Working Paper 430

How do healthy rivers benefit society?

A review of the evidence

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All errors or admissions are the responsibility of the authors.

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Abbreviations

Abbreviation	Description
DRR	Disaster risk reduction
ESPA	Ecosystem Services for Poverty Alleviation programme
ESS	Ecosystem service
EU	European Union
HH	Household
IHA	International Hydropower Association
HSAP	Hydropower Sustainability Assessment Protocol
IWRM	Integrated water resource management
MEA	Millennium Ecosystem Assessment
ODI	Overseas Development Institute
PES	Payment for ecosystem services
TEEB	The Economics of Ecosystems and Biodiversity initiative
WCD	World Commission on Dams
WFD	Water Framework Directive (European Union)
WRM	Water resources management
WRD	Water resource development
WWAP	World Water Assessment Programme
WWF	World Wildlife Fund

Glossary

Term	Definition
Driver	External factors driving changes in river ecosystems. These drivers reflect dynamic processes of human development, as well as bio-physial drivers such as climate change.
River / river system	Natural streams of water flowing in channels and emptying into larger bodies of water.
River basin	The land area that is drained by a river and its tributaries. The terms ‘watershed’ or ‘catchment’ can be similarly defined.
River ecosystem	(See freshwater ecosystem)
River health	The overall state or condition of a river. Often assessed in relation to water quality, environmental flows, connectivity of river habitats, and biodiversity, among other indicators.
Economic benefit	Contributes directly to sectors of the national economy and/or provides employment.
Ecosystem processes	The biological, geochemical and physical processes that take place and interact within an ecosystem.
Ecosystem functions	The role that specific ecosystem components and processes play in contributing to the overall working of the system.
Ecosystem services	The aspects of ecosystems that can be utilised (actively or passively) to produce benefits for humans.
Ecosystem structure	The abiotic and biotic components of an ecosystem.
Environmental flows	The quantity, timing, and quality of water flows required to sustain riverine ecosystems and the human livelihoods directly dependent on them.
Freshwater ecosystem	The living organisms and non-living materials interacting as a system in an inland aquatic environment, such as a river.
Pressure	Direct threats or stresses on the river which have implications for ecosystem processes and functions and affect river health.
Social benefit	Contributes to the well-being of individuals and communities, and the functioning of society.
Societal benefit	The benefits individuals, communities and societies derive from rivers through the use of ecosystem services. The realisation of benefits requires some form of human intervention.
Strategic benefit	Contribute to national and trans-national interests, and are often highly politicised. These benefits tend to be indirect, realised through the social or economic benefits derived from rivers.
Wetland	Wetlands include a wide variety of habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, and seagrass beds.

Executive summary

Key findings

1. Rivers have the potential to provide a wide range of benefits to society but are often exploited to deliver a narrow range of objectives, to the detriment of river health and other human needs (i.e. sub-optimal investment decisions).
2. Many social benefits derived from rivers are dependent on good 'all round' river health, including cultural and aesthetic values, or secure livelihoods such as those based on inland fisheries or flood recession agriculture.
3. Economic benefits, such as those derived from commercial agriculture or hydropower, tend to rely on just a few aspects of river health (such as flow) and require built infrastructure (such as dams), entailing significant trade-offs with other benefits.
4. Strategic benefits are indirectly related to river health and the causal relationships (or lack of) are more difficult to prove, for example energy security through hydropower requires flows, but but not high water quality.
5. Rivers not only provide services and benefits, but also disservices such as flood risks which have to be managed.
6. The realisation of benefits requires human intervention, underpinned by infrastructure, institutions and other forms of capital.
7. Individuals or groups of people in society have differentiated ability to make use of the benefits rivers provide due to differences in access and entitlements to resources.
8. More research is needed to understand the spatial and temporal dimensions of river-society relationships.
9. Rivers should be managed to deliver a wider range of benefits, and account for potential trade-offs. The costs of river development (externalities) need to be better accounted for in decision-making.
10. Conservation agencies such as WWF could better speak to the interests of powerful decision-makers by framing river health in terms of social, economic and strategic benefits.

Background and objectives

Rivers are essential to human well-being. However, many rivers around the world are severely degraded or at risk, which undermines their ability to provide critical ecosystem services and related benefits. In order to better engage decision-makers in conservation efforts, WWF believes there is an urgent need to synthesise and strengthen the evidence base regarding the relationship between improved river health and the benefits human societies derive from rivers – social, economic or strategic. As a first step, this paper a) critically reviews evidence from the literature and b) proposes a framework for more detailed exploration of specific causal linkages between river health and benefits to society, including indicators that might be used for assessing benefits. This has included the development of hypothetical 'causal chains' for fisheries, irrigated crop production and hydropower.

Methods

Relevant literature was identified and assessed using quick scoping review (QSR) methods, capturing research from a range of disciplines. QSRs are intended to reduce (or make explicit) potential sources of bias and add a level of rigour, compared to traditional literature reviews. The review was conducted in several distinct stages: 1) defining the scope and review questions, 2) selection and review of keystone literature, 3) forward and backwards citation tracking, or snowballing, to identify additional papers of relevance, 4) data extraction and analysis, and 5) targeted gap-filling. More than 100 papers were reviewed. Experts were consulted at each stage, including a roundtable session to discuss the conceptual framework and emerging findings from the analysis.

General findings

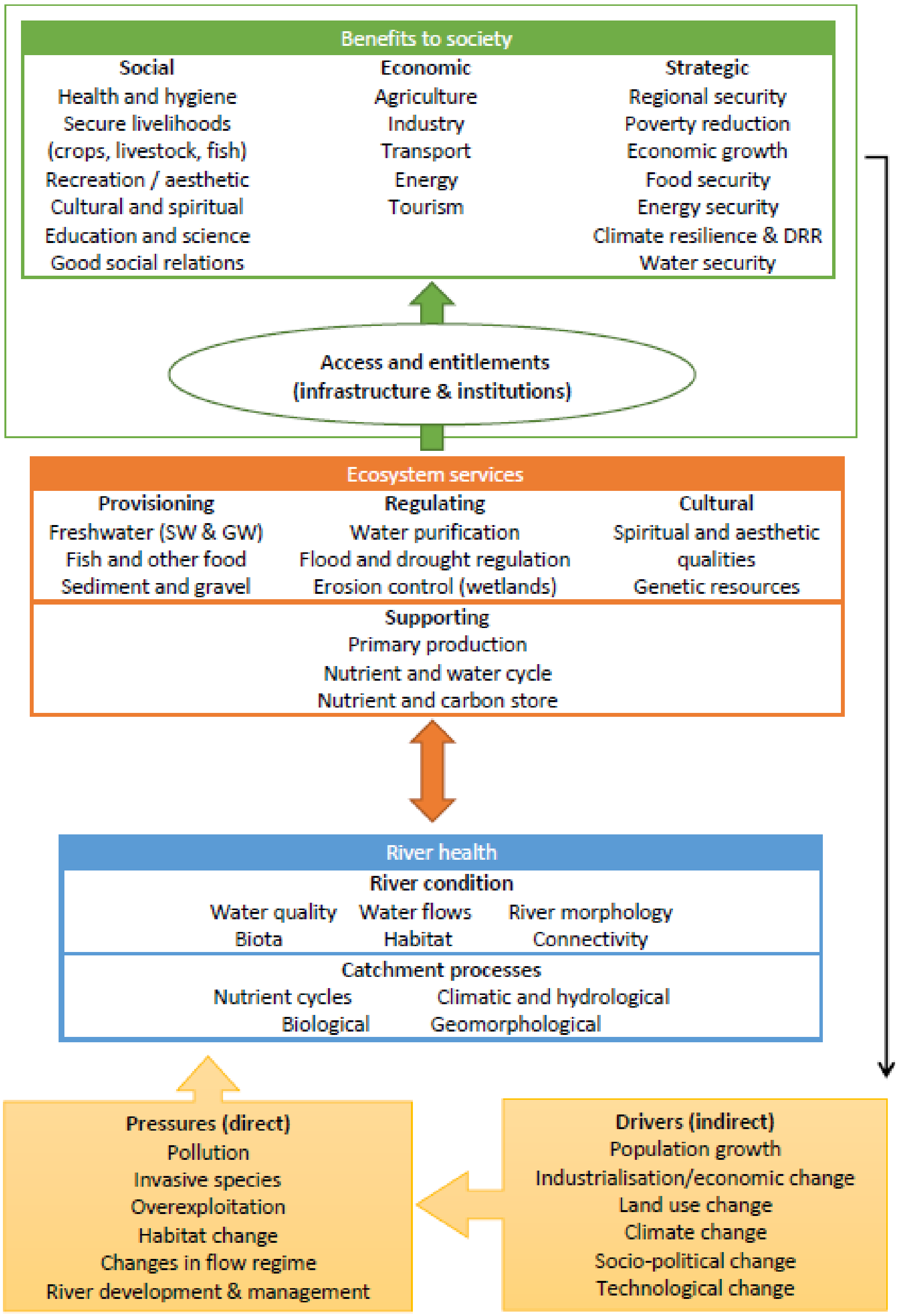
We found a marked divergence between the ecosystem services (ESS) and water resources management (WRM) literature in their treatment of river-society relationships. In the reviewed papers ESS authors tend to focus on ecology and the benefits of ecosystem preservation, whilst WRM authors are more focused on harnessing rivers for human benefit, including mitigation of water-related risks, and water resource development (WRD) such as hydropower and irrigation for socio-economic goals. The evidence suggests that rivers have the potential to provide a wide range of benefits to society, for example supporting key livelihood activities and economic sectors, nurturing social relations and spiritual well-being, and contributing to strategic goals such as food-energy-water security, poverty reduction or climate resilience. However, different types of benefit depend more or less on different indicators of river health, such as water quality, flows or biodiversity. Some benefits require good health across multiple indicators. To a large extent the portfolio of benefits will depend on how a river is managed. A few papers note that access to water and other resources, as well as exposure to risks, are socially differentiated, for example, over-exploitation of ecosystems disproportionately affects the livelihoods of the poor and future generations. Major reviews highlight the importance of institutions in addressing these inequalities.

Conceptualising causal relationships

To better visualise the complex interactions between the river and society, we developed a conceptual framework showing the relationship between the river health, ecosystem services, different societal benefits, and the drivers and pressures which threaten rivers (see figure below). These relationships are depicted in relatively simple terms, whilst acknowledging that the relationships between river health and societal benefits are highly complex and there are a number of uncertainties, feedback loops and confounding factors at play. The framework can be developed in much more detail for specific benefit streams, or causal chains, of interest.

The conceptual framework attempts to integrate thinking from the ESS and WRM literature, and also draws on the social sciences such as political economy research. It is primarily a research tool, but can also inform the design, monitoring and evaluation of WWF's freshwater programmes to assess the extent to which initiatives focused on improved river management deliver benefits to target stakeholders and wider society.

Figure 1: Understanding the relationships between river health and societal benefits – a conceptual framework



Fisheries

Fisheries are a common benefit derived from rivers. The reviewed literature plus further evidence from subject specific research suggests that healthy river indicators including sufficient water quality, flow and connectivity are essential to support fishery productivity. The literature also provides clear evidence that fisheries support livelihoods, nutrition, cultural and spiritual values and recreational activities. For example, in Nigeria, fishing rituals are related to fertility, and in the USA, first nations attach high spiritual values to the salmon population of the River Elwha. In Scotland, recreational fisheries provide crucial income and employment for local communities. Fisheries also support poverty reduction and food security, although the relationships are complex. For example, in some developing countries fishing can be a subsistence livelihood of last resort. This encourages unsustainable fishery practices, and over-exploitation which reduces potential harvests and creates a negative cycle of poverty. There is also evidence that the benefits derived from fisheries may be 'sacrificed' for the development of large-scale infrastructure such as dams for hydropower or irrigation. For example, dams on the Paraná river in Brazil resulted in increased efforts to harvest fish, a decrease in the migratory species preferred by consumers, and a decline in market value and incomes.

Irrigated agriculture

Irrigated agriculture is another critical benefit which humans derive from rivers. As with fisheries, crops grown under irrigated systems support livelihoods, with the potential for significant revenue generation with commercial production. Irrigation can also support food security through improved stability of food supply in areas subject to drought and seasonal variability, increased food availability and better incomes for farmers. However, the stream of benefits is largely determined by the objectives of the scheme investor and irrigation design, management and performance. Benefits may also be unevenly distributed. People close to irrigation schemes and dams are at higher risk of diseases while high level benefits such as food security are dispersed. Furthermore, expansion of irrigation is a major pressure on water ecosystems. Over-abstraction can cause river degradation. Reduced downstream flows devastate ecosystems, as flow is the most important factor for bioidiversity. Agricultural inputs including pesticides and fertilisers cause pollution and eutrophication. Infrastructure such as diversions and impoundments also disrupt ecosystems and negatively affect other services. Downstream water users may be subject to reduced allocations which threaten their livelihoods, or alternatively, irrigators can lose access to water in favour of large urban centres, as alternative higher-value uses. This illustrates the importance of applying a political-economy lens to the societal benefits of river ecosystems.

Hydropower

The most controversial causal chain is related to hydropower. Hydropower requires sufficient water flows and sediment control, although water quality is much less important. As such, a relatively 'unhealthy' river can still produce energy. Hydropower is often justified by narratives around economic growth and social development. There is evidence that hydropower production can support energy security by increasing availability. However, the relationship between hydropower and households' access to electricity is shaped by political factors and geographic constraints. Dispersed rural communities which house many of the poor in the developing world cannot easily access electricity derived from hydropower, and off-grid solutions may be more appropriate. Furthermore, hydropower development has high social, economic and environmental costs, including degradation of river ecosystems and biodiversity loss. This has a knock on effect on other potential benefits, such as fisheries. The costs of hydropower are often disproportionately borne by the poor and marginalised, although there are options to rebalance the trade-offs and 'winners and losers' through compensation, benefit sharing, preferential tariffs and investment in social goods.

Conclusions

Despite their potential, rivers are often exploited to deliver a relatively narrow range of objectives, to the detriment of river health as well as other human needs. This is primarily because the management of rivers and their ecosystems has tended to occur in silos, with poor cross-sectoral coordination and a lack of integrated planning, and often driven by political expedience, resulting in sub-optimal outcomes. Predominant approaches have failed to tackle mounting anthropogenic pressures on rivers, and most efforts have focused on the problem of water quantity, ignoring other key river health characteristics. Water quality, for example, is just as important for satisfying basic human and environmental needs, yet has received less investment, scientific support, and public attention. On the positive side, researchers and practitioners are calling for change, and there is increasing adoption of multi- and trans- disciplinary approaches, encompassing the development of new decision-support tools.

Sustainable management of river ecosystems requires a stronger inter-disciplinary approach, and reclaiming the 'water sector' from the margins to the centre of policy-making. The costs of river development (economic, environmental and social externalities) need to be better accounted for in planning processes, as well as an explicit consideration of who wins and who loses, and how to compensate the latter. Finally, a widespread shift in thinking is needed so that ecosystems are not viewed as consumers of water, but rather an essential component of water security.

Recommendations for WWF

Examine WWF's policy positions:

- Re-frame WWF's narrative around river health in social, economic and strategic terms to better speak to powerful interests
- Acknowledge the fact that river health is not the only factor determining benefits from rivers
- Promote inclusion and equitable allocation of benefits

Apply the conceptual framework to specific river basin programmes:

- Be clear about the specific societal benefits the programme seeks to address, and how these will be monitored
- Identify the trade-offs involved in river management and the stakeholders affected by river development, including measures to mitigate risks or compensate 'losers' where necessary
- Identify factors other than river health that determine the nature and distribution of benefits, particularly people's ability to access and their entitlements to river resources

Commission further research to:

- Conduct a critical analysis of methods and indicators to assess causal relationships and measure outcomes, to inform programme monitoring and evaluation
- Develop causal chains for specific benefits and test these theories of change by applying them to WWF programmes or case studies
- Consider addressing gaps in the evidence around river disservices, and temporal and spatial dynamics of river-society relationships.

1 Introduction

1.1 Overview

Rivers are essential to human well-being. However, many rivers around the world are severely degraded or at risk, which undermines their ability to provide critical ecosystem services (Wong et al., 2007). In order to better engage decision-makers in conservation efforts, there is an urgent need to synthesise and strengthen the evidence base regarding the relationship between improved river health and the benefits human societies derive from rivers. As a first step, this paper critically reviews evidence from the literature and proposes a framework for more detailed exploration of specific causal linkages between river health and benefits to society.

1.2 Rivers at risk

Rivers provide a range of services that can be exploited for the benefit of human society. They have the potential to provide freshwater for domestic consumption, livelihoods and commercial production (agriculture, livestock and fisheries), industry and energy, and are used for transport and tourism, all contributing to national economic growth and poverty reduction (Emerton and Bos, 2004; TEEB, 2013). Riverine ecosystems also play a key regulatory function in our environment, supporting biodiversity, transporting sediment and nutrients, diluting pollutants and waste, and regulating floods and droughts (*ibid.*). Many of these services are intrinsically related to factors indicative of river health, such as water quality, ecological status and flows (Finlayson and D'Cruz., 2005).

Comprehensive assessments conducted by WWF and others have identified multiple pressures facing river systems in developing and developed countries, including: over-extraction, which diminishes flows; infrastructure developments such as dams, which disrupt flows; pollution, which makes river water toxic for humans and wildlife; and invasive species, which disrupt habitats and trophic systems (Wong et al., 2007). Many of these pressures will intensify with land use change, industrialisation and population growth, and climate change will have a negative multiplier effect, for example reduced rainfall will exacerbate the effects of pollution due to decreased flows and lower absorptive capacity (Vörösmarty et al., 2005).

One of society's greatest challenges in the twenty-first century is therefore to ensure that freshwater ecosystems continue to provide services essential to human well-being over the long-term, in the face of multiple pressures (Poff et al., 2015). Equally important, and often politically challenging, is to secure access to ecosystem services for poor and marginalised groups, and to ensure that the benefits derived from rivers, as well as the costs associated with resource exploitation, are distributed in an equitable way across society (Adekola et al., 2014; Newborne, 2014).

In some countries, such as the USA, efforts are being made to reverse river degradation, including the removal of dams, and to assess the outcomes for both environment and people (e.g. Gowan et al., 2005; Lewis et al., 2008). However, it is evident from recent global analyses that, for the most part, past management approaches have largely failed to address the anthropogenic threats to freshwater ecosystems, or to account for the complexities of linked natural-social processes (Vörösmarty et al., 2010). The science underpinning decision-making has also struggled to respond to the pace of change. For example, until recently ecosystem services research has largely evolved in isolation from mainstream water resources management. New decision frameworks are needed to guide investments in water resources management and development, in which environmental health and the principle of equity are placed at the heart of national water security and human well-being (Poff et al., 2015).

1.3 Research objectives and questions

This paper was commissioned by WWF UK to: 1) provide a review of the evidence about the links between river health and the benefits that societies derive from rivers, and identify areas of uncertainty; and 2) initiate the development of a framework to identify connections between river health and priority socio-economic benefits, including indicators to assess benefits.

The review will inform WWF programme design, monitoring and evaluation, providing a basis to assess the extent to which projects focused on improved river management deliver benefits to target stakeholders and to wider society, as well as identifying areas for further investigation. More broadly, it is hoped this review will encourage discussion among policy-makers and water sector practitioners regarding the potential economic and social returns on investments in sustaining and restoring healthy rivers.

This paper addresses the central question:

> What is the relationship between improved river health and benefits to society?

A sub-set of questions have guided the review process and framework development:

1. What is the range of benefits human societies derive from rivers, and how might they be measured?
2. Which benefits are dependent on river health, and how robust is the evidence for causal linkages between river health characteristics and specific benefits?
3. What are the trade-offs between different types of benefits, and who benefits?

For the purposes of this review we are interested in the health of, and benefits derived from, rivers and riverine ecosystems, which encompasses connected wetlands, shallow groundwater, deltas, lakes and reservoirs. River health refers to the overall state or condition of a river. Good river health is often assessed in relation to water quality, environmental flows, connectivity of river habitats, and biodiversity, among other indicators (Finlayson and D'Cruz, 2005; Speed et al., in press). We consider a healthy river to be distinct from a 'natural river' – the former being utilised in a sustainable manner while the latter is at, or very close to, its natural state with minimal human disturbance. The Ramsar Convention promotes the concept of wise use, recognising that alteration of the river and its ecosystems can facilitate realisation of benefits, but that the level of alteration should not degrade the system itself (Ramsar Convention Secretariat, 2010). A number of river health classifications have been developed around the world (see Box 1).

Box 1: River health classifications

There are a number of classification systems that define rivers according to ecological characteristics, as well as from a management perspective. The EU Water Framework Directive (WFD), for example, aims at preventing the deterioration of water bodies and promoting sustainable use (European Commission, 2003). Under the WFD a river's condition can be rated as high, good, moderate, poor or bad. 'High' represents natural conditions with no, or very minor, human impacts, and other classes imply increasing deviation from the undisturbed condition (*ibid*.). The elements that are used to assess water status are generally biological, such as fish and invertebrate populations, or chemical, such as the concentration of heavy metals, pesticides and nutrients, although hydro-morphological characteristics may also be considered (UK Environment Agency, 2012). Similarly, the South African River Health Programme uses an integrated index to assess ecological status, defined as 'the ability of a river to support an array of indigenous species and provide a variety of goods and services' (River Health Programme, 2011: 15). Rivers are graded as natural, good, fair or poor from both an ecological (biodiversity) and management (extent of resource exploitation) perspective. In Australia, the International Water Centre in Brisbane has developed River Health Scorecards. The centre has also worked closely with the Chinese government to inform efforts to develop government systems for routine monitoring of river health, including environmental flows (Speed et al., 2012).

Societal benefits are the benefits that individuals, communities and societies derive from the services a river ecosystem provides. In this paper they are broadly classified as social, economic and strategic, and can include direct and indirect, tangible and intangible, benefits. These classifications are further elaborated in Chapter 3. In our review we consider the benefits rivers and their ecosystems provide at a broad scale, rather than micro-level analyses of specific ecosystem processes or social groups.

1.4 Paper outline

In Chapter 2 we present the methodology used to conduct the review. Chapter 3 provides a synthesis of the main findings from our analysis. These insights inform the development of the conceptual framework, detailed in Chapter 4, which includes a typology of benefits and example indicators. The linkages between river health characteristics and specific societal benefits are explored in more detail in Chapter 5, which present hypothetical 'causal chains' for fisheries, crop production and hydropower, again based on the literature reviewed. The 'causal chains' unpick relationships between specific aspects of river health and benefits to society, and demonstrate how the conceptual framework might be applied to a particular benefit stream or case study of interest. We conclude in Chapter 6 with a summary of key findings and recommendations for future WWF programming and research.

2 Methods

2.1 Key features of the review process

The review provides a rapid assessment of the evidence for the range of benefits society derives from healthy rivers, with a broad scope. Evidence was collated from both the scientific and grey literature using a similar approach to the Quick Scoping Reviews (QSR) described by Collins et al. (2014). QSRs are ‘designed to greatly reduce bias which can be found in more basic Literature Reviews and provide a systematic, transparent and practical method to review evidence’ (*ibid*.: p2). They draw on the methods developed for Systematic Reviews (Box 2).

Box 2: What is a Systematic Review?

A Systematic Review is ‘a rigorous method to map the evidence base in an unbiased way, to assess the quality of the evidence and to synthesise it’ (Hagen-Zanker and Mallett, 2013 citing DFID, 2013).

Systematic Review methodology has been used extensively in the health sciences, but has only recently been introduced to international development research. The term is often used to refer to formal, statistical meta-analyses aimed at testing a particular hypothesis. However, others argue for a broader definition, making the case that systematic data selection and methodological transparency can also be applied in qualitative reviews which seek to answer exploratory questions (Tucker et al., 2014; Barrang-Ford et al., 2015).

While methods are diverse, a systematic review process generally includes the following steps: 1) definition of study scope and research questions; 2) systematic document selection, based on a set of inclusion and exclusion criteria and an appraisal of study quality; 3) systematic document analysis and synthesis of evidence, in line with the research questions (Berrang-Ford et al., 2015).

Given some of the pitfalls of rigid methodologies and practical challenges involved, Hagen-Zanker and Mallett (2013) recommend a more reflexive evidence-focused approach for international development research, compliant to the basic principles of systematic reviews but allowing for tailoring to improve the overall quality of the findings, particularly where time and budgets are constrained.

A QSR-type review has a number of pros and cons compared to other forms of review. On the one hand, it is impossible to incorporate the full range of opinion and depth of knowledge surrounding a broad topic such as ours in a rapid review process. There was limited scope to explore the epistemologically contested narratives presented within different disciplines, which might be possible in a more in-depth review. Moreover, unlike a Systematic Review, a QSR does not attempt to critically assess the quality of the evidence, which typically entails a formal weighting of the literature according to its relevance to the research question and robustness of methods used (Collins et al., 2014).

On the other hand, flexible and tailored approaches are arguably better suited to international development policy questions, compared to more rigid review processes (Hagen-Zanker and Mallett, 2013). Although a QSR may be less robust than a full Systematic Review, it gives a balanced and policy-relevant assessment of the evidence where time and resources are limited. Addressing a specific set of research questions with clear methodology adds a level of rigour not seen in more traditional literature reviews and allows the reviewers to reflect on the nature of the evidence base (Berrang-Ford et al., 2015). A QSR can also highlight gaps or gluts in the data available, informing future research directions and development of policies and programmes (Collins et al., 2014).

In order to manage the sheer volume of studies available on rivers and their management, we have adapted the QSR approach. This introduces certain biases. First, our review is largely restricted to the water resources management (WRM) and ecosystem services (ESS) and ESS valuation literature, although we recognise that there would be value in expanding the review to include more evidence from other disciplines, particularly the social and political sciences. Second, rather than comprehensive database searches we started with keystone literature and used snowballing (i.e. citation tracking) methods, drawing heavily on expert guidance throughout the process (see next section for details). While these methods are valid, citation tracking systems are much better developed for journal papers than for the grey literature. Due to limited time we were unable to develop a rigorous approach for the latter.[1] Therefore, we have only snowballed from the four academic papers on our keystone list. The potential skew in evidence is partly mitigated by the fact that many of the grey literature sources were reviews in themselves, some very recent, and therefore already captured significant portions of the relevant literature, including non-academic sources. Nonetheless, this remains a source of bias. For the in-depth analysis of specific causal chains and the development of the conceptual framework, targeted searches and expert recommendations were used to address obvious gaps in the collated evidence.

2.2 Steps undertaken

The review was conducted in several distinct stages, namely: 1) defining the scope and review questions, 2) selection and review of keystone literature, 3) forward and backwards citation tracking, or snowballing, to identify additional papers of relevance, 4) data extraction and analysis, and 5) targeted gap-filling. Experts were consulted at each stage, including a roundtable session to discuss the conceptual framework and emerging findings from the review, and agree on causal chains for further development. Use of citation tracking (or ‘snowballing’) and expert knowledge have been found to be efficient approaches to identify documents in comparison with database searches (Tucker et al., 2014, citing Greenhalgh and Peacock, 2005). The latter is particularly useful where access to scientific databases may be limited (Collins et al., 2014).

2.2.1 Defining the scope and research questions

One benefit of a QSR such as this is that it encourages discussion between the researcher and the commissioning client (Collins et al., 2014). WWF has played a

[1] Initial attempts to track citiations from the grey literature using Google Scholar presented mixed results. Some papers were simply not picked up by the search engine, whereas other searches produce multiple lists of citations depending on the links followed. Another problem we faced was that the review papers such as Emerton and Bos (2004) had hundreds of citations – far more than we could scan for relevance, let alone review.

key role since the beginning of the process in helping to shape the review questions and determine the parameters of the review, commenting on the proposed approach. Discussions with other experts, initial searches of academic databases (JSTOR, Web of Science) and the internet (Google Scholar) and hand-searching of specific websites (e.g. UN-Water, World Bank, TEEB) also helped to refine the research questions and methods.

2.2.2 Identification of keystone documents

A shortlist of ten keystone documents (Annex 1) was identified as a starting point for the review, drawing on the initial searches and expert recommendations. As recommended by Collins et al. (2014) priority was given to synthesis or review studies and meta-analyses, in order to best capture evidence in the time available. We also included widely cited authors or papers. Case studies were omitted at this stage. Keystone papers had to meet the inclusion and exclusion criteria described in Annex 2 to ensure relevance to the central research question. Efforts were made to ensure a balance across the disciplines of economics, environmental science and WRM, including both academic and grey literature, and the final list was confirmed by experts to contain leading documents in these fields.

2.2.3 Snowballing

Using the four journal articles (Auerbach et al., 2014; Pahl-Wostl et al., 2013; de Groot et al., 2012; Grey and Sadoff, 2007) from the list of keystone papers as a starting point, we used forward and backwards citation tracking to identify further literature for review.[2] The tracking went back one step (papers cited by the keystone document) and forward one step (papers that cite the keystone document). Each new paper identified through this process then went through a selection process. This entailed the successive screening of titles, abstracts and full content to determine relevance, using a set of inclusion and exclusion criteria (Annex 2). An additional 33 papers were identified through these methods.

A key criterion was that papers included a substantive focus on the social, economic or strategic benefits societies derive from rivers. Papers which only discussed ecosystem processes and functions, or those limited to social or governance processes without reference to river conditions, were excluded. In terms of research quality, the review only included journal articles and, for grey literature, research papers that had undergone peer review and/or were published by reputable sources. A cut-off date of 2004 was applied to limit the scope of the review, based on the assumption that Emerton and Bos (2004) and MEA (2005) provide comprehensive reviews of the earlier literature. In citing secondary evidence, however, efforts were made to check original sources for verification. Only papers available in the English language were included.

2.2.4 Data extraction and analysis

Each document shortlisted for inclusion in the review (i.e. the keystone papers and tracked literature) was analysed using a simple qualitative data extraction sheet in Excel. Basic information was recorded such as the title, date, authors and source of the paper. For the purposes of classification, we also took note of the nature of the research (e.g. review or primary research), disciplinary perspective or conceptual approach, the regions or locations covered, scale of analysis, and the types of natural systems and social benefits considered (see Annex 3).

[2] The intention was to track the literature through an academic database, but access proved difficult and we instead relied on Google Scholar.

Categories used to extract information for content analysis were informed by the review questions and covered: key methodological points (methods used, discussion of their strengths and limitations), any indicators used and assessment of these, estimated monetary values (for ESS valuations), insights regarding the links between river health and societal benefits (broken down into social, economic and strategic benefits), opportunity costs and trade-offs, distribution of benefits within society, spatial or temporal patterns of benefit distribution, pressures affecting riverine ecosystems and river management, policy implications and knowledge gaps. One challenge was ensuring that these categories were relevant to the range of studies included in the review, which varied in approach, terminology and methodology. This required adaptation of the initial set of categories and relied to a large extent on the judgement of the two reviewers.

2.2.5 Targeted gap-filling

The purpose of the targeted search was to determine whether the gaps identified in the evidence were a product of our review methodology or genuine knowledge gaps, to better inform our conceptual framework. This was a more flexible process than the first part of the review, and an opportunity to hone the search to explore the relationships between different aspects of river health and specific societal benefits. At this stage the search terms and inclusion/exclusion criteria were tailored to the topics of interest, namely fisheries (10 additional papers), agriculture (12) and hydropower (18). Key words were used to search for relevant papers, and where necessary the reference lists of these papers were tracked back to original sources (resulting in a small number of papers which precede 2004). Subject specialists provided additional recommendations. The gap-filling exercise also encompassed a number of conceptual papers, not all specific to rivers, to ensure that the development of our framework was informed by the latest thinking in ESS science. This included the Ecosystem Services and Poverty Alleviation (ESPA) conceptual framework developed by Fisher et al. (2014) for the UK Environmental Science Research Council's ESPA programme (see Annex 3).

2.2.6 Expert roundtable

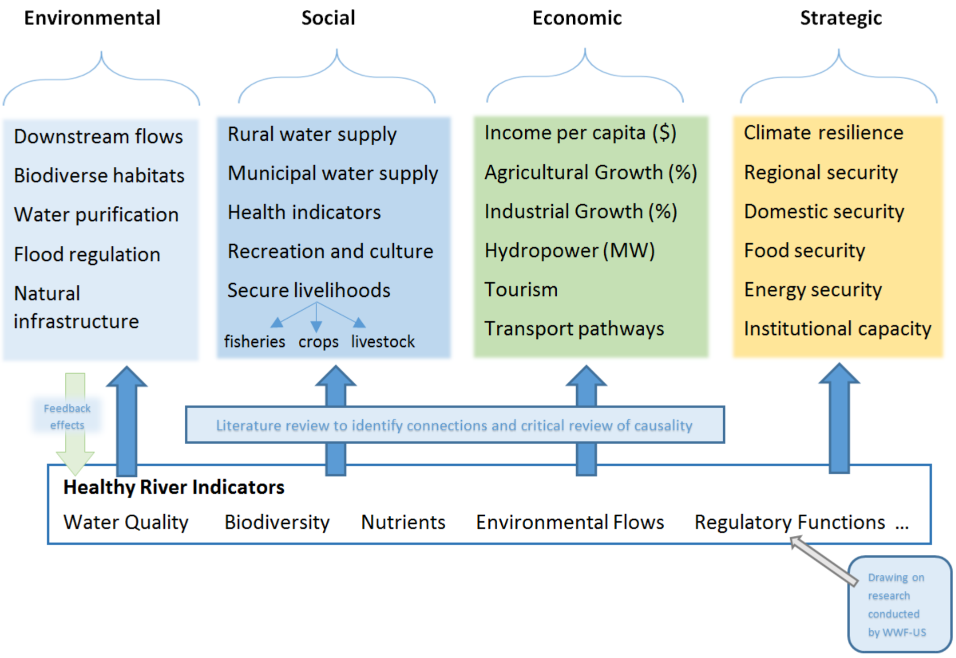
Mid-way through the review process an expert roundtable was held to critically evaluate the approach, discuss and validate emerging findings, and modify the conceptual framework. This was also an opportunity to narrow the scope of the remainder of the review to focus on specific benefit streams, or casual chains, to pursue further. Subject specialists provided additional input to the development of the causal chains (see Acknowledgements for a list of names).

2.2.7 Developing the conceptual framework and causal chains

An initial draft of the conceptual framework (figure 2 below) was produced early on in the process to guide the review. This was particularly useful in defining search terms and establishing criteria for including or excluding papers. Later iterations of the framework have facilitated further targeting of literature searches. The framework, in turn, has been informed by the findings of the review and has evolved markedly over the course of the research.

More detailed conceptual diagrams, or theories of change, were subsequently developed for the linkages between river health and the benefits derived from fisheries, agriculture and hydropower (Chapter 5). These represent 'reasonable' assumptions regarding the nature of these relationships, based on the literature reviewed and insights from subject specialists. This exercise has enabled us to make conservative statements regarding the strength of evidence for each linkage.

Figure 2: An early draft of the conceptual framework



3 General findings from the review

3.1 Nature of the reviewed literature

A total of 43 papers were captured through identification of keystone literature and the snowballing process. In this chapter we present our analysis of this body of literature, including key characteristics of the papers reviewed, and the information they contain on connections between river health and societal benefits, making note of potential sources of bias where relevant. This analysis, together with the gap-filling exercise, has informed the development of our conceptual framework and causal chains presented in the next two chapters.

The review includes literature spanning a number of different disciplines, methods and geographic scales, and included both primary and secondary evidence (see Box 3). There is a marked divergence between the ecosystem services (ESS) and water resources management (WRM) literature in their treatment of river-society relationships. In the papers we have reviewed ESS authors tend to focus on ecology and the benefits of ecosystem preservation, whilst WRM authors are more focused on the harnessing of rivers, including mitigation of water-related risks, for socio-economic development.

Box 3: Key characteristics of the reviewed literature

Of the 43 'keystone' and 'tracked' papers reviewed by the authors:

- Almost half (22) were global or multi-country studies and the remainder were country case studies (21). Of the global and multi-country studies, 11 were reviews and 6 meta-analyses.
- The geographic coverage of case studies was somewhat skewed: USA (6), Europe (4), Africa (5), Latin America (2), South Asia (1), Southeast Asia (1) and China (2).
- The literature focused on surface water, including river systems, wetlands, freshwater ecosystems, coastal wetlands and lakes or reservoirs. Groundwater was not explicitly included, however, some of the water security literature considered the role of aquifers as part of the broader hydrological system.
- The dominant approaches and methodologies used were ESS and valuation (26), and WRM (5), or water security (6); other framings included risk management (metrics, modelling and decision-making) (2), political economy (2), and transboundary conflict and cooperation including benefit sharing (5), with some overlaps.
- Thirty papers were primary research and the remainder review articles. Seven papers were meta-analyses such as systematic reviews.

The ESS literature includes seminal reviews produced by the MEA (2005), Emerton and Bos (2004) and TEEB (2010, 2013), as well as reviews linking ESS with social benefits such as food security and nutrition (e.g. HLPE, 2015) and a number of meta-analyses (e.g. de Groot et al., 2012) and case-studies (e.g. Adekola et al., 2015). Major reviews tend to focus on understanding the ecological processes and anthropogenic drivers and pressures which change the delivery of various ESS. For example, the MEA (see Finlayson and D'Cruz, 2005) describes how human activity has resulted in a loss of services from inland water systems, while the TEEB (2013) outlines the benefits of wetlands and the relationship between services, drivers and pressures.

There are multiple frameworks found across the ESS literature with subtle differences in the classification of services and the definitions used. In general, less attention is paid to how specific services translate into human well-being, or benefits, one exception being the TEEB (2013) which provides some discussion of socio-economic outomes. There is also little mention of the potential for healthy ecosystem to provide 'disservices', such as the risks rivers pose to society in terms of floods or drought, or water-related diseases.

A specialised branch of the ESS literature is that of economic valuation, or other means to quantify benefits, for example monetising services such as fisheries (e.g. Delgado et al., 2013; Butler et al., 2009) or the flow of goods and services from sites such as wetlands or lakes (e.g. Adekola et al., 2015; Zhang et al. 2014; Bander et al., 2011) or the impacts of interventions such as dam removal (e.g. Provencher et al., 2008) (see Box 4). Although valuation has important limitations, it allows policy makers to understand and trade-off costs and benefits of different decisions which may alter the flow of services, for example, the monetised benefits of a hydropower dam in comparison to the costs imposed on fishery production due to the loss of connectivity. However, there is a bias in both the reviewed literature, and more generally as recognised by Finlayson and D'Cruz (2005), towards quantification of more tangible services. Intangible services such as the spiritual value of a wetland are more difficult to value.

Box 4: Ecosystem services valuation

Valuation literature provides an economic framework to quantify ESS. Many ESS are positive 'externalities' which are not accurately priced by the market (de Groot et al., 2012). Valuation allows decision-makers to better account for and assess the monetised costs and benefits of different water resource strategies, or the opportunity costs of water resource developments (WRD) which reduce the provision of ESS. The standard valuation framework is Total Economic Valuation (Emerton and Boss, 2004; MEA, 2005; EEA, 2010), which considers the following:

TEV = Use values (direct use of fish, meat, medicine, timbre, fodder) + Indirect values (flood control, regulation of water flow and supplies, carbon sequestration, nutrient retention, climate regulation) + Option values (future uses, some unknown) + Non-use values (existence value intrinsic to resource)

In reality, quantification of option and non-use values is difficult, and 'intrinsic value' cannot be empirically assessed (Korsgaard and Schou, 2010).

There are many methods to quantify ESS according to the nature of the service itself. Korsgaard and Schou (2010) suggest the following:

- Marketed goods: market prices (value equal to total market revenue of goods), production function (estimated value an input of production) and net factor income (value as net revenue with costs)

- Non-marketed goods: replacement cost (costs of alternative technology) and mitigative expenditure (to avoid damage)
- Non-marketed services: a) revealed preferences - travel cost method (estimate demand through willingness to pay for travel), hedonic pricing (estimate willingness to pay using price differentials for related products); and b) stated preferences - contingent valuation (hypothetical questions regarding willingness to pay)

It is also possible to transfer values (or benefits), in other words estimating the value of an ESS using an existing valuation estimate from a similar study site. However, this method can generate significant errors (EEA, 2010).

Valuation is an important methodology because it helps decision-makers to balance trade-offs, and can act as an initial step for payment for ESS schemes (PES) (Emerton and Bos, 2004). Valuation is best able to capture the marginal value of a specific ESS provided by an individual system, however, all the methods discussed have limitations, bias and errors, and cannot capture the true value of an ecosystem (e.g. see de Groot et al., 2012). Some authors also object to the anthropocentric monetisation of nature (e.g. see Gowan et al., 2005; Korsgaard and Schou, 2010).

The WRM and water security literature we reviewed was mainly qualitative in nature, including traditional literature reviews, conceptual development, some political economy analysis and use of case studies to support arguments and conclusions. River-society relations were mostly framed in terms of harnessing water resources for human benefit, through infrastructure development (such as dams), management and governance. Keystone literature included the widely cited paper by Grey and Sadoff (2007) on water security, renowned water governance experts (Pahl-Wostl et al., 2013) and a review of methods and indicators to assess water security (Mason and Calow, 2012). These, and other reviewed papers, treat the environment as one of multiple water users, with less explicit recognition that ecosystem processes and functions underpin human well-being and social development. However, there are also competing discourses among authors in this field which were not captured by our review. In particular, the Grey and Sadoff (2007) paper is the subject of extensive critiques, including the response by Hatfield-Dodds (2006) (see also Pahl-Wostl et al., 2013).

The WRM-related research reviewed was generally ‘solutions oriented’, advocating or critiquing particular management approaches in a context of increased societal demands and pressures on resources (e.g. see van Beek and Ariens, 2014). The focus is often on water quantity and quality for human use, and risk mitigation (e.g. see Whittington et al., 2013). Anthropogenic impacts are considered in relation to how they amplify water insecurity, for example increased withdrawals exacerbate competition between water users (Whittington et al., 2013). The need to maintain water ecosystem health as a precondition to the realisation of societal benefits is often not an explicit part of the methodological framework. This disconnect between the WRM and ESS thinking is unhelpful for policy-makers and practitioners, although there have increasingly been efforts to bridge the gap. For example, Tickner and Acreman (2013) straddle the disciplines and consider the integration of water security with the preservation of environmental flows, and potential trade-offs.

In summary, the conceptual tools and methods that can be used to understand river-society relationships are diverse, and include both qualitative and quantitative approaches from a variety of disciplines. As noted above, the literature we reviewed has included traditional reviews, meta-analyses, case studies and economic valuations, as well as discursive and conceptual pieces. It was beyond the scope of this study to assess the relative merits of these methodologies in generating robust findings, or their relevance to different decision-making contexts, however this would be a useful avenue for further review and analysis.

3.2 Relationships between river health and benefits for society

Box 5: Summary of main findings

- The reviewed literature suggests that rivers provide a wide range of social, economic and strategic benefits to society
- Many of these benefits are closely related to indicators of river health; whereas some benefits require good 'all round' health, others are contingent on only some aspects of river health
- It is more difficult to determine linkages between national and super-national strategic benefits and river health
- Some benefits, such as hydropower and crop production, require infrastructure which can have negative impacts on river health and entails trade-offs between different types of benefits

Our analysis of the reviewed literature reveals many benefits that river systems provide for society. Major review papers tend to outline a range of different social, economic and strategic benefits (Emerton and Bos, 2004, Finlayson and D'Cruz, 2005; EEA, 2010; WWAP, 2012; TEEB, 2013). For example, Emerton and Bos (2004) describe direct uses for households such as clean and adequate water, and productive and consumptive use for agriculture and industry (Emerton and Bos, 2004). Finlayson and D'Cruz (2005) mention different economic sectors which rely on inland water systems including transportation, agriculture and energy, and river-dependent livelihood options including fisheries, livestock, forestry and foraging. The WWAP (2012) adopts a dual framing of WRM and ESS language to describe how water quantity and quality are required for human health, agriculture, industry and energy, and strategic benefits of climate resilience and food security. TEEB (2013) distinguishes between different river health characteristics and particular benefits, for example water quality and quantity which support water for consumption and sewage treatment (with health benefits), local climate regulation and natural storage which provides climate change adaptation and mitigation, and water supply for production supports livelihoods, local development and poverty eradication.

Explicit connections between river health characteristics and certain benefits are made by a number of authors. For example, secure livelihoods are an important social benefit, and Korsgaard and Schou (2010) discuss how people in developing countries rely directly on the provision of ESS for foraging, fisheries and agriculture. The authors emphasise that alterations in flow regimes caused by dams and weirs, and abstractions for agriculture, has led to widespread degradation of aquatic ecosystems and ESS, with a disproportionate cost for the poor. They note that poor communities have few alternatives if ESS provision deteriorates, and as such the value of a specific ESS, such as fisheries, is related to the value of life or the cost of changing livelihoods.

Emerton and Bos (2004) also cite multiple case studies which relate social benefits to river health, for example improved water quality resulted in recreational benefits in the USA (Feather et al., 1999), nitrogen abatement resulted in improved human health in Sweden (Gren, 1995). In contrast, ecosystem degradation and damage of the Indus River Delta had devastating socio-economic impacts in Pakistan (Iftikhar, 2002). Hill et al. (2013) discuss in detail how water quality and flows are essential to provide water for consumption and recreation. Finally, Gowan et al. (2005) describe the spiritual value of the Elwha River for First Nation communities, and note that the loss of connectivity caused by the Elwha dam was highly offensive to deeply help cultural beliefs around the role of the river and the services it provides. Therefore, the reviewed literature provides evidence of the relationship between river health indicators including flow, water quality and connectivity, and social benefits including livelihoods, health and hygiene, recreation and spiritual values.

In terms of economic benefits, various authors from the review make the connection between rivers and economic sectors including agriculture, industry, transport, energy and recreational or touristic activities. Emerton and Bos (2004) again use case studies to make the connection between river health indicators and benefits, for example the importance of upstream catchment protection to ensure sufficient flows for hydropower production in Cambodia (Emerton et al., 2002). Finlayson and D'Cruz (2005) discuss how biodiverse river wetlands can generate significant incomes from tourism and recreational activities. The authors (*ibid*.) also describe how river modification can provide benefits for transportation, agriculture and hydropower, but note how alterations to the river can also have negative impacts. Vörösmarty et al. (2005: p190) describes how 'water is a required input generating value-added in all sectors of the economy', but elaborate further on how economic sectors also cause significant damage to rivers through over-abstraction (agriculture and tourism), dams and reservoirs (hydropower and agriculture), and pollution (industry and thermoelectric cooling). The reviewed literature suggests that the concept of trade-offs is of increasing importance in relation to different types of economic benefits, and the question of 'who' benefits. For example, Hoeinhaus et al. (2009) assess the economic cost of hydropower dams on the local fishery economy, and concludes that the societal and economic importance of fisheries in developing countries should provide leverage for river conservation.

The reviewed literature also refers to strategic benefits, particularly among authors in the fields of WRM, water security and water governance. Rivers are seen as a platform for cooperation and reducing conflict (Grey and Sadoff, 2007; Korsgaard and Schou, 2010; Zeitoun et al., 2013), a resource for disaster risks reduction (e.g. see Constanza et al., 2008 and Ghermandi et al., 2010), carbon sequestration and climate regulation (Hill et al., 2013, Zhang et al., 2014), growth, poverty reduction and economic development (Finlayson and D'Cruz, 2005; Grey and Sadoff, 2007; Brouwer and Hofkes, 2008; Butler et al., 2009; Korsgaard and Schou, 2010; TEEB, 2010; Whittington et al., 2013), food security (TEEB, 2010; HLPE, 2015), energy security (Hurford and Harou, 2014; Men et al., 2014 and, of course, 'water security' (van Beek and Arriens, 2014).

The relationship between strategic benefits and river health indicators is not as clearly delineated. TEEB (2010) relates biodiversity loss to costs for individual and societal well-being and security, although the concept of 'security' is not well defined. The role of wetland conservation or river catchment processes is discussed for flood and storm management and carbon cycle (Constanza et al., 2008; Brander et al., 2006). However, at the strategic level, it becomes apparent that some benefits are more contingent on river health than others. For example, benefits such as transboundary cooperation may not depend on river health, but can support sustainable management to protect river health (Zeitoun et al., 2013).

Threrefore, the evidence suggests that different benefits depend more or less on different indicators of river health, while other require good health across multiple indicators, such as fisheries or recreational uses (Van Houtven et al., 2007), or are only indirectly or tentatively linked to river health in the case of strategic benefits. Some authors also recognise the risks associated with rivers, for example the problems of dealing with too much or too little water, and related uncertainty which makes planning and management difficult (e.g. Mason and Calow, 2012), however the ESS literature is notably silent on the question of 'disservices'.

Certain benefits seem to be given more attention in the reviewed literature than others. The social benefits of fisheries or the trade-offs between fisheries and other benefits were discussed by multiple authors (e.g. see Auerbach et al., 2014, Butler et al., 2009; Hoeinhaus et al., 2009). Hydropower was also analysed in detail in different papers (e.g. see Men et al, 2014; Hurford and Harou, 2014; van Beek and Arriens, 2014; Alhassan, 2009). The latter may reflect the bias of forward tracking from Grey and Sadoff (2007). However, hydropower is also a highly lucrative sector which entails significant trade-offs with distributional implications, and as such there is a large amount of literature in support of different sides of the debate (Hurford and Harou, 2014). Our finding that the evidence base is skewed towards certain types of benefits is supported by Finlayson and D'Cruz (2005), who note that cultural and spiritual values are poorly documented.[3]

A few papers note that access to water and other resources, as well as exposure to risks, are socially differentiated (e.g. HLPE, 2015). The meta-analysis by de Groot et al., (2012), for example, shows that over-exploitation of ecosystems disproportionately affects the livelihoods of the poor and future generations. Major reviews highlight the importance of institutions in addressing access issues, for example WWAP (2012) emphasises the role of transparent decision-making and robust governance mechanisms as essential pre-requisites to re-dress power imbalances and ensure equitable distribution (or re-distribution) of benefits. Other authors provide potential tools, frameworks and models to understand trade-offs between different objectives in water management (e.g. Hurford and Harou, 2014). However, the reviewed literature does not provide much evidence regarding the role of socio-political dynamics and individual agency in determining how benefits are distributed across society. This is an important gap. It is partly a product of our review methods, but also reflects the historic disconnect between political economy thinking and mainstream water resources management. Several authors are now attempting to address this gap. For example, Adekola et al. (2015) focus their paper on developing countries and low-income livelihoods in response to the lack of evidence around distributional issues.

[3] Carabine et al. (2015) (a gap-fill paper) also identify evidence gaps in the role of ESS for climate resilience and disaster risk reduction (DRR).

4 Framing river-society relationships

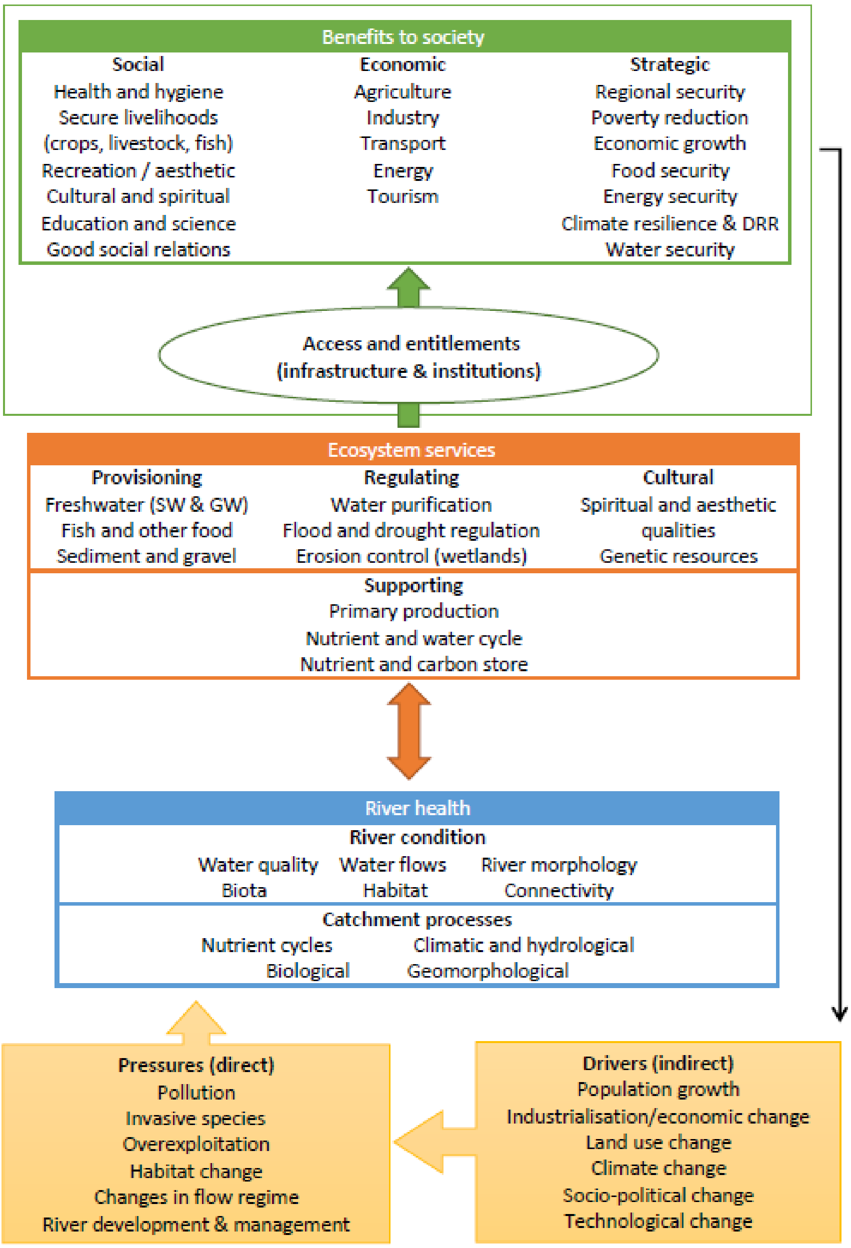
4.1 The purpose of our conceptual framework

The conceptual framework outlined in this chapter draws on the scoping review, particularly recent advances in thinking about connections between ecosystem processes and functions and human well-being (e.g. Fisher et al., 2014; Fisher et al., 2009). Expert consultation also informed conceptual development. The framework is the result of our efforts to organise the evidence of relationships between river health and societal benefits in an accessible format, and provide a tool for further analysis and programme design. In figure 3 these relationships are depicted in relatively simple terms, whilst acknowledging the complexities involved. The conceptual diagram can be developed in much more detail for specific benefit streams, or causal chains, of interest, as illustrated in the next chapter.

In our framework we attempt to bridge the divide between two disciplines – ESS and their valuation, the focus of ecologists and environmental economists, and integrated WRM or water security approaches, favoured by engineers and other water sector practitioners. We also draw on the social sciences and political economy thinking to understand how benefits are realised and by whom. On a practical note, we acknowledge that placing ecosystems at the centre of the analysis will have less traction with decision-makers than a focus on social and economic outcomes. As such, we focus on these human benefits.

As well as being a research tool, the framework is intended to inform the design, monitoring and evaluation of WWF's freshwater programmes, providing a basis to assess the extent to which initiatives focused on improved river management deliver benefits to target stakeholders and wider society. A typology of benefits complements the framework, and provides tentative example indicators. Further work is needed to develop and test appropriate assessment methods and indicators for use by WWF and other organisations.

Figure 3: Understanding the relationships between river health and societal benefits – a conceptual framework



4.2 The river ecosystem

4.2.1 Characteristics of a healthy river

River health refers to the overall state or condition of a river, including its ecosystems. As stated in the Millennium Ecosystem Assessment:

> "Determining how much water can be allocated to human uses or distorted through flow stabilisation (such as dam construction) without loss of ecosystem integrity is central to an understanding of how freshwater ecosystems support human well-being." (Vörösmarty et al., 2005: 177)

As noted previously, indicators of river health can include water quality and flows, biodiversity or species composition, and connectivity, as well as other factors such as habitat characteristics or river morphology (Finlayson and D'Cruz, 2005; Speed et al., in press; see also European Commission, 2003; River Health Programme, 2011). The health of a river is a reflection of catchment processes, which in turn has implications for the services a river can provide (Speed et al., in press).[4] Catchment processes such as infiltration and runoff, and the generation and flows of sediment, nutrients and other chemicals, are shaped by interactions between the hydrological cycle, topography, geology and vegetation of the basin. The nature of these interactions varies significantly between and within rivers (*ibid*.). An alpine river will provide a different set of services as compared to a river in temperate or tropical geographies, for example.

4.2.2 Services provided by healthy river ecosystems

Unlike river or ecosystem health, ESS only make sense in reference to humans. Given some of the confusions in the literature regarding terminology, Fisher et al. (2009, drawing on Boyd and Banzhaf 2007) propose a broad definition of ESS that encompasses ecosystem structures, processes and functions, but only those that have the potential to be utilised by humans. 'Ecosystem services are the aspects of ecosystems utilised (actively or passively) to produce human well-being' (p645). We adhere to this definition, as it seems to fit with the Millennium Ecosystem Assessment's (MEA, 2005) categorisation of services. However, like Fisher et al., we depart from the MEA in distinguishing between service and benefit (defined below).

The MEA categorisation of the services provided by ecosystems has been widely adopted in the ESS literature, albeit with some adaptations. The MEA usefully distinguishes between provisioning, regulating, cultural and supporting services (Box 6 below), with supporting services underlying the provision of all other services. In our framework we highlight those services most relevant to rivers. For cultural services, only those thought to be attributable to the river, such as aesthetic qualities, are considered services, whereas others, such as good social relations, are re-categorised as benefits.

Box 6: Categorising ecosystem services

Provisioning services are the products people can obtain from ecosystems. In a riverine ecosystem they include freshwater, fish and other foodstuffs, and construction materials such as sand, reeds and gravel.

Regulating services relate to the benefits people obtain from the regulation of ecosystem processes, such as the role wetlands play in water purification, flood and drought regulation, and erosion control.

Cultural services relate to the nonmaterial value of ecosystems, for example recreational benefits are derived from a river's aesthetic qualities.

Supporting services are those that are necessary for the production of all other ecosystem services, such as primary production, nutrient cycles and storage, water cycles, and carbon storage.

Source: Adapted from MEA (2005)

[4] A significant body of literature exists on these different elements and their inter-linkages, and a detailed review is beyond the scope of our study. For example, Acreman et al. (2014) provide a review of the literature that considers river health in terms of flow regimes, and there are various reviews of evidence of links between flow regime and river ecosystems (e.g. Poff and Zimmerman, 2010).

Certain aspects of river health will be more important for some ESS (and therefore societal benefits) than others, and vice versa. For example, good water quality and adequate flows are particularly important for the provisioning of clean freshwater (benefits including improved human health), and are in turn determined by regulating processes, such as water purification, and supporting services, such as the water cycle (see Vörösmarty et al., 2005).

Riverine ecosystems can also provide disservices, such as flooding or disease, although as with beneficial services these depend on how the river is managed (Fisher et al., 2014, citing Dunn, 2010). The lack of emphasis on disservices in the literature, including in the MEA, is surprising given that some can be life-threatening (*ibid*.). An exploration of disservices is beyond the scope of this review. However, as with services, in theory their pathways could be traced through the framework, resulting in detrimental impacts on society as opposed to benefits.

4.2.3 Pressures and drivers of change

Understanding how anthropogenic drivers and pressures affect ecosystem processes lies at the heart of much of the ESS literature. The conceptual framework developed by MEA (2005) has its origins in the Drivers-Pressures-States-Impacts-Responses (DPSIR) framework. Importantly, the MEA moves away from linear models of change to incorporate feedback loops and multiple temporal and spatial scales (Tomich et al., 2010).[5]

Drawing on existing frameworks (see Tomich et al., 2010 for a summary) we differentiate between external drivers of change and direct pressures on river ecosystems. External drivers reflect global, regional and national dynamics of human development, as well as bio-physical drivers, and include: climate change, population growth and other demographic changes, industrialisation or economic transformation, land use change and urbanisation, technological change, and other socio-political factors such as changes in governance or conflict. These drivers in turn create more direct pressures on the river which affect river health and ecosystem processes and functions, namely: over-exploitation, pollution (temperature and chemical), invasive species, and disruptions of natural flow regimes due to engineering interventions.

Changes to the river ecosystem clearly have implications for the portfolio of services a river is able to provide, and therefore, one would expect, the benefits society can derive. However, the relationships between human interventions, the health of a river ecosystem and the benefits people derive are complicated and there are several sources of uncertainty (Box 7), which means that establishing the nature of causal linkages can be difficult.

[5] Concerns regarding the impacts of socio-eonomic development on natural systems are also raised in the WRM literature, however the environment is often defined as a water user and therefore in competition with humans.

Box 7: Acknowledging complexity in linked ecological-social systems

Whilst it is not possible, nor desirable, to capture the intricacies of linked ecological and social systems in a simple conceptual framework, it is important to acknowledge some of the sources of complexity and uncertainty. These include:

- **Internal ecosystem dynamics:** Ecosystem processes are often non-linear, involving feedback loops between different biological, physical and chemical processes occurring at different levels of the system. Although there have been substantial advances in the last few decades, scientific understanding of the ecological dynamics responsible for ESS provision, such as the role of biodiversity, is still in its infancy (de Groot et al., 2012).
- **Responses to external pressures or interventions:** There is much uncertainty regarding how much exploitation or disturbance different ecosystems can withstand or the nature of tipping points beyond which certain functions may be lost entirely (TEEB, 2010). Similarly, little is known about how changes in river basin management affect different components of the hydrological cycle and therefore ecosystem processes and functions (Vörösmarty et al., 2005). Researchers such as Gilvear et al. (2013) are pioneering the development of new tools to better assess the impacts of river restoration efforts on ecosystem service provision over different time scales, for example.
- **The rapidly evolving governance context:** Whilst river ecosystems can provide multiple benefits, the realisation and distribution of these benefits is largely determined by the governance context, which is dynamic. Decision-makers are faced with growing, competing demands for resources and increasing risks, for example due to conflict or climate change. Although the science is improving, gaps remain in our understanding of interactions between different drivers and future trajectories of change are highly uncertain (MEA, 2005; Vörösmarty et al., 2010). At the same time, decision-making arenas for WRM have expanded to encompass a diverse set of actors and polycentric governance is increasingly the norm (Pahl-Wostl et al., 2013). New approaches to natural resources management are urgently needed and there is much debate about what forms these should take, given the diversity of existing institutions and power dynamics at play.

4.3 Societal benefits

Benefits are frequently equated with ecosystems services. We argue that benefits are distinct from services, the former derived through the use of a service and requiring some form of human intervention. A benefit is best understood as 'the point at which human welfare is directly affected and the point where other forms of capital (built, human, and social) are needed to realise the gain in welfare' (Fisher et al., 2009: p646). To illustrate, clean water provision (a service) is dependent on the ability of an ecosystem to filter out pollutants, among other functions. Consumption of that water, which reaps benefits in terms of human health, requires know-how and tools for abstraction.

4.3.1 Types of benefits

A wide range of benefits can be derived from the services a river ecosystem provides, which we have broadly classified as social, economic and strategic. These are not necessarily discrete or hierarchical categories - there will be inter-linkages or areas of overlap and different kinds of benefits can manifest at different spatial or temporal scales. The framework attempts to account for direct tangible benefits (e.g. water for agriculture), as well as intangible benefits (e.g. cultural values) and indirect outcomes at strategic levels (e.g. regional security).

Informed by the review, we have developed a typology of benefits (see below) to accompany the framework, including potential indicators. Many of these indicators are taken from Scholes et al. (2010) who provide useful guidance on assessing the state of, or trends in, ecosystem services and human well-being. Where indicators were not identified in the literature we have drawn on our prior knowledge and discussions with experts to make our own suggestions (these are italicised). Some ESS and benefits cannot be monitored or measured directly, therefore proxies are necessary. We were not able to critically review indicators or assessment methods in the time available, and highlight this as an area for further investigation.

We define social benefits as those which contribute to the well-being of individuals and communities, and the functioning of society. This can include secure livelihoods, health and nutrition, good social relations, science and education, mental health and spiritual satisfaction. Much of the ESS literature focuses on human well-being as the outcome of ESS provision. The ESPA framework, for example, views poverty reduction as synonymous with improvements in well-being (Fisher et al., 2014). However, decision-makers are often interested in economic and strategic factors, which are better addressed in the WRM literature.

Figure 4: A typology of social benefits potentially derived from rivers

Benefit to society	Description of benefit	Potential indicators
Secure livelihoods: fisheries, crops and livestock	Freshwater fisheries can provide an important source of protein and income, particularly in developing countries (Hoeinhaus et al., 2009); floodplain and irrigated agriculture support subsistence farmers in riverine areas, and in semi-arid regions can help mitigate the effects of dry periods on production (HLPE, 2015); rivers provide water for livestock consumption, grazing areas and fodder, important for pastoralist communities (*ibid*.).	• Production: fish stocks or catches (total/ per unit effort); crop yield; area planted/ irrigated; livestock numbers or biomass • Market: value of fish/agricultural produce (e.g. market price); % income from fish, crops or livestock (meat, dairy, hides); gross profit • Diet/nutrition: Household consumption of cereals and vegetables, fish, meat and milk; protein or caloric intake; digestible energy in food; *stunting measures* (Scholes et al., 2010; Korsgaard and Schou (2010; *Authors' own*)
Secure livelihoods: other	Harvest of wild foods and animals for household consumption; wood for fuel and local construction; harvest of medicinal plants (Scholes et al. 2010)	• Offtakes of given species; stocks of given species • Harvest of timber products • Income from sale of timber or charcoal (Scholes et al., 2010)
Health and hygiene	Healthy freshwater ecosystems play a role in dilution and filtration of pollutants (agricultural, industrial) and human and animal waste, as well as reducing water-borne or water-related diseases; health benefits are obtained from using clean water for drinking, cooking, bathing and washing clothes, and the reduced risk of vector-borne infections (Vörösmarty et al., 2005).[6]	• Disease: expected longevity at birth; childhood mortality; DALYs; disease incidences and death rates (e.g. malaria, diarrhoea, cholera); access to improved water sources; prevalence of water-related pathogens or vectors • Exposure to toxins: exceedance of guidance limits (Scholes et al. 2010)

[6] Freshwater systems can also be a source of disease or toxins if not well- managed.

Aesthetic and recreational	Aesthetic enjoyment from appreciation of natural features, and (local) recreational activities e.g. walking, boating, fishing, bird watching, hunting (Finlayson and D'Cruz, 2005; EEA, 2010).	• House prices • Visitor opinion polls • Existence value/ bequest value • Types of activities • Types or numbers of visitors • Presence of species of interest (Scholes et al., 2010; Sun et al., 2015; TEEB, 2013)
Spiritual and cultural	Inland waters are closely associated with the development of human culture, and in some cultures rivers have deep religious significance; on a personal level healthy rivers can also contribute to spiritual fulfilment and mental well-being (Finlayson and D'Cruz, 2005).	• Presence (or number/area) of sites, landscapes or species of spiritual, religious or cultural significance • Protection status of sites • Existence and bequest values (Scholes et al., 2010; Emerton and Bos, 2004; Finlayson and D'Cruz, 2005)
Social relations	Rivers play an important role in conflict or stability (Mason and Calow, 2012); many conflicts over water are localised (WWAP, 2012).	• Absence of conflict; displacement due to conflict • Sense of belonging/happiness measures (Scholes et al. 2010)
Education and science	Opportunities for formal and informal education, training and research provided by healthy, biodiverse ecosystems (Finlayson and D'Cruz, 2005; EEA, 2010); restoration of unhealthy rivers also provides interesting avenues for research (e.g. Gilvear et al., 2013).	• Presence of sites or species of scientific/educational value • Presence of scientific or education programmes • Number of papers or patents (Sun et al., 2015; Scholes et al., 2010; TEEB, 2013; Finlayson and D'Cruz, 2005)

We define economic benefits as those which contribute to the national economy and/or provide employment, for example agricultural production, energy production, industrial development, transport and tourism. Economic benefits are not only realised at the macro-scale, but can be manifested at various scales, for example in household incomes. In this respect there is some overlap with the livelihoods dimension of social well-being.

Figure 5: A typology of economic benefits potentially derived from rivers

Benefit to society	Description	Potential indicators
Agriculture	Irrigation depends on water of sufficient quality and quantity, and other ESS such as sediment flows and nutrient cycles, as key factors influencing crop yields (HLPE, 2015); commercial irrigation can provide benefits in terms of employment, tax revenues and food security (Oates et al., 2015). However, irrigation is extractive and entails opportunity costs, which can be significant downstream (TEEB, 2013).	• Area / % cultivated land under irrigation; agricultural water productivity; yields • Net income; tax revenues • Numbers employed full time or seasonally in irrigated agriculture (Mason and Calow 2012; Hurford and Harou, 2014)
Industry	Water is an important input for manufacturing, and is also used for lubrication, dyeing, cooling and washing; effective operation of an industry requires a sustainable supply of water in the right quantity, of the right quality, at the right place, at the right time and at the right price (WWAP, 2012); as with irrigation, this is generally extractive.	• Volumes consumed by the sector; water productivity; embedded water/ virtual water footprint • Water tariffs and revenues • Water treatment costs (inputs/waste) • % of industries / value of assets / number of suppliers located in water scarce or flood prone areas • *Tax and export revenues; sales of manufactured goods (volumes, profits)* (Mason and Calow, 2012; WBCSD, 2015; *Authors' own*)

Transport	Rivers and water bodies are used to transport people and materials; water transport can be more cost-effective compared to other forms, particularly for bulk commodities, and can help to expand regional trade (Rasul, 2015).	• *Costs of river transport; tax revenues* • *Number of licenced ferries or commercial carriers* • *Volume and economic value of waterborne freight carried on inland waterways* (*Authors' own*)
Energy	Rivers are important for hydropower generation, which in some countries represents a large proportion of the energy mix; other sources of energy/electricity require water for various production processes e.g. extraction of raw materials, cooling in thermal processes, cleaning materials, cultivation of crops for biofuels (WWAP, 2012); harnessing rivers for energy production often entails significant trade-offs (Nilsson et al., 2005).	• Installed/potential capacity • Energy produced (MW) • Hydropower revenue • *% population with access to electricity* (Hurford and Harou, 2014; *Authors' own*)
Tourism	Rivers can be important destinations for both local and international tourists for activities such as fishing, boating, and wildlife viewing, which can provide tax revenue and employment (e.g. see Butler et al. 2009).	• Sector turnover; gross profit; tax revenue; tourist expenditure • Number of visitors; prices/entry fees; • Jobs in the tourist industry (Scholes et al. 2010; Butler et al. 2009

Strategic benefits contribute to national and trans-national interests, and are often highly politicised. They include regional security (e.g. transboundary conflict and cooperation), poverty reduction and economic growth, the water-energy-food security nexus, disaster risk reduction (DRR) and climate resilience. These benefits are often indirect, for example realised through social or economic benefits, and establishing linkages to river health can be difficult due to confounding factors.

Figure 6: A typology of strategic benefits potentially derived from rivers

Benefit to society	Description	Potential indicators
Regional security	Cooperation on transboundary waters can bring economic, environmental, social and political gains (Sadoff and Grey, 2005; Rasul, 2015), although these are not necessarily contingent on river health; river degradation can contribute to political tensions (Grey and Sadoff, 2007).	• Cooperation; absence of conflict • Water risks experienced by downstream countries (scarcity, pollution, floods) • Process indicators e.g. presence of a treaty; treaty content; negotiation and benefit-sharing initiatives (Roebeling et al., 2014; Rasul, 2015; Zeitoun et al., 2013; De Stefano et al., 2012)
Food security	There is a strong link between water security and food security, as agriculture is responsible for 70% of withdrawals globally (van Beek and Arriens 2014); water is also essential for good nutrition and health, which are inter-dependent and also related to the health of the water system (HLPE, 2015).	• % rural households classified as food insecure • Global Hunger Index scoring • *Food prices relative to incomes* • *Food shortages measures* (HLPE, 2015; IFPRI, 2015; *Authors' own*)
Climate resilience	River ecosystems (e.g. wetlands) have some natural capacity to buffer against climate variability and change (TEEB, 2013); human resilience is also achieved through the realisation of other social and	• Carbon sequestration/storage • Climate or soil moisture index • Frequency and intensity of floods and droughts • Awareness (e.g. access to information,

	economic benefits (see Carabine et al., 2015).	early warning systems) • Options for mitigating or coping with risk (e.g. access to credit) and flexibility (e.g. livelihood diversity) • See also DRR indicators (TEEB, 2013; Schipper and Langstone, 2015; Bergamini et al., 2013)
Disaster risk reduction (DRR)	Societies face risks relating to the overabundance or insufficiency of water, both in absolute and relative or temporal terms (Mason and Calow, 2012); healthy wetlands can help mitigate the impacts of flooding, including in urban areas, and river catchments can play a role in drought mitigation (Emerton and Bos, 2004)[7], but healthy rivers can also be a source of hydrological risk.	• No. or % of people living in flood prone area; losses of life; no. of people injured/requiring medical treatment • Value of assets at risk; damage to property/assets (estimated loss or restoration cost) due to floods • Number of people living in drought prone areas; loss of lives; number of people affected by famine • Loss of assets due to drought e.g. livestock deaths, crop losses (Scholes et al., 2010; TEEB, 2013; Pahl-Wostl et al., 2013)
Energy security	Electricity generation is a necessary condition for many social and economic activities; development of hydropower can help bridge the gap between supply and demand (Rasul, 2015); over-reliance on this energy source can also pose a risk in areas subject to high levels of rainfall variability (Halleagatte et al., 2012); water is also required for other forms of energy production (see economic benefits).[8]	• Energy intensity (by sector) • Reserves-/resources-to-production ratio • Firm energy • *Frequency/duration of black outs* • % of rural and urban HH with/without access to electricity • Prices and affordability (e.g. share of HH income spent on fuel or electricity) • % energy derived from hydropower/ diversity of supply • Reliance on imports (%) • *Availability of water for cooling* (see water security indicators) (Hurford and Harou, 2014; IAEA, 2005; *Authors' own*)
Poverty reduction	The poor are more reliant on environmental capital (Hatfield-Dodds, 2006) and disproportionately affected by loss of ESS (de Groot et al., 2012); harvesting of certain ESS to support livelihoods can have positive effects on the poor, either directly, through multiplier effects or 'trickle down' (Korsgaard and Schou, 2010; Hurford and Harou, 2014; Men et al., 2014).	• *Proportion of poor people who directly rely on river ecosystems for their livelihoods (fisheries, crops, livestock, foraging)* • *Changes in % of people living in poverty and extreme poverty (rural)* *(Author's own)*
National economic growth	Investments in water management and infrastructure development can be a cause of growth, a prerequisite or a consequence (Grey and Sadoff, 2007), however river development can also result in the loss or degradation of ecosystems There are trade-offs and opportunity costs to consider.	• *GDP growth rates in water-related sectors (e.g. irrigation)* • *Revenue from exports (e.g. energy, agricultural)* • *Diversification of the economy (or degree of reliance on water-related sectors)* *(Authors' own)*
Water security	Water security means having sufficient water (quantity and quality) for the needs of humans (all uses) and ecosystems,	• Water storage capacity (built or natural) • Water stress (e.g. renewable water resources per capita)

[7] Traditional approaches to dealing with water related hazards have largely relied on large-scale infrastructure, leading to increasingly unsustainable trade-offs e.g. flood protection at expense of floodplain services. Water-related risks are increased by the concentration of people and assets in floodplains (Pahl-Wostl et al. 2013).
[8] This was not explicitly mentioned in the literature we reviewed, but was highlight as important by experts.

	matched by the capacity to access and use it, resolve trade-offs, and manage water-related risks, including flood, drought and pollution (Mason and Calow, 2012)	• Water poverty • Water use intensity by economic activity • Municipal water supply deficit[9] • Governance/process indicators e.g. IWRM planning, water monitoring efforts (TEEB 2013; Mason and Calow, 2012)

As discussed in Chapter 3, the evidence suggests that some benefits are more contingent on river health than others. For example, the extent to which rivers have to be healthy to deliver strategic benefits such as transboundary cooperation is questionable. It is possible to cooperate over a polluted river, although one would hope that any formal agreement between riparian states would include measures to address sustainability. Different aspects of river health are also important for different benefits. Some benefits, such as fisheries, require good 'all round' health and are underpinned by a number of different ecosystem services. Others, such as hydropower generation, rely on a more limited range of services. In this instance river flows and water storage are more important than water quality, although sediment loads can affect generation. The 'causal chains' presented in Chapter 5 unpick the relationships between river health, ecosystem services and benefits to society in greater detail, and serve to demonstrate how the conceptual framework might be applied to a particular benefit stream or case study of interest.

4.3.2 Access and entitlements

Multiple factors contribute to the realisation of benefits, beyond the health of the river ecosystem. For example, to access a freshwater fishery an individual may require a boat and nets, entitlements to access the river and to fish, and for those wishing to sell their catch, access to markets, amongst other things. The fisherman needs to draw on physical capital (infrastructure, technology) and social capital (institutions) (see Box 8). As societies are not homogenous, some individuals will be better placed than others in this regard.

> 'An ecosystem service is defined as much by the characteristics of those people benefiting from the service, as it is by the ecology underpinning the service' (Fisher et al., 2014: p38, citing Rounsevell et al., 2010).

In the literature initially reviewed we found few explicit references to entitlements, and little evidence that attention was paid to social differentiation, power and agency, which determine how benefits are realised and by whom. Gap-filling was therefore required for the development of our framework and causal chains. This included Fisher et al.'s (2014) paper outlining the ESS framework developed for the ESPA programme, in which people - their preferences, entitlements and capitals - are placed at the centre of the analysis. Inspired by Fisher et al., we highlight the importance of entitlements, meaning legally or socially constituted claims on natural resources (Mearns, 1996), in determining access to, and use of, ESS and shaping the distribution of benefits. Entitlements are largely determined by institutions, formal or informal, although their realisation also requires other forms of capital.

[9] Shortfall between planned and actual water supply to urban users.

Box 8: Forms of capital

The concept of capitals, drawn from economics, is increasingly being incorporated into both livelihoods and ESS thinking, and has been included as a component of the ESPA framework (Fisher et al., 2015). Five types of capital, or assets, are commonly identified (see Scoones, 1998):

- **Natural capital** is the stock of natural assets (e.g. geology, soil, air, water and biota), as well as the ecosystem services on which people can draw.
- **Physical capital** comprises infrastructure, tools and technologies and other physical assets.
- **Financial capital** includes income, savings, and access to credit.
- **Human capital** includes education, knowledge and skills, as well as human health and capacity to work.
- **Social capital** refers to social relationships and institutions (formal and informal), including rules, norms, and different forms of organisation.

To give a hypothetical example of how these capitals might interact - a lake is a form of natural capital that provides the ecosystem service of water supply. Yet not many people live around the lake, so physical capital is needed in the form of a dam, pump and pipeline to exploit the service and supply people. Financial capital is needed to fund construction. Human capital, if the form of experts, and social capital, in the form of organisational structures and rules, are required to manage the system. As such, different forms of capital are needed to reap benefits from the ecosystem services provided by rivers, and contribute to human well-being (see Fisher et al. 2014 for further discussion).

Whilst a natural river ecosystem, or ‘natural infrastructure’[10], provides essential services for society, often built infrastructure is required to enhance the level or reliability of services, and to enable people to reap benefits. For example, man-made structures such as dams can significantly increase water storage capacity and mitigate the risks associated with variable river flows (Grey and Sadoff, 2007), whilst canals or pipelines channel water to the point of use, for example for irrigation, industry or human consumption. However, the introduction of these technologies can also negatively impact river health and undermine the provision of other services, entailing trade-offs. The concept of ‘wise use’ promoted by the Ramsar Convention recognises the need to secure benefits for society over the long-term through the protection of ecosystems (Ramsar Convention Secretariat, 2010). There is growing interest worldwide in the benefits associated with river restoration (e.g. Auerbach et al., 2014; Lewis et al., 2008; Gilvear et al., 2013).

4.3.3 Managing trade-offs

Managing river systems for the benefit of society clearly involves opportunity costs and trade-offs. Firstly, there are trade-offs at the level of the ecosystem – some services are synergistic whereas others are not. For example, altering the water regime in a wetland can lead to the delivery of a different set of ESS, and does not necessarily mean that the wetland is less or more healthy (Acreman et al., 2011). Secondly, broader-scale development decisions can entail the loss of services

[10] The term ‘natural’ or ‘green’ infrastructure is utilised by some authors (e.g. TEEB, 2013; Tickner and Acreman, 2013) to mean natural structures or systems, such as wetlands or mangroves, that serve a water management function akin to built structures, for example providing physical protection from storms or floods, or purifying water. Arguably these terms are inter-changeable with ecosystem services.

provided by a healthy river in favour of those derived from built infrastructure. For example, construction of a dam can provide economic and strategic benefits through hydropower generation, irrigated crop production and flood management. However, such impoundments also bring about major changes in the river regime, commonly causing interruptions in the transport of sediments, and loss of traditional services such as fisheries (Finlayson and D'Cruz, 2005).

Grey and Sadoff (2007) argue that investments in water security always have social and environmental costs. Asymmetries of power mean decisions on river management or development are rarely objective. The poor and marginalised often 'lose out' to more influential actors (see Komakech et al., 2012). Negative effects are multiplied as the poor and most vulnerable sections of the population (including women) also disproportionately rely on ESS for their lives and livelihoods, particularly as a livelihood strategy of 'last resort' (Korsgaard and Schou, 2010).

It can be difficult to assess the relative value of benefits derived from rivers by different social groups or at different scales, for example comparing the social benefit of a livelihood for low-income households against the commercial benefit of irrigated agriculture (Hurford and Harou, 2014). The use of economic valuation is problematic, as values are partly defined by the wealth of the ESS beneficiaries, and therefore wealthier households may be willing to pay more for certain services (as they are able to better conceive of high value goods, see Korsgaard and Schou, 2010). Moreover, some services are accessible to all, as public goods, such as aesthetic or spiritual values, whereas others are excludable. The latter applies to provisioning services, such as freshwater fisheries, which are generally characterised by extractive or consumptive use (Fisher et al., 2009). This has implications for the nature of opportunity costs and how benefits are valued.

To ensure the equitable distribution of river-related benefits, decisions regarding trade-offs need to be transparent, inclusive and based on the best available evidence, which may require a range of decision-making tools (Hurford and Harou, 2014; Pahl-Wostl et al., 2013; WWAP, 2012).

4.3.4 Spatial and temporal patterns

The spatial and temporal patterns of ESS also have implications for who is able to access and benefit from the service, and therefore incentives for investing in river management or restoration. Many provisioning services are location-specific and seasonal in nature, whilst often non-provisioning services (regulating, cultural and supporting) and related benefits are enjoyed in different locations and over different timescales to the inherent cost of provision (Gilvear et al., 2013). Fisher et al. (2009) usefully distinguish between:

1) In-situ service provision - where benefits are realised in the same location as the service e.g. the use of deposited sediment for floodplain agriculture.

2) Omni-directional service provision - where people in the surrounding landscape benefit from a service e.g. use of a river to water livestock.

3) Directional service provision - where benefits are realised in a different but specific location and time e.g. regulating services provided by a catchment benefit downstream users.

Because the benefits derived from a healthy river tend to accrue to people at multiple spatial levels, including those beyond the immediate vicinity of the river or even the river basin, it is important to understand how interactions across scales shape the nature and distribution of benefits (Lebel et al., 2008). For example, tourism and recreation activities surrounding national parks can attract non-local and international visitors. The prioritisation of these types of benefits sometimes conflicts with local community needs to convert land to agriculture. Lebel et al. (2008) provide a framework to explore these cross-scalar interactions and improve understanding of the politics that shape conservation decisions in watersheds.

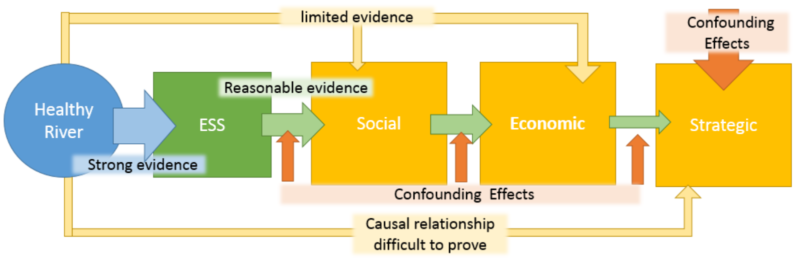
5 A closer look at causal linkages

5.1 Introduction

In this chapter we explore three benefit streams in detail – fisheries, irrigated crop production and hydropower - breaking down the conceptual framework into a number of theories of change. These hypothetical 'causal chains' represent plausible assumptions regarding the relationships between specific aspects of river health, ecosystem services and various social, economic and strategic benefits. Potential linkages between river health and different benefits were determined using evidence from the initial review (see Chapter 3) and, where necessary, a targeted gap-filling process.

Each link in the causal chain requires careful scrutiny. For some relationships, particularly first level relationships between river characteristics and ESS, there is a large body of literature available, spanning different academic disciplines. However, for other relationships further up the chain, it can be difficult to attribute cause and effect (see figure below). For strategic benefits such as food security, poverty reduction and growth there are many confounding factors. Furthermore, people's access and entitlements to ESS can prevent or enable benefit realisation, and certain benefits entail significant trade-offs. Whilst we can make some general observations regarding the evidence base for causal linkages and confounding factors, this remains a largely theoretical exercise in its current form. Further testing is needed to validate the theories of change, including identification of necessary conditions for these relationships to hold. This could include rigorous assessment of the primary evidence base, application of these theories of change to real-life examples, or research to address specific gaps in knowledge.

Figure 7: Strength of evidence along the causal chain – a hypothetical example



5.2 Fisheries

Box 9: Fisheries – summary

- There is strong evidence to suggest that healthy rivers provide multiple benefits to society through fishery provision
- Healthy river indicators including sufficient water quality, flow and connectivity are essential to support fishery productivity
- The literature provides clear evidence that fisheries support livelihoods, nutrition, cultural and spiritual values and recreational activities
- There is also evidence that fisheries can support poverty reduction and food security, although the relationships are complex
- Access can affect the realisation of these benefits, for example access to the river for fishing, access to fish as a food according to household feeding patterns, or access to markets for income
- Over-exploitation of fisheries can reduce the flow of benefits
- Benefits from fisheries are often sacrificed for the development of large-scale infrastructure such as dams for hydropower or irrigation

Fisheries are a major provisioning service provided by freshwater ecosystems (MEA, 2005; TEEB, 2013). When humans harvest this resource through catching, consuming and/or selling fish (for consumption or as ornamental pets), the provisioning ecosystem service translates into various societal benefits which are realised at different scales, represented by the figure below. The relative importance of benefits varies with context. In developing economies many poor people rely on fisheries for their livelihoods, as a vital source of protein and an opportunity for cash income (Korsgaard and Schou, 2010). However, in the developed world freshwater fisheries are often most valued as a recreational activity, which can generate cumulative economic benefits in the local economy (for example see Butler et al., 2009). Fisheries can also provide spiritual or cultural values, and drive social patterns including human migration or cultural ceremonies (Gowan et al., 2005; Shyllon, 2007).

As with many ESS, the state of the river ecosystems, for example indicators related to water quality, connectivity and flow, will determine the possibility of providing fishery services, the range of benefits and their economic value (Auerbach et al., 2014; Hoeinhaus, D. et al., 2009; Van Houtven et al., 2009). To understand the causal chain, and the evidence base (or lack thereof), it is necessary to assess the relationship at each stage.

Figure 8: Linkages between fisheries, river health and benefits to society

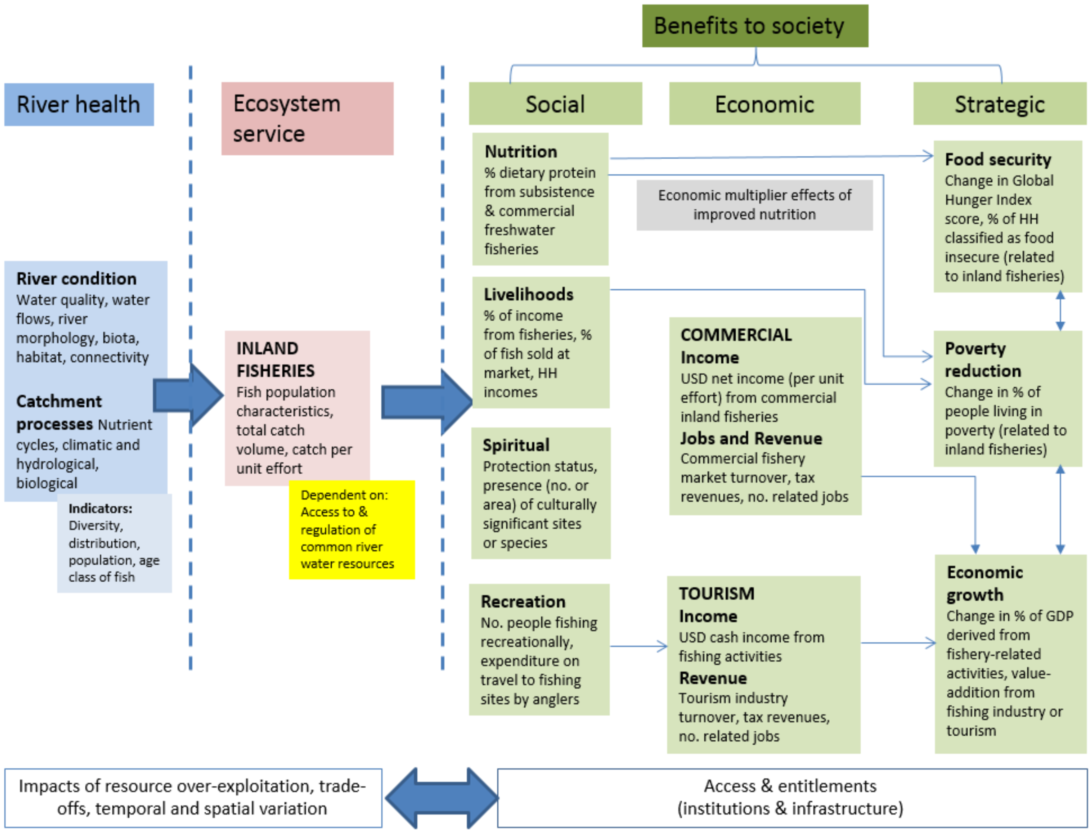


Figure 9: Factors which affect access to and realisation of benefits related to fisheries

Benefit	Factors which affect access to and realisation of benefits
Nutrition	- Cost of the fish at market, household wealth, and/or the ability to directly access fisheries for harvest affects whether the household can have fish in their diet - Internal household dynamics may affect access to fish as a food, for example preferential serving of male head of household or male child - Utilisation of fish proteins is affected by general health of the individual
Livelihoods	- Access to the river is required, as well as boats, nets, rods and skills to harvest - Access to land or alternative income may reduce dependence on fishery livelihoods - Access to markets, market competition, efficiency and preferences will affect price - Cultural and institutional constraints (e.g. around gender) can affect participation - Expansion of the resource and over-exploitation can reduce yields
Spiritual	- Ability to access river site or pay site fees
Recreation	- Resources to pay for transport, site fees, permits and equipment - Rules regarding access (e.g. permitting rules and processes)
Commercial fisheries	- Commercial enablers including business environment, infrastructure for ponds, processing, packaging and value addition - Access to finance and markets to sell products
Food security	- Depends on availability of sufficient food (i.e. avoiding fishery over-exploitation) - Varies with access, which is partly dependent on income and resources - Requires utilisation through adequate intake and ability to absorb nutrients
Poverty reduction	- Depends on proportion of people who rely on fisheries for income - Related to the ability to diversify into other livelihood strategies and the protection of fisheries from over-exploitation
Economic growth	- Depends on proportion of the economy which is related to the fisheries sector - Multiplier effects possible through re-investing surplus revenue from fisheries

5.2.1 Ecosystem services

Natural science literature explores the first stage of the relationship between river health indicators, particularly water quality and flows, and the structure of a fish community, i.e. species present, their relative abundance, life stages, size distribution and spatial and temporal distributions (e.g. for freshwater fisheries see Alabaster and Lloyd, 1982). The relationship is complex. A deterioration in certain freshwater quality factors such as suspended solids pollution or temperature may result in a short term reduction in certain species and an increase in others, as the effects are realised through the trophic chain. In the medium to longer term, reduced growth rates, food availability and under-development of eggs and larva could reduce the abundance of fish and harm the fishery (Alabaster and Lloyd, 1982). Water flow is of equal or greater importance, for example breeding patterns rely on flooding patterns or river connectivity. Barriers along the river which alter flow and disrupt connectivity can have major impacts on productivity (e.g. see Hoeinhaus et al., 2009; Tickner and Acreman, 2013). Countries with developed environmental protection regimes such as the USA and members of the EU have legislation which sets certain ecological standards for fishery sites, or parameters for river and lake restoration to support fish habitats, such as the EU Water Framework Directive (see European Commission, 2003).

5.2.2 Livelihoods and nutrition

Social and economic benefits

The second stage relationship between fisheries and household level consumption or income generation is explored in the ESS literature, with specific case study examples from low-income countries (e.g. see Adekola et al., 2015; Korsgaard and Schou, 2010; Hoeinhaus et al., 2009) . Korsgaard and Schou (2010) conduct a meta-analysis of 27 economic valuation studies in developing countries to research the extent to which the livelihoods of rural populations in developing countries depend directly on the provision of aquatic ecosystem services. Fisheries are identified as a vital livelihood strategy for food for survival, and to provide income flows. The relative weighting of these two objectives depends on broader social indicators for the household, for example a household with land assets and diversified income strategies may consume less fish than a landless household. Certain studies use valuation techniques to quantify the value of fishery services, for example the net monetary value of fishing activity in the Niger Delta generated approximately USD 3,400 per household (Adekola et al, 2005).

In relation to nutrition, HLPE (2014) explains that fish is one of the most efficient converters of energy into high-quality food for human consumption, and a primary source of protein and nutrients in certain regions. Kawarazuka and Béné (2011) conduct a systematic review to assess the potential for fisheries to improve micro-nutrient deficiencies in developing countries. The authors find that locally available small fish have a high level of essential micro-nutrients and offer potential as a ‘cost-effective’ strategy to improve nutrition indicators for the poor in developing countries. However, they also note a lack of rigorous evidence to assess the impact of fish consumption on nutrition (*ibid*.).[11] This is supported by the HLPE (2014), who observe that debates have concentrated on biological sustainability and economic efficiency of fisheries and not nutrition.

Smith et al. (2005) review the livelihood function of inland fisheries in developing countries and identified that freshwater ecosystems such as river and lakes provide

[11] Although there is a need for more robust evidence, grey literature and policy documents clearly state the essential role of fisheries for nutritious diets.

fisheries which require relatively few resources to exploit, and as such are 'accessible and important in the livelihoods of poor people' (p360). The authors identify four different fishery livelihood strategies, including (1) primary livelihood for survival (subsistence and nutrition) (2) part of a diversified, semi-subsistence livelihood, often driven by seasonal constraints around planting and harvesting crops (3) specialist occupation (targeted market production) and (4) part of a diversified savings and accumulation strategy (for more asset rich households) (*ibid*.: p359).

When fish are sold at the market for a profit, households can also reap economic benefits from income creation. There is a direct link between fishery provision and commercial value, however market prices for fish are also determined by proximate and external demand and supply dynamics, including consumer preferences for certain types of fish, the availability of substitutes for that fish product or alternative markets, scarcity and value-addition (Hoeinhaus et al., 2009). Both the net market value and the subsistence potential of fish is related to the amount of embedded energy and indirect cost required to harvest the resource, for example in the fisher's labour, knowledge and resources required (boat, fuel, nets etc.) (*ibid.*). Formal or informal institutions and rules may also affect acces, for example, in Nigeria, the livelihood strategies of women fish traders were shaped and constrained by gender norms (Udong et al., 2010). These access and entitlement factors can limit or facilitate access to fishing benefits, discussed in detail below.

Strategic benefits

This part of the causal chain considers the link between fishing livelihoods and strategic, policy level objectives related to poverty reduction and food security. This relationship is explored in development studies and economics literature, focused on livelihood frameworks and incomes (e.g. see Martin et al., 2013; Smith et al., 2005; Ellis and Ade Freeman, 2004; Béné, 2003; Allison and Ellis, 2001), and public health literature related to nutrition and food security (e.g. see Kawarazuka and Béné 2011). However, the reviewed literature presented limited systematic, quantitative analysis which directly attributes the ESS of fisheries provision to these top level benefits. This reflects multiple conflating political economy aspects related to access, entitlements and counter-factuals which create 'noise' around causality. For example, Béné (2003) discusses the perceptions and realities in the relationship between fisheries and poverty, and the potential negative cycle created by fisheries as an open access resource, and 'last resort' livelihood strategy, leading to Hardin's 'tragedy of the commons'- over exploitation, declining returns, lower incomes, low labour costs and a negative cycle of poverty. Similarly, Allison and Ellis (2001) describe how expansion of fisheries and resource depletion threaten both livelihoods and nutritional status of low-income households – overuse of the ESS can actually have a negative feedback effect on the potential to realise benefits.

Other researchers adopt an integrated perspective in an effort to unpack the fishing/poverty relationship and relevant factors. Smith et al. (2005) categorise different types of fishery livelihoods, and suggests that household income derived from fishing is related to characteristics affecting each step of our suggested causal chain, including that of the fishery (yields, seasonality, effective demand), the fisher (household asset endowment and livelihood objectives), the micro-, meso- and macro-economic environment (vulnerability, labour, resources and markets) and the institutional context (social, cultural and political determinants of access to fisheries, and common resource governance capacity). Applying this at the case study level, Martin et al. (2013) discuss how fishing is an important livelihood activity for all wealth groups in the lower Mekong, in Laos, but forms a greater proportion of income, employment and food security for the poor.

The debate regarding fisheries and poverty also applies to coastal fishing, for example Belhabib et al. (2015) assess official and estimated data for West Africa on fish catches, employment, fisher incomes, fish consumption per capita and fish contribution to animal protein consumption. The authors argue that fisheries provide value as a social safety net, and can potentially provide high incomes, but note that over-exploitation is resulting in increasing costs, declining yields, and driving down both incomes and cash value economic contribution to GDP (*ibid.*). This negative cycle also raises questions regarding dependence on fish protein.

The concept of food security is more abstract than poverty, and therefore establishing the evidence base is even more challenging. Household level food security is referenced in livelihoods literature (e.g. Smith et al., 2005) while a national framing is more often used in papers relating to marine fisheries, for example Belhabib et al. (2015). However, there is limited evidence for the rationale underlying the relationship with fish as an ESS. Nutrition is an indicator of food security, and therefore literature supporting the first level relationship can also provide evidence for food security, when considered with integrated concepts which include access and availability, education, and utilisation dimensions. Béné (2003) suggests that these socio-institutional mechanisms which govern access to fishery resources are the most critical factors affecting vulnerability to poverty and food insecurity, more than the resource itself. This illustrates how political economy becomes a key determining factor for the realisation of benefits.

5.2.3 Culture and recreation

Social, economic and strategic benefits

There is a reasonable amount of literature which describes how fisheries are an integral component of the spiritual or cultural value which communities attach to rivers (see Gowan et al., 2005 for the ecosystem service perspective; Shyllon, 2007 for an anthropological view). The realisation of the benefit can range from aesthetic appreciation of the presence of fish in a river, to deep-seated cultural values attributed to the existence of fisheries, with dedicated social rituals. For example, the Elwha Tribe in the USA protested strongly against the Elwha river dam, which they perceived as a ‘profound injustice’ due to the detrimental impact on the river’s salmon populations (Gowan et al., 2005). The Argungu fishing festival (Fashin Ruwa) in Nigeria marks the end of the agricultural season and the beginning of the fishing season. The festival is related to historic fertility rites and promotes taditional livelihoods and river conservation (Shyllon, 2007).

Fisheries also present an opportunity for recreational fishing, which is not driven by the need to consume fish for survival or for income. Recreational fishing occurs often as a tourist activity, and in certain areas local and national governments have established an economic industry around the allocation of fishing permits and ancillary services for visitors. The recreational benefit of fishing is well-covered in the ESS literature, with review articles which include fisheries as one of multiple benefits of rivers and lakes (e.g. see Auerbach et al., 2014), and specific case studies focused on a particular water catchment (e.g. see Gowan et al., 2005 on the Elwha river, USA) or the benefit stream related to fishing (e.g. see Butler et al., 2009 on recreational rod fisheries in the River Spey, Scotland).

The relationship between recreational fisheries and economic benefits is also discussed in the literature, with clear rationals which link the primary social benefit (recreation) with additional, cumulative economic benefits structured around the industry, i.e. expenditure by anglers on equipment, travel, accommodation and services in the local community (Radford et al., 2004). Authors such as Butler et al. (2009) apply the travel cost method to quantify willingness to pay by recreational anglers to enjoy fishing rights. The authors (*ibid*.) also survey and analyse expenditure data and find that anglers spend GBP 11.8 million in the Spey catchment annually, contributing GBP 12.6 million to households through the multiplier effect. Gowan et al. (2005) apply contingent valuation methods to the Elwha, estimating the potential monetised benefits of removing the dam, partly in order to restore fisheries (particularly salmon populations), at between USD 3.47 and USD 6.275 billion.

The final stage of the benefit chain from economic to strategic benefits of tax revenue and further economic development is referenced by some authors (e.g. Butler et al., 2009). However, there is limited discussion of the role of re-investment and closing the cycle through protecting and sustaining the river to ensure an ongoing flow of fishery goods and services.

5.2.4 Drivers, pressures and trade-offs

Despite the multiple societal benefits which freshwater fisheries provide, they are also one of the planet's most threatened natural resources (Smith et al., 2005; HLPE, 2014). Fisheries as an ecosystem service are sensitive to the entire range of healthy river indicators, and changes in water quality (chemicals, pH, temperature, hormones, nutrients, transparency), flows, habitats and species will affect fishery compostions (Alabastor and Lloyd, 2013). Indirect drivers such as industrialisation, land use change, population growth and climate change generate direct threats to river, lakes and wetland ecosystems through over-extraction, changed flow patterns, pollution, loss of habitat and over-fishing (Auerbach et al., 2014; MEA, 2005; Smith et al., 2005). HLPE (2015) notes that with increased competition for water, fish, inland capture fisheries and aquaculture often suffer most as water allocation priorities are focused on other sectors. However, the authors also state that better integration of fisheries with water management system leads to improved water quality overall, and therefore positive feedback effects also exist (*ibid*.).

There is also complexity in the causal chain, driven by the feedback effects of over-exploitation, declining ESS provision and further marginalisation of those who most depend on the resource. Over-fishing or a reduction in certain key species (according to consumer preferences) affects the state of the river, lake or wetland ecosystem. In the long run, increased fishing effort results in a shift from large to small species composition, but the process follows a non-linear pattern, for example as fishing effort increases, the combined yield may initially increase or remain constant and then decline with a non-linear response (Smith et al., 2005). The social and economic value may change even if biomass is constant, because consumer preferences for larger or rarer fish species result in lower market prices, and although smaller fish can be equally or more nutritious (Hoeinhaus et al., 2009; Kawarazuka and Béné 2011).

Preservation of fishery services may require trade-offs with other potential benefits or uses of rivers. For example, river diversions for surface water irrigation can reduce flows and agricultural run-off negatively impacts fish communities. Dams for hydropower or irrigation change flow regimes and connectivity and can prevent fish from following natural migratory patterns which are necessary to reproduce. Hoeinhaus et al. (2009) analyse the effects of dams on the Paraná river in Brazil, and identify three levels of negative effects on fishery benefits: an increase in the energetic costs of harvesting fish, a decrease in migratory species preferred by consumers, and a resultant decline in market value and incomes. Other authors extensively discuss the benefits of de-commissioning and removing dams, or applying safe minimum standards to protect eco-system services such as fisheries (e.g. see Gowan et al., 2005; Auerbach et al., 2014). In contrast, some researchers promote the benefits of dams for development, growth and regional cooperation (e.g. see Grey and Sadoff, 2007). The motivations and agenda which drive decisions around rivers are highly political, as are the epistemological arguments in favour and against different development agendas.

5.3 Irrigated crop production

Box 10: Irrigated crop production - summary

- Healthy river indicators including water quality and water flows make irrigation systems possible and support better crop yields
- Evidence suggests that crop production through surface water irrigation systems can support livelihoods, poverty reduction, growth and food security
- The causal relationship between river health and the benefits of irrigation is framed by the constraints and opportunities of the agricultural sector in a given context, for example market access
- As such, there is mixed evidence around causal relationships, for example irrigation can support livelihoods only if the appropriate sites, technologies and management structures are adopted
- Unintended consequences of irrigation on rivers include reduced downstream flows and water quality deterioration due to toxic pesticides and changes to nutrient composition
- The negative impacts of irrigation can result in trade-offs with other ESS such as fisheries and water for consumption

Rivers can provide multiple societal benefits through supporting irrigated agriculture. Irrigation requires adequate volumes of freshwater of sufficient quality, and floodplain recession agriculture relies on deposits of soils and nutrients (HLPE, 2015; Delgado et al., 2013; Komakech et al., 2012). Globally, rainfed agriculture is still the dominant production system. However, irrigation development in combination with other farming inputs was critical to the success of the Green Revolution and supports the high intensity production methods necessary to meet food demand in densely populated regions (Oates et al., 2015). Furthermore, in areas with variable climates or at risk of increasing variability under climate change, irrigation development could help to mitigate the effects of dry periods, resulting in more stable yields, with the potential for positive economic and social multiplier effects (HLPE, 2015). As with fisheries, the crops grown under irrigated systems support livelihoods, with the potential for significant revenue generation with commercial production. Irrigation can also support food security through improved stability of food supply in areas subject to drought, increased food availability and better incomes for farmers. However, the stream of benefits is largely determined by the objectives of the investor (whether government, smallholders or the commercial private sector) and the design, management and performance of the irrigation scheme (see Oates et al., 2015).

Figure 10: Linkages between crop production, river health and benefits to society

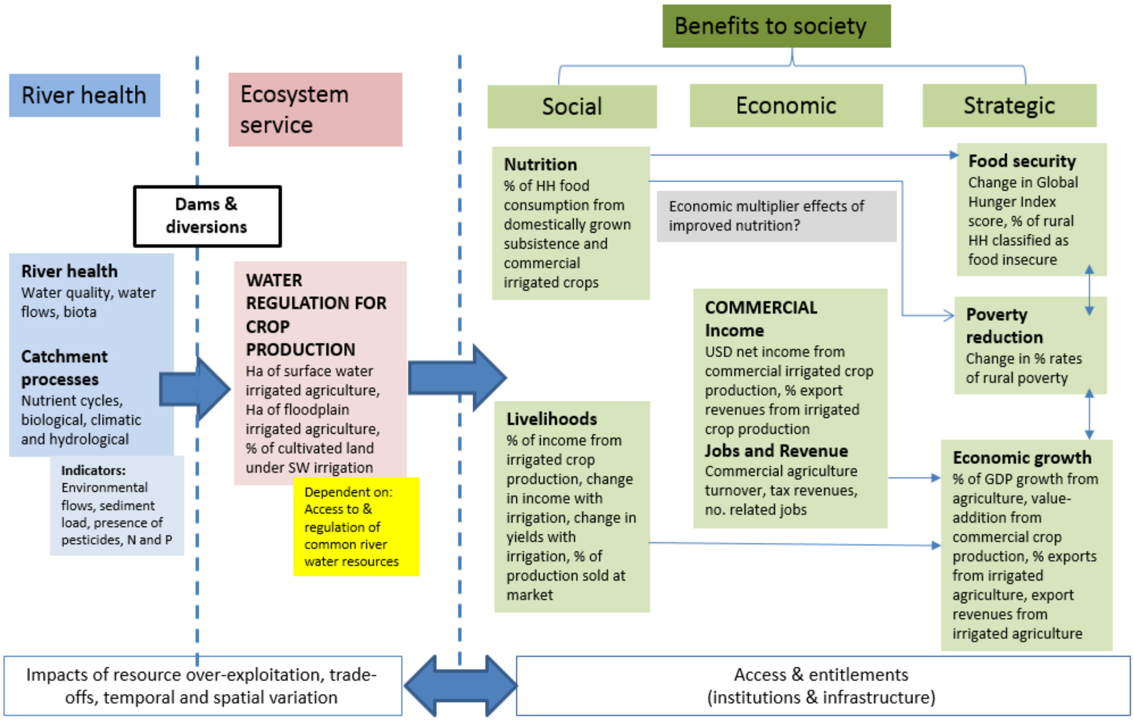


Figure 11: Factors which affect access to and realisation of benefits related to irrigated crop production

Benefit	Factors which affect access to and realisation of benefits
Nutrition	- Cost of the crop at market, household wealth, and/or the ability to directly access land for production affects whether the household will have improved access to food - Household dynamics which affect access to food crops or diversified diets, for example preferential serving of male head of household or male child, or cultural beliefs around diets for children - Utilisation of nutrients from food is affected by general health of the individual
Livelihoods	- Benefits depend on functionality of water source and availability, type of system, infrastructure and institutional rules governing site management - Access to land is required for production, but full benefits realised with complementary technologies including inputs, extension and post-harvest technology - Access to alternative income may reduce dependence on crop production - Access to agricultural markets and market competition and efficiency - Cultural and institutional constraints e.g. around gender can affect participation in agricultural water management and complementary technologies - Expansion of upstream irrigation can reduce and pollute water for downstream users
Commercial production	- Benefits depend on functionality of infrastructure and site management - Commercial enablers including business environment, availability of large land masses for economies of scale, processing, packaging and value addition - Access to finance can facilitate economies of scale and investment risks - Access to international market is required for trade, with tariffs and unstable prices
Food security	- Requires appropriate distribution of food resources and food stores - Requires utilisation through adequate intake and ability to absorb nutrients
Poverty reduction	- Depends on proportion of people who rely on agriculture for income - Related to the ability to intensify and commercialise the agricultural sector, to

		produce surplus, increase incomes and provide employment for rural populations
Economic growth	- -	Depends on proportion of the economy which is related to agriculture Multiplier effects possible through re-investing revenue from agricultural production

5.3.1 Ecosystem services

Irrigation and flood plain agriculture requires different types of ecosystem services, including the provision of water of sufficient quality and volume, and the regulation of water and nutrient flows (HLPE, 2015). As with fisheries, the first stage relationship of the mechanics between ecological processes and irrigation provision is discussed in the natural science literature. For example Boyd (2012) describes water quality needs for irrigation, which must have certain minimum standards of salinity, dissolved solids and chemical composition. In systems with intensive use of pesticides and water recycling, pollution from agriculture has major health and food quality impacts on irrigation uses downstream. Keystone literature in the fields of environment, ecology and development policy also identify the importance of ecosystem integrity for continued 'availability, quality and stability' of freshwater for irrigation and other purposes, and note that changes or deterioration in freshwater ecosystems can threaten the provision of water (HLPE, 2015:19; TEEB, 2013).

5.3.2 Social and economic benefits

The relationship between irrigated crop production and potential socio-economic benefits is explored in environmental literature (e.g. see Naiman and Dudgeon, 2011), development research (e.g. see Domenech and Ringler, 2013) and grey literature (e.g. see HLPE, 2015). The HLPE (2015) report discusses the connection between healthy freshwater ecosystems which provide water of sufficient quality and quantity for irrigation, and the potential for irrigation to increase crop yields and support nutrition and food security. Conversely, the authors also note that poor quality irrigation water may not have the desired impacts on crop production, and can have negative impacts on human health (*ibid.*). Impacts include diarrhoeal diseases which reduce nutritional status, or cancers as a result of poorly controlled pesticide use. Rosegrant et al. (2009, cited in Domenech and Ringler, 2013) model the potential impact of tripling the area of cultivated land under irrigation in Africa, and suggest this would result in two million fewer malnourished children than the low irrigation scenario. However, Domenech and Ringler (2013) note that there is a lack of research which provides robust evidence regarding the impact of irrigation on nutrition indicators.

Improved livelihoods for the rural poor is often cited as a justification for major irrigation schemes in developing economies (e.g. see Hussain and Hanjra, 2003 and Smith, 2004), and the validity of this relationship is implied in water security literature which advocates water resource development supported by appropriate institutions (e.g. see Grey and Sadoff, 2007; Whittington et al., 2013). Large donors have supported this narrative (e.g. see World Bank, 2006). Hurford and Harou (2014) explain that increased access to irrigation can improve livelihoods for economically marginalised groups, and that construction of supporting infrastructure such as dams have cumulative non-water-related benefits such as employment.

However, this assumes that schemes perform adequately. Oates et al. (2015) provide an extensive discussion of the many dependent factors which affect irrigation scheme performance, which can limit potential income and livelihood benefits. Case studies in Ethiopia, Morrocco and Mozambique revealed that irrigation schemes often performed poorly and did not deliver on a wide set of (sometimes incoherent) objectives. Furthermore, similar to fisheries, irrigation as a livelihood strategy is complex and subject to potentially competing interests and negative feedback effects. Lankford (2005, cited in Ellis and Freeman, 2005) outlines key constraints regarding the role of irrigation for sustainable livelihoods, noting that irrigation consumes high volumes of water which might negatively affect livelihoods downstream, and that in most cases water resources are sufficiently constrained to create competition. Lankford (2005) suggests certain conditions under which irrigation can contribute to reduced poverty, including appropriate physical and technical context, acceptable social, institutional and human transaction costs, minimised economic transaction costs and sufficient time, and all of these are framed by farmers' perceptions. As such, the potential for irrigation to improve yields and therefore support social outcomes must be subject to carefully considered evaluation. In particular, decision makers must consider the needs of both upstream and downstream users, and potential impacts on other ESS.

Similar to fisheries, irrigated crop production is possible at multiple scales, with different actors, from smallholder farmers working on small and non-contiguous plots, to large-scale commercial farms. Commercial irrigation combined with other agricultural practices can significantly improve yields. Expansion of irrigation systems and input use has contributed to global productivity gains and reduced food prices in global markets (HLPE, 2015). Small-scale and micro irrigation technologies can also improve yields for smallholders. FAO suggests that further expansion of irrigation is an essential component of increased food production to meet rising demand by 2050 (Conforit, 2011). As such, many governments and donors have embraced the irrigation agenda, for example through the Comprehensive African Agricultural Development Programme (CAADP) and the New Alliance for Food Security and Nutrition. Irrigation also allows for production of higher value horticulatural commodities which can generate export revenues, however, these crops often consume more water and may increase water stress in a region (Oates et al., 2015). As such, large-scale irrigated agriculture can help meet domestic food demands, generate revenues and provide postive multiplier effects such as employment and tax revenues, however, these benefits depend on market access, and water thirsty cash crops may involve trade offs.

5.3.3 Strategic benefits

It is more difficult to find rigorous evidence which explores the causal relationship between irrigation and the strategic benefits which are frequently referred to in high profile reports such as HLPE (2015) and TEEB (2013). Strategic benefits are related to social and economic benefits - livelihoods can support reduced poverty, agricultural growth and trade can drive GDP and nutritional status is an indicator of food security. However, similar to fisheries, attributing causality is extremly difficult.

Policy and academic literature suggests that for developing economies with limited resources, agricultural intensfication is a route out of poverty (e.g. CAADP, see NEPAD, 2010; Dercon, 2012). Agriculture provides employment for large rural populations and increased yields can drive up incomes (Dercon, 2012). The sector can also support development of ancillary services and light manufacturing through food processing (HLPE, 2015). This can support growth and poverty reduction in certain contexts, when agricultural revenues are prudently invested in catalytic public sectors such as health and eduction.

Food security was a further justification for early irrigation scheme development, and is now attracting increased attention in the context of increasing population, a declining resource base and climate change (e.g. see Oates et al., 2015 and HLPE, 2015). A large amount of the reviewed literature discusses the potential benefit of food security (e.g. TEEB, 2013), but often without detailed explanation of how irrigation or flood-plain agriculture contributes to this goal, and the trade-offs with other, potentially complementary services or benefits (for example, water for fisheries). The HLPE (2015) suggests an integrated agro-ecological approach for food security which maximises the productivity of available resources through context-specific soil, water and biodiversity management regimes informed by local knowledge. This recognises the inter-connected role of ecosystem health, man-made technology to harvest benefits, and the importance of tailoring the realisation of benefits to local resource and socio-economic environments.

5.3.4 Drivers, pressures and trade-offs

Expansion of irrigation is a major pressure on water ecosystems (Vörösmarty et al., 2005). Irrigated crop production is the top consumer of freshwater resources, accounting for 70% of water withdrawals, of which approximately 60% is sourced from surface water including rivers, although these figures are generally higher in water scarce environments (HLPE, 2015). Some of this water returns to the ground or surface water system through return flows, although it may be polluted. Some of the water is lost through evapo-transpiration, and the remainder is consumed by the plant.

Finlayson and D'Cruz (2005) observe that countries aiming for food self-sufficiency may have entrenched patterns of water scarcity through expanding irrigation withdrawals at an unsustainable rate, which will generate future food insecurity. In countries with historically weak food production capacities the principle of self-sufficiency is often at the heart of the policy agenda, but short-sighted decisions regarding irrigation investments could exacerbate existing pressures on land and water resources. As such, irrigation has mixed effects in terms of climate resilience and socio-economic development. In the short term, irrigation can reduce sensitivity of the agricultural sector to immediate risks of agricultural drought, which can affect famer's incomes and food security. However, in the long-run, irrigation could be an unreliable investment in contexts where there are risks of meteorological and hydrological droughts of increasing frequency, severity and duration (see Oates et al., 2015).

Irrigation can also have many negative feedback effects on rivers and provision of other ESS. Over-abstraction can generate local climate changes, resulting in increased temperature, and driving degradation of the river (Finlayson and D'Cruz, 2005). Reduced downstream flows devastate ecosystems, as flow is the most important factor for bioidiversity (Tickner and Acreman, 2013). Irrigation infrastructure such as diversions and impoundments also disrupt ecosystems and negatively affect other services (TEEB, 2013). Agricultural inputs including pesticides and fertilisers cause pollution (HLPE, 2015). Nitrates and phosphates result in eutrophication and algal blooms. Pesticides with long and complex degradation pathways can cause long term contamination, concentrate within the trophic chain and make the water unfit for use, and fish unfit for consumption (Butler et al., 2009; Finlayson and D'Cruz, 2005). The HLPE (2015) emphasises the need to preserve all river ecosystem functions to ensure the future of the water resource, and to satisfy the quantity and quality needs of diverse users.

In addition to trade-offs, the distribution of benefits, including alternative water uses, must be considered. Naiman and Dudgeon (2011) explore the role of local effects, for example, people close to irrigation schemes and dams are at higher risk of diseases while high level benefits such as food security are dispersed. Downstream water users may be subject to reduced water allocations which threaten their livelihoods, or alternatively, irrigators can lose their access to water in favour of large urban centres, as alternative uses are of higher-value (Komakech et al., 2012; Hurford and Harou, 2014). Domenech and Ringler (2013) identify key factors which shape the impact irrigation has on rural communities, including water source and availability, type of system, access to inputs, socioeconomic features of the household, and the institutional rules governing water access and maintenance of water system. Again, this illustrates the importance of applying the political-economy lens to the framework of ecological-societal benefits of river ecosystems.

5.4 Hydropower

Box 11: Hydropower - summary

- There is evidence that hydropower production can support energy security by increasing energy availability
- Hydropower requires sufficient water flows and sediment control, although water quality is much less important
- The relationship between hydropower and households' access to electricity is shaped by political factors and geographic constraints
- The development of hydropower dams often incurs high social, economic and environmental costs, and degraded ESS; these costs are often borne by the poor and marginalised; as such, hydropower is a controversial benefit of rivers
- There are options to rebalance the trade-offs and 'winners and losers' of hydropower, for example through benefit sharing

Hydropower is one of the most contentious societal benefits provided by rivers. Dams, impoundments and weirs allow electricity generation in a context of increasing global demand. However, this infrastructure can also result in fundamental changes to river flow and connectivity and may negatively impact other river health indicators such as sediment control and channel maintenance, biodiversity and regulatory processes and functions (Nilsson et al., 2005). This can alter the provision of ecosystem services and associated benefits, in terms of quantity, quality and allocation (Hurford and Harou, 2014; Tickner and Acreman, 2013; Hoeinhaus et al., 2009). The controversy around dam planning, construction and operation reflects this.

Often, the net impact of large dams (including those used for hydropower) is a 'reallocation of benefits from local riparian users to new groups of beneficiaries at a regional or national scale' (WCD, 2000: p17). The loss of certain benefits is justified by an over-arching narrative which promotes the role of dams to facilitate growth and development, and the concepts of water and energy security (e.g. see Grey and Sadoff, 2007; Whittington et al., 2013). This has generated revived interest among government and donors in large dam construction in developing countries (Alhassan, 2009; Ansar et al., 2014). In contrast, in the developed world, there is a growing movement around the benefits of impoundment and weir removal and free-flowing river restoration, in an effort to recapture and enhance ecosystem services such as fisheries and spiritual values (e.g. see Auerbach et al., 2014; Gowan et al., 2005). As such, the causal linkages between the social, economic and strategic benefits of hydropower must be considered within the context of trade-offs with other potential benefits.

Figure 12: Linkages between hydropower generation, river health and benefits to society

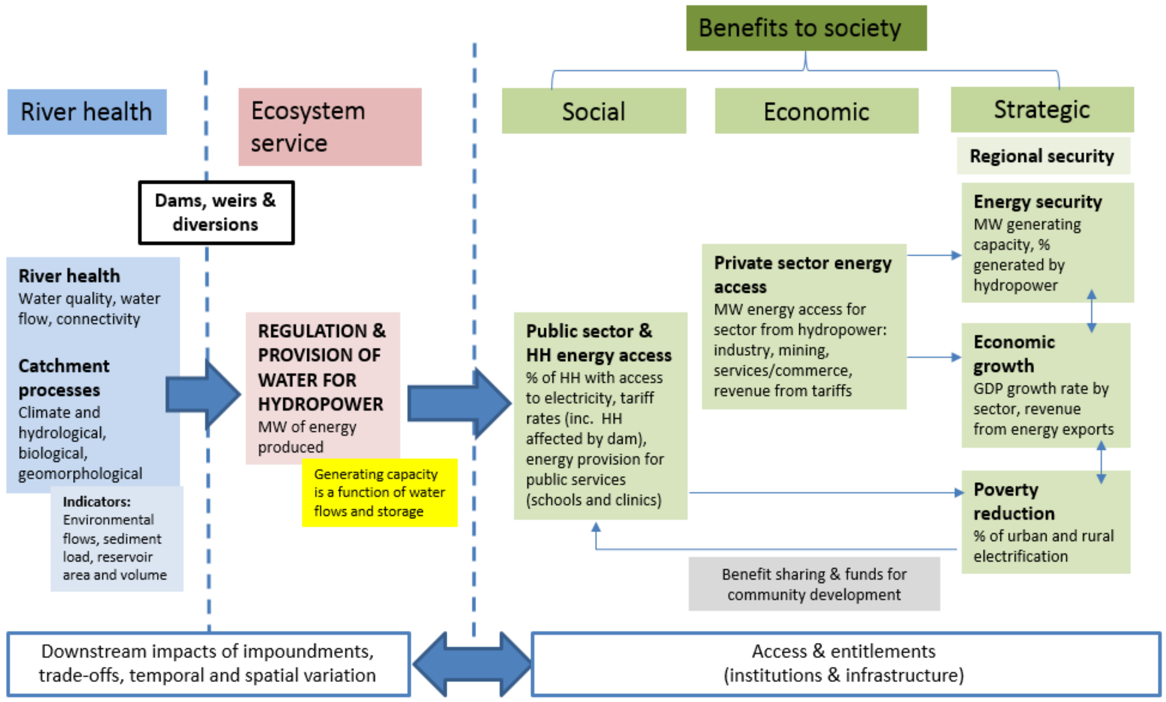


Figure 13: Summary of factors which affect access to and realisation of benefits related to hydropower production

Benefit	Factors which affect access to and realisation of benefits
Public sector / HH energy access	- Infrastructure and grid access to households including poor and dispersed homes - Cost of electricity tariffs and ability of household to pay
Private sector energy access	- Infrastructure and grid access for commercial companies - Tariff rates and ability for the private sector to generate sufficient revenues to pay
Energy security	- Requires buy-in to cooperative actions by riparian states - Important to consider energy security 'for what' and 'for who' as national security may not translate to household electricity access
Poverty reduction	- Depends on provision of electricity to households and services which improve welfare including centres for health and education - Can be supported through positive cycles of re-investment e.g. benefit sharing
Economic growth	- Depends on proportion of the economy which is related to high energy consuming sectors such as extractives and heavy industry - Multiplier effects possible through re-investing revenues from major industries

5.4.1 Ecosystem services

The first level relationship between the river characteristics required for hydropower, the construction of dams and weirs and the feedback effects on rivers is explored extensively in different types of literature, including natural sciences and environmental management (Nilsson et al., 2005; Magilligan and Nislow, 2005), ecosystem services and valuation (Hoeinhaus et al., 2009; Auerbach et al., 2014), water resources management and security (Tickner and Acreman, 2013; Skinner and Haas, 2014) and technical and grey literature (WCD, 2000; International Rivers, 2007; Krchnak et al., 2009).

There are three types of hydropower: storage schemes, where a dam stores water in a reservoir in order to power a turbine(s) and generator(s); 'run-of-river', which also powers a turbine although with little or no water storage, using instead the natural flow of the river; and pumped storage, which incorporates two reservoirs in a lower and upper basin and releases water at times of peak demand (IEA, 2010). In order to function, hydropower depends on river flows and 'head', the potential energy of water dropping from a high to lower level. Technical literature suggests that the most important river indicator required for hydropower production is water flows and 'head' for the turbines to spin, and water quality, nutrient and sediment control to prevent damage or clogging of the turbines, for example due to siltation or algal blooms (IEA, 2010). For all types of hydropower, civil and mechanical engineering works are required to 'harvest' the benefit of a river's hydropower potenial. This 'built' infrastructure compares to 'natural' infrastructure provided by river systems and wetlands such as flood retention (TEEB, 2013). Impoundment dams can create greater disruption to the river through changing connectivity, flows and creating reservoirs. 'Run-of-river' dams are generally perceived to have less impact, although multiple small schemes can also have major impacts.

5.4.2 Social and economic benefits

The resurging interest in hydropower production in emerging economies, particularly through large dams, is premised on provision of household electricity access and power for key economic sectors including industry, mining and commerce. Energy poverty is a major issue in developing countries, and limited access to electricity for schools, hospitals and households creates barriers to improved welfare and social development indicators (Hogarth and Granoff, 2015). As such, increased household electricity access is a development priority for donors and the first objective of the UN Sustainable Energy for All initiative (SE4ALL) launched in 2010. Hydropower is cited as a 'renewable' source, as per the third SE4All global target. Academic literature framed within the water security debate generally assumes that hydropower will provide improved household electricity, without providing detailed discussion of the issues of access and allocation which affect the causal chain (e.g. see Sadoff et al., 2015, van Beek and Arriens, 2014; Whittington et al., 2013).

However, research focused on practical application of development policies suggests that the expansion of hydropower production may not result in improved household access to electricity. Hogarth and Granoff (2015) highlight that currently almost half of electricity consumption in Africa is used for industrial activities, primarily mining and refining, and that plans for increased generation are focused on further provision for extractive industries, industrialisation and increasing demands of existing users. Similarly, Newborne (2014) analyse hydropower expansation in Brazil, and found that dams planned for construction in the Amazon were destined to supply electricity for high energy-intensive industrial uses such as aluminium production. Both reports emphasise the distinction between large hydropower dams which feed into the national grid and are well suited for providing energy to industry or high density urban populations, in contrast to the needs of rural, remote and dispersed communities who may require off-grid solutions (Newborne, 2014; Hogarth and Granoff, 2015).

Therefore, when considering the potential social and economic benefits of hydropower, it is important to assess who the planned beneficiaries are and how to monitor access to planned benefits (for example, tariff rates and connection charges). Further research is required to better understand the factors which constrain or faciliate household and sectoral access to energy generated by hydropower.

5.4.3 Strategic benefits

The final stage of the causal chain considers the link between hydropower production and strategic objectives related to regional and energy 'security', economic growth and poverty reduction. The reviewed literature seems to converge on discussion of these high level benefits. Academic literature framed within the water security debate explores the relationship between transboundary WRM, including WRD such as hydropower dams and the potential for improved regional security. Sadoff and Grey (2005) suggest that transboundary rivers provide development opportunities through riparian cooperation yielding socio-economic, political and environmental benefits. There is extensive contention around this paper, with a response provided by Hatfield-Dodds (2006). As such, it should be noted that authors such as Grey and Sadoff are generating an argument in favour of WRM as a space for regional security, as opposed to presenting evidence of the causal relationship. In some states, competition and conflict may be politically favoured.

The literature provides case-study evidence of transboundary cooperation. Rasul (2015) uses trans-boundary rivers in South Asia as a study of the potential benefits of cooperative WRM, focused on development of hydropower as an example. The author suggests that regional cooperation provides a positive cycle of cooperation – collective action can help overcome the constraints such a a lack of financial resources, investment risk, limited expertise or low demand (*ibid*.). The Mekong River Commission in South-East Asia, developed a framework to resolve inter-state disputes around hydropower development (Matthews and Geheb, 2014), however, the inability to achieve consensus for major projects has affected state buy-in and implementation challenges remain. The forum has served as a platform for cooperation between member states, and has also received funding from international aid agencies to support cooperative projects around fisheries, flood control and IWRM.

Both academic and grey literature suggest that the primary strategic benefit offered by hydropower is energy security, which implies that dams can provide a reliable source of electricity (Rasul, 2015; Hurford and Harou, 2014; Men et al., 2014; TEEB; 2013). Storage hydropower schemes can act as load balancers within an electricity network, which can increase capacity and reliability of supply, and has lower negative impacts on human health and climate in terms of pollution and carbon than alternative energy solutions (Newborne, 2014). However, much of the literature reviewed which mentions energy security does not present a compelling and disaggregated discussion of who benefits from this.

Furthermore, excessive dependence on hydropower as the main source for electricity creates path-dependency and a reliance on large infrastructure which is vulnerable to climate risks and variability (Hallegatte et al., 2012). Below average precipitation and drought can lead to oscillating reservoir levels and supply issues, which raises issues regarding the sustainability of dependence on hydropower for energy security. This emphasises the importance of river health indicators such as water flow and hydrological catchment processes for hydropower production. For example Brazil's dependence on hydropower (around 70%) has been brought into question by low reservoir levels due to recent drought and construction of a number of run-of-river hydropower schemes, combined with minimal investment in other renewables such as wind and solar power (Newborne and Welham, 2014). Therefore, although there is a relationship between hydropower and energy security, the literature does not provide sufficient evidence of the necessary conditions and distribution of this benefit.

The relationship between hydropower production, poverty and growth is analysed from a strategic angle in the water security literature (Sadoff et al., 2015 Whittington et al., 2013), and development research (e.g. see Hogarth and Granoff, 2015). Hogarth and Granoff (2015) explain that energy itself does not reduce poverty, but delivers 'energy services' which can directly and indirectly improve household welfare (through direct consumption, power for productive activities and electricity for public services such as schools and health centres). Energy can also supply economic sectors such as mining which contribute to export revenues, tax and GDP growth, and can help development when re-invested.

5.4.4 Drivers, pressures and trade-offs

For most hydropower infrastructure, the net impact is altered downstream hydrology, which changes other physical characteristics of the river, including geomorphological processes, and results in ecosystem transformation across the watershed (Magilligan and Nislow, 2005). This can have positive impacts, such as improved flood control and irrigation opportunities (WCD, 2000, IHA, 2010). However, there is also the potential for negative ecological consequences, such as reduced floodplain productivity, decreased dynamism of deltas, loss of mangroves and wetlands, salt intrusion and extensive changes to aquatic communities, leading to losses of entire species of freshwater fish (Nilsson et al., 2005). The magnitude of impacts varies with scheme type. Large storage schemes require dams which severely disrupt river systems, through inundation (flooding the reservoir), fragmentation and flow manipulation (Nilsson et al., 2005). Small weirs have less impact on flows, but can interrupt fish runs, sediment flows and riparian structures, and even run-of-river schemes ('small hydro') can be highly disruptive to the river (Nilsson and Berggren, 2000). Therefore, the infrastructure required to capture the benefit of hydropower production results in immediate trade-offs with other ecosystem services and their potential beneficiaries. The literature provides a range of evidence exploring the dual direction relationship between hydropower infrastructure and healthy rivers.

Therefore, although the literature suggests that hydropower delivers a range of benefits, these also entail significant environmental and social trade-offs. The World Commission on Dams (WCD, 2000) found that large dam construction for hydropower had not delivered sufficient benefits to justify 'unacceptably high' social and environmental costs, including displacement of millions of people, habitat destruction and lost ESS. ESS literature attributes values to the loss of ecosystem services as a result of river disruption. For example, as described above, Hoeinhaus et al. (2009) assess the impact of major hydropower dams on artisanal fisheries in Brazil, identifiying 'cascading impacts' including changes in fishery composition, increases in the expended energy, and a decrease in market value and incomes. HLPE (2015) cites case studies where dam development has destroyed local livelihoods and forced communities into reliance on cash-crops and buying food for consumption from markets, resulting in dietary shifts which decreased nutritional outcomes (Bisht, 2009, cited in HLPE 2015). Resettlement is often in areas with poorer resources, for example, lower water quality or reduced access, which has negative effects on health (Mehta, 2009, cited in HLPE, 2015). However, HLPE (2015) also notes that many people, often in urban areas, have benefited from the food and energy provided by irrigation and hydropower as a result of large dams.

There are options to rebalance the impacts of dam projects in terms of 'winners and losers'. Certain authors focus on the social equity perspective, for example Men et al. (2014) explore the different costs and benefits of two hydropower projects in Cambodia and the potential for benefit sharing. They find that the project has not delivered the promised benefits for communities to compensate for the loss of livelihoods, for example, electricity has been provided at the general tariff or higher rates than for urban consumers, and a promised fund for community development hasn’t materialised (Men et al., 2014). Generally, it cannot be assumed that hydropower production will provide benefits to poor households. Conversely, as discussed, the poor are more reliant on environmental capital and as such, the environmental cost of hydropower development can undermine the resource base of the poor and amplifies the actual loss of livelihoods and social structures (Hatfield-Dodds, 2006). Benefit sharing can attempt to mitigate this loss but only when certain conditions are met (Skinner and Haas, 2014).

Proponents of hydropower also suggest that it is possible to mitigate and control the negative impacts of hydropower production costs, through environmental and social impact assessments, compensation and favourable access to project benefits. Our review suggests there is a substantial body of evidence around the trade-offs for dams and potential tools to help policy-makers assess various factors, with case-studies of valuation and modelling of trade-offs (e.g. see Gowan et al., 2005; Hurford and Harou, 2014). The International Hydropower Assocation’s (IHA) Hydropower Sustainability Assessment Protocol (HSAP) was developed as a response to criticisms of the WCD and contains social and environmental safeguards for large dams. Skinner and Haas (2014) provide an assessment of HSAP and other voluntary and donor-drive frameworks, with consideration of distribution of benefits.

For risk mitigation, Ansar et al. (2013) suggest that policy makers should avoid excessively large projects, reduce site specific risks including those related to climate change and geo-hydrology, and ensure accountable processes that mitigate time lags and corruption risks. Hedging for climate risk is especially pertinent, given deep uncertainty regarding future precipitation, variability and effects on flows, and the high-cost and long-life span of hydro infrastructure. In addition, decision-makers must re-assess who will benefit from hydro-power production and unpack the assumption that WRD will automatically support both poverty reduction and growth. The trade-offs for hydropower are inter-related with the causal chains for fisheries and agriculture also discussed in this paper. This highlights how river systems with multiple ESS provide a range of benefits for different users. The water, energy and food nexus (exemplified by the interactions between causal chains for fisheries, crop prodution and energy) must be managed as components of a complex system, with the river at its heart (Hurford and Harou, 2014).

6 Conclusions and recommendations

6.1 Conclusions

The objectives of this paper were: to review the evidence for the relationships between river health and the social, economic and strategic benefits societies derive from rivers; and to develop a conceptual framework and typology of benefits to inform WWF programming and future research on causal linkages. The latter objective included the development of hypothetical 'causal chains' (or theories of change) to better understand the benefits related to freshwater fisheries, irrigated crop production and hydropower generation, and reflect on the evidence base for linkages to river health.

6.1.1 The benefits societies derive from rivers

Rivers have the potential to provide a wide range of benefits to society, for example supporting key livelihood activities and economic sectors, nurturing social relations and spiritual well-being, and contributing to strategic goals such as food-energy-water security, poverty reduction or climate resilience. However, rivers can also present a risk, delivering disservices. To a large extent the portfolio of ecosystem services and associated benefits will depend on how a river is managed, as well as the pattern of human development in a given context. For example, a healthy wetland can play a role in mitigating the risks associated with flooding, however in some cases natural flooding patterns pose a threat to people or their assets and some form of intervention is needed.

Despite their potential, rivers are often exploited to deliver a relatively narrow range of objectives, to the detriment of river health as well as other human needs. This is primarily because the management of rivers and their ecosystems has tended to occur in silos, with poor cross-sectoral coordination and a lack of integrated planning, and often driven by political expedience, resulting in sub-optimal outcomes. Predominant approaches have also failed to tackle mounting anthropogenic pressures on rivers, and most efforts have focused on the problem of water quantity, ignoring other key river health characteristics. Water quality, for example, is just as important for satisfying basic human and environmental needs, yet has received less investment, scientific support, and public attention. On the positive side, researchers and practitioners are calling for change, and there is increasing adoption of multi- and trans- disciplinary approaches, encompassing the development of new decision-support tools.

6.1.2 Linkages between societal benefits and river health

Many social benefits derived from rivers are dependent on good 'all round' river health, including cultural and aesthetic values, or secure livelihoods such as those based on inland fisheries or flood recession agriculture. For example, sufficient water quality, flow and connectivity of habitats are all essential to support fishery productivity. In contrast, economic benefits, such as those derived from commercial agriculture or hydropower, tend to rely on just a few aspects of river health. For example, hydropower production is dependent on river flows and water storage but not water quality, with the exception of sediment loads. Irrigated crop production requires water of sufficient quality and quantity, but connectivity is far less important. Strategic benefits are indirectly related to river health and the causal relationships (or lack thereof) are more difficult to prove. Many strategic outcomes are a product of different social, economic and political processes.

In our framework we note that the relationships between river health and societal benefits are highly complex and there are number of uncertainties, feedback loops and confounding factors at play. For example, there are uncertainties regarding internal ecosystem dynamics, responses to external pressures and the resulting portfolio of ecosystem services. Feedback effects include the impact of over-exploitation of ecosystem services, such as fisheries, on river health, which can lead to negative cycles of ecosystem degradation if not carefully managed. In turn, the management and use of river ecosystems and their services is determined by the broader governance context, which is evolving rapidly. Future trajectories of socio-economic change are highly uncertain.

The causal chains also reveal a number of factors that affect the relationship between river health and societal benefits and make it difficult to establish direct causation. For example, in order to reap livelihood benefits a fisherman requires access to the river for fishing. Nutritional benefits can only be derived if an individual has access to fish as a food source, which can be influenced by household dynamics. The ability to derive an income from fishing is contigent on access to markets and market prices, which in turn depends on other variables. At the strategic level the relationship becomes weaker still. The realisation of benefits requires human intervention, underpinned by infrastructure, institutions and other forms of capital, and is strongly influenced by factors unrelated to river health.

6.1.3 Trade-offs and the distribution of benefits

Individuals and groups of people in society have differentiated capacity to make use of ecosystems services due to differences in access and entitlements to resources. For example, cultural and institutional constraints around gender can affect participation in agricultural water management and access to complementary technologies. Evidence also shows that poorer households are at a relative disadvantage compared to richer households in exploiting fisheries or irrigated crop production as income earning opportunities, as opposed to purely subsistence activities. These factors need to be taken into account when considering river management options.

When making choice about river management and development there will inevitably be trade-offs between different interests and objectives. In particular, the realisation of economic benefits requires significant investment in built infrastructure, such as dams or diversions, with negative impacts on river health and other benefit streams, such as fisheries. Moreover, many economic uses such as industry and agriculture are highly consumptive in nature, with similar implications. The desired outcomes of river management, including the state of the river itself, are ultimately social constructs, determined by choices, funding and resources, and politics. Often it is the poorest and most marginalised groups that ‘lose out’, as they have little power to influence decision-making processes.

In conclusion, sustainable management of river ecosystems requires a stronger inter-disciplinary approach, and reclaiming the ‘water sector’ from the margins to the centre of policy-making. The costs of river development (externalities) need to be better accounted for in planning processes, as well as considerations of who wins and who loses. Moreover, a widespread shift in thinking is needed so that ecosystems are not viewed as consumers of water, but rather an essential component of water security. Our conceptual framework is a step in this direction.

Box 12: Reflections on the review methods

A full understanding of connections between river health, ecosystem services and the many associated benefits for society requires assessment of a vast amount of evidence spanning multiple disciplines. We have presented a transparent method to assess a sample of this research and explore specific causal connections, with sources of bias made explicit. Full Systematic Reviews are resource intensive, entailing systematic searches, screening of references and analysis of papers to create a 'database' of findings. Our use of snowballing from keystone documents and targeted gap filling for specific causal chains offered a practical middle-ground, combining elements of a Systematic Review with the flexibility of a more traditional Literature Review. This approach has yielded positive results, but there were challenges. The screening and analysis process was time consuming. Our methods also introduced a degree of bias and certain areas of literature were not well covered. For example, political economy literature was under-represented, yet is fundamental to understanding how benefits are distributed across society and decisions regarding trade-offs. With more time and resources, options to address these biases could include expanding the list of keystone documents to capture a larger pool of evidence, and developing robust methods for tracking grey literature, including reliability criteria.

6.2 Recommendations for WWF

6.2.1 Advocating for river conservation

A key message emerging from the literature is that current river management practices, particularly the emphasis on built infrastructure, tend to favour a limited range of societal benefits to the detriment of river health. On the other hand, policy makers are often not fully aware of the opportunity costs and trade-offs involved, or the alternatives available, including options to investment in more 'natural' solutions. **WWF has a unique opportunity to re-frame policy discussions around river health in social, economic and strategic terms,** working closely with stakeholders to identify the potential outcomes of management interventions. A focus on the things that decision-makers care most about, and use of language they are familiar with, will be much more effective than an exclusive emphasis on river health, or even ecosystem services.[12]

When making claims about the benefits of conservation activities, river health is not the only variable to consider. **Institutions and infrastructure play an important role in determining people's access and entitlements to ecosystem services.** This has implications for the extent to which members of society can derive benefits from rivers and river restoration, the nature of those benefits, and how they are distributed. WWF can advocate for transparency and inclusion in decision-making processes, to ensure that equity issues are addressed, promoting the needs of vulnerable or marginalised groups to those in positions of power and influence. Trade-offs need to be made explicit.

[12] Whilst the introduction of ecosystem services as a concept has been a step in the right direction, and is gaining traction in some quarters, adoption by decision-makers has been slow.

6.2.2 Programme design

An important question to ask in designing WWF's river conservation programmes is '**what kind of social, economic or strategic outcomes does the programme seek to support and how can these be monitored'?** Our review has shown that rivers have the potential to provide a wide range of benefits to people or societies, but the nature of these benefits will depend on how they are managed. WWF needs to be explicit about which of these benefits an intervention would address, and which sectors or groups in society the benefits would accrue to, rather than making general statements about impacts. This should also be reflected in programme monitoring and evaluation frameworks, with baselines and indicators that incorporate both socio-economic and river health or ecosystem service data.

Two closely related questions are '**what are the trade-offs'** and **'who are the winners and losers'?** As this paper illustrates, some trade-offs are inevitable and it is often the poor that lose out. The potential positive and negative impacts of different programme options on different stakeholder groups should be assessed and compensation mechanisms indentified where necessary. There are a range of tools available to aid this planning process, such as stakeholder mapping excersises, participatory scenario planning or political economy analysis. The inclusion of vulnerable groups, including women, will be particularly important to ensure equitable outcomes. Further thought is needed as to how trade-offs and unintended impacts might be monitored, which was beyond the scope of this review.

Consideration is also needed of how benefits are realised and over what scales – '**what factors, other than improved river health, determine whether people will benefit from the river, and can they be addressed by the programme'?** Developing theories of change that outline the causal pathways from the proposed conservation intervention to expected outcomes are useful to highlight areas of uncertainty and potential confounding factors where other forms of intervention may be needed. Analysis of the political economy context in which the programme is being implemented can help to identify who the powerful actors are and their priorities, the role that access and entitlements play in enabling different groups to benefit from the river, and implications for how benefits are distributed.

In light of these questions, WWF should carefully consider the kinds of partnerships needed to ensure desired outcomes are achieved. Where there are gaps in WWF expertise, external consultants can support planning and design, or evaluation processes. Strategic collaborations with other organisations, such as research institutes or NGOs, may also be needed where the issues identified fall beyond the remit of WWF programmes, for example social development interventions or research to address evidence gaps.

6.2.3 Directions for further research

With a view to informing WWF's monitoring and evaluation of river basin programmes, **it would be beneficial to conduct further critical analysis of indicators and methods that can be used to assess the benefits derived from rivers**. Ideally, monitoring of an intervention would occur at each stage of the causal chain, to determine the change in status of the river, impact of improved river health on ecosystem services, and the contribution of the latter to changes in various societal benefits, as well as the confounding factors and trade-offs at each stage. Few papers in our review explicitly discuss indicators or provided a critical reflection on methods. Whilst economic valuations can be useful, they are a distinct field and have a number of limitations.

The causal chains we have developed for agriculture, fisheries and hydropower are a novel aspect of the research, and have allowed us to explore the relationships between river health and specific benefits to society in more detail. We welcome the opportunity to develop our framework further by **exploring other causal chains of interest or analysing these concepts in case study sites**. The use of such tools allows us to identify and evaluate ecosystem services, benefits and trade-offs and are fundamental to the sustainable management of riverine ecosystems.

Finally, the literature identifies a number of evidence gaps, which presents avenues for future research. Whilst water resource managers talk of water security and risks, **there has been very little discussion in the ESS literature of disservices.** These could potentially be explored through frameworks such as ours. Furthermore, there is increased interest in conceptualising **the role of cross-scalar and temporal dynamics in river-society relationships**, including the impacts of river restoration efforts on ecosystem services provision, and benefits to different parts of society. These are exciting areas in which to develop new theories and build a stronger evidence base.

References

Acreman, M.C., Harding, R.J., Lloyd, C., McNamara, N.P., Mountford, J.O., Mould, D.J., Purse, B.V., Heard, M.S., Stratford, C.J. and Dury, S. (2011) 'Trade-off in ecosystem services of the Somerset Levels and Moors wetlands', *Hydrological Sciences Journal* 56 (8): 1543-1565

Acreman, M.C., Overton, I., King, J., Wood, P., Cowx, I., Dunbar, M.J., Kendy, E. and Young, W. (2014) 'The changing role of science in environmental flows', *Hydrological Sciences Journal* 59 (3-4): 433-450

Adekola, O., Mitchell, G. and Grainger, A. (2015) 'Inequality and ecosystem services: The value and social distribution of Niger Delta wetland services', *Ecosystem Services* 12: 42-54

Alabaster, J. and Lloyd, R. (1982) *Water quality criteria for freshwater fish*, Butterworths: London

Alhassan, H. (2009) 'Viewpoint - Butterflies vs. Hydropower: Reflections on large dams in contemporary Africa', *Water Alternatives* 2 (1): 148-160

Allison, E. and Ellis, F. (2001) 'The livelihoods approach and management of small-scale fisheries', *Marine Policy* 25 (5): 377-388

Ansar, A., Flyvbjerg, B., Budzier, A. and Lunn, D. (2014) 'Should we build more large dams? The actual costs of hydropower megaproject development', *Energy Policy* 69: 43-56

Auerbach, D.A., Deisenroth, D.B., McShane, R.R., McCluney, K.E. and Poff, N.L. (2014) 'Beyond concrete: accounting for ecosystem services from free-flowing rivers', *Ecosystem Services* 10: 1-5

Belhabib, D., Sumaila, U. and Pauly, D. (2015) 'Feeding the poor: contribution of West African fisheries to employment and food security', *Ocean and Coastal Management* 111: 72-81

Béné, C. (2003) 'When fishery rhymes with poverty: a first step beyond the old paradigm on poverty in small-scale fisheries', *World Development* 31(6):

Bergamini, N., Blasiak, R., Eyzaguirre, P., Ichikawa, K., Mijatovic, D., Nakao, F. and Subramanian, S.M. (2013) 'Indicators of Resilience in Socio-ecological Production Landscapes (SEPLs)', *UNU-IAS Policy Report*, United Nations University, Yokohama, Japan. Available from: http://archive.ias.unu.edu/resource_centre/Indicators-of-resilience-in-sepls_ev.pdf

Berrang-Ford, L., Pearce, T. and Ford., J.D. (2015) 'Systematic review approaches for climate change adaptation research', *Regional Environmental Change* 15 (5): 755-769

Bisht, T.C. 2009. Development-induced displacement and women: the case of the Tehri Dam, India', *Asia Pacific Journal of Anthropology* 10 (4): 301–317

Boyd, C. (2012) *Water quality: an introduction*, Springer Science and Business Media: New York

Boyd, J. and Banzhaf, S. (2007) 'What are ecosystem services? The need for standardized environmental accounting units', *Ecological Economics* 63 (2–3): 616–626

Brander, L. et al (2011) 'Using meta-analysis and GIS for value transfer and scaling up: Valuing climate change induced losses of European wetlands', *Environmental and Resource Economics* 52: 395-413

Brander, L., Florax, R. and Vermaat J. (2006) 'The empirics of wetland valuation: A comprehensive summary and meta-analysis of the literature', *Environmental and Resource Economics* 33: 223-250

Brouwer, R. and Hofkes, M. (2008) 'Integrated hydro-economic modelling: Approaches, key issues and future research directions', *Ecological Economics* 66: 16-22

Butler, R., Radford, A., Riddington, G. and Laughton, R. (2009) 'Evaluating an ecosystem service provided by Atlantic salmon, sea trout and other fish species in the River Spey, Scotland: The economic impact of recreational rod fisheries', *Fisheries Research* 96: 259-266

Carabine, L., Venton, C., Tanner, T. and Bahadur, A. (2015) 'The contribution of ecosystem services to human resilience, a rapid review', *ODI Working Paper*, ODI: London

Collins, A., Miler, J., Coughlin, D. and Kirk, S. (2014) *The Production of Quick Scoping Reviews and Rapid Evidence Assessments: A How to Guide*, Joint Water Evidence Group April 2014, Beta Version 2. Available from: https://connect.innovateuk.org/web/jweg

Conforit, P (ed) (2011) *Looking ahead in world food and agriculture: Perspectives to 2050*, FAO: Rome, available from: http://www.fao.org/docrep/014/i2280e/i2280e00.htm

Constanza et al. (2008) 'The value of coastal wetlands for hurricane protection', *Ambio* 37(4): 241-248

de Groot, R., Brander, L., can der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L., ten Brink, P., can Beukering, P., (2012) 'Global estimates of the value of ecosystems and their services in monetary units', *Ecosystem Services* 1: 50-61

Delgado, L., Sepulveda, M., Marin, V. (2013) 'Provision of ecosystem services by the Aysén watershed, Chilean Patagonia to rural households', *Ecosystem Services* 5: 102-109

Dercon, S. (2012) 'Is green growth good for the poor?' *Policy Research Working Paper 6231*, World Bank: Washington DC

De Stefano, L., Duncan, J., Dinar, S., Stahl, K., Strzepek, K.M., Wolf, A.T. (2012) 'Climate change and the institutional resilience of international river basins', *Journal of Peace Research* 49 (1): 193–209.

DFID (2013) 'Systematic Reviews in International Development', DFID Policy Paper, London: UK Department for International Development. Available from: https://www.gov.uk/government/publications/systematic-reviews-in-international-development/systematic-reviews-in-international-development

Domenech, L. and Ringler, C. (2013) 'The impact of irrigation on nutrition, health and gender: a review paper with insight for Africa south of the Sahara', *IFPRI Discussion Paper 01259*

Dunn, R.R. (2010) 'Global mapping of ecosystem disservices: the unspoken reality that nature sometimes kills us', *Biotropica* 42(5): 555–557

EEA (2010) 'Scaling up ecosystem benefits: A contribution to The Economics of Ecosystems and Biodiversity (TEEB) study', *EEA Report No 4/2010*, European Environment Agency: Copenhagen. ISSN 1725-9177

Ellis, F. and Ade Freeman, H. (2004) 'Rural livelihoods and poverty reduction strategies in four African countries', *Journal of Development Studies* 40 (4): 1-30

Emerton, L. and Bos, E. (2004) *Value: counting ecosystems as water infrastructure*, IUCN: Gland, Switzerland and Cambridge, UK. Available at: https://cmsdata.iucn.org/downloads/value_en.pdf

Emerton, L., Seilava, R. and H. Pearith (2002) 'Bokor, Kirirom, Kep and Ream National Parks, Cambodia: Case Studies of Economic and Development Linkages, Field Study Report' in: *Review of Protected*

Areas and their Role in the Socio-Economic Development of the Four Countries of the Lower Mekong Region, International Centre for Environmental Management, Brisbane and IUCN - The World Conservation Union Regional Environmental Economics Programme, Karachi

European Commission (2003) 'Rivers and Lakes – Typology, Reference Conditions and Classification Systems', *Guidance Document No. 10, Common Implementation Strategy for the Water Framework Directive (2000/60/EC),* Produced by Working Group 2.3 – REFCOND, Luxembourg: Office for Official Publications of the European Communities.

Feather, P., Hellerstein, D. and H. LeRoy (1999) 'Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP', *Agricultural Economic Report No. 778*, Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Washington DC

Finlayson, C.M. and D'Cruz, R. (2005) 'Inland water systems', Chapter 20 in *Ecosystems and Human Well-being: Current State and Trends*, Millenium Ecosystem Assessment, Island Press: Washington DC

Fisher, B., Turner, R. and Morling, P. (2009) 'Defining and classifying ecosystem services for decision making', *Ecological Economics* 68 (3): 643-653.

Fisher, J., Patenaude, G., Giri, K., Lewis, K., Meir, P., Pinho, P., Rounsevell, M. and Williams, M. (2014) 'Understanding the relationships between ecosystem services and poverty alleviation: a conceptual framework', *Ecosystem Services* 7: 34-35

Ghermandi et al. (2010) 'Values of natural and human-made wetlands: A meta-analysis', *Water Resources Research* 46: 1-12

Gilvear, D.J., Spray, C.J. and Casas-Mulet, R. (2013) 'River rehabilitation for the delivery of multiple ecosystem services at the river netowrk scale', *Journal of environmental management* 126: 30-43

Gowan, C., Stepheson, K. and Shabman L. (2005) 'The role of ecosystem valuation in environmental decision making: Hydropower relicensing and dam removal on the Elwha River', *Ecological Economics* 56: 508-523

Greenhalgh, T. and Peacock, A. (2005) 'Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources', *British Medical Journal* 331: 1064-5

Gren, I. (1995) 'The value of investing in wetlands for nitrogen abatement', *European Review of Agricultural Economics* 22: 157-172

Grey, D. and Sadoff, C. (2007) 'Sink or swim: Water security for growth and development', *Water Policy* 9: 545-571

Hagen-Zanker, J. and Mallet, R. (2013) 'How to do a rigorous, evidence focused literature review in international development', *ODI Guidance Note*, ODI: London

Hallegatte, S., Shah, A., Lempert, R., Brown, C. and Gill, S. (2012) 'Investment decision making under deep uncertainty', *Policy research working paper 6193*, World Bank: Washington DC

Hatfield-Dodds, S. (2006) 'Water strategies for sustainable development: What is required to ensure 'responsible growth'?', Discussion Paper - A response to the 'Water for Growth and Development' theme document from the 4th World Water Forum, CSIRO and Steve Hatfield-Dodds. Available from: http://www.sea-user.org/download_pubdoc.php?doc=3332

Hill, B., Kolka, R., McCormick, F. and Starry, M. (2013) 'A synoptic survey of ecosystem services from headwater catchments in the United States', *Ecosystem Services* 7: 106-115

HLPE (2014) 'Sustainable fisheries and aquaculture for food security and nutrition', *HLPE Report 7*, High Level Panel of Experts on Food Security and Nutrition (HLPE), Committee on World Food Security, FAO: Rome

HLPE (2015) 'Water for food security and nutrition', *HLPE Report 9*, High Level Panel of Experts on Food Security and Nutrition (HLPE), Committee on World Food Security, FAO: Rome

Hoeinhaus, D. et al (2009) 'Effects of river impoundment on ecosystem services of large tropical rivers: Embodied energy and market value of artisanal fisheries', *Conservation Biology* 23 (5): 1222-1231

Hogarth, R. and Granoff, I. (2015) 'Speaking truth to power: why energy distribution, more than generation, is Africa's poverty challenge', *ODI Working Paper 418*, Overseas Development Insitute, London, and Oxfam, Oxford. Available from: http://policy-practice.oxfamamerica.org/static/media/files/FINAL_speakingpowertotruth_SH.pdf

Hurford, A. and Harou, J. (2014) 'Balancing ecosystem services with energy and food security - Assessing trade-offs from reservoir operation and irrigation investments in Kenya's Tana Basin', *Hydrological Earth Systems Sciences* 19: 3259-3277

Hussain, I. and Hanjra, M. A. (2003) 'Does irrigation water matter for rural poverty alleviation? Evidence from South and South-East Asia', *Water policy* 5(5): 429-442

IFPRI (2015) Global Hunger Index, accessed 08/10/15. https://www.ifpri.org/topic/global-hunger-index

Iftikhar, U. (2002) 'Valuing the economic costs of environmental degradation due to sea intrusion in the Indus Delta', in IUCN *Sea Intrusion in the Coastal and Riverine Tracts of the Indus Delta - A Case Study*, IUCN - The World Conservation Union Pakistan Country Office, Karachi

IAEA (2015) *Energy indicators for sustainable development: guidelines and methodologies*, Vienna: International Atomic Energy Agency. Avaiable at: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1222_web.pdf

IEA (2010) *Renewable Energy Essentials: Hydropower*, International Energy Agency, OECD/IEA. Available at: http://www.iea.org/publications/freepublications/publication/hydropower_essentials.pdf

IHA (2010) *Hydropower Sustainability Assessment Protocol*, International Hydropower Association: London

International Rivers (2007) 'Hydrological effects of dams', Excerpted from McCully, P., *Silenced Rivers: The Ecology and Politics of Large Dams*. Accessed on 01/07/15. Available at: http://www.internationalrivers.org/hydrological-effects-of-dams

Jacobson, M. (2009) 'Review of solutions to global warming, air pollution and energy security', *Energy Environmental Science* 2: 148-173

Kawarazuka, N. and Béné, C. (2011) 'The potential role of small fish species in improving micro-nutrient deficiencies in developing countries: building evidence', *Public Health Nutrition* 14(11): 1927-1938

Komakech, H.C., van der Zaag, P. and van Koppen, B. (2012) 'The Last Will Be First: Water Transfers from Agriculture to Cities in the Pangani River Basin, Tanzania', *Water Alternatives* 5(3): 700-720

Korsgaard, L. and Schou, J. (2010) 'Economic valuation of aquatic ecosystems in developing countries', *Water Policy* 12: 20-31

Krchnak, K., Richter, B. and Thomas, G. (2009) 'Integrating environmental flows and hydropower dam planning, design and operations', *Water Working Notes 51004, Note No. 22*, World Bank: Washington

Lankford, B. ‘Irrigation, livelihoods and river basins’, in Ellis, F. and Freeman, H. (2005) *Rural livelihoods and poverty reduction policies*, Routledge studies in development economics, Routledge, London and New York. pp. 274-293

Lebel, L., Daniel, R., Badenoch, N., Garden, P. and Imamura, M. (2008) 'A multi-level perspective on conserving with communities: Experience from upper tributary watersheds in montane mainland Southeast Asia', *International Journal of the Commons* 2 (1): 127-154

Lewis, L., Bohlen, C. and Wilson, S. (2008) 'Dams, dam removal and river restoration: A hedonic property value analysis', *Contemporary Economic Policy:* 26 (2): 175-186

Magilligan, F. and Nislow, K. (2005) ‘Changes in hydrologic regimes by dams’, *Geomorphology* 71 (1-2): 65-78

Martin, S., Lorenzen, K. and Bunnefield, N. (2013) ‘Fishing farmers: fishing, livelihood diversification and poverty in rural Laos’, *Human Ecology* 41(5): 737-747

Mason, N. and Calow, R. (2012) ‘Water security: from abstract concept to meaningful metrics - An initial overview of options’, *ODI Working Paper 357*, Overseas Development Institute: London

Matthews, N. and Geheb, K. (2015) ‘Hydropower development in the Mekong region. Political, socio-economic and environmental perspectives’, Oxford: Routledge

MEA (2005) 'MEA conceptual framework’, Chapter 1 in *Ecosystems and Human Well-being: Current State and Trends*, Millenium Ecosystem Assessment, Island Press: Washington DC

Mearns, R. (1996) ‘Environmental entitlements: pastoral natural resource management in Mongolia’, *Cahiers des Sciences Humaines* 32: 105-132

Mehta, L. (2009) ‘Liquid dynamics: rethinking sustainability in water and sanitation’, *IHDP Update 2*. Available at: https://www.ehs.unu.edu/file/get/7698

Men, P., Thun, V., Yin, S. and Lebel L. (2014) 'Benefit sharing from Kamchay and Lower Sesan 2 hydropower watersheds in Cambodia', *Water Resources and Rural Development* 4: 40-53

Naiman, R. and Dudgeon D. (2011) 'Global alteration of freshwaters: influences on human and environmental well-being', *Ecological Resources* 26: 865-873

NEPAD (2010) *CAADP Review: renewing the commitment to African agriculture, Final Report, March 2010*, New Partnership for African Development (NEPAD) Planning and Coordinating Agency, African Union. Available at: http://www.nepad.org/system/files/CAADP%20Review%20-%20March%2020101.pdf

Newborne, P. and Welham, B. (2014) 'Joining the grid, sustainable energy in Brasil', *ODI Development Progress Case Study Report*, Overseas Development Institute: London. Available at http://www.developmentprogress.org/sites/developmentprogress.org/files/case-study-report/brazil_full_report_-_final_small.pdf

Newborne, P. (2014) ‘Advancing hydropower sustainability, from project design to sector planning’, *ODI Development Progress Discussion Paper 2*, Overseas Development Institute: London. Available from: http://www.developmentprogress.org/sites/developmentprogress.org/files/case-study-report/brazil_discussion_paper_-_final_small.pdf

Nilsson, C. and Berggren, K. (2000) ‘Alterations of riparian ecosystems caused by river regulation’, *Bioscience* 50 (9): 783-792

Nilsson, C., Reidy, C., Dynesius, M. and Revenga, C. (2005) ‘Fragmentation and flow regulation of the world’s large river systems’, *Science* 308 (5720): 405-408

Oates, N., Jobbins, G., Mosello, B. and Arnold, J. (2015) ‘Pathways for irrigation development in Africa – Insights from Ethiopia, Morocco and Mozambique’, *Future Agricultures Working Paper 119*, Future Agricultures, IDS, Brighton. Available at: http://www.future-agricultures.org/publications/research-and-analysis/working-papers/1956-pathways-for-irrigation-development-in-africa-insights-from-ethiopia-morocco-and-mozambique

Pahl-Wostl, C., Palmer, M. and Richards, K. (2013) ‘Enhancing water security for the benefits of humans and nature — the role of governance’, *Current Opinion in Environmental Sustainability 5*: 676–684

Poff, N.L. and Zimmerman, J.K.H. (2010) Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows, *Freshwater Biology* 55:p194–205

Poff, N.L-R., Brown, C.N., Grantham, T.E., Matthews, J.H., Palmer, M.A., Spence, C.M., Wilby, R.L., Haasnoot, M., Mendoza, G.F., Dominique, K.C. and Baeza, A. (2015) ‘Sustainable water management under future uncertainty with eco-engineering decision scaling’, *Nature Climate Change* 6: 25–34

Provencher, B., Sarakinos, H., Meyer, T. (2008) 'Does small dam removal affect local property values? An empirical analysis', *Contemporary Economic Policy* 26 (2): 187-197

Radford, A., Riddington, G. and Anderson, J. (2004) ‘The economic impact of game and coarse angling in Scotland’, *Research Report*, Environment and Rural Affairs Department, Scottish Executive, Edinburgh. Available at: http://www.gov.scot/Publications/2004/03/19079/34371

Ramsar Convention Secretariat (2010) *Wise use of wetlands: Concepts and approaches for the wise use of wetlands*. Ramsar handbooks for the wise use of wetlands, 4th edition, vol. 1. Ramsar Convention Secretariat, Gland, Switzerland.

Rasul, G. (2015) 'Water for growth and development in the Ganges, Brahmaputra, and Meghna basins: an economic perspective', *International Journal of River Basin Management* 13 (3): 387-400

River Health Programme (2011) *State of Rivers Report: Rivers of the Breede management area*, Department of Water Affairs, Western Cape, Republic of South Africa. Available from: https://www.dwa.gov.za/iwqs/rhp/state_of_rivers/WCape/Breede2011.pdf

Roebeling, P., Alves, H., Rocha, J., Brito, A., Almeida, P and Mamede, J. (2014) 'Gains from transboundary water quality management in linked catchment and coastal socio-ecological systems: A case study for the Minho region', *Water Resources and Economics* 8: 32-42

Rosegrant, M. W., Ringler, C. and Zhu, T. (2009) ‘Water for Agriculture: Maintaining Food Security under Growing Scarcity’, *Annual Review of Environment and Resources* 34: 205–223

Sadoff, C. and Grey, D. (2005) 'Cooperation on international rivers', *International Water Resources Association* 30 (4): 1-8

Sadoff, C., Hall, J., Grey, D., Aerts, J.C, Ait-Kadi, M., Brown, C., Cox, A., Dadson, S., Garrick, D., Kelman, J., McCornick, P., Ringler, C., Rosegrant, M., Whittington, D. and Wiberg, D. (2015) *Securing Water, Sustaining Growth: Report of the GWP/OECD Task Force on Water Security and Sustainable Growth*, University of Oxford, UK

Schipper, E.L.F. and Langstone, L. (2015) ‘A comparative overview of resilience measurement frameworks: analysing indicators and approaches’, *ODI Working Paper 422*, London: Overseas Development Institute. Available from: http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9754.pdf

Scholes, R., Briggs, R., Palm, C. and Duraiappah, A. (2010) ‘Assessing state and trends in ecosystem services and human well-being’, in: Ash, N. et al. (eds) *Ecosystems and human well-being: a manual for assessment practitioners*, Island Press: Washington

Scoones, I. (1998) ‘Sustainable livelihoods: a framework for analysis’, *IDS Working Paper 72*, Institute of Development Studies, Brighton. Available at: https://www.staff.ncl.ac.uk/david.harvey/AEF806/Sconnes1998.pdf

Shyllon, F (2007) ‘Argungu fishing festival in Northwestern Nigeria: Promoting the idea of a sustainable cultural fest’, *International Journal of Cultural Property*: 14 (3): 329-337

Skinner, J. and Haas, L. (2014) ‘Watered Down? A review of social and environmental safeguards for large dam projects’, *Natural Resource Issues No. 28*, International Institute for Environment and Development, London. Available at: http://pubs.iied.org/17517IIED.html

Smith, L. (2004) ‘Assessment of the contribution of irrigation to poverty reduction and sustainable livelihoods’, *International Journal of Water Resources Development* 20 (2): 243-257

Smith, L., Khoa, S. and Lorenzen K. (2005) ‘Livelihood functions of inland fisheries: policy implications in developing countries’, *Water Policy* 7 (4): 359-383

Speed, R., Li, Y., Tickner, D., Huang, H., Lei, G., Yu, L., Wei, Y., Zhao, Z., Sayers, P. and Naiman, B. (in press) *River Restoration: A strategic approach to planning and management*, Paris: UNESCO

Speed, R., Gippel, C., Bond, N., Bunn, S., Qu, X., Zhang, Y., Liu, W. and Jiang, X. (2012) *Assessing river health and environmental flow requirements in Chinese rivers*, Brisbane: International WaterCentre. Available at: http://watercentre.org/portfolio/rhef/attachments/technical-reports/assessment-of-river-health-and-eflow-requirements-in-chinese-rivers

Sun, X., Xiong, S., Zhu, X., Zhu, X., Li, Y. and Li, L. (2015) 'A new indices system for evaluation ecological-economic-social performances of wetland restorations and its application to Taihu Lake Basin, China', *Ecological Modelling* 295: 216-226

TEEB (2010) *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesisof the approach, conclusions and recommendations of TEEB.* The Economics of Ecosystems and Biodiversity (TEEB). Available from: http://www.teebweb.org/publication/mainstreaming-the-economics-of-nature-a-synthesis-of-the-approach-conclusions-and-recommendations-of-teeb

TEEB (2013) *The economics of ecosystems and biodiversity (TEEB) for water and wetlands*, TEEB report. IEEP, London and Brussels; Ramsar Secretariat, Gland.

Tickner, D. and Acreman, M. 'Water security for ecosystems, ecosystems for water security', in Lankford, B., Bakker, K., Zeitoun, M. and Conway, D. (eds) (2013) *Water security: principles, perspectives and practices*, Routledge: Oxford

Tomich, P.T., Argumedo, A., Baste, I., Camac, E., Filer, C., Garcia, K., Garbach, K., Geist, H., Izac, A-M., Lebel, L., Lee, M., Nishi, M., Olsson, L., Raudsepp-Hearne, C., Rawlins, M., Scholes, R. and van Noordwijk, M. (2005) ‘Conceptual frameworks for ecosystem assessment: their development, ownership and use’, in: Ash, N., Blanco, H., Brown, C., Garcia, K., Henrichs, T., Lucas, N., Raudsepp-Hearne, C., Simpson, R.D., Scholes, R., Tomich, T., Vira, B. and Zurek, M. *Ecosystems and human well-being: a manual for assessment practitioners*, Island Press: Washington DC

Udong, E., Niehof, A. and van Tilburg, A. (2010) ‘The livelihood strategies of women fish traders in adapting to cultural and institutional constraints in Ibaka, Nigeria,’ *Mast* 9 (2): 65-93. Available at: http://www.marecentre.nl/mast/documents/Mast2010_9.2_Udong_Niehof_Tilburg.pdf

Tucker, J., Daoud, M., Oates, N., Few, R., Conway, D., Mtisi, S. and Matheson, S. (2014) ‘Social vulnerability in high poverty climate change hotspots: a review of the state of knowledge’, *Regional Environmental Change* 15 (5): 783-800.

UK Environmental Agency (2012) 'Method statement for the classification of surface water bodies v3', *Water Framework Directive Monitoring Strategy Jan 2013*, UK Environmental Agency. Available at:https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/290506/LIT_5769_ ed4e2b.pdf

van Beek, E. and Arriens, W. (2014) 'Water security: putting the concept into practice', *GWP TEC Background Papers No. 20*, Global Water Partnership Technical Committee (TEC), Stockholm.

Van Houtven, G., Powers, J. and Pattanayak, S. (2007) 'Valuing Water Quality improvements in the United States using meta-analysis: Is the glass half full or half empty for national policy analysis', *Resource and Energy Economics* 29: 206-228

Vörösmarty, C.J., Lévêque, C. and Ravenga, C. (2005) 'Freshwater', Chapter 7 in *Ecosystems and Human Well-being: Current State and Trends*, Millenium Ecosystem Assessment, Island Press: Washington DC

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, G., Glidden, S., Bunn, S.E., Sullivan, C.A., Reidy Liermann, C. and Davies, P.M.. (2010) 'Global threats to human water security and river biodiversity', *Nature* 467: 555-561.

WBCSD (2015) Global Water Tool, website. Accessed 30/09/2015. http://www.wbcsd.org/work-program/sector-projects/water/global-water-tool.aspxv

Whittington, D., Sadoff, C. and Allaire, M. (2013) 'The economic value of moving towards a more water secure world', *GWP TEC Background Papers No. 18*, Global Water Partnership Technical Committee (TEC), Stockholm.

Wong, C., Williams, C., Pittock, J., Collier, U., Schelle, P. (2007) *World's top 10 rivers at risk*, WWF International: Gland, Switzerland. Available from: http://assets.wwf.org.uk/downloads/worldstop10riversatrisk.pdf?_ga=1.4734580.635295424.1423839358

World Bank (2006) *Shaping the future of water for agriculture: a sourcebook for investment in agricultural water management*, World Bank: Washington DC

World Commission on Dams (2000) *Dams and development: a new framework for decision-making, The report of the World Commission on dams*, World Commission on Dams, Earthscan Publications Ltd: London

WWAP (2012) 'Managing Water under Uncertainty and Risk', *World Water Development Report 4*, World Water Assessment Programme, UNESCO: Paris

Zeitoun, M., Goulden, M. and Tickner, D. (2013) 'Current and future challenges facing transboundary river basin management', *WIREs Climate Change* 4 (5): 331-349

Zhang, Y., Zhou, D., Niu, Z., Xu, F. (2014) 'Valuation of lake and marsh wetlands ecosystem services in China', *China Geographical Sciences* 24 (3): 269-278

Annex 1 – Keystone literature

No.	Citation	Reasons for inclusion
1	Emerton, L. and Bos, E. (2004) *Value: counting ecosystems as water infrastructure*, IUCN: Gland, Switzerland & Cambridge, UK.	Synthesis of economic evaluation techniques as applicable to water-related ESS; synthesis of ESS literature up to 2004.
2	MEA (2005) Current State and Trends Assessment: Ch7 freshwater & Ch20 inland water systems (Finlayson and D'Cruz, 2005)	Landmark publication, underpinned by extensive reviews of the literature; captures thinking on ESS up to 2005.
3	TEEB (2013) The economics of ecosystems and biodiversity (TEEB) for water and wetlands, TEEB report. IEEP, London and Brussels; Ramsar Secretariat, Gland.	TEEB is an important ESS assessment initiative; this paper focused on water-related services specifically.
4	de Groot et al. (2012) 'Global estimates of the value of ecosystems and their services in monetary units', *Ecosystem Services* 1:50-61	Meta-analysis with a substantial component on water.
5	Auerbach et al (2014) 'Beyond the concrete: Accounting for ecosystem services from free-flowing rivers', *Ecosystem Services* 10: 1-5	Discussion of trade-offs of water infrastructure in relation to different river system benefits.
6	EEA (2010) 'Scaling up ecosystem benefits: A contribution to The Economics of Ecosystems and Biodiversity (TEEB) study', EEA Report No 4/2010, European Environment Agency: Copenhagen.	Contains numerous references to water and related ESS and a chapter on wetlands.
7	Grey, D. and Sadoff, C. (2007) 'Sink or swim: Water security for growth and development', *Water Policy* 9: 545-571.	Widely cited and influential paper on water resources management.
8	Mason, N. and Calow, R. (2012) 'Water security: from abstract concept to meaningful metrics - An initial overview of options', *ODI Working Paper 357*, Overseas Development Institute: London.	A useful non-ESS paper on indicators, or metrics, which also discusses some of the problems associated with measurement.
9	Pahl-Wostl, C., Palmer, M. and Richards, K. (2013) 'Enhancing water security for the benefits of humans and nature — the role of governance', *Current Opinion in Environmental Sustainability* 5: 676–684.	A key author on governance of water resources.
10	HLPE (2015) 'Water for food security and nutrition', *HLPE Report 9*, High Level Panel of Experts on Food Security and Nutrition (HLPE), Committee on World Food Security, FAO: Rome	A major recent report which explicitly discusses the relationship between water ecosystems and one of the key societal benefits they provide, i.e. food security and nutrition.

Annex 2 – Inclusion and exclusion criteria

	Inclusion criteria	Exclusion criteria
Relevance - theme	The title or abstract explicitly refer to one of the following: river, riverine, basin, delta, wetland, freshwater, lake, reservoir, watershed And one of: ecosystem service, benefit, value, valuation, trade-off, opportunity cost, green/natural infrastructure, natural capital, poverty, economic growth, risk (to the economy or people), well-being The paper has a substantive focus on societal (social, economic, strategic) benefits from rivers	Sources with no explicit mention of these (or closely related) terms Sources which give only partial or underdeveloped focus to societal benefits from healthy rivers
Scale	Rivers, river basins, sub-basins and related freshwater ecosystems at the larger scale	Micro-level studies will be excluded
Geopolitical region	Global (any region, country or river basin)	n/a
Quality	The document is a research output, either in the peer reviewed literature or (for grey literature) published by a reputable source Include: journal articles, working papers, conference papers, reports from reputable organisations, book chapters (if available)	Non-research documents e.g. policy documents, position pieces Research reports which are not peer-reviewed or published by a reputable source (i.e. qaulity unknown)
Date	Documents should be published after 2004 i.e. after key IUCN and MEA publications	Documents published before 2004 will be excluded, unless considered a seminal work, or providing information on a specific topic not covered elsewhere
Representation/ saturation	Borderline documents will be included if they address a geographical area, type of benefit, or methodology which is not yet well represented in the literature identified Where the same research is documented multiple times (e.g. an original research paper, later summarised in a review), the most recent article will be prioritised to restrict the review to a manageable number of articles and ensure breadth of coverage	Borderline documents will be excluded if they address a geographical area, type of benefit, or methodology which is already covered in the literature identified Where the same research is documented multiple times, older articles will be excluded
Language	English	Documents published in any language other than English

Annex 3 – Evidence map

An Excel spreadsheet containing a ‘map’ of the literature included and analysed in the review is downloadable as a separate file.

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