Environment Agency natural capital condition indicator mapping

Phase 1 evidence review

Chief Scientist's Group report

October 2023

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Published by:

Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH

www.gov.uk/environment-agency

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Keywords:
Natural capital, ecosystem services, condition, rivers, Quick Scoping Review, indicators, data

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Project number:
F/2223/0682

Citation:
Environment Agency (2023) EA Natural Capital condition indicator mapping. Environment Agency, Bristol.

Acknowledgements

The project team would like to thank all contributors to this report, particularly to workshop participants, and to Jo Bayes, Vicky Beaumont-Brown, Deborah Dunsford, Alison Holt, Anthony Hurford, Richard Jeffries, Gemma Kinsey, Ceri Lewis, Neil Preedy, Lesley Rippon, John Robotham, Jatinder Singh Mehmi, Alison Smith, Jo Spink, and Sharon Thomas for their review contributions.

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Dr Robert Bradburne
Chief Scientist

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Executive summary

This project is part of the Defra-wide Natural Capital and Ecosystem Assessment (NCEA) Programme, and is part of a suite of Environment Agency (EA) projects assessing the need for, and where necessary, developing new or improved natural capital indicators, metrics, maps and tools to support wider understanding of the services, benefits, and values that are derived from natural capital assets. This report focuses on condition in rivers and how this impacts on ecosystem service provision. In particular, it:

- reviews the links between natural capital asset condition and the provision of ecosystem services, and
- determines if it is possible to map condition from existing data, reviews approaches to doing this, and identifies evidence and data gaps.

The development and demonstration of best practice evidence review methodology was an important component of this project and a valuable outcome in its own right. A co-design process was used, building on previous work on user needs, and then involving staff at the EA through an online workshop process to further refine needs and the scope of the project. These informed the natural capital assets being examined, the ecosystem services included, and the aspects of condition to be assessed.

Based on the workshop outcomes, it was decided to concentrate on two types of assets: natural and artificial rivers. The split of river assets was chosen due to the differences in how condition may be measured. Ten ecosystem services were assessed based on importance to the EA and supplemented by those where knowledge is lacking. These were: water for drinking/agriculture/industry; water flow regulation; water quality regulation; habitat and population maintenance; characteristics and features of biodiversity that are valued; health and wellbeing; aesthetic experiences; education, training and investigation; recreation and tourism; and spiritual and cultural experiences.

Understanding the meaning of condition in the context of rivers was one of the key first steps. It became clear that there are multiple ways of assessing condition, and it varies depending on the ecosystem service under consideration. For the purpose of this project, we are therefore defining good condition as the state of the asset that enables high provision of the ecosystem service being assessed. Condition is most commonly associated with multiple aspects of naturalness, resilience, connectivity, and access, and crucially, it is strongly influenced by perception and value judgements, particularly for cultural ecosystem services.

The first objective of the project was to review the links between natural capital asset condition and the provision of ecosystem services. To do this, a Quick Scoping Review (QSR) was undertaken. A QSR provides a standardised, structured and transparent approach and was co-designed with the EA steering group. Search terms were developed using a PICO (Population, Intervention, Control, Outcome) framework and were based on the assets, ecosystem services and condition terms identified in the scoping phase of the project.

The QSR revealed that the amount and strength of evidence available varied greatly, depending on the ecosystem service, and a summary RAG rating is shown in the table below. Although evidence of links between condition and ecosystem services was generally available, there is much less evidence concerning the details of the relationship between them. Non-linear and threshold responses are likely in many cases, but this is an area that requires more research.

The second main objective of the project was to identify how asset condition can be inferred from existing data. For each ecosystem service, a series of flow charts describing supporting processes, condition assessment methods and indicators were produced. The review of data, indicators and tools was able to identify a large number of datasets that could be of use in measuring, mapping or modelling condition. For some ecosystem services there were lots of data and tools available (e.g., water flow regulation; habitat population and maintenance), but some gaps were apparent (e.g., education, training and investigation; spiritual and cultural experience). A summary of the level of confidence in the indicators is shown in the table below. The condition indicators were assessed for usability and relevance. From this review, gaps in data and indicators have been identified. To fill data gaps and improve the flow charts, short, medium and/or long-term options have been suggested for future development.

Summary RAG rating (Red = low, Amber = medium, Green = high) showing the level of confidence in the condition indicators, and the strength of the evidence found in the QSR.

Ecosystem service	Condition indicators	Evidence (QSR)
Water for drinking, agriculture and industry		
Water flow regulation		
Water quality regulation		
Habitat and population maintenance		
Characteristics and features of biodiversity that are valued		
Aesthetic experiences		
Health and wellbeing		
Recreation and tourism		
Education, training and investigation		
Spiritual and cultural experiences		

A brief review of the OxCam Local Natural Capital Plan approach to mapping habitat condition was undertaken, as it provides one of the only examples of mapping condition at a landscape scale and so can be used to inform discussion of potential landscape scale approaches. This approach uses existing data and inferences to assign condition to a range of habitats, but is primarily aimed at terrestrial habitats. Outputs are useful for strategic decision-making at the landscape scale, but at a local scale, or if precise estimates are required, site surveys and assessment will still be required. It does incorporate river habitats, and assigns condition to each waterbody based on the Water Framework Directive (WFD) overall waterbody class. This is a useful approach if a single summary indicator of condition is required, but it does tend to ignore cultural services (although water quality affects the delivery of cultural services). It would be possible to develop a few key cultural services indicators if a summary approach for these services, analogous to overall waterbody class, was desired.

The project findings are discussed in relation to different approaches to modelling. This could be based on developing a range of different indicators showing multiple aspects of condition for each ecosystem service, or on developing more complex models that capture as many aspects of condition as possible in one model. Simple or summary indicators are also feasible, depending on the purpose.

Finally, a series of next steps and recommendations are presented. A key first step will be to prioritise the wide range of indicators outlined in this project and then develop a series of indicators and maps with national coverage. Filling gaps in data and evidence is also discussed, along with extending the assessment to other habitats or additional ecosystem services.

1. Introduction

The Environment Agency (EA) aims to improve and increase the quality, consistency, accessibility, and use of natural capital evidence and have set up a Natural Capital Project to improve the EA's evidence base. This is part of the Defra-wide Natural Capital and Ecosystem Assessment (NCEA) Programme[1]. The project is assessing the need for, and where necessary, developing new and/or improved natural capital indicators, metrics, maps and tools to support wider understanding of the services, benefits, and values that are derived from natural capital assets. A review of needs identified three interlinked evidence gaps that have been prioritised: mapping a) the natural capital baseline, b) condition, and c) ecosystem services. The current project is related to priority b): natural capital condition indicator mapping.

The project focuses on rivers, although this may be expanded in follow-on work. Rivers are important habitats for delivering ecosystem services (Smith et al., 2017), for example water abstraction, climate regulation (Wong et al., 2017) and recreation (Natural England, 2019). However, provision of ecosystem services in aquatic environments is understudied compared to terrestrial systems (Holland et al., 2011).

Provision of ecosystem services is at risk from habitat degradation and loss of natural capital stocks (Millennium Ecosystem Assessment, 2005). This needs to be urgently addressed to ensure sustainable long-term human wellbeing. However, natural capital geospatial evidence is patchy with lots of gaps, particularly in relation to condition. There is a need to improve the quality of natural capital evidence to identify areas most at risk of loss or degradation of ecosystem services.

It is generally understood that habitats in better condition are more capable of delivering ecosystem services (Harrison et al., 2014; Pullanikkatil et al., 2016). However, the link between condition and delivery is a crucial knowledge element that needs to be explored further. This project was therefore commissioned to review the links between condition and the provision of ecosystem services in rivers, and to determine if it is possible to map asset condition from existing data, review approaches and identify gaps.

The main objectives were to:

- Review the links between natural capital asset condition and the provision of ecosystem services.
- Identify how asset condition can be inferred from existing data.
- Identify where existing evidence and methods are robust and where there are evidence and data gaps or issues.
- Make recommendations on evidence gaps and on the data and indicators appropriate for mapping condition in the next phase.

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[1] Natural Capital and Ecosystem Assessment Programme - GOV.UK (www.gov.uk)

Based on the findings of the current phase, a second phase of the project will then develop and trial a number of the approaches to condition mapping identified here.

An important component of the project was that it was designed to be interactive with EA staff, who were fully involved in shaping the project through a series of workshops, and by active participation in the review team. The project ran from January to the end of June 2023. It was commissioned by the EA Natural Capital Team and delivered by Natural Capital Solutions Ltd, in conjunction with the River Restoration Centre.

1.1 Report structure

The first part of the project focused on gaining a better understanding of key definitions of assets, condition, and ecosystem services, and these are set out in Section 2. User needs were then assessed, through a review of existing projects at the EA, and workshops with EA staff, which enabled us to refine the scope and shape the rest of the project (Section 3). The project then progressed through three parallel workstreams:

- Assessing the evidence base linking asset condition to change of flow of ecosystem services, through a QSR of the evidence (Section 4).
- Reviewing datasets and methods to assess river asset condition, including identifying gaps and options to take forward (Section 5).
- A brief review of the OxCam Local Natural Capital Plan (LNCP) approach to mapping habitat quality (Section 6).

Conclusions are presented in Section 7. Appendices provide further information on user needs (Appendix A), the full results of the stakeholder workshops (Appendix B), and further analysis of the articles reviewed in the QSR (Appendix C). Two Excel spreadsheets accompany this report:

1. **Appendix D: Literature review database and knowledge map**. This provides a complete list of the papers that passed through the first screening of the literature review described in Section 4, a knowledge map for the final selection of papers, as well as grey literature and additional papers reviewed.
2. **Appendix E: Natural capital mapping indicators**, which provides a comprehensive list of data; tools, methods and models; and indicators identified in Section 5. This includes key information on each entry, a link to the data source, and an assessment of each one.

A set of PowerPoint slides are also available that summarise the key results of this project.

Please note that the project provides a QSR of the evidence linking condition to the flow of ecosystem services, and a quick review of datasets and indicators of condition, and as such will not be comprehensive. It aims to capture key data and information and there will inevitably be some gaps. It is the first step in a longer process to enhance natural capital evidence about rivers at the EA.

2. Defining key terms

In this section, we set out key definitions for assets, condition and ecosystem services, which are then applied throughout the rest of the project.

Natural capital assets (see Section 2.3) are specific elements within nature that provide goods and services to people (Natural Capital Committee, 2014). Assets are usually described in terms of their extent (quantity), location and condition (quality). Approaches to map natural capital assets (particularly habitats) have advanced in recent years and it is now possible to accurately map which habitats are present, their extent and spatial location over multiple scales. However, it is also important to understand the condition of the assets, but this has proved to be much more challenging at a landscape scale and is hence the focus of this project. In this project we are concentrating on rivers, hence river assets are described in more detail below.

2.1 River assets

The EU WFD defines a river as “a body of inland water flowing for the most part on the surface of the land but which may flow underground for part of its course” [2]. Streams are included in the definition of rivers and are not considered separately in the remainder of this report. Rivers influence and are influenced by surrounding habitats and the wider catchment context in which they are situated. It is therefore important to consider the condition of rivers within their catchment context, but we do not focus on the catchments and floodplains separately, which is beyond the scope of this project.

Below are detailed potential sub-categories or exclusions for riverine assets within the scope of this project.

Perennial and intermittent or ephemeral rivers

A perennial river is a watercourse that flows at all times, whereas an intermittent or ephemeral river (e.g., winterbourne) is a watercourse that ceases flow at some point in time and space (Datry et al., 2018). Perennial and intermittent rivers tend to have different ecosystem services, and intermittent rivers are less well studied than perennial rivers (Messager et al., 2021; Natural Capital Committee, 2014).

[2] WFD Directive 2000/60/EC OF THE European Parliament and the council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities. Official Journal L 327, 22/12/2000 P. 0001 – 0073.

Canals

The WFD defines canals as artificial water bodies and does include them within the rivers assessment. Similarly, the literature tends to include canals within flowing water systems (Dehini & Gomes, 2022). However, it is pointed out that canals and ditches actually inhabit an intermediate state as they are neither completely flowing nor completely stagnant (Langheinrich et al., 2004) .

Defining condition for canals can be more challenging as there is no pre-disturbed state for comparison[3]. Consequently, the WFD assesses them for ecological potential rather than status. While canals are manmade and often found within urban areas, they still have the potential to provide high-quality habitats and rich biota (Joyce et al., 2018; Rothwell et al., 2010; Walker & Hassall, 2021).

Natural, heavily modified and artificial rivers

The WFD defines a heavily modified water body (HMWB) as “a body of surface water which as a result of physical alterations by human activity is substantially changed in character” and an artificial water body (AWB) as “a body of surface water created by human activity”. Within HMWBs, hydromorphological alterations are permanent, significantly change the river characteristics, and cannot be removed without compromising the use of the river (Erba et al., 2019). Both HMWBs and AWBs are assessed using ecological potential rather than ecological status. Ecological status and ecological potential are designed to be comparable approaches so theoretically will not affect any associations between condition and ecosystem services.

Upland and lowland rivers

Lowland rivers are generally defined as being present below 200m elevation, and upland rivers between 200m and 500m elevation. There are some differences between upland and lowland rivers, and each faces different pressures (Jarvie et al., 2008; Rothwell et al., 2010). For example, upland stream systems tend to have high sediment yields, steep channel gradients and high runoff (Joyce et al., 2018). Lowland rivers tend to be subject to greater environmental pressures due to agriculture and population density (Neal et al., 2012).

Freshwater, brackish and saline

Transitional waters are defined by the WFD as “bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows”. These are defined from Mean High Water boundaries taken from Ordinance Survey and the EA and are classified separately from rivers. Ecosystem services from these transitional waters are not well covered in the literature (Tagliapietra et al., 2020). Note that this project is limited to freshwater systems only.

Other

Headwater streams are not usually recognised as bodies of surface water under the WFD (Lassaletta et al., 2010). However, headwater streams and other small waterbodies including ditches and springs can still be important for biodiversity and ecosystem services (Biggs et al., 2017; Hill et al., 2014). These were included as part of the project. However, as they are generally not included under the WFD, information on condition was limited.

2.2 Condition

Condition (or quality) can be defined in a number of different ways, and we briefly introduce a few of the more common approaches here. Defining what is meant by condition became an important question to put to stakeholders at the workshops (Section 3), to ensure that we captured the full range of perspectives in this project.

There are a number of different frameworks that assess water quality or condition for the UK, including the WFD, Source Apportionment-GIS Tool (SAGIS), River Habitat Survey (RHS), Bathing Water quality data and Harmonised Monitoring. Assessments can generally be split into four categories:

- Biological e.g., fish
- Hydromorphological e.g., river continuity
- Physicochemical e.g., dissolved oxygen
- Chemical e.g., pollution forecast

There are other categories occasionally mentioned which include culture, history and public rights of way. WFD defines surface water status as "the general expression of the status of a body of surface water, determined by the poorer of its ecological status and its chemical status". Good ecological status is achieved when the water body's biological community exhibits little change from the expected natural community (Naddeo et al., 2007). All waterbodies are monitored on an ongoing basis to assess progress towards achieving good ecological status or good ecological potential (for heavily modified rivers) and data are publicly viewable on the Catchment Data Explorer[3].

The Biodiversity Metric 4.0 assesses river condition using MoRPh5 field surveys, which use 32 indicators to calculate a condition score. Canals are included in this as a river type. The indicators again fall into the previously mentioned categories and are split into features from the:

- Bank top
- Bank face
- Channel – water margin
- Channel bed

[3] https://environment.data.gov.uk/catchment-planning/

For sites that are designated as a Site of Special Scientific Interest (SSSI) or Special Area of Conservation (SAC), Common Standards Monitoring Guidance has been developed (JNCC, 2016), with separate guidance documents available for rivers, canals, ditches, and lakes. To assess condition, existing information and field survey data is combined to determine the pass or fail of a series of different attributes, which are then collated to assign a single condition. These fall under the following headings: flow, water quality, habitat structure, fine sediment, negative indicators, biological assemblages, indicators of local distinctiveness, and direct human disturbance.

Natural England is moving towards a more integrated approach to biodiversity decision-making, focused around considering ecosystem function and particularly the naturalness of that function (Mainstone et al., 2018). This overlaps with ideas around condition. According to Natural England, **natural ecosystem function** is an ecological state generated by natural environmental processes (hydrology, chemistry, soil and sediment processes, vegetation controls and native biological assemblages) that are unmodified by human activities (Figure 1). It generates naturally functioning habitat mosaics, which are dynamic and ecologically resilient. These mosaics provide a wealth of ecosystem services.

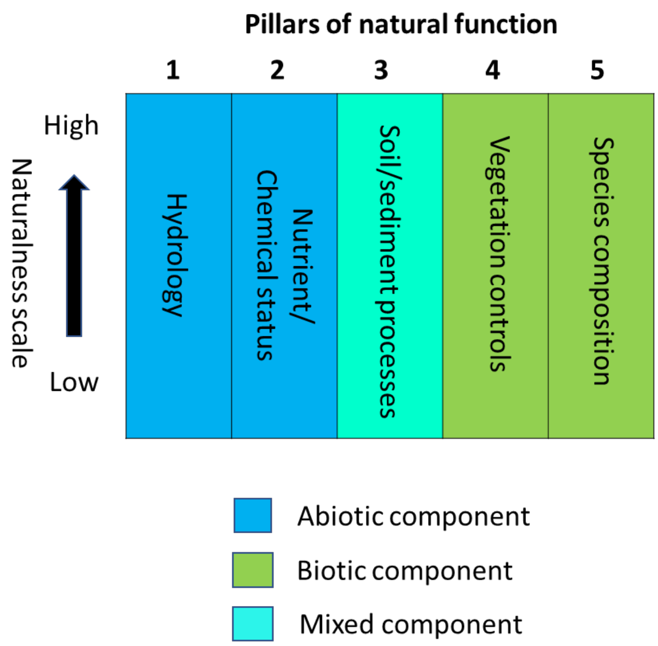


Figure 1: Natural process framework showing the elements or pillars of natural ecosystem function (from Mainstone et al., 2018).

2.3 Natural capital and ecosystem services

Natural Capital is defined as:

> *"...elements of nature that directly or indirectly produce value or benefits to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions"* (Natural Capital Committee, 2014).

It is the stock of natural assets (e.g., soils, water, species) that produces a wide range of ecosystem services that provide benefits to people. These benefits include food production, regulation of flooding and climate, pollination of crops, and cultural benefits such as aesthetic experiences and recreational opportunities. Different types of ecosystem service are shown in Figure 2.

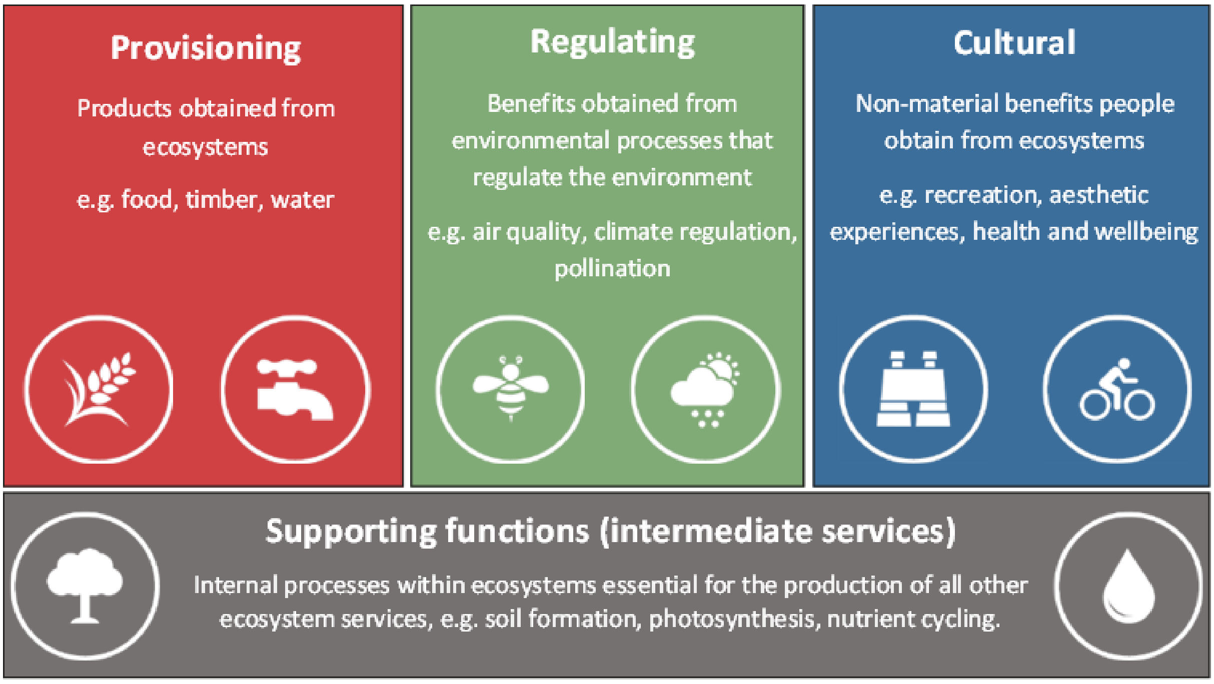


Figure 2: Key types of ecosystem services (based on Millennium Ecosystem Assessment (2005) and CICES (Haines-Young & Potschin, 2018). Note that supporting or intermediate services are now categorised as ecological functions (Haines-Young & Potschin, 2018). They are the underpinning structures and processes that give rise to ecosystem services, and link to the Natural England definition outlined above (Figure 1).

Ecosystem services are thus defined by the Common International Classification of Ecosystem Services (CICES) as "*the contributions that ecosystems make to human wellbeing*"[20]. Using MA and CICES V5.1 (Haines-Young & Potschin, 2018; Millennium Ecosystem Assessment, 2005), and recent literature surrounding ecosystem services provided by rivers, a table has been compiled containing the main services for consideration in this project (Table 1). These are focused on ecosystem services that could be provided by rivers. We have also merged a number of the CICES categories where the additional detail was not useful (e.g., 12 different categories of cultivated plants and reared animals merged into one category), and used some older names and definitions from MA (2005), where these are more intuitive. It is acknowledged that although internationally agreed terminology and definitions of ecosystem services have been in place for some time (i.e., CICES), these are not always the most meaningful and are not fully incorporated across the sector, including within the EA. The corresponding ecosystem service terms that are currently more commonly used within the EA are therefore also provided in Table 1 to enable interpretation.

Table 1: Ecosystem services provided by river ecosystems, with definitions adapted from CICES 5.1 (Haines-Young & Potschin, 2018) and MA (Millennium Ecosystem Assessment, 2005). The overarching ecosystem service terms commonly used within the EA are also included, with sub-headings in brackets where applicable.

Category	Service	Current EA terminology	Definition
Provisioning	Water (for drinking /agriculture /industry)	Water supply (Public water supply; Industrial/ agricultural use; Cooling/energy generation; Other)	The natural storage, retention and supply of freshwater. Fresh water abstracted (or potential for abstraction) for human uses.
	Hydropower	Renewable energy (Hydropower)	The flow of water that can be converted to electrical or mechanical energy
	Cultivated plants and reared animals	Food (Aquaculture; Fish)	The ecological contribution to the growth of plants and algae under aquaculture that can be harvested and used as raw material for the production of food, non-nutritional purposes or a source of energy (e.g., watercress)
			The ecological contribution to the growth of cultivated aquatic animals that can be used as raw material for the production of food, non-nutritional purposes or a source of energy (e.g., farmed fish)
	Wild produce		Parts of the standing biomass of a non-cultivated plant species or non-domesticated, wild animal species and their outputs that can be harvested and used as raw material for the production of food, non-nutritional purposes or a source of energy (e.g., wild fish)
Regulating	Water quality regulation	Water quality regulation (Pollution	Regulation of the chemical condition of fresh waters by plant or animal species that enable human use or health

	Waste removal	dilution; Water purification - filtration by habitats)	Transformation or fixing and storage of an organic or inorganic substance by a species of plant, animal, bacteria, fungi or algae that mitigates its harmful effects and reduces the costs of disposal by other means. The reduction in concentration of an organic or inorganic substances by mixing in a freshwater ecosystem that mitigates its harmful effects and reduces the costs of disposal by other means.
	Water flow regulation	Water flow regulation	Hydrological cycle and water flow regulation (including flood control, and coastal protection). The capacity of ecosystems (e.g., vegetation, soil) to retain water and release it slowly. Buffering of the impacts of natural hazards and disruptions. Structure and storage capacity of vegetation can reduce the effects of storms, floods and droughts.
	Erosion control	Hazard regulation (Erosion regulation)	Regulation of the erosion of soil (for example through vegetative cover). Roots stabilize the soil and foliage intercepts rainfall, preventing erosion and compaction of the soil.
	Carbon sequestration and storage	Climate regulation (Global climate - Greenhouse Gas regulation)	Uptake and storage of carbon from the atmosphere. Regulation of the concentrations of gases in the atmosphere that impact on global climate or oceans
	Local climate (temperature) regulation	Climate regulation (Local climate - temperature and precipitation)	Mediation of ambient atmospheric conditions by virtue of presence of plants that improves living conditions for people. Regulation of microclimate, transpiration from leaves, shade, shelter from wind, and moderation of local heat island effects.
	Fire protection	Hazard regulation	The reduction in the incidence, intensity or speed of spread of fire by virtue of the presence of plants and animals that mitigates or prevents potential damage to human use of the environment or human health and safety

	Pollination and seed dispersal	Pollination	Natural pollination (especially by insects) is crucial to plant reproduction, without which many wild plant species would go extinct and current levels of agricultural production would be impossible or very expensive. The dispersal of seeds that are important to people.
	Pest and disease control	Disease and pest control	The reduction by biological interactions of the incidence of species that prevent or reduce the output of food, material or energy from ecosystems, or their cultural importance, by consumption of biomass or competition
	Habitat and population maintenance	Habitats	The presence of ecological conditions (usually habitats) necessary for sustaining populations of species that people use or enjoy. Rivers as wildlife corridors, enhancing connectivity and resilience of populations.
Cultural	Recreation and tourism	Recreation	Human values derived from recreational uses of ecosystems, including their often substantial tourism potential. Natural ecosystems are often used as places for relaxation and recreation, including hiking, camping, fishing, and nature viewing.
	Health and well-being	Physical health and Mental health	The role of natural landscapes and urban green space for maintaining mental and physical health is increasingly being recognised. Using nature to destress.
	Aesthetic experiences	Cultural heritage (Aesthetic value and sense of place)	Most people enjoy natural scenery and landscapes; the beauty of nature. This is important not just for human enjoyment but can also have economic importance by influencing property prices.
	Education, training and investigation	Education	Natural areas provide numerous opportunities for study, education, and research, as well as references for monitoring environmental change.

	Spiritual and cultural experiences	Cultural heritage (Cultural heritage; Spiritual and religious value)	The things in nature that help people identify with the history or culture of where they live or come from or that have spiritual importance for people. Nature is a common element of all major religions. Natural landscapes also form local identity and sense of belonging.
	Characteristics and features of biodiversity that are valued	Cultural heritage	The things in nature that we think should be conserved because of their non-utilitarian qualities (existence value). The things in nature that we want future generations to enjoy or use for whatever reason (option or bequest value).

2.3.1 Natural capital logic chain

The natural capital logic chain (Haines-Young & Potschin, 2010) illustrates the links between natural capital assets, the ecosystem services that flow from those assets, the benefits that these provide, and the values that these benefits are given (Figure 3). It also shows that pressures and drivers of change influence management interventions, which in turn affect these connections. As society changes how we value different benefits this can also have a feedback effect on the system, driving change.

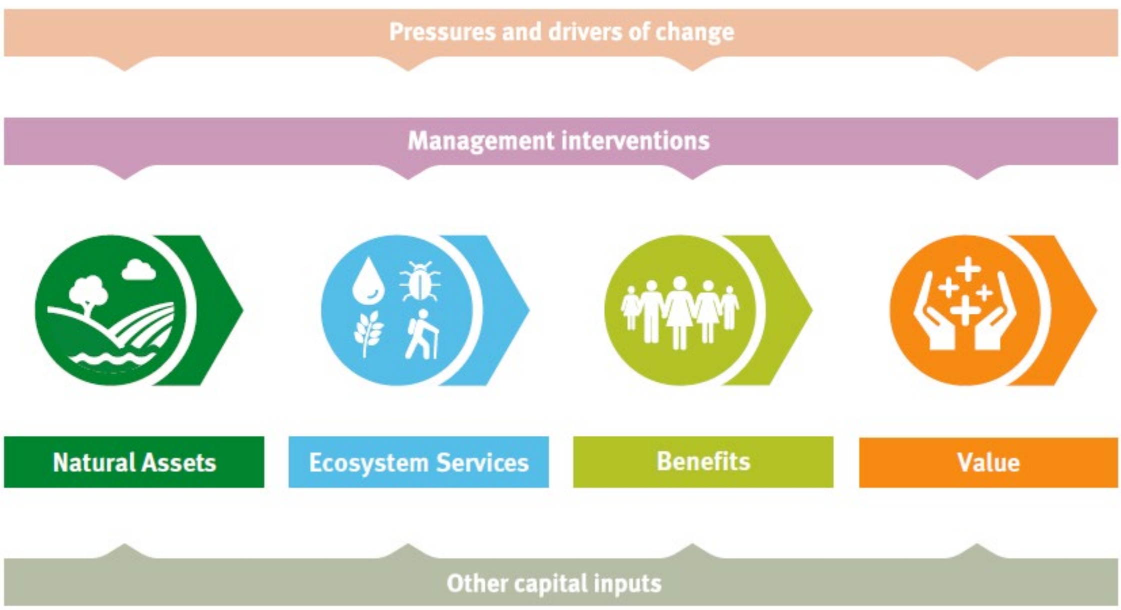


Figure 3: The natural capital logic chain, (Haines-Young & Potschin, 2010). Note that ecosystem function (or intermediate/supporting services) from Figures 1 and 2, sit between natural assets and ecosystem services in many versions of this logic chain.

In this project we are focussing on first two steps of the logic chain; natural capital assets and the ecosystem services that flow from those assets. In particular, the condition of assets and the links between asset condition and ecosystem service flow. We are not considering benefits or values, although that is being considered as part of the wider NCEA Programme.

3. Considering user needs and refining scope

In this section, we outline the methods and results from two stakeholder workshops held in February 2023, which were used to assist in refining the project scope.

A co-design process was used throughout this project, building on previous work on user needs, and then involving interdisciplinary experts across the EA, through a workshop process, to further refine needs and the scope of the project.

User needs have previously been surveyed by the EA, through the Natural Capital Mapping Needs Review (Environment Agency, 2022), and the development of natural capital indicators is subject to an ongoing review (Natural Capital Indicators in EA Monitoring Project). The results are summarised in Appendix A and were used to inform the development of the project.

Two online workshops were run with key users on the 6th and 9th February 2023 to assist with project scope and direction. Participants represented teams from across the EA, including Natural Capital and Ecosystem Assessment Programme, Fisheries, Biodiversity and Geomorphology, Sustainable Places, Flood Risk Management, Water, Land and Biodiversity, Public Health, Funding, and Agriculture and ELM (Environmental Land Management) scheme.

The work described in Section 2 and the projects above was used to inform these workshops. The first workshop focused on strategic needs, and the second one focused on user needs. Both workshops followed similar formats:

- Introduction to the project, background and key concepts.
- Collaborative breakout room exercise to discuss the question "what does condition mean to you?" (Section 3.1). Participants were asked to vote for up to three comments that they thought were most important to the discussion.
- Second exercise using a poll in Google Forms to answer questions about ecosystem services and assets (Section 3.2).
- Final exercise which was different in the two workshops; the first one focused on the broader question of policies, needs and evidence gaps (Section 3.3), whereas the second one looked at metrics and scales required (Section 3.4).

There was some overlap of participants between the first and second workshop; however, those who had attended the first workshop did not join the second one until Exercise 3, which ensured there was no duplication in answers. The outcomes from these workshops are outlined below, and full results can be found in Appendix B.

3.1 Definitions of condition (workshop exercise 1)

As condition is the primary focus of this project, and it was shown in Section 2.2 that it can be assessed in a number of different ways, it was important to capture the range of ways in which it can be understood in the context of rivers. This was then used to directly shape the literature review (Section 4) and identification of indicators of condition (Section 5).

A total of 102 comments were received across both workshops and these were subsequently grouped by the project team into 11 themes plus an 'other' group (Figure 4). The full results from this exercise can be found in Appendix B.

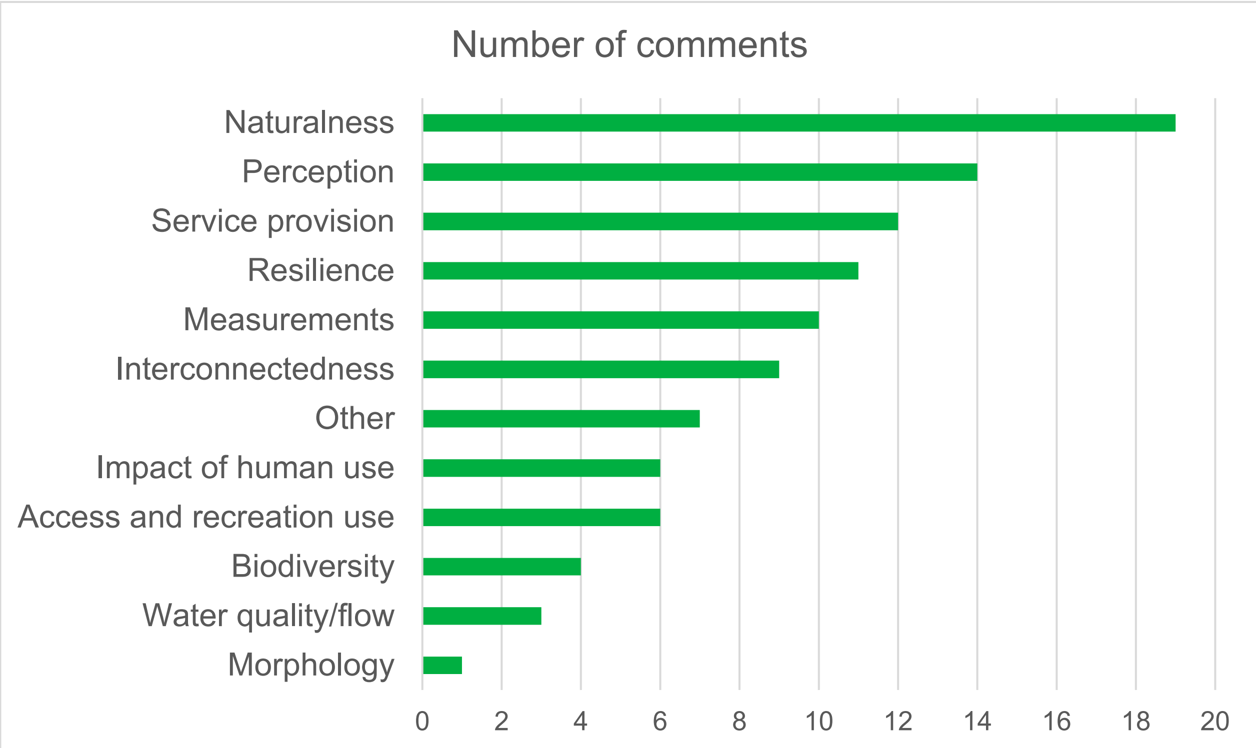


Figure 4: Number of comments on condition by theme.

The most common theme mentioned was naturalness (n=19), defining it as the extent of deviation from a natural condition baseline. There was some discussion on this, with participants pointing out that man-made baselines can also be valuable and discussing issues around shifting baselines. Naturalness as a deviation from a baseline is also not relevant for artificial rivers, although perceptions of naturalness can still be of interest.

The next most common theme was around these ideas of perception (n=14), where the subjectiveness of condition was brought up independently across both workshops, indicating its importance in participants' minds. It was also mentioned that there are many different types of condition that may interact with each other. The ability of the river to provide ecosystem services was also mentioned repeatedly as a basis for condition (n=12). A word cloud highlighting the most common words used by participants is shown in Figure 5. 'Ecosystem' and 'services' were unsurprisingly some of the most commonly mentioned words, as well as 'natural', which directly links to the naturalness theme having the most comments (Figure 4). Other words that appeared several times were:

- Good – this relates to condition generally rather than any specific theme
- Naturalness – naturalness theme
- Measure – measurements theme
- Value
- River – this relates to condition and the whole project generally
- Provide – this relates to condition generally
- System – this relates to several themes mentioned, including but not limited to interconnectedness, biodiversity and resilience

When participants voted on which comments they considered to be most important, all themes except morphology received at least one vote. The most voted for themes were perception, naturalness and resilience (13 total votes for comments falling into the perception theme, 13 total votes for comments falling into the naturalness theme, and nine total votes for comments falling into the resilience theme). The three most voted for comments, with five votes apiece, are quoted below:

- "Good' condition will entirely depend on the observer/user. What do we want to value? A carp angler's view would be different to mine for example" – *categorised as perception*
- "The ability of an asset to provide the ecosystem services it could provide in ideal condition" – *categorised as naturalness*
- "The potential for an ecosystem to continue to exist in either its current state or in reference to a benchmark ... or undergo change (whether natural or anthropogenic). It's not a value judgement" – *categorised as naturalness*

These provide useful additional insight into what participants determined as the most important aspects of condition. The most voted-for themes and comments broadly correlate with the number of comments for each theme, supporting the idea that participants view naturalness and perception as the most important themes to focus on.

Figure 5: Word cloud of most common words used when describing condition.

Outcomes

The discussion of condition at the workshops has proved valuable in informing the rest of the project. To perform a literature review (Section 4) it is necessary to input key search terms, and the themes and words suggested by workshop participants were used directly to identify the search terms. The ideas around condition were also used to build the flow charts showing how to assess condition for each ecosystem service (Section 5). It ensured a greater breadth of coverage than may have been achieved without the workshop. Beyond this, there are a number of key comments that could guide and inform future work on condition stemming from this project, for example mentioning potential conflicts between different ecosystem services.

3.2 Ecosystem services and assets to consider (workshop exercise 2)

To ensure that the scope of the project was manageable within the time and resources available, workshop participants helped to refine the ecosystem services and assets to be assessed, through a polling exercise. A total of 40 polls were completed across both workshops.

3.2.1 Ecosystem services

Participants were asked to score a range of ecosystem services provided by riverine ecosystems on importance and availability of information (Table 2, overleaf). The three services scored as most important were water provision, water quality regulation and water flow regulation. Characteristics and features of biodiversity that are valued, and health and well-being, were scored as next most important. The three services scored as least important were pollination and seed dispersal, hydropower, and wild produce.

When the importance scores were combined with the availability scores (reversed so that low availability of information gave a high score), health and wellbeing had the highest overall score (high importance and low availability of information). This was followed by spiritual and cultural experiences, education, training and investigation, characteristics and features of biodiversity that are valued, and aesthetic experiences. The prevalence of cultural services indicated a data gap here. These services acted as additional priorities for identification in the literature review.

Within the comments, participants pointed out the importance of being aligned with the Environment Bill (clean and plentiful water). Comments were made on the availability of Public Rights of Way (ProW) data for the wider public, and the need for data on water standards required for immersive sports. Use of rivers for transport and the uplift in property value provided by the proximity to rivers were also mentioned as services to consider.

Table 2: Ratings of different ecosystem services, listed in order of importance. Importance (5 = most important) and data gaps (5 = most data gaps) were rated on a scale of 1-5 and the average is reported here (n = 40). Score is calculated as the sum of importance and data gaps. The services with highest scores in this column are in bold and were additional priorities for study. The final set of ten ecosystem services that were taken forward in the rest of the project are highlighted in yellow.

Ecosystem services	Importance	Data gaps	Score
Water for drinking/agriculture/industry	4.55	0.41	4.96
Water quality regulation	4.50	0.91	5.41
Water flow regulation	4.23	0.87	5.10
Characteristics and features of biodiversity that are valued	4.08	**2.15**	**6.23**
Health and wellbeing	3.90	**2.71**	**6.61**
Recreation and tourism	3.85	2.03	5.88

Habitat and population maintenance	3.75	1.78	5.53
Waste removal	3.64	1.41	5.05
Aesthetic experiences	3.62	**2.60**	**6.22**
Erosion control	3.58	2.18	5.76
Carbon sequestration and storage	3.55	2.48	6.03
Education, training and investigation	3.53	**2.74**	**6.27**
Spiritual and cultural experiences	3.43	**3.14**	**6.57**
Pest and disease control	3.23	2.82	6.05
Local climate temperature regulation	3.13	2.36	5.49
Fire protection	3.03	3.00	6.03
Cultivated plants and reared animals	2.95	1.61	4.56
Pollination and seed dispersal	2.95	3.00	5.95
Hydropower	2.83	0.87	3.70
Wild produce	2.44	2.92	5.36

3.2.2 Assets to consider

Participants were also asked to score a list of riverine natural capital assets on which they considered to be important for inclusion in the scope of the project. Catchments were scored as highest importance (Table 3), followed by lowland and upland rivers. Ditches were scored lowest. While artificial assets were regarded as less important than natural ones, the majority of users reported that all the assets deliver benefits, albeit in different ways (i.e. one user noted that whilst small streams are not important for water supply, they are very important for biological resilience), affecting the ecosystem services ultimately delivered by the whole catchment.

Participants were also asked about assets that were not within the scope of this project but that may be useful for future research into condition (Table 4). Floodplains were scored highest, followed by estuaries, groundwater and lakes. Reservoirs were seen as least important, and there were some comments suggesting that these should be included with lakes. Within other comments, lakes and estuaries were the assets most frequently mentioned, closely followed by floodplains, wetlands, and groundwater, while some users mentioned urban waterways, springs and priority rivers.

Table 3: Assets to include in the current project scope and their average importance scores (3 = most important).

To include in scope	Scores
Catchments	2.92
Lowland rivers	2.87
Upland rivers	2.82
Chalkstreams	2.75
Headwater streams	2.68
Heavily modified water body	2.68
Intermittent rivers	2.42
Artificial water body	2.05
Canals	2.03
Ditches	1.86

Table 4: Assets to consider in the future and their average importance scores (3 = most important).

Assets for future consideration	Scores
Floodplains	2.89
Estuaries	2.76
Groundwater	2.65
Lakes	2.61
Saline influenced transitional	2.55
Fens	2.54
Reedbeds	2.41
Ponds	2.33
Reservoirs	2.15

3.2.3 Outcomes

This exercise informed the scope of the condition mapping and literature review protocol, with the decision to focus on the first seven services in order of importance. These are: water for drinking/agriculture/industry; water quality regulation; water flow regulation; characteristics and features of biodiversity that are valued; health and wellbeing; recreation and tourism; and habitat and population maintenance. This was supplemented by also investigating the ecosystem services receiving the highest combined importance and (lack of) data availability score. Additional ecosystem services highlighted in this way are spiritual and cultural experiences; education, training and investigation; and aesthetic experiences. Further services could be investigated as part of follow up work.

As there was importance placed on most of the assets included within the scope of the project, following further discussion we decided to split our categories simply into natural and artificial rivers only rather than using any further subcategories like upland/lowland. Information on categories such as headwaters and chalkstreams was also captured as part of the literature review, but not analysed separately. The catchment and floodplain context in which a river flows has a major influence on rivers and was taken into account, but these aspects have not been analysed separately.

3.3 Policies, needs and evidence gaps (workshop exercise 3a)

The Environment Agency needs to enforce policies and in order to do so, certain needs and evidence gaps need to be filled. A total of 27 policies were mentioned, ranging from local scale (n=3, e.g., local plans) to national (n=16, e.g., Biodiversity Net Gain) and international (n=8, e.g., UN Sustainable Development Goals). A full list can be found in Appendix B.

Some of the main needs identified were stronger links between policies, more integration of financial incentives and natural capital including tools to enable this, improved metrics and monitoring data, including assessment of multiple benefits (environmental net gain) and environmental quality, evidence of benefits, and understanding the role/benefits of natural processes and nature-based solutions (NBS) in improving environmental quality, tackling climate change and managing flood risk.

Evidence gaps were identified including:

- How ecosystem service provision changes with condition and how to use existing data to understand condition (i.e., the overall focus of this project).
- Data required – including health and wellbeing data, water temperature, visitor numbers, land use, nutrient sources, and carbon sequestration.
- Quantified effectiveness and benefits of measures promoted in policies, and of the natural spaces themselves.
- Future projections and predictions, including the effect of climate change and drought.
- Valuation and natural capital information to integrate into policies, and how to use policies to support financial incentives.
- Risk to natural capital assets and ecosystem services.
- Water quality aspects of the biodiversity metric, and impact assessment / sensitivity analysis of introducing biodiversity net gain.
- Format of information such as storage capacity, improved data sharing between organisations, and increased accessibility of spatial data.

Note that a number of the evidence gaps raised are beyond the scope of the current project, but will be used to inform the wider NCEA project.

3.4 Metrics and scales required (workshop exercise 3b)

The second workshop focused on discussions and comments on metrics, maps and evidence needed, and then scale and level of detail required. In this case, metrics were considered to be measures to help improve understanding of asset condition, although we did not get into a discussion of definitions during the workshop, and it is likely that the term has been used interchangeably with the term indicators. To make the exercise more manageable, the number of ecosystem services included in the discussion was reduced by grouping the cultural services together, where it was discussed and agreed that answers would heavily overlap, and by removing a few of the ecosystem services with lower importance scores identified in Exercise 2 (hydropower, wild produce, pollination and seed dispersal, fire protection, cultivated and reared animals). In total, eight ecosystem services were discussed: water (for drinking / agriculture / industry); water quality regulation; water flow regulation; erosion control; carbon sequestration and storage; habitat and population maintenance; local climate (temperature) regulation; and recreation and cultural services. This was supplemented with a discussion of some aspects of condition, particularly biological/ecological quality, but with other aspects brought up by participants, including geomorphological processes, resilience, iconic species or landscapes, waste regulation, physical change due to climate change, and soil health and capacity. A summary is shown below (Figure 6), with full results in Appendix B.

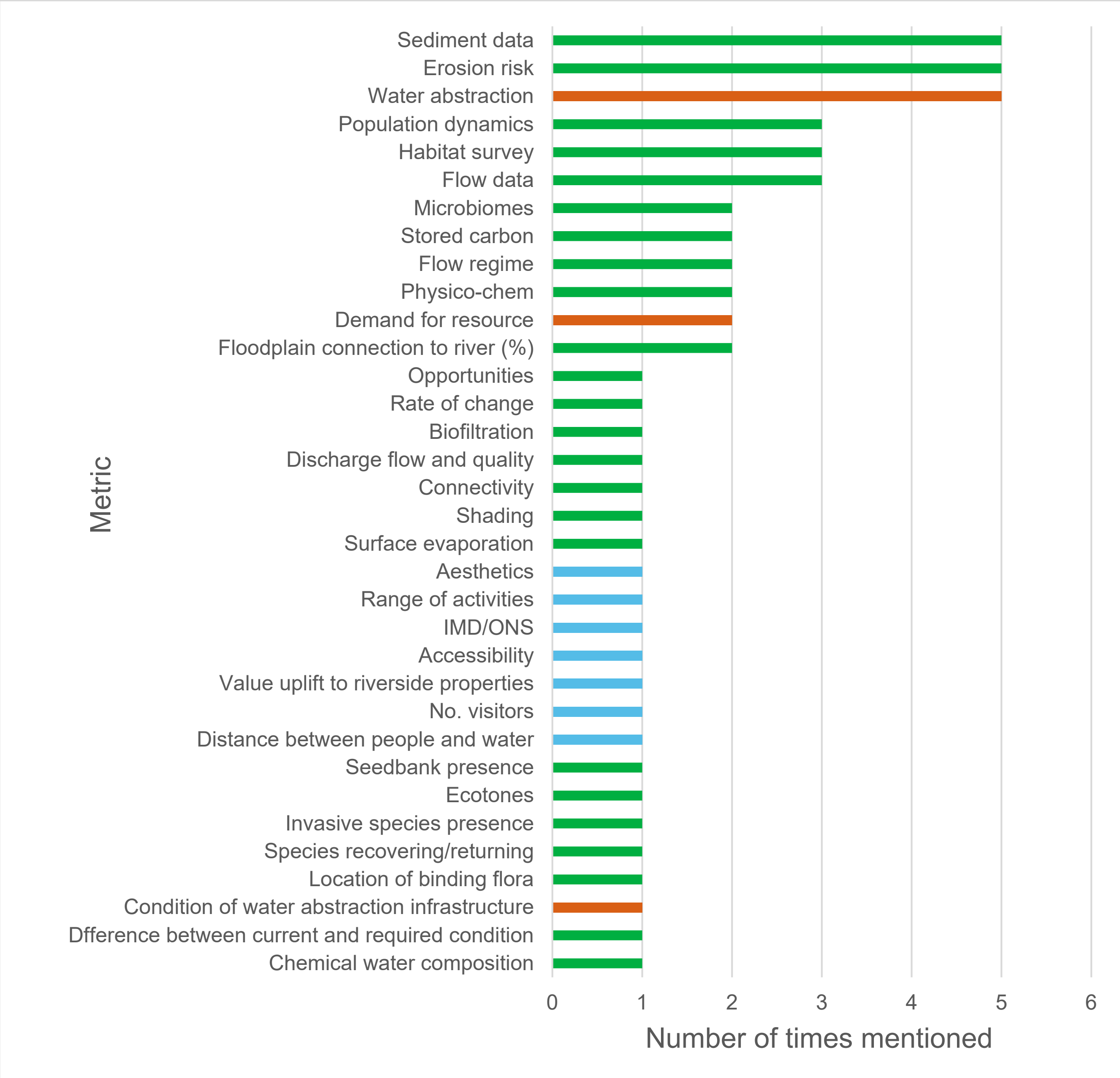


Figure 6: Metrics requested in Exercise 3b (metrics and scales required) and the number of times they were mentioned in the interactive exercise. Orange = provisioning service, green = regulating service, blue = cultural service. IMD = Index of Multiple Deprivation, ONS = Office for National Statistics.

Several metrics were suggested for most of the ecosystem services on which the workshop focused. These included abiotic evidence (e.g., temporal and spatial variation in water flow, erodibility of bank materials), biotic evidence (e.g., location and quantity of natural binding flora, presence/absence of invasive species), and human evidence (e.g., visitor numbers, accessibility). These are displayed in Figure 6. Most of the metrics were specific to the service, but several were mentioned multiple times. The most commonly mentioned ones were sediment data, erosion risk and information on water abstraction, followed by population dynamics, habitat surveys and flow data. These are mainly abiotic metrics, but there are also some biotic ones.

Most metrics were required at a national scale (especially for national reporting purposes) and a smaller scale, such as local authority or ward level for local decision making (Figure 7). Scales relating to the environment itself were also mentioned, such as at waterbody or catchment scale. In addition to specifics, the need for a variety of scales was mentioned several times.

A number of emerging projects and potential data sources were brought up by participants (Table 5). There were eight EA projects mentioned, three Defra projects, three Natural England projects, two UK Centre for Ecology and Hydrology (UKCEH) projects and two others (scientific papers).

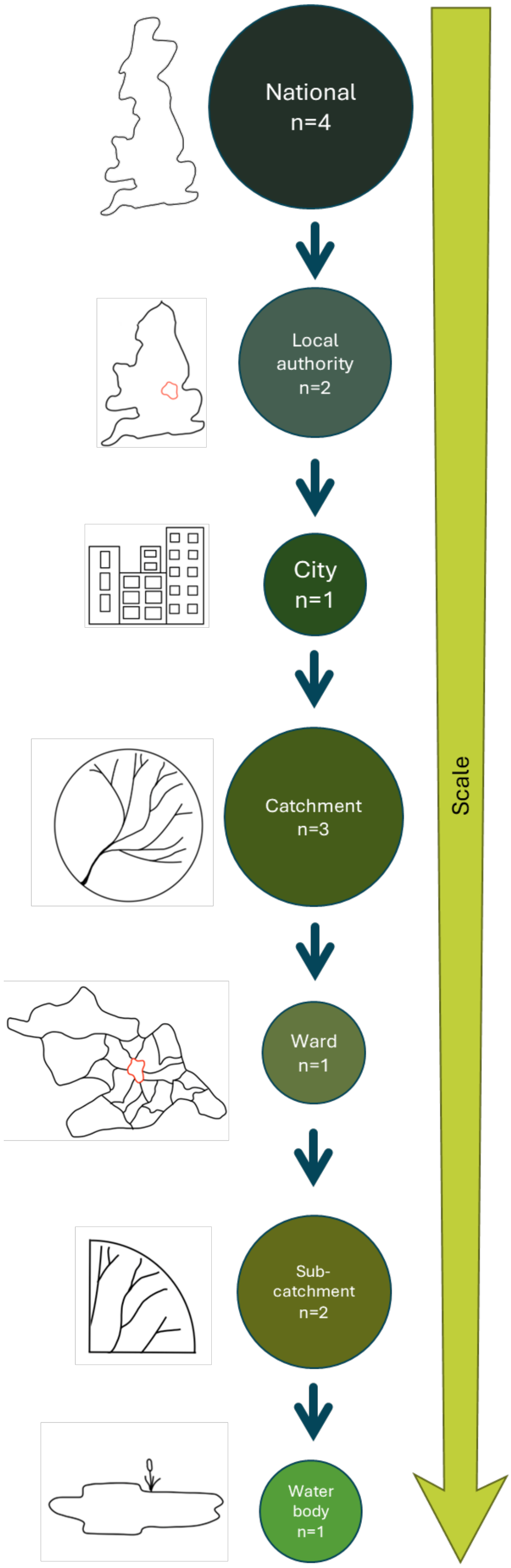


Figure 7: Different scales required by users. Circle size indicates number of times mentioned.

Table 5: Emerging evidence, and other projects and data sources documented by workshop participants, related to river condition.

Organisation	Project
NE	• People in Nature Survey • Areas of "high potential" for recovery based on location in Nature Recovery Networks (NRN) • An approach to landscape sensitivity
EA	• Hype model outputs • LIDAR to map trees /shade next to rivers • Working with Natural Processes Toolkit • ALERT TOOL • Natural Environment Investment Readiness Fund team • Measuring resilience to flooding and coastal change • Catchment resilience • Approaches to Assessing Risks to Natural Capital
UKCEH	• RIVPACS • Remote condition monitoring work
Defra	• England Ecosystem Survey • Water Industry National Environment Programme review • Report of progress of Defra 25-year Environment Plan Indicator B6 development
Other	• Water temperature monitoring in Scotland and projected change to 2050 (Birmingham University) • McHarg, Design with Nature (1971)

3.5 Conclusion and project scope

The review of key terms, existing information on user needs and subsequent workshops helped the project team to clarify and refine the scope of the project to be taken forward over the subsequent stages. The project aims to understand how changes in condition impact ecosystem service delivery. Key points are summarised here:

Natural capital assets – the focus of the project is on rivers. There was a lot of importance placed on floodplains and catchments at the workshops, which were the two highest scoring asset classes. Rivers operate as a system, depending upon the landscape in which they occur, and should not be assessed outside of the context of their catchments. Systems thinking is also a key part of the natural capital approach (and the ecosystem approach). In the analyses that follow, we therefore consider the condition of rivers within their catchment context, but do not focus on the catchments, floodplains and groundwater baseflow separately.

Defining assets

Within the river asset classes, we decided to split our categories simply into natural and artificial rivers only rather than using any further subcategories like upland/lowland.

Artificial rivers are defined as ‘a surface water body which has been created in a location where no water body existed and which has not been created by the direct physical alteration or movement or realignment of an existing water body’ (European Commission, 2003). Artificial river waterbodies include completely artificial dug canals, water diversions, leats and reservoir feeders (Environment Agency, 2009). Natural rivers are defined as ‘surface water bodies that are naturally occurring within the landscape and originally formed by natural processes’. It is important to note that anthropogenically modified rivers are classed as ‘natural’ within this context, as they were present prior to alteration.

Ecosystem services – to ensure that the scope of the project was manageable with the available resources, we decided to investigate the ecosystem services in the order of importance identified by the workshop attendees, supplemented by those services for which there is very little existing information (almost exclusively cultural services). The ten selected ecosystem services are highlighted in Table 2. Each ecosystem service was defined to inform the study going forwards (see Table 1).

Condition –the meaning of condition in relation to the delivery of ecosystem services in rivers stimulated intensive discussion, which can be summarised by categorising the contributory attributes (Section 3.1, Figure 4). This then determined the literature search (Section 4) and informed the flow charts and data and indicators review (Section 5). Naturalness, itself a term that covers a broad range of attributes, was ultimately deemed to be the most important indicator of condition. although a broad range of other factors were also mentioned (Figure 4) and were included in the next stages of the project.

Defining condition

It is clear that there is no one single way of measuring condition, as it varies depending on the ecosystem service under consideration. For the purpose of this project, we are therefore defining good condition as the state of the asset that enables high provision of the ecosystem service being assessed. Condition is most commonly associated with naturalness, resilience, connectivity, and access, and crucially, it is strongly influenced by perception and value judgements, particularly for cultural ecosystem services.

Policies, needs and evidence gaps – the identified policies were used to inform the work going forward (Section 3.3, Appendix B), particularly around specific aspects of condition and the context for those requirements. We investigated evidence gaps where they relate to condition, with broader evidence gaps used to inform the wider NCEA Project. This part of the workshops was the most open ended, resulting in discussion that covered a broad range of topics (Section 3.3). Some of this has less direct bearing on this phase of the project but still provided invaluable data for the wider project by suggesting future directions for work.

Metrics and scales required – the metrics and emerging evidence suggested in the workshops (Section 3.4; Figure 6, Table 5) were investigated in one of the next stages of the project (reviewing datasets and methods to assess river asset condition) and information collected on scale was used to inform the development of the indicators.

4. A Quick Scoping Review assessing the evidence linking asset condition to changes in the flow of ecosystem services

In this section, we outline the background, methods and results of the literature review undertaken to assess the state of current evidence linking asset condition to changes in ecosystem service flow.

4.1 Introduction

The aim of this part of the project was to provide a synoptic overview of the evidence linking changes in river condition with changes in the ecosystem services provided, using a Quick Scoping Review (QSR) of the scientific literature. A QSR (Collins et al., 2015) is a type of evidence review designed to provide informed conclusions on the characteristics and volume of the evidence base as well as a synthesis of the evidence in relation to a specific research question.

The review of key terms, existing information on user needs and subsequent workshops, described in Sections 2 and 3 were used to clarify and refine the scope of the review. The assets, condition and ecosystem services to be investigated, are the key elements of the review, and were directly used to populate the conceptual framework for the QSR, as described in Section 6.2.

In view of the potential breadth of research on individual ecosystem services, the approach taken was therefore to collate a representative sample of literature that was most likely to be relevant, supplemented by a search of grey literature and some additional scientific papers that were known to the review team. It is therefore important to note that the QSR will not provide a complete picture of the available evidence, although this is not considered critical to the outcomes achieved.

An Excel spreadsheet accompanies this review, containing all the papers that passed through the first screening, as well as key information (a knowledge map, explained below) derived from the papers that passed the second screening and were selected for detailed review.

4.2 Methodology and papers sampled

The report was conducted following the QSR guidelines (see Collins et al., 2015). QSRs follow a standardised, structured and transparent approach, and for this project the approach was developed by the review team using a Protocol document. The subject matter for this review was potentially very large, hence the approach does not attempt to review every possible paper, but to use an objective, structured process to select a suitable subset of key papers for review. This approach is most appropriate to meet policy and practice evidence requirements (Collins et al., 2015).

4.2.1 PICO elements and scope

The primary question addressed by this QSR was: How does asset condition affect the delivery of ecosystem services from rivers?

As part of the QSR protocol, a PICO (Population, Intervention, Control, Outcome) framework was used to identify the underlying concepts from the primary research question to form the basis of a search strategy. The PICO would also aid the search for evidence using keywords that would ensure focus and clarity of the questions.

Table 6: PICO table.

PICO model	
Population	River waters and their floodplains
Impact	High quality/good condition
Control	Low quality/poor condition
Outcome	Change in delivery of ecosystem services

Secondary questions: How does the delivery of ecosystem services vary by asset class (especially natural rivers compared to artificial rivers)?

The outcome part of the PICO table indicates a variety of ecosystem services, and the primary (and secondary question) can be further split into X questions based on the ecosystem service analysed.

Scope and search locations

Limits to the scope of the review are reported in Table 7.

Table 7: Limits to the scope of the review.

Scope of the work	Restrictions
Geographical reference	UK > northern Europe > temperate regions
Climatic conditions	Temperate
Language	English
Date restrictions	None
Population restrictions	Rivers

4.2.2 Search terms (keywords)

The search for published literature was conducted in Scopus as the most comprehensive database of peer-reviewed literature (Elsevier, 2023), and its broad interdisciplinary coverage, sophisticated search interface and bibliometric dashboard. Scopus searches consist of a string of search terms that can be concatenated using Boolean operators. The operator ‘OR’ finds documents that contain any of the terms, while ‘AND’ finds only those documents that contain all of the terms. W/n is a proximity operator to search for words near one another, within the n number of words specified. Terms can be searched for in specific documents fields by specifying the field name (e.g., ‘TITLE-ABS’ will only search through title and abstract). Multiple word endings and starting can be matched using wildcards (*). The review team and steering group formulated the keywords to be used in the search through a co-design process. Keywords were informed by the workshops (especially around definitions of condition which were used as impact keywords) and the definitions of ecosystem services reported in Section 2 (used as outcome keywords). The full list of keywords is shown in Table 8.

Control keywords were not formulated as these would only indicate a low quality or poor condition river (high naturalness/low naturalness) and would have been redundant. Population, impact and outcome keywords were concatenated using ‘AND’, meaning a paper would be selected if matching any of the population and impact and any of the outcome keywords. As this search yielded 502,341 results it was decided that the papers should also make explicit mention of ecosystem services or assets. This cut the number of hits to 4,550. The search was initially performed using title, abstract and keywords but some words such as pollut* and fish* gave a biased sample of the literature when including keywords in the search, hence the search was limited to abstract and title.

Table 8: Keywords used in the literature search. The codes shown in the outcome keywords relate to the ecosystem services codes in Table 2.

Keywords	
Population keywords	river* OR headwater* OR floodplain* OR riparian* OR bluespace* OR *stream*
Impact keywords	value OR naturalness OR perception OR resilience OR *connect* OR *morpholog* OR pollut* OR condition* OR character* OR access OR qualit* OR anthropogenic
Outcome keywords	ES 1 = (water W/1 (drink* OR industr* OR flow OR storage OR supply OR quality OR abstraction)) ES 2 = flood* OR drought OR {natural hazard*} OR runoff* ES 3 = nutrient* OR nitrogen OR phosphorus OR sediment* OR water qualit* ES 4 = intrinsic* OR existen* OR bequest OR option* ES 5 = society OR *social OR health OR wellbeing OR crime OR {social benefits} OR {antisocial behaviour} ES 6 = recreatio* OR touris* OR fish* OR exercis* OR {physical activity} ES 7 = *diversity OR habitat OR ecology* ES 8 = aesthetic OR scen* OR landscape OR experien* ES 9 = education* OR training ES 10 = spiritual* OR cultural
Other keywords	ecosystem* W/1 (service* OR asset*)

Some of the keywords reported in the table yielded no results and were therefore removed from the search string. To complement the sensitivity testing of the search strategy, emerging results were also assessed using network visualisation (see Figures 8 and 9 and section below), to ensure that meaningful results were emerging. The final search terms used are shown in the box below. This returned **3605 papers** (journal articles and reviews, conference papers, and book chapters).

Final search string used in Scopus search:

TITLE-ABS((ecosystem* W/1 (service* OR asset*)) AND (river* OR headwater* OR floodplain* OR riparian* OR bluespace* OR *stream*) **AND** (value OR naturalness OR perception OR resilience OR *connect* OR *morpholog* OR pollut* OR condition* OR character* OR access OR qualit* OR anthropogenic) **AND** (water W/1 (drink* OR industr* OR flow OR storage OR supply OR quality)) OR nutrient* OR nitrogen OR phosphorus OR sediment* OR runoff OR flood* OR drought OR biodiversity OR habitat OR society OR *social OR ecology* OR health OR wellbeing OR recreatio* OR touris* OR fish* OR exercis* OR aesthetic OR scen* OR landscape OR cultur* OR experien* OR intrinsic* OR existen* OR option* OR education* OR training OR investigation) **AND LANGUAGE** (english)

A strategy for targeting key grey literature (relevant information published outside traditional sources) was also developed for the review. The following websites were searched for published reports: EA, Natural England, NatureScot, Natural Resources Wales (NRW), UKCEH, and Natural Environment Research Council (NERC). In addition, internal searches were conducted in the EA and Natural England intranets.

4.2.3 Screening of results and network visualisation

Once the search strategy had been refined, the number of papers was narrowed down in two phases. A **first screening phase** was done by a single reviewer by removing those titles that were not relevant (not explicitly mentioning rivers, watersheds, freshwater). Through this process 794 papers were selected.

VOSviewer (van Eck & Waltman, 2010) is a software tool for constructing and visualizing bibliometric networks for analysing large sets of scientific publications The software uses Principal Component Analysis and Natural Language Processing algorithms to identify patterns, trends, and relationships from the title and abstract fields of large corpora of bibliographic information. The maps arrange this information into coherent clusters, which can help to identify emerging or established research topics or interdisciplinary research areas. VOSviewer was used for this purpose to visualise clusters in the screened Scopus search (see Figures 8 and 9). This is known as term co-occurrence map and indicates major research topics in articles and reviews indexed by Scopus. Each term occurs in at least ten publications and only 60% of the most-frequently occurring terms are visualised. The size of the circles in the visualisations relate to the number of times the word or phrase appears across all the articles. Related terms are grouped into the same colour. Lines between terms indicate where terms are used together and the distance between terms indicates how often they co-occur; the smaller the distance the larger the number of co-occurrences and the stronger the terms are related to each other.

In Figure 8 we can see three main clusters: the red cluster identifies more of the physical entities (see ‘stream’, ‘species’ and ‘sediment’), while the blue cluster identifies more of the mechanisms and potential stressors due to interventions, ‘land use change’. The green cluster identifies themes more related to people where it's possible to see ‘citizen’, ‘household’, ‘stakeholder’, ’cultural ecosystem service’ as well as ‘China’ since this is where a lot of this kind of research comes from. Overall, the maps highlight the degree to which rivers are contested spaces with multiple pressures affecting their condition, and the need to manage the supply and demand of ecosystem services. This trend is further emphasised by the “overlay visualisation” showing how terms evolve from “state” related biotic indicators such as “fish”, towards abiotic indicators like “precipitation” and “water yield” which may reflect a transition of rivers towards increasingly unstable and unpredictable systems.

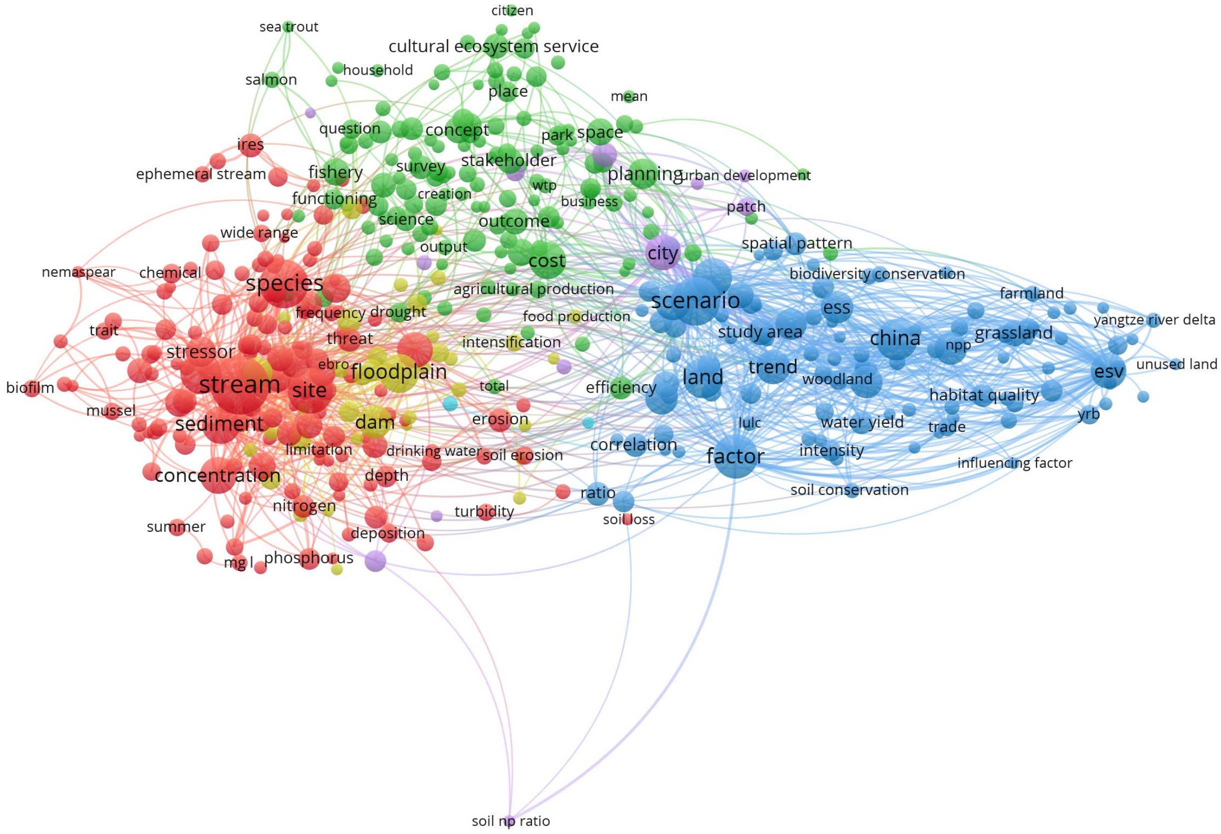


Figure 8: Network visualisation of results remaining after first screening phase selecting 794 papers.

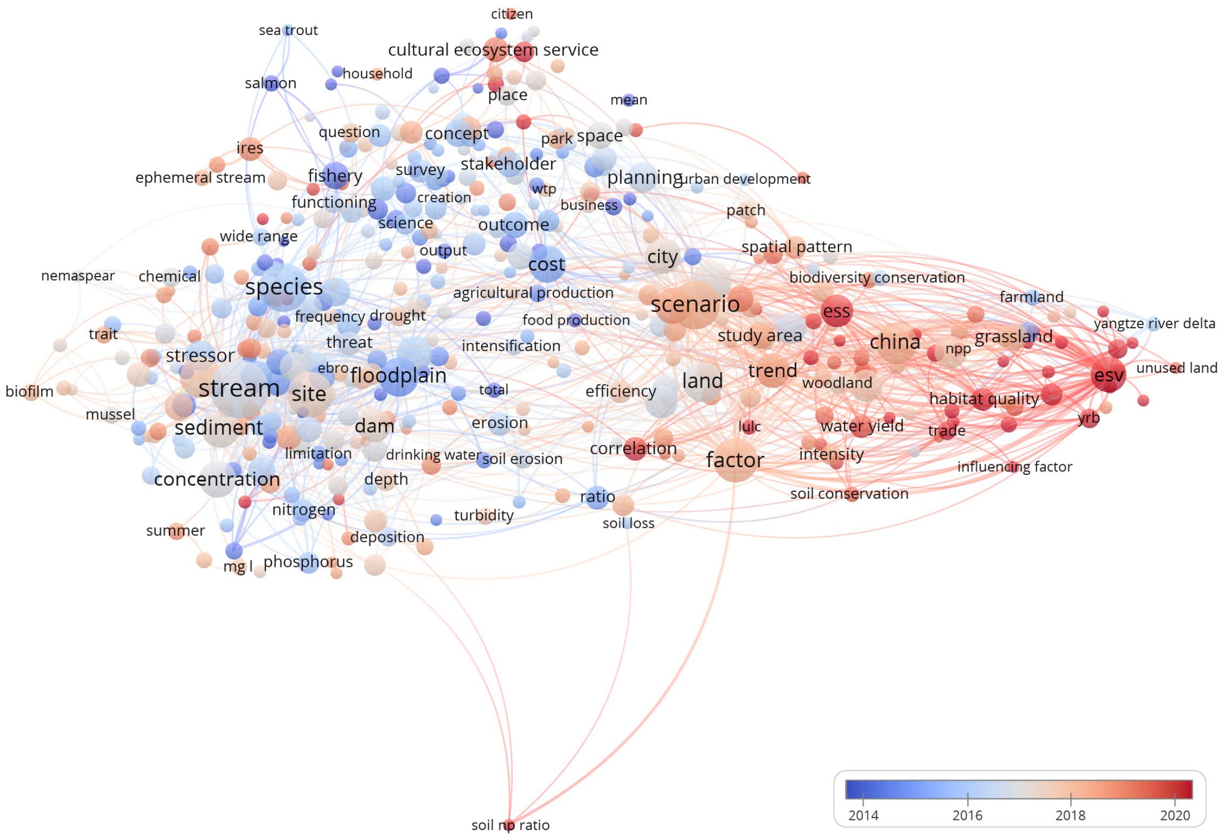


Figure 9: Overlay visualisation of results remaining after first screening phase selecting 794 papers.

In Figure 9, the overlay visualisation shows how academia has shifted its focus in time from more traditional papers focusing on species and habitats (note the blue-shaded 'floodplain', 'species', 'salmon') towards a holistic view of rivers focusing on ecosystem services and their value (not visible but in the background) 'esv' and towards a greater inclusion of social sciences and cultural ecosystem services compared to the greater focus on provisioning services of previous years. It's also evident how China is becoming a leading country in this field of research.

In the first screening process the risk of bias was low, but once papers that mentioned rivers were selected, further screening would have been more prone to bias. For the second screening phase a Delphi approach was then adopted to further narrow the number of papers. The Delphi approach entails that multiple people (six reviewers volunteered for the task) review some (or in some cases all) of the papers and determine which ones are relevant in answering the research questions, in order to minimise single person bias. The review team found it was usually necessary to read whole abstracts to determine whether a paper was relevant. Reviewers started the screening process at different places on the list to ensure that all papers were reviewed by more than one person.

Each reviewer gave a score of '1' to relevant papers and '0' to non-relevant ones. Each reviewer also made use of question marks (which were later assigned a score of 0.5) next to some papers that sounded less relevant but worth examining briefly, or where there was uncertainty (see 'Full PICO output' tab in 'Natural Capital condition mapping-Appendix D-Knowledge map').

Relevance was based on three criteria:

- Does the paper explicitly address a change in delivery of one or more ecosystem services?
- Is this related / due to a change in condition?
- Is the study geographically relevant? Although note that this criterion was applied less strictly as it was considered that a paper from a different climate zone might still be relevant for some cultural services, where fewer papers were expected.

Results from all the participants were brought together. In total:

- 533 papers were screened by three different people.
- 261 papers were screened by four different people.

Records screened by four people were given a weighting of 0.75, so that all scores were equalised and out of a total of three.

The whole screening process is outlined in Figure 10.

The weighted score showing the number of times each paper was selected was calculated, with the number of records given different scores shown in Table 9. Papers with a score of 1.875 (n=45) and above were carried forward and used in the knowledge mapping. A score of 1.875 and above indicates that at least two reviewers have deemed the paper as relevant. Papers achieving a score greater than 1 (indicating that more than one reviewer found the papers to be relevant), were used to supplement the initial list where gaps were apparent in the knowledge map. This provided an additional 66 papers to consider.

Table 9: Number of records and cumulative records of scores assigned to the 794 papers by 6 reviewers.

Weighted score	Number of records	Cumulative records
3	8	8
2.5	2	10
2.25	5	15
2	21	36
1.875	**9**	**45**
1.5	45	90
1.125	**21**	**111**
1	154	265
>0 and <1	221	486
0	308	794

After the initial review of the top 45 papers and grey literature, knowledge mapping revealed that for some of the services very few papers were found and that some key evidence had been left out by our search strategy. A gap filling exercise was then carried out by examining the next 66 papers that had received a score of 1.125 or 1.5, along with a few additional papers recommended by members of the review team. This exercise was focused on those ecosystem services with fewer results, but key papers for other services were also added. In total, 20 extra papers were added (see ‘Extra papers’ tab in accompanying Knowledge map spreadsheet, Appendix D) to our review.

4.2.4 Knowledge map

In this step, key information was extracted from each paper selected by the aforementioned screenings (see ‘Natural capital condition mapping - Appendix D - knowledge map’). In particular: geographic location, asset type (river, freshwater, entire watershed etc.), study type (observational, review, qualitative, experimental) was recorded to provide a more detailed characterisation of the literature. For each ecosystem service reviewed, a different column was created in the spreadsheet to record the aspects of condition affecting the ecosystem service and if there was a positive or negative relationship. The data gathered through the knowledge mapping process is summarised in Figure 11.

The majority of the studies selected came from Europe and within this group, the UK was the most represented country (19 studies), while many studies came from the USA (8), and some were global studies (6). As expected, the largest number of studies were observational, followed by reviews and some examples of experimental and modelling, while only one qualitative study was selected. As regards the temporal distribution of the papers selected, only one predated 2000, 15 papers were published between 2000 and 2010 and 50 were published from 2011 to 2023. The ecosystem services for which very few papers were gathered (four each) were ‘water for drinking/agriculture/industry’ and ‘characteristics and features of biodiversity that are valued' closely followed by ‘spiritual and cultural experience’ and ‘education training and investigation’ (six and seven, respectively); ‘health and wellbeing’, ‘aesthetic experience’, ‘water flow regulation’ and ‘water quality regulation’ were addressed in 13 or more papers (13, 14, 14 and 17 respectively) and lastly ‘recreation and tourism’ and ‘habitat and population maintenance’ had the greatest amount of papers (26 and 31, respectively).

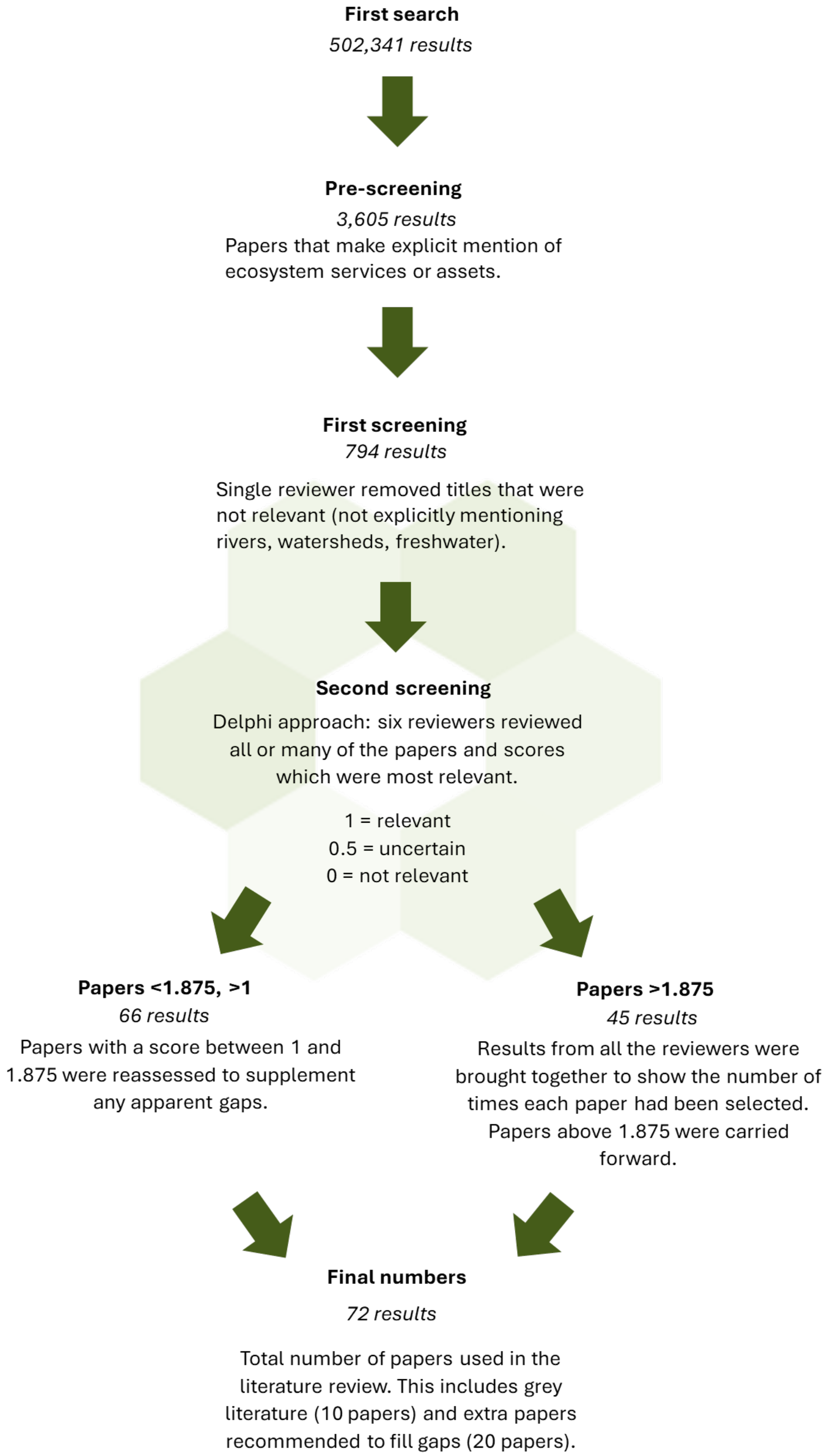


Figure 10: Overview of the entire screening process.

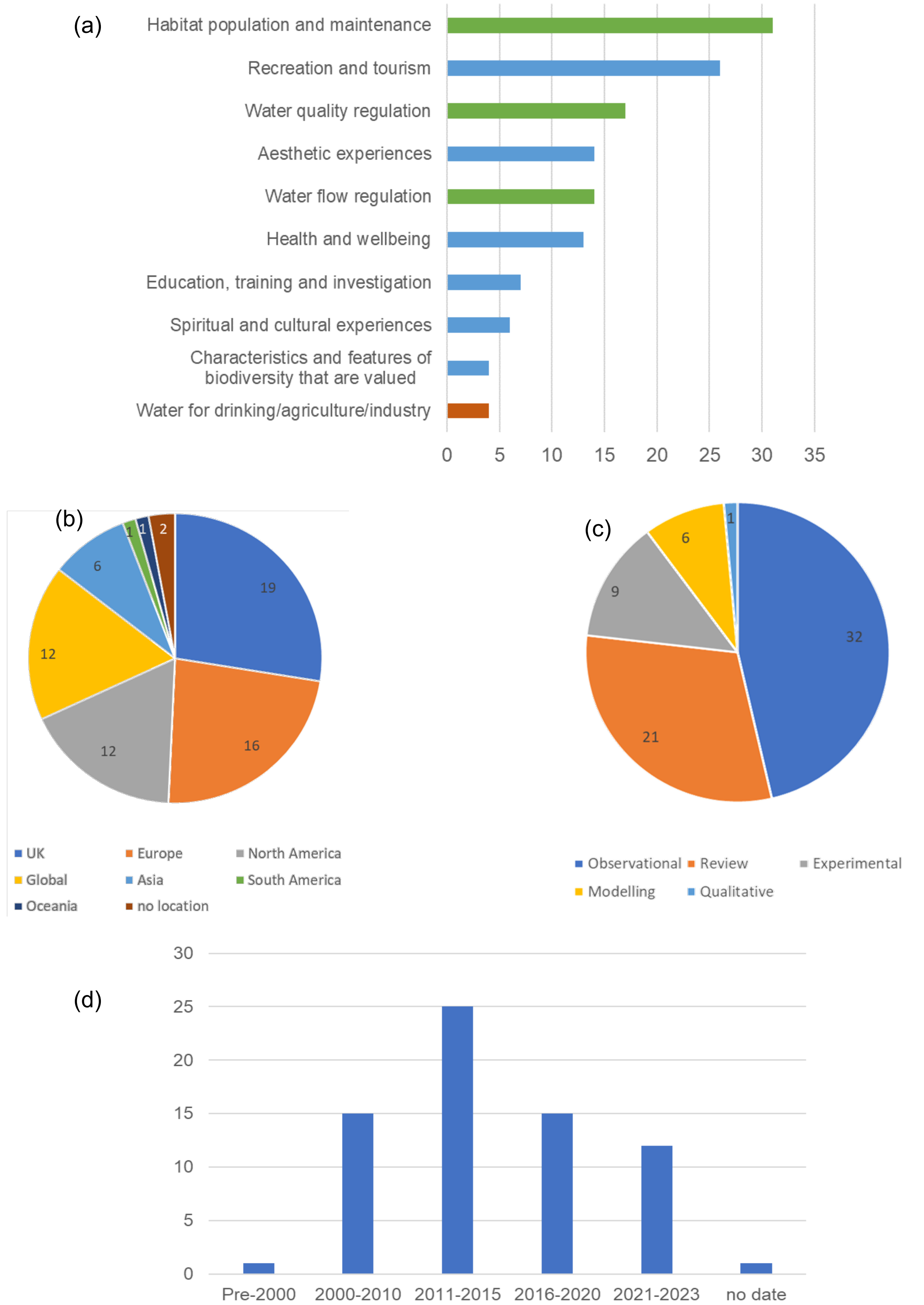


Figure 11: Summary of the knowledge map. Number of studies by ecosystem services (a), geography (b), type of study (c), and year published (d).

The grey literature selected was almost entirely from the UK (with only one EU-wide study) and largely took the form of reviews (with two observational studies). ‘Water flow regulation’, ‘water quality regulation’ and ‘habitat population and maintenance’ were the ecosystem services most represented (six, five and five grey literature items), followed by ‘recreation and tourism’ with three items and ‘health and wellbeing’ with one item.

4.3 Literature review

Following the production of the knowledge map, the evidence from the selected literature (72 studies in total) was synthesised into a narrative summary. For each ecosystem service we present the evidence to answer the primary research question: how does asset condition affect the delivery of ecosystem services from rivers?

In this review, we explore which aspects of condition aid the delivery of a given ecosystem service, the relationship between different aspects of condition and ecosystem services delivery, how this varies by asset class (the secondary research question), and the strength of the evidence base. Each ecosystem service is presented in turn in the sections below, although there is inevitably some overlap between these, particularly within the regulatory services and within the cultural services. We end by briefly highlighting key knowledge gaps, where further evidence is required.

Provisioning services

4.3.1 Water for drinking, agriculture and industry

Water abstraction is the process of taking water from a natural source for human use. The condition of a river is a relatively small factor in the amount of water a river can provide; this is much more affected by the condition of the whole catchment system, climate and weather patterns. Water abstraction can have a significant impact on a river's ecosystem and condition, especially when done excessively or without proper regulation. Experts rate interventions related to infrastructure and intensive land use as having negative effects on the availability of water for agricultural, industrial use or for human consumption (except for dyke relocation), and regard restoration of rivers to benefit the availability of water (Schindler et al., 2014). A study comparing a near nature-state floodplain with a scenario where the riverbed is straightened, floodplain terrain is flattened and surrounding land use changed into arable, reveals the scenario had a 36% reduction in water retention volume compared to the near nature-state (Pithart et al., 2010). The hydrogeomorphological state of a river also affects the water availability: water storage is high in anastomosing, medium in meandering and low in leveed, constricted and braided rivers (Thorp et al., 2010).

Regulating services

4.3.2 Water flow regulation

Water flow regulation refers to the management of water levels in rivers. This is often achieved through the construction of dams, reservoirs, weirs, locks, levees and other infrastructure which alter natural flow patterns (Lian et al., 2012). Dams for example, can reduce the natural flow variability of a river, causing downstream areas to experience lower flows during dry periods and higher flows during wet periods (Mohamoud et al., 2009), and vice versa can reduce flow during wet periods; this is desirable as it can provide benefits such as flood control, irrigation, and hydroelectric power but it can also have negative impacts on the ecosystems downstream.

A consistent finding in the literature is that greater naturalness of the riparian habitat and the absence of artificial structures greatly helps in achieving flood regulation without harming the downstream ecosystems, compared to the building of structures to retain water, though in some cases these structures are necessary in protecting humans and property. Expert-based assessments suggest management interventions for water extraction, building of infrastructure and intensive land use don't yield any benefits to the water flow regulation capacity of rivers while restoration and rehabilitation measures increase the service (Schindler et al., 2014). A lot of evidence has been collected around the concept of 'working with natural processes' (Burgess-Gamble et al., 2018), but it is beyond the scope of this QSR to review this. One example is found in a study showing concreting of the banks, urban development and the removal of riparian forest recorded in anthropogenic sections of a Polish river which increased average annual flow by twofold (SSQ from 3.0 to 6.41 m^3/s), compared to semi-natural river sections (Hanczaruk & Kompała-Bąba, 2019). Increasing riparian vegetation has been shown to have positive effects on water flow, slowing the flow of water as it moves toward the river (Natural England, 2015). Simulation studies also show lower flow speeds and flood peaks in restoration scenarios (Burek et al., 2012).

The amount of sediment can impact water flow. Sediment from agriculture and urban land uses reduce river conveyance, which can in turn increase flood risk (Stone & Shanahan, 2011). In the UK, data was collected on hydrology, river habitats, invertebrates, geomorphology and sediment across five river sites showing sediment maintenance can modify water flow, with different impacts recorded across sites; dredging reduced flow type diversity (e.g., patterns on the water surface, velocity, flow direction and influence of river bed substrate), artificial riffle creation increased flow type diversity and vegetation maintenance modifies flow condition (Bettess et al., 2011).

The phase of development of a river determines its capacity for flood alleviation. In anastomosing rivers (type of river with multiple, interconnected, coexisting channel belts on alluvial plains), water is diffused over the floodplain, thus flood peaks are maximally attenuated; a reduced ability for flood attenuation is found in sinuous, single thread and laterally active rivers where flood and drought refugia are reduced but still present. In channelised and quasi-equilibrium stages of the river evolution, flood and drought refugia are limited. The intermediate stages of the river evolution model (degrading, arrested degradation, degradation and widening, renewed incision and aggrading and widening) don't seem to provide significant flood alleviation benefits (Cluer & Thorne, 2014).

Restoration and rehabilitation projects are considered to improve water flow (Schindler et al., 2014). Restoration work comprising improved habitat, opening of obstructions, removal of a spillway and deculverting in the River Glaven (UK), gave the river a more natural hydrology, improving water flow regulation. Beaver reintroduction is an important tool for flood amelioration (Scotland's Nature Agency, 2017). Beaver dams impound flow by increasing open water extent from which all the other impacts follow; these include increased surface and subsurface water storage, altered flow hydrology, and geomorphic heterogeneity (Larsen et al., 2021). In England, Beaver dams were monitored, and during storms, the flow of water was reduced and the lag time between rainfall peak and flow peak was increased indicating flow attenuation; even more impressive was the effect recorded during the largest storms, showing average flood flows were reduced by 60% (Puttock et al., 2021). A similar effect is achieved with riparian woodland, which through the production of woody debris decreases water velocity, increasing the travel time of water across the catchment (Mott, 2006).

4.3.3 Water quality regulation

A lot of research has been carried out on factors affecting water quality. Widely understood are the problems related to the micro-organisms present in human and animal waste products (particularly for drinking water quality), eutrophication due to excess nitrogen and phosphorus from agriculture and urban areas (Lundqvist & Falkenmark, 2000), and the presence of toxic heavy metals that is made worse by acidification (Lundqvist & Falkenmark, 2000). However, as noted in Section 6.4.3, these relate to the causes of poor water quality and not the ecosystem service of water quality regulation delivered by plants and animals in or close to the river. Hence these types of study are not reviewed in depth here.

These water quality issues are made worse by human interventions related to extraction, infrastructure and intensive land use (Schindler et al., 2014). Water abstraction, for example, can cause changes in the concentration of dissolved minerals, nutrients, and pollutants, and the higher the abstraction ratio, the less water remains in the stream, reducing the dilution effect and the self-purification capacity (Lundqvist & Falkenmark, 2000). A study investigated the treatment cost per unit of wastewater by a sewage treatment plant to quantify the impact of hydropower facilities and revealed an extra 3,550,000 yuan (c. £400,000) were needed to pay for extra treatment costs related to increased water pollution at one of the sites (G. Wang et al., 2010).

Organisms naturally present in rivers are capable of maintaining water quality, and generally, water quality is positively related to biodiversity (Ricketts et al., 2016). For example, though other pathways to nitrogen loss exist, respiratory denitrification by bacteria is thought to be the main nitrogen loss mechanism in freshwater ecosystems (Heathwaite, 2010). Excess nitrates from fertilizers and human and animal waste constitute a threat for the safety of our river waters. Rivers that have more agriculture in the catchment have more nitrogen in water, while those catchments where forest is more abundant have lower nitrogen levels (Yao et al., 2016), although again this is driven by processes in the catchment rather than in the channel or riparian zone.

Restoration and rehabilitation projects generally have positive effects on water quality (Schindler et al., 2014). Urban stream restoration, using reedbed creation in Mayesbrook Park (London, UK) for example has been shown to improve water quality (Everard & Moggridge, 2012). A high-level review of existing evidence reports that excluding livestock, reducing canalisation and increasing planting of riparian vegetation has positive effects on water quality (Natural England, 2015). The addition of riparian trees, for example, can improve water quality by removing added phosphorus and nitrates before they enter the water, and acting as a physical barrier to prevent pesticides reaching watercourses (Woodland Trust, 2016). While the beneficial effect of riparian woodland on water quality is understood, a better quality riparian woodland doesn't provide additional benefits to water quality; other factors such as the habitat adjacent to the riparian woodland strip and the habitat composition within the catchment are more important factors affecting service delivery than riparian woodland quality (Terrado et al., 2015).

High-level synthesis of studies of woody debris in rivers reveals that woody debris can have a positive impact on water quality via the removal of fine silt from the water system (Mott, 2006). The addition of dead wood to increase the complexity of a river showed that restored parts of the stream had a greater ability to retain Coarse benthic organic matter (CBOM) which, in turn, positively affected water quality, while Coarse particulate organic matter breakdown rates were not affected. The longer water residence time caused by the slower flow enhanced the uptake of NH4 (ammonium) and PO4 (phosphate) (Acuña et al., 2013). A qualitative assessment of beaver introduction to the River Leven and River Forth catchments in Scotland suggests water quality is improved after beaver translocation; through dam creation that in turns leads to wetland creation, runoff is reduced causing fewer contaminants to reach the water body (Nature Scot, 2017).

Other types of restoration projects that don't directly impact rivers can still affect freshwaters. A comparison of drained peatland, recently blocked drains and intact peatland streams shows changes in physicochemical variables such as higher concentrations of fine particulate organic matter (FPOM), NO_3 and suspended sediment concentration (SSC) in drained sites compared to intact peatland; intact and drain-blocked sites have overall higher water quality (Ramchunder et al., 2012).

The changes a river goes through during its evolution profoundly affect its ability to purify water. Anastomosing rivers forming network channels are considered to have a high capacity to cycle nutrients and store sediments, producing high water clarity; the large amount of vegetation around network channels also keeps water temperature low. In sinuous single-thread and laterally active rivers, sediment storage and nutrient cycling is reduced compared to anastomosing rivers, while the effects of shading are maintained (Cluer & Thorne, 2014). Channelised rivers have limited capacity for nutrient cycling given the simplification of the channel, and lower water clarity, hyporheic exchanges (exchanges in transitional areas where groundwater and surface water meet) and temperature amelioration compared to the previous river evolutionary stage (Cluer & Thorne, 2014). General improvement in water quality related to sedimentation of particulate matter, and biological water quality (based on macroinvertebrate counts) is greater in non-channelised watercourses; heavy-metals concentration is the only aspect that does not differ between channelised and non-channelised rivers (Lundy & Wade, 2011). In the degrading phase of a stream evolution, nutrient cycling is further reduced and becomes ineffective in arrested degradation phases. Nutrient cycling then becomes dysfunctional in degraded and widening rivers with further reductions in renewed incision phases. The capacity to deliver the service improves in aggrading and widening rivers. The clarity of the water further improves in quasi-equilibrium stages while nutrient cycling remains weak; laterally active rivers instead, have moderate water clarity and increased nutrient cycling (Cluer & Thorne, 2014).

Water quality, sedimentation and water temperature regulation are linked. Hydromodification (alteration of the natural flow of water through a landscape) has been associated with general water quality degradation as it increases water temperature and sedimentation (Mohamoud et al., 2009). Agriculture and urban land use also affect water quality through increased sediments which decrease dissolved oxygen content (Stone & Shanahan, 2011). Everard (2010b, 2010a) describes the effects of restoration work on the River Avon in Wiltshire, and on the River Glaven in North Norfolk; ecosystem service delivery was assessed and both catchments saw a positive effect of restoration on water quality through increased sediment capture.

4.3.4 Habitat population and maintenance

Restoration and rehabilitation projects benefit river habitats (Griffin et al., 2015); this is achieved in several ways, but often it happens by increasing habitat diversity and revegetation (Everard, 2010a, 2010b). Restoration projects, however, sometimes come with infrastructure for recreation which may not be beneficial to riparian ecosystems (Schindler et al., 2014), allowing visitors to impact habitats and disturb wildlife. It has been suggested that in restored river sites that see increased visitor numbers, a reduction in hours or days the site is accessible would not affect recreation but would help flora and fauna; areas with dense vegetation would also discourage visitors from accessing that part of the site, creating wildlife refugia (Kaiser et al., 2021).

Riparian vegetation is important in supporting riparian habitats; factsheets from Natural England evidence how excluding livestock and reducing canalisation are strongly associated with greater riparian ecosystem health (Natural England, 2015). Riparian woodland in particular plays a crucial role in river ecosystem health. Riparian trees positively affect habitat and population maintenance as these provide structural complexity and may connect areas of woodland, creating wildlife corridors (Woodland Trust, 2016). Fish sampling in Brazil revealed functional and taxonomic composition of species to be greater in restored rivers: specialised and intolerant fish species have been found to occupy forested areas (preserved areas) and to be less abundant in areas with intermediate condition; degraded areas were instead mostly occupied by detritivores, tolerant and small-sized species (Casatti et al., 2012). Riparian woodland is also a source of woody debris which create niche habitats with differing temperatures and water flow, providing shelter for fish and invertebrates as well as larger species like otters (Mott, 2006). In a restoration project, the addition of dead wood to a stream channel increased fish biomass (Acuña et al., 2013). For similar reasons, beaver translocation in Scotland has been suggested to have positive effects as this species act as catalyst for woodland creation (Nature Scot, 2017).

Interventions that stop peatland drainage have been shown to benefit riparian and in-stream organisms as well. A study in northern England explains that undrained sites have higher benthic macroinvertebrate taxon richness compared to drained sites; abundance of pioneer species such as Ephemeroptera is similar in drain-blocked and intact sites, while the abundance of Plecptera and Tricoptera is still different between intact and drain blocked-sites, suggesting a lasting impact of drainage has not yet allowed the drain-blocked sites to recover (Ramchunder et al., 2012).

Biodiversity and the functional groups supported by rivers change with river evolutionary stages. By changing the extent of open water area, changes in species assemblages are induced and primary productivity is affected (Larsen et al., 2021). Biodiversity and the proportion of native biota are thought to be greater in anastomosing river sections (Thorp et al., 2010), as these support high primary productivity (Cluer & Thorne, 2014); sinuous single thread channels have reduced morphological complexity and bank length (compared to anastomosing rivers) and see a reduction in biodiversity and productivity, while the floodplain vegetation communities change from wetland to more terrestrial ones. In the following evolutionary stage, species are unable to adapt to the disturbance caused by the channelisation, so trophic diversity and species richness decrease dramatically together with productivity; floodplain vegetation that is disconnected from the channel will further shift towards terrestrial. In the degradation phase, benthos is destroyed, species richness and productivity decrease further, and a lower water table negatively affects floodplain vegetation. In the arrested degradation phase some riparian plant communities are able to start early succession and while productivity and species richness remain low, some species will colonise the channel; a similar scenario continues in the degrading and widening phase. Plant communities are dysfunctional in the renewed incision phase as the cycle of incision prevents recovery of habitats, the proportion of native biota is still low, and productivity collapses. Productivity recovers in aggrading and widening rivers, which also sees a return of aquatic, emergent and riparian plants; further increase in productivity is seen in quasi-equilibrium stages which also see a small improvement in biodiversity and establishment of aquatic, emergent and riparian plant communities. Finally, laterally active rivers see an improvement in biodiversity, moderate productivity and increased extent of riparian and floodplain plant communities (Cluer & Thorne, 2014).

Urbanization imposes enormous changes on the form and function of the riverine landscape (Gurnell et al., 2007). Increased proportions of impervious surfaces in the surrounding land, stormwater drainage systems, pollution, and channel modifications alter catchment hydrology, flows, sediment regimes, water quality, and lateral connectivity (Gurnell et al., 2007; Paul & Meyer, 2008; Walsh et al., 2005). These in turn impact on the ecology and biodiversity of urban river systems, which commonly display reduced biotic richness, and increased dominance of the species tolerant of such conditions. This set of environmental stressors and the resulting biological impoverishment has been referred to as the "urban stream syndrome" (Walsh et al., 2005), and these effects extend into the riparian zone through impacts on hydrology, soils and vegetation (Groffman et al., 2003). Hydromodification accompanying urbanisation, causes water quality degradation (higher water temperature, lower dissolved oxygen, increased sedimentation) that in turn affects aquatic habitat structure causing loss of aquatic populations (Mohamoud et al., 2009). A comparison of Polish river sections shows plant communities are richer in seminatural sections compared to anthropogenic ones (Hanczaruk & Kompała-Bąba, 2019). Intense management of streamside vegetation such as removal of trees and bushes to allow construction projects along the river, alters the community structure, for example in Rekolanoja, Finland, the proportion of bird species inhabiting lush vegetation and deciduous forests had declined, and the proportion of species common in urban habitats had increased (Yli-Pelkonen et al., 2006). In some cases, urban rivers are channelised and the high flow velocity does not allow the establishment of permanent vegetation which in turn does not contribute to primary productivity (Lundy & Wade, 2011).

Diffuse pollution from agriculture also badly affects rivers flora and fauna but, in some instances, interventions related to urbanisation can improve river habitats. The effects of anthropogenic land use change from agriculture to suburban on a headwater stream in Poland over 44 years were examined and found an increased habitat and population diversity as sewage systems were improved as a result of urbanisation and reduced agricultural pressure (Bylak et al., 2022).

Agriculture and urbanisation place some of the greatest pressures on river ecosystems. Note that these pressures, although not a direct measure of river condition, can be used as indicators of condition, hence the evidence linking these pressures to habitat population and maintenance is reviewed further below. The use of such indicators is also explored further in Section 5. These pressures operate at a catchment scale; as discussed earlier, rivers are profoundly affected by their catchments and although the review is focusing on river condition and ecosystem services, it is not possible to consider the condition of a river in isolation from its catchment.

Nitrogen and phosphorus enrichment is the main issue arising from agriculture in the river catchment as these are the main drivers of primary productivity in aquatic habitats. Nitrogen-fixing cyanobacteria seem to meet some seasonal limitations and the focus of control measures has so far been on phosphorus from point and diffuse pollution which induces excessive algal growth leading to shading and thus reducing the growth of other plants (Heathwaite, 2010). It is not clear whether urban or arable land use is impacting more on river ecological status; in West Virginia analysis of bacterial community richness in rivers across differing land uses reports a higher resilience to agriculture than urban land use (Martin et al., 2021), but these effects can be highly context dependent.

Excess sediment also has a negative impact on riparian communities. Negative impacts of sediment from agriculture and urban land use effect a variety of ecological groups including fish, aquatic plants and macroinvertebrates; large amounts of fine sediments can damage fish gills, reduce food availability and reduce dissolved oxygen content (Stone & Shanahan, 2011). A four-factor experiment across 64 stream mesocosms in China was carried out to assess the effects of sedimentation, flow velocity and nutrient enrichment on invertebrate communities. Results indicated that invertebrate abundance decreases with increased sediment and that while flow velocity and nutrient enrichment affect community composition, the main factor shaping communities was sediment (Juvigny-Khenafou et al., 2021).

Human interventions in rivers that are related to extraction, infrastructure and intensive land use have negative effects (with the exception of fishery-intensive interventions and dyke relocations; Schindler et al., 2014). One of the main effects of water abstraction on rivers, for example, is the reduction of water flow, which can lead to the drying up of the riverbed. This can have devastating effects on the river's ecosystem, affecting the fish population, plant life, and other aquatic species that depend on the river's water flow to survive. Furthermore, the artificial structures required for water abstraction act as a barrier for species, altering connectivity (Lundqvist & Falkenmark, 2000).

Greater diversity indicates greater ecosystem productivity, and this is affected by toxic pressure. A study estimated the economic impacts of polluted sediments based on the average ecosystem service value provided by estuarine or freshwater ecosystems. The differences in total ecosystem service value among biomes could be generally explained by the differences in productivity, with higher productivity resulting in higher ecosystem services values (Wang et al., 2021).

Sand mining negatively affects the ecological communities of rivers (Ekka et al., 2020). Mining contaminates water and negatively affects fish assemblages (notable are histopathological lesions on trout), fisheries production and reduces the diversity of the benthic community as a whole (Jordan & Benson, 2015).

Pollutants such as heavy metals from industry and other sources are damaging to aquatic life (e.g., chromium, copper, silver and zinc), and the problem is exacerbated by acidification (Lundqvist & Falkenmark, 2000). In upland freshwaters, acidification is the most significant factor affecting ecological health, reducing species richness and causing the loss of acid-sensitive organisms across all trophic levels as it affects some species directly (via a change in the water chemistry) or indirectly (changing food availability or habitat; Allott, 2009).

Invasive species represent a different kind of threat to the river habitat. Field surveys of Scottish rivers found, for instance, invasive plant species to have a high negative effect on macroinvertebrates (Seeney, 2019).

Cultural services

4.3.5 Characteristics and features of biodiversity that are valued

There are a number of ‘willingness to pay’ studies demonstrating how the public values features of the environment, but reviewing those is beyond the scope of this review. Streams are areas where people get in contact with nature and are valued highly (Yli-Pelkonen et al., 2006). A questionnaire administered in England and Wales found people are willing to pay to improve freshwater condition; local improvements were valued much more than national improvements and the improvement from medium to high condition was valued more than poor to medium condition (Metcalfe et al., 2012).

4.3.6 Health and wellbeing

Our physical and mental health are inextricably linked to our environment, and greater exposure to bluespaces promotes physical activity, well-being and improves general health and wellbeing (Gascon et al., 2017). Rivers, more than other greenspaces, have been shown to improve mental well-being (Bergou et al., 2022). Interviews with residents in southern Finland revealed that streams are desirable environments offering silence (in otherwise noisy and stressful urban environments), relaxation, and the water moving in the stream is considered pleasing (Yli-Pelkonen et al., 2006). In the US, salivary cortisol measures combined with GPS data and surveys of hikers revealed that visitors to riparian areas that were more biodiverse and with higher aesthetic value, had decreased cortisol and improved well-being compared to visitors to other habitats. Wildlife presence was not related to lower cortisol, but hikers attributed higher aesthetic quality to areas with high biodiversity. The authors suggest that since biodiversity is a proxy for ecological function, hikers gain more well-being benefits when the habitat has a 'natural feel' (Opdahl et al., 2021). Interestingly, biodiversity surveys and questionnaires administered to the public in the UK show that in ecologically complex habitats such as riparian areas, the public is ill-equipped at judging species-richness (with the exception of birds), thus while a positive relationship between well-being and perceived biodiversity was revealed, the study did not find a relationship between well-being and species-richness (Dallimer et al., 2012). Thus, these studies show that people gain greater health and wellbeing benefits from places that they perceive to be nicer, which could be related to aesthetics, or perceptions of naturalness or biodiversity, but it is not necessarily related to measured biodiversity.

The changing flow of water can impact the accessibility of rivers and their banks, preventing people from using the space for exercising or enjoying the mental health effects of the river; In India, the increased flow of water in the monsoon season has been shown to affect health and well-being as access to the River Beas is limited during that period (Ncube et al., 2021). Evidence also shows flood risk to be linked to psychological effects such as anxiety when it rains, flashbacks to past flood events, anxiety about future flood events and long-term physical effects like heart conditions (Miller et al., 2012). To reduce these impacts, strengthening of flood defences, flood resistance and resilience, and the communication of these interventions to the public are key (Miller et al., 2012).

When river waters are polluted, these can lead to various health problems. In this case, the condition of the river has a direct bearing on health, although this would be regarded as a disbenefit, rather than a benefit. More than 100,000 chemicals including persistent pollutants are present everywhere in the environment and found in human and animal tissue samples (Lundqvist & Falkenmark, 2000). Heavy metals extracted and produced for industrial, agricultural and other purposes have severe adverse health effects which are exacerbated by acidification that makes them more bioaccessible (Lundqvist & Falkenmark, 2000). Mining-related contaminants such as cadmium, arsenic and radon in river waters have been associated with higher rates of cancer (Jordan & Benson, 2015). Diffuse pollution from agriculture and livestock increases nitrogen and phosphorus concentrations which affect the quality of drinking water (Heathwaite, 2010); nitrates have also been reported to be especially dangerous for infants (Lundqvist & Falkenmark, 2000). The health effects of pollution are also worsened by intense water abstraction, making pollutants more concentrated (Lundqvist & Falkenmark, 2000). Polluted water can also affect the quality of food, as fish and other aquatic species absorb harmful pollutants that can accumulate in their tissues.

Waterborne diseases and pests are also a big threat to public health. In the UK, surfers and wild swimmers reported sewage pollution and dry spills to have caused vomiting, sickness and Leptospirosis after swimming (Slack et al., 2022), in rivers as well as in coastal areas. The presence of riparian woodland has the potential to regulate water temperature, in turn reducing the proliferation of some organisms causing diseases such as *E. coli* (Mokondoko et al., 2016). Excluding livestock from riparian areas has also been shown to reduce the abundance of *E. coli* in waters (Natural England, 2015).

6.3.7 Aesthetic experiences

Rivers have high aesthetic value compared to other types of habitats and despite being impacted by human activities, urban streams provide high aesthetic value (Yli-Pelkonen et al., 2006).

The literature analysed shows that features of rivers that are manmade and give a non-natural feel decrease the aesthetic experience. Expert assessments report interventions related to extraction, infrastructure and intensive land use (e.g., water and mineral resource extraction, traffic and navigational infrastructure, energy conversion) reduce landscape aesthetics, with the exception of fishery extensive management and dyke relocations (Schindler et al., 2014). An observational study in southeast China using a monetary valuation method where the cost of travel to a tourist spot near a hydropower facility is used as a proxy for the aesthetic value of the site, (G. Wang et al., 2010) shows landscape aesthetics to be negatively affected by hydropower. The presence of manmade infrastructure that allow access to a site is instead perceived positively when naturalness of the site is low (Junker & Buchecker, 2008).

The majority of restoration and rehabilitation projects are beneficial to river aesthetics, with the following exceptions: the removal of topsoil, recreational infrastructure, removal of dams and weirs and lowering of the floodplain (Schindler et al., 2014). Analysis of social media content reveals that restored river sites are more appreciated by the public, especially where more open landscapes are present (Kaiser et al., 2021). Channelised urban rivers are viewed as less aesthetically pleasing (Lundy & Wade, 2011), while meanders are more attractive. The addition of meanders and increased opportunity for wildlife sightings (especially birds) in the River Skerne in England, increased its 'natural feel' making it more attractive to the public after rehabilitation (Åberg & Tapsell, 2013). Similarly, semi-structured interviews with locals revealed scenic beauty to be increased after the restoration scheme in the River Dearne (England) due to the environment being cleaner, increased morphological diversity and enhanced habitat quality for flora and fauna (Westling et al., 2014). The scale of the restoration efforts also seems to play a role in the aesthetic experience, with larger-scale projects being more positively viewed compared to smaller restoration projects (Poledniková & Galia, 2021).

There is consensus that more ecologically valuable rivers are considered more aesthetically pleasing, however, public perceptions are strongly context-dependent and are informed by the cultural background of the individual, and visual preferences often do not reflect changes in ecological condition (Arsénio et al., 2020). A photo questionnaire of braided rivers with variable amounts of water and gravel revealed a gap in perceptions between scientists and civil servants, and the wider public. Scientists and civil servants were aware of the value of the functional processes occurring in braided rivers while the wider public did not seem to appreciate it, seeing large amounts of gravel in riverscapes as not aesthetically pleasing, almost considering it an 'alien' element in need of management actions (Le Lay et al., 2013). Studies suggest this perception gap can be closed when the public has the opportunity to learn, for example, wood reintroduction in rivers for restoration is considered dangerous and not aesthetically pleasing in those countries where this restoration approach has not been used, while in countries where the public has already experienced the approach, perceptions are more positive (Piégay et al., 2005). People are able to detect small improvement in eco-morphological quality when these happen in rivers changing from channelised with narrow banks, to more meandered with larger banks (Junker & Buchecker, 2008), but other types of improvements may not be as obvious to the general public.

Water levels also affects people's aesthetic perceptions. Ncube et al., (2021) found that river provision of aesthetic experience is highest at higher water levels (during and post-monsoon) in India, and decreased over time with increased water abstraction and pollution. It is possible that people in the UK also find lower water tables to be less attractive, but there is little evidence to confirm this, and winterbournes in their dry phases still provide some aesthetic experience (Datry et al., 2018b). Sediment have also been reported to impact on river aesthetics with more fine sediment and high suspended loads in the river attracting fewer visitors (Stone & Shanahan, 2011) showing people prefer clear waters.

4.3.8 Education, training and investigation

Rivers are an important part of the local environment for teachers and pupils to learn about nature (Yli-Pelkonen et al., 2006), for anglers to learn about aquatic life (Snyder, 2007) and for the wider public.

Given the chance to choose outdoor settings to educate pupils, teachers prefer rivers more than other types of urban nature, although rivers are also seen as more hazardous (Simmons, 1998), therefore measures improving safe access to the river would be beneficial for this ecosystem service. An expert-based assessment found positive effects of the following interventions on education and training: sediment addition onto the river bed, removal of bank fixations, lateral floodplain reconnection, channel oxbow and pond creation, creating natural habitat from forest, agro-land or extraction sites, control of invasive species, creation of gravel banks, land use extensification, recreational infrastructure, dyke relocation and extensive fisheries (Schindler et al., 2014), confirming local schools derive great benefits from local stream restoration work (Everard & Moggridge, 2012). Management options considered to have negative effects were also identified in: bank or bed stabilisation, channel corrections, intensive fishery, agriculture and forestry practices, navigational infrastructure, settlement and traffic infrastructure (Schindler et al., 2014).

As regards to the influence of water flow level, Ncube et al., (2021) found that the provision of formal and informal learning opportunities in India doesn’t change with water levels over the year, and has instead decreased over time with increased water abstraction and pollution.

4.3.9 Recreation and tourism

Rivers are important areas for recreation and physical activity (Yli-Pelkonen et al., 2006). Rivers where perceived naturalness is high are used more frequently for recreational purposes. A study mapping recreation along rivers shows the delivery of the service is positively related to naturalness, water clarity and water flow (Kerr & Swaffield, 2012).

Through increased landscape attractiveness, restored river sites see more recreational activity (Everard & Moggridge, 2012; Kaiser et al., 2021; Schindler et al., 2014). Poledniková & Galia (2021), for example, found an increase in recreational function from photo-simulated river restoration scenarios. Conversely, when landscape attractiveness is decreased through the addition of artificial structures, fewer visitors are expected (Schindler et al., 2014). In southeast China, travel-cost methods reveal the value of recreational activity to be lower in sites close to hydropower facilities (G. Wang et al., 2010) and channelised rivers have been shown to have low potential for recreation compared to natural rivers (Lundy & Wade, 2011; Natural England, 2015). However, artificial structures that improve access to the river enhance the delivery of recreation and tourism.

Surveys of public perception of before and after rehabilitation of the River Skerne in England show visitation rate increased after river rehabilitation, mostly due to the opportunity for wildlife watching. The addition of footpaths, bridges and the availability of a circular path increased walking, cycling and jogging and despite being artificial, these features were considered crucial for the enjoyment of the river (Åberg & Tapsell, 2013).

Another aspect of access to a site is closeness to large settlements; rivers that are closer to big cities receive more visitors (Doi et al., 2013). A national scale study across England and Wales revealed that the effect of closeness to populations has a bigger effect on recreational use than site-specific, more local factors (such as Environmental Quality Index, taxon richness, freshwater biodiversity); these factors indicate that regional patterns in visitation are driven by population and distance, whereas high river quality is more important at the smaller, local scale (Holland et al., 2011).

Relationships between river condition and recreational use also differ depending on the type of activity. In Japan, lower biodiversity and ecosystem health (across 109 sites) were related to low recreational use, but fish diversity, habitat structure and water quality were the factors affecting fishing and playing in rivers, while the number of people walking and engaging in sports was related to water quality and the size of the surrounding population (Doi et al., 2013).

In the UK, water quality data from WFD were combined with surveys of walking, boating, fishing and swimming activities. Analysis shows walking to be strongly associated with good and high water status (despite being the activity having the least contact with water), while the other activities were not predicted by WFD. However, some of the indicators used in assessing WFD status may not be relevant to recreation; while the presence of litter may discourage swimmers, this has little impact on the WFD status, and what is considered a good water temperature (for WFD standards) may not be ideal for swimming. Similarly, poor water clarity (not appreciated by swimmers, as they prefer clear water; see Miller et al., 2012) isn't always an indicator of poor (or good) ecological health. The authors argue that the wider public is ill-equipped to distinguish between WFD status and that it is easier to distinguish between poor and medium WFD status than between good and high status, making the relationship between WFD status and recreation non-linear. For sports such as swimming, boating and angling, the presence of infrastructure allowing the sport to take place appears to be the most important factor rather than water condition, while walkers can be more responsive to WFD status given the lack of such constraints. (Ziv et al., 2016).

Angling is closely associated with the presence and abundance of the species or functional group of interest rather than habitat structure (Smith et al., 2017), but tends to be higher when river waters are clearer (Miller et al., 2012). Fish populations are affected by water quality (Lundqvist & Falkenmark, 2000) and available habitat for reproduction. A comparison between a near nature state floodplain with a simulation where the riverbed was straightened, floodplain terrain flattened and land use changed into arable, resulted in the scenario having a 50% reduction in fish catch due to lack of suitable habitat for fish reproduction (Pithart et al., 2010). The addition of dead wood to restore the complexity of a stream channel, forming dams and deflectors has instead been shown to increase opportunities for angling (Acuña et al., 2013). Fish catches have also been shown to be negatively affected by fine sediment deposition and high suspended loads from human sources (agriculture and urban land use; Stone & Shanahan, 2011).

Some river restoration projects target the recovery of fish populations and are assumed to also affect biodiversity and improve other types of recreational activities, but this is not always the case; the type of restoration intervention carried out is crucial in determining the outcome for the delivery of ecosystem services. In Finland, habitat condition for salmonids was improved mostly by increasing channel width, and while this increased fishing opportunities, only slight improvements in naturalness and access were achieved, yielding small changes in other recreational activities (Marttila et al., 2016).

Everard (2010b, 2010a) described the positive effects of river restoration work on recreation and tourism. On the Bristol Avon and River Glaven, fish stocks were enhanced by improving spawning and nursery habitats, which led to an increase in angling, but further tourism benefits were seen from enhanced wildlife, promoting birdwatching, photography and informal recreation as well as increased wildfowl stocks potentially available for shooting. The rehabilitation of the River Pajakkajoki (Finland) was aimed at enhancing attractiveness of natural areas along the river by improving accessibility (adding parking spots, nature trails with benches and provisions for disabled people) and fish spawning condition, through the restoration of rapids, natural spawning and fry sites, as well as basins for adult fish. A survey of residents and non-residents stated that the improvement was high for both fishing and other recreation, and visitors were willing to pay for the fish habitat, although the amount was very low (< 10 euro per year; Polizzi et al., 2015).

Little evidence is available on the relationship between hydrogeomorphological condition and recreation, but recreation is assumed to be high in anastomosing, medium to low in constricted and meandering and low in leveed and braided rivers (Thorp et al., 2010). As the amount of water changes at different evolutionary stages of the river, or a riverbed becomes dry, recreational activities will be affected. In the UK, a number of paths adjacent to rivers become flooded at high water levels, thereby impacting access and recreation. Evidence of this has also been found in India; recreation and tourism have been reported to be at the highest capacity at lower water levels (when riverbanks are accessible, before the monsoon season) and the provision has decreased over time due to water abstraction and pollution (Ncube et al., 2021). Dry phases can, however, offer unique opportunities for other types of recreation such as visiting parts of subterranean rivers (Stubbington et al., 2020).

4.3.10 Spiritual and cultural experiences

Cultural ecosystem services are often intangible and difficult to quantify but are vital for creating a sense of community, identity and belonging, as they contribute to social cohesion, sense of place and resilience. Spirituality is an essential aspect of human life, and it is deeply connected to nature. Many cultures around the world have traditional beliefs and practices that link them to rivers, which they consider sacred. In India, for example, the River Beas is of crucial importance in the local culture and spiritual ceremonies, but the changing levels of water due to the monsoon season and upstream abstraction don't seem to affect the provision of this service, which is high at any water level (Ncube et al., 2021). Similarly, a review of ecosystem services provided by dry and temporary riverbeds outlined the importance of dry riverbeds in spiritual and cultural heritage, particularly in stories from indigenous people, showing this ecosystem service is not significantly impacted by changing water levels (Steward et al., 2012).

In Western countries, rivers are more associated with local culture, shaping the local identity (Yli-Pelkonen et al., 2006) and referenced in popular culture and in the literature. Festivals connected to rivers occur all over the UK, highlighting the importance of rivers to cultural experience, but there is a lack of evidence on the impact of river conditions on these cultural experiences, although it is likely that a minimum, perhaps moderate, condition would be required. Fly-fishing seems to be one of the few exceptions, as this sport, widely practiced in Western countries, has spiritual and quasi-religious connotations, a 'lived religion' according to Snyder (2007), that has produced a lot of literature. The understanding of the natural world required by this activity drives fly-fishers closer to nature, to which they start feeling more connected (Snyder, 2007). Even in this case, it can only be assumed that the river condition should be acceptable for a fish population to be present for the activity to take place, although game fish generally require rivers to be in better condition than coarse fish.

Expert-based assessment revealed that interventions related to extraction, infrastructure and intensive land use have negative effects on spiritual and cultural experience, except for fishery extensive interventions and dyke relocations. On the other hand, restoration and rehabilitation programmes increase the delivery of this ecosystem service, as well as projects that improve recreational infrastructure (Schindler et al., 2014).

4.4 Gaps

The relationship between river condition and the delivery of ecosystem services needs to be studied further, but the degree of uncertainty about this relationship varies greatly, depending on the ecosystem service analysed.

For the majority of the ecosystem services analysed here, a lot of the mechanisms explaining how certain conditions affect ecosystem services are clear, though, for some river types such as winterbournes and intermittent rivers, evidence is poor. The understanding of the factors driving the "characteristics and features of biodiversity that are valued" is also extremely poor and very little is available for "spiritual and cultural value" and for "education and training". This is to be expected for these less tangible ecosystem services that are much harder to measure than other ecosystem services and for which additional research using more interdisciplinary approaches, including branches of social sciences, would be required.

Even for those relationships for which underlying mechanisms are well understood, the effect size is not. This is largely due to differences in measuring outcomes, which could be overcome by introducing standardized methods of measuring the delivery of ecosystem services. Time delays between changing conditions and outcomes should also be factored in. Furthermore, studies very often focus on a relatively small spectrum of river types (e.g., different types of conditions measured only in urban rivers) or spectrum of conditions. This could be addressed by larger, more representative, landscape-scale studies. Another aspect worth noting is that the majority of the studies analysed here report either linear relationships or no relationships (which may indicate the plateau part of the relationship), most likely as the research only analysed part of the range of the existing conditions. It is known that relationships in nature are complex, mostly non-linear or plateau at some point. Better modelling of these response curves might help to identify threshold values that are useful for practical management.

Going forward a set of indicators for each ecosystem service should be agreed upon, standardized and measured in landscape-scale studies encompassing a variety of river types and conditions.

4.4.1 Stakeholder response

On the 4th of May 2023 a third workshop was held to present the QSR findings and gain feedback on priorities and next steps. Attendees were presented with the preliminary finding of the QSR and asked which of the identified gaps they considered to be the most important to fill. Answers were summarised by theme (Figure 12), with full results shown in Appendix B (Workshop 3). Gaps in indicators were commented on by six people, while other areas only received one or two comments. Key areas of discussion included:

- Need to understand how well existing metrics and indicators (including the 25 Year Environment Plan indicators) describe condition of ecosystem services, so that gaps can be identified and filled.
- Understanding the key elements of condition.
- Need for quantification of, and indicators for, connectivity.
- Identification of thresholds.
- Need to understand temporal patterns and if rivers are still responding to historical interventions. Also if the baseline is shifting.
- Importance of resilience as a component of condition and understanding key factors that confer resilience.
- Importance of climate change and assessment of ecosystem services in relation to this, particularly water temperature, carbon storage and sequestration, and local climate regulation.
- Further work required on who will use the information and how that shapes required outcomes.

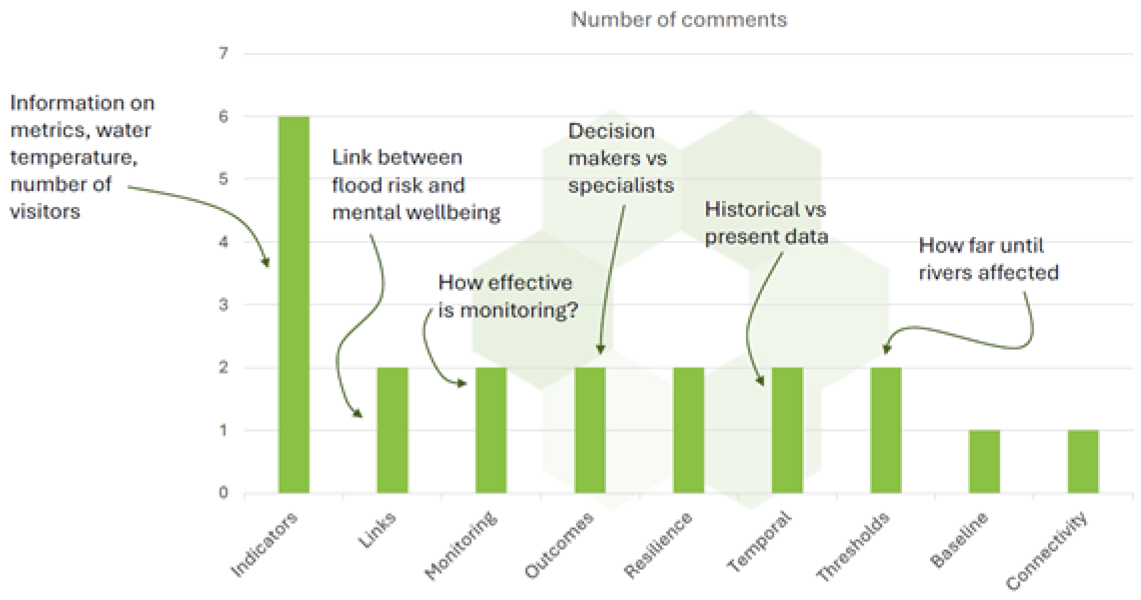


Figure 12: Number of responses grouped by themes to the question 'What are the gaps' during May 4th, 2023, workshop.

5. Reviewing datasets and methods to assess river asset condition

In this section we describe the methods and results of reviewing datasets and methods to assess river asset condition, including identifying gaps and options to take forward.

5.1 Methods

5.1.1 Approach to developing indicators

A process-based approach towards condition assessment following Potschin & Haines-Young ecosystem cascade model was adopted (Figure 13). In this model, ecosystem services are delivered by processes and functions underpinning natural assets. Asset condition is therefore assessed by establishing the ability of functions and processes to deliver services at a level required by society. Using this framework, condition assessment is not an absolute metric of asset quality, as traditionally perceived and advocated in major legislation such as the WFD but is relative to the service levels assets are expected to deliver. The choice of indicators and the definition of acceptable levels is therefore likely to differ from existing quality indicators and scales.

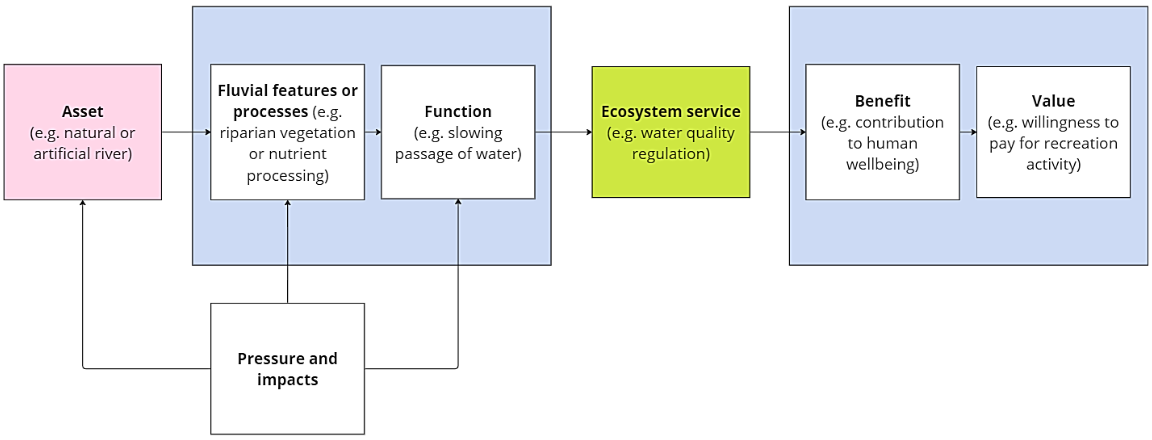


Figure 13: Adaptation of the ecosystem service cascade model (Potschin & Haines-Young, 2011).

Figure 14 shows how this framework was applied to identify indicators of asset condition The first step involved identifying the processes, features and functions that support the delivery of each ecosystem service. A list of natural capital condition indicators was then identified alongside the datasets, methods and metrics that could be used to represent or characterise them.

In the case of cultural services, the notion of natural processes and functions is less relevant, as ecosystem service provision mainly relies on factors defined by society and individuals, such as values, perceptions, access or usage. When assessing cultural services, we therefore included societal and individual categories of indicators as well as natural ones.

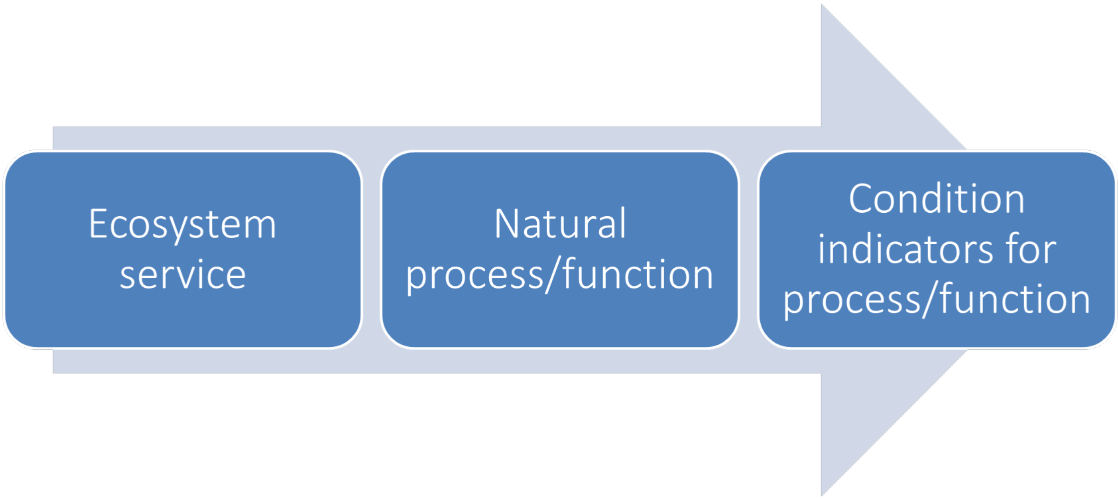


Figure 14: Process based development of indicators.

We identified a hierarchy of evidence and methods for assessing asset condition (Figure 15). Condition can be:

- **measured,** using monitoring and historical data.
- **predicted**, for example, using hydrological, hydraulic or groundwater models.
- **Inferred**, through the identification of potential signs of pressures and/or impacts e.g., floodplain disconnection due to the presence of embankments.

Direct measurement data is considered the most reliable approach. Where such data are unavailable, deterministic or statistical models can be used to predict condition and offer a suitable alternative. Where measurement data are not available and modelling is not feasible, evidence of potential pressures and impacts on indicators can be used to assess condition.

It is unlikely that all indicators will be adequately monitored across the entire river network both in space and time. Models, such as 2D flood models, tend to be expensive to develop and run, and are often limited to specific parts of catchments (e.g., areas sensitive to flooding). The quality of data and model outputs will also greatly vary depending on sampling, modelling techniques and assumptions made. Wherever possible and feasible, a combination of methods should be used to produce assessments of condition, so as to maximise geographical coverage and accuracy.

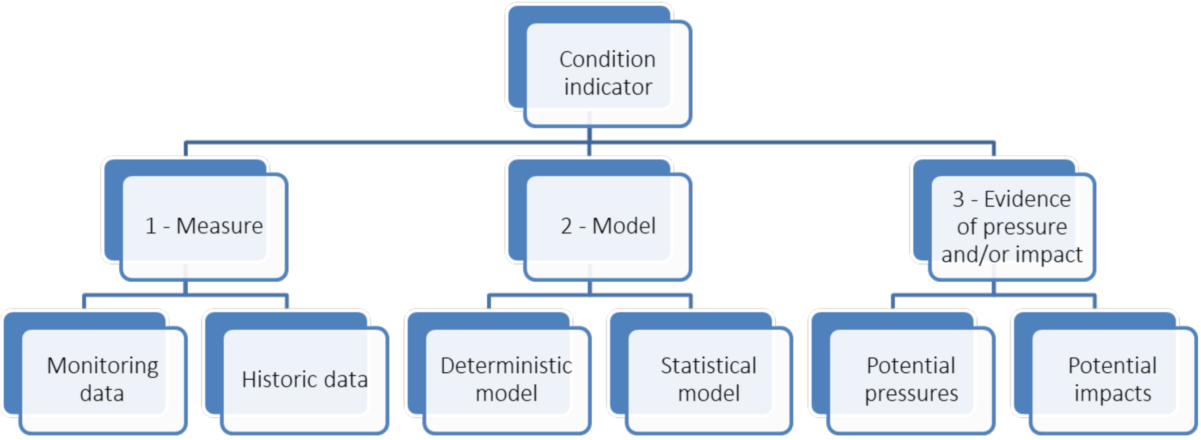


Figure 15: Hierarchy of evidence used to assess condition.

To identify condition indicators, a series of workshops were run (see Section 3.1 and Figure 4 for key results). The outputs from the discussion included indicators of asset condition such as 'naturalness', 'resilience', 'interconnectedness', 'access and recreation use', 'biodiversity', 'water quality'; as well as methods for deriving condition: 'perception', measurements', 'impact of human use', and 'service provision'. During the workshops, participants indicated that condition may need to be assessed at different scales. For example, the level of provision of the 'habitat population and maintenance' ecosystem service can be assessed using indicators of population viability and habitat suitability at reach, river, catchment or river basin scales. Different tools and metrics may be used to reflect the scale of measurements. For reach or river scales, a Population Viability Analysis (PVA) may be conducted, whereas for catchment or river basin scales, a Meta-Population Viability Analysis (MPVA) will be preferred. In the same way, habitat suitability at catchment or river basin scales may be assessed using habitat quality metrics including elements of habitat isolation and fragmentation, to reflect the wider spatial coverage and potential connectivity issues.

For each ecosystem service, a series of flow charts describing supporting processes, condition assessment methods and indicators were produced and are discussed in the next section. Data sources and methods used as condition indicators are recorded in the separate spreadsheet 'NC condition mapping - indicators datasets & models.xslx'. This includes a review of relevant existing mapping initiatives, datasets and tools. We have included data sets where relevant, even when these do not provide a complete assessment of condition.

The asset condition indicators were assessed for usability and relevance. The concept of usability was defined by Nielsen (1993) based on an international standard for product development. Usability is 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' (ISO 9241; 11: 1994). Keil et al. (1995) suggested assessing usability according to two criteria, usefulness and ease of use.

Perceived usefulness is defined as:

> *'the degree to which a person believes that using a particular system would enhance his or her job performance'.*

Perceived ease of use is:

> *'the degree to which a person believes that using a particular system would be free from effort'.*

This can be summarised in a graph split into four quadrats representing varying levels of usability (Figure 16; Westmacott, 2001). This framework was used during the workshops to identify with potential users and experts the level of usability of models and tools.

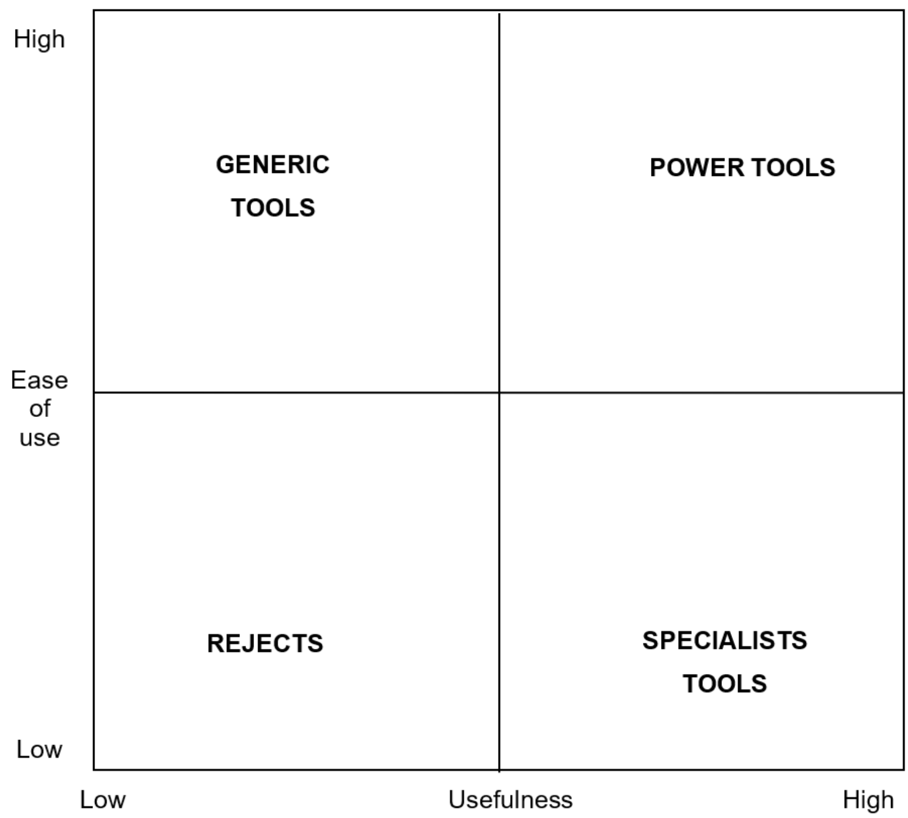


Figure 16: Usability framework (Westmacott 2001).

Dataset indicator usability was defined by: accessibility of data, spatial coverage, frequency of updates, potential future updates, and ease of use. Usability was simply rated as 'Low', 'Moderate and 'High'. Relevance was defined by how much of the process it could assess. A highly relevant dataset therefore would be able to explain the process well enough to assess condition. From this review, gaps were identified. To fill data gaps and improve the flow charts short, medium and/or long-term options were suggested for future development. Dataset and method indicators for artificial river condition were not assessed for usability. Further review of the use of these indicators is needed to address this gap.

5.2 Mapping assets

Natural and artificial river locations are well documented, and the EA possesses a licence for the Ordnance Survey Water Layer (Ordinance Survey, 2023). The layer is based on the former Detailed River Network developed by the EA using OS MasterMap, which was improved and is now maintained by Ordnance Survey (OS). The layer delineates rivers and artificial water bodies at a fine scale (1:1250 to 1:10,000). The layer is, however, subject to copyright and cannot be shared with the wider public.

Ordnance Survey produced a simplified version of the Water Layer containing 189,000 polylines covering 153,000 km of rivers in Great Britain including canals and estuaries. The scale of the map is coarser than the Water Layer (1:15,000 to 1:30,000). The layer was simplified by removing vertices along polylines, resulting in the polylines not closely following the river course. The layer suffers from a series of problems, especially gaps due to the presence of structures such as roads, bridges, dams and culverts.

A project was initiated by the River Restoration Centre in collaboration with GeoData Institute and funded by a consortium of organisations including Ordnance Survey, NatureScot, the Rivers Trust. The project aims to correct the existing OS Open rivers network so that it can be used widely as an open-source resource for data derivation and visualisation. The 'Open Rivers' network will feature natural rivers and will not include canals and other artificial water bodies. The resource will be available by the end of July 2023 and could form the basis for displaying natural capital data in England. The EA is also producing an 'Analysis Ready Water Network' that will be used for data derivation and analyses but that cannot be made publicly available because of IPR restrictions. Outputs will be transferred to the OS Open Rivers network for public use. There is an opportunity to combine both initiatives and transfer EA derived data on the corrected version of the network that is being produced by the RRC, GeoData and OS.

Maps of canals and artificial rivers are available as part of the OS Water Layer. The OS Open river layer contains some artificial rivers that were removed from the corrected version. Therefore, there is no consistent open-source artificial river network available. An open-source map of canals can be downloaded from the Canal and River Trust (CRT) web portal (Canal and River Trust, 2023). A way of sourcing non-canal artificial rivers needs to be devised to cover missing water bodies.

5.3 Ecosystem services

Based on the workshop outputs (Section 3.2), 10 ecosystem services, as defined in Table 1, were selected to identify the most appropriate and useful indicators for assessing how asset condition affects ecosystem service provision.

For each of these ecosystem services, the process detailed above was followed. The ecosystem services have been ordered by ecosystem service type (provisioning, regulating and cultural), definitions of which are outlined below.

Provisioning

This category of ecosystem service covers products that are directly obtained from ecosystems.

5.3.1 Water for drinking, agriculture and industry

"The natural storage, retention and supply of freshwater. Fresh water abstracted (or potential for abstraction) for human uses."

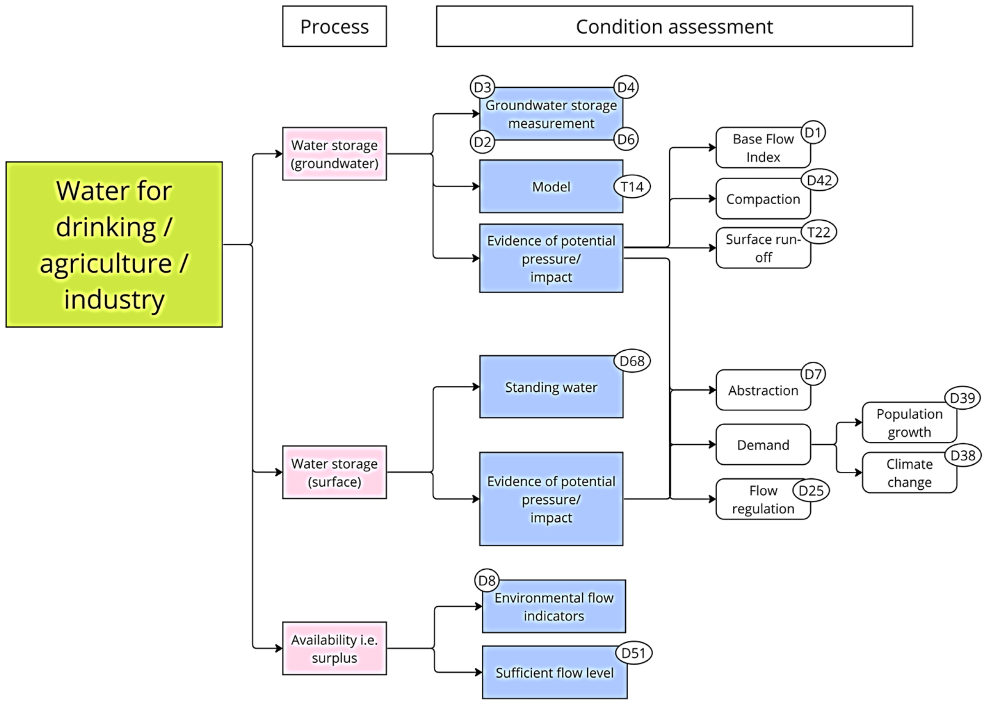
Natural rivers

Condition assessment flow chart

Figure 17 shows the condition assessment method for 'Water for drinking, agriculture and industry' in natural rivers. Water provision is an essential ecosystem service that relies on the processes that support the delivery of an adequate volume of water to meet ecological and human needs.

The provision of water is dependent on multiple fluvial features, habitats and hydrological processes. Key processes include: surface and groundwater storage, runoff and distribution. Water retention habitats such as lakes, wetlands, and groundwater aquifers, play a critical role in accumulating and storing water during periods of excess rainfall, ensuring a steady supply during drier periods. Additionally, the distribution of water is facilitated by the interconnected network of rivers and streams, allowing water to be transported and made accessible for various purposes, e.g., agriculture, industry, and household use.

An important aspect of water provision is the sustainability and capacity of extracting water without affecting ecosystem health and therefore the long-term supply of other ecosystem services. Previous studies have used the amount of water abstracted as an indicator for the provision of water (Maes et al., 2016). This implies that the more water is abstracted, the greater the asset condition. This is an example of the importance of considering processes that sustain water availability such as water storage.



Datasets

D1- Base Flow Index- NRFA
D2- Ground water level data- BGS
D3- WellMaster hydrogeological database- BGS
D4- River flow data- EA
D6- Hydrological summary- CEH
D7- Water abstraction tables-EA
D8- Flow compliance bands (WFD cycle 2 river water bodies)-EA
D25- AMBER Barrier Atlas
D38- Hydrological projections for UK (eFLaG)
D39- Population density- ONS
D42- Soil compaction risk map (European Comission JCR)
D51- Q95 flow percentile statistic- NRFA
D68- UK Lakes Portal

Tools/methods/models

T14- AquiMod 2
T22- CERF model

Figure 17: Natural – Water for drinking/agriculture/industry

Assessment of indicators

Groundwater level is monitored and can be measured directly to assess the supply of water available for potential abstraction. These data are accessible through the British Geological Survey (BGS) (e.g., groundwater water level data). These data have good temporal continuity which allows for comparison between years and can aid in the prediction of future trends. This dataset could be a good indicator but is currently lacks in spatial coverage. It forms part of the UKCEH Hydrological Summary (UKCEH, 2023) which also supplies valuable information on aquifer function by producing statistics based on quantitative analysis of these data. However, this is spatially constrained to site-specific data obtained from observation borehole points.

The AquiMod groundwater model, developed by the BGS, can be used for assessing groundwater levels. AquiMod is user-friendly, particularly for individuals with limited experience in hydrological modelling (British Geological Survey, 2022). However, the model's usefulness may be hindered by the required input of observed groundwater level data to run the model. Other limitations of the model are due to the lumped model structure which produces a modelled hydrograph across the catchment area, and so provides no detail of finer scale variation (Mackay et al., 2014).

In the absence of comprehensive monitoring or modelled data, the assessment of groundwater storage condition relies on the use of indicators evaluating potential pressures and impacts. The National River Flow Archive (NRFI) Base Flow Index (BFI) is a derived flow statistic that may give an indication of the condition of groundwater processes (Gustard et al., 1992). Estimation of infiltration and runoff processes may affect recharge of groundwater storage sources. The risk of compaction map offers a broad overview of how land and soil structure may affect infiltration. The continuous estimation of river flows (CERF) model is a regionalised rainfall-runoff model that predicts flow duration statistics (Griffiths et al., 2008). It may be more useful for modelling runoff, however, and requires more specialised knowledge to be used.

To ensure the sustainability of groundwater resources, other pressures like demand and climate change must be considered. The abstraction licensing dataset could be used to indicate the change in abstraction pressure overtime, reflecting demand, using annual abstraction statistics. However, this dataset is not the most usable as it is currently only updated to 2018 and the data are presented at a regional scale only. The effects of climate change are indicated by hydrological projections for the UK in the Enhanced Future Flows and Groundwater (eFLaG) dataset (Hannaford et al., 2022). The dataset has clear metadata and is based on UK climate projections (UKCP18), on groundwater levels and recharge based on 54 borehole sites.

The UK Lake Portal is a source of information, that can provide data on large surface water retention habitats. This ‘large surface water retention habitats’ data can be used as an indicator for condition because it provides information about surface water storage. The usability of the dataset is high, but it does not account for smaller forms of surface water storage, such as smaller ponds or wetlands. Evidence of pressures and impacts such as abstraction and pressures from increasing demand and climate change projections are similarly usable and relevant to surface water storage in assessing impacts to long-term provision of water. The hydrological projections for the UK dataset (eFLaG) provides groundwater climate projections and assesses the impact on river flow in 200 catchments across the UK.

The NRFI flow percentiles are derived flow statistics that can be used to analyse river flow data and water availability. The Q95 percentile is the flow (measured in cubic meters per second) which was equalled or exceeded for 95% of the flow record. It indicates significant low flows which is relevant to understanding the availability of water for abstraction (NRFI, 2015). However, the data must be extracted from the NRFI website manually, so may not be the most usable indicator.

Understanding the amount of water available without compromising environmental quality can be assessed using environmental flow indicators as flow compliance bands. Environmental flow indicators are used to indicate where abstraction pressures are negatively affecting river habitats and species and are important for maintaining healthy flows. They are mapped for the WFD cycle 2 river water bodies (Environment Agency, 2022b).

Gap analysis

Most of the indicators demonstrate a moderate to high usability, are relevant, but do not fully explain water storage in the form of groundwater and small retention features. Therefore, the following data gaps were identified in this review:

- Easily accessible groundwater level monitoring data points to fully assess the condition of groundwater storage. The number of groundwater level monitoring sites with available data on the BGS website is being updated, but more could be done to collate a national dataset of groundwater data.
- Data on depth to assess area of smaller water retention features for assessing surface water storage.

Option appraisal

In the short-term, existing available datasets could be used to provide some indication of water storage and availability.

In the longer term, the following should be considered:

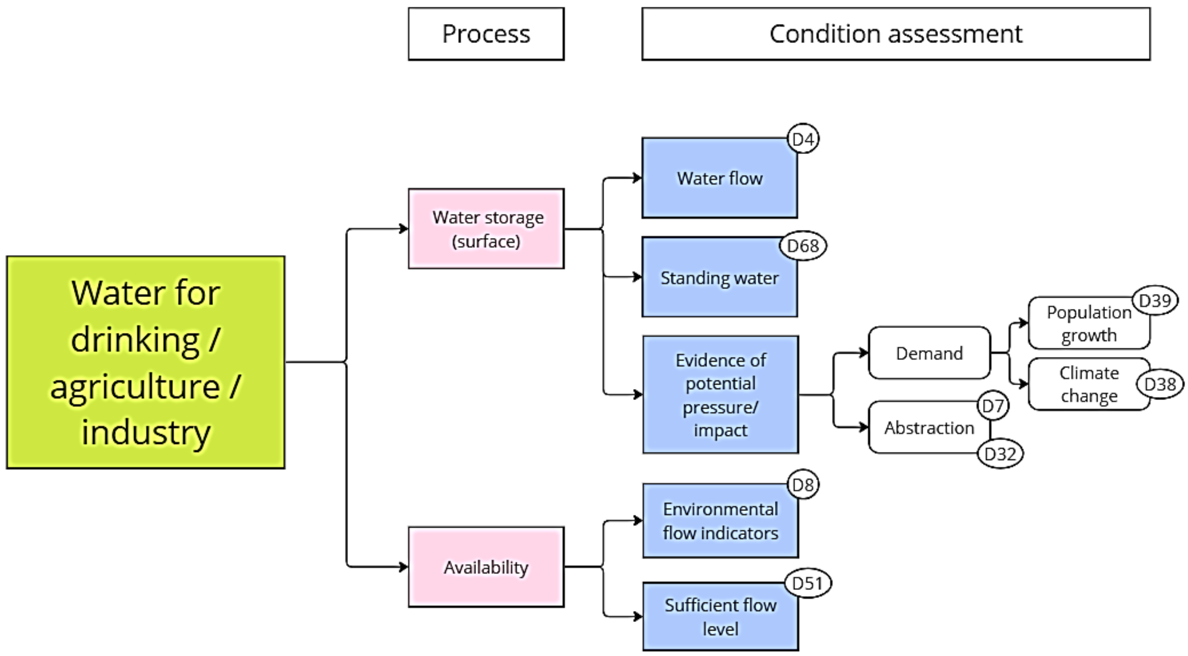
- To assess water storage, other datasets such as the BGS 'depth to groundwater' and 'aquifer designation' layers could be used to assess groundwater storage. Additional models could be found or developed for areas lacking data.
- To assess smaller water retention features, a detailed assessment of smaller surface water areas could be conducted using google earth imagery. Keele et al., (2019) describe the use of google earth to identify river features relevant to ecosystem services. This includes the use of remote sensing to identify lakes, floodplain features and wetlands. The OS MasterMap may also provide mapped information on lakes and smaller water retention features.
- The 25-year environment plan indicators B2: 'Serious pollution incidents to water', B5: 'Waterbodies achieving sustainable abstraction criteria', E8: 'Efficient use of water' and 'F3: Disruption or unwanted impacts caused by drought' indicator could be relevant to assessing water provision. B2, B5 and E8 are available, but the others are not currently available for reporting.

Artificial rivers

Condition assessment flow chart

Figure 18 shows the condition assessment method for 'Water for drinking, agriculture and industry' in artificial rivers. The ability of an artificial river to carry water is important and dependant on many factors. These include: volume and flow rate in the canal, the demand for water, and any regulations or agreements in place regarding water use.

Water supply in canals originates from rivers, groundwater or lakes and so artificial rivers do not directly provide water. This water is diverted into canals where it can be transferred from region to region and abstracted at various points using pipelines and pumps. This is especially important in allowing recovery to over-abstracted regions by transferring water from regions with lower demand. For example, the Grand Union Canal transfer scheme has been proposed as an option to reduce the pressure of abstraction to Chilterns chalk streams as part of the Chalk Streams First initiative (Rangeley-Wilson, 2020).



Datasets
D4- River flow data- EA
D7- Water abstraction tables- EA
D8- Flow compliance bands (WFD cycle 2 river water bodies)-EA
D32- Canal pumping stations
D38- Hydrological projections for UK (eFLaG)
D39- Population density- ONS
D51- Q95 flow percentile statistic- NRFA
D68- UK Lakes Portal

Figure 18: Artificial – Water for drinking/agriculture/industry

It is important to manage water abstraction from canals sustainably, considering the needs of both people and the environment. This ensures that the provision of ecosystem services from canals is maintained in the long term, while also supporting sustainable development and the well-being of local communities.

Assessment of indicators

In general, the assessment of indicators is similar to those identified for natural rivers. However, there are a few key differences detailed below.

Groundwater storage is not assessed for artificial rivers and so all water storage processes are assessed for surface water including water flow in the canal channel as well as standing water features such as reservoirs. Water flow can be assessed using EA Hydrology data as well as the UK Lake Portal resource.

Pressures and impacts from climate change and abstraction, also need to be assessed for artificial rivers using the same eFLaG dataset and population density to estimate changing demand. The Canal and Rivers Trust has data on the location of canal pumping stations which could be useful in assessing the location of abstraction points.

The application of Environmental Flow Indicators (EFI) to artificial rivers may depend on their ecological significance and the presence of sensitive aquatic species. If an artificial river supports a significant freshwater ecosystem, then EFIs may be required to ensure its ecological integrity. However, if a canal or artificial river does not support significant freshwater ecosystems, EFIs may not be necessary. Sufficient flow levels may need further assessment as flow requirements for purposes such as navigation may be different from natural rivers.

Gap analysis

Most of the indicators demonstrate high to moderate usability and relevance. The review also identifies some data gaps:

- Data on water level and canal dimensions to understand the capacity of the channel to store and transfer water.

Option appraisal

In the short-term, existing available datasets could be used to provide some indicators of water storage for the 'Water for drinking, agriculture and industry' ecosystem service.

In the longer term, the following should be considered:

- Identification of any relevant data to assess channel capacity, potentially by contacting the Canal and Rivers Trust.
- Further assessment of flow needs for artificial river types would be useful to understand how sufficient flow can be defined. This could be indicated by regulations on water flow or the purpose of the artificial river.

Regulating

Regulating services are obtained where the regulation of ecosystem processes provides benefits. The naturalness of ecosystem function is therefore an important element of the condition assessment.

5.3.2 Water flow regulation

"Hydrological cycle and water flow regulation (including flood control, and coastal protection). The capacity of ecosystems (e.g., vegetation, soil) to retain water and release it slowly. Buffering of the impacts of natural hazards and disruptions. Structure and storage capacity of vegetation can reduce the effects of storms, floods and droughts.

Natural rivers

Condition assessment flow chart

Figure 19 shows the condition assessment method for ‘Water flow regulation’ in natural rivers. This service encompasses various processes that support the controlled movement of water within and between ecosystems. It involves the regulation and management of water flows and storage that mitigates the risk of flooding and drought.

The service is supported by natural processes and habitat features. Features, such as ponds, wetlands and vegetation play a central role in controlling and managing the movement of water. Vegetation acts as a natural buffer, intercepting rainfall, reducing surface runoff, and promoting water infiltration into the soil. Natural storage areas collect excess flow and then release it during dry periods to maintain consistent flows.

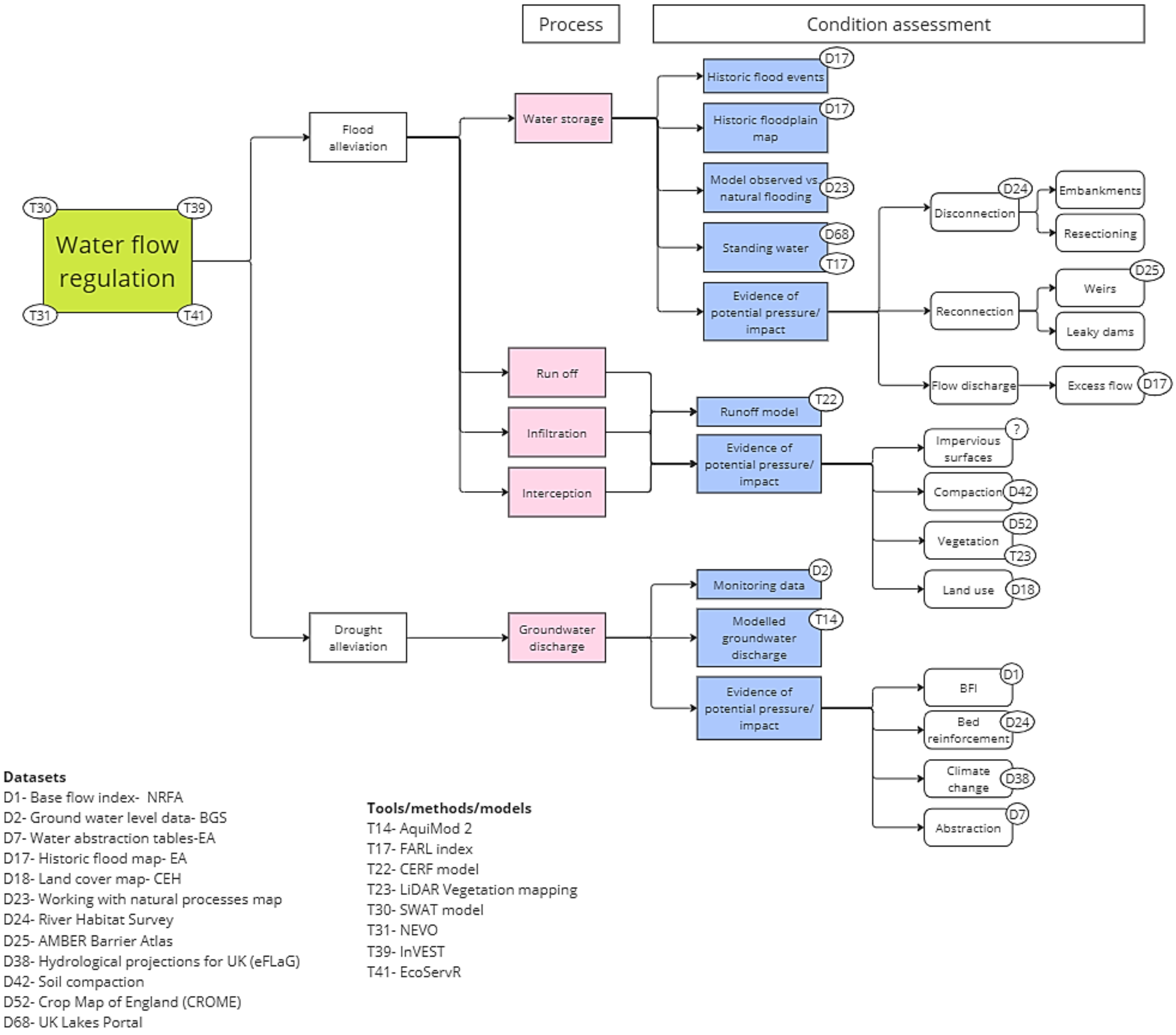


Figure 19: Natural – Water flow regulation

Assessment of indicators

The potential for water to be stored to reduce flood risk can be assessed using several indicators. Firstly, analysis of historic flood event data, combined with historic flood maps

(Environment Agency, 2023) can provide information on past flood extents. Incorporating hydrogeomorphological methods can be used to delineate outer flood extents as well as identify key floodplain features, including flood channels which are important for conveying high-flow floodwaters (Riverdene Consultancy, 2015). Assessment of previous floodplain inundation areas is indicative of floodplain storage capacity. Furthermore, the mapping of floodplains' potential for reconnection and utilization in natural flood management was undertaken in the EA Working with Natural Processes project. This provides valuable insights into the potential for future enhancement prospects. An issue with mapping anthropogenic floodplains is that it is difficult to differentiate between natural channel evolution and human impacts, which makes basing condition on naturalness difficult. Some pressures and impacts such as weirs and physical modifications are easier to assess through historical information, but other legacy anthropogenic disturbances such as the removal of wood and beaver extirpation are more difficult to identify (Powers et al., 2022).

The extent of water flow attenuation by adjacent habitats and features can be inferred from the presence of standing water features. The UK Lakes Portal is highly usable source of information, providing a map of large water retention habitats including lakes and reservoirs. To quantify the contribution of these habitats to flood attenuation, the Flood Attenuation by Reservoirs and Lakes (FARL) index, derived from the Flood Estimation Handbook (FEH), can be used (NRFI & CEH, 2023). Smaller features that retain water, such as floodplain ponds and wetlands, are not accounted for within these indicators but play an important role in buffering flood events.

The extent and severity of flooding has been exacerbated by anthropogenic pressures and impacts including hydromorphological modifications. For example, lateral disconnection of rivers from their floodplains by resectioning and creation of embankments. These modifications are recorded in flood defence asset maps and RHS. Furthermore, floodplain reconnection features such as weirs and leaky dams may increase floodplain water storage. Evidence of weirs and other barriers are documented in the Adaptive Management of Barriers in European Rivers (AMBER) Barrier Atlas. However, features such as leaky dams, although documented in natural flood management projects, are less comprehensively recorded. Flow discharges, from storm overflow discharges, may exacerbate flooding if discharge exceeds storage capacity.

The remaining hydrological processes such as runoff, infiltration and interception cannot be directly measured, however, there are some runoff and flood models which incorporate these processes and can reflect changes in condition. For example, the Continuous Estimation of River Flows (CERF) model is a rainfall-runoff model that can provide an overview of runoff dynamics within a catchment by analysing the relationship between precipitation and flow data from gauged sites (Griffiths et al., 2008). Use of this model may require more specialist knowledge as it requires an assessment of the likelihood of producing good simulations at ungauged sites.

These processes are affected by pressures and impacts such as the presence of impervious surfaces, compaction, land use change, and deteriorating ecosystem conditions (Vári et al., 2022). Quality of riparian and floodplain vegetation, particularly density and roughness of floodplain vegetation can influence interception. This can be assessed based on habitat data from the Crop Map of England and the UKCEH Land Cover Map, supplemented using LiDAR (Light Detection and Ranging) vegetation mapping methods. Compaction maps such as the Soil Compaction Risk map of Europe can be used to indicate potential runoff or infiltration processes.

Groundwater discharge is important to provide baseflow to rivers during dry periods. This can be assessed similarly to groundwater storage for the ecosystem service 'water for drinking, agriculture and industry'. The same groundwater level data and model from the BGS can be used, but again, this is spatially constrained. Similarly, the Base Flow Index can be used to reflect impacts to groundwater. Additionally, the connectivity of the hyporheic zone, which can be affected by bed reinforcement, will be important in maintaining the ability for groundwater to discharge into the main river flow. This is recorded in RHS. The eFLaG dataset is relevant to understanding future drought risk.

Gap analysis

Most indicators demonstrate high usability, apart from those with more specialised methodologies. The relevance of the data indicators is generally high and multiple different datasets and methods could be used to assess condition. The assessment also identifies some data gaps:

- Data identifying impervious surface in floodplains.
- Comprehensive data on the location of leaky dams.

Option appraisal

In the short-term, existing available datasets could be used to provide some indication of most processes related to the 'Water flow regulation' ecosystem service.

In the longer term the following options could be developed:

- Additional datasets could be identified to fill in the gaps. For example, identification of impervious surfaces may be possible from detailed land use data, Google Earth imagery, or satellite data such as Sentinel. Better habitat and land use maps could also be produced using tools such as Ecoserv-R, and new products such as the Natural England's Living England Map.
- Mapping floodplain extent using the hydrogeomorphic approach.
- Using Google Earth or satellite data to identify smaller flood retention features (Keele et al., 2019).
- Additional research could be focussed on implementing floodplain mapping approaches that consider naturalness (e.g., from Powers et al (2022) methodology).
- Other tools and models that model water flow as a whole, should be investigated. These include the Soil & Water Assessment Tool (SWAT), Natural Environment Valuation Online (NEVO), Integrated valuation of ecosystem services and Trade-offs (InVEST) and EcoServ-R. Many of these tools include runoff models that take land use (and other factors) into account, but not other aspects of condition.

Artificial rivers

Condition assessment flow chart

Figure 20 shows the condition assessment method for ‘Water flow regulation’ in artificial rivers.

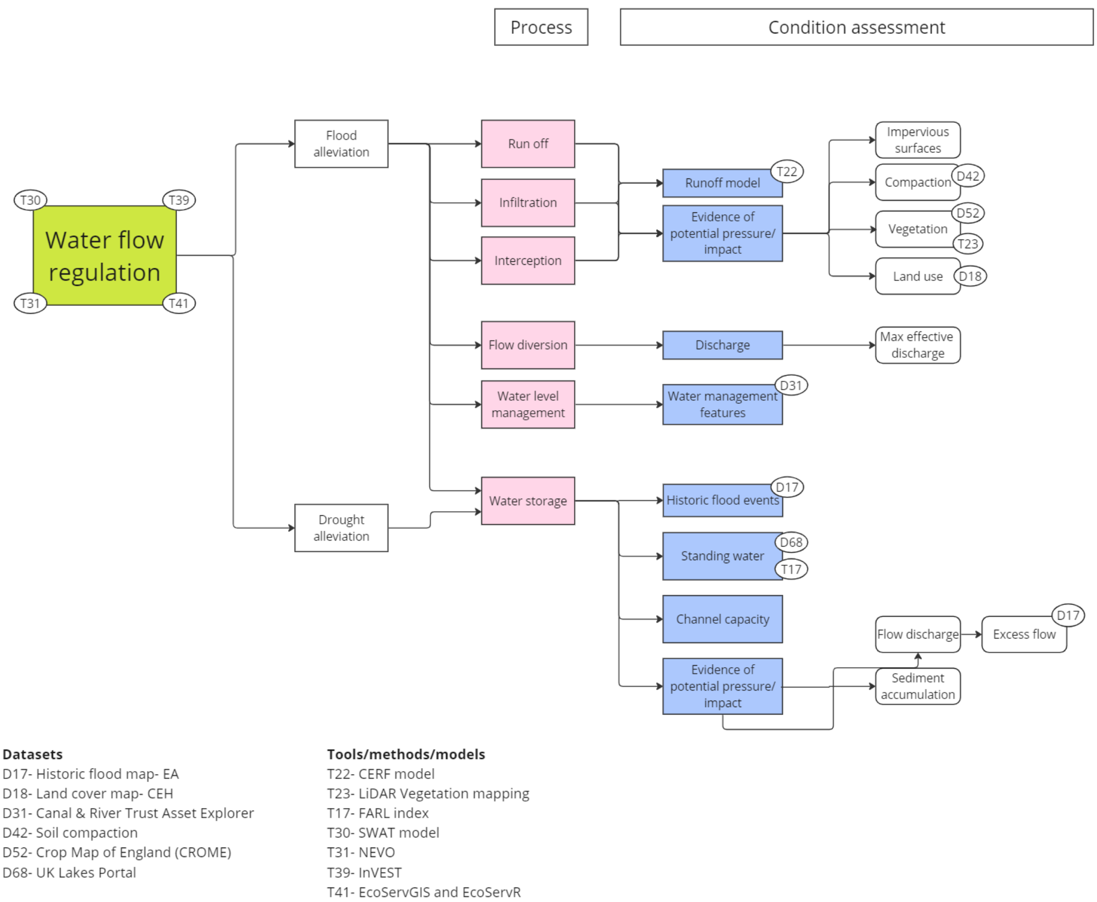


Figure 20: Artificial – Water flow regulation

In comparison to natural rivers, less in-channel vegetation is typically present as channels are designed to have uniform flow regimes and are constructed with concrete beds which prevent vegetation growth. This means artificial rivers are less able to hold back water in the channel in comparison to natural rivers.

Instead, artificial rivers can regulate water flow by serving as storage reservoirs of excess water from connected rivers during periods of high flows and release it back during dry periods. This can help to reduce the impact of floods downstream by attenuating the peak flow and providing additional water storage during droughts. The capacity of the artificial river’s channel to convey floodwaters can influence its ability to provide flood alleviation services. The channel should be designed to accommodate high flows without overflowing or causing damage to adjacent properties.

Assessment of indicators

Runoff, infiltration and interception are important processes within and surrounding artificial rivers and can be assessed using the CERF model and evidence of pressures and impact as assessed for natural rivers. Identifying impervious surfaces is particularly relevant for artificial rivers that are located in urban areas.

The assessment of water storage is different from that of natural rivers as they do not have natural floodplains. However, historical flooding datasets and mapping techniques are still useful for assessing water storage. This also includes surface water storage features. Storage of water within the artificial river itself is important. Data on channel capacity has not been identified but would be useful to indicate this. Potential pressures and impacts, such as sedimentation, can reduce the channel capacity so is important to consider, but the review did not find a relevant dataset to assess this.

In contrast to natural rivers, artificial rivers are often designed with water management features that may affect water flow regulation. For example, flow diversion features may influence the water level within the canal or artificial channel. Other water level management features such as locks and sluices are important to consider. The Canal and Rivers Trust has a comprehensive map of these features which will be a useful indicator.

Gap analysis

The relevance of the data indicators is generally high with multiple different datasets and methods that could be used to assess condition. The assessment also identifies some data gaps:

- Data on water level and canal dimensions to understand channel capacity.
- Mapping of flow diversion
- Sediment accumulation in canals (potentially datasets of mitigation features e.g., sediment basins or settling ponds).

Option appraisal

In the short-term, existing available datasets could be used to provide some indication of processes related to the ‘Water flow regulation’ ecosystem service.

In the longer term, the following options could be developed:

- Contacting Canal and Rivers Trust to advise about available datasets to fill gaps such as channel capacity, flow diversions and sediment accumulation.
- Other options as described under the natural rivers section.

5.3.3 Water quality regulation

"Regulation of the chemical condition of fresh waters by plant or animal species that enable human use or health."

Natural rivers

Condition assessment flow chart

Figure 21 shows the condition assessment method for 'Water quality' in natural rivers. The main processes identified for the provision of good quality water were nutrient processing and chemical and sediment capture by plants. Plants and algae absorb and process nutrients and heavy metals. Macrophytes and filter feeders trap fine sediments and associated chemicals. These processes contribute to improved water quality but are difficult to measure or even assess.

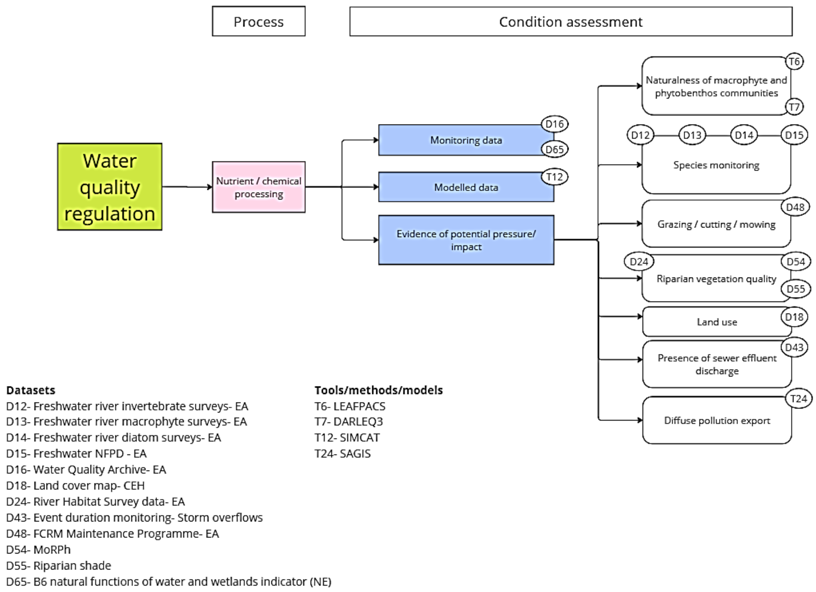


Figure 21: Natural – Water quality regulation

Assessment of indicators

There are several indicators identified as useful to understand water quality, however, they do not fully capture the processes that regulate condition. There are at present no indicators, data or tools that can readily be applied to the assessment of this ecosystem service.

Water quality monitoring gives some indication of the ability of the river to regulate its chemical and nutrient condition. The EA water quality archive provides accessible, long-term monitoring data which can be useful in establishing change over time. Water quality monitoring data is often collected at specific sampling points, which may not capture the full complexity of the river system as water quality may vary significantly across different locations, seasons and flow conditions. Monitoring data provides excellent information about concentrations of nutrients and chemicals present in the water, but it may not offer insights into the underlying processes that affect water quality such as hydrological dynamics, biogeochemical interactions, microbial activity, sediment movement and vegetation interactions. Due to this, water quality monitoring is insufficient for a comprehensive determination of this ecosystem service.

Water quality models, such as the EA's Simulation of Catchments (SIMCAT) model, may be used to assess water quality. SIMCAT is a valuable tool for simulating hydrological and water quality processes within a catchment, however, it relies on input data and assumptions that may not capture the full complexity of the river system (Cox, 2003). It is, therefore, necessary to integrate SIMCAT outputs with other data sources and approaches including field observations, water quality monitoring data, ecological assessments, and additional modelling tools that account for biological processes, sediment-water interactions, and the role of riparian zones. Evidence of potential pressures and impacts can supplement monitoring and modelled data to include this complexity.

Macrophyte and phytobenthos biological indices and models indicate the river nutrient status but do not provide any specific information on chemical processing. The WFD LEAFPACS and DARLEQ (Diatom Assessment of River and Lake Ecological Quality) models were designed to produce assessments of nutrient enrichment against a reference status describing near-natural water quality. We could assume that assemblages described as unimpacted by the models indicate an adequate potential for nutrient and chemical regulation. However, the absence of impact may also be due to a lack of stressors or a natural lack of plant growth due to shading. It is therefore not entirely feasible to use naturalness models to this end. Similarly, macroinvertebrates indices such as BMWP (Biological Monitoring Working Party) and the WHPT (The Whalley Hawkes Paisley Trigg), indicate water quality status with specific reference to organic pollution but do not provide any information on biological processing.

The quality and extent of riparian vegetation will influence the delivery of chemicals and fine sediments to the channel and can thus function as an indicator of chemical processing. Information about mowing or vegetation clearance can be obtained from the EA maintenance programme. RHS and MoRPh (Modular River Physical Habitat) physical habitat assessment methods both record riparian features. This can be used to assess riparian quality, for example, the Riparian Quality Index can be calculated from RHS data to represent the complexity, naturalness and continuity of the riparian zone (RRC, 2019).

The presence of point source and diffuse pollution can indicate impacts on water quality but provide little information on processing. The event duration monitoring of storm overflows dataset is regularly updated and indicates point source pollution from overflow events. It is used to assess the frequency and duration of pollution events and evaluate the impact on water quality. Land use mapping may provide information on risks for diffuse pollution. Alternatively, the SAGIS model may be used to indicate diffuse pollution export from land as well as point sources.

The B6 Natural functions of water and wetland ecosystems indicator currently in development will address the naturalness of ecosystem functions. These functions will include those which regulate water quality and so will be relevant to assessing the condition of this ecosystem service.

Gap analysis

Although relevant to monitoring water quality, none of the identified data indicators fully reflect nutrient and chemical processing. Furthermore, the indicators are typically more specialist. Therefore, there are data and modelling gaps from this review:

- Additional models that would enable us to assess the contribution of biological processes and sediment interactions on water quality status are required to assess this ecosystem service.

Option appraisal

In the short-term, riparian vegetation indices alongside macrophyte data could potentially provide some indication of nutrient and chemical processing. This would have limited application and would not fully enable the assessment of condition.

In the longer term, the following options could be developed:

- Identification or development of chemical capture, storage and processing models by vegetation, sediment and biota. Presence and extent of features and habitats could be used to assess water quality. For example, presence of wetland habitats, abundance and diversity of macrophyte communities and presence of large wood or log jams.

Artificial rivers

Condition assessment flow chart

Figure 22 shows the condition assessment method for ‘Water quality’ in artificial rivers. The ability of artificial rivers to regulate water quality is highly dependent on waterbody use, purpose and management regime. Plants and algae absorb and process nutrients and heavy metals. Macrophytes and filter feeders trap fine sediments and associated chemicals. These processes contribute to improved water quality but are difficult to measure or even assess.

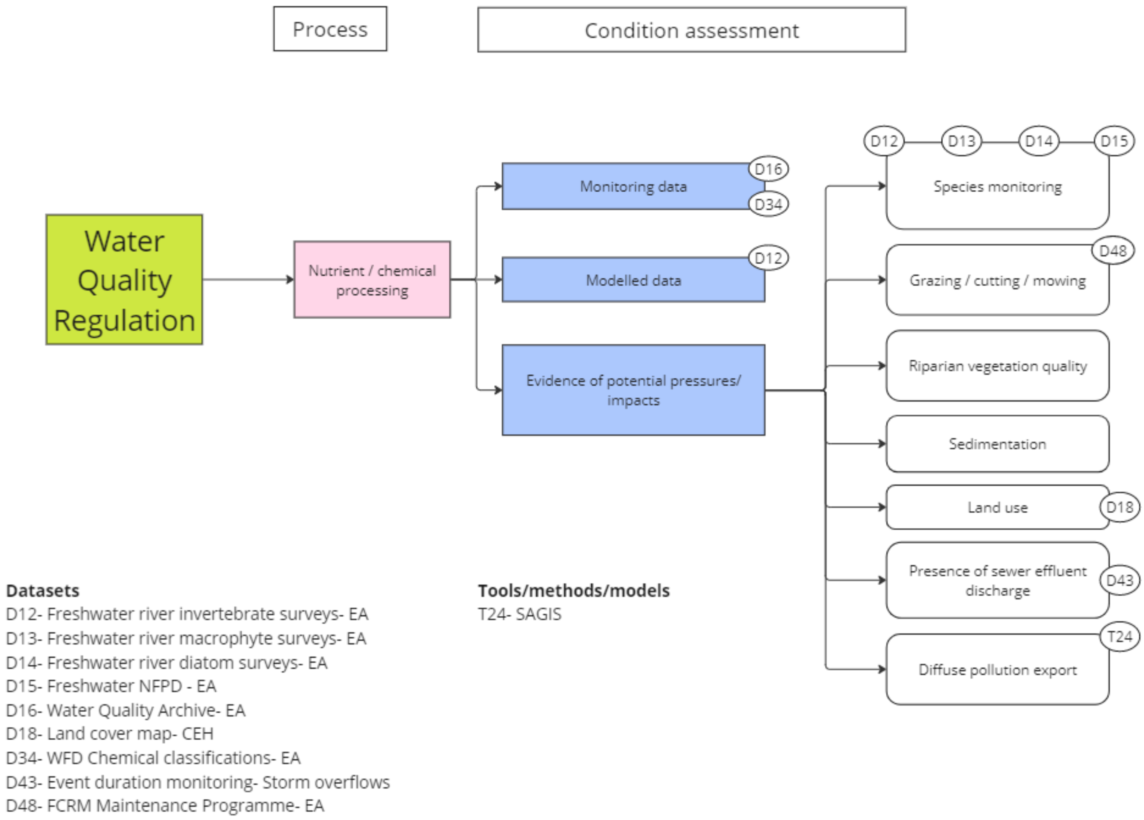


Figure 22: Artificial – Water quality regulation

Assessment of indicators

The indicator assessment for artificial rivers is very similar to natural rivers as the indicators will be assessed in the same way. However, there are some differences described below. The main processes identified for the provision of good quality water were nutrient and chemical processing.

Indicators relating to naturalness, such as ‘Naturalness of macrophyte and phytobenthos communities’, were removed as there are no natural reference conditions for artificial rivers. However, riparian and in-channel vegetation can still be assessed using Urban River Survey data, which gives an indication of vegetation extent.

Artificial rivers may have less species monitoring/surveys conducted than natural rivers. Therefore, more work is needed to determine the spatial extent of these datasets for artificial rivers.

Gap analysis

The analysis of indicators reveals that some indicators are usable with several more specialist indicators. As with the assessment of natural rivers, the data indicators do not fully reflect nutrient and chemical processing. The assessment also identifies further data gaps:

- Data on the impact of sedimentation on water quality in artificial rivers (could include records of where mitigation has been put in e.g., sediment basins or settling ponds)
- Models or data to assess the contribution of biological processes and sediment interactions to water quality status.

Option appraisal

In the short-term, existing available datasets measuring potential pressures and impacts could give some indication of nutrient and chemical processing, but would not fully assess condition.

In the longer term the following options could be developed:

- Review of the coverage of current datasets for example, species monitoring spatial extents.
- Further review work to identify or develop models of chemical capture, storage and processing by vegetation, sediment and biota.

5.3.4 Habitat and population maintenance

> "The presence of ecological conditions (usually habitats) necessary for sustaining populations of species that people use or enjoy."

Natural rivers

Condition assessment flow chart

Figure 23 shows the condition assessment for 'Habitat population and maintenance'. Several complex processes are involved in creating good quality habitats for sustainable populations. Hydromorphology provides a template for describing and assessing the physical and hydrological characteristics of rivers, and their impacts on habitat creation and maintenance. Hydromorphological processes either relate to the movement of water or sediment. Processes such as precipitation run-off, water storage and discharge, sediment erosion, transport and deposition drive the distribution of features that species use for spawning, feeding or as refuge areas.

Aside from carrying water and sediment, rivers connect to their wider environment and create corridors for species and sediment movement. Connectivity is a crucial function of river ecosystems. There are three types of connectivity. Longitudinal connectivity enables the movement of species, water and sediment along the river and is affected by physical modifications such as dams or weirs. Lateral connectivity to the floodplain enables water and sediment storage and access to floodplain habitats such as wetlands and oxbow lakes. It is mainly prevented by alteration to a river's cross-section or the building of embankments. Vertical connectivity between groundwater and the river channel through the hyporheic zone provides habitats for invertebrate species and nurseries for fish eggs and can be impacted by bed reinforcement and dredging.

Water quality is a key driver of species distribution and ecosystem health. The EA has collected data over decades on water chemistry and uses complex indices based on invertebrates to assess aspects of organic and non-organic pollution, such as WHPT and PSI (Proportion of Sediment-sensitive Invertebrates).

Biological elements participate in habitat creation and structure. Species such as beavers create dams and macrophytes and trees influence flow and sediment deposition, modifying the mosaic of available habitats. The presence of invasive species or maintenance activities such as tree or weed cutting may impact natural biological processes, influencing morphology.

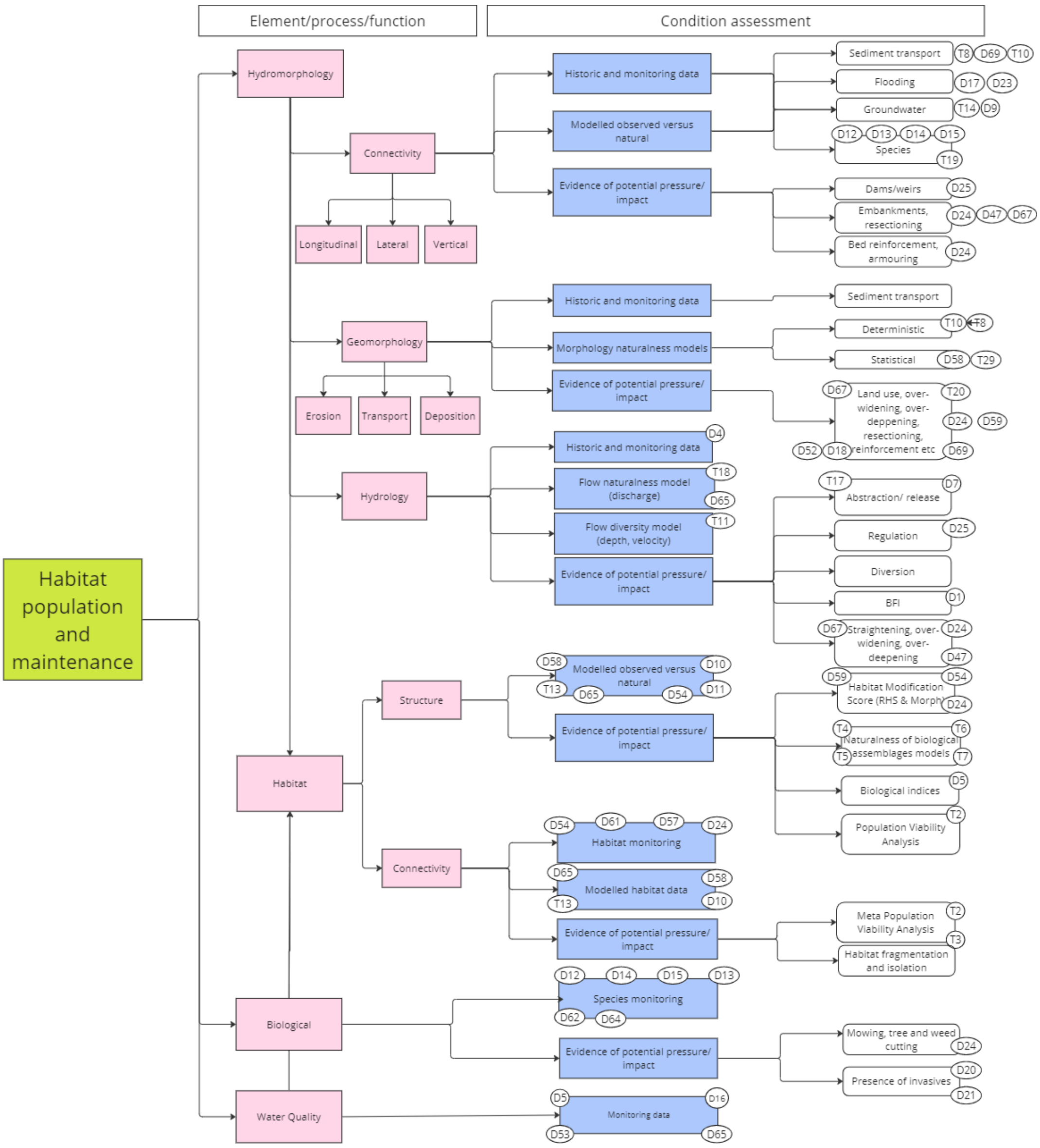
Habitat structure and connectivity are driven by hydromorphological and biological processes and their suitability is influenced by water quality. The forms (e.g., riffles and pools, bars) that are used by species at site or reach scale can be predicted using deterministic or statistical models. Impacts on habitats can also be inferred from the presence of engineering structures and other signs of management. Identifying reference condition can be problematic, as few rivers have escaped management impacts. Models offer some level of assessment of departure from the natural state, but long-term impacts are more difficult to assess.

Biological indices and models can be used as indicators of habitat suitability for species and communities. This is approached by looking at trends in monitoring data, using models of naturalness, indices or evidence of disturbance (e.g., invasive species). Existing models and indices only provide a snapshot in time and do not always represent the sustainability of existing populations. PVA models enable the assessment of population dynamics over multiple years by running simulations, using species life history parameters, such as fecundity and egg survival.

A PVA model, however, is itself a snapshot of a single population in space. Populations become extinct because of local pollution or natural events and habitats may be re-colonised by individuals from nearby populations. This is why it is important to consider the connectivity of existing habitats and potential populations for their long-term survival. Habitats for individual species or communities can be mapped across the network using models and their connectivity assessed using simple indices of fragmentation and isolation. More complex analyses and simulations including species life history parameters, migration and extinctions can be performed to produce large-scale assessments of population dynamics as an MPVA.

Assessment of indicators

Naturalness of geomorphological processes is difficult to assess without access to past conditions and using detailed monitoring data. Most rivers in England have suffered from some sort of management action in the recent or distant past, and it is difficult to find records of natural systems. Naturalness can be inferred from models using RHS data from semi-natural sites. Models predicting semi-natural geomorphic activity, flow types, channel substrate and channel vegetation structure were produced using geostatistical techniques across the entire river network. An index of departure from naturalness was produced to measure the level of potential impact on natural habitats (River Habitat Survey, 2021). Other approaches exist such as the River Condition Assessment developed as part of Biodiversity Net Gains assessment which is based on an expert model linking observed versus expected habitat features using a river typology. Regime equations linking channel forms (e.g., riffle pool occurrence, width, depth) to bank-full width or catchment characteristics have been produced by several authors for UK rivers (Thorne et al., 1997). Deterministic models predicting water and sediment movement such as Shetran can also be used to identify channel and floodplain forms in unconstrained environments. Caesar is a channel evolution model that can be used to predict channel form change over hundreds of years under unconstrained conditions. The model outputs can be compared to the current condition, thus providing an assessment of potential departure from natural states. 2D hydraulic models have also been used with Habitat Suitability Curves (HSC) to map habitats for fish species using depth, velocity and channel substrate (PHABSIM). The approach is quite intensive and requires the collection of observational data on fish preferences for depth, velocity and substrate. HSCs have been produced for a limited number of species so far and do not include other important habitat features such as cover by shading.



Datasets

D1- Base flow index- NRFA
D5- WFD cycle 2 river classification
D7- Water abstraction tables- EA
D9- WFD Groundwater Bodies Cycle 2 classification
D10- Priority River Habitat - Rivers - NE
D11- Priority River Habitat- Headwaters- NE
D12- Freshwater river invertebrate surveys- EA
D13- Freshwater river macrophyte surveys- EA
D14- Freshwater river diatom surveys- EA
D15- Freshwater NFPD - EA
D16- Water Quality Archive- EA
D17- Historic Flood Map- EA
D18- Land cover map- CEH
D20- Non-native species surveys- EA
D21- Pressure from invasive species- JNCC
D23- Working with natural processes map- EA
D24- River Habitat Survey data
D25- AMBER Barrier Atlas
D47- AIMS Asset Bundle Flood Defences- EA
D54- Modular River Survey condition assessment
D53- River temperature projections- chalk streams
D57- Citizen River Habitat Survey data
D58- RHS hydromorphological indices
D61- Habitat network, reedbeds- NE
D62- Species distribution maps (BRC)
D64- Mammal survey data (Mammal Society)
D65- B6 natural functions of water and wetlands indicator (NE)
D66- UK Canal map (IWA)
D67- Flood Risk Management Assets (EA)
D69- Brookes capital works map

Tools/methods/models

T2- RAMAS Metapopulation
T3- Akcakaya population models
T4- Fisheries Classification Scheme 2
T5- RICT/RIVPACS
T6- LEAFPACS 2
T7- Darleq3
T8- Shetran sediment modelling equations
T9- HEC-RAS sediment transport modelling
T10- CAESAR channel evolution model
T11- 2D/3D hydraulic models
T13- Physical Habitat Simulation (PHABSIM)
T14- AquiMod 2
T16- Habscore
T17- Flood Estimation Handbook Web Service/database- CEH
T19- Individual base models (species distribution)
T20- Historic fluvial audits
T29- Regime equations

Figure 23: Natural – habitat and population maintenance

Models of fine sediment transport and accumulation were also produced using surface run-off models and RHS data (Naura et al., 2016) for the entire river network. The models predict the quantity of fine sediment from agricultural origin delivered to individual 500m reaches on the river network. The dataset and model outputs include other sources of fine sediments such as bank erosion, sewage treatment works and urban run-off. The model's outputs were turned into an index assessing the risk of fine sediment accumulation on biota that was tested against fish species distribution (Naura et al., 2016).

The naturalness of longitudinal connectivity can be assessed using sediment transport models and potentially models like Shetran and Caesar that can predict sediment transport in unconstrained conditions. These would have to be compared to values measured in the field. Unfortunately, sediment budget data is not available for most of the river network and there are no historic records or monitoring apart from assessment of fine sediment in suspension. An alternative is to use evidence of modifications affecting connectivity, recorded in EA Flood Risk Management Asset datasets and, to a lesser geographical extent RHS, as well as online datasets such as the AMBER Barrier Atlas (AMBER, 2020). The same applies to lateral and vertical connectivity. For lateral connectivity, it is possible using models, to map natural flood boundaries as described in the 'Working with natural processes to reduce flood risk' project (EA, 2021) hydrogeomorphological method that uses contour maps, records of previous floods and geomorphological surveys. The method was applied to a few rivers in the UK and showed a very good match to historic and modelled flood data.

Hydrological data and models are available across the UK for gauged and ungauged sites. Most rivers have been historically modified to manipulate flows for water consumption, agriculture and via land-use change. It is therefore difficult to find historical data for natural flow conditions. Flow naturalness can be assessed using models such as LowFlows. A dataset of flow naturalness and impacts is available for all water bodies in England. The dataset is limited as it only applies to the outlet of water bodies and therefore does not provide a continuous assessment along the river network. It provides, however, an assessment of abstraction and discharge impacts on river flows. The impact of flow regulation can be assessed using the FARL metric. The FARL metric is derived using an equation relating the size of reservoirs to the size of the upstream catchment. FARL and other meaningful hydrological metrics can be produced using the FEH database or web-service.

The quality of natural habitats can be inferred from RHS data using the Habitat Modification Score (HMS) and hydromorphological indices predictions for semi-natural sites. The predictions were produced for the entire river network and the EA has a licence for these datasets. They enable the calculation of Hydromorphological Impact Ratios that assess departure from semi-natural condition (not including naturalness of the land use). Data can also be extracted from the Flood Risk Management Asset database as mentioned above.

Habitat quality can also be inferred from biological quality elements. Assessing the naturalness of biological community structure using existing monitoring data is limited because of the absence of long-term historical datasets. Instead, models predicting the naturalness of biological assemblages can be used. There are a few models that estimate ecological health based on deviation from pristine reference conditions. The River Invertebrate Classification Tool (RICT; (Freshwater Biological Association, 2023) is used to classify macroinvertebrates and the Fisheries Classification System 2 (FCS2) assesses the naturalness of fish assemblages under the WFD. RICT was based on a sample of reference condition sites that were historically selected for their water quality. Although hydromorphological quality was added to the assessment, it tends to provide predictions that are biased towards water quality elements (based on Marc Naura previous analysis of PSI data using RICT predictions). The FCS2 includes, as an assessment of hydromorphological quality, the RHS HMS that it uses it as part of a Bayesian modelling framework to infer species densities in the absence of modifications. This assumes that the HMS, which is a composite index, is a good predictor of habitat suitability for fish. Models for predicting the naturalness of macrophyte and diatom communities (LEAFPAC and Darleq3) do not include hydromorphology and mainly cover water quality and nutrient status. As such, they have limited applicability to assessing habitat naturalness.

The EA also produces biological indices, some of which are related to the models mentioned above, to describe potential hydrological (LIFE score) or morphological (PSI index) pressures.

To assess habitat connectivity, it is necessary to produce maps of habitat types across the river network. No such maps exist at present and there is no river typology in use. To be biologically relevant, it would be best for habitat maps to be species specific rather than generic hydromorphological types as observed in the literature (e.g., Montgomery & Buffington, 1997). Using RHS data and RHS-derived hydromorphological indices, it is possible to map habitats for species. NRW and Natural England (NE) recently produced maps of habitat suitability for water voles across the entire river network using RHS hydromorphological indices and other information derived from GIS (Geographic Information Systems; e.g., land use). The resulting maps were used to assess habitat connectivity and links to existing water vole populations and identify habitat corridors to restore or protect them. This approach is similar to an MPVA discussed below but requires fewer data on species' life history. It is, in essence, a landscape analysis approach. Indices describing habitat fragmentation and isolation could also be derived.

Evidence of pressure on habitat can also be inferred using a series of datasets. Invasive species (DEFRA, 2022) may have a negative impact on native species and data on the change in invasive non-native species are available as part of the UK Biodiversity Indicators (2022). Evidence of pressure and impacts includes the degree of shading which could affect the use of habitats as well as species survival. Information on tree cutting and mowing from the EA maintenance programme may also provide valuable insights into potential impacts.

PVA is a method used to identify threats to species and evaluate the likelihood of a population's survival long term. PVA typically involves using species-specific data, e.g., population size, reproductive rates, and environmental factors, to develop models that predict a population's growth, decline, and risk of extinction. MPVA is a variation of PVA that focuses on a group of subpopulations or local populations connected by dispersal or migration. It takes into account the dynamics of population connectivity and spatial structure, as well as the interactions between subpopulations and the surrounding landscape. MPVA can provide insights into the effects of habitat fragmentation, isolation, and degradation on the persistence of metapopulations. Limitations of the use of PVA or MPVA include the data being difficult to collate, and models have only been produced for a few species. The models are also hard to validate as they require long-term datasets. Population dynamics models are specialist tools that require a substantial amount of research and investigation. They can however produce indications of generic trends and likelihood of extinction that can be useful for management purposes.

Gap analysis

The EA has access to a wide variety of indicators for the assessment of habitat population and maintenance ecosystem service. An analysis of the indicators shows moderate to high degrees of relevance and usability for most indicators. Most of the datasets required have national coverage and good spatial resolution. However, a series of key data gaps could be identified:

- Sediment transport data are rarely collected and there is no assessment/index of sediment transport process quality or naturalness. The use of sediment transport models (e.g., using Caesar or other 2D models) should be investigated for mapping sediment transport at catchment scale
- The impact of abstraction on groundwater connectivity to the hyporheic zone would need to be assessed using existing data and models.
- Assessments of lateral connectivity to the floodplain would need to be improved, as existing maps do not account for major capital work impacts through cross-sectional modification.
- Flow naturalness assessment datasets derived using LowFlows only concern outlets from individual water bodies.
- Habitat modification assessment is only available at RHS sites at present (about 10% of the river network). Information on pressures could be inferred for the entire river network using a combination of datasets such as the Flood Risk Management Asset map, Morph pro and geo-statistically derived maps using RHS such as the Channel Resectioning Index map, used as part of the 25-year environmental plan B6 indicators. Alternatively, aerial photos combined with Google street view could be used to map modifications across the entire river network and produce a simplified RHS Habitat Modification Score. This has been demonstrated as part of a recent project for the World Bank and implemented across the entire river network in Bulgaria (RRC, 2022). Although, not all modifications were recorded, it was possible to identify major structures such as weirs, bridges and culverts as well as channel realignment and resectioning.
- River temperature would need to be monitored and/or modelled across the entire river network.
- Habitats for species or communities would need to be modelled and mapped using existing data such as RHS hydromorphological indices and other map -based data. This would enable the assessment of habitat connectivity, habitat and population

isolation/fragmentation, the identification of ecological corridors, and would provide a surrogate assessment of meta-population viability reducing the complexity and time needed to undertake MPVA. The RRC is conducting an Ofwat innovation project called CatchmentLife attempting to model habitat suitability for WFD species. The data and models could be used to map habitats across the entire river network.

Option appraisal

In the short-term, existing monitoring data and other datasets licenced to the EA could be used to provide some meaningful indicators for most processes related to the 'Habitat population and maintenance' ecosystem service.

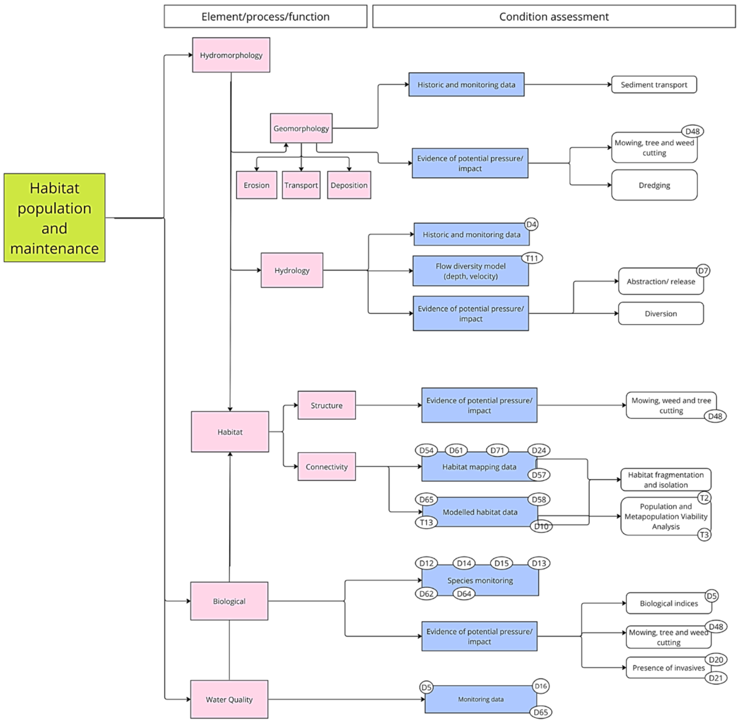
In the medium and longer term, a series of developments should be investigated:

- Investigate the use of existing EA/JBA 2D and CAESAR models to produce maps of sediment transport and major impacts on river processes.
- Production of habitat suitability maps for key species and communities using existing RHS-derived hydromorphological indices maps.
- Pilot project mapping modifications using the method developed and implemented on Bulgarian rivers with addition of LIDAR data, and comparison to field data and EA Flood asset map.
- Collation of groundwater data from water companies to assess impacts on groundwater recharge.
- Modelling the combined impacts of structures such as embankments and cross-sectional modifications to floodplain connectivity.
- Investigation into the use of RHS and Flood asset data and geostatistical techniques to map habitats and their modifications across the entire river network.
- Modelling and monitoring river temperature.
- Alternative existing indicators could be used to assess 'Habitat population and maintenance'. For example, other 25 year environment plan indicators such as B7- 'Health of freshwaters assessed through fish populations'. B1- ' Pollution loads entering waters' and B2- 'Serious pollution incidents to water' could be used to assess pressures and impacts on water quality affecting species.

Artificial rivers

Condition assessment flow chart

Processes supporting habitat population and maintenance in artificial rivers are limited due to the man-made nature of systems. Although geomorphological processes are present, erosion and transport processes tend to be limited by the slow-flowing nature of the system and the dominant processes are transport and deposition of fine sediment. Artificial river hydrology is generally controlled and restricted to acceptable levels for navigation or other purposes. The resulting habitats tend to be quite monotonous and show less diversity than in natural systems. They are mainly driven by slow-flowing depositional environments and macrophyte growth.



Datasets

D4- Hydrology data- EA
D5- WFD cycle 2 river classification
D7- Water abstraction tables- EA
D10- Priority River Habitat - Rivers - NE
D12- Freshwater river invertebrate surveys- EA
D13- Freshwater river macrophyte surveys- EA
D14- Freshwater river diatom surveys- EA
D15- Freshwater NFPD - EA
D16- Water Quality Archive- EA
D18- Land cover map- CEH
D20- Non-native species surveys- EA
D21- Pressure from invasive species- JNCC
D24- River Habitat Survey data
D48- FCRM Maintenance Programme- EA
D54- Modular River Survey condition assessment
D53- River temperature projections- chalk streams
D57- Citizen River Habitat Survey data
D58- RHS hydromorphological indices
D61- Habitat Networks - Reedbeds- NE
D62- Species distribution maps (BRC)
D64- Mammal survey data (Mammal Society)
D65- B6 natural functions of water and wetlands indicator (NE)
D66- UK Canal map (IWA)
D71- Urban River Survey- EA

Tools/methods/models

T2- RAMAS Metapopulation
T3- Akcakaya population models
T4- Fisheries Classification Scheme 2
T5- RICT/RIVPACS
T6- LEAFPACS 2
T7- Darleq3
T11- 2D/3D hydraulic models
T13- Physical Habitat Simulation (PHABSIM)

Figure 24: Artificial – Habitat population and maintenance

Assessment of indicators

Sediment transport is limited to the suspended load in artificial rivers. We did not find any data sources related to sediment transport or sedimentation although some may be available from the CRT. Potential pressures and impacts on artificial systems could be in the form of maintenance activities such as weed cutting or dredging for which there may be data available through the CRT.

Habitat structure and connectivity data may be available through RHS and Urban River Surveys (URS) as well as CRT ecological surveys and maps of locks. A ‘canal’ RHS was also produced in the late 1990s and some 600 sites were surveyed on canals by CEH.

It is not clear whether biological monitoring data cover all artificial water bodies. Macrophyte data would be valuable to assess the condition of habitats for invertebrate and fish species preferring standing waters.

Gap analysis

Information on lock location, macrophyte distribution and maintenance activities would be required to assess ecosystem services related to artificial rivers.

Maintenance activity such as dredging or weed cutting could provide information on sediment transport as well as potential impacts on resident species.

Option appraisal

The CRT should be contacted to investigate the availability of monitoring data for habitats, species, maintenance activities and lock location.

Cultural

As this type of ecosystem service is concerned with non-material benefits, a significant number of condition assessments are based upon perception and as such it may be harder to find existing data to support this assessment. For these ecosystem services, we found that it was harder to define particular 'processes' that supported the service, and so we looked directly at the condition assessments.

5.3.5 Characteristics and features of biodiversity that are valued

> "The things in nature that we think should be conserved because of their non-utilitarian qualities (existence value). The things in nature that we want future generations to enjoy or use for whatever reason (option or bequest value)."

Natural rivers

Condition assessment flow chart

Figure 25 shows the method of condition assessment for the ecosystem service: 'Characteristics and features of biodiversity that are valued'. Two separate 'value types', namely, the current existence value along with the bequest value were measured. The bequest value can be defined as the value that is derived from conserving nature and its benefits for future generations (DEFRA, 2007).

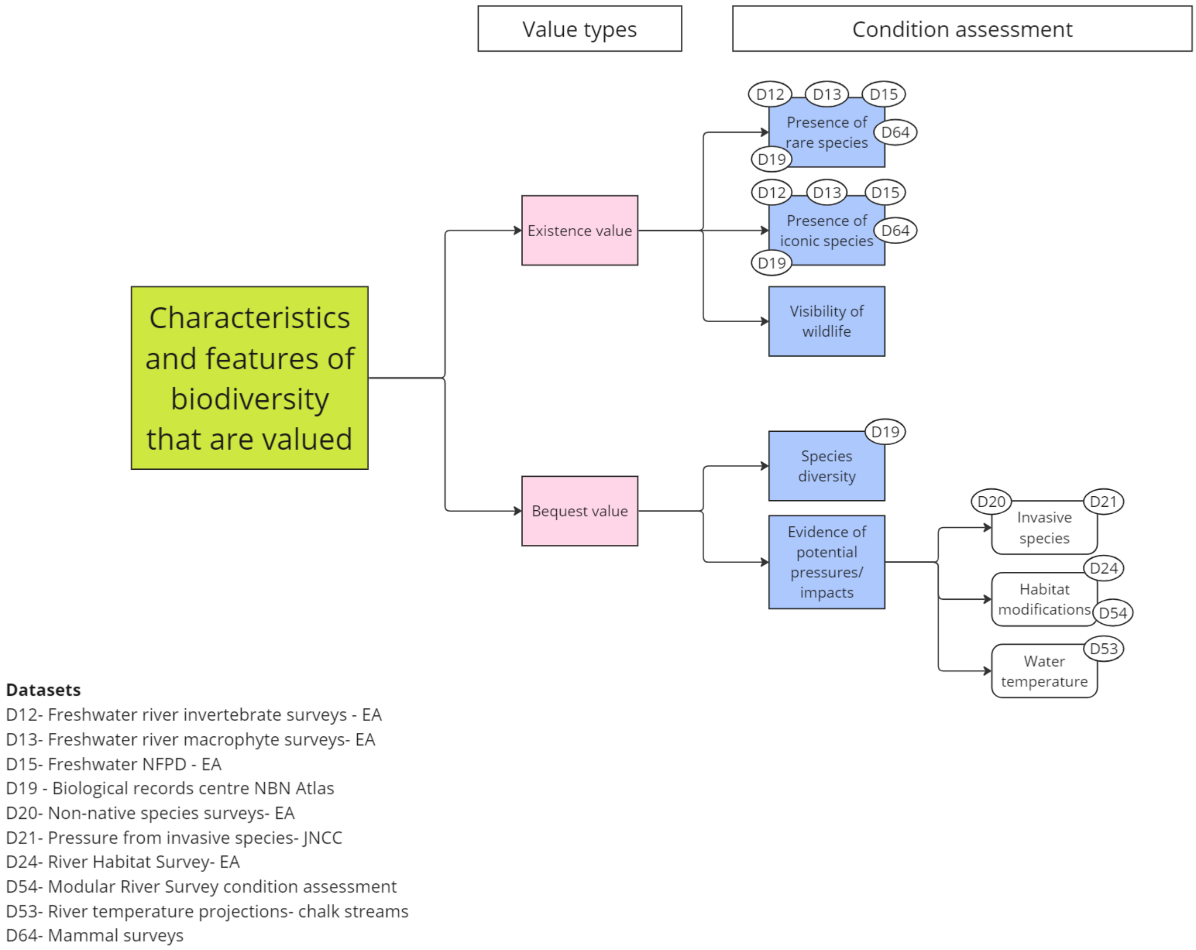


Figure 25: Natural – Characteristics and features of biodiversity that are valued

Rivers serve as important habitats for species that are globally threatened with extinction (Dudgeon et al., 2006). Particular attention should be paid to the presence of rare and iconic species as typically these will have a higher cultural value placed upon them than more common species.

The sense of attachment to the natural environment is strengthened by the ability to see the wildlife so this has been included as an indicator (Westling et al., 2014). Perception is a key factor influencing what is valued although this may prove hard to measure as people's perceptions and values are subjective e.g., one person may value the fact they can see a biodiverse area whereas for another just *knowing* that the area contains a high degree of biodiversity will be enough.

For future generations to benefit from this ecosystem service, species diversity should be preserved, and this can be assessed using current evaluations of diversity. Potential pressures and impacts that can have long-term effects on biodiversity are the presence of invasive species, the presence and extent of habitat modification, (lack of) habitat connectivity and increases in water temperature due to climate change.

Assessment of indicators

To assess biodiversity and identify the presence of iconic species, existing EA species monitoring data can be used. The datasets are easy to access, have national coverage and are regularly updated on the EA Ecology and Fish Data Explorer (Environment Agency, 2020). The ‘Mammal surveys’ dataset is a potential additional data source; however, its spatial and temporal coverage is limited to individual projects.

The ‘Biological records centre NBN Atlas’ also holds data on the abundance of many species, is open access and is appropriate for gaining an understanding of the diversity of species. It has several mapping tools available to use to view the data (National Biodiversity Network, 2017).

Pressures and impacts can be assessed using invasive species datasets such as the EA ‘non-native species surveys’, and the Joint Nature Conservation Committee (JNCC) ‘Pressure from Invasive Species’ which covers UK Biodiversity Indicator B6 and shows trends in invasive non-native species coverage on land and coastal areas (JNCC, 2021). Data coverage for these datasets may not be at an appropriate spatial scale to use for catchment or river assessments.

Pressures and impacts on habitats can be assessed using the EA ‘River Habitat Survey’ open access data. The ‘Modular River Survey’ can also be used to assess physical habitat condition although it may be less accessible and it currently has limited coverage.

Water temperatures are not currently monitored systematically. Water temperatures were modelled for chalk streams (‘river water temperature projections for English Chalk streams’) but no other datasets were found for the rest of the river network.

Gap analysis

The following gaps were identified:

- Data relating to perception and the ‘visibility of wildlife’ Water temperature data for the entire river

Option appraisal

In the short-term, there are data sources available to assess this ecosystem service, whilst recognising it will not provide a complete understanding. An accepted definition of what constitutes a ‘rare’ or an ‘iconic’ species is necessary to ensure that this data can be filtered consistently.

In the medium-term, further review of data covering the presence of rare or iconic species is needed, e.g., any other taxa not included in the current data sets, as well as information on species diversity. The 25 year environment plan B7 indicator (Health of freshwaters assessed through fish populations) could be used.

For the long-term, visibility of wildlife to people measured need to be derived or collected through surveys or by an analysis of site access and wildlife presence.

Data on water temperature could be collected or modelled to help with the assessment of potential pressures and impacts. Other indicators of potential pressures and impacts could be added (e.g., poor water quality or low flows)

Artificial rivers

Condition assessment flow chart

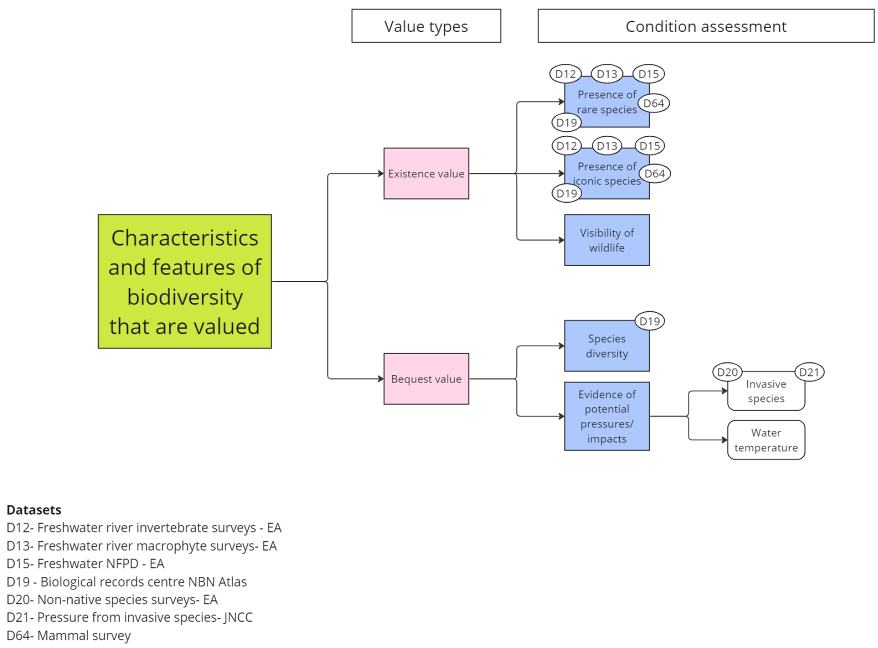


Figure 26: Artificial – Characteristics and features of biodiversity that are valued

Assessment of indicators

The condition assessment flow chart for artificial rivers is similar to natural rivers. The only difference is that for artificial rivers we have not considered the pressure/impact of habitat modification as the artificial river can almost be considered as a 'created' habitat.

Provided species diversity survey data has been collected on artificial rivers as well, the appropriateness of using them for indicators is the same as the natural rivers condition assessment flow chart.

Gap analysis

The gaps present in natural rivers are also present for artificial rivers. Additionally, we have not identified any data for water temperature in artificial rivers. This information may be present and further investigation is required, in discussion with the CRT who may identify more data sources or other ways of assessing the condition of the ecosystem service.

Option appraisal

Provided there is sufficient survey data for artificial rivers then there may be enough data sources to be able to assess this ecosystem service in the short-term. Defining ‘rare’ and ‘iconic’ species is required to ensure the data is filtered and used correctly. The condition assessment flow chart and data sources should be reviewed with specialists in artificial rivers e.g., CRT.

In the medium-term, as per natural rivers, ensuring the data for species diversity and rare/iconic species has sufficient coverage.

In the long-term, as per natural rivers, investigate how the visibility of wildlife could be measured e.g., local surveys).

5.3.6 Health and wellbeing

> “The role of natural landscapes and urban green space for maintaining mental and physical health is increasingly being recognised. Using nature to destress.”

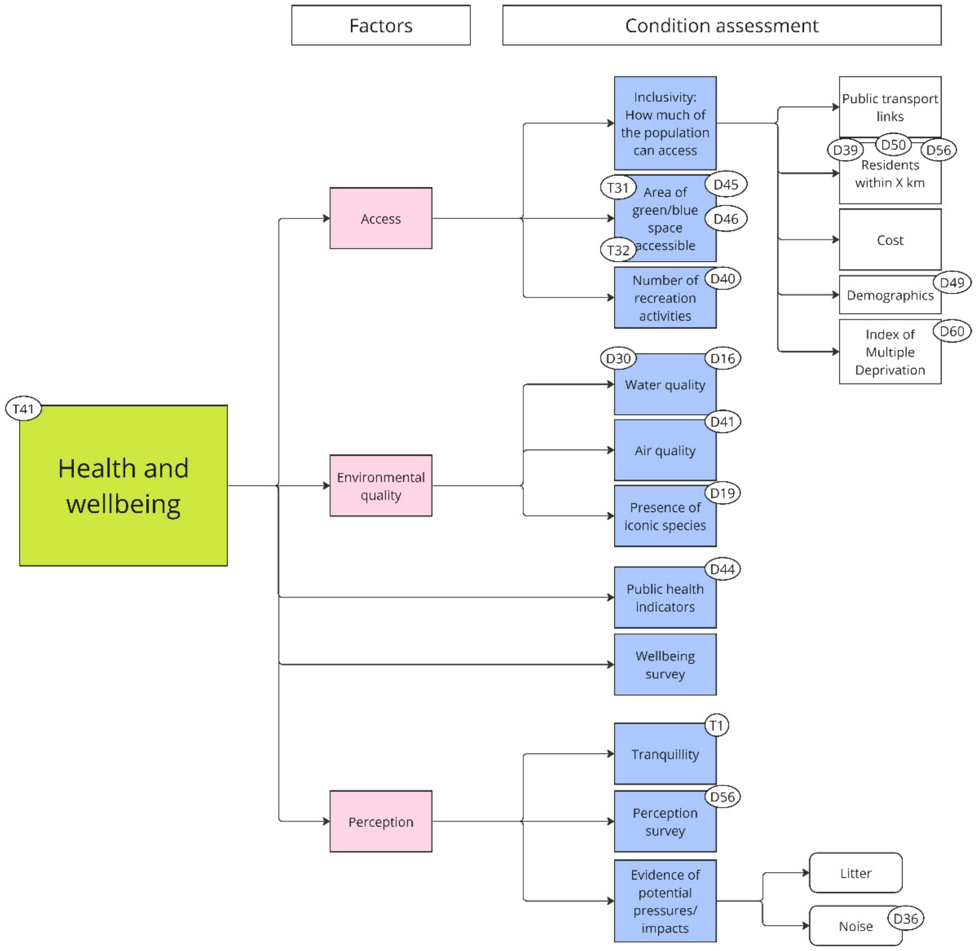
Natural rivers

Condition assessment flow chart

Figure 27 shows the method of condition assessment for the ecosystem service Health and Wellbeing. We defined the factors that affect the provision of this service to be:

- Access – as there is evidence to suggest that experiences in nature can have a positive effect on mental and physical health (Maller et al., 2006)
- Environmental quality – on the assumption that a severely degraded natural environment may not have as beneficial an impact as a healthy natural environment.
- Perception – assuming that if peoples’ perception of a landscape is positive then this may lead to positive wellbeing outcomes.

Additionally, there may be indicators such as Public Health Indicators or any wellbeing surveys that can be used to directly measure the condition of the ecosystem service.



Datasets
D16- Water quality archive- EA
D19- Biological records centre NBN Atlas
D30- Bathing Water- EA
D36- Strategic noise mapping- Defra
D39- Population Density- ONS
D40- Active Places- Sport England
D41- Modelled background pollution data- Defra
D44- Health and Wellbeing data- The Rivers Trust
D45- Accessible waterside PRoW and ANG- The Rivers Trust
D46- Green Infrastructure Portal- NE
D49- Cultural identity data- ONS
D50- Monitoring of Engagement with the Natural Environment- NE
D56- People and Nature Survey- NE
D60- Index of Multiple Deprivation

Tools/methods/models
T1- Tranquillity map
T31- NEVO
T32- ORVal
T41- HEAT

Figure 27: Natural – Health and wellbeing

Assessment of indicators

There are several examples of ‘Inclusivity: How much of the population can access’ that are considered:

- The ONS Population Density from 2021 census data shows residents per square km and could provide sufficient information to determine how many people live within a specified distance to rivers.
- The ‘Monitor of Engagement with the Natural Environment (MENE)’ and subsequent ‘People and Nature Survey’ can be used to understand people’s ability

to access nature, but this data needs analysing to determine if it can inform condition assessment of a particular asset.

- To assess the ecosystem service benefits for different communities, the Cultural Identity data from the ONS provides information on how people identify in terms of ethnicity, religion, sexual identity and language. It is updated every 10 years, is easily accessible, and covers England and Wales with a variety of geographic scales, so could be used to assess population near to rivers based on how they identify – not just as a whole.
- The Index of Multiple Deprivation mapping tool or .csv download allows further assessment of inclusivity taking into account poverty levels.
- The Outdoor Recreation Valuation (ORVal) and NEVO tools model the number of visits to parks, greenspaces and footpaths, based on a statistical recreational demand model. For use here this would need to be restricted to riverside areas and converted to number of visitors (based on visit rates) for use in health and wellbeing assessments. The G3 (Enhancement of green and blue infrastructure) 25 year environment plan indicator could also be used to assess this.

The area of green/blue space that is accessible can be assessed by using the 'Accessible waterside PRoW and ANG (accessible natural greenspace) (inland)' map layer that identifies 'waterside resource that is more likely to be publicly accessible because it is either in proximity to a Public Right of Way (within 10m) and/or is a waterbody adjacent to Accessible Green Infrastructure (within 1m; The Rivers Trust, 2023), and the Green Infrastructure portal. This portal has a mapping tool with layers including: blue infrastructure, population density, ethnicity, and Index of Multiple Deprivation (IMD) decile – all examples identified here.

Presence of infrastructure such as footpaths and cycle trails may be beneficial in widening access to health and wellbeing benefits. The Active Places Power data source has information about facility types but is more suited to sports/leisure centres rather than river-based activities such as fishing, swimming, boating, etc.

The environmental quality of the ecosystem is relevant and condition can be assessed by water quality, air quality and presence of iconic species. If water quality is bad, then the health benefits of swimming would be reduced and it could lead to adverse health impacts. The 'Bathing Water Quality' data set primarily shows coastal sites, as only a few river sites are designated for bathing. The Water Quality Archive contains monitoring data from England, is updated monthly, can be downloaded as .csv and provides sufficient information to assess water quality at the site level. Many studies point to the negative effects of air pollution on health (Dominski et al., 2021). Modelled background pollution data for each year/pollutant is available at 1x1km resolution and provides sufficient data to include as an indicator of condition. Iconic species present can be identified using the same data sources as in the 'Characteristics and features of biodiversity that are valued'.

Direct Public Health Indicators are included in The Rivers Trust mapping tool that shows where increasing provision of green/blue space may have the greatest benefit on wellbeing. This tool shows where there are current health and wellbeing issues across England. Different licences may apply to the variety of data sources used.

Data on people's perceptions may be difficult to obtain, especially at a spatially appropriate scale to map to a particular river. The CPRE, with Northumbria University, developed a Tranquillity Map of England (The Countryside Charity, 2007) and the People and Nature Survey which follows on from the MENE survey, records people's attitudes and enjoyment of the natural environment. Further investigation into both these sources of data is required to understand their applicability to assessing Perception in regards to Health and Wellbeing.

Potential pressures/impacts on perception can include Litter and Noise. Defra's 'Strategic noise mapping (2017)' covers noise produced by major roads, rail and airports and could potentially be used in this condition assessment.

Gap analysis

Several data sources have been identified for Access but there are gaps for:

- Public transport links, although as there are plenty of maps (bus/train) available, this should be possible to find with further investigation.
- Cost of entry/access to sites
- Number of activities

Environmental Quality looks to have much better coverage of data sources and can be assessed using the data identified.

Whilst there are some data sources to measure perception it is unlikely that in its current form it is sufficient to assess the condition of the asset, and further collation/investigation is required.

Option appraisal

In the short-term, there are data sources that can be used immediately, particularly for the assessment of environmental quality, where there is already sufficient data. Various datasets to assess access can also be used but require some work to pull together in the most meaningful way. Defining 'iconic' species is required to ensure the data is filtered and used correctly.

In the medium-term, data sources covering people's perceptions and wellbeing should be identified. This could be collected using local surveys. Additionally, maps of transport links should be compiled to aid in the assessment of access.

For long-term use, further research into linking perception and wellbeing to blue space (rivers) is required.

Additional models such as the Health Economic Assessment Tool (HEAT) could be assessed for usefulness.

Artificial rivers

Condition assessment flow chart

Figure 28 shows the condition assessment flow chart for Artificial rivers. As the ability of a river to provide health and wellbeing is not necessarily linked to its naturalness, the conditions to be assessed are the same as for Natural rivers.

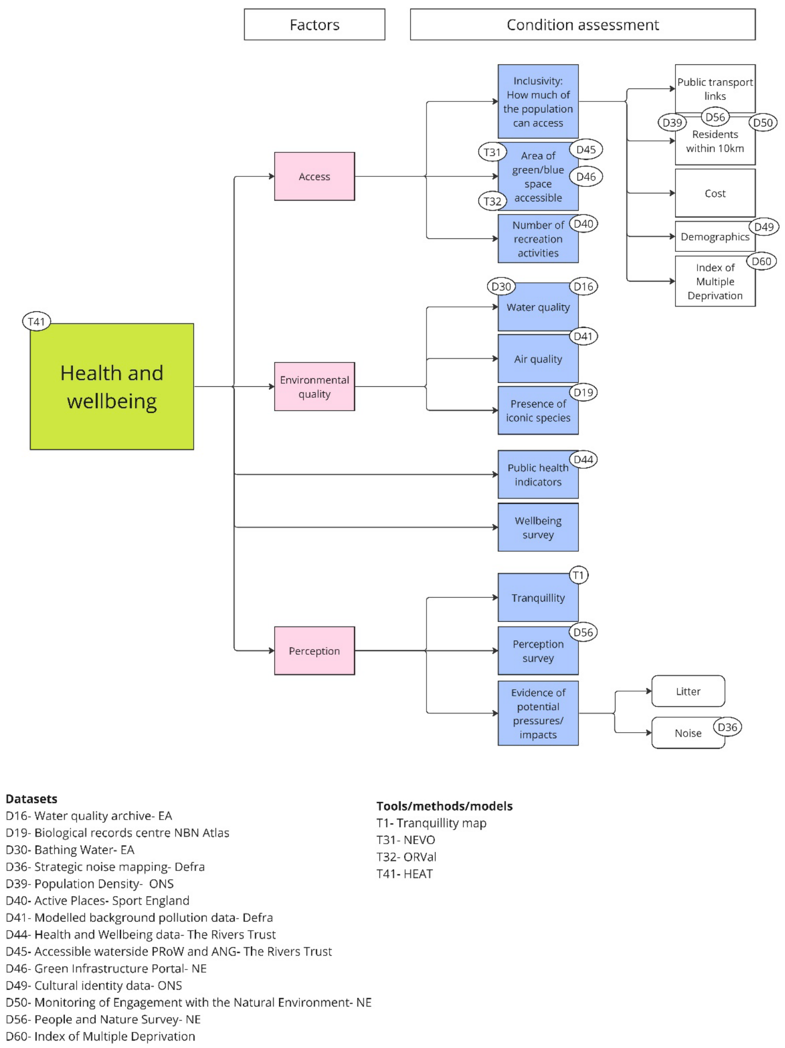


Figure 28: Artificial – Health and wellbeing

Assessment of indicators

The same indicators are used for artificial and natural rivers.

Gap analysis

The gaps in data/indicators for artificial rivers are the same as for natural rivers.

Option appraisal

In the short-term, the condition assessment flow chart and data sources could be reviewed with specialists in artificial rivers e.g., CRT.

The medium/long-term options for Artificial rivers are the same as for Natural rivers.

5.3.7 Aesthetic experience

“Most people enjoy natural scenery and landscapes; the beauty of nature. This is important not just for human enjoyment but can also have economic importance by influencing property prices.”

Natural rivers

Condition assessment flow chart

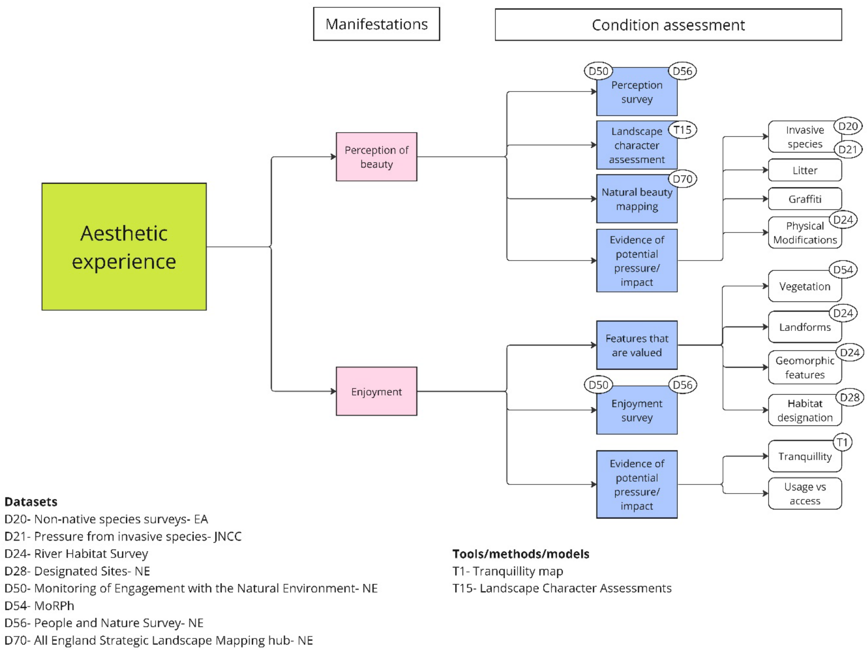


Figure 29: Natural – Aesthetic experience

Figure 29 shows the condition assessments for the ‘aesthetic experience’ ecosystem service. The two manifestations of aesthetics considered are the perception of beauty and the enjoyment of this experience, both are subjective qualities that may prove difficult to assess.

Assessment of indicators

To assess ‘perception of beauty’ we can use survey data measuring people’s perception via the ‘MENE’ (D50) and more recent ‘People and Nature’ surveys or by looking at the landscape itself. Landscape character assessments (LCAs) describe different landscape types but have been completed by individual councils rather than at national level. Natural England / LUC (Land Use Consultants) have developed the ‘All England Strategic Landscape Mapping Hub’, which has ‘55 layers grouped into the six Natural Beauty factors’ (Natural England & LUC, 2022). These ‘factors’ are landscape quality, scenic quality, relative wildness, relative tranquillity, natural heritage and cultural heritage. To assess the enjoyment of the aesthetic experience, survey data measuring enjoyment such as MENE or the People and Nature Survey, provide valuable information. Additionally, species survey and RHS data can be used to provide an indication of naturalness, beauty (for special features such as waterfalls etc.) and uniqueness. Designated Sites such as SSSIs, Areas of Outstanding Natural Beauty (AONB) and National Nature Reserves (NNR) may be a good indicator of sites that are valued. Another way to measure enjoyment would be to compare site usage and access. If a site is accessible but not being used, then this may indicate that people are not deriving much enjoyment from it (although other factors may influence this).

An alternative way to assess aesthetic experiences is through the impact on amenity value (e.g., house price uplift). House prices show significant positive price variations with greater proximity to greenspace and water, considered separately and together, and this has been investigated in some detail by the ONS (2019). They developed a standard method, based on hedonic pricing, to assess value based on distance from green and blue spaces (ONS, 2019).

Gap analysis

Gaps identified:

- The People and Nature Survey and the MENE survey require further investigation to determine if they are spatially appropriate for measuring perception for catchment or river assessments.
- No single dataset for all landscape character assessments.
- No data identified for litter or graffiti as pressure/impact. Local councils/parish councils could be approached.
- No data for usage vs accessibility for sites

Option appraisal

In the short-term, data sources identified can be used to assess the landscape and features. The People and Nature and MENE surveys need to be investigated to determine if they can be used for assessing individual assets.

The medium-term option is to expand on the data sets identified and investigate the feasibility of obtaining data on usability vs access. It would also be useful to investigate the indicators developed as part of Natural England’s All-England Strategic Landscape Mapping Assessment to see if some of these could be used for the river environment.

In the long-term, further data on people’s enjoyment and perception of beauty needs to be gathered by local perception surveys.

Additional models such as the Scenic Quality model in InVEST could be investigated, although this is more suited for investigating the impact of structures on the landscape, so may not be appropriate.

Artificial rivers

Condition assessment flow chart

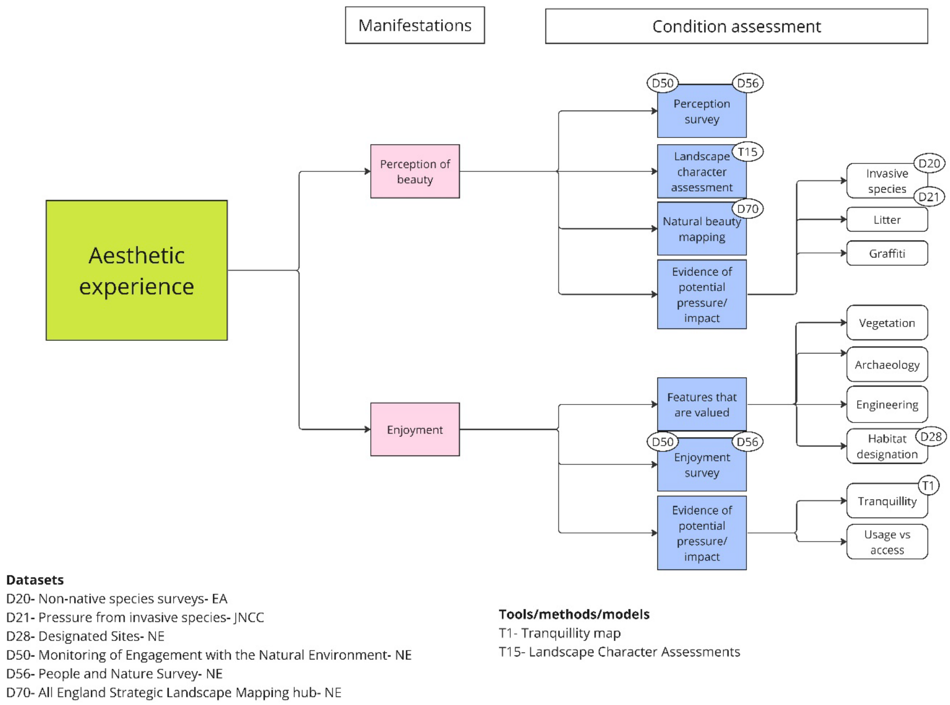


Figure 30: Artificial – Aesthetic experience

Figure 30 shows the condition assessment flow chart for Aesthetic experience for Artificial rivers. Much of this is the same as for Natural rivers, however physical modifications are not viewed as a pressure/impact and different features are valued.

Assessment of indicators

The data sources identified are the same as for natural rivers and have the same considerations when applied to artificial rivers.

Different features in artificial rivers may be valued, such as any archaeological or engineering aspects. The design and features present in an artificial river, like a canal, can impact its aesthetic appeal. Factors such as the type of materials used for construction, the style of bridges and locks, and the presence of artwork or other decorative elements can all contribute to the canal's visual appeal.

Gap analysis

As well as the gaps identified for Natural rivers, there are gaps for:

- Archaeology features that may be valued
- Engineering features that may be valued

Option appraisal

In the short-term, the condition assessment flow chart and data sources should be reviewed with specialists in artificial rivers e.g., CRT.

In the longer term, data sources of engineering and archaeological features that are valued are to be identified. Further data on people's enjoyment and perception of beauty needs to be gathered for individual natural capital assets such as rivers and canals. These gaps could be filled using surveys.

5.3.8 Education, training and investigation

"Natural areas provide numerous opportunities for study, education, and research, as well as references for monitoring environmental change."

Natural rivers

Condition assessment flow chart

Figure 31 shows the condition assessments for 'Education, training and investigation'. This has been split into the existing use and the potential use of the asset for Education, training and investigation.

Existing use can be for research projects, school visits, volunteering opportunities, training or for any monitoring purposes.

Potential use can be assessed by looking for the number of sites (accessible, designations like SSSI, natural etc.) within a defined distance of a place of education.

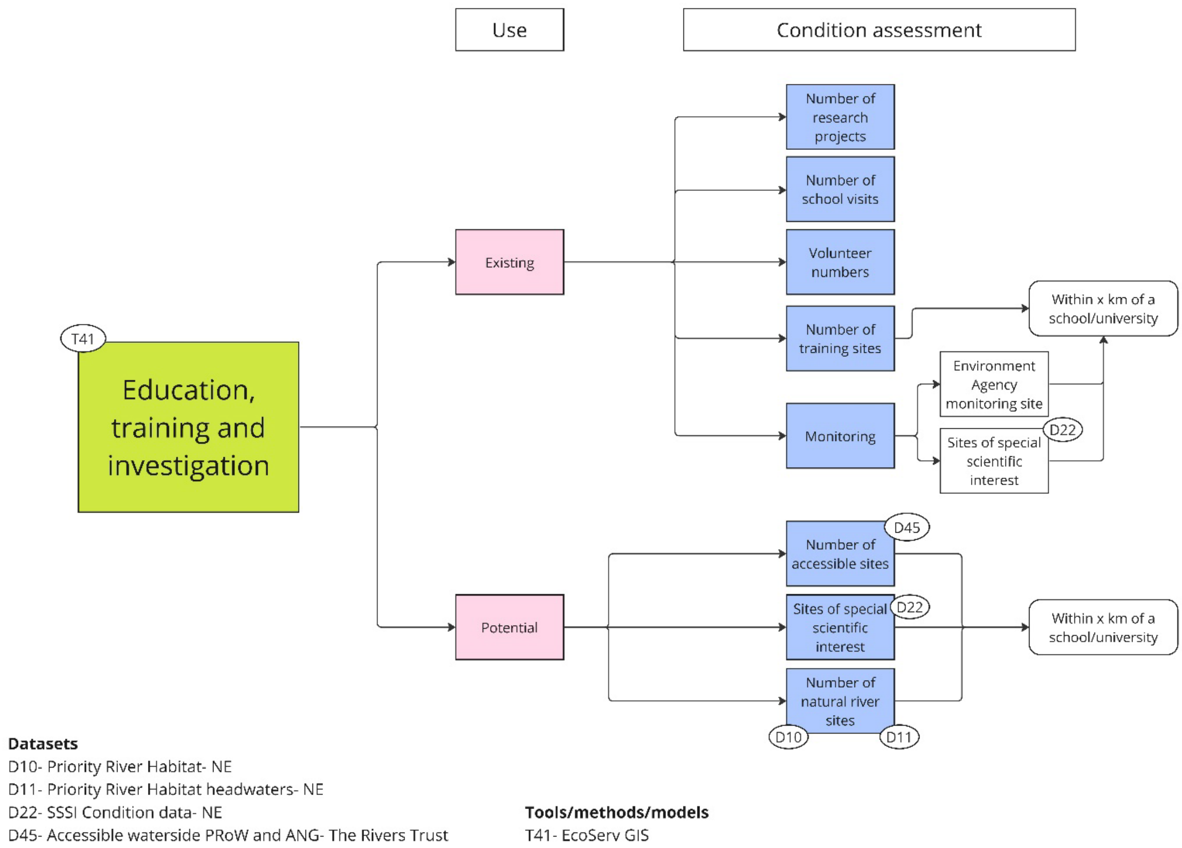


Figure 31: Natural – education, training and investigation

Assessment of indicators

Existing scientific investigation could be measured by the number of research projects being conducted at a site; however, no data source has been identified that could be used for this. Individual searches for research papers for sites could be performed. School visit numbers would be informative regarding the educational use of an asset, but no data source has been identified. Volunteer opportunities often involve an element of education or training and so the number of volunteers engaged in river activities or work can be considered when making an assessment. Training may also take the form of boating, fishing or other recreational activities and this could also be used in conjunction with proximity to education providers. This data could be collected from Rivers Trusts.

Indicators of scientific and investigative interest could be sites that are monitored by the EA along with survey sites. As SSSIs are defined by their biological or geological interest they may reflect greater opportunity to engage in education. Natural river sites can be identified by using the Priority River Habitat data sources.

As potential use cannot be measured by looking at the number of existing visits/projects etc., it can be assessed by investigating the proximity of different types of sites that are within a defined distance to a place of education. Whilst the flow diagram shows number of sites within a distance to a place of education, if it is an individual site being assessed it may be more appropriate to measure the number of places of education within a specified distance to the site e.g., if the site is an SSSI, then measure how many places of education are within a certain distance. The location of schools and higher education facilities can be obtained from OS VectorMap District.

EcoServ GIS offers an Education Knowledge model, which considers both the capacity of the natural environment to deliver the service, based on the accessibility and diversity of habitats, and demand for the service, based on the number of young people in the local population, the education scores of the local population (based on Index of Multiple Deprivation scores) and travel distance from schools.

Gap analysis

There are several data gaps found within this review:

- There was limited data found to assess existing use, apart from some monitoring data e.g., SSSIs. Whilst no data source has been identified for EA monitoring sites as part of this quick review, there should be a number that can be used e.g., fish surveys

Option appraisal

In the short-term monitoring site data sources and the location of places of education need to be collated. This will enable a more complete picture of existing monitoring use, as well as potential uses.

Longer term needs include gathering more data on number of research projects to give further information on the current use for investigation. It would also be useful to investigate the use of the EcoServ GIS Education Knowledge model. The Children's People and Nature survey dataset should be considered as a potential data source in further work. Data on school visits, volunteer numbers and training sites could be obtained from local river groups and Rivers Trusts to complete the assessment.

Long-term, data can be collected on school visits, volunteer numbers and training sites to complete the assessment.

Artificial rivers

Condition assessment flow chart

The condition assessment flow chart for Artificial rivers is shown in Figure 32.

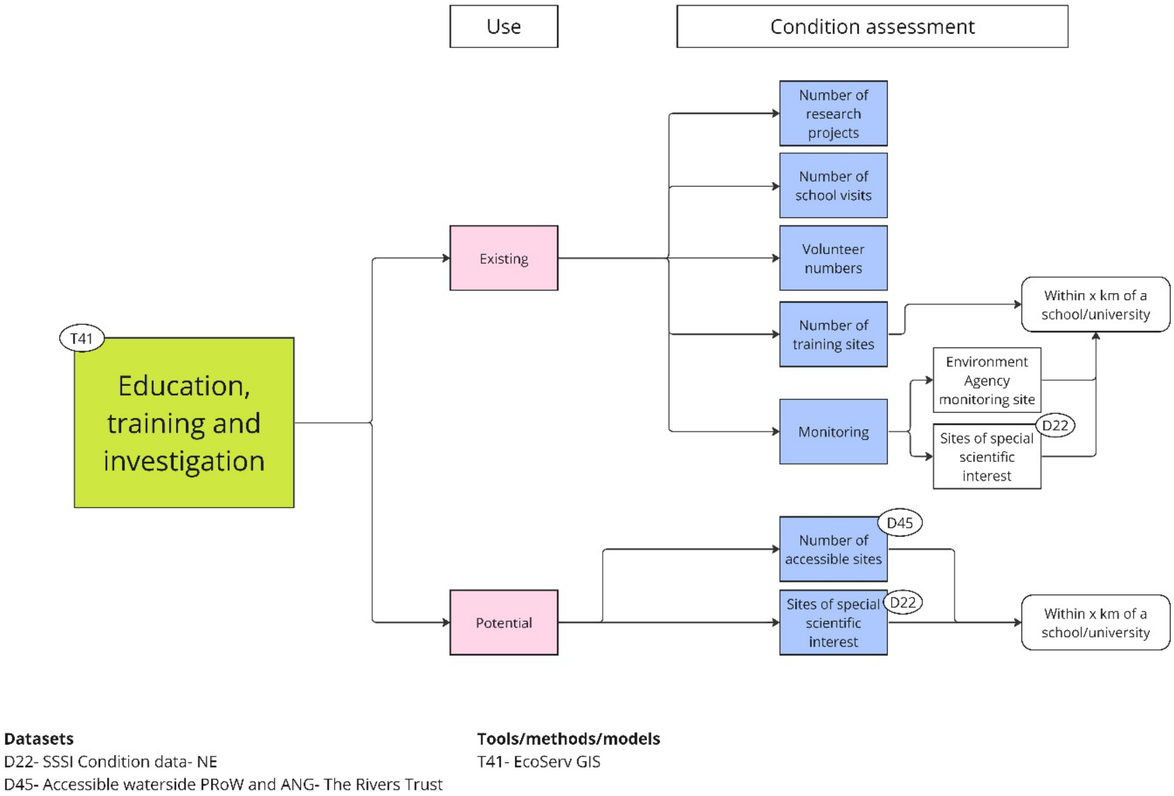


Figure 32: Artificial – Education, training and investigation

Assessment of indicators

For artificial rivers, the flow chart has the same indicators for Existing and Potential uses as Natural rivers, apart from the absence of Number of Natural River Sites.

Gap analysis

As per natural rivers gap analysis.

Option appraisal

In the short-term, the condition assessment flow chart and data sources are to be reviewed with specialists in artificial rivers e.g., CRT. The option appraisal is the same as for natural rivers.

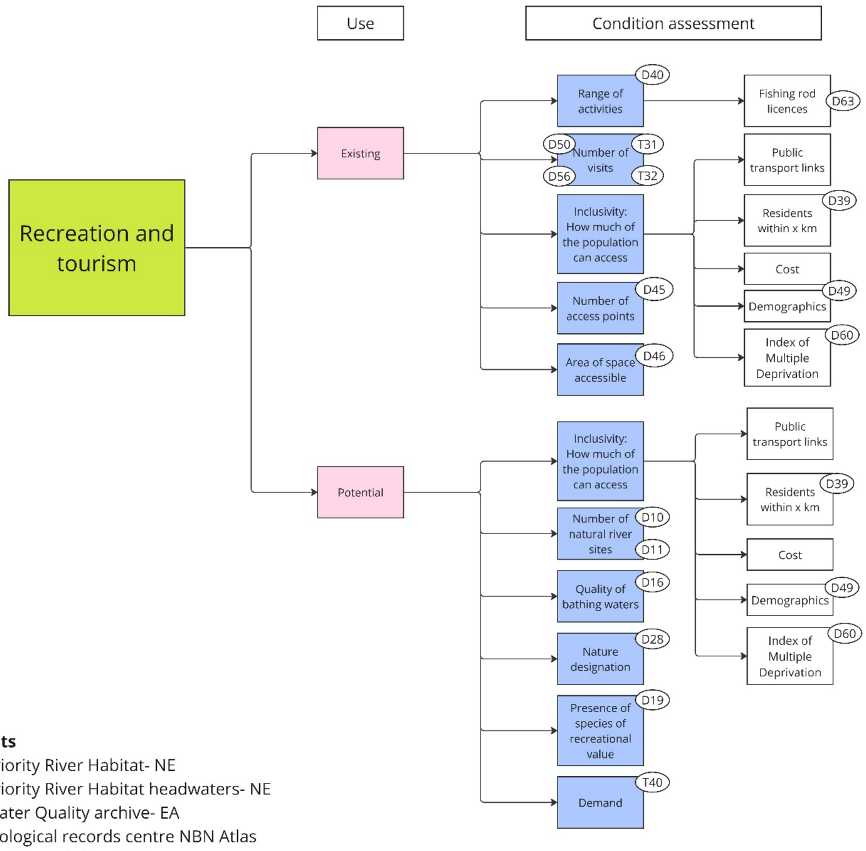
5.3.9 Recreation and tourism

“Human values derived from recreational uses of ecosystems, including their often-substantial tourism potential. Natural ecosystems are often used as places for relaxation and recreation, including hiking, camping, fishing, and nature viewing.”

Natural rivers

Condition assessment flow chart

Figure 33 shows the condition assessment flow chart for ‘Recreation and tourism’. Its existing use is related to the ability of people to access the site. Its potential for use not only considers its accessibility but also the naturalness of the site and the demand.



Datasets
D10- Priority River Habitat- NE
D11- Priority River Habitat headwaters- NE
D16- Water Quality archive- EA
D19- Biological records centre NBN Atlas
D28- Designated sites- NE
D39- Population Density - ONS
D40- Active Places- Sport England
D45- Accessible waterside PRoW and ANG- The Rivers Trust
D46- Green Infrastructure Portal- NE
D49- Cultural identity data- ONS
D50- Monitoring of Engagement with the Natural Environment- NE
D56- People and Nature Survey- NE
D60- Index of Multiple Deprivation
D63- Annual summary of rod license sales- EA

Tool/method/model
T31- NEVO
T32- ORVal
T40- EcoServ R/GIS

Figure 33: Natural – Recreation and tourism

Assessment of indicators

The quality of existing use can be assessed by the range of activities available. As fishing is an important recreational activity related to natural rivers it is shown in the flow chart, however, other activities should be considered too. The ‘Annual Summary of rod licence sales’ is readily available and updated annually. However, it lacks spatial coverage as it only shows the number of anglers across 15 areas of England. Other methods, such as estimating angler expenditure could be used for assessing this ecosystem service (Butler et al., 2009).

The number of visits is a good indicator of the recreation and tourism ecosystem service. The MENE survey, and subsequently the People and Nature Survey, captures the time spent in nature, but further investigation is required to determine the spatial constraints of the data. The MENE dashboard displays data at the Local Authority level which may be too high a level for conducting condition assessment at river scale. The ORVal and the NEVO tools model the number of visits to parks, greenspaces and footpaths, although this would need to be restricted to riverside areas.

Inclusivity can be assessed in the same way as for the 'Health and Wellbeing' ecosystem service, looking at Public Transport links, residents, cost, demographics and index of multiple deprivation.

The 'Accessible waterside PRoW and ANG' dataset will give a good indication of accessible sites, based on proximity to public rights of way, along with the Green Infrastructure portal, which provides a mapping tool with several layers to visualise accessible space including access points. The G3 (Enhancement of green and blue infrastructure) 25 year environment plan indicator could also be used.

The presence of facilities also plays a key role in determining visit numbers, particularly car parking, toilets, cafes, and the accessibility of paths. These are built facilities (built capital), rather than natural capital, but are nevertheless important to take into account, and are built into models such as ORVal and NEVO.

Potential use can be assessed by identifying sites that are accessible and have high ecosystem quality. The number of natural river sites can be found using the Natural England Priority River Habitat data sets. This assumes that natural rivers may provide opportunities for recreational/tourism activities e.g., fishing, wildlife watching.

To ensure some recreational activities, such as swimming, are safe and enjoyable, good water quality is required. The EA water quality data archive could be used to assess this condition.

If the site has a designation, such as SSSI, SAC, NNR, etc. then its potential for recreation/tourism related to wildlife viewing may be increased as people may be more likely to want to visit. The Natural England Designated Sites layer is provided on the open access MAGiC (Multi-Agency Geographic Information for the Countryside**)** map, allowing this information to be easily viewed.

There may be species present that are of recreational value e.g., trout for fishing, and this can be assessed using the 'Biological records centre NBN Atlas', or other survey data. The B7 'Health of freshwaters assessed through fish populations' 25 year environment plan indicator may also be useful to assess this.

Finally, the demand for recreation and tourism can be used as an indicator. One example of this is the Ecoserv-R/GIS Accessible Nature demand model, which models and maps demand based on three indicators: population density, health scores (from the Index of Multiple Deprivation), and distance.

Gap analysis

For existing use, gaps identified within this review are:

- Range of activities – no comprehensive data source identified.
- Number of visits to a particular stretch of river may require some modifications of ORVal/NEVO and may not be provided by the MENE/PANS surveys.
- No public transport links, although as there are plenty of maps (bus/train) available which could be added with further review. No open access data on cost of entry to sites.

For potential use, gaps identified are:

- The same data gaps are present for public transport links and cost of entry to sites.

Option appraisal

There are sufficient data sources available to provide a basic assessment of the ecosystem service in the short-term, as there is coverage of accessibility and the naturalness/quality of the environment. Demand can also be modelled.

In the medium-term further information should be gathered on the number of visits/visitors and types of activities that this ecosystem can support, as this is a key indicator of condition. This may be available at a local scale from organisations such as the National Trust. Mapping of public transport links should be achievable. Information on other recreational activities could be obtained from contacting boating, canoeing, open water swimming and walking clubs within specific areas.

Other models could be assessed, such as the InVEST Recreation model. This model is based on the density of geotagged photos in Flickr, as a proxy for visitation. Flickr is no longer commonly used, but it may be possible to find an equivalent. Mobile phone data has also been used to map visits and this approach could also be investigated further. Visit data can then be compared to site condition data to determine patterns driving visitation.

Artificial rivers

Condition assessment flow chart

For artificial rivers, the condition assessment flow chart is shown below in Figure 34. This has mostly the same indicators as natural rivers considering existing and potential uses. One difference is that the number of natural river sites as this not applicable to artificial rivers. Instead, the availability and quality of infrastructure, such as boat ramps, fishing docks, and toilets, can impact the ability of the artificial river to provide recreation and tourism opportunities. Adequate infrastructure can enhance visitors' experiences and attract more tourists.

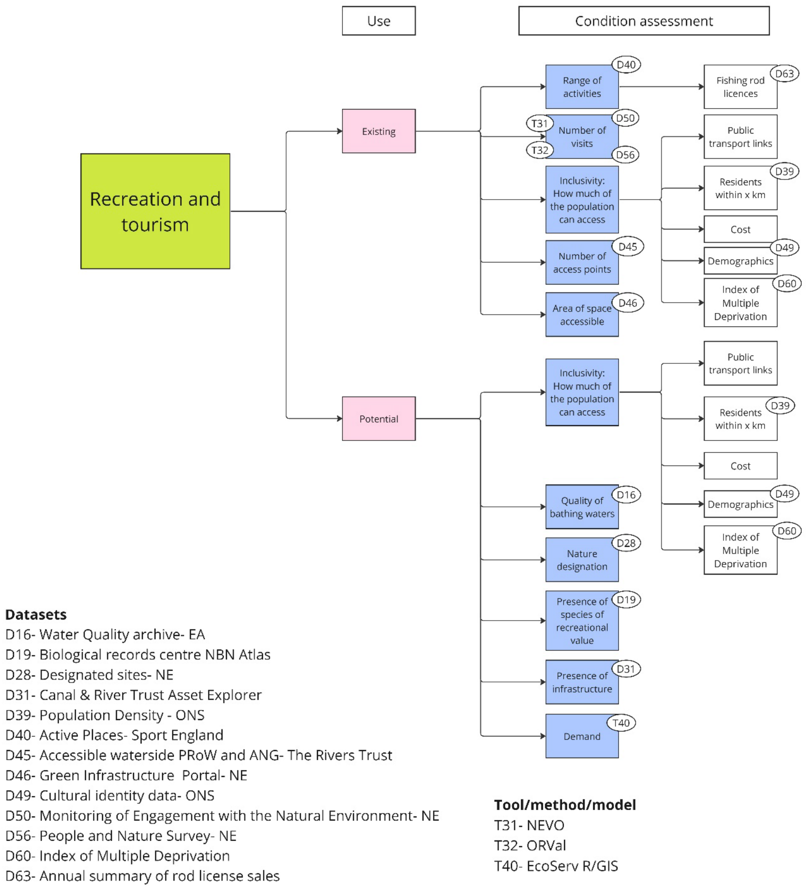


Figure 34: Artificial – Recreation and tourism

Assessment of indicators

As per natural rivers, indicators cover accessibility of sites, range of activities and numbers of visits or visitors for the current use. For potential use, presence of infrastructure that could be beneficial to visitors is an important indicator. The ‘Canal & River Trust Asset Explorer’ provides open-access maps of assets that form the Trust’s network. This includes observation points, bridges, docks, and lakes, ponds and fisheries (points), which are positive for recreation and tourism.

Gap analysis

As per natural rivers gap analysis.

Option appraisal

In the short-term, the condition assessment flow chart and data sources are to be reviewed with specialists in artificial rivers e.g., CRT. If satisfactory, then the medium and long-term option appraisal is the same as for Natural rivers.

5.3.10 Spiritual and cultural experiences

> "The things in nature that help people identify with the history or culture of where they live or come from or that have spiritual importance for people. Nature is a common element of all major religions. Natural landscapes also form local identity and sense of belonging."

Natural rivers

Condition assessment flow chart

Figure 35 shows the condition assessment flow chart for 'Spiritual and cultural experiences'. This has been split into historical and spiritual expressions. For each of these, there are two perspectives:

- Insider – which is personal to the observer and could be viewed as a subjective experience.
- Outsider – which looks at more external factors that could be measured, such as records of features.

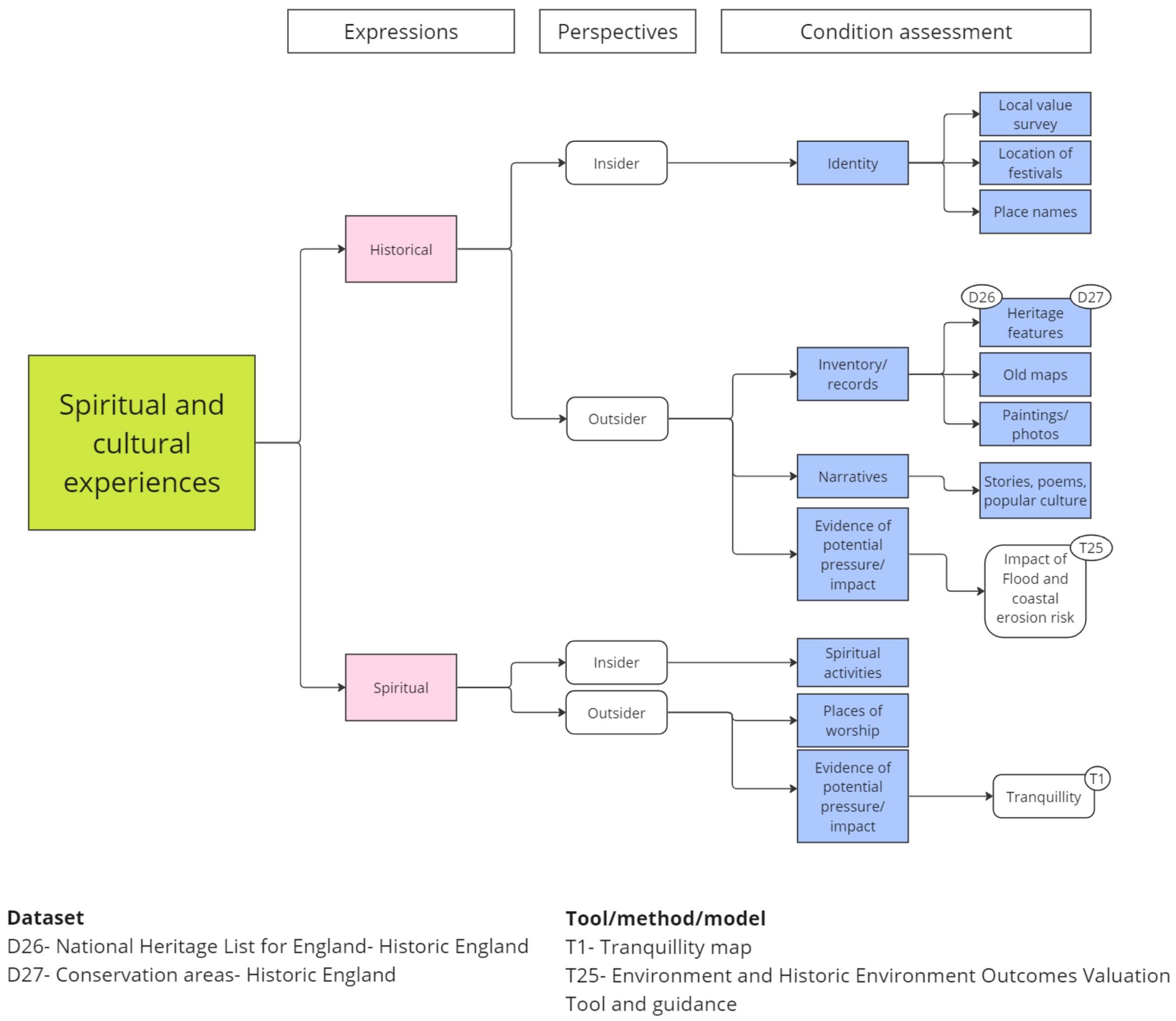


Figure 35: Natural – Spiritual and cultural experiences

Assessment of indicators

How people connect and identify with a place, in this case a river, is crucial in how much value this ecosystem service can deliver. To assess local identity and community engagement, local value surveys, the location of any festivals connected to rivers, and any place names (e.g., towns with the name of the river in them) can be used as indicators.

An important indicator is the presence of heritage features or historical records that describe how people used rivers in the past. This can help people connect to their local identity and ancestors. For example, there is evidence on floodplains of water meadows that were used in the past to irrigate crops (Historic England, 2018). Historic England provides a National Heritage List for England that shows the location of all nationally protected historic buildings and sites in England. This dataset is updated daily and provided in an ESRI (Environmental Systems Research Institute) REST format. Additionally, Conservation Areas as designated by local planning authorities may be used. Other records, such as old maps, paintings or photos referencing the river should also be considered.

Rivers are often referenced in stories, poems and popular culture and these narratives should be considered as indicators of cultural value.

The EA Environment and Historic Environment Outcomes Valuation tool and guidance can be used to measure the monetary value of the impact of flooding on historic sites, that may adversely affect this ecosystem service.

To understand the spiritual benefits of this ecosystem service, spiritual activities/experiences and any places of worship are considered. Sites that are viewed as spiritual are often tranquil, so the Tranquillity map may be of some use in assessing this.

Gap analysis

There are many gaps in data for assessing the condition of this ecosystem service:

- Identity, local value surveys, locations of festivals and place names
- Data for records of old maps is likely to be a gap in identification as part of this brief review rather than an absence of records.
- Data on old paintings/photos
- Stories/poems/references in popular culture
- Spiritual activities (which may be hard to find).
- Data on places of worship was not identified as part of this review but may be available or can be collated from several different sources.
- The Tranquillity map would have to be investigated further to determine if it is appropriate for assessing the condition of this ecosystem service.

Option appraisal

In the short-term, there are insufficient data sources to assess this ecosystem service. Places of worship and historical maps may be the easiest way to obtain data to improve this.

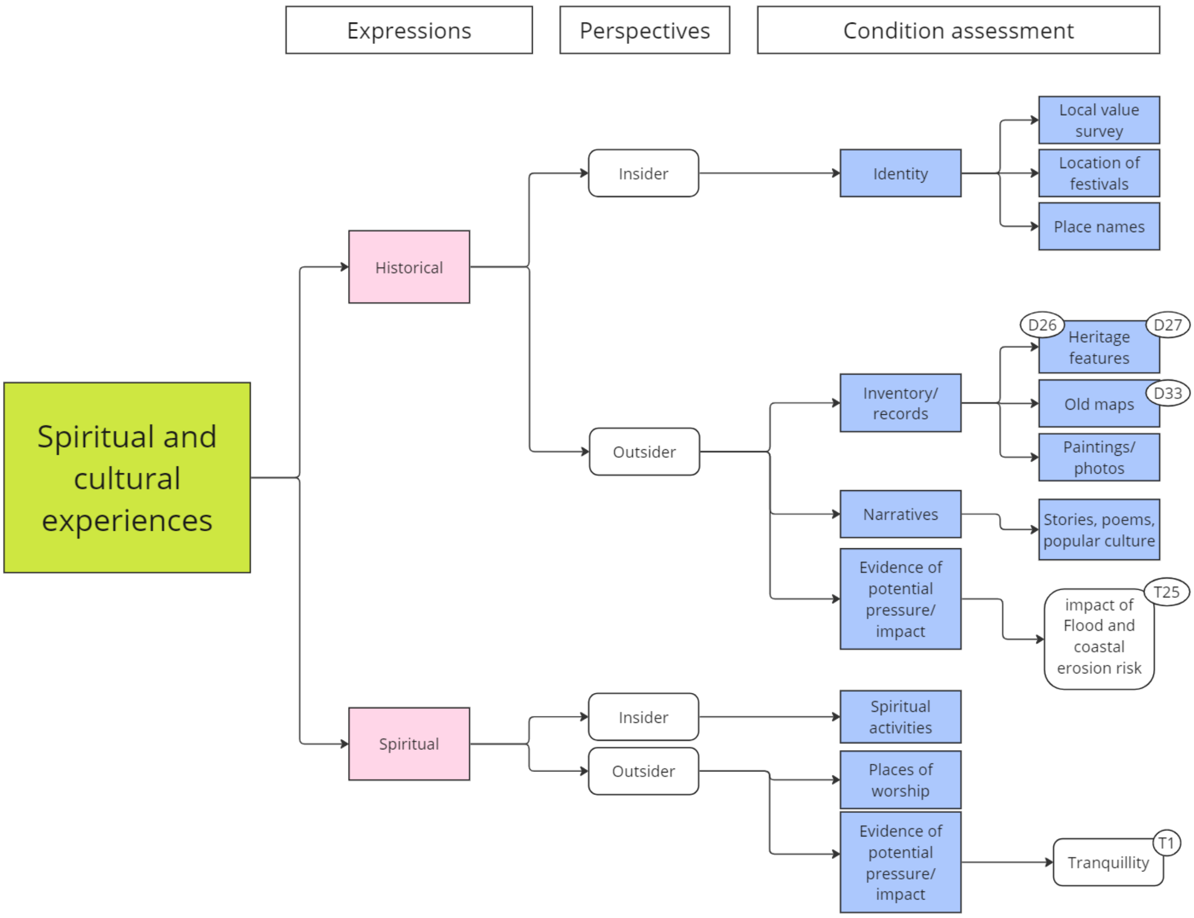
In the medium-term, data could be obtained on place names, i.e. where rivers are referenced in place names.

Natural England's All-England Strategic Landscape Mapping Assessment developed a series of maps and indicators around cultural heritage across the wider landscape. Similarly, Natural Resources Wales have developed LANDMAP, which includes mapping of historic and cultural landscapes. It would be useful to assess if some of the indicators and methods developed for either of these projects could be relevant for riverine landscapes.

Longer-term, more data is required to assess this ecosystem service. This includes local value surveys to determine how people identify and engage with a river, understanding what spiritual activities take place there and what narratives have been built around the river.

Artificial rivers

Condition assessment flow chart



Dataset
D26- National Heritage List for England- Historic England
D27- Conservation areas- Historic England
D33- Lost waterways map

Tool/method/model
T1- Tranquillity map
T25- Environment and Historic Environment Outcomes Valuation Tool and guidance

Figure 36: Artificial – Spiritual and cultural experiences

The condition assessment flow chart for artificial rivers, Figure 36 above, considers the Historical and Spiritual perspectives in the same manner as Natural rivers. An artificial river may have historical and cultural significance. It can provide opportunities for people to connect with their cultural heritage or learn about local history with events and festivals such as boat parades.

Assessment of indicators

The way the condition of this ecosystem service is assessed is the same as for natural rivers, however, an additional lost or abandoned waterways map from the Canal & River Trust shows ‘potential restoration projects, proposed new canal links and historic waterways across England and Wales’. This can be used to inform the assessment of the historical value of the ecosystem service.

Gap analysis

The gaps present here are the same as those identified for natural rivers with the exception that there is a data source identified for Historic maps: Lost waterways map.

Option appraisal

As per natural rivers, in the short-term, there are insufficient data sources to assess this ecosystem service. Places of worship and any further old maps may be the easiest to obtain to improve this, although the condition assessment flow chart and data sources should be reviewed with specialists in artificial rivers e.g., CRT.

Medium and long-term options are as per Natural rivers.

5.3.11 Data sources

- Enabling a Natural Capital Approach (ENCA) resource
- 25-Year Environment Plan indicators
- MAES indicator framework for assessing ecosystem services.
- ONS indicators
- Natural England Natural Capital Atlases
- Scoping a State of Natural Capital Report (2022)
- NE’s Needs Analysis for Natural Capital Evidence Across Natural England report
- The Rivers Trust CaBA Data portal
- Environment Agency Ecology and Fish Data Explorer; Catchment Data Explorer
- CEH data portals
- Biological Records Centre
- Natural England data portal
- Canal & Rivers Trust

6. The OxCam LNCP approach to mapping habitat condition

In this section we outline the OxCam LNCP approach and its applicability to the current project.

6.1 Introduction

The OxCam Local Natural Capital Plan (LNCP) approach to mapping habitat condition was a pilot project that used existing data and inferences to map natural capital asset condition across Northamptonshire and Peterborough, covering both terrestrial and aquatic habitats. It focused on condition from the perspective of habitats and biodiversity (particularly in relation to the Biodiversity Metric) and did not consider other aspects of condition. The project team were asked to review this approach, as it provides one of the only examples of mapping condition at a landscape scale and so can be used to inform discussion of potential landscape scale approaches. The OxCam project focussed on all habitats, both terrestrial and aquatic, hence it is a broader assessment that anything considered to this point in this report. Note that the OxCam project was undertaken by Natural Capital Solutions (Rouquette, 2020) and we acknowledge the potential conflict of interest in now reviewing this approach.

The OxCam project was commissioned by the Nene Valley Nature Improvement Area Board and the Northamptonshire Local Nature Partnership and was funded by the OxCam (LNCP) Project. The approach has since be used in a number of other locations (see Section 6.5).

In this section we summarise the approach developed for that project, and the results obtained. We then go on to examine more recent updates, the main uses of the outputs, and its potential for national use. Its relevance to the current work is also discussed.

6.2 Aim and approach

Information on habitat condition is often missing from natural capital baseline assessments or asset registers, which regularly focus on the extent of habitats, yet information on condition can prove invaluable. Accurate assessment of habitat condition usually requires a site visit, but this is time-consuming, costly, and not always possible due to access restrictions. There is therefore a need for a method to assess condition of habitats at a landscape scale using existing data.

The aim of this project was therefore to **determine if it was possible to assess the condition of habitats at a landscape scale, using existing data and inferences**.

The first step was to create a detailed natural capital asset (habitat) basemap for the whole study area. To do this, Ordnance Survey MasterMap polygons were used as the underlying mapping unit. A series of different data sets were then used to classify each polygon to a detailed habitat type and to associate a range of additional data with each polygon.

To map condition, the project then followed a three-step approach:

1. Condition was assigned to all habitats of low or no biodiversity interest.
2. SSSI and Local Nature Reserve/Local Wildlife Sites/ County Wildlife Site (LWS) condition data were used to assign condition to the best quality wildlife sites. This uses the assumption that all semi-natural habitats within the unit or site are assigned that condition[4].
3. A number of rules and assumptions were developed, based on other data sources, to assign condition to several of the remaining habitats.

To help guide the process, determine the usefulness of the outputs and guide recommendations going forward, a stakeholder workshop was held as a fundamental part of the project. Rules and assumptions were developed in conjunction with stakeholders and experts (both within the workshop and separately) and were only taken forward if considered reliable and robust.

6.3 Results

The approach to mapping condition developed for this project enabled 95.4% of the area to be assigned a condition with reasonable confidence[5]. Using the Biodiversity Metric 2.0 (version that was current at the time), conditions were assigned to each category ranging from ‘good’ to ‘poor’, with two N/A categories for agriculture and other non-natural habitats. When used in the metric, these categories are also given a score from 0-3.

Based on descriptions in the Biodiversity Metric 2.0, it is possible to assign condition categories to several low-quality categories without the need for any further information. This includes all built habitats such as buildings and infrastructure (N/A – other), arable (N/A – agriculture), improved grassland (poor), and gardens (poor). When these categories were assigned across the study area, 1.475M polygons covering 230,000 ha were given a condition category, accounting for 83.4% of the total study area.

[4] Condition of a unit cannot be greater than the least favourable feature within the unit. Note however, the features considered for SSSIs are only those that are designated, so on occasion may not always be directly concerned with habitats.
[5] Confidence in results based on expert opinion from stakeholders, as it was not possible to test the results against independent data.

Condition data for SSSIs and LWS then enabled condition to be assigned to 9,600 ha of semi-natural habitats, representing 3.5% of the total area.

In the third step, a series of rules and assumptions were developed based on external data sources, expert advice, and discussions with stakeholders, to assign condition to several of the remaining habitats. Robust assumptions could be made about the condition of broadleaved woodland, coniferous woodland, mixed woodland on ancient woodland sites, amenity grassland, and water bodies, and these are outlined in Table 11. The process of inferring condition for these habitats, resulted in an additional 23,900 ha of habitats being assigned a condition, or 8.7% of Northamptonshire and Peterborough.

Table 10: Habitats where it was felt that a condition could be inferred and the explanation for how the condition was assigned.

Habitat	Condition	Reason
Broadleaved woodland	Moderate	National Forest Inventory condition data (Forestry Commission, 2020) shows that 92% of broadleaved woodlands in England are given a condition score of intermediate – assume best, more favourable woodlands will be in designated sites, so remaining likely to be moderate.
Coniferous woodland	Poor	Almost all coniferous woodlands in the study area are plantation woodlands – Biodiversity metric assigns poor.
Mixed woodland on ancient woodland sites	Moderate	Because they are likely to be PAWS (Plantations on Ancient Woodland Sites)
Amenity grassland	Poor	Following Biodiversity Metric 2.0 – although there is a chance some of these could be being managed for biodiversity but felt that would be a small minority.
Quarries / mineral extraction sites	N/A – Other	Assumed that these habitats are unlikely to provide much value
Water	Variable	WFD overall waterbody class was used to assign condition to water habitats.

Source: Summary of Table 9 in Rouquette (2020)

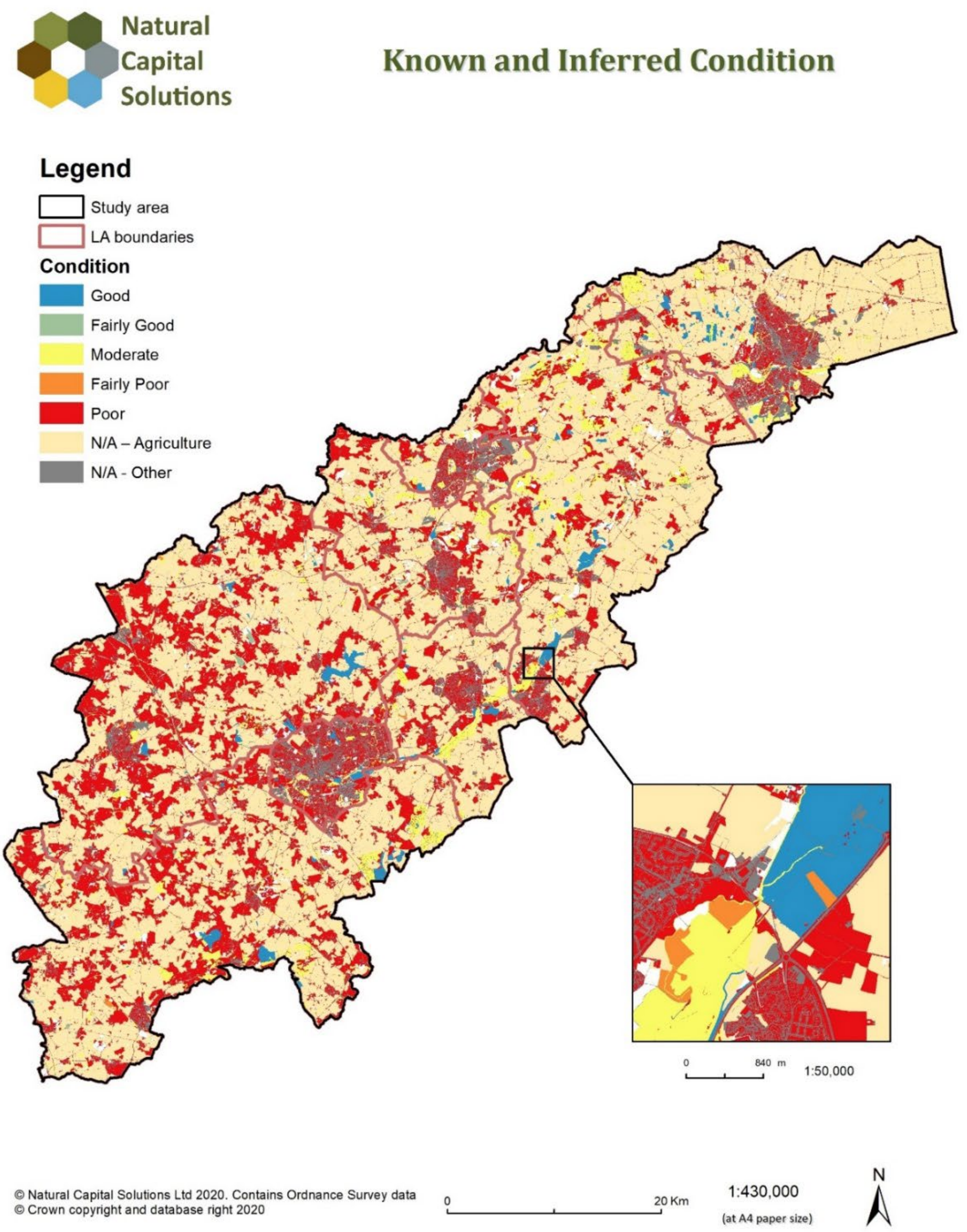


Figure 37: Final map of condition (from Rouquette, 2020), showing all habitats and sites where condition had been assessed or could be assigned with reasonable confidence. Note that unassigned areas shown as white space.

Following this process, 12,500 ha of habitat remained unassigned, or 4.6% of the study area, which was predominantly rough and semi-improved grasslands, mixed woodland, scattered trees, and floodplain grazing marsh. The workshop discussed the idea of assigning all unclassified habitats to a standard 'moderate' category to enable completeness of the mapping, however, it was decided that it was better to produce a condition map with gaps where there was reasonable confidence in the categories assigned, rather than one that was complete but relied on a significant number of assumptions, that outweighed the usefulness of the product. The final condition map is shown in Figure 37.

6.4 Assigning condition to aquatic habitats

WFD overall waterbody class was used to assign condition to water habitats. WFD categories of high, good, moderate, poor, and bad, were translated directly into good, fairly good, moderate, fairly poor, and poor condition categories, respectively. This was done to match the nomenclature to that used in the Biodiversity Metric and to ensure consistency of category names across terrestrial and aquatic habitat types. We used the most detailed WFD River Waterbody catchments (the study area contained 117 different waterbodies) and overlaid this data layer onto the basemap. All water areas within each waterbody were assigned to the condition category of the waterbody.

The approach of the OxCam project was to apply a single summary condition for each habitat unit across the study area. Therefore, using the WFD overall waterbody class was chosen as the best way to arrive at this summary. When considered in the context of the current project, this approach is suitable if only a single summary of condition is required, especially if the focus is around condition for biodiversity. However, where a more nuanced approach is required, or the condition for different ecosystem services is of interest, a wider range of indicators (as detailed in Section 5) or different indicators would be required.

6.5 Further use of the approach and updates

Since developing the approach in 2020, it has been used to map condition and biodiversity units in a number of other places, including South Yorkshire, Cambridgeshire, Buckinghamshire, West Lothian, and a number of estates and land holdings across the country. The scores have been updated to Biodiversity Metric 3.1 and will be updated again to version 4.0 (released March 2023).

Note that in more recent projects, most stakeholders have preferred that all remaining unassigned habitats are given a rating of 'moderate', to provide completeness of mapping and to ensure that all biodiversity units are calculated and included. This likely reflects changing use of the output, from being purely focussed on condition, to being more focussed on biodiversity units and biodiversity net gain (see below).

6.6 Potential uses

Stakeholders who have previously received the condition and biodiversity units mapping, were emailed for feedback on the uses of these outputs, which is reported here. The forthcoming requirement to achieve at least 10% biodiversity net gain on new developments has driven a focus on understanding baseline biodiversity units (BU). Although developers will need to calculate this accurately, based on ecological fieldwork, there is interest in establishing indicative scores across wider areas. For example, Buckinghamshire Council are interested in establishing indicative BU scores across all their allocated sites and sites identified for screening under their forthcoming local plan. Some local authorities (e.g., Cambridgeshire) have a policy of 'doubling nature'. Although not always clearly defined, this may not be focussed on doubling land areas, but in doubling the number of biodiversity units being delivered. In these cases, mapping condition is a necessary prerequisite for calculating baseline biodiversity units.

Another key area of interest at present is around the Local Nature Recovery Strategy (LNRS) process. Mapping condition gives a more complete picture of the state of nature in an area and can be used to highlight locations where habitat enhancement works could be focused. It can hence feed into both the Local Habitat Map and the Statement of Biodiversity Priorities. Another user stated that the condition map looks useful for them at a Ward scale (but not at site scale) to help them determine where they have a good nature network already forming, and also where opportunities lie for habitat improvements (including where there are gaps in good condition habitat).

A further potential use, highlighted by the Wildlife Trust for Bedfordshire, Cambridgeshire and Northamptonshire, was to use the condition map to target areas for survey. In particular, areas of semi-natural habitat that have not been assigned a condition (blank areas on the map), or areas where condition assessment dates from a long time ago.

Informing internal discussions was another area highlighted, with one local authority user stating that "…the Condition maps are actually coming in very handy when talking to Planning colleagues and Property colleagues too."

Note that not everyone agreed that the outputs were universally useful. One stated that while the condition map had potential, the biodiversity unit one did not, due to the large number of assumptions made and that it does not pick up small features (e.g., field margins, wildflower verges, hedgerows).

6.7 Conclusions and recommendations

The OxCam approach was developed for assessing condition at a catchment or county scale across all terrestrial and aquatic habitats. As such, it does not focus in any detail on rivers, using a simple but effective approach to capture condition of aquatic habitats. WFD overall waterbody class is intended as a summary of the status of each waterbody, capturing elements of ecological (biological, physico-chemical and hydromorphological) and chemical condition. Where one simple measure is required to summarise the condition of a waterbody, this would appear to be the most suitable approach (but see Section 7). Where more detail is required, or specific aspects of condition are of interest, then other condition indicators being investigated during this project may be more suitable.

Where interest is focussed on the condition of all habitats at a catchment scale (not just rivers), the approach developed for the OxCam LNCP is effective. It is not feasible or practical to assess condition in the field across large areas, but this information is nevertheless useful, hence the approach developed in the OxCam LNCP project has an important role to play. The maps can be used for strategic decision-making at the landscape scale, but at a local scale or if precise estimates are required, site surveys and assessment will still be required.

An alternative approach to mapping condition and biodiversity units has been developed for Greater Manchester (TEP 2020). Exact methodological details are not provided, but ecological designations were used as a proxy for habitat condition and strategic importance. It is likely, therefore, that this assumes that all SSSIs are in good condition, all LNRs are in the same (presumably lower) condition and all habitats that are not designated will receive a lower condition again. This method has the appeal of simplicity, but these types of generalisations would lead to a number of discrepancies.

Another approach trialled in Buckinghamshire[6], involved local biological recorders visiting and assessing sites in their area. A website was created showing sites where condition information was lacking, recorders selected a site of interest and then filled in an online form about condition and other site attributes. This approach was good at engaging the local biological recoding community, but it was difficult to achieve consistency in assessments from different individuals, and although data was collected from over 150 sites, large gaps remained.

To test the robustness of the OxCam approach it would be beneficial if the results of the condition mapping were tested in the field. This would require visiting a number of sites and carrying out a condition assessment in situ and comparing the results to the desk-based output.

The OxCam report also revealed that a large number of LWS do not have a recent condition assessment. Given the increasing focus on assessing condition for a whole range of different applications, it would be a good idea if these sites could be assessed (and funding released to enable this) as a matter of priority. The unassigned habitats could also provide a targeted set of sites that can be prioritised for site-based habitat condition assessments. As these are often un-designated but potentially good quality habitats, these sites are potentially vulnerable and should be a priority to investigate further.

The OxCam approach does come with a number of caveats. For example, the habitat basemap is based on OS MasterMap, which does not capture field margins and

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[6] Buckinghamshire and Milton Keynes Environmental Records Centre, unpublished.

boundaries, hence the assessment will not take into account well managed field borders, which could downplay the value of these areas. One user felt that sharing maps that missed out these features could alienate the farmers/landowners who are making efforts to increase biodiversity. Furthermore, assumptions were made to match up the different condition assessments – SSSI, LWS and Biodiversity Metric. These were not developed to assess condition in the same way or for the same purpose, hence there are inevitably going to be some inconsistencies. Indeed, in some instances SSSI condition assessments may not be related to habitats at all. It would be good to use a more standardised approach to condition assessment for different habitats and designations (also including SACs and SPAs), and it is understood that Natural England are reforming the monitoring process, which will improve consistency.

Despite these caveats, the approach appears useful if used in its intended way and can easily be rolled out nationally (although it does require a detailed habitat basemap). It will always require a health warning that it should be used as indictive and at Ward or landscape/catchment scale only and is not a substitute for field surveys at a local or site scale. The overall usefulness and uses of the outputs are not entirely clear at this stage as it has not been in use for very long, and policy changes that could drive new uses are only starting to come into effect. However, potential emerging applications include identification of sites and habitats that are not in good condition and can be the focus of restoration and enhancement projects[7], identification of sites for survey work, Local Nature Recovery Strategies, natural capital investment plans, broad assessments of baseline biodiversity units and biodiversity net gain for planning and development, and to assist with targeting for the new ELM scheme.

[7] There is a new government target to "restore or create more than 500,000 hectares of wildlife-rich habitat by 2042". This work could be used to highlight where to focus effort, so the benefits are maximised, such as plugging gaps in the nature recovery network.

7. Conclusions

This project has reviewed the links between natural capital asset condition and the provision of ecosystem services, and identified how asset condition can be inferred from existing data. It has also identified where existing evidence and methods are robust and where there are evidence gaps or issues, and made recommendations on evidence gaps and on the data and indicators appropriate for mapping condition in the next phase of the project. All of these objectives have been met, with key findings and discussion points set out below.

Methodology

A key outcome of the project has been the development of a logical framework and objective methods to examine condition in relation to ecosystem services. In the review of the link between condition and ecosystem services flow (Section 4), we followed the methodology of a Quick Scoping Review. The approach was co-designed by the consultancy team and the EA steering group and aimed to be transparent, repeatable and objective, offering a best-practice example of how to conduct a review of this nature. This enabled us to take a huge subject area and identify a representative sample of academic papers (supplemented by a grey literature search) to deliver meaningful results over a relatively limited review period.

The review of data, indicators, tools and models (Section 5) was built on a solid logical framework that links ecosystem functions and processes that drive ecosystem service delivery, to elements that make up those processes and could be related to aspects of condition. This built on the natural capital logic chain, which is the accepted theoretical framework underlying ecosystem services science. It enabled the project team to identify indicators, datasets, and some tools, models and methods that could potentially be used to examine or map condition.

Co-design was an important element of this project: stakeholders were involved early on in helping to define the scope of the project through a workshop process and were involved again as results were emerging, to help refine outputs and shape analyses. The outputs of the workshops near the start of the project directly provided key terms and the framework for the data and literature reviews. Furthermore, the literature review (Quick Scoping Review) was conducted as a collaboration between the consultancy team and the EA's steering group, further embedding the co-design principles and enhancing the usefulness and reliability of the outputs. A further benefit of the wider workshop process has been that a large group of staff at the EA have learnt more about ecosystem services and have bought into the process in a way that could not have been achieved by merely presenting results.

It is hoped that the processes and methods developed and demonstrated for this project, and the co-design practices used, provide an exemplar for projects of this nature going forwards, and are an important outcome in their own right.

Defining condition

This project is focused on condition in the context of rivers. Therefore, one of the key first steps was to understand what condition means and this was achieved through an examination of existing approaches (such as WFD) and consulting with a wide range of EA experts through the workshops. It became quickly apparent that there are multiple ways of assessing condition and that this varies depending on the ecosystem service under consideration. We therefore defined good condition as the state of the asset that enables high provision of the ecosystem service being assessed. Condition is most commonly associated with naturalness or natural processes, but perception and value judgement were also considered very important, particularly for cultural ecosystem services. Other aspects of condition that were examined included resilience, connectivity, access, and human impact. Note also, that the term quality is often used interchangeably with condition and we have treated them the same in this project.

Results

The first objective of the project was to review the links between natural capital asset condition and the provision of ecosystem services (Section 4). The review found that for some ecosystem services there was lots of evidence available, such as habitat and population maintenance, recreation and tourism, and health and wellbeing, but there was very limited evidence for some services, particularly for characteristics and features of biodiversity that are valued, spiritual and cultural value, and education and training. There was a lot of evidence around water quality, but much less in relation to the ecosystem service of water quality regulation. Table 11 presents a summary of the evidence found for each ecosystem service.

Although evidence of links between condition and ecosystem services was generally available, there is much less evidence concerning the nature of the relationship between them (the response curve). Although a linear response is often assumed (i.e. as condition improves, delivery of the ecosystem service will also continue to improve in a similar way), this may well not be the case. For example, there is some evidence that people can distinguish quite well between a river in poor compared to moderate condition, but are less able to distinguish between improvements beyond that. Likewise, certain activities may not be advisable when rivers are in a poor condition (e.g., fishing, swimming), but may occur once condition reaches a certain threshold. These non-linear and threshold responses are interesting but are an area that requires more research.

The second main objective of the project was to identify how asset condition can be inferred from existing data (Section 5) and the review of data, indicators and tools was able to identify a large number of data sets that could be of use in measuring, mapping or modelling condition. For some ecosystem services there were lots of data and tools available (e.g., water flow regulation, habitat population and maintenance, recreation and tourism), but some gaps were apparent (e.g., education, training and investigation; spiritual and cultural experience). Water quality regulation provides a particular difficulty as there are a vast number of indicators and datasets relating to the measurement of water quality, or factors that could affect water quality, but very few that are directly concerned with the regulation of water quality through biological processes. See Table 11 for a summary of indicators found for each ecosystem service.

The third objective of this project was to identify where existing evidence and methods are robust and where there are evidence gaps or issues. Key gaps are listed above, but we also present an overall assessment of the strength of the evidence and overall confidence in the indicators and evidence using a RAG rating. This is shown by the colours in Table 11, with red indicating low confidence in the evidence or indicators, amber indicating medium confidence, and green indicating high confidence.

Table 11: Summary of the key results of the review of condition indicators and the QSR. Colours indicate a RAG rating (Red = low, Amber = medium, Green = high) showing the level of confidence in the indicators and the strength of the evidence found.

Ecosystem service	Indicators summary	Evidence summary
Water for drinking, agriculture and industry	The indicators selected for assessing water provision relate to processes such as water storage and water availability. Most of the indicators demonstrate a moderate to high usability. For natural rivers the indicators are relevant but do not fully explain water storage in the form of groundwater and small floodplain retention features. For artificial rivers there are gaps in the identification of data to support indicators of artificial river channel capacity.	Water storage capacity depends on the evolutionary stage of the river, being high in anastomosing rivers, medium in meandering, and low in leveed, constricted and braided rivers. Water storage is enhanced by beaver dams. Interventions related to extraction, infrastructure and intensive land use have negative effects on the availability of water for agricultural, industrial use or for human consumption (except for dyke relocation); river restoration benefits the availability of water.
Water flow regulation	The indicators assessing water flow regulation take into account hydrological processes such as water storage, run off, infiltration and interception. The analysis of indicators reveals that most indicators demonstrate high usability, including a few more specialised methodologies. The relevance of the data indicators is generally high with multiple different datasets and methods that could be used to assess condition. A comprehensive source of data for floodplain features was not identified, but this could be supplemented with data collection on the ground and from LiDAR.	Management interventions for water extraction, building of infrastructure and intensive land use don't yield any benefits for water flow regulation, while projects reinstating a more natural hydrology of the riparian habitat helps flood regulation. Riparian trees and vegetation improve water flow by reducing surface run-off, and woody debris decreases water velocity which increases travel time of water across the catchment. Beaver dams decrease flood risk Sediment from human sources can increase local flood risk via decreasing conveyance.
Water quality regulation	There are at present no indicator datasets or models that can comprehensively assess this ecosystem service. Many of the identified indicators include pressures and	Water quality issues are made worse by human interventions related to extraction, infrastructure and intensive land use.

	impacts on the processes that regulate chemical condition, but do not fully assess the ecosystem functioning to deliver this service.	Restoration work increases sediment capture and erosion regulation via methods such as excluding livestock from banks and reducing canalisation. Reedbed creation has also been shown to improve water quality. Riparian vegetation can remove N and P runoff from soils before they enter the river and act as a physical barrier against pesticides. Woody debris helps to remove fine silt from watercourses. Sediment can decrease water quality through reduced clarity as well as chemical quality such as dissolved oxygen content.
Habitat and population maintenance	The indicators reflect a detailed assessment of the processes, functions and features that support sustained populations of species. These include hydromorphological processes, habitat structure and features, biological processes and water quality. There are gaps in sediment transport datasets and water temperatures. Using existing datasets, it should be possible to produce useful maps that will contribute to assessing most required indicators.	Increased sediment from human sources has a negative effect on ecological groups including fish, aquatic plants and invertebrates. Riparian woodland provides structural complexity and can connect other areas of woodland to create woodland corridors. Woody debris provides niche habitats for a range of species, from invertebrates to otters. River restoration schemes increase habitat diversity and revegetation, but these interventions need to be managed so that public access doesn't affect wildlife. Invasive riparian species have a strong negative impact on macroinvertebrates. Biodiversity and the functional groups supported by rivers change with river evolutionary stages. N and P are the main issue arising from agriculture and urban land use in the river catchment inducing excessive algal growth leading to shading and thus reducing the growth of other plants.
Characteristics and features of	Characteristics and features of biodiversity were assessed based on 'existence' and 'bequest' values. Although there is generally good availability of data	People are willing to pay to improve freshwater condition; local improvements are valued more than national improvements and the

biodiversity that are valued	indicators for species presence, there is less information on how wildlife is perceived, for example the visibility of wildlife.	improvement from medium to high condition is valued more than poor to medium condition.
Aesthetic experiences	Aesthetic experience was assessed using indicators relating to perceived beauty and enjoyment. These indicators were more subjective and so there were less indicator datasets identified to fully capture this service. The gaps in data could be supplemented with local surveys and data collection.	The majority of restoration and rehabilitation projects are beneficial to river aesthetics as these improve ecological health of the river and hence the perceived naturalness. Proximity to hydropower facilities and features reduces the natural feel of a river and reduces the aesthetic experience of users. There is a gap between scientists and civil servants, and the wider public that seem unaware of the value of braided rivers, with large amounts of gravel seen as less aesthetically pleasing. Wood reintroduction is seen as pleasing only in those countries where this type of project has been carried out already.
Health and well-being	Indicators for the assessment of health and wellbeing included factors such as access to sites, environmental quality and perception of the landscape, as well as direct public health indicators. There were highly usable datasets identified to assess environmental quality. Data relating to access were identified, but further review of local data sources may supplement data for assessing the number of visitors. There was less data identified to assess perception, but this data could be collected using local visitor surveys.	High concentrations of mining related contaminants are associated with high cancer rates, and acidification makes heavy metals more bioaccessible, with adverse health effects. Other adverse effects have been recorded from high concentrations of N and P. Waterborne diseases are a threat to public health. Riparian woodland regulates water temperatures and can reduce the proliferation of harmful organisms. Streams offer silence and gentle noises allowing relaxation, more so than other environments. Visitors to streams receive well-being benefits from areas they *perceive* to be more biodiverse. However, people's identification skills are poor and there is no clear link between biodiversity and wellbeing.

		Changing water levels affect health and wellbeing as access to the river is restricted. Increased flood risk also has a negative impact on mental health.
Recreation and tourism	The assessment for recreation and tourism included a range of indicators including access to sites, range of activities and environmental quality. There were generally many easily usable and relevant data sets, however there were some data gaps, particularly relating to quantifying range of activities the asset can provide. Other gaps, such as data on number of visits to sites could be collected from local surveys.	Recreation is positively related to naturalness, landscape attractiveness, water clarity and water flow. The addition of artificial structures negatively affects recreation but artificial structures increasing access to the site enhance the attractiveness of the area. Regional patterns in visitation are driven by population and distance, with rivers that are closer to big cities receiving more visitors; high river quality is more important at the smaller, local scale. River rehabilitation (improvement in condition) enhances opportunities for recreation, especially as it increases wildlife sightings. Recreational fishing is also majorly affected by these projects, increasing opportunities for angling. Some river restoration projects targeting fish populations may not benefit other types of recreation; the type of restoration intervention carried out is crucial in determining the outcome for the delivery of the ecosystem service as relationships between river condition and recreational use vary depending on the type of activity. Recreation is assumed to be high in anastomosing, medium to low in constricted and meandering and low in leveed and braided rivers.
Education, training and investigation	Indicators identified for assessing education, training and investigation included assessing existing use from information on volunteer numbers, school visits, research projects and training and monitoring sites. This information is not available at a national scale and so	Streams are important environments for teachers and pupils in local schools, but are less safe compared to other options, thus measures improving safety would benefit the service. Changing water levels don’t seem to affect this ecosystem service.

	would need to be collected from local sources such as Rivers Trusts.	
Spiritual and cultural experiences	There is some data available on heritage features, but no indicator datasets were found that related to spirituality or identity. More data relating to this ecosystem service could be collected using local value surveys.	Streams are culturally important areas, shaping local identity. Changing water levels don't seem to affect the provision of this ecosystem service Interventions such as extraction, infrastructure and intensive land use have negative effects on spiritual and cultural experience Restoration and rehabilitation programmes increase the delivery of this ecosystem service.

Approaches to modelling and assessing condition

One interesting aspect that has emerged from this project has been discussion around approaches to modelling and assessment of condition. The flow charts and indicator development outlined in Section 5, take a traditional reductionist approach to modelling, by considering the complex processes that drive each ecosystem service. This means that each indicator will potentially provide useful detailed knowledge, but will only provide part of the picture. On the other hand, the ecosystem approach is, by its nature, a holistic, systems-based approach that attempts to examine the whole social-ecological system at the same time, breaking down silos between different disciplines. Indicators developed for ecosystem services tend to try to capture the whole ecosystem service in one model. This can generally be achieved through developing models with multiple components, or by developing simple metrics as proxies.

When taking this work forward to develop indicators of use nationally, there will need to be discussion about whether it is best to develop a range of different indicators showing multiple aspects of condition for each ecosystem service, or to develop more complex models that capture as many aspects of condition as possible in one model. Example of the latter include water flow regulation models (such as InVEST), ecosystem services models (such as Ecoserv-R/GIS) and demand models. These models often contain aspects of condition that were highlighted in the flow charts. There are also generic ecosystem services models that could be investigated further, such as the Environmental Benefits of Nature (EBN) tool and the Nature Tool for Urban and Rural Environments (NATURE), both of which use simple expert derived scores for each habitat, but weight these based on additional information that may capture elements of condition. These are likely to be better when assessing a range of habitats (rather than just rivers) and are likely to be too simple for inclusion here, but may be worth considering in some situations, and are included in the accompanying spreadsheet for completeness (T37 and T38 in Appendix E).

Another approach is to use a single summary output to indicate condition for an entire stretch of river (waterbody). This was the approach taken by the OxCam Arc project (Section 6), which used overall waterbody class from the Water Framework Directive assessments. This is itself based on a number of indicators, incorporating biological, physico-chemical, hydromorphological and chemical condition, hence it summarises a range of more complex indicators. This is likely to be the best approach if a single summary answer is wanted, focussed on regulating services, but it does tend to ignore cultural services (although water quality affects the delivery of cultural services). Public access is a key indicator for cultural services, and it would be possible to develop a few key cultural services indicators if a summary approach analogous to overall waterbody class was desired. In general, assessing condition for cultural services needs to consider different aspects compared to assessing condition for regulating services. It may therefore be sensible to develop a different indicator framework for these services, to sit alongside WFD overall waterbody class, which captures condition for regulating services fairly well.

Natural England consider natural ecosystem function to be the key attribute of natural capital assets and divide this into five pillars of natural function (hydrology, chemistry, soil and sediment processes, vegetation controls and native biological assemblages; Figure 1). This is closely related to the ideas of naturalness discussed here and could be developed further as indicators of condition that would affect multiple ecosystem services. Although, as for WFD overall waterbody class, this is focused on regulating services and would not cover condition in relation to cultural services very well.

The overall aim of the wider project is to produce maps of natural capital condition that can be used nationwide. This first phase of the project has focussed on developing the conceptual framework and evidence base for each ecosystem service and identifying potential data, indicators, tools and models. Although not stated explicitly, we have assumed that the majority of the indicators and models could be used to create mapped outputs. These are spatially explicit, hence mapping them spatially should not be a problem in most cases. It will be in the second phase of the project, when the mapped output will be developed.

In terms of scale and coverage, the accompanying spreadsheet (Appendix E) records the geographic coverage of the data sets that could be used to develop the indicators and maps, and almost all of these cover the whole of England or even wider, which should allow nationwide coverage. There are differences in the scale at which these data sets and indicators are available, so outputs may vary in their scale. It should be feasible to produce condition assessment outputs for each waterbody, but it may be possible to map at more detail for some aspects of condition. For example, some of the ecosystem service models and demand models described above can model at a very high (10m or better) resolution.

More broadly, and in the absence of detailed condition data, the approach to mapping condition over terrestrial and riverine habitats presented in Section 6, is an effective way of mapping natural capital condition at the landscape scale, although is less effective at site scale. There are a number of emerging applications that can make use of such maps.

Caveats and challenges

The principal caveat of the work presented here is that it was a *quick* review of the data and evidence. As such, it is not intended to be comprehensive and there are bound to be gaps where we did not identify data or evidence, rather than there being no evidence. We do not consider this to be a major problem, as the aim is that this is the first phase of a longer project, setting up the conceptual framework and performing a scoping review to highlight key evidence and gaps. The next stage of the project will be able to carry out a more in-depth assessment and a feasibility study around particular indicators to take forward.

The natural capital and ecosystem services approach is a holistic approach that incorporates a wide breadth of subject areas, ranging from water quality to hydrology, and from ecology to social science (amongst others). As such, it is hard to be a subject expert in each area and to perform a comprehensive review of each ecosystem service. We attempted to tackle this by bringing together a consultancy team that paired river experts with natural capital experts, and importantly, we co-designed the project with the EA steering group and closely involved a wider group of stakeholders with diverse skills, through the workshop and review process. It is equally important that the next phase of the project continue to work with subject specialists by setting up a multidisciplinary team, or by further close engagement with a range of stakeholders.

Next steps and recommendations

This project has identified a wide range of data sets and evidence and can be taken forward in a number of ways:

Prioritising indicators – a key next step will be to prioritise the indicators identified here. We have identified a wide range of indicators of condition for each ecosystem service, along with a gap analysis and an options appraisal presenting short, medium and long term options for taking this forward (Section 5). There is also an assessment of usability for all data, indicators, tools, methods and models (shown in the accompanying spreadsheet in Appendix E). This provides a comprehensive resource and evidence base, but there now needs to be an assessment of which ones should be taken forward, and priorities over the short, medium and long term. There are clearly a number of indicators which could be used straightaway, but may need to be collated and mapped to provide a usable product. In other cases, we have identified potential indicators or approaches, but these will require some work or modification for use in the context required. Longer term options have been identified where considerable work or research is required and EA priorities will dictate which of these should be taken forward and when.

Developing indicators and maps – once prioritised, the next phase of the project will be to develop the indicators and produce maps with national coverage. This should continue the process begun here, and involve stakeholders in the development and refinement of the indicators.

Presenting results – the final part of Workshop 3 asked for suggestions on how the results of both the indicator work and the literature review should be presented (full results in Appendix B). It was suggested that the mapping (when complete in the next phase) should be linked to the Analysis Ready Water Network, or an open river network, but also that it should be made open and accessible, with the data available online. A data platform or data tool could be developed for viewing and sharing the maps and data. In a similar ethos, it was generally felt that the QSR review should be fully accessible, shared internally and externally, and if accepted should also be published in an academic journal.

Gap filling – in conjunction with the indicators to take forward, we have also identified gaps in the evidence base. It would be useful to identify which are priorities for the EA and then to develop research projects and work programmes to investigate key areas of interest. This overlaps with the indicator work, as some of the gap filling will enable new indicators to be produced.

Extending habitats – this project has focussed on rivers, but it could be extended to consider other habitats such as lakes and estuaries, wetland habitats such as marsh, fen, reedbeds, bogs, and floodplain grassland mosaics (floodplain grazing marsh), and terrestrial habitats. This could use the methodological approach developed here, which would save time in project development.

Additional ecosystem services – due to time constraints, this project focused on ten different ecosystem services. These were chosen through the workshop process as the ones that are either considered most important, or where there is considered to be significant lack of knowledge. We have therefore reviewed the ecosystem services that were considered key. However, there are a number of others that could be of interest, particularly local climate (temperature) regulation, and carbon sequestration and storage. The services that were identified as next most important in the workshops were waste removal, and erosion control, although the former overlaps heavily with water quality regulation. It was highlighted that ecosystem service terminology and definitions are not used consistently across the EA or different disciplines, and this can lead to some confusion. Going forward it would be beneficial to move towards consistent ecosystem service terminology.

List of abbreviations

AMBER	Adaptive Management of Barriers in European Rivers
ANG	Accessible Natural Greenspace
ANGSt	Accessible Natural Greenspace Standard
AONB	Area of Outstanding Natural Beauty
AWB	Artificial Water Body
BFI	Base Flow Index
BGS	British Geological Survey
BMWP	Biological Monitoring Working Party
BNG	Biodiversity Net Gain
BU	Biodiversity Units
CERF	Continuous Estimation of River Flows
CICES	Common International Classification of Ecosystem Services
CRT	Canal and River Trust
DARLEQ	Diatom Assessment of River and Lake Ecological Quality
DEFRA	Department for Environment, Food and Rural Affairs
EA	Environment Agency
EBN	Environmental Benefits of Nature
EFI	Ecological Forecasting Initiative
eFLaG	Enhanced Future Flows and Groundwater

ELMS	Environmental Land Management Scheme
ENCA	Enabling Natural Capital Approach
ESRI	Environmental Systems Research Institute
FARL	Flood Attenuation by Reservoirs and Lakes
FCRM	Flood and Coastal Risk Management
FCS2	Fisheries Classification System 2
FEH	Flood Estimation Handbook
GIS	Geographic Information System
HEAT	Health Economic Assessment Tool
HMS	Habitat Modification Score
HMWB	Heavily Modified Water Body
IMD	Index of Multiple Deprivation
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
LCA	Landscape Character Assessment
LiDAR	Light Detection and Ranging
LNCP	Local Natural Capital Plan
LNRS	Local Nature Recovery Strategy
LUC	Land Use Consultants
LWS	Local Wildlife Site
MA	Millennium Ecosystem Assessment
MAGiC	Multi-Agency Geographic Information for the Countryside

MENE	Monitor of Engagement with the Natural Environment
MoRPh	Modular River Physical Habitat field survey
MPVA	Meta-Population Viability Analysis
NATURE	Nature Tool for Urban and Rural Environments
NBS	Nature-Based Solution
NCEA	Natural Capital and Ecosystem Assessment
NCES	Natural Capital and Ecosystem Service
NCRAT	Natural Capital Register and Account Tool
NCS	Natural Capital Solutions
NE	Natural England
NEVO	Natural Environment Valuation Online
NNR	National Nature Reserves
NRFI	National River Flow Archive
NRW	Natural Resources Wales
ONS	Office for National Statistics
ORVal	Outdoor Recreation Valuation
OS	Ordnance Survey
PAWS	Plantations on Ancient Woodland Sites
PICO	Population, Intervention, Control, Outcome
PRoW	Public Rights of Way
PSI	Proportion of Sediment-sensitive Invertebrates index

PVA	Population Viability Analysis
QSR	Quick Scoping Review
RCA	River Condition Assessment
RHS	River Habitat Survey
RICT	River Invertebrate Classification Tool
RRC	River Restoration Centre
SAC	Special Area of Conservation
SAGIS	Source Apportionment GIS system
SIMCAT	Simulation of Catchments
SSONC	Scope of State of Natural Capital indicators
SSSI	Sites of Special Scientific Interest
SWAT	Soil & Water Assessment Tool
UKCEH	UK Centre for Ecology and Hydrology
WFD	Water Framework Directive
WHPT	The Whalley Hawkes Paisley Trigg

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Appendix A: Defining user needs

User needs have previously been surveyed by the EA, within the Natural Capital Mapping Needs Review (Environment Agency, 2022a), and the development of natural capital indicators is subject to an ongoing review (Natural Capital Indicators in EA Monitoring Project). The results are summarised here and were used to inform the workshops (Section 3).

Natural Capital mapping needs review

Methodology

The survey was available online for respondents to complete from the 13 January to 4 February 2022. In total, the survey received 62 complete responses. Some participants noted that they were providing just one response on behalf of a team or organisation.

Of the respondents, 83.9% were from the EA, 4.8% were from Natural England, 3.2% were from Defra, and the remaining 8% were individuals from Forest Research, Essex Wildlife Trust, Local Nature Partnerships and Essex County Council.

The detailed analysis of the survey consisted of a thorough review of all survey outcomes to identify the geospatial evidence needs of end users.

Following the identification of data needs, a gap analysis was undertaken to determine whether end users' geospatial data needs were met by existing data. Following on from the gap analysis, a set of recommendations (see Table 13-1 Summary of Recommendation and Prioritisation in (Environment Agency, 2022a) have been made, with an indication as to priority, alongside a supporting rationale.

Natural capital asset baseline

Many respondents (40.3%) were not currently using any natural capital asset maps. Those that were using natural capital asset maps, mostly felt that both national and regional maps were not currently meeting their needs. 85% of respondents said they would benefit from non-habitat based natural capital asset mapping.

The key requirements: freely accessible and available for download, good level of granularity, consistency – a single version of the truth, ease of interpretation, links with wider programmes (e.g., the Flood and Coastal Risk Management (FCRM) programme), the ability to supplement mapping with additional data (including 'local' data), exploring impacts of different scenarios (such as land use change) and monetisation of benefits.

To understand the types of existing data that could be included in a natural capital asset baseline, respondents were asked to score a series of different data sets from least to most suitable. The results showed the largest number of respondents felt the Priority

Habitat Inventory (37%), National Forestry Inventory (32%) and Ancient Woodland Inventory (40%) would be most suitable. Other datasets with a notable number of respondents scoring it as most suitable include the Centre for Ecology and Hydrology (CEH) Land Cover Map (26%), Crop Map of England (24%), Natural England Living England habitat map (21%) and Agricultural Land Classification (29%). No data set received a significant number of low scores, suggesting respondents felt all were suitable to some extent. There were some data sets that many respondents were unaware of, including the UK SeaMap 2018 (53%) and Natural England's Living England Habitat Map (39%).

Need: Local and national natural capital asset baseline mapping. A central online dashboard, providing a single interactive natural capital baseline web map for England based on freely available data. The spatial data supporting the web map needs to be available for download by users.

Existing datasets: Current examples that could be built upon include:

- CEH Land Cover map
- Natural England's Natural Capital Atlases: Mapping Indicators for County and City Regions
- Defra's Magic Map
- NRW Natural Capital portal (Wales only)
- Natural England's Living England Habitat Map
- Copernicus' CORINE Land Cover
- EA's WFD data (including freshwater and groundwater) and Detailed River Network

Recommendations: A habitat map that will allow users to understand assets present in their area of interest, particularly their extent. Many available datasets could be combined to achieve this need. The UKCEH Land Cover map and Natural England's Natural Capital Atlases may provide a good starting point to deliver a baseline map, yet limitations presented themselves in regards to licensing and resolution. Living England may be utilised to overcome the above challenges and is therefore recommended for use as the basis for an online interactive map. Living England will also undergo future updates to incorporate wider datasets. Users identified data such as the Priority Habitat Inventory, National Forestry Inventory and Ancient Woodland Inventory as important datasets for developing a natural capital asset baseline. Consideration will need to be given as to whether Living England is suitable for mapping linear features such as rivers and how it could be linked with condition data derived from other sources, which will be of particular importance to assessing the water environment. Subsequent updates to Living England could also look to incorporate abiotic assets. Survey respondents identified water bodies, (both surface and groundwater) and soils data as key data gaps, including the location of ordinary watercourses.

Need: Assessment of condition of assets and supply and demand of ecosystem service.

Recommendations: Several data sources and tools address the need for asset condition data to some degree, with significant limitations. EcoservR is able to provide ecosystem service supply and demand mapping for the following services: carbon storage; air purification; water purification; pollination; local climate regulation; noise regulation and accessible nature. The methods employed for EcoservR in determining ecosystem service supply and demand should be considered for application alongside the natural capital asset baseline provided by Living England. Manipulation of outputs may be needed to ensure alignment. The EcoservR approach aligns to the EA's OxCam LNCP project.

Need: Model different interventions to assess the impact on ecosystem services provision and identify opportunity areas for improvement.

Existing data: NEVO

Recommendations: Few tools exist to model changes. NEVO is acceptable, but contains only a few ecosystem services and does not identify areas for opportunities.

Need: The ability to quantify each element of the logic chain consistently and automatically (e.g., assets; ecosystem service supply, demand and flows; benefits (and associated monetisation); risks; and opportunities for enhancements.

Condition mapping

It was suggested that there is limited spatial data (insufficient for the majority of users) depicting asset condition, highlighting the need for a national dataset with good coverage across a range of condition indicators. Without this it would be challenging to target environmental enhancements, such as biodiversity net gain. The majority of respondents (75%) currently use asset condition data in their work; however, 70% also felt that existing data is insufficient for their requirements.

Need: National, spatial data set covering a range of indicators at the site scale.

Existing data:

- Natural England's Natural Capital Atlases
- CEH Natural Capital Maps, covering data on: soil carbon; soil nitrogen; soil pH; soil phosphorus; soil bacteria; soil invertebrates; headwater stream quality; carbon in vegetation; nectar plant diversity for bees and plant indicators for habitats in good condition.
- OxCam LNCP – Approach to determine whether natural capital asset condition can be inferred from existing data.
- Various water quality datasets, including WFD status, bathing water quality, freshwater river ecology survey data etc.

Recommendation: The Natural England Atlas and indicator work provides a starting point, supported by the UKCEH Natural Capital Maps. However, these datasets are patchy in terms of coverage of indicators. Consideration needs to be given as to what condition data is needed. The OxCam LNCP work undertook a review of whether condition data can be inferred from existing resources. This work should be explored further to ascertain whether there is scope to adopt such an approach nationally and how this could be aligned to: Natural England's Natural Capital Indicators for quality, the 25 Year Environment Plan and potentially the Environment Act 2021 statutory targets.

Unmet need: Improved local condition data that is collected regularly.

Recommendations: Consideration needs to be given as to what condition data are needed. Site scale condition data are required for use of tools such as the EBN tool and the Biodiversity Metric.

Methods of collating such data needs to be determined. Owing to resource constraints, the role of citizen science should be considered in filling such data gaps and the wider benefits of such an approach, including social value creation. It was suggested that WFD condition data is too coarse in resolution for meaningful application. There is a need to explore specific data gaps and identify where more local data is needed. The recommendation for a single data repository (or online dashboard) would provide a place for local data to be uploaded and updated. The ability to track changes in natural asset condition over time would help to identify assets in decline. This information could be used to target intervention and support the prediction of future conditions under different stressors.

Unmet need: Guidance to demonstrate how condition data influences ecosystem service provision.

Ecosystem service mapping

Need for an interactive ('live'), easily accessible tool that can allow input of local data, could help with project planning and stakeholder engagement, by demonstrating current and potential ecosystem service provision. The majority of respondents do not currently make use of ecosystem service mapping within their roles, with only a third claiming to do so.

Need: Ecosystem service mapping

Existing data/tools: EA's OxCam LNCP Ecosystem Services, EcoservR, Greater Manchester Combined Authority's Ecosystem Services Opportunity Mapping Toolkit, Natural England's 'Assessing the potential for mapping ecosystem services in England based on existing habitats'.

Recommendations: Building on the OxCam LNCP, a scoping study should identify the most suitable approach to ecosystem service mapping nationwide. Through discussions with Natural England, it has been identified that the EBN Tool is currently the closest method to assessing Environmental Net Gain available. Mapping should be sufficiently granular to allow users to prioritize within sites (for example a 10x10m resolution as utilised in EcoServR). NCRAT (Natural Capital Register and Account Tool) could be used to support the valuation of ecosystem services.

Need: tool that demonstrates current and potential value of ecosystem services that schemes may impact.

Existing data:

- EA NCRAT
- EA's Natural Capital Metrics Tool – Allows the user to understand the wider benefits of planned interventions in a non-monetary capacity.
- Other tools: ORVal, NEVO, B£ST, i-Tree etc. Defra's ENCA

Recommendations: the NCRAT tool is undergoing further development to include wider indicators potentially relating to soils and biodiversity. NCRAT is non-spatial and cannot be used at a site-scale. NCRAT however could support the valuation of ecosystem service changes. Further user testing of NCRAT is likely to be required to ensure valuation methodologies are robust.

Natural Capital Metrics Tool would benefit from further testing such as at the 'pre-Strategic Outline Case' stage of a flood risk management project, to highlight the benefits of nature-based approaches. There is no 'live tool' that allows adjustment of habitat types.

Opportunity and demand mapping

Mapping supply against demand can identify where there are opportunities for enhancing natural capital and associated ecosystem service provision. The majority of survey respondents (80.6%) do not currently make use of ecosystem service opportunity and demand mapping.

GAP: National opportunity and demand mapping.

There are many datasets which identify poor asset condition and these could act as a proxy for potential enhancement.

It is recommended that a scoping study is required to review opportunities to develop opportunity mapping, based upon existing datasets which provide information on asset condition (as an example). An alternative and/or complementary approach could be to develop opportunity mapping following the development of ecosystem services mapping.

Pressures and risk mapping

Drivers and pressures on natural capital which can lead to risks in relation to the continued provision of ecosystem services.

GAP: National pressures and risks mapping.

There are no distinct natural capital pressures and risks datasets and/or tools available. However, there are many datasets which potentially provide information in relation to natural capital drivers, pressures and risks (dependent upon the definitions used and the elements considered for inclusion). A scoping study is required to firstly determine what natural capital drivers, pressures and risks are of interest to the EA. There is insufficient literature across the discipline to discern which drivers, pressures and risks should be assessed within a natural capital assessment.

Beneficiaries mapping

In a natural capital context, beneficiaries are those individuals or groups that receive the benefits flowing from natural capital assets as ecosystem services. Over 80% of respondents are not currently using beneficiaries mapping, but 35% wouldn't know how to use it even if it was available. Those that indicated they did use beneficiaries mapping suggested they use maps such as flood risk maps, Indices of Multiple Deprivation maps, and more bespoke tools and data sets such as the NEVO tool.

GAP*:* National beneficiaries mapping. Examples of existing data and/or approaches include the number of properties at risk from flooding, or the number of people who can access a greenspace (using the Accessible Natural Greenspace Standard (ANGSt)). It is recommended that a scoping study is completed which determines for each ecosystem service of interest (a) who the beneficiaries are (supported by Defra's ENCA), (b) the associated benefit area of each ecosystem service provided, and (c) data and/or approaches which will facilitate the above elements being mapped.[8]

Natural Capital indicators in EA monitoring project

The Defra 25 Year Environment Plan has committed to adopting a natural capital approach to managing the natural environment so that it continues to deliver vital services which support the economy and society.

There is a need to design monitoring networks so that these measure attributes that tell us about ecosystem function, which determine the flow of ecosystem services they provide. How effective ecosystems are at delivering services which benefit people, depends on how extensive they are (quantity), how well they function (condition) and where they are situated in relation the people who benefit (location). These three aspects, together, determine the 'state of natural capital'.

A key gap in our natural capital evidence base is understanding and measuring the flow of ecosystem services, benefits and value to society from freshwater habitats, and the implications if they deteriorate. Existing natural capital geospatial evidence such as Natural England's Living England Habitat Maps and Natural Capital Atlases do not adequately represent freshwater, coastal or estuarine environments. This evidence gap led to the development of a project delivered by UKCEH for the EA in 2021 (Maskell &

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[8] There is potential for this to be partially supported through the use of Natural England's Green Infrastructure Framework and associated mapping tool: https://designatedsites.naturalengland.org.uk/GreenInfrastructure/Map.aspx

Norton, 2021) and the follow-on Natural Capital Indicators in EA Monitoring Project, being delivered by the EA.

The aim of these two projects was to assess whether the data collected by NCEA monitoring networks supports assessment and reporting on natural capital indicators and to prioritise gaps and risks in the proposed monitoring to establish a fit for purpose natural capital baseline. Subsequently, the NCEA programme is looking to introduce improved, broad scale, long term monitoring of water bodies.

The project gathered an understanding of how the EA quantify the quantity, quality and location of the following natural capital water assets: lakes, small streams, estuaries and coasts, groundwater (including water dependent terrestrial ecosystems). This was achieved though identifying the NCES (Natural Capital and Ecosystem Service) indicators monitored within the EA's proposed Sentinel water environment monitoring network and their current targeted water environment monitoring, against what NCES data is needed by the EA's tools, policy and reporting work.

The project used the list of natural capital indicators defined by Natural England for England in 2018 (subsequently updated in 2020) as the benchmark for this investigation. Lusardi et al., (2018)[9] provided a list of ecosystem services provided by natural capital assets that focused on which measures would be useful, instead of which measures were currently being monitored.

Monitoring was then evaluated against policy drivers and reporting requirements such as the 25 Year Environment Plan indicators for lakes, small streams, estuaries and coasts, and groundwater (including water dependent terrestrial ecosystems)[10] , i.e. B3, 4, 5, B6, 7, the Environment Bill Targets[11], Local Nature Recovery Strategies evidence needs (as set out in 2020/21 pilots)[12] , the Scope of State of Natural Capital indicators (SSONC), the Office of National Statistics Freshwater Ecosystem Account[13] and the (ONS) UK National Natural Capital Accounts.

Tools were also considered including Defra's ENCA, the EA's NCRAT, Natural England's Natural Capital Atlas, the Environmental Benefits from Nature Tool, the NEVO tool, and EcoservR. A spreadsheet 'Ecosystem Services tools' was created which includes a

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[9] Natural Capital indicators are those defined In Lusardi et al., (2018)

[10] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/992970/Outcome_Indicator_Framework_for_the_25_Year_Environment_Plan_2021_Update.pdf

[11] https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted

[12] https://www.gov.uk/government/publications/local-nature-recovery-strategy-pilots-lessons-learned/local-nature-recovery-strategy-pilots-lessons-learned

[13] https://www.ons.gov.uk/economy/environmentalaccounts/methodologies/naturalcapital

summary spreadsheet listing the ecosystem services (as in Lusardi et al., 2018) scored against each of the tools.

Another spreadsheet was made available (Appendix_3_EA_Monitoring_data_detailed) containing information on what indicators, measurements and metrics are currently recorded within the habitats, the spatial coverage, sampling density, frequency of sampling, status i.e. whether it is likely to be continued, and data accessibility. A summary of this was added to the main spreadsheet (Appendix_2_Indicator_lookup) under the headings 'Environment Agency data' - 'Monitoring data current' and 'Monitoring data proposed'.

Gaps in indicator data were identified through a workshop and in follow up work with the EA and UKCEH monitoring experts, using the main spreadsheet (Appendix_2_Indicator_lookup) and have been assessed as Yes/No or Possibly. A 'Way Forward' column was added to provide recommendations as to how each gap should be addressed.

Appendix B: Synthesised exercise results from workshops

Workshops 1 and 2

Exercise 1: Condition

Table B1. Answers to the question "what does condition mean to you?" synthesised from workshops 1 and 2. These have been grouped into 11 key themes. As this is raw data, any spelling or grammatical errors have not been edited.

Condition theme	Comment
Access and recreation use	Accessibility - to users
	At what point does human access to a place start to reduce "condition", e.g., hard paving, disturbance?
	The services are for people so condition should be related to public satisfaction. I some cases highly modified townscapes provide such services (e.g., Avon in Bath).
	Does/should a river in 'good' condition mean people value it by visiting and using it for recreation etc & get lots of value/mental & physical health benefits
	If people want to swim, it needs to be (chemically) safe
	Accessibility
Biodiversity	Ecology - biodiversity (sp.)
	Support Flora and Fauna
	it's about more than species, it includes having the appropriate age, size classes, structure, mosaic size
	species richness

Impact of human use	The impact of environmental degradation on the capacity of a habitat to provide services that benefit humans
	Can a river do what it needs to? Move around, process nutrients etc. Adapt in high and low flows
	How much the environment is impacted by human activity
	How is a system managing in the face of all the pressures we put on it?
	Measure of environmental degradation by human activity to assess when intervention is required due to impact (on function?)
	Some measure of threshold - how close is the ecosystem to (irreparable?) damage?
Interconnectedness	good to look at the condition as a system so not just the freshwater bit of the naturalness/ resilience & the condition of the whole water systems.
	We don't have good scientific understanding of ecosystem functions - largely because we don't understand the bacterial and fungal components that are so important in biogeochemical functions. Anoxic taxa are very important.
	Physical and biotic environments cannot be separated, they are interdependent.
	1. Connectivity between and within habitats. 2. Scale - large enough critical mass to be resilient and able to adapt.
	clarity of connectivity and its relative importance
	is condition static or dynamic - does trajectory in time and space matter?
	Spatial scope - For rivers - can their condition be separate from the wider catchment - they are a function of inputs of sediment, water etc?

	fragmentation, the converse of connectivity with implications for resilience
	don't forget about ecotones, part of connectivity that is often overlooked
Measurements	In my experience, I've focused on condition of SSSIs, so Natural England's Favourable Condition Tables - but they are aimed at very specific habitats / species which may have been identified 30 years ago - I don't think this is how we'd want to look at condition for NC.
	Do we need different assessments for each group of ecosystem services? e.g., regulatory / recreation?
	probably something measurable/quantifiable
	WQ - physico-chem; WQ - biology; WR - flow, availability, levels; geomorphology; connectivity; length/area
	Practically measurable - frequency, scale, analysis,
	being able to value what we cannot see or measure e.g., ancient soils and their processes
	Health
	There are lots of ways of describing condition, environment quality ratios are used often and in WFD
	simplistically “Ecological” condition. Its current status.
	Condition of what? … habitat, ecosystem, services?
	Scale is a key issue. Should we judge condition at a site level, or at a catchment scale? I think it might be more important to assess whether the whole system is producing the required services, rather than look section by section. .
Morphology	Morphology - dynamic, connectivity with flood plain

Naturalness	Extent of deviation from natural condition
	Landscape - sense of place (cultural)
	The ability of an asset to provide the ecosystem services it could provide in ideal condition
	Value as a proportion of the potential value for a given asset
	Natural species composition
	For BNG (Biodiversity Net Gain) the overarching river condition is defined by naturalness (as per NE). This is important as it links to policy as well (priority rivers). The snapshot that is River Condition Assessment looks very specifically at physical habitat change. The ecosystem flow from RCA is therefore limited.
	Whenever looking at condition, I personally look at it compared to a baseline. Condition could reflect, how close an asset/service is, to its full potential.
	Are we interested in natural or is that a red herring. Man-made ecosystems are valuable and provide services that we want, usually more intensively.
	how close fluvial environments are to natural. From near natural to unnatural.
	the characteristics of a natural asset, potentially compared to some reference 'natural' expectation - what point in time (past/future) should we consider naturalness?
	Condition is related to quality. We need a clear paradigm to define what we mean by quality. Under WFD, this is the degree of naturalness. The biotic and abiotic components that define naturalness is type-specific.
	The nature (type) of environment and biota that it supports. This is what provides the services. Anthropogenic ecosystems are actually more valuable!!

	Urban landscapes can be beautiful - go visit Venice, New York, London.
	We are reasonably good at defining the natural biota and physical environment and their degree of naturalness. We haven't converted that to functions and services yet.
	consideration of shifting baselines
	Deviation from a defined reference
	requiring minimal or negligible management or maintenance
	The potential for an ecosystem to continue to exist in either its current state or in reference to a benchmark ... . or undergo change (whether natural or anthropogenic). It's not a value judgement
	naturalness
	Presence/absence of 'alien' elements - this could be chemicals or invasive species
Perception	Condition is subjective. Different people perceive this differently - what can be measured and what is perceived.
	Some people perceived good condition - as tidy (uniform) and clean. However from an ecological angle - scruffy is better.
	Aesthetics - good condition means it looks nice & people want to engage & interact with the river
	'good' condition will entirely depend on the observer/user. What do we want to value? A carp angler's view would be different to mine for example :)
	Condition is very dependent on its use - policy/reporting.

	What is the purpose? I would like to think how we are planning the use our understand of condition or it could mean anything for me depending on what i am doing?
	How many "types" of condition are there for one system? A single condition of 'naturalness', or condition of each separate and distinct elements a system has/provides.
	Ultimately, we're trying to get people to 'value' the natural capital - beauty should be included. This plays into social and economic benefits.
	The biota and environment determine the ecosystem and its functions, so you need to describe it.
	Therefore, the things we include in our condition assessment are the things that will end up being managed?
	Condition is... a value judgement (we include the things we decide to!)
	Condition is an expression of state, assigning an adjective e.g., "good", "poor", "harsh" etc
	Condition could mean how something looks - "that pond looks horrible"; or it could be how much biodiversity there is - "that pond is packed full of species"...equally from a flood risk perspective, the pond might be in good engineering condition as a water retaining feature.
	Is condition fundamentally relative? So what are we comparing present condition on a scale or otherwise? So on what basis are we saying something is good, bad, poor etc. And how are these comparisons defined? What is ideal, what is the reference? What is the baseline (prehuman, 1900s???). This contains a multitude of value judgements? Nat K often presents single values without providing a frame, but there is a huge role for making opp cost visible in what we are missing out on.
Resilience	Measure of resilience?

	resilience or naturalness in terms of: natural process and function - sediment/ soil delivery - natural channel processes - channel morphology -habitat and landscape condition
	Resilience of a system/asset. V. resilient = good condition.
	?? some rivers are less resilient as they are more sensitive to change ?? even though they currently may be in a very natural state??
	potential to adapt/evolve
	capacity of asset & ecosystem services to respond/adapt to pressures/ uses
	Condition demonstrates the resilience of the system / it's state of health
	resilience is vital, noting that ecosystems can be in alternative stable states of poor condition
	Resilience to the impact a warming world - e.g., tree cover near rivers
	Sustainability
	An ecosystem that can withstand extremes/shocks - resilient?
Service provision	The extent to which the service is provided, i.e. not necessarily natural but delivering a big outcome maybe?
	Condition = the ability pf the asset to deliver the ecosystem services
	(EA) - some services are provided by physical processes - e.g., natural maintenance of all the fluvial features - that's a 'maintenance service'. That's different to a service provided by the ecosystem.

	Condition means how healthy is an asset to be able to maintain services and benefit provision that we prioritise (local, regional, national, international) - the amount or spatial coverage of the asset, the quality of the asset, is the asset in the place where it's needed, is the asset spatially fragmented - so how resilient is the asset to be able to maintain service provision - is it resilient to pressure, is it susceptible to pressure, is it already impacted but recoverable, is it impacted beyond recovery
	potential to provide services - both those currently recognised (and potential future services?)
	Condition represents the ability of an asset to have the capacity to maintain provision of services and benefits that are prioritised by society – local, regional, national, international
	What are the thresholds of health (condition) – we have a challenge to be able to define categories of condition – but we need to be able to define condition in terms of the services prioritised by society
	Condition needs to cover the current state of assets in the environment that provide the ecosystem service-the NE pillars. What are the KEY parts of the state which would impact the service if changed. i.e. flood, channel modification, flows. Clean water, nutrient pollution, chemicals
	Measure of the health (quality) of the ecological components of the system and their ability to provide ES
	Condition is specifically what you would measure in terms of things important to the ecosystem service.
	A measure of "functioning" – are the ecosystem services operating fully to potential (multiple metrics?)
	we don't have any conflicts between elements of ecosystem services e.g., recreation and disturbance

Water quality/flow	WQ – Phys chem
	WR – flow, levels, availability
	Aspects such as WQ (elements), how modified the river is & how it supports biology/ecology
Other	A river and floodplain is a NC asset (or suite of assets) – perhaps it should be called a fluvial asset?
	A spectrum along the river self-purification spectrum.
	Potentially misleading level of certainty or uniformity (in space/time) and lack of nuance
	Historically condition that needs a potential response are the things that have legally binding objectives set for them. RBMPs, SSSIs. Etc
	Condition is... something that we need to have a response to
	includes an indication of certainty of our impression of condition

Exercise 2: Assets and ecosystem services

Synthesised results from the google form survey are presented below. Score means have been calculated for presentation purposes.

1. Which ecosystem services are of most interest (in riverine habitats)?

Service	Mean importance (1 = least important, 5 = most important)
Water for drinking/ agriculture/ industry	4.6
Water quality regulation	4.5
Water flow regulation	4.2
Characteristics and features of biodiversity that are valued	4.1
Health and wellbeing	3.9
Recreation and tourism	3.9
Habitat and population maintenance	3.8
Waste removal	3.6
Aesthetic experience	3.6
Erosion control	3.6
Carbon sequestration and storage	3.6
Education, training and investigation	3.5
Spiritual and cultural experiences	3.4
Pest and disease control	3.2
Local climate temperature regulation	3.1
Fire protection	3.0

Cultivated plants and reared animals	2.9
Pollination and seed dispersal	2.9
Hydropower	2.8
Wild produce	2.4

2. How would you rate the data availability for each of these ecosystem services?

Service	Mean availability (1 = least available, 5 = most available)
Water for drinking/ agriculture/ industry	4.6
Water quality regulation	4.1
Water flow regulation	4.1
Characteristics and features of biodiversity that are valued	2.8
Health and wellbeing	2.3
Recreation and tourism	3.0
Habitat and population maintenance	3.2
Waste removal	3.6
Aesthetic experience	2.4
Erosion control	2.8
Carbon sequestration and storage	2.5
Education, training and investigation	2.3
Spiritual and cultural experiences	1.9

Pest and disease control	2.2
Local climate temperature regulation	2.6
Fire protection	2.0
Cultivated plants and reared animals	3.4
Pollination and seed dispersal	2.0
Hydropower	4.1
Wild produce	2.1

3. ***Please add any additional comments or extra ecosystem services you may want us to consider***
    - Align with Environment Bill targets on water as a starting point – Clean and plentiful water
    - Bit of a niche one: At some point we are going to need to differentiate between immersive sports (i.e. where we are putting our mouths underwater for long periods) where we need higher bacteria standards versus splashing around.
    - For urban environments/river restoration – uplift in land values, economic improvement etc.
    - Not sure my opinion matters....it's presumably more about the overall "value" of these assets to society
    - Physical maintenance of rivers and floodplains by flows of energy and matter (water, sediment and biotic material). This is absolutely critical. Imagine if rivers and floodplains vanished. Where would our wastewater go? Where would floodwater go? Also, I suggest you remove erosion control as a service. It implies that erosion is bad. Erosion is simply a form of habitat recycling. Imagine if your recycling wasn't taken away, or the leaves never fell and re-grew each season. Think of erosion as an important process please.
    - Are there specific services where the asset is a species. This is useful and would help in nature recovery funding for species.
    - Consideration of ecosystem services within catchments that impact on or contribute to ecosystem services in river/lakes. Data availability for these may not be the same.
    - Photosynthesis. Carbon capture and temperature regulation (oceans)? No mention of the global services these ecosystem functions provide. Questions seemed very parochial and not comprehensive.
    - natural process and function – alongside erosion control
    - Transport / wider energy infrastructure – power stations
    - Cultural habitat
    - I feel quite strongly that there is very little public understanding of the value and availability of public rights of way. Many map applications which have this information demand money for it, or make it hard to easily access.

- Using water for cooling and heating returned water through industrial processes (admittedly part of waste)

4. ***Which of these asset types would you rate to be more important to be included in the scope of the project?***

Asset	Mean importance (1 = least important, 3 = most important)
Catchments	2.92
Lowland rivers	2.87
Upland rivers	2.82
Chalkstreams	2.75
Headwater streams	2.68
Heavily modified water body	2.68
Intermittent rivers	2.42
Artificial water body	2.05
Canals	2.03
Ditches	1.86

5. ***Why do you want us to consider those assets?***
   - I think all will need to be considered at some point, but it would be better to focus in detail at a smaller number to begin with
   - Crucial to the work of the EA and Climate Adaptation and Resilience
   - For many issues the catchment drives the condition of the water.
   - Catchment consideration enables linkages across the system rather than consideration of assets in isolation estuaries
   - Catchments top of the list please (because they are a 'system' and we need to better understand what services a catchment provides (i.e. the sum of its parts)
   - Those assets that we have a realistic chance in influencing/changing/directing.
   - Canals, artificial water bodies – of value, but not as important as naturally-created assets.
   - Relevant for policy – BNG
   - Water environments flow between these different types of environment so should all be considered important. However, the availability of ecosystem services will vary, particularly when artificial water bodies are concerned (more likely to be around

recreation and cultural heritage). Similarly, ditches may have limited value depending on size and cumulative impact.

- All river types are important for different purposes. Small streams not important for water supply but very important for biological resilience.
- consideration as a system would be very beneficial
- All deliver benefits
- Important components to consider when making decisions on water environment management
- because I'm the designer for the NCEA small streams network and the lakes network and I want some guidance on what we're designing/collecting is the right thing - although we've clearly already put the cart before the horse.
- Chosen based on where interventions would have the most impact – otherwise I think all waterbodies should be considered equally. The least 'natural' canals and HMWBs probably, generally, have the most cultural value
- They are important and integral parts of the system that produces services
- To fully understand the river network & pressures across it – interconnectivity etc.

6. What other asset categories should we include?

- Urban waterways specifically
- "rivers/waters near people (towns, tourist spots etc)"
- Wetlands
- lakes and ponds in relation to rivers, estuaries
- floodplains (or are they implicit in the assets) and drainage (i.e. the watershed)
- Consider lakes for future project
- floodplains
- Floodplains. Lakes. Wetlands. And, in time, estuaries and coasts.
- Specific river types according to Priority rivers (most included here)
- Subterranean waters, springs, transitional waters, fens, bogs.
- estuaries, coastal waters – at the very least the links.
- Lakes, flood plains (could be included in catchments)
- Groundwater, Air Quality
- lakes & estuaries, GW

7. The following are out of scope for this project, but which are important for future consideration?

Asset	Mean importance (1 = least important, 3 = most important)
Floodplains	2.89
Estuaries	2.76
Groundwater	2.65
Lakes	2.61

Saline influenced transitional	2.55
Fens	2.54
Reedbeds	2.41
Ponds	2.33
Reservoirs	2.15

8. ***Any further comments on these?***
    - Saltmarshes – good for Carbon sequestration and climate resilience. Reedbeds can have a similar role.
    - treat the river as a system and consider connectivity which may be important
    - Don't understand how you can consider the "river" without the floodplain...? Big opportunity missed if that's the case
    - Lakes are very much more accessible to people than rivers (is my perception), they add interest to the landscape, accessible by footpaths, many offer recreation just as water sports/fisheries/nature reservoir. The reservoir, which shouldn't be classed separately, as well as many natural lakes are major drinking water supplies. They appear somewhat overlooked from an EA/NCEA nat cap perspective.
    - Rivers and floodplains should ideally be considered together as one asset – they do not exist independently – the condition of one is inextricably linked to the condition of the other – resilience should allow dynamic adjustment across a floodplain
    - You really should include floodplains. They are part of fluvial systems.
    - peat bogs?
    - Again, link to policy BNG
    - All are important. It doesn't matter where you start. Need to develop the conceptual framework, so start with one or two.
    - Lakes and reservoirs have very high NC capital value because of the recreational opportunities they provide such as sailing, swimming, fishing..but obviously that are distinct and different to each other and should be considered separately
    - Ideally we need a good understanding across all of the types above

Exercise 3a: Policies, needs and evidence gaps (Workshop 1)

Table B2. Raw outputs from exercise 3a (workshop 1). As this is raw data that has just been categorised, any spelling or grammatical errors have not been fixed. Green = take forward due to relevant needs. Yellow = useful comment but not directly relevant within current scope. Orange = not relevant to this project.

Policy	Needs within EA	Evidence gaps
BNG	• BNG is only part of the description of condition. Look more at ENG rather than BNG alone. • Integrated Asset Management (wider value proposition) • BNG will generate the funding. Where the delivery is should look at wider environmental benefits as well as being nature positive. • Biodiversity Net Gain • Carbon budgeting mandatory in large project business cases • Low carbon concrete • Multiple benefits mandatory in large project cost: benefit analysis • Standardisation of wider ecosystem service metrics • NC Registers & Accounting • robust metrics • Trade offs	• WQ aspects of Biodiversity Metric • Risk to assets & ES • BNG impact assessment & sensitivity analysis • How ecosystem service provisions changes with condition
Nutrient neutrality	• NBS for flood risk (i.e. more NBS)	• Nutrient neutrality – data gaps will be locally specific. Main gaps are probably going to be related to land use and nutrient sources
WFD	• Better recognition of wider benefits and the breadth of those benefits • Broader understanding of what value could be gained by doing things differently • how can this support carbon credits • how can this support wider financial incentives. • Environmental quality objectives • Catchment management • Role of natural processes in improving environmental quality – self-purification – major objective driving our work	• how can this support wider financial incentives. • Future of WFD • Effectiveness of measures • Evaluation! • Land use change to achieve WQ targets • Reducing budget for monitoring (reducing grant in aid from govt to fund public service • Do we need to develop future projections (drought)

		• Water Framework Directive objectives – sustainability, naturalness • Priorities for investment • Need for Local & Regional structure plans (or what will replace them) • Closer working with NE and LPAs around impacts of development on water quality (nutrients) and where mitigation is required – and how much	
LNRS/ NRNs/ habitat creation targets/ELMS generally		• Reducing budget for monitoring (reducing grant in aid from govt to fund public service • EA Advice to inform wider environmental outcomes for Local Nature Recovery Strategies • Defra 25-year plan targets • Working with natural processes • Economics and benefits of sustainability • TCFD (Taskforce on Climate-related Financial Disclosures) & TNFD (Taskforce on Nature-related Financial Disclosures) • need for tools to use natural capital data to support leverage of blended finance in a consistent way across projects • tool to link Defra SMART objectives to river restoration interventions • Stronger links between LNRS, NRN and water environment • European sites conservation • Catchment focus • Funding for river AND FLOODPLAIN restoration • Landscape recovery and countryside stewardship +	• Future condition predictions? • Lack of understanding what other organisations/ stakeholders are doing, and approaches they are adopting. • would be ideal to have natural capital tools for all Landscape Recovery projects to provide a baseline for future and for negotiating blended finance
25-year plan and EIP		• monitoring changes to report on the targets / advisory and regulatory changes. E.g., we need to support the government to reduce sediment pollution by 40% • Reliable monitoring data sets, especially from 3rd party • re-consider how we interpret and report our monitoring data • how do we report our own data alongside some of these more social information that people are	• evidence looking at the system would help us to invest and collaborate with wider policy areas. So looking at river/ floodplain, estuary etc. the marine NCEA is looking at some of these outcomes. • How to relate existing data assessment methods (e.g., WFD status, to NC metrics, in context of condition in a

		interested in. This might make our status reporting more accessible and relevant/ influential. • how can we use this information as part of our regulatory role • how does this support future development of existing monitoring systems and evidence gathering • Outcome measures / framework • replicable methods for calculating natural capital benefits, that water companies have capacity for • Reporting against targets • Looking for trends • Development of 'indicators' • Flood risk work	place, but also how to infer to whole asset • We don't know some of the gaps yet because we don't know exactly how we should be measuring things • Health and wellbeing/ society data (research) • Quantified benefits of blue space
Nature-based Solutions		• Change to criteria to get funding • Better evidence of the benefits. So that the options cant through the appraisal processes	
ENG and land use policies		• Need for evidence on ecosystem services from different conditions of the asset. • NBS standard approach within Flood risk policy – what are the benefits? • Sustainable asset management • need to be able to measure carbon uptake from different assets • Land use strategy? • close links to LNRS	• Valuing the function of the floodplain
Net zero and climate change act		• EA reducing its own emissions • Keeping rivers cool • EA advocating for others to reduce Carbon • also leads to tree planting objectives to sequester carbon • Carbon literacy training • EA looking for ways to mitigate / adapt to CC • Working with natural processes	• We don't know how CC will affect ecosystem condition • Carbon sequestration rates for different habitats • How tree planting vs natural regen. For climate affects land use
Local plans and localised decision making		• Thinking & measuring (?) the 'people' side – or working with those that do already • Guiding frameworks for more local decision making • Public accessibility to EA estate • Mechanisms to link local and national choices	
UN SDG		• Common metrics	

Private financing	• Public goods for public services • Citizen science • Increase private funding/finance of Natural Capital – need for mechanisms to enable this.	
Waste/circular economy	• Landfill tax • Emerging chemical pollutants	• Effect of new pollutants on ecosystem services / natural capital • CC effect on closed landfills e.g., coastal
OM4 scoring and appraisal guide	• FCRM solutions in EA and RMAs • NFM and NBS (FCERM national strategy)	
Levelling Up, EIA and SEA approaches	• move away from designations based significance to systems based decision • Requests for large sets of evidence at short notice • Need simple GIS tools with all the evidence	• lack of case studies or retrospective application of NC • lack of PPA

Other policies mentioned:

- NVZs
- Environment Act Targets - species decline, restore water bodies, deliver net zero, halve waste per person, reduce air pollution, restore marine habitats in MPAs
- Environment Improvement Plans
- Emission 2030
- Drought - what if get another summer like the last - an another?
- Flood risk assessment and planning approval process
- Env Act Targets /OEP
- Species reintroductions (beavers!)
- ARP3/4 (Climate change adaptation)
- Designated bathing waters
- Statutory public navigations
- Energy dependency policy (fracking, wind and hydro)
- successors to IPENS theme plans

Other evidence gaps mentioned:

- Water temperature data
- EA can't own/store all this data so need to improve live-linkage and access to the info other organisations have
- Upstream/downstream linkage: Upstream catchment change will do what to downstream services?
- Monitoring of actual visitor numbers (cf Orval data)
- Spatial data on public access, recreation, aesthetics
- Ability to spatially overlay data on ecosystem benefits
- Evaluation and projection capability: if we implement policy X it will have Y benefit

Exercise 3b: Metrics and scales required (Workshop 2)

Table B3. Raw outputs from exercise 3b (workshop 2). As this is raw data that has just been categorised, any spelling or grammatical errors have not been fixed. Green = take forward due to relevant metrics. Yellow = useful comment but not directly relevant within current scope. Orange = not relevant to this project.

Ecosystem service / condition aspect	Metrics, maps and evidence	Scale and level of detail needed
Water flow regulation	• Requirement to know how water flow varies. Both temporarily and spatially • Protected flows e.g., high or low level Q values per waterbody • Upland Mire - active upland wetland storage • What % of floodplain is connected to river • % area floodplain connected to river • Live river flow data. • Ideally a measure of water abstraction (only likely to be licensed amount). • Locations of measurements & abstractions. • Demand (likely to be modelled) of downstream user need. • 25 YEP indicators (B5) on flow	• Large scale variation - from catchment for use in extraction levels. • Protected flows e.g., high or low level Q values per waterbody • Catchment scale • National /England for reporting for 25YEP/EIP23 • Sub-basin
Water quality regulation	• WQ elements for 25YEP/EIP23 indicators and Env Act Targets: P, N soil etc • We have WFD WQ metrics (but they don't include sediment or nitrogen). Challenge to map these to locations beyond the locations where the samples are taken and we measure the data • Measure phys chem and chem in water samples. • Better understanding of the environmental requirements of the different components of the ecosystem so we know how to protect them • Better understanding of the microbial communities important for this, so we may miss their status in our assessments of state of environment • Modelled / quantified differences between existing water quality and desired or required water quality	• England scale for national reporting, but data also needed at finer spatial scales for local decision making • England level for national reporting for 25YEP/EIP23 Env Act
Water provision	• resource demand: future forecasting (incl. climate change) • Condition of infrastructure that facilitates and supports abstraction • How would we measure water provision geospatially - at points of extraction or related to demand of local population • Benchmarking sustainable volume potentially available for abstraction	• Water resource zone and/or hydrological catchment

		• Also factor in expected rainfall (natural variability & climate change scenario driven changes). • Quantity of water available in 'upstream' storage (natural aquifers, marsh /swamp, reservoirs...).	
Erosion		• Measured and modelled flow regimes (volume & flow speed). • Erodibility of bed / bank materials. • Location / quantity of natural binding flora (trees...). • Likelihood of large debris from upstream being used to create 'traumatic' events affecting banks. • Sediment data - transport in the system and at the river mouth • Sediment typing - river bank / soil etc - to target interventions • Erosion risk mapping - to target strategic interventions • Sedimentation rates - to understand ecological impacts • I suspect we have information from River Habitat Survey, but we don't map it • Erosion is not always bad, ecologically. We need the right type of specific erosion. Exposed river sediments support their own biota. • positive: coastal processes and ERS, negative, rivers out of regime because of soil from fields entering watercourses • soil erosion - Defra (and BGS?) datasets and vulnerability maps - relevance for NCA and ecosystem services	• Waterbody level detail • AFNE Geomorphology team's work on working with natural processes
Carbon		• Need for understanding of how much stored carbon we gain from each habitat. As habitats can be mapped, and carbon not so much! • responses to climate change (ITE have done this???) • Woodland Carbon Code • Peatland Carbon Code • Saltmarsh carbon code in development • New codes - soil/ seagrass/ saltmarsh/ oyster beds, hedgerows etc. • Organic carbon loading of the water • A number of reports and measurements available on carbon sequestration of different habitats including wet ones. • We are measuring dissolved organic carbon in the River Surveillance Network but I'm not sure this is what is meant by "carbon" in this context.	

Habitat / population maintenance	• Not really sure what this means. Our biological assessments give some measure to this. Lots of the indicators either existing or in development also look at this. • Abundance targets are a bit counterproductive - some species thrive in disturbed habitats • How does this service relate to condition of ecology referred to below? Is this something specific and different? • Species recovering/returning • river habitat survey or similar • Presence/absence of invasive species • A lot of work looking at what species data is available done for development of new Environment Act targets • ecotones, mosaics, • Habitat data produced from amalgamating SSSI data. • mycorrhizae, VAM, healthy decomposer organism systems • all aspects of population dynamics including inter and intra specific competition • presence of viable seedbanks	• Sub-catchment scale. Often Habitat is at a SSSI Feature scale • At a scale suitable to the activity occurring. E.g., Point source • Need England data for species for Env Act targets & EIP 23 • If the NC output is being used to influence decision - then the finer scale it can be delivered at - the better. It will be used to influence FCRM capital schemes or Partner projects
Recreation / cultural services	• Extraction and planting for timber industry. Need data on the location and amount. • Distance between people and freshwater x number of people • zoning studies /metadata sets and bird disturbance toolkit type things • Need to consider canals and ditches more than we currently do because these are important in urban environments • Need to ensure valuation of services covers the shole of society, not just white middle-class or landowners • see research from Exeter university • Evidence gap - we have tools to quantify recreational value from green space - but not blue space • No. of visitors • Uplift to value of waterside businesses and properties • Accessibility to water/site • Provision of sufficient water to enable on-water recreation and provide the 'draw' for bankside recreation • IMD/ONS data • Integrity of landscape (type) • Range of activities - angling, swimming, paddle boarding • Aesthetics - interactions and access for recreation - in the eye of the beholder :) • MENE survey & its refresh - can we do more?	• Need information at different scales for different purposes - catchment, local authority • Ward level

Temperature regulation	• Water shading maps - Keeping Rivers Cool and an as yet unnamed all water dataset. Use aspect, land and tree cover to map relative shade. • Gauged data - both upstream and downstream of industrial abstractions. • Rate of surface evaporation? • Amount of shading • Essential - as a hidden element of climate change. I think this element is particularly valuable. Link to Keeping Rivers Cool • see research from Uni of Birmingham	• Waterbody scale
Biological / ecological quality	• Understanding of the link between type-specific ecological communities and the services that they provide • Research on the services provided by natural types-specific ecosystems/-biological communities • population dynamics, age and size class distribution, population dynamics, recruitment, inter and intra specific competition - what does a pristine ecosystem look like • presence of alternative stable states in degraded and healthy ecosystems • intact and functioning soils, such as podzols for heathland etc • Importance of site location, in the contribution to ecological quality. Maps and metrics needed to record "site worth" • Gap - ecosystem function and measures of resilience. WFD metrics don't do that. • ecology, invertebrates, macrophytes, phytoplankton, species. • We have WFD reference-based metrics for a range of biology, i.e. change from a defined reference condition. The survey data could be used in different ways (number of species for example). The WFD metrics take a specific view of "condition". but this might not be what we need from a NC point of view.	• Meta population scale. • Need to relate to river typology in relation to the natural ecosystems that they support • same need for national and local data requirements as for water quality.
Geomorphological processes	• RHS, Morph, Placemarker, fluvial audit	
Resilience	• what are the key drivers or keystones that are essential to enable resilience of different ecosystems - these MUST be monitored as indicators • connectivity • Talk to the insurance industry - they could perhaps help.	• City scale • Value of reduced risk - don't know what the metric would be.
Iconic species or landscapes	• lynchpins for ensuring people value the environment for its own intrinsic or existence value	
Waste regulation	• Discharge flow & quality • Sediment capacity to biodegrade??	• Waterbody level detail

	• Can we calculate dilution /sedimentation of pollutants: what biotic and abiotic processes are active? • Estuaries and inshore waters - biofiltration (mussels are our friend!)	
Physical change due to climate change	• Location, rate of change • Risks e.g., erosion • Opportunities e.g., habitat creation • For planning FRM, development, assets, woodland creation, habitat creation	• For planning FRM, development, assets, woodland creation, habitat creation
Soil health and capacity	• to inform landscape restoration interventions 'right thing right place'	

Emerging evidence / other projects:

- Water resources GIS
- EA Hype model outputs
- Moorland Change map: NE datasets showing burning/cutting and bare peat. Linked to carbon being lost
- Check with NEIF for learning about new carbon codes - soil/hedgerows etc.
- check with ReMeMaRe for saltmarsh, seagrass and oyster bed Carbon.
- People in nature Survey - NE
- EA Geomatics team using LIDAR to map tress /shade next to rivers
- Uni B'ham - involved in water temperature monitoring (in Scotland) and projected change to 2050
- RIVPACS (principles) - predicts the natural biological community of different river types - needs to be extended to lakes, plants, etc
- We are working on this in national geomorphology team -'natural processes toolkit'
- NCEA - England Ecosystem Survey (soil research and data collection across England). NE aspect. Scale of land parcels.
- Change detection Map: NE work. Down to the meter, and available across all England.
- CEH research on remote condition monitoring.
- NCEA: Living England Map. Machine learning combined with remote sensing to produce all of England habitat map. (Available on Magic - NE led)
- Don't forget - McHarg, Design with Nature (1971)
- ALERT TOOL - created by EA geomatics to help determine how to best place agricultural interventions at a sub-field boundary scale
- NE work has highlighted areas of "high potential" for recovery due to their location in the Nature Recovery Network.
- Talk to the Natural Environment Investment Readiness Fund team for learning. General point.
- Need data & evidence at a range of & inter-scalable to enable reporting and or planning
- Dependencies with 25YEP and EIP23 metrics/indicators
- WINEP review

Workshop 3

Exercise 3, question 1: what are the remaining gaps following project findings?

Theme	Comment
Baseline	• Shifting baseline
Connectivity	• Connectivity • connectivity, indicators/measurement/quantification
Indicators	• Clear information on the metrics and indicators we already use for condition/ES (and where we can quantify) vs where we can't and have gaps - to help understand where we need to go in future. Show clearly where we know and can quantify links vs where we can't. • metrics in 25yr environment plan how well we can describe ES's associated with it; policy relevance, filling in of gaps that matter through this, to help priorities - may policy relevant, map of 25yr plan into natural capital, extra component to flow charts how well do they feed into this • Water temperature (and especially peak water temperatures) is cross-cutting - does it fall between gaps in data flows? Climate ecosystem service provision scoped out but it's a good driver for outcomes. Think about how to use water temperature as pressure and indicator. • connectivity, indicators/measurement/quantification • Data on number of people on beaches and litter on the beach • Number of visitors for beaches and status recorded
Links	• quantitative link between flood risk and mental wellbeing
Monitoring	• confidence that monitoring is effective • how effective is routine monitoring answering questions?
Outcomes	• Missing customer focus? Not necessarily explored enough (needs beyond EA). Specialists may have a different focus to decision makers. • lessons learned- WFD purist scientific method not helped in practical delivery; how will it be used in decision making; about customers for this information- not been explored thoroughly enough
Resilience	• Which are the key elements of condition? Resilience, divergence from naturalness • resilience: what are the essential species and edaphic parameters that confer resilience to perturbation; linked to resilience - intact food webs

Temporal	• history: water courses responding to milling, enclosures act, railway, roman and medieval flood defences - which channels are still responding geomorphologically to historical interventions • Historical vs present data; climate change - impact data; Rainfall patterns
Thresholds	• Thresholds - how far until affected • Threshold identification

Exercise 3, question 2: how to fill the gaps

Recommendations for filling gaps
Go back to NE NC indicators and check how well we (EA) have interpreted them for freshwater - to see how effectively monitoring answers the questions we need to answer for NC. Conversation with NE would give us confidence that we are collecting the right things - or identify that we are not collecting the right things and need to make changes. Links to Indicators in EA monitoring project.
networks help with condition
proximity to river a priority for many different ecosystem services; e.g., chalk catchments inaccessible
Anything simple we can do around proximity/access for recreation and wellbeing?
seedbanks and seed movement in wetland and aquatic systems - is it "build it and the plants will come!"? can the propagules even reach the places that we want them?
Avoid using proprietary data - only use open source - I've had an issue with UKCEH data and will have to re-compile data as a result
proper data retention so that we can measure long term change
post-project monitoring needs to be done; BNG
EA scientist references in reports
soil structure work
WFDT

NE - floodplain wetland mosaic
deviation from natural flow
Oddly this just cropped up – so in case it is of use – various NC approaches at global level are referred to: https://www.admcf.org/research-reports/accounting-for-biodiversity/ I thought it mentioned a 100m resolution map somewhere as well on biodiversity condition but cannot find it now.
Discussion around access relating to more deprived areas - we (public health & equity team) are working on a project around environmental equity data, albeit in the early stages, but it will involve aligning with the updating of the Indices of Multiple Deprivation (IMD). In case the data we are using for this work is also helpful for you, I've linked it here: https://data.cdrc.ac.uk/dataset/index-multiple-deprivation-imd
Green flag award/scheme for public accessibility data
The wildlife trust might be a good source of data for school visits, so would SSSIs.
Landscape character assessment will give info on what people find more aesthetically pleasing.
Look for natural history community engagement for potential data.
Search for pollution incident dataset
Check for water companies data they may have blockages points and frequency.
Keep Britain tidy -> might have map of fly tipping
For demand for high water quality can search for petition for bathing water status
Search for nuisance odours dataset
Within historic England valuation look for new village green movement.
Check sustainable places for extra data/studies.

Exercise 3, question 3a: how to present literature review outputs

- Internal and external (including academics)
- gov.uk
- Across NCEA
- reach out/collaborate with academics
- science journals
- Provide a case study or worked examples
- training - we are planning some nature gain training for all staff
- published externally
- Ideally shared with area teams, who may be the end user/decision makers of these tools and approaches
- Publish data on the web in a form that other researchers (and us in 5-years' time) can access and use

Exercise 3, question 3b: how to present data outputs

- Mapping linked to Analysis Ready Water Network (or an open river network)
- Make open and accessible
- demo in real life case study
- publish data online
- I'm very keen on data that can be shared with other systems - diagnostic or otherwise.
- twitter?
- web tool; Defra data platform

Appendix C: VosViewer results from QSR

Condition is viewed by ecosystem service specialists in relative terms. The definition of what ‘good river condition’ is, changes in relation to the ecosystem service analysed, in contrast to a more traditional definition of river condition. In order to highlight potential differences in the way condition is viewed we ran another Scopus search using the terms ‘TITLE-ABS-KEY(river AND condition AND "ecosystem service")’ and reported VosViewer outputs (Figure C1, C2).

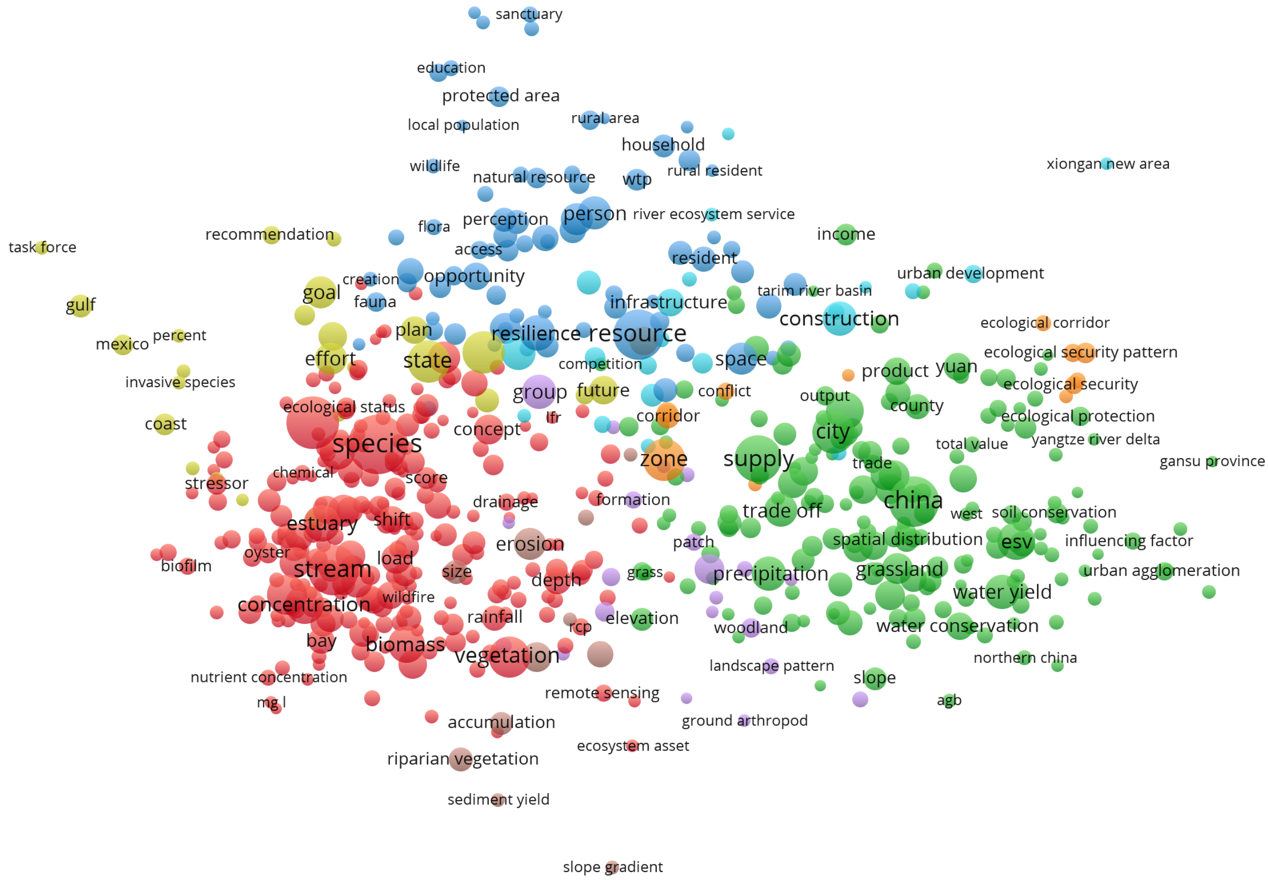

Figure C1. Network visualisation of Scopus search ‘TITLE-ABS-KEY(river AND condition AND "ecosystem service")’.

Clusters seem to differ slightly compared to the previous search (see Figure 9). The red cluster identifies physical entities, in blue it is possible to identify the more human component and in green the mechanisms, while the yellow cluster seem to suggest metrics and targets. The Xiongan new area, which is a new development in China (considered as the city of the future) that is meant to meet ecosystem service demand shows as a new topic of research.

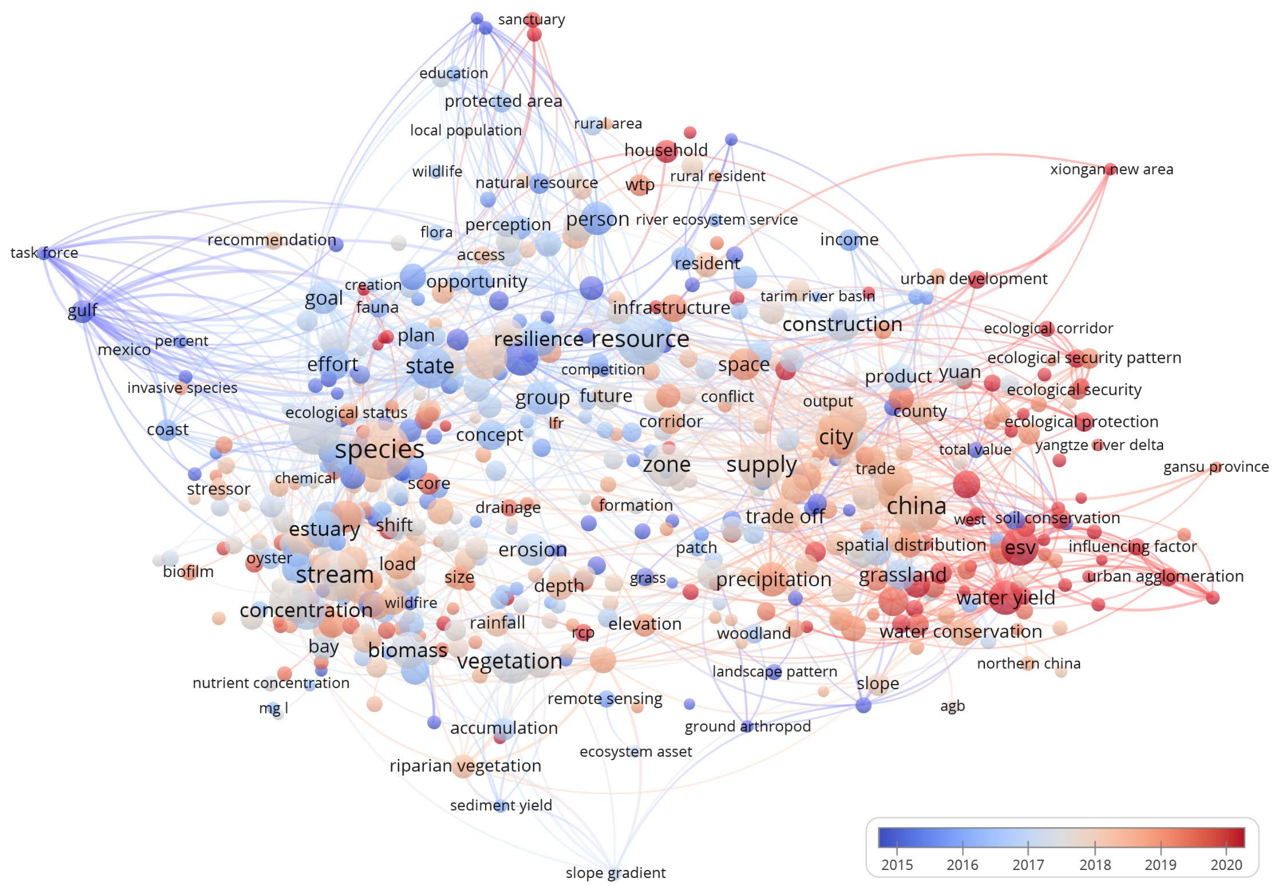

Figure C2. Overlay visualisation of Scopus search ‘TITLE-ABS-KEY(river AND condition AND "ecosystem service")’.

We are also providing all of the files to enable exploration of the VosViewer outputs as part of this appendix. All VosViewer figures are reproducible using the ‘Scopus_first screening.csv’ and ‘Scopus_river condition ecosystem service’. Alternatively, it is possible to import the mapfiles that users can explore in VosViewer (‘Scopus_first screening_mapfile’ and ‘Scopus_river condition ecosystem service_mapfile’) or the text files (‘Scopus_first screening_text output’ and ‘Scopus_river condition ecosystem service_text output’).

These files are available in a separate folder:
Natural capital condition mapping - Appendix C – VosViewer).

Appendix D: Literature review database and knowledge map

A complete list of the papers that passed through the first screening of the literature review described in Section 4, a knowledge map for the final selection of papers, as well as grey literature and additional papers reviewed can be found in:

'Natural capital condition mapping – Appendix D – knowledge map.xlsx'

Appendix E: Natural capital mapping indicators

A comprehensive list of data; tools, methods and models; and indicators identified in Section 5 can be found at:

‘Natural capital condition mapping – Appendix E – indicators datasets & models.xlsx’.

This includes key information on each entry, a link to the data source, and an assessment of each one.

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