Actions include peatland restoration, establishment of riparian buffer strips and creation of SuDs. Such actions will not only help Scottish Water adapt to climate change but also provide wider public goods (e.g. enhance biodiversity, capture and store carbon, and improve health and wellbeing).

Other examples of buyer-led initiatives in Scotland includes efforts around water stewardship within the food and drinks industry (Irving 2023). For example the Chivas Brothers' River Within programme funds riparian tree planting and river restoration to improve water security and regulate water temperatures for the benefit of both wild salmon and whisky production. Tools like the Replenish framework and its volumetric water benefit accounting metric, have been used by companies to support investment in wetland restoration and water stewardship.

5.2 Natural capital markets: Opportunities for River Basin Management Planning

RBMP drives strategic plans for land-based NbS that address human pressures on the water environment and provides a framework to evaluate these NbS against key outcomes. This was highlighted during the forum on Scotland's Approach to RBMP and Natural Capital hosted by Scottish Nature Finance Pioneers in May 2025. RBMP4 was seen as an opportunity to identify and prioritise catchment-based NbS that deliver multiple benefits, including improved water quality, biodiversity, and flood management, within a holistic framework that could align climate, nature and water policies and support coordinated investment. Here, we consider how RBMP aligns with emerging market-based approaches.

The fourth round of RBMP (2027-2033) provides an opportunity to align water objectives with private sector interests and market-based mechanisms by setting a clear vision to deliver multiple benefits, articulating the logic pathways from NbS to environmental, societal and economic benefit, supporting dialogue at catchment and river basin scales and providing a cohesive framework for water metrics and monitoring. Through this coordination, RBMP could help support decision-making around trade-offs and ensure that market-based approaches complement regulatory priorities alongside the delivery of Water Framework Directive (WFD) objectives.

Identifying key pressures, ecosystem services and beneficiaries

Market-based mechanisms can incentivise action to address human pressures and impacts, and, as evidenced in our literature review, effectiveness depends on ensuring good practice and the 'right NbS in the right place' (CIEEM good practice guide, Gann *et al.* 2019). NbS that improve the condition of terrestrial natural capital assets can ameliorate pressures acting on hydrology and sediment processes, leading to downstream improvements in freshwater ecosystems, their functioning and ecosystem service provisioning. As such, addressing such pressures within the wider catchment delivers multiple ecosystem benefits meeting a range of policy objectives, including for the water environment.

To ensure NbS deliver meaningful outcomes, they must be strategically designed with the local context in mind – ensuring outcomes and objectives address the needs within a catchment in addition to delivering market-driven benefits like carbon, nutrients or natural flood management.

Because each catchment has a unique distribution of land uses, asset types and stakeholder interests, it is important to understand how natural capital assets are (or could potentially be) distributed within a catchment and how they contribute to ecosystem service flows and the condition of the water environment.

Align market-based mechanisms with water outcomes

Effective use of market-based mechanisms depends on understanding what drives funder or buyer demand. Buyers may be motivated by a number of factors, including supply chain resilience, alignment with corporate mandates, brand positioning or reduced operating costs, risks or impacts. Asset managers are known to make investment choices that align with mandated ESG targets, creating greater demand for projects that deliver against these outcomes (Irving 2023). Investment or funding motivations may vary based on buyer or beneficiary priorities, strategic targets, impacts and dependencies. For example, some seek high integrity credits with detailed monitoring and verification requirements (e.g. to offset GHG emissions), while others prefer flexible options aligned with corporate goals or reporting needs to demonstrate supply chain resilience.

Prioritising water outcomes as part of national nature or net zero targets and strategies could be a key precursor to aligning market demand, creating clear policy signals to encourage entities to integrate water outcomes into mandated ESG frameworks.

Government-led initiatives can further support water-related outcomes within markets by aligning regulatory and economic incentives with these priorities. Key questions to consider include how water outcomes could be valued within established or emerging nature markets or natural capital accounting frameworks. Indeed, as barriers to investment often relate to the lack of the right policy and economic incentives to drive demand (Irving 2023, Trim and Jones 2025), the right incentives can reduce market uncertainty and help de-risk investment in emerging water-related markets.

Creating a dialogue around natural capital within RBMP

Dialogue and engagement within catchments can clarify how natural capital assets contribute to key natural capital flows and resulting ecosystem services, allowing for the identification and prioritisation of key benefits across different river basins, where each basin may have different priorities, trade-offs, key stakeholders and supply and demand drivers. For example, adverse impacts on water quality and water resources from intensive agriculture represents a key natural-related risk for the food and drinks sector. Consequently, developing strategic priorities and robust metrics to baseline, set targets and monitor against these water-related functions and services are of clear interest within catchments where the food and drinks sector is a key beneficiary. Strategic approaches like SEPA's One Planet Choices (Melville *et al.* 2023; Adams *et al.* 2023; Adams *et al.* 2024) can help identify a common set of goals and objectives to deliver multiple outcomes, while also aligning with the water outcomes set under the WFD. This type of approach can support the development of an economic (business) case for NbS and potentially facilitate delivery of water outcomes via market-based mechanisms.

Creating a cohesive framework to communicate water related metrics and outcomes

To build buyer confidence in emerging market-based mechanisms there is a need to streamline and standardise monitoring approaches to evidence outcomes for the water environment and align with RBMP priorities and WFD outputs. There are numerous existing metrics and tools available for natural capital and waterbody assessment, and these provide a range of outputs that represent different ecological and/or economic values (Section 7: Tools and data relevant to targeting of natural capital NbS; Riverwoods Measuring & Monitoring Framework 2024; McCarthy 2025; Stepchinski *et al.* 2025). Markets or market-based mechanisms that focus on a limited number of water-related metrics or outcomes (e.g. storage, flood mitigation, etc.) can incentivise NbS that improve that particular aspect but fail to deliver more holistic ecosystem improvement (Lave and Doyle 2020).

A holistic, standardised approach for monitoring and metric selection would provide a clear direction for monitoring and evaluation, increase transparency and build buyers' confidence alongside helping to ensure emerging natural capital markets are consistently and effectively quantifying water benefits.

Additionally, aligning NbS monitoring with SEPA's monitoring approach is valuable to track broader-scale change and ground truth new methods (Irving 2023). This type of standardised framework would also ensure that relevant ecosystem functions which underpin delivery of ecosystem services are consistently characterised, helping to build our understanding of both the appropriateness of indicators and the effectiveness of NbS (Cooksley *et al.* 2025).

Integrated monitoring and evaluation frameworks communicate how various metrics can be used to evaluate the suite of functional linkages within river systems that underpin ecological integrity (Fischenech 2006). They can serve as a useful decision-support tool to help tailor metric selection and assessment methodologies to the specific goals of a project. Such frameworks can increase transparency and support alignment across projects, identifying which aspects of ecosystem function or condition are being assessed and whether there are important gaps in what is being measured (Stepchinski *et al.* 2025). For example, the Stream Functions Pyramid (Figure 10) illustrates key riverine functions, how they are interconnected, which metrics and methods may serve as meaningful indicators for various aspects of ecosystem function, and how they can be scored within an integrated approach (Harman *et al.* 2012).

These types of integrated multi-index frameworks can build understanding of the linkages between

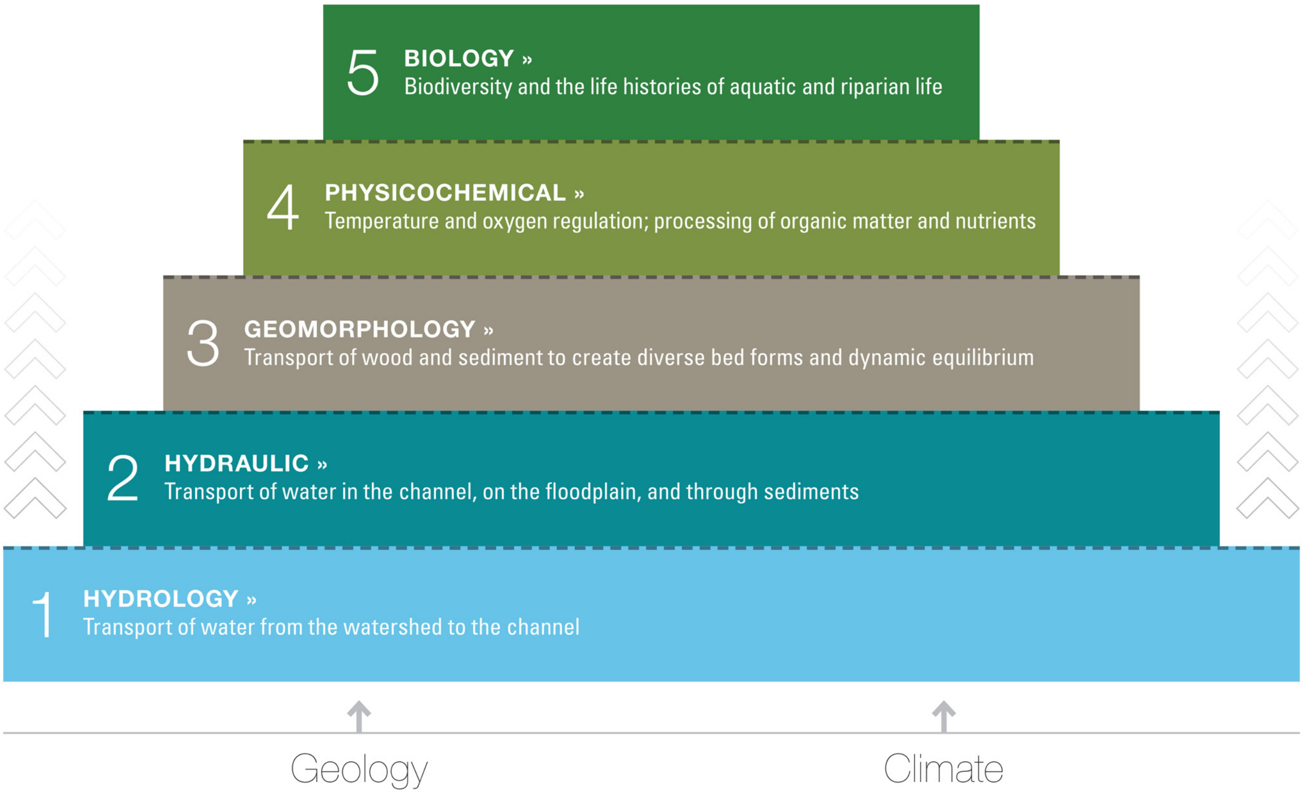


Figure 10: Stream Functions Pyramid outlining the five hierarchical functions of streams: hydrology, hydraulics, geomorphology, physicochemical and biology. (Source: https://stream-mechanics.com/stream-functions-pyramid-framework/).

drivers, pressures, states and impacts and their development has been recommended for protected areas monitoring of freshwaters and wetlands in Scotland (Gosling *et al.* 2025). A similar decision-making framework, aligning objectives with relevant metrics, has been proposed to support project-level monitoring within the Scottish Rivers Fund (McCarthy 2025). Developing an integrated conceptual framework would allow SEPA to align existing WFD monitoring outputs alongside other established or new monitoring approaches which may require different levels of effort (screening, rapid and more detailed assessments), scale (catchment versus project-level granularity) or application (e.g., nature markets, citizen science approaches or expanded monitoring within headwaters and small streams). Aligning metrics for market-based mechanisms with existing monitoring schemes (e.g. SEPA, citizen science), where appropriate, not only adds value to these schemes, but also could improve the cost/efficiency of MRV processes (a potential barrier to emerging natural capital markets), ensuring MRV is tailored to project objectives and is commensurate with the scale and complexity of a project (see the River Restoration Centre's Practical River Restoration Appraisal Guidelines for Monitoring Options (PRAGMO)).

Coordination across agencies and market intermediaries, e.g., via the SEPA-led Water Metrics and Standards working group, would be beneficial to align metrics or approaches developed for different purposes (e.g., protected areas monitoring, planning, natural capital markets, RBMP, WFD, etc.). A single conceptual monitoring and evaluation framework would provide consistency and transparency in monitoring and measuring uplift whilst recognising the multiple benefits provided by the water environment.

Alignment with strategic policy or market-based incentives for catchment-scale action

The RBMP framework creates an opportunity to identify and prioritise actions from an integrated catchment perspective. Multiple projects or NbS can be aggregated and implemented together to improve the water environment, including for water quality, water resources, biodiversity and flood management, which often require an integrated approach to alleviate pressures and deliver outcomes at the catchment scale. From a market perspective, aggregation at a catchment scale can be advantageous, as the size and scale of individual NbS often does not align with the scale of investment typically sought by the private sector or the scale needed to meaningfully address pressures.

As such, delivery structures are needed that can aggregate smaller projects together to create the right enabling conditions for larger private investment and cumulatively contribute to improved condition (e.g. farmer cooperatives, local Landscape Enterprise Networks) (Irving 2023). Through economy of scale (e.g. project design, registration, legal contracts, validation, ongoing MRV), aggregation can make entering natural capital markets more financially viable, while simultaneously reducing individual risk.

Strategic policy alignment and collaborative, catchment-focused public sector leadership plays a vital role in enabling market-based mechanisms. There are several opportunities to better integrate the water environment into existing or emerging markets in Scotland:

- Promoting and advancing the inclusion of water metrics and outcomes within developing codes and standards, including the Ecosystem Restoration Code, the Woodland Carbon Code, Peatland Code and biodiversity enhancement under NPF4 and other market-based mechanisms like PES initiatives.
- Researching how current or future regulations for activities affecting the water environment could underpin regulatory or compliance-driven market use cases.
- Developing an integrated monitoring and evaluation framework to improve transparency, increase comparability of outcomes across projects, and help ensure metrics are selected to robustly monitor key functions and project outcomes.
- Within the strategic catchment planning process, engaging with existing collaborative landscape scale or catchment scale partnerships, including Rivers or Fisheries Trusts, Regional Land Use Partnerships (RLUPs) and others that offer potential for scaling investment, fostering shared learning and resources, and delivering multiple benefits.
- Engaging across sectors to align policies and strategies with the water environment and the ecosystem services it delivers. For example, ensuring national priorities around net zero, climate resilience and adaptation, biodiversity and agriculture (e.g. whole farm plan, natural flood management and others are prioritising water outcomes and incentivising good practice NbS that support water environment condition.

Key to success is enabling use of good-practice guidance, tools and conceptual frameworks that support consistent implementation of NbS and alignment in the monitoring of outcomes.

Existing resources and good practice guidance should be regularly reviewed and evaluated to identify gaps and opportunities, build from existing approaches, where possible, and adapt guidance in line with the latest innovations and research. Embedding good-practice that delivers multiple benefits (including for the water environment) ensures the ‘right NbS in the right place’ and provides more consistency in how NbS are implemented and evaluated.

6.0 Logic models

Logic models provide a means of visually representing the logical sequence where inputs and activities result in specific outcomes. Here we have used logic models to synthesise evidence drawn from the ecosystem service assessment (Section 2), semi-systematic review (Section 3) and valuation evidence (Section 4). These models link natural assets, NbS, and functional processes (i.e. ecological and hydrological), to demonstrate how NbS influence the delivery of ecosystem services and, in turn, societal and environmental outcomes. Our models also provide monitoring metrics that link to the SEPA monitoring framework, alongside additional metrics.

Four logic models were developed with each model aligned to a separate RBMP outcome – specifically water resources, water quality, ecological condition, and physical condition (Figure 11; Figure 12). The models articulate the relationships between natural assets, NbS, riverine functions, desired outcomes and ecosystem services.

For ease of interpretation, four separate models are provided. However, it is important to note that they are interconnected. For example, NbS that deliver water resources outcomes by improving hydrologic (runoff) processes also support other outcomes, as improving hydrologic processes may result in improvements in water quality and the physical condition of waterbodies. These, in turn can result in benefits to aquatic biodiversity. Collectively, the models provide a structured framework for integrating scientific evidence with policy goals, identifying suitable monitoring indicators, and supporting adaptive management and decision-making in catchment-scale planning.

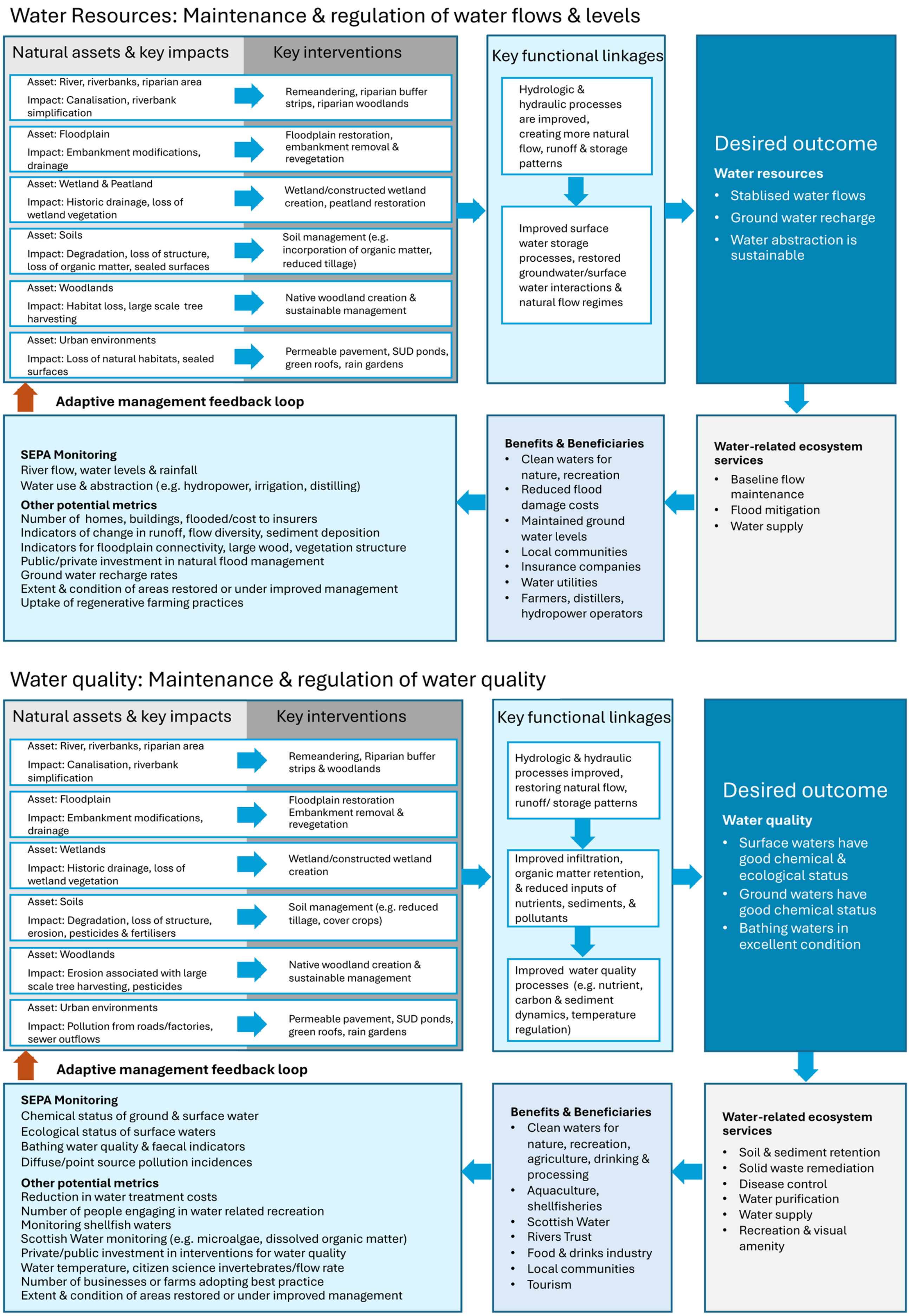
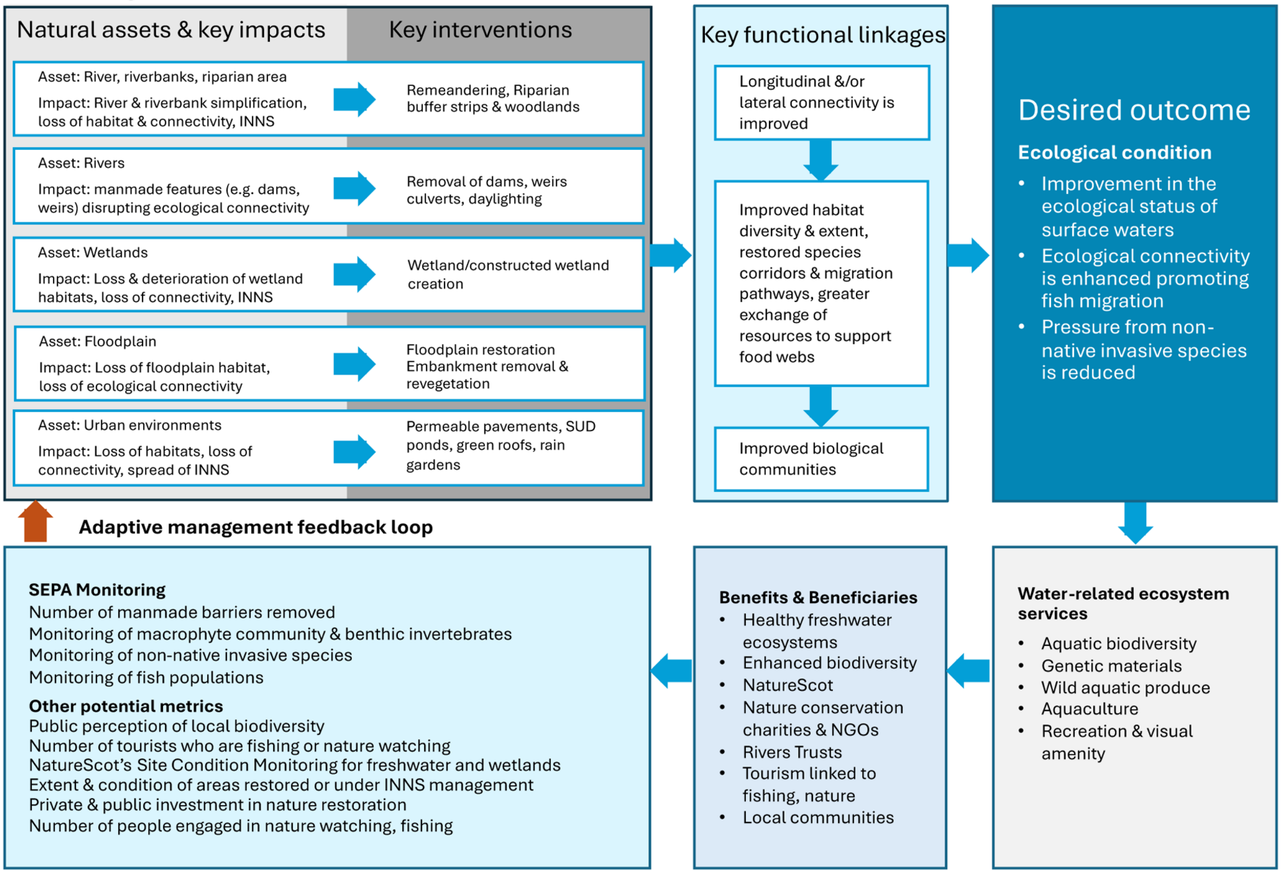


Figure 11: Logic models for Water resources (top) and Water quality (bottom).

Ecological condition: Restore habitat/connectivity for fish & other aquatic biodiversity including the control of INNS



Physical condition: Restore the morphological & physical condition

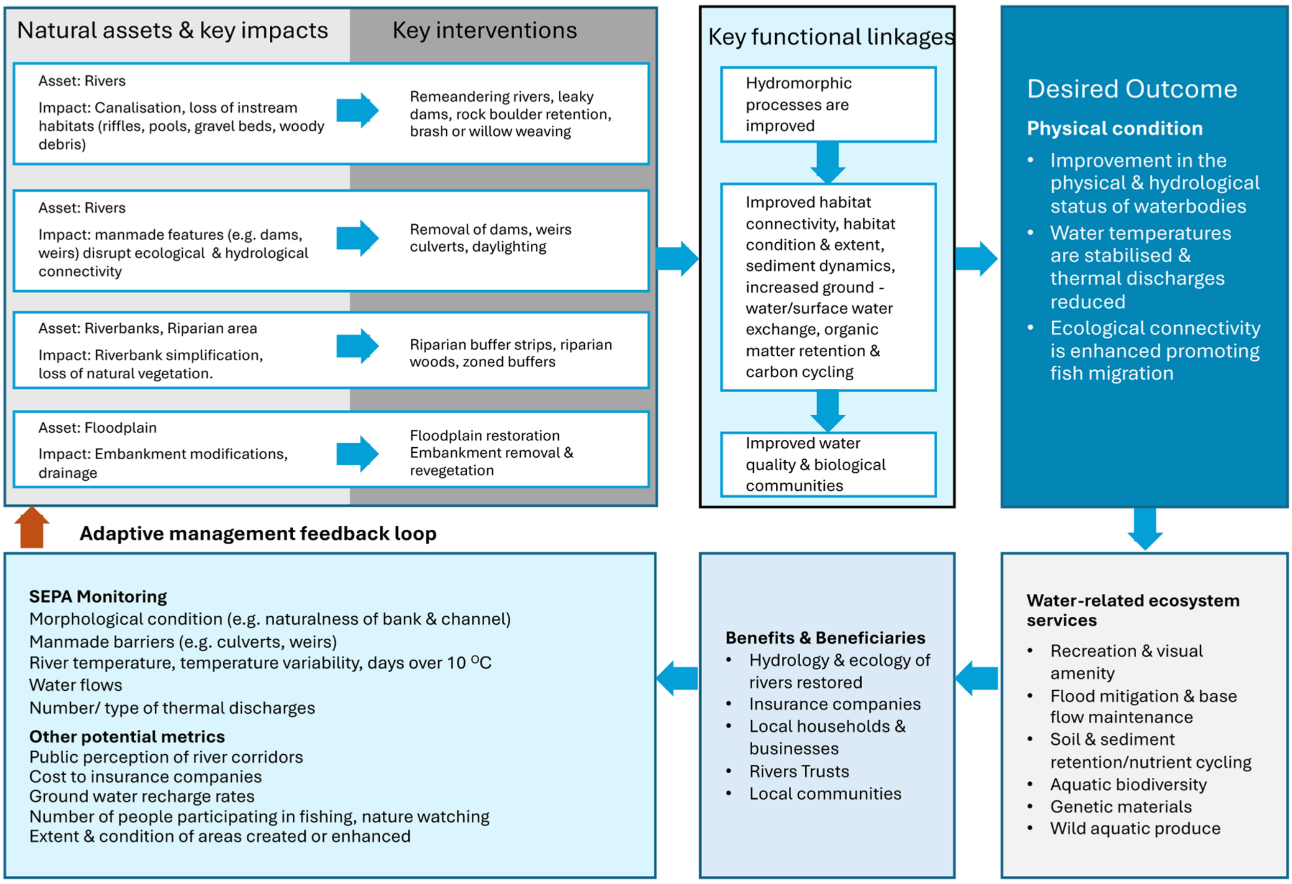


Figure 12: Logic model for Ecological condition (top) and Physical condition (bottom).

7.0 Tools and data relevant to targeting of natural capital NbS

Catchment management in Scotland is complex, reflecting the interplay between land use, hydrology, biodiversity, and socio-economic factors. Effective investment in natural capital, such as peatlands, woodlands, floodplains, and riparian zones, depends on understanding where NbS will yield the greatest benefit for the water environment. Reliable data on the type, extent and condition of natural assets in a catchment alongside the use of modelling or decision support tools is crucial to help spatially prioritise NbS to deliver water quality outcomes and wider co-benefits across a catchment (Gagkas 2021).

A desk-based review was undertaken to identify potential datasets and tools that could help deliver a natural capital approach to RBMP. This review built upon the collation of natural capital models, datasets and tools conducted by Rivington *et al.* (2025). We collated over 70 relevant data resources and over 80 spatial or decision support tools used in Scotland, the UK, Europe, and internationally (see accompanying MS Excel database). Tools range from national frameworks (e.g. SEPA Drought Risk Assessment Tool) to local-scale decision aids (e.g. flood modelling, soil erosion risk models, and woodland opportunity mapping). Approximately half are spatially explicit GIS-based tools designed for prioritisation or scenario modelling, while the remainder include economic valuation tools, ecosystem accounting platforms, and web-based visualisation dashboards.

With respect to delivering outcomes of RBMP, the most valuable datasets are those produced by SEPA. SEPA's Water Classification Hub and River Basin Management Plan mapping provide essential information on ecological status, pressures, and restoration opportunities at the waterbody scale. These datasets are fundamental for diagnosing degradation and aligning natural capital NbS with regulatory priorities.

Overland water flows can be spatial modelled combing baseline data on soil properties, rainfall, land use, hydrology and topography. In identify high-risk areas, the resultant overland flow maps can inform the strategical placement of NbS to disperse overland flows and intercept pollutants (e.g. bunds, hedgerows, riverwoods, ponds and wetlands). Such modelling is being used in England to predict the impact of wetland and woodland creation on phosphorus and nitrogen reductions in the Nutrient Reduction Standard for Interceptor Wetland and Interceptor Woodland Projects with the potential to quantifying water quality uplift in the Woodland Water Code.

High-resolution LiDAR (Light Detection and Ranging) data offer another cornerstone for targeting NbS. LiDAR captures fine-scale topography and hydrological features, supporting models of surface flow, erosion risk, and floodplain connectivity. This enables precise identification of areas where NbS such as wetland creation, re-meandering, or riparian planting will provide maximum hydrological and biodiversity benefits (see Scottish Remote Sensing Portal). The Dreel Burn Investment Readiness Partnership is currently using LiDAR data to identify optimum locations for wetland and hedgerow creation. Data, however, remains patchy across Scotland. The ongoing Scotland Land LiDAR Programme (2025–2027) aims to provide national coverage, which will be updated every 3–4 years.

The Rivers Corridor Database integrates spatial data on soils with riparian corridor attributes (terrain, land cover) to support decision-making (e.g. targeting riparian areas suitable for riverwood or floodplain creation). As this database is not widely available, the development of a user-friendly platform would enhance accessibility. NatureScot's Nature Networks Toolbox complements these spatial layers by signposting further tools which can identify areas where habitat restoration or creation would most effectively improve ecological connectivity.

In considering the multiple benefits that NbS can provide, integrated models, such as NatureScot's Natural Capital Tool can help drive more coherent action across sectors ensuring that wider social, economic and environmental benefits are accounted for in decision-making (Gagkas 2021). The Natural Capital Tool therefore has strong potential to underpin a natural capital approach to RBMP. It is easy to use and openly available and supports the full decision-making process from understanding the natural capital baseline and opportunities, to modelling the relative, biophysical and economic impacts of implementing NbS.

Building on EcoServR's spatial models, this tool creates a baseline and estimates the relative percentage change in a range of ecosystem services that could be delivered by implementing a specific NbS in a specific location (Figure 13). The tool

Figure 13: Ecosystem services included in the Natural Capital Tool. (Source: https://www.nature.scot/doc/natural-capital-tool).

currently lacks information for some ecosystem services that are key to RBMP (e.g. water quality). However, it is constantly evolving with plans to expand the range of ecosystem services across relative, biophysical, and economic valuations. The biophysical and economic valuations are currently only available for carbon and timber, but will imminently include access to nature, flood regulation and air quality, with additional services currently being assessed for future inclusion. Plans are also in place to extend the maximum modelling area to over 10,000 km^2 (currently 150 km^2) increasing alignment with typical catchment-based projects. These proposed changes will further increase the applicability of the tool for RBMP. The creation of case studies, to demonstrate how the tool can be used in catchment scale design, and to evidence wider public goods to beneficiaries and potential buyers, will further support uptake of the tool and strengthen its role in RBMP decision-making.

Data sources span hydrology, land cover, soils, biodiversity, and ecosystem service indicators. Around one-third of datasets are publicly accessible through SEPA, NatureScot, or SG open data portals; others require licence or institutional access (e.g. Ordnance Survey base data, proprietary habitat layers). Together, these resources provide a rich but fragmented evidence base. The data and tools collated in the accompanying spreadsheet provide a robust toolkit to help target NbS towards where they deliver a wide range of ecosystem services, building on the findings of the literature review. However, these resources are dispersed across agencies and vary in resolution and accessibility.

Pulling together the right data and tools to is key to strengthening stakeholder understanding of the complex linkages between natural assets within a catchment, the water environment, and the pressure facing them in addition to identify future risks and actions to mitigate those risks (Kerr et al. 2023).

These data and tools also facilitate more holistic decision-making by targeting on-the-ground action to deliver multiple benefits. Notable in this space are UKCEH's e-planner, The Rivers Trust Replenish toolbox, and Rethink Carbon. Catchment-scale tools are better provided for, for example NatureScot's Natural Capital Tool, RIVERTOOL, SCALAGO, and the CaMMP Toolbox, Storm Water Management Model (SWMM), Automated Geospatial Watershed Assessment (AGWA) and QUESTOR.

There is currently no one-size-fits-all and it is likely that individual projects will continue to need to meet their needs by pulling together a bespoke toolbox that addresses the specific project context. The EKN Tool Assessor provides a useful platform that can be used to help users pinpoint the most relevant tools to meet their needs.

This report provides a solid foundation, but further work is needed, ideally in parallel with Scotland's RBMP process, to synthesise and operationalise these datasets and tools to greatest effect.

8.0 Recommendations

Adopt a catchment-scale approach to future RBMP

Catchments provide the appropriate spatial scale to understand environmental pressures, linkages between terrestrial and freshwater environments, and to identify risks, opportunities and beneficiaries. With increasing pressures on land and water resources alongside limited public funding, joined-up thinking is essential to drive investment choices that ensure public expenditure generates multiple returns. Each catchment is unique with different pressures, impacts, opportunities and challenges. RBMP should promote strategic, systems-level thinking to ensure that the right NbS are implemented in the right places, at appropriate scales and are designed and managed to support and restore ecosystem functions that deliver multiple benefits. By tailoring a natural capital approach within catchments, there is an opportunity to leverage existing opportunities and actions to enhance benefits for the water environment.

Strategically align policy and funding decisions

RBMP provides a framework to improve understanding of how different sectors depend on the water environment and how those dependencies are vulnerable to climate and environmental change. Applying a natural capital approach within RBMP will help align decision-making, investment and action across policy areas (e.g. health and wellbeing, planning and development, biodiversity, climate resilience and sustainable land use). This will ensure that the value of natural resources and the benefits they provide are systematically recognised, increase the visibility of water-related benefits and reinforce the cross-sectoral relevance of RBMP. Successful alignment with RBMP depends on embedding natural capital principles within wider policy levers and investment frameworks to support solutions that deliver multiple benefits and support water outcomes. Including water-related outcomes within national nature and net zero targets and strategies would provide clearer policy signals to natural capital markets, helping align demand and encouraging organisations to integrate water outcomes into their business models or corporate reporting.

Strengthen evidence and integrated modelling

We identified clear links between natural assets within a catchment, NbS to protect and improve the condition of these assets, and the delivery of a range of ecosystem services. However, the evidence base was not comprehensive, with limited evidence for the impact that certain NbS (i.e. hedgerows, control of INNS, and upland and lowland grazing management) have on the water environment. To address this gap, we recommend targeted evidence reviews to better understand the contribution of these NbS on RBMP outcomes and identify appropriate scales for implementation. Where significant uncertainty remains, additional research and effective monitoring would strengthen understanding of the effects of these actions on the water environment and associated ecosystem services.

Relatively robust economic valuations exist for the ecosystem services delivered by specific assets. However, valuations that capture changes in asset condition (including improvements resulting from NbS) and service delivery are often context specific, meaning transferring values beyond the original study areas can introduce inaccuracies. Further integrated modelling is recommended to quantify and evaluate how specific NbS influence service flows over time and across spatial scales. This is particularly important where the evidence base remains limited (e.g. grazing management, hedgerow creation and control of INNS). Modelling is also needed to assess how different NbS interact at a catchment scale, recognising that interactions may be synergistic, neutral or result in trade-offs or unintended consequences. Incorporating future climate and land-use scenarios will support more robust forward-thinking cost-benefit analyses. Strengthening the evidence base on the costs and benefits of NbS will help identify where longer-term benefits (e.g. restoring soil health, enhancing water infiltration and storage) can outweigh short-term costs (e.g. reductions of yield).

Develop an integrated monitoring framework

We recommend the development of an integrated monitoring and evaluation framework to standardise metrics and approaches to evidence water-related outcomes and build transparency, comparability and alignment between projects and programmes. This would ensure water-related outcomes are consistently and effectively quantified, thus strengthening confidence among buyers, investors and regulators. An integrated framework could also help to communicate important functional linkages between NbS and the water environment, enabling metrics to be tailored to project objectives, scale and complexity. Aligning metrics for market-based mechanisms with existing monitoring schemes (e.g. SEPA WFD monitoring, protected areas and citizen science initiatives) would improve efficiency, adding value to these schemes and ensuring consistency with WFD monitoring requirements and other national objectives. Coordination across agencies and market intermediaries to develop a shared conceptual framework would provide clarity, transparency and a stronger foundation for natural capital approaches linked to the water environment.

Unlock private investment

A natural capital approach strengthens the evidence base for investing in actions that protect, enhance and restore natural assets, including sustainable agriculture, flood risk management, peatland restoration and woodland creation, which all benefit the water environment. As natural capital markets evolve, they will offer an increasingly powerful mechanism to fund NbS, particularly where NbS can reduce risks, costs and impacts or otherwise contribute to greater resilience and ecosystem service delivery. To maximise impact, market-based mechanisms need to deliver the right NbS in the right places, driving integrated outcomes for water, nature, wellbeing, sustainable land-use and climate resilience. However, while buyers and delivery partners exist, the natural capital market mechanisms that link them may not be sufficiently mature or scalable. Greater flexibility in market design, alongside clear standards, pricing structures and risk-sharing arrangements will help mobilise private investment. With many catchment-based initiatives already underway in Scotland, it is important to draw on their experience to identify the challenges faced in securing private investment and identify practical solutions to overcome these challenges.

We therefore recommend a comprehensive review of recent and current catchment-based natural capital initiatives, alongside targeted stakeholder workshops to capture lessons learned, identify key (or missing) demand drivers, and inform future market development. With uncertain demand for voluntary nature markets in Scotland, we also recommend exploring the role that high-integrity compliance markets could play in mobilising private investment for water-related initiatives. Further research is needed to explore how current or future regulations affecting the water environment (e.g., NPF4 and Environmental Authorisations (Scotland) Regulations or mandatory corporate reporting mechanisms could underpin a regulatory or compliance-driven market. Any market framework would require careful design and regulation, alongside a robust MRV framework to ensure quantifiable, additional and durable benefits for the water environment.

Support practical delivery

A wide range of tools and datasets are available to support decision-making. However, there is a need to improve how these resources are collated, standardised and embedded within existing policy, regulatory and market-based mechanisms to support consistent, locally-relevant decision-making and on-the-ground delivery. Supporting a natural capital approach across all stages of delivery requires:

Planning: RBMP should proactively engage with land-managers, communities and beneficiaries to improve understanding of how NbS that protect, restore, and enhance natural capital assets can build resilience and safeguard future service delivery. Building a shared understanding supports more holistic decision-making and encourages both private and public investment in NbS. Tools can support this decision-making by helping to prioritise and spatially target NbS within a catchment to maximise the benefits delivered while also considering trade-offs (e.g. agricultural production) and ensuring long-term sustainability. Identifying where interventions are likely to deliver the greatest benefits will help to inform and prioritise investment.

Design and management: A comprehensive suite of good-practice guidance documents will help ensure actions support multiple benefits, improve ecosystem functions and water outcomes. Guidance should draw on the latest research, tools and innovations and consider key design elements (e.g. size, plant species, structure), placement within the landscape, appropriate scale of implementation, and short and long-term management recommendations to ensure NbS retain their effectiveness.

Monitoring impact: Robust integrated frameworks support alignment between selected water metrics and project scope, scale and desired outcomes (see related recommendation: Development of an integrated framework to align water metrics and outcomes). Monitoring should support adaptive management, enabling refinement over time to optimise the outcomes achieved. To reduce costs, monitoring should build from existing monitoring programmes (e.g. SEPA, NatureScot, Scottish Water and citizen science initiatives) and where practical, align with MRV requirements of emerging natural capital-based-mechanisms.

To build capacity to deliver such initiatives on the ground, we recommend developing case studies and knowledge exchange mechanisms to share practical learning on processes, tools and delivery challenges.

Strategic priorities for embedding a natural capital approach within RBMP

Strategically align policy and funding decisions.
Ensure climate, nature, health and wellbeing, planning and sustainable land use policies recognise and account for natural assets and the benefits they provide for the water environment. Better alignment and integration across these areas will help deliver more targeted and effective outcomes.

Adopt a whole catchment-scale approach to RBMP.
Catchments provide an appropriate scale for decision-making both ecologically and for coordinating action across policy areas. Managing land and water at this scale enables cumulative pressures and interactions to be understood and strategically addressed.

Strengthen evidence and integrated modelling.
Improve understanding of how different NbS impact the water environment and wider ecosystem services. Modelling to account for trade-offs, synergies and climate change to inform more robust decisions, reduce unintended consequences and build climate resilience.

Develop an integrated monitoring framework.
Establish an integrated monitoring and evaluation framework that aligns metrics with RBMP priorities and reflects underlying ecosystem functions. Consistent, transparent and quantifiable metrics will build confidence among regulators, investors and delivery partners.

Unlock private investment.
Private investment is needed to close the funding gap for nature restoration. Credible blended finance models can attract investment where barriers to market participation are addressed and high-integrity mechanisms are developed to drive demand.

Support practical delivery.
Share learnings, develop clear guidance and build capability to translate strategy into effective catchment-scale action. To facilitate delivery, collate existing data and tools. Strengthening capacity on the ground is essential to embed a natural capital approach in catchment management.

Figure 14: Key strategic priorities.

9.0 Conclusions

As Scotland enters the fourth cycle of River Basin Management Planning (RBMP), we have a critical policy window to embed a holistic natural-capital approach within catchment management. Previous RBMP cycles have made significant progress in addressing pressures on the water environment. However, by primarily focussing on NbS near to waterbodies, opportunities for broader landscape-scale NbS may not have been fully realised. This forthcoming RBMP cycle provides an opportunity to integrated natural capital thinking more fully, creating an interconnected framework that transcends policy areas to meet wider objectives for biodiversity, climate resilience, net zero and sustainable land use.

Our review highlights the fundamental role that Scotland's water environment plays in sustaining ecosystem services that underpin environmental, economic and societal wellbeing. Clear functional links exist between natural assets, their condition, land use decisions and the delivery of water-related and wider ecosystem services. Recognising these interdependencies, provides the evidence for RBMP to evolve towards a systems-level approach that supports multi-functional NbS and improves alignment across biodiversity, climate resilience, sustainable land use, economic and health and wellbeing policy objectives.

A natural capital approach provides a decision support framework that can be embedded within existing policy, regulatory and investment frameworks. As Scotland seeks to lever private investment to bolster public funding, the fourth cycle of the RBMP provides an opportunity to align catchment-based management with emerging natural capital markets. Through adopting a natural capital approach within the fourth RBMP cycle, Scotland can enhance the resilience of its water environment while delivering co-benefits for nature recovery, climate adaptation, and societal wellbeing.

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11.0 Appendix 1: Water-related ecosystem services

Table 15: CICES water dependent ecosystem services cross referenced to the SEEA framework

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Provisioning: Ecosystem services						
Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown for nutritional purposes	*Plants that are cultivated in fresh or salt water that we eat*	*Harvesting of cultivated seaweed/watercress (e.g. Locavore)*	Aquaculture provisioning services	Aquaculture provisioning services are the ecosystem contributions to the growth of animals and plants (e.g. fish, shellfish, seaweed) in aquaculture facilities that are harvested by economic units for various uses. This is a final ecosystem service.
Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated for fibres and other materials by in-situ aquaculture for direct use or processing (excluding genetic materials)	*Plants that are cultivated in fresh or salt water that we can use as a material*	*Harvesting of reeds for thatching (e.g. RSPB Tay Reedbeds)*		
Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown as an energy source	*Plants that are cultivated in fresh or salt water that we can use as an energy source*	*Emerging opportunity: Harvesting algae or reeds for anaerobic digesters to produce biogas*		
Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	*Animals that are cultivated in fresh or salt water that we eat.*	*Fish farming - juvenile salmon, rainbow trout, brown trout*		
Biomass	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excl. genetic materials)	*Animals that are cultivated in fresh or salt water that we can use as a material*	*Fish skin as a byproduct for leather production or collagen extraction*		
Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture as an energy source	*Animals that are cultivated in fresh or salt water that we can use as a source of energy*	*One plan trials using aquaculture waste for anaerobic digestion*	Other provisioning services	
Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	*Food from wild plants*	*Harvesting of wild watercress, water mint*	Wild fish and other natural aquatic products provisioning services	Wild fish and other natural aquatic biomass provisioning services are the ecosystem contributions to the growth of fish and other aquatic biomass that are captured in uncultivated production contexts by economic units for various uses, primarily food production. This is a final ecosystem service.
Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing (exc. genetic materials)	*Materials from wild plants*	*Harvesting of reeds for thatching*		
Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy	*Materials from wild plants, fungi and algae used for energy*	*Harvesting of reeds or willow for biodigesters or fuel*		
Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	*Food from wild animals*	*Salmon, trout fishing*		
Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	*Materials from wild animals*	*Fish skin as a byproduct for leather production or collagen extraction (e.g. bags from fish leather)*		
Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used as a source of energy	*Material from wild animals that can be used as a source of energy*	*Fish oil (theoretical)*		

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Genetic material from all biota	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	*Seed collection*	*Harvesting the seeds of native wetland plants to obtain species of local provenance (Eadha Enterprise)*	Genetic material services	Genetic material services are the ecosystem contributions from all biota (including seed, spore or gamete production) that are used by economic units, for example (i) to develop new animal and plant breeds; (ii) in gene synthesis; or (iii) in product development directly using genetic material. This is most commonly recorded as an intermediate service to biomass provisioning.
Genetic material from all biota	Genetic material from plants, algae or fungi	Higher and lower plants (whole organisms) used to breed new strains or varieties	*Plants. fungi or algae that we can use for breeding*	*Culturing of algae (SAMS work)*		
Genetic material from all biota	Genetic material from plants, algae or fungi	Individual genes extracted from higher and lower plants for the design and construction of new biological entities	*Genetic material from wild plants. fungi or algae that we can use*	*Collection of rare wetland plants for genetic banking (Royal Botanic Garden Edinburgh: RGBE)*		
Genetic material from all biota	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population	*Animals used for replenishing stock*	*Salmon broodstock collection, rearing of freshwater pearl mussels in captivity (e.g. Freshwater Biological Association)*		
Genetic material from all biota	Genetic material from animals	Wild animals (whole organisms) used to breed new strains or varieties	*Wild animals that we can use for breeding*	*Use of wild salmon in breeding projects (e.g. Atlantic Salmon Trust)*		
Provisioning: Geosystem outputs						
Division	**Group**	**Class**	**Simple descriptor**	**Example Scotland**	**SEEA**	**SEEA Description**
Water	Surface water used for nutrition, materials or energy	Surface water for drinking	*Drinking water from sources at the ground surface*	*Natural springs providing drinking water*	Water supply services	Water supply services reflect the combined ecosystem contributions of water flow regulation, water purification, and other ecosystem services to the supply of water of appropriate quality to users for various uses including household consumption. This is a final ecosystem service.
Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	*Surface water that we can use for things other than drinking*	*Distilleries utilising surface waters for cooling purposes*		
Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source	*Hydropower*	*Use of water for hydro/ hydro electric power (e.g. Lanark Hydro Electric Scheme)*		
Water	Surface water used for nutrition, materials or energy	Coastal and marine water used as energy source	*Wave or tidal power*	*The use of wave or tidal power to produce energy*		
Water	Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking	*Drinking water from the below ground*	*Extraction of ground water for drinking purposes (e.g. wells, boreholes)*		
Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as a material (non-drinking purposes)	*Sub-surface water that we can use for things other than drinking*	*Extraction of ground water for crop irrigation*		
Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as an energy source; regulation of heating and cooling	*Sub-surface water that we can use as a source of energy*	*Exploration of using heat from the water to regulate building temperatures (e.g. Cuningar Loop, Glasgow)*		

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Regulating: Ecosystem services						
Transformation of biochemical or physical inputs to ecosystems	Reduction of nutrient loads and mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	*Decomposing wastes or polluting substances*	*Aquatic plants and micro-organisms breaking down pesticides from agricultural runoff*	Solid waste remediation; Water purification services - Retention and breakdown of other pollutants	Solid waste remediation services are the ecosystem contributions to the transformation of organic or inorganic substances, through the action of micro-organisms, algae, plants and animals that mitigates their harmful effects. This may be recorded as a final or intermediate service. Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health. This may be recorded as a final or intermediate ecosystem service.
Transformation of biochemical or physical inputs to ecosystems	Reduction of nutrient loads and mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	*Filtering wastes or sequestering pollutants*	*Constructed wetlands which act as natural filters, removing nitrates, phosphates, and sediments from agricultural runoff*		
Regulation of baseline flows and extreme events	Erosion control	Control of water erosion rates	*Controlling or preventing soil or sediment loss by running water*	*Riparian vegetation providing stability to bank (e.g. willow planting: Ayrshire Rivers Trust - Garnock Connections), intercepting soils (e.g. buffer strips)*	Soil erosion control services	Soil erosion control services are the ecosystem contributions, particularly the stabilising effects of vegetation, that reduce the loss of soil (and sediment) and support use of the environment (e.g., agricultural activity, water supply). This maybe recorded as a final or intermediate service
Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation	Regulation runoff and base flows	*Ecosystems controlling river and lake levels during normal conditions*	*Wetlands, peatlands and floodplains slow water flows (e.g. floodplains restoration within the Eddlestone Water project)*	Water flow regulation services	Water regulation services are the ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and gradually release water during dry seasons or periods through evapotranspiration and hence secure a regular flow of water. This may be recorded as a final or intermediate ecosystem service.

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation	Regulation of peak flows	*Controlling the peaks in river levels; mitigating flood waves*	*SUDs, wetlands, leaky dams, peatlands, absorb and slow down water flows*	Peak flow mitigation and River flood mitigation services	Water regulation services are the ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and hence mitigate the effects of flood and other extreme water-related events. Peak flow mitigation services will be supplied together with river flood mitigation services in providing the benefit of flood protection. This is a final ecosystem service.
Regulation of baseline flows and extreme events	Hazard mitigation	Surge and flood wave mitigation	*Protecting people from flooding*	*Well functioning catchments, with natural rivers, riparian vegetation, floodplains, peatlands and wetlands provide natural flood management*	Peak flow mitigation and River flood mitigation services	Coastal protection services are the ecosystem contributions of linear elements in the seascape, for instance coral reefs, sand banks, dunes or mangrove ecosystems along the shore, in protecting the shore and thus mitigating the impacts of tidal surges or storms on local communities. This is a final ecosystem service.; River flood mitigation services are the ecosystem contributions of riparian vegetation which provides structure and a physical barrier to high water levels and thus mitigates the impacts of floods on local communities. River flood mitigation services will be supplied together with peak flow mitigation services in providing the benefit of flood protection. This is a final ecosystem service.
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	*Pollinating our fruit trees and other plants*	*Aquatic stage of hoverflies such as the common dronefly*	Pollination services	Pollination services are the ecosystem contributions by wild pollinators to the fertilization of crops that maintains or increases the abundance and/or diversity of other species that economic units use or enjoy. This may be recorded as a final or intermediate service.

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Regulation of baseline flows and extreme events	Hazard mitigation	Fire protection	*Protecting people from fire*	*Maintenance of water levels in the uplands reduces fire risk, rivers and streams act as natural fire breaks*	Other regulating and maintenance services	
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	*Spreading the seeds of wild plants*	*Spread of seeds along watercourses allowing riparian vegetation to thrive. Can also provide a disservice in spreading INNS*		
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining or regulating nursery populations and habitats or breeding grounds (Includes gene pool protection)	*Providing habitats for wild plants and animals that can be useful to us*	*Provisioning of breeding habitat for a range of protected species including spawning habitat for salmon and trout, habitat for freshwater mussels and water voles*	Nursery population and habitat maintenance services	Nursery population and habitat maintenance services are the ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy either through the maintenance of habitats (e.g., for nurseries or migration) or the protection of natural gene pools. This service is an intermediate service and may input to a number of different final ecosystem services including biomass provision and recreation-related services.
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining or regulating refuge habitats	*Providing habitats for wild plants and animals that can be useful to us*	*Riparian vegetation provides refuge for water voles, otters*		
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining or regulating feeding grounds	*Providing habitats for wild plants and animals that can be useful to us*	*Wetlands and peatlands provide foraging habitats for declining wading birds*		
Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)	*Controlling pests and invasive species*	*Insects such as dragonflies and amphibians such as frogs prey on midge larvae*	Pest and disease control services	Biological control services are the ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of pests on biomass production processes or other economic and human activity. This may be recorded as a final or intermediate service.
Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control	*Controlling disease*	*Riparian vegetation reduces the risk of pathogens entering the watercourse, fish and wading birds feed on mud snails reducing risk of liver fluke*	Pest and disease control services	Disease control services are the ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of species on human health. This is most commonly a final ecosystem service.

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of macronutrients in freshwaters by living processes	*Controlling the chemical quality of freshwater*	*Maintenance of healthy biotic communities ensures nutrient balance in rivers, ponds and lochs*	Water purification services: Retention and breakdown of nutrients	Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health. This may be recorded as a final or intermediate ecosystem service.
Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of macronutrients in salt waters by living processes	*Controlling the chemical quality of salt water*	*Saltmarsh vegetation ensuring nutrient balance in estuaries*		
Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans, and the maintenance of continental atmospheric/ oceanic circulation patterns	*Regulating our global climate*	*Value of wetlands at sequestering and storing carbon is becoming increasingly recognised*	Global climate regulation services; Rainfall pattern regulation services (sub-continental)	Global climate regulation services are the ecosystem contributions to the regulation of the chemical composition of the atmosphere and oceans that affect global climate through the accumulation and retention of carbon and other GHG (e.g., methane) in ecosystems and the ability of ecosystems to remove (sequester) carbon from the atmosphere. This is a final ecosystem service. Rainfall pattern regulation services are the ecosystem contributions of vegetation, in particular forests, in maintaining rainfall patterns through evapotranspiration at the sub-continental scale. Forests and other vegetation recycle moisture back to the atmosphere where it is available for the generation of rainfall. Rainfall in interior parts of continents fully depends upon this recycling. This may be a final or intermediate service.
Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration at local scales	*Regulating the physical quality of air for people*	*Rivers and SUDS in urban areas provide evaporative cooling reducing impacts of extreme heat*	Local (micro and meso) climate regulation services	Local climate regulation services are the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) through the presence of vegetation that improves the living conditions for people and supports economic production. Examples include the evaporative cooling provided by urban trees ('green space'), the role of urban water bodies ('blue space') and the contribution of trees in providing shade for humans and livestock. This may be a final or intermediate service.

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Regulating: Ecosystem services						
Regulation and maintenance of geophysical	Regulation of baseline flows and extreme events	Abiotic regulation of liquid flows	*Physical barriers to flows*	*Natural levees or floodplains providing water storage, helping to regulate water flows reducing flood risks*	Flood mitigation	Coastal protection services are the ecosystem contributions of linear elements in the seascape, for instance coral reefs, sand banks, dunes or mangrove ecosystems along the shore, in protecting the shore and thus mitigating the impacts of tidal surges or storms on local communities. This is a final ecosystem service.; River flood mitigation services are the ecosystem contributions of riparian vegetation which provides structure and a physical barrier to high water levels and thus mitigates the impacts of floods on local communities. River flood mitigation services will be supplied together with peak flow mitigation services in providing the benefit of flood protection. This is a final ecosystem service.
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution or transport of wastes by freshwater and marine ecosystems	*Diluting or removing wastes*	*Discharge of dilute treated wastewater and stormwater runoff into waterbodies. This practice is closely monitored by SEPA*	Solid waste remediation; Water purification services - Retention and breakdown of other pollutants	Solid waste remediation services are the ecosystem contributions to the transformation of organic or inorganic substances, through the action of micro-organisms, algae, plants and animals that mitigates their harmful effects. This may be recorded as a final or intermediate service. Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health. This may be recorded as a final or intermediate ecosystem service.
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Mediation of wastes by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)	*Natural processing of wastes*	*Physical breakdown of plastics by rivers*		

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Regulation and maintenance of geophysical	Maintenance of physical, chemical, abiotic conditions	Maintenance and regulation by inorganic natural chemical and physical processes of fresh or salt waters	*Regulating living conditions by the physical environment*	*In areas with aquifers, water movement through substrate naturally filters and balances chemical properties*	Water purification services: Retention and breakdown of nutrients	Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health. This may be recorded as a final or intermediate ecosystem service.
Regulation and maintenance of geophysical	Maintenance of physical, chemical, abiotic conditions	Maintenance and regulation by inorganic natural chemical and physical processes of atmosphere	*Regulating living conditions by the physical environment*	*Regulation of atmosphere through waterbodies acting as a buffer (e.g. urban rivers providing cooling during periods of extreme heat)*	Local (micro and meso) climate regulation services	Local climate regulation services are the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) through the presence of vegetation that improves the living conditions for people and supports economic production. Examples include the evaporative cooling provided by urban trees (‘green space’), the role of urban water bodies (‘blue space’) and the contribution of trees in providing shade for humans and livestock. This may be a final or intermediate service.

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Cultural: Ecosystem services						
Physical and experiential interactions with natural environment	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting, i.e. broadly recreational activities	Elements of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	*Using the environment for sport and recreation; using nature to help stay fit*	*Fishing, kayaking, wild swimming*	Recreation-related services	Recreation-related services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (i.e. visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting. This is a final ecosystem service.
Physical and experiential interactions with natural environment	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting, i.e. broadly recreational activities	Elements of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	*Watching plants and animals where they live; using nature to destress*	*Bird watching, nature reserves (e.g. Lochwinnoch, Loch Leven)*	Visual amenity services	Visual amenity services are the ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual. This service combines with other ecosystem services, including recreation-related services and noise attenuation services to underpin amenity values. This is a final ecosystem service.
Intellectual and representative interactions with natural environment	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Elements of living systems that enable scientific investigation or the creation of traditional ecological knowledge, including the importance of between and within species genetic diversity	*Researching nature*	*Research into aquatic species (e.g. impact of climate change on salmon)*	Education, scientific and research services	Education, scientific and research services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment. This is a final ecosystem service.
Intellectual and representative interactions with natural environment	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Elements of living systems that enable education and training, including the importance of between and within species genetic diversity	*Studying nature*	*Pond dipping, kick sampling to explore freshwater biota*		
Intellectual and representative interactions with natural environment	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Elements of living systems that are resonant in terms of culture or heritage	*The things in nature that help people identify with the history or culture of where they live or come from*	*Cultural heritage such as former mill towns (e.g. New Lanark: UNESCO World Heritage site)*	Spiritual, artistic and symbolic services	Spiritual artistic and symbolic services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media. This is a final ecosystem service.
Intellectual and representative interactions with natural environment	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Elements of living systems that enable aesthetic experiences	*The beauty of nature*	*Areas of Outstanding Natural Beauty such as Loch Lomond*		

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Intellectual and representative interactions with natural environment	Indirect, interactions with living systems	Elements of living systems used for entertainment or representation outside the setting concerned	*The things in nature used to make films or to write books*	*Inspiration of books and films (e.g. Loch Ness), poetry (e.g. Afton Water) or song (e.g. Loch Lomond)*	Spiritual, artistic and symbolic services	Spiritual artistic and symbolic services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media. This is a final ecosystem service.
Spiritual, symbolic and other cultural interactions with natural environment	Elements of living systems that are indirectly appreciated and have significance for people without their presence in the environmental setting.	Elements of living systems that have symbolic meaning, capture the distinctiveness of settings or their sense of place	*Using nature as a national or local emblem, or referencing a particular area as distinctive in some way (e.g. The Yorkshire Dales)*	*River Clyde and Clyde Canal reflect Glasgows industrial past and the growth of towns such as Falkirk*		
Spiritual, symbolic and other cultural interactions with natural environment	Elements of living systems that are indirectly appreciated and have significance for people without their presence in the environmental setting.	Elements of living systems that have spiritual or religious meaning	*The things in nature that have spiritual importance for people*	*Mythical creatures such as kelpies and the Loch Ness monster. Sacred sites such as St Fillan's well*		
Spiritual, symbolic and other cultural interactions with natural environment	Other biophysical characteristics of species or ecosystems that are appreciated in their own right by people	Elements or features of living systems whose contemporary existence or conservation is important to people, including the importance of between and within species genetic diversity.	*The things in nature that we think should be conserved*	*Loch Lomond and the Trossachs National Park, River Tweed SSSI.*	Ecosystem and species appreciation services	Ecosystem and species appreciation concerns the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use.
Spiritual, symbolic and other cultural interactions with natural environment	Other biophysical characteristics of species or ecosystems that are appreciated in their own right by people	Elements or features of living systems whose inter-generational existence or conservation is important to people, including the importance of between and within species genetic diversity	*The things in nature that we want future generations to enjoy or use*	*Wide range of projects aimed to protect our water environment including the Eddleston Water, Dreel Catchment and Loch Leven*		

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Cultural: Geosystem outputs						
Physical and experiential interactions with biophysical environment	Direct, in-situ and outdoor interactions with geophysical systems that depend on presence in the environmental setting	Characteristics of geophysical systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	*Using the environment for sport and recreation; using nature to help stay fit*	*Wild swimming, riverbank walks*	Recreation-related services	Recreation-related services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (i.e. visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting. This is a final ecosystem service.
Physical and experiential interactions with geophysical environment	Direct, in-situ and outdoor interactions with geophysical systems that depend on presence in the environmental setting	Characteristics of geophysical systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	*Watching plants and animals where they live; using nature to destress*	*Bird watching in lochs, watching beavers/otters in rivers*	Visual amenity services	Visual amenity services are the ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual. This service combines with other ecosystem services, including recreation-related services and noise attenuation services to underpin amenity values. This is a final ecosystem service.
Intellectual and representative interactions with geophysical environment	Direct, in-situ and outdoor interactions with geophysical systems that depend on presence in the environmental setting	Elements of geophysical systems that enable scientific investigation or the creation of traditional ecological knowledge	*Researching nature*	*Research into hydrology, water flows, flood risks*	Education, scientific and research services	Education, scientific and research services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment. This is a final ecosystem service.
Intellectual and representative interactions with geophysical environment	Direct, in-situ and outdoor interactions with geophysical systems that depend on presence in the environmental setting	Elements of geophysical systems that enable education and training	*Studying nature*	*Pond dipping, kick sampling to explore freshwater biota*		
Spiritual, symbolic and other interactions with geophysical environment	Other biophysical elements of species or ecosystems that are appreciated in their own right by people	Elements or features of geophysical systems whose contemporary existence or conservation is important to people	*The things in nature that we think should be conserved*	*RAMSAR Sites, Nature Reserves, Natura 2000 sites*	Ecosystem and species appreciation services	Ecosystem and species appreciation concerns the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use.
Spiritual, symbolic and other interactions with geophysical environment	Other biophysical elements of species or ecosystems that are appreciated in their own right by people	Elements or features of geophysical systems whose inter-generational existence or conservation is important to people.	*The things in nature that we want future generations to enjoy or use*	*Many actions to support and restore waterbodies, including remeandering, and controlling INNS*		

Division	Group	Class	Simple descriptor	Example Scotland	SEEA	SEEA Description
Intellectual and representative interactions with geophysical environment	Direct, in-situ and outdoor interactions with geophysical systems that depend on presence in the environmental setting	Elements of geophysical systems that are resonant in terms of culture or heritage	*The things in nature that help people identify with the history or culture of where they live or come from*	*Cultural heritage regarding rivers and lochs (e.g. Garnock Connections Landscape Partnership's Working Voices)*	Spiritual, artistic and symbolic services	Spiritual artistic and symbolic services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media. This is a final ecosystem service.
Intellectual and representative interactions with geophysical environment	Direct, in-situ and outdoor interactions with geophysical systems that depend on presence in the environmental setting	Elements of geophysical systems that enable aesthetic experiences	*The beauty of nature*	*Glens and waterfalls such as the Falls of Clyde*		
Intellectual and representative interactions with geophysical environment	Indirect, interactions with geophysical systems	Elements of geophysical systems used for entertainment or representation outside the setting concerned	*The things in nature used to make films or to write books*	*Inspiration of books and films (e.g. Loch Ness), poetry (e.g. Afton Water) or song (e.g. Loch Lomond)*		
Spiritual, symbolic and other interactions with geophysical environment	Elements of geophysical systems that are indirectly appreciated and have significance for people without their presence in the environmental setting	Elements of geophysical systems that have symbolic meaning	*Using nature to as a national or local emblem*	*The Bonnie Banks o' Loch Lomond, capturing national pride in Scotland's beauty*		
Spiritual, symbolic and other interactions with geophysical environment	Elements of geophysical systems that are indirectly appreciated and have significance for people without their presence in the environmental setting	Elements of geophysical systems that have sacred or religious meaning	*The things in nature that have spiritual importance for people*	*Sacred/holy wells such as St Ronan's Well*		

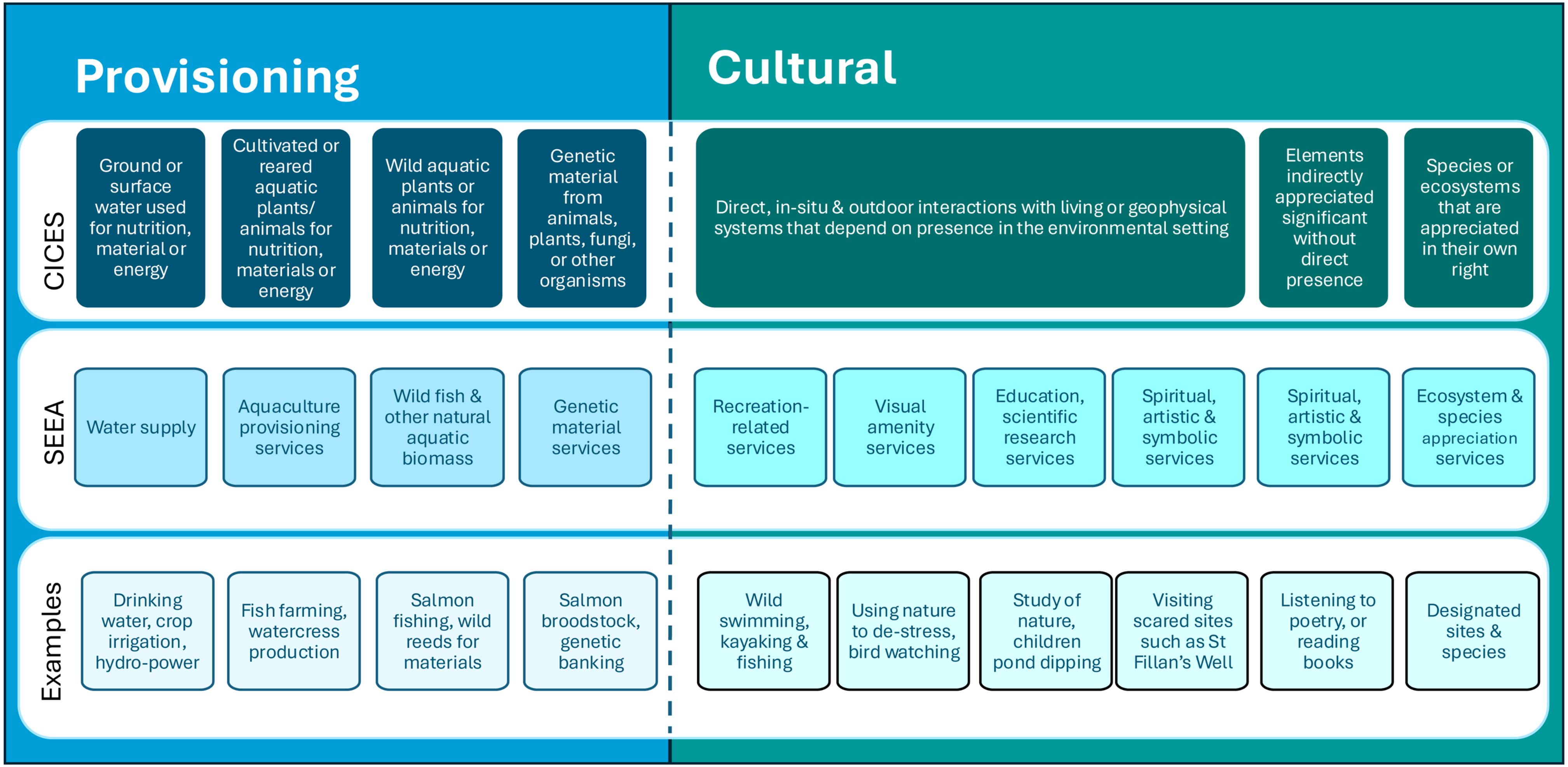

Figure 15: Diversity of ecosystem services provided by the water environment: Provisioning and Cultural Services.

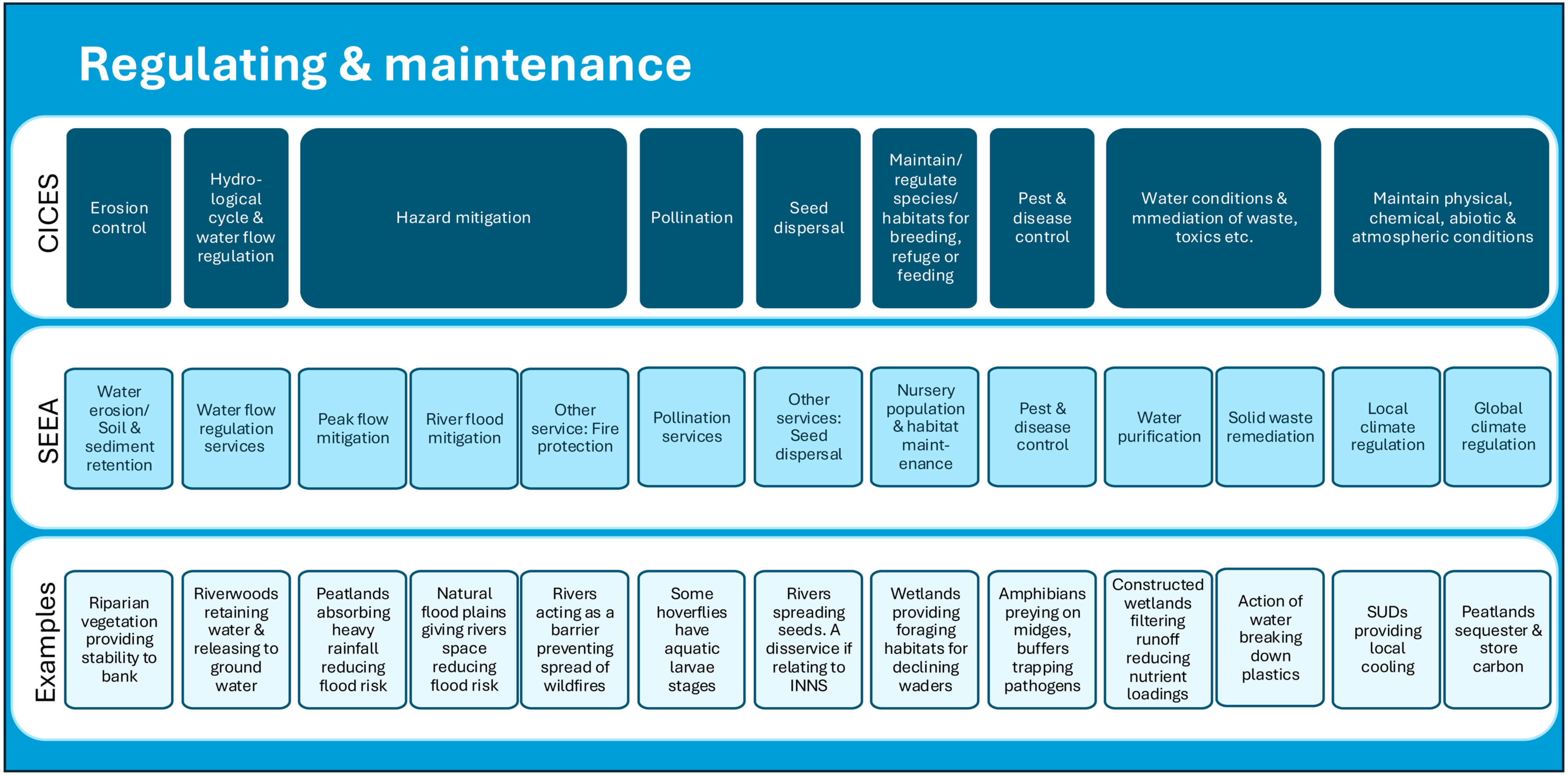

Figure 16: Diversity of ecosystem services provided by the water environment: Regulating and maintenance services.

12.0 Appendix 2: Literature review methodology

Table 16: Search terms used to identify literature through Web of Science.

	Title	Water management OR catchment OR Watershed OR River management OR river basin management OR Water quality OR Water condition OR Hydrological management OR Water resource management OR Aquatic resource management OR Water control OR Hydraulic management OR integrated land management OR natural capital
AND	Topic	diffuse pollution OR organic matter OR sediment OR erosion OR degrad* OR agri* OR forest* OR urban* OR abstraction OR drainage OR river flow pattern OR dam OR canalisation OR channel* OR soil OR wetland OR peat OR biodiversity OR ecolog* connect* OR habitat OR floodplain OR invasive species OR bank* OR flood OR climate change OR thermal regulation
AND	Title	Catchment OR Watershed OR Drainage area OR Water basin OR River basin OR Flood basin OR Floodplain OR Flood zone OR River valley OR Alluvial plain OR protected areas
AND	Topic	Review OR Literature review OR Systematic review OR meta*
NOT	Topic	Arid OR Tropical OR Asia OR Africa OR South America OR China OR Chinese or IRAN or MEXICO or EGYPT or ARGENTINA or RUSSIA or PAKISTAN or SAUDI ARABIA or SOUTH KOREA or TURKEY or JAPAN or COLOMBIA or ISRAEL or ETHIOPIA or INDONESIA or TAIWAN or BANGLADESH or ECUADOR or MALAYSIA or CAMEROON or CUBA or KENYA or SRI LANKA or TUNISIA or IRAQ or ZAMBIA or VENEZUELA or SINGAPORE or QATAR or ARAB EMIRATES or PHILIPPINES or NAMIBIA or LIBYA or KUWAIT or KAZAKHSTAN or GHANA or COSTA RICA or URUGUAY or PERU or MOROCCO or JORDAN or CHILE or BURKINA FASO or NIGERIA or VIETNAM or AUSTRALIA or NEPAL

Table 17: Search terms used to identify evidence though Elicit.

Search	Search term	No. sources extracted
1	nature-based solutions to catchment watershed management and river basin management planning	25
2	natural capital approach to catchment watershed management and river basin management planning	25
3	nature-based solutions/NbS to regulating water flows including surface water storage, retention processes and flood risk	10
4	nature-based solutions/NbS to mitigate diffuse pollution	10
5	nature-based solutions/NbS to protect and enhance aquatic biodiversity	10
6	nature-based solutions/NbS to protect and enhance the physical and thermal conditions of waterways including rivers, streams	10

Table 18: Overview of broad NbS groups alongside the NbS in each group.	
NbS group	**NbS included in each broad NbS group**
Agroforestry	Agroforestry
Constructed wetlands	Reactive nutrient traps; Overland sediment traps/bunds, Redirection of agricultural drainage systems to off-channel ponds, constructed wetlands or slow flowing ditches; Water saturated buffers
Ponds	Pond creation (see SUDS for urban)
Floodplain restoration	Restoration of extensively managed floodplains, Reconnection of backwaters side channels and oxbows
River restoration	Re-meandering; Installation of leaky dams wood debris; Rock boulder retention or introduction; Brash or willow weaving; Reintroduction and sympathetic management of beavers
Hedgerows	Creation and restoration of hedgerows shelterbelts
Lowland grazing management	Adaptive multi-paddock grazing (mob grazing); Reduce grazing pressure in lowland intensive grassland systems; Move feeding points to prevent poaching and provide alternative watering
Upland grazing management	Reduce grazing pressure in the uplands (including both livestock and deer)
Peatland restoration	Peatland restoration: Rewetting gully blocking reprofiling encouraging natural revegetation
Control INNS	Control of INNS
Remove manmade structures	Removal of weirs culverts and other barriers; Daylighting (opening rivers up)
Riparian buffers	Herbaceous buffers; 3D or zonal buffers with multiple vegetated zones
Riparian woodland	Wooded buffer strips and riverwoods
Soil management	Reduced tillage; Winter cover; Incorporation of organic matter; aeration techniques; targeted fertiliser applications
Urban	Permeable pavements; SUDS Ponds and raingardens; Green roofs and green walls
Wetland restoration	Wetland restoration including fens, swamps, marshes (non-floodplain); Saltmarsh restoration
Woodland restoration	Restoration and sustainable management of native woodlands (including conversion of coniferous plantations)

Table 19:Overview of the SEEA ecosystem services (United Nations 2021).		
SEEA Subtype	**SEEA Description**	**Name in outputs**
Provisioning		
Crop provisioning services	Crop provisioning services are the ecosystem contributions to the growth of cultivated plants that are harvested by economic units for various uses including food and fibre production, fodder and energy. This is a final ecosystem service.	Crop
Grazed biomass and livestock production provisioning services	Grazed biomass provisioning services are the ecosystem contributions to the growth of grazed biomass that is an input to the growth of cultivated livestock. This service excludes the ecosystem contributions to the growth of crops used to produce fodder for livestock (e.g., hay, soybean meal). These contributions are included under crop provisioning services. This is a final ecosystem service but may be intermediate to livestock provisioning services. Livestock provisioning services are the ecosystem contributions to the growth of cultivated livestock and livestock products (e.g., meat, milk, eggs, wool, leather), that are used by economic units for various uses, primarily food production. This is a final ecosystem service. No distinct livestock provisioning services to be recorded if grazed biomass provisioning services are recorded as a final ecosystem service.	Grazed biomass livestock
Wood provisioning services	Wood provisioning services are the ecosystem contributions to the growth of trees and other woody biomass in both cultivated (plantation) and uncultivated production contexts that are harvested by economic units for various uses including timber production and energy. This service excludes contributions to non-wood forest products. This is a final ecosystem service.	Wood
Aquaculture provisioning services	Aquaculture provisioning services are the ecosystem contributions to the growth of animals and plants (e.g. fish, shellfish, seaweed) in aquaculture facilities that are harvested by economic units for various uses. This is a final ecosystem service.	Aquaculture
*Wild fish and other natural aquatic products provisioning services	Wild fish and other natural aquatic biomass provisioning services are the ecosystem contributions to the growth of fish and other aquatic biomass that are captured in uncultivated production contexts by economic units for various uses, primarily food production. This is a final ecosystem service.	Wild aquatic produce
*Wild animals, plants and other biomass provisioning services	Wild animals, plants and other biomass provisioning services are the ecosystem contributions to the growth of wild animals, plants and other biomass that are captured and harvested in uncultivated production contexts by economic units for various uses. The scope includes non-wood forest products (NWFP) and services related to hunting, trapping and bio-prospecting activities; but excludes wild fish and other natural aquatic biomass (included in previous class). This is a final ecosystem service	Wild terrestrial produce
Genetic material services	Genetic material services are the ecosystem contributions from all biota (including seed, spore or gamete production) that are used by economic units, for example (i) to develop new animal and plant breeds; (ii) in gene synthesis; or (iii) in product development directly using genetic material. This is most commonly recorded as an intermediate service to biomass provisioning.	Genetic materials
Water supply	Water supply services reflect the combined ecosystem contributions of water flow regulation, water purification, and other ecosystem services to the supply of water of appropriate quality to users for various uses including household consumption. This is a final ecosystem service.	Water supply
Regulating and Maintenance		
Soil and sediment retention services	Soil erosion control services are the ecosystem contributions, particularly the stabilising effects of vegetation, that reduce the loss of soil (and sediment) and support use of the environment (e.g., agricultural activity, water supply). This may be recorded as a final or intermediate service. Landslide mitigation services are the ecosystem contributions, particularly the stabilising effects of vegetation, that mitigates or prevents potential damage to human health and safety and damaging effects to buildings and infrastructure that arise from the mass movement (wasting) of soil, rock and snow. This is a final ecosystem service. Landslide mitigation services are the ecosystem contributions, particularly the stabilising effects of vegetation, that mitigates or prevents potential damage to human health and safety and damaging effects to buildings and infrastructure that arise from the mass movement (wasting) of soil, rock and snow. This is a final ecosystem service.	Soil and sediment retention
Baseline flow maintenance services	Water regulation services are the ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and gradually release water during dry seasons or periods through evapotranspiration and hence secure a regular flow of water. This may be recorded as a final or intermediate ecosystem service.	Baseline flow maintenance
Rainfall pattern regulation services	Rainfall pattern regulation services are the ecosystem contributions of vegetation, in particular forests, in maintaining rainfall patterns through evapotranspiration at the sub-continental scale. Forests and other vegetation recycle moisture back to the atmosphere where it is available for the generation of rainfall. Rainfall in interior parts of continents fully depends upon this recycling. This may be a final or intermediate service.	Rainfall regulation
**Peak flow and River flooding mitigation services	Water regulation services are the ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and hence mitigate the effects of flood and other extreme water-related events. Peak flow mitigation services will be supplied together with river flood mitigation services in providing the benefit of flood protection. This is a final ecosystem service. River flood mitigation services are the ecosystem contributions of riparian vegetation which provides structure and a physical barrier to high water levels and thus mitigates the impacts of floods on local communities. River flood mitigation services will be supplied together with peak flow mitigation services in providing the benefit of flood protection. This is a final ecosystem service.	Flood mitigation

SEEA Subtype	SEEA Description	Name in outputs
Storm mitigation services	Storm mitigation services are the ecosystem contributions of vegetation including linear elements, in mitigating the impacts of wind, sand and other storms (other than water related events) on local communities. This is a final ecosystem service.	Storm mitigation
Aquatic: Nursery population and habitat maintenance services	Nursery population and habitat maintenance services are the ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy either through the maintenance of habitats (e.g., for nurseries or migration) or the protection of natural gene pools. This service is an intermediate service and may input to a number of different final ecosystem services including biomass provision and recreation-related services.	Biodiversity aquatic
Terrestrial: Nursery population and habitat maintenance services	Nursery population and habitat maintenance services are the ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy either through the maintenance of habitats (e.g., for nurseries or migration) or the protection of natural gene pools. This service is an intermediate service and may input to a number of different final ecosystem services including biomass provision and recreation-related services.	Biodiversity terrestrial
Biological control services	Biological control services are the ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of pests on biomass production processes or other economic and human activity. This may be recorded as a final or intermediate service. Disease control services are the ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of species on human health. This is most commonly a final ecosystem service.	Biological control
Pollination services	Pollination services are the ecosystem contributions by wild pollinators to the fertilization of crops that maintains or increases the abundance and/or diversity of other species that economic units use or enjoy. This may be recorded as a final or intermediate service.	Pollination
Retention and breakdown of nutrients and other pollutants	Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health. This may be recorded as a final or intermediate ecosystem service.	Water purification
Solid waste remediation	Solid waste remediation services are the ecosystem contributions to the transformation of organic or inorganic substances, through the action of micro-organisms, algae, plants and animals that mitigates their harmful effects. This may be recorded as a final or intermediate service.	Solid waste remediation
Noise attenuation services	Noise attenuation services are the ecosystem contributions to the reduction in the impact of noise on people that mitigates its harmful or stressful effects. This is most commonly a final ecosystem service.	Noise attenuation
Soil quality regulation services	Soil quality regulation services are the ecosystem contributions to the decomposition of organic and inorganic materials and to the fertility and characteristics of soils, e.g., for input to biomass production. This is most commonly recorded as an intermediate service.	Soil quality regulation
Air filtration services	Air filtration services are the ecosystem contributions to the filtering of air-borne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components, particularly plants, that mitigates the harmful effects of the pollutants. This is most commonly a final ecosystem service.	Air filtration
*Aquatic: Local (micro and meso) climate	Local climate regulation services are the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) through the presence of vegetation that improves the living conditions for people and supports economic production. Examples include the evaporative cooling provided by urban trees ('green space'), the role of urban water bodies ('blue space') and the contribution of trees in providing shade for humans and livestock. This may be a final or intermediate service.	Local climate aquatic
*Terrestrial: Local (micro and meso) climate	Local climate regulation services are the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) through the presence of vegetation that improves the living conditions for people and supports economic production. Examples include the evaporative cooling provided by urban trees ('green space'), the role of urban water bodies ('blue space') and the contribution of trees in providing shade for humans and livestock. This may be a final or intermediate service.	Local climate terrestrial
Global climate regulation services	Global climate regulation services are the ecosystem contributions to the regulation of the chemical composition of the atmosphere and oceans that affect global climate through the accumulation and retention of carbon and other GHG (e.g., methane) in ecosystems and the ability of ecosystems to remove (sequester) carbon from the atmosphere. This is a final ecosystem service.	Global climate regulation
Cultural		
**Recreation-related and Visual amenity services	Recreation-related services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (i.e. visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting. This is a final ecosystem service. Visual amenity services are the ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual. This service combines with other ecosystem services, including recreation-related services and noise attenuation services to underpin amenity values. This is a final ecosystem service.	Recreation and visual amenity
Education, scientific and research services	Education, scientific and research services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment. This is a final ecosystem service.	Education scientific and research

SEEA Subtype	SEEA Description	Name in outputs
Spiritual, artistic and symbolic services	Spiritual artistic and symbolic services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media. This is a final ecosystem service.	Spiritual artistic and symbolic

*To provide additional information both Aquatic: Nursery population and habitat maintenance services and Local (micro and meso) climate were subdivided into aquatic and terrestrial categories.

**Some similar categories had insufficient information in the literature to distinguish between them and consequently these were combined.

13.0 Appendix 3: Literature review results

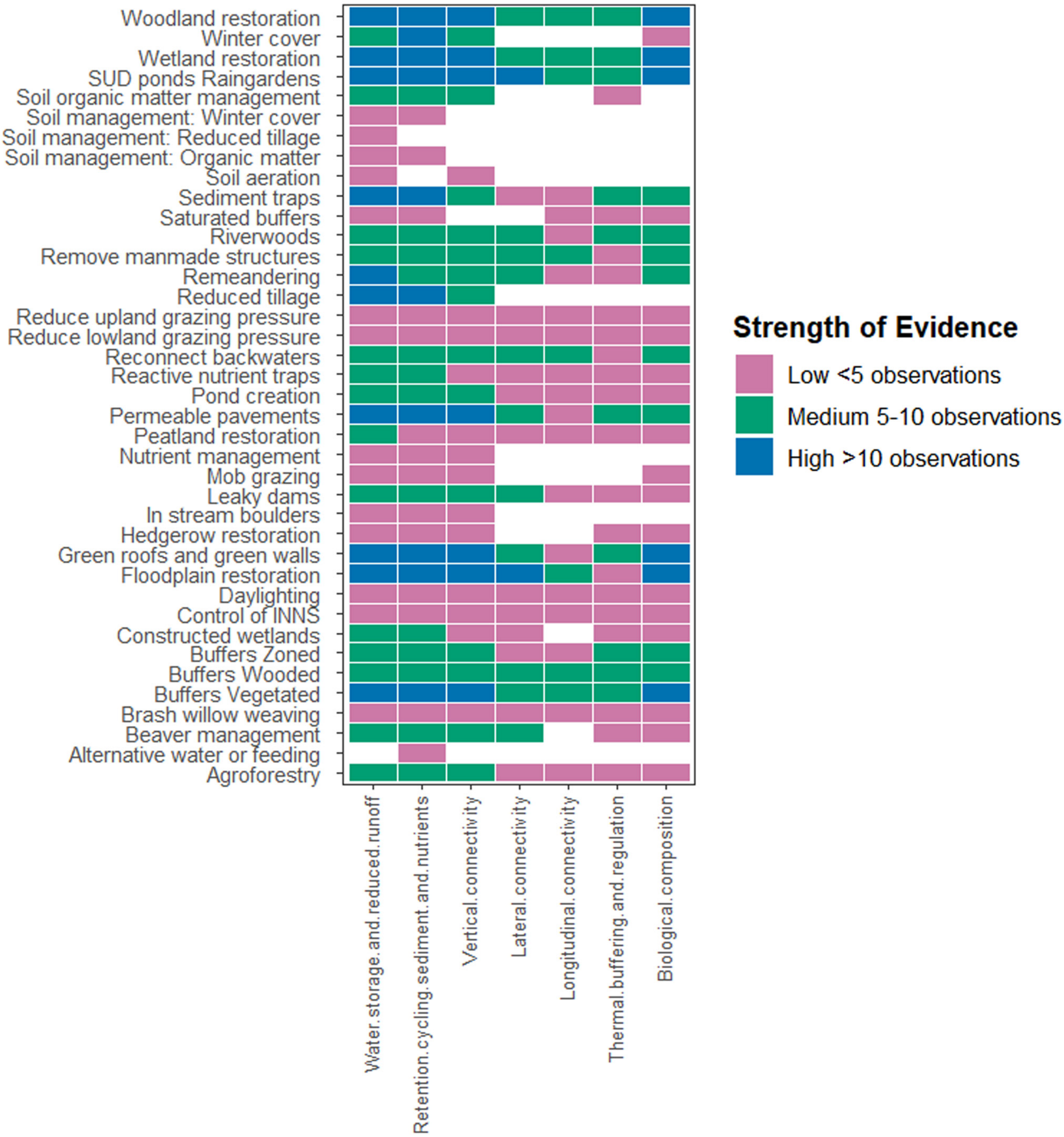

Figure 17: Functional linkages between detailed NbS and the water environment.

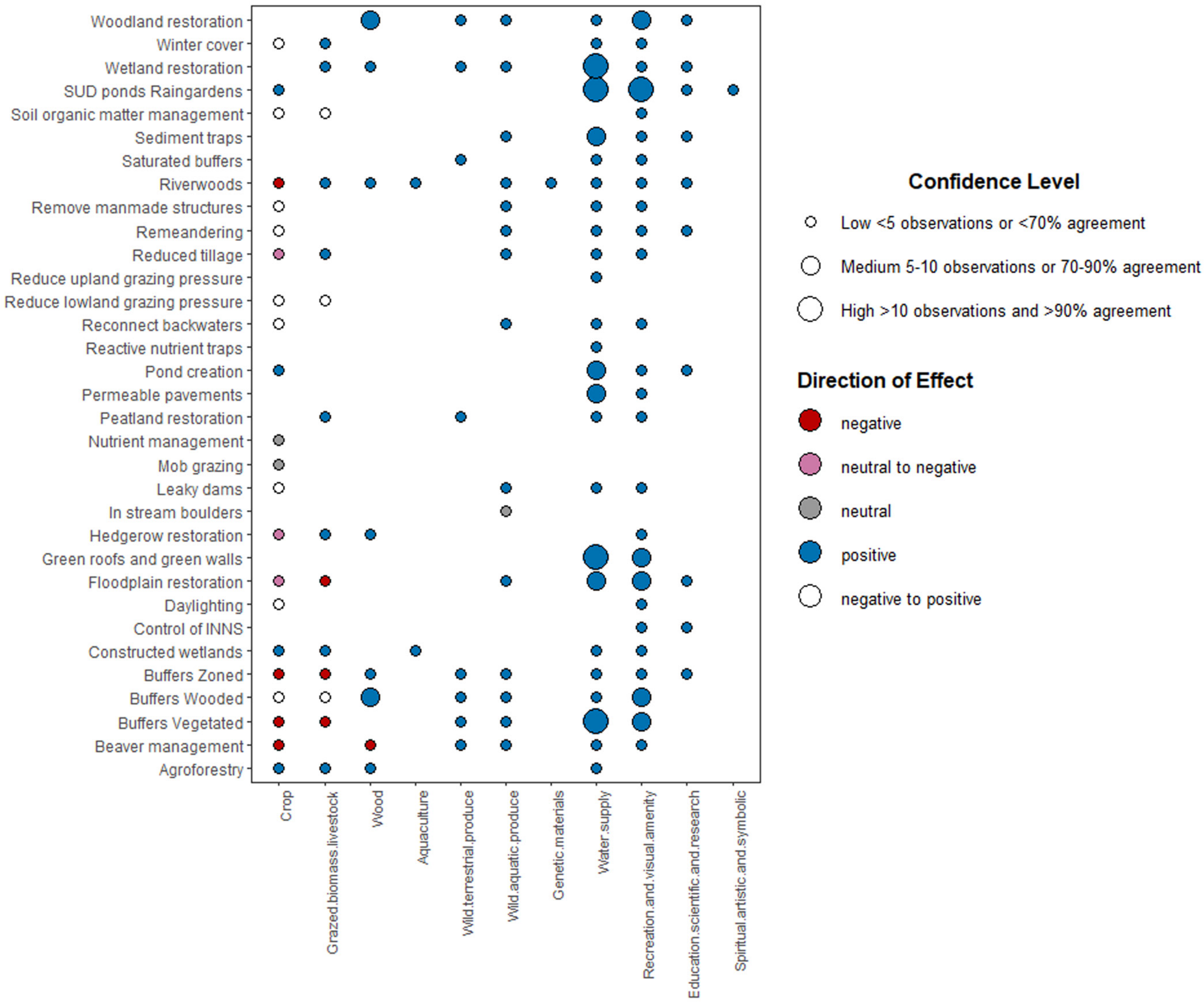

Figure 18a: Evidence synthesis for our 37 detailed NbS and provisioning and cultural services. Bubble colour reflects the direction of effect and shape size reflects the level of confidence.

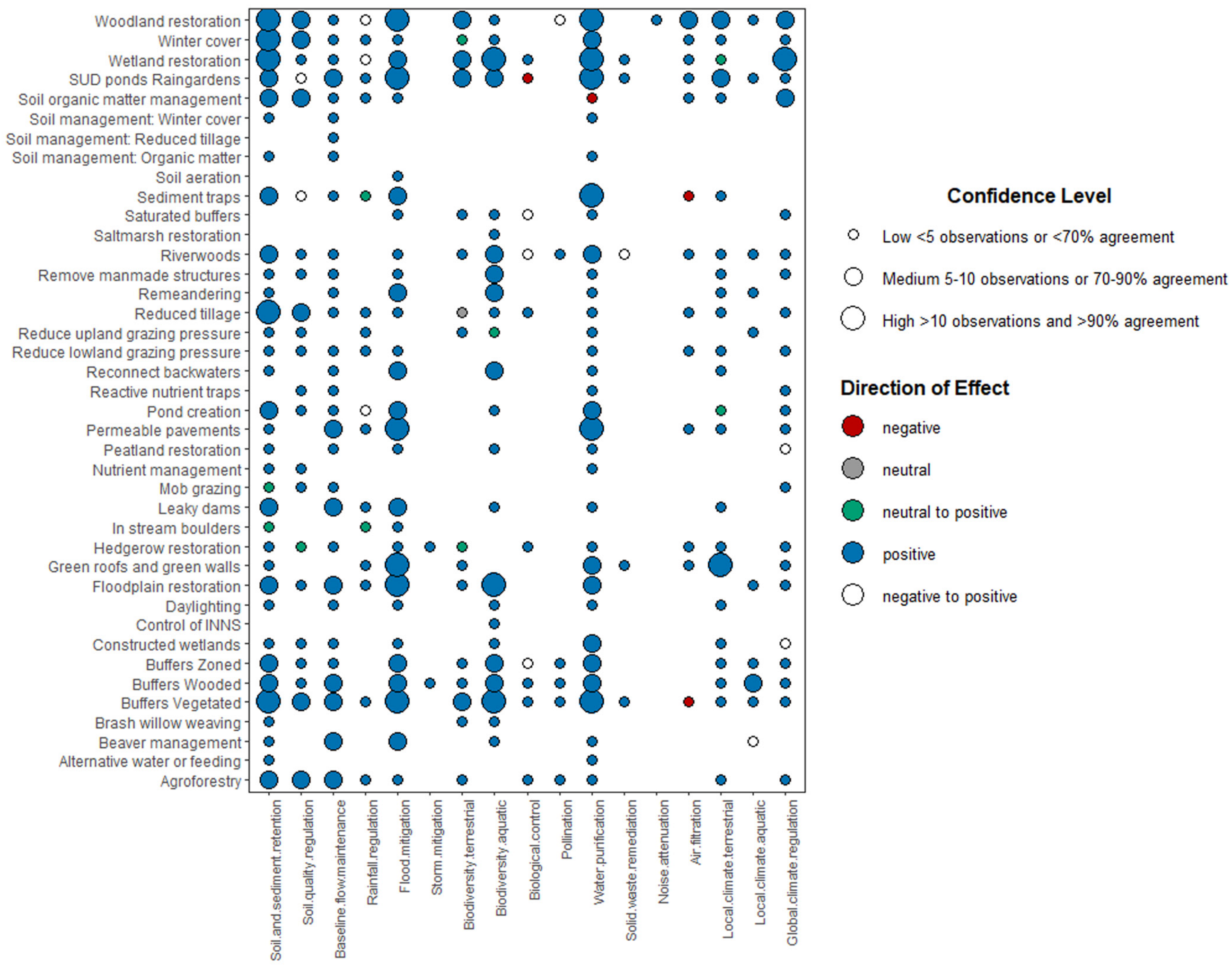

Figure 18b: Evidence synthesis for our 37 detailed NbS and regulating and maintenance services. Bubble colour reflects the direction of effect and shape size reflects the level of confidence.

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