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JEL classification: Q21, Q25, Q56

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1. Introduction

National accounting is a system for gathering, organising and presenting key information about economic activity. Such accounts have been developed over a period of 80 years and are of proven usefulness. Economic policy making – fiscal policy as well as monetary policy – relies on these accounts as a systematic set of information about the state of the economy.

A key feature of the national accounts is that they represent integrated stock-flow accounts. That is, they include:

i) accounts providing information about the flows of goods and services produced by the economy and used either for consumption or for investment in capital designed to maintain, replace or augment the future production of goods and services; ii) accounts relating to the stock of produced and financial assets. Such accounts are fully consistent with the flow accounts because they use the same investment flow information to reflect new additions to the stock of capital, offsetting estimated depreciation as the corresponding outflow from the capital stock.

Both the flow and stock accounts are important for well-based economic policy and other decision making. They are all based on a specific concept of value and to establish this it is necessary to know both the quantities of goods and services at each stage of their production and the price that should be attached to those quantities. In traditional national accounts, most prices can be observed as a market price. A sizeable minority, over a quarter by value[1], have no such market and an implicit price has to be imputed by other means.

As useful as the national accounts are, it is a commonplace that they have limitations. In particular, some of the key items that people desire and value, are invisible in the traditional national accounts[2]. One such major omission is the value people and economies gain from assets provided by nature. Experimental supply and use tables for natural capital accounts in the UK estimates "the direct gross value added of nature to the UK economy in 2020 to be £51 billion; this is larger than the equivalent estimate for the construction of buildings, telecommunications, or insurance services industries" (ONS, UK, 2023). At the same time, exploitation of natural capital leads significant risks to society and economy, especially for agricultural and manufacturing sectors (Alvarez et al., 2024).

It therefore seems a possibly useful step to extend the traditional national accounts to embrace the depletion of natural resources as an additional production value stemming from natural assets (UN, 2025). This paper addresses some of the issues involved working towards such an extension, specifically in the context of the valuable services provided by freshwater ecosystems[3].

[1] For example, those relating to public services free or nearly free or the price to be attached to owner-occupied housing.

[2] A classic statement of the issue was provided by Robert Kennedy in 1968: "Yet the gross national product does not allow for the health of our children, the quality of their education or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country, it measures everything in short, except that which makes life worthwhile." *Speech at the University of Kansas, March 1968.*

[3] Fresh water is obviously only one of a multiplicity of natural assets providing services to humanity. But it seems a good place to start. First, water is crucially important as an asset, indeed ultimately essential to life itself. Second, many of the problems implicit in extending national accounts to include services from water are the same as those involved in including other natural assets. So, lessons learnt in the context of water may, to an extent, be useful in these other areas.

Moreover, it seems a particularly opportune time to undertake such an endeavour. Part of the strength and credibility of traditional national accounting lies in the fact that countries generally compile their accounts within internationally agreed guidelines. At global level, these are provided by the United Nations System of National Accounts (SNA). This facilitates comparability of the national accounts of different countries. But it also guards against suspicions that accounts are being manipulated in the light of political interests in particular countries. These same advantages can now be obtained for natural capital by the advent of similar UN guidelines relating to compiling natural capital accounts. The United Nations System of Environmental-Economic Accounts – Central Framework (UN SEEA-CF), dating from 2012 – has been joined by the United Nations System of Environmental-Economic Accounts – Ecosystem Services (UN SEEA EA) promulgated in 2021. The SEEA EA represents nowadays the main framework for ecosystem accounting, with 90 countries compiling SEEA EA compliant accounts by 2023 (UN Statistical Commission, 2024) and others following its principles (e.g., U.S. Office of Science and Technology Policy et al., 2023). These developments highlight the growing need for alignment with international accounting standards. In this context, the UK, along with other countries, faces the challenge of identifying appropriate valuation methods for Water Ecosystem Services (WES) that comply with UN guidelines as further detailed in Ekins et al. (2025). This represents a critical step for consistently integrating natural capital into national accounts.

The paper aims to explore the suitability of economic valuation techniques for the main macro categories of WES, including provisioning, regulation and cultural services, as well as their effectiveness in capturing and integrating these values within the accounting and management of UK water system. Section 2 provides an overview of the steps necessary to develop water ecosystem services (WES) accounts as well as of the main challenges of doing so. A detailed discussion on valuation methods proposed by the SEEA EA follows (Sections 2.1, 2.2 and 2.3). The aim is not only to provide a complete list of such methods, but also to critically assess their applicability, especially in the context of water ecosystem services.

2. Developing accounts for Water Ecosystem Services (WES)

The SEEA guidelines referenced above have been carefully designed to enable full articulation of natural capital accounts that conform with the traditional national accounts compiled under the SNA. To exploit the opportunities fully, the extended accounts need to be compiled at both stock and flow levels. This articulation will enable that:

- movements in the valuation of the stock of natural assets, such as water, provide essential information about the sustainability of these natural assets, in just the same way that the national accounts give information about the stock of produced capital and thus its ability to support continuing economic production and consumption
- the flow of services from natural assets gives information about how productively those natural assets are being used to provide services that benefit humanity. Such services are additional (and frequently complementary) to the services covered by the traditional national accounts and should be considered together. But there is no presumption that the two sets of services change in the same way.

Water resources originate from the various natural processes and sources within the Earth's hydrological cycle and provide essential goods (e.g., drinking water, irrigation water) and services (e.g., hydroelectricity generation, transport). WES can be classified as

- Provisioning services, which refer to use of freshwater and groundwater, aquatic resources or hydro services in providing inputs into the production of goods and services that are themselves valued
- Regulating services, represented for example by water purification, flood and erosion control and climate regulation
- Cultural services, which include recreational and tourist opportunities, as well as amenity, spiritual and aesthetic values

In practice, making progress in compiling extended accounts covering such services involves at least two steps.

The first one is to delineate the significant services that water provides and thence the accounts that need to be created. In this context, avoiding double counting is particularly important. Some water-related services - particularly provisioning services, though fewer, if any, regulating or cultural services – are already included in the national accounts. Extension of the national accounts that duplicated recognition of such series would obviously be wrong. Ensuring that this does not happen is important, so accounting needs to be conducted with care. However, there are no great conceptual issues involved in this.

A second and more significant challenge arises in valuing the ecosystem services that water provides. Value is the product of the physical quantity of such services - for example, the number of gallons of water supplied for commercial or domestic purposes or the number of miles travelled to enjoy waterways - multiplied by the price of a unit of the good or service. The SEEA-EA insists that the basic principle should be valuation at exchange values, the price that would be paid freely in a market if such a market existed. Exchange values differ from wider definitions of value, such as, for example, might be relevant to appraisal and cost-benefit analysis because they exclude any degree of consumer surplus or other considerations that might be proper to include in economic appraisal. The great advantage of using an exchange value principle is that it allows compilation of Environmental Accounts which can articulate fully and consistently with national accounts, which are also compiled on this basis. We, therefore, adhere to this basis for our valuation. Vardon et al. (2023) recognize that observing the exchange price for water is complicated since the market price paid for services provided by water is either not directly observable or is a concessional price (2008 SNA, para 3.131-3.134), which does not reflect the value of the service. In this case, other methodologies need to be employed to impute a price for each such service.

Ecosystem services are not unique in lacking a market from which a price can be established. As noted earlier, much of the national accounts must be compiled including services for which no market exists. This applies to over a quarter of the goods and services comprised within gross domestic product. Nevertheless, in compiling extended accounts covering water services, it remains a fundamental issue. The SEEA EA provides a catalogue of possible methodologies for addressing this issue, as well as an order of preference between them. However, the catalogue provided by SEEA EA is at a general level, and it needs to be used as a basis for building specific methodologies suitable for imputing a price for each ecosystem service covered. Such methodologies can be used, of course, only if there are data that enable their application. Furthermore, the SEEA EA chapters on economic valuation of ecosystems (chapters 8 and 9) are not yet recognized as standards and future revisions are likely to be happening as a result of forthcoming empirical applications. This paper aims to investigate the economic techniques applicable to value some representative WES in the UK and to widely reflect on the challenges and opportunities of economically assessing ecosystems and their services.

The paper starts examining this issue in more detail by examining the economic valuation methods available in the environmental economics literature and assessing their compatibility with those recommended by the SEEA EA for valuing ES. It then provides a detailed overview of possible valuation methods for WES, examines their application in the literature and makes some considerations on their feasibility and effectiveness in capturing ES exchange values. Finally, the discussion is framed within the UK context, considering the development of water accounts (of which this paper form's a part) in alignment with the SEEA EA guidelines.

2.1. Economic valuation methods

The environmental economics literature offers a wide range of well-established and tested valuation methods for market and non-market goods and services, which can, in principle, be used in accounting. The potential use of such methods for accounting purposes has been already investigated by the literature. Atkinson and Obst (2017) investigate the potential of environmental economics to be applied in national accounting, highlighting the importance of institutional context in evaluating ES. More recent studies (e.g., Fenichel et al., 2024) further support the use of nonmarket valuation methods in ecosystem accounting. Markandya et al. (2022) discuss at length the distinction between valuation methods for ex-ante assessment such as cost-benefit analysis and methods for ecosystem accounting which are instead (ex-post assessments. Chapters 8 and 9 of SEEA EA (2021) set out the principles and methods for ecosystem accounting, providing a hierarchy of tools as shown in Figure 1.

In chapter 8, the SEEA EA recalls the principle for accounting and reports that in SNA two primary alternative methods exist: market prices of similar goods, and replacement costs. However, these principles are not applied to ecosystem services in chapter 9, "Accounting for ecosystem services in monetary terms", since in this chapter the replacement costs method is listed among the least desirable methods. It is therefore essential to reflect on the alternative economic methods available for WES.

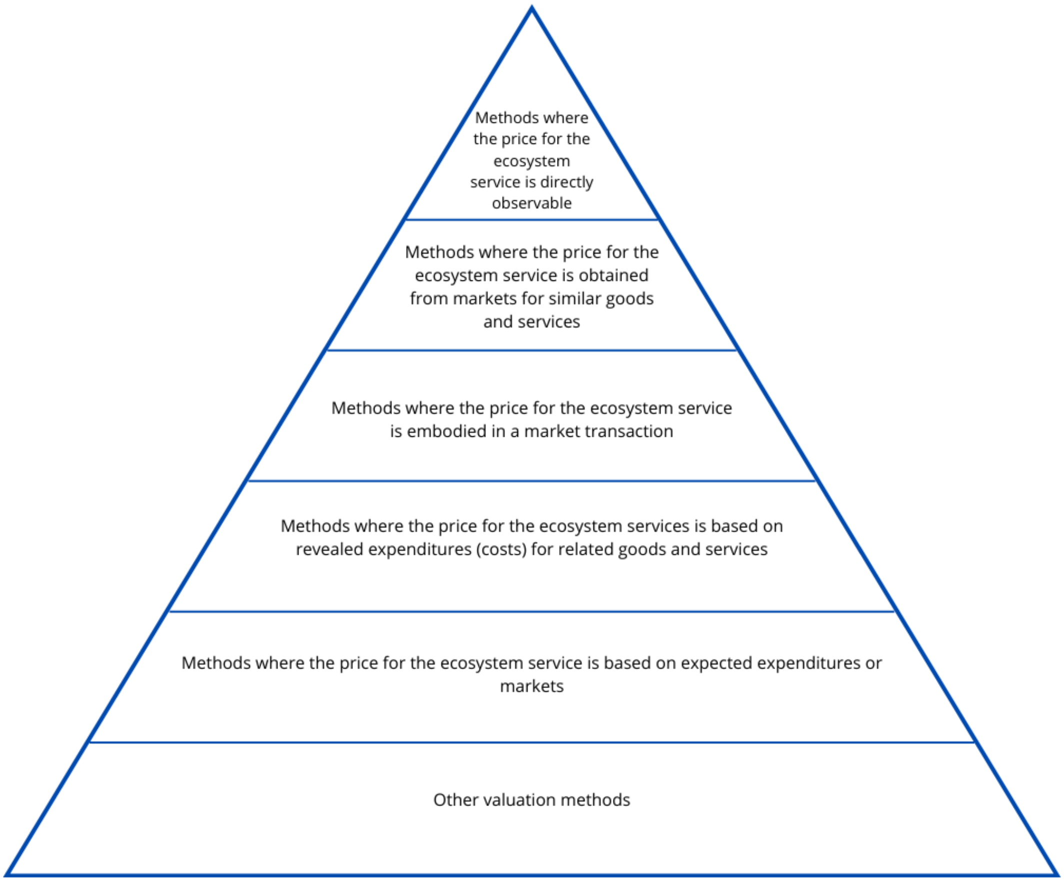

Figure 1. Hierarchy of economic valuation approaches for ecosystem accounting. Source: UN et al., 2021

Price directly observable in the market and price derived from similar markets represent the gold standards, although it appears rare that we can apply them in practice, especially for water.

Considering prices directly observable in the market, Vardon et al (2023) highlight a long list of water characteristics which reduce the possibility observing a price that represent a "true exchange price" (Vardon et al 2023, p. 13). Markandya et al. (2022) report an example where they see the possibility to observe the price in the market. They report the example of the owner of a wetland who can charge water companies for the water purification services provided by the wetland, but it seems highly unrealistic that water companies will pay a separate price for the water purification. It is likely that water companies will pay a price for their abstraction rights which will also include an unobservable price for the service. Similarly, Vardon et al. (2023) report that in Colombia there are water fees used to fund improvements of environmental conditions and water quality. Presumably, also in this case the value of water needs to be singled out. Applications that claim to apply a direct and observable price in water accounting are Bekri et al. (2024), Keith et al. (2017), Ouyang et al. (2020), and Rismawati (2024). Even though these studies rely on market prices (e.g., financial costs or water tariffs) retrieved from national accounts, they estimate a value which does not represent the ecosystem contribution. In these studies, the economic value of WES incorporates other inputs such as manmade and human labour costs leading to the risk of double counting. As repeatedly emphasized in the SEEA EA framework, the primary objective of ecosystem service (ES) accounts is to isolate the value generated by ecosystems themselves. Therefore, it seems unlikely that directly observable prices for WES will be found in markets.

At the same time, if Payment for Ecosystem Services (PES) come to be designed and traded for specific WES, it may be that a direct market price might become available. Although PES are not yet being used for accounting purposes, they comprise voluntary transactions from buyers and sellers who are prepared to trade ES under the condition that the service is continuously provided. This method is focused on two principles: conditionality (ongoing service provision) and additionality (rewarding actions that wouldn't otherwise occur). PES have been particularly effective in watershed projects and water funds, which leverage public-private partnerships to reduce costs and promote long-term conservation (Fu et al., 2018; Goldman-Benner et al., 2012), and these transactions can be used to identify and account for WES. An application of PES proposed for valuing the water provisioning service is provided by Fu et al. (2018). However, Markandya et al. (2022) and SEEA EA (2021) discourage the use of PES for ecosystem accounting, as they are designed to support the implementation of broad ecosystem restoration interventions or similar policies rather than reveal prices for specific services.

Similarly, obtaining a price from similar markets appears problematic. Markandya et al. (2022) report the same example as the SEEA EA (2021), i.e., non-marketed non-wood forest products such as mushrooms may be assigned the price of marketed products coming from a similar forest, but such examples where WES can be priced from similar markets are rare. Furthermore, what is a similar market? Are WES traded, for example, in Colombia, similar to those in the UK?

Consequently, the gold standard methods for valuing ecosystems appear inapplicable to WES. Practitioners are therefore left with the three main remaining categories, summarised by Table 1:

- Methods where the price for the ecosystem service is embodied in a market transaction
- Methods where the price for the ecosystem services is based on revealed expenditures (costs) for related goods/services
- Methods where the price for the ecosystem service is based on expected or simulated expenditures for related goods and services.

These categories include three approaches familiar to the literature of environmental economists and recognized in the ISO 14008 for environmental assessment and ecosystem services valuations:

- Market-based methods (using market price values)
- Cost-based methods
- Preference-based methods (related to the behaviour of individuals and the expenditure they incur)

This overlapping of methods creates opportunities for deploying the literature of environmental economics to facilitate ecosystem accounting. At the same time, confusion might emerge in terminology, technicalities and empirical applications. Moreover, the SEEA EA guidelines (point 9.66, p. 201) realistically recognize that "the method that is applied will often depend on data availability". These conditions open the door to reconsider the economic valuation techniques and their applicability to WES. Table 1 summarises SEEA EA techniques which more often are also applied in the environmental economic literature to assess ecosystem services. It shows the SEEA EA grouping for economic valuation methods (column 1) and the various methods belonging to each group (column 2). Finally, column 3 shows to which category, i.e., provisioning, regulation and cultural, each method can be applied.

Table 1: Valuation methods for the monetisation of ecosystem service

SEEA EA grouping	**Valuation method**	**Ecosystem service: provisioning (P); regulation (R); cultural (C)**
Methods where the price for the ecosystem service is embodied in a market transaction	Resource rent & residual value	P, C
	Production function/ productivity change	P, R
	Hedonic pricing	P, R, C
Methods where the price for the ecosystem services is based on revealed expenditures (costs) for related goods/services	Travel cost	R, C
	Averting behaviour	P, R
Methods where the price for the ecosystem service is based on expected or simulated expenditures for related goods and services	Replacement costs	P, R, C
	Avoided damage costs	P, R, C
	Simulated exchange value	C

While Table 1 synthesises the SEEA macro-categories of valuation methods most frequently encountered in the literature for WES, there is also the possibility to use "value transfer techniques" as an alternative assessment method. This technique envisages the possibility to transfer the primary monetary value for one ecosystem service assessed in one place to a second place where the ecosystem and society hold similar characteristics. While this is a pragmatic approach to assess WES when data scarcity prevents monetization with other techniques the validity of this method is still under investigation (Grammatikopoulou et al., 2023).

The next section further deepens the discussion on evaluation and examines, through a top-down and bottom-up approach, the methods applicable and applied in the literature to evaluate WES.

2.2. Valuation methods and applications for WES

In revising the economic methods for WES, we integrate top down and bottom-up approaches. The top-down component is based on the hierarchy of methods recommended in Figure 1 and recent SEEA EA reviews, studies and publications on water and ecosystems (Markandya et al., 2022, Vardon et al., 2023, Vardon et al., 2025). This is complemented by bottom-up evidence gathered by a systematic literature review. The review aims to analyse the empirical applications of these methods for valuing WES and to assess their coherence with accounting principles and the feasibility of adopting these methods for UK WES accounts. First, we build on two existing systematic reviews: one on water accounts (Vardon et al., 2025) and the second one on the monetary valuation of ecosystem services (Markyanda et al., 2022). Since our objective is to examine SEEA EA-consistent applications only, we also conduct a targeted literature search using keywords related to economic valuation and WES[4]. The selected studies were then screened for compatibility with our analysis. As a result, we identified 33 relevant studies, comprising 25 academic papers and 8 reports. Together, these studies assess a total of 43 distinct WES, with the provisioning ES being the most frequently evaluated (23 cases), followed by regulating ES (17 cases) and, to a much lesser extent, cultural services (2 cases).

In terms of alignment with the methodological hierarchy presented in Figure 1, we find that only a small fraction of studies (about 15%) claim to have employed methods where the price of the ecosystem service is directly observable (Level 1). Notably, none of the selected studies apply methods from the second tier, which relies on prices derived from markets for comparable goods and services. A larger share, approximately 40%, uses methods where the price of the ecosystem service is embodied in a market transaction (Level 3), while around 6% rely on approaches based on revealed expenditures for related goods and services (Level 4). The majority of studies, nearly 64%, adopted methods based on expected or simulated expenditures (Level 5), with an additional 12% employing other valuation approaches within this category. These findings suggest a predominant reliance on indirect valuation methods, with little empirical application of direct market-based approaches. The following discussion explores the specific valuation methods identified in the literature, their applications, and how they align with the various levels of the methodological hierarchy.

Resource rent and residual value

The resource rent method is a widely recognised approach for estimating the economic value of provisioning ecosystem services. The method estimates the resource rent as the net value after subtracting all production costs, including intermediate inputs, labour costs, and the user cost of fixed capital, from the total revenue generated by marketed output. The residual value method estimates the economic value of water by calculating the rental price, where rent is determined in a market where it is assumed that there is a supply and a competitive demand (United Nations, 2021). For water, this approach is commonly used to assess its contribution to agricultural production by subtracting the costs of other inputs (such as labour, capital, land, and manufactured inputs such as fertilisers and pesticides) from total revenue or output, with the remaining value attributed to water as the residual input. The method, similar to calculating the resource rent, has been predominantly applied to irrigation water at local scales, given its data-intensive nature (Al-Karablieh et al., 2012; Ashfaq et al., 2005; Berbel et al., 2011; Kiprop et al., 2015; Yokwe, 2009), but it has also been used at a national level to value irrigation water (Bekri et al., 2024).

It is worth mentioning that the 2025 SNA, which aims to expand the previous version by incorporating aspects of the valuation and depletion of natural capital, distinguishes between the "resource rent" and "natural resource rent". The latter represents "the surplus value accruing to the extractor of an asset after all costs have been taken into account". Additionally, resource rent

[4] The systematic literature review was conducted using the Web of Science database, applying four search strings to identify relevant studies. The first search string was: ("economic valuation" OR "monetary valuation" OR "ecosystem accounting") AND ("water ecosystem services" OR "water provisioning" OR "water purification"). The second search string included: ("ecosystem accounting" OR "monetary accounting" OR "monetary values" OR "valuing" OR "SEEA EA" OR "SNA") AND ("water provisioning" OR "water purification" OR "freshwaters" OR "wetland ecosystem"). The third search string consisted of: ("economic value" OR "residual value method") AND ("water values" OR "water supply" OR "irrigation water"). The fourth search string was: ("economic valuation" OR "economic evaluation" OR "water accounts" OR "payment for ecosystem services" OR "avoided damage costs") AND ("water ecosystem service" OR "water-related ES" OR "water provision" OR "flood protection" OR "green water"). Only studies that aligned with the SEEA EA approach and employed exchange value estimates were included in the final selection.

differs from "rent on natural resources", which refers to "the income receivable by the owner of a non-produced natural resource or another non-produced non-financial asset for putting the asset at the disposal of another institutional unit for use in production". Finally, the 2025 SNA recommends the residual value method as the most suitable to estimate the resource rent (SNA Update, 2024).

Resource rent and residual value approaches are the most used method among those applications where prices (and associated values) are embodied in market transactions, and they have been applied to value water provisioning service (Bekri et al., 2024; Berbel et al., 2011; Capriolo et al., 2020; Comisari et al., 2011; Edens and Graveland, 2014; INEGI, 2021; Kiprop et al., 2015; Koko et al., 2021; ONS UK, 2024).

Both residual and resource rent methods are widely used by the UK Office for National Statistics (ONS), which often derives the estimates using broad industry classification and addresses the volatility of input and output prices adopting 3-5 year moving averages. This method can be used for WES in the UK where ONS has already published resource rent values for water provisioning in their recent natural capital accounting reports (ONS UK, 2024).

The criticism of the method lies in the lack of spatial and temporal precision of value which might undermine the measuring of WES for policy decision making. Furthermore, the residual value is attributed solely to the water asset, although it is reasonable to assume that it also reflects the value of other assets, including intangible ones such as data and organisational capacity.

Productivity change method

The productivity change or production function method estimates the value of water provisioning services by treating water as an input in the production of a marketed good. This approach often involves applying partial and general equilibrium models to assess the effects of reduced water supply on output across various sectors of the economy (Calzadilla et al., 2013; Roson & Damania, 2016), particularly in pricing water-related services in agriculture and other sectors where detailed production data is available. Examples of applications that value water provisioning services by using a productivity change method include Grammatikopoulou et al. (2020), Nahuelhual et al. (2007), while examples for water purification are Piaggio & Siikamäki (2021) and Horváthová (2022). Studies for valuing water provisioning services formalize a regression function where the provision of one market product (e.g. drinking water or crops) is a function of a number of productive inputs such as flows of water from natural resources and other production factors such as energy and labour costs. The method provides valuable information to assess ecosystem services, but a number of challenges still limit its deployment in accounting for WES. Data gathering and quality assessment are time- and resource-intensive as many ecological and economic interactions are complex and difficult to quantify. Water ecosystems exhibit dynamic, non-linear relationships, making it hard to model their contributions accurately. Spatial and temporal variability further complicates assessments, as water services fluctuate due to seasonal changes and climate impacts. External factors like pollution, land-use changes, and policy constraints also affect the reliability of economic estimates. Finally, uncertainties in model assumptions, such as linearity and substitutability of inputs, may not fully capture ecological realities, leading to potential misestimations of service values.

In the UK, if time and budget allow, this methodology could be applicable to assess green water[5] or other WES following the methodologies applied by Fezzi and Bateman (2015). In this application, the authors apply non-linear modelling strategies to assess the effect of climate change on agricultural production, but their production function ignores green water data possibly due to challenges in data collection.

Hedonic pricing

The hedonic pricing method estimates the premium added to property or rental values (or other composite goods) due to the influence of an ecosystem characteristic (e.g., clean water, nearby parks). This approach is frequently applied to quantify the benefits of amenities that enhance the attractiveness of specific locations for residents. To isolate the effect of these ecosystem features, other property characteristics (such as size, number of rooms, heating, and garage space) are standardised and incorporated into the analysis. In the context of WES, the hedonic pricing method has been applied to estimate the value of various services, particularly those linked to recreational, aesthetic, and water quality benefits (Lansford & Jones, 1995; Mei et al., 2018; Moore et al., 2020). To the best of our knowledge, no study in the literature uses the hedonic price method to evaluate ES provided by freshwater ecosystems. At the same time, in the UK there are few examples of this method which could be expanded to include WES for supporting water accounting initiatives. Gibbons et al. (2014) and Nafilyan et al. (2019) are two potential studies to consider. At the same time, time and resources for compiling the data needed might represent the main barriers to adopt this method for WES.

Averting behaviour method

The averting behaviour method assumes that individuals spend money to prevent or reduce the negative effects of environmental impacts. The observed expenditures reflect the perceived value of the ecosystem service (e.g., the cost of a water purifier). While this approach is relatively easy to apply, accurately linking expenses to specific ecosystem services can be challenging, and expenditures may reflect more than just the avoidance of negative environmental effects. An example of application of the averting behaviour method to valuing the water provisioning service is provided by Das et al. (2019). In the UK, a possible application is to assess for example the cost faced by households or industries of purifying their water via water treatment equipment or storing the water in private water tanks. These values are already included in ordinary SNA tables, but they can be partitioned with appropriate data collection and analysis and attributed to the correct flow of ecosystems.

Travel cost method

The travel cost method is a well-established nonmarket valuation method, and it has been widely used to value recreation (Lupi et al., 2020). This method, however, has traditionally been used to estimate welfare values, focusing on the wellbeing people derive from recreational experiences within the natural environment. The only study that applies the travel cost method for valuing water recreation ES is Lankia et al. (2022). The authors, however, combine the estimation of a recreation demand function estimated by means of the travel cost method with the Simluated Exchange Value (SEV) method, listed in the "Methods where prices are based on expected

[5] Green water refers to water (mostly rained water) stored in soil and available for plants growth, essentially is the soil moisture.

expenditures or markets", at the bottom of the pyramid. For ecosystem accounting, the exchange value can be estimated by aggregating travel expenditure data. Examples of such an approach are provided by Capriolo et al. (2020) and the UK Natural Capital Accounts (ONS UK 2024). ONS estimate the value of recreation and tourism as the amount spent to enable visits to the natural environment, such as transport, car parking and admission costs. However, the main drawback of this strategy is that it attributes all the expenditures to the ecosystem, not being able to isolate the ecosystem contribution.

Replacement cost

The replacement cost approach estimates the value of a WES by evaluating the cost of replacing it with a human-made alternative that provides similar benefits. For this method to be valid, the substitute must fulfil several criteria: it should perform the same function as the ecosystem service, be the most cost-effective option; and there must be a willingness to pay for it if the ecosystem service is no longer available (United Nations, 2021). The OECD report on water scarcity (Leflaive, 2024) identifies a number of tools useful to value water provision with replacement costs.

The replacement cost method is one of the most used methods for valuing WES, primarily for regulating services such as flood control (Broadmeadow et al., 2018; NBS, 2021), water flow regulation (Turpie et al., 2022), and water purification (Banco Mundial et al., 2021; Heins et al., 2020; La Notte et al., 2012 and 2017). It is also applied to water provisioning (Ashagre et al., 2018; Edens and Graveland, 2014; Horlings et al., 2020; Remme et al., 2015; Vardon et al., 2019). To the best of our knowledge, this method has not yet been applied in the UK. However, it could be highly relevant for valuing both provisioning and regulating WES by considering suitable human-made alternatives (e.g., desalination, nature-based solutions, etc.) that are in line with the most prevalent practices in the country, thus providing a basis for estimating potential replacement costs.

Avoided damage costs

The avoided damage costs method estimates the value of WES by considering the costs that would arise if these services were lost. The focus is on the potential damages that would occur due to the absence or degradation of ecosystem services, particularly those that prevent negative outcomes, such as flooding, water contamination, or soil erosion. This method involves quantifying the damages that would result from losing the service and then valuing those damages using prices consistent with the exchange value concept (i.e., the market price or the market costs of the damages which are being avoided), and it has been used to value both water provisioning and regulating (flood control and water purification) services (Angeles & Peskin, 1998; Ashagre et al., 2018; Captiolo et al., 2020; Gallay et al., 2021; South African National Biodiversity Institute and Statistics; 2021; Turpie et al., 2022).

In the UK, water companies are investing significantly in infrastructure, such as constructing reservoirs, upgrading treatment plants, and implementing nature-based solutions to tackle challenges like nutrient pollution and improvements in water quality[6]. These investments could provide a reference point for estimating the potential costs of avoided damages.

[6] In 2024, Ofwat approved the PR24 final determinations, which will see a quadrupling of new investment over the next five years to improve performance, secure water supplies, and enhance water quality. Key investments include £6 billion for nutrient

At the same time, the method presents potential criticisms which could stem from accounting for externalities and therefore breaking the accounting rules to only report positive values. A possible solution is suggested by La Notte et al. (2017) where sustainability thresholds are deployed to identify overuse. Furthermore, investment in damage avoidance solutions could diverge from the actual value of the ecosystem service.

Simulated Exchange Value (SEV) method

The simulated exchange value (SEV) method estimates the price and quantity of an ecosystem service as if it were traded in a hypothetical market. SEV uses nonmarket valuation techniques (e.g., travel cost or stated preferences) to estimate a demand function which is then combined with a simulated supply curve and a hypothetical market structure. It has been theorised by Caparrós et al. (2003; 2017), who acknowledge its main drawbacks, i.e., it is sensitive to the assumptions made to build the supply curve and it relies on simulated transactions. Concerning WES, Lankia et al. (2023) provide the only application of SEV to value water-based recreation ES.

Other valuation methods

Among the other valuation methods, the SEEA EA includes shadow prices, opportunity costs, stated preference techniques, prices from economic modelling and qualitative approaches. Section 9.5 of SEEA EA is dedicated to the value transfer method, which accounts for spatial variation in prices. A few examples of the application of value transfer in water accounting exist, including the local case in Colombia presented by Díaz-Pinzón et al. (2022), and the water accounts for Guatemala by Banco Mundial et al. (2021). Regarding the latter, the studies analysed to estimate the value of different WES include different concepts of value, such as welfare estimates. Given the complexities of incorporating spatial variation across locations, the UN guidelines conclude that the "further testing and best practice guidelines in defining credible market exchange conditions for value transfers is needed" (UN et al., 2021). We also note that when including the observed price in a similar market at the top of the pyramid of valuation methods, it is unclear how this approach differs from the value transfer method and why the former should be considered superior to the latter. Possibly, value transfer often involves values estimated through other methods rather than directly observed prices, however the underlying principle, i.e., using a price from a comparable context, is essentially the same.

2.3. Discussion

The review we have conducted on valuation methods using both top-down and bottom-up approaches has provided meaningful insights into the pyramid of methods proposed by the SEEA EA as well as a starting point to select the most appropriate valuation methods for WES in the UK.

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pollution upgrades, £3.3 billion for nature-based solutions, and £2 billion to unlock £50 billion in funding for major projects, including new reservoirs and water transfer schemes.

One key finding concerns inconsistencies in terminology. Many studies use different names for valuation methods, even when the procedures align with those defined by the SEEA EA. The same issue applies to ecosystem services, which are not always referred to using consistent terminology, for example, water filtration and water purification services may describe the same service. As highlighted earlier in this paper, one driver of such inconsistency in terminology is the overlap between methods proposed by the SEEA EA and those developed by environmental economic literature. Rather than building on the well-established body of research on non-market valuation methods and exploring the usability of such methods for ecosystem accounting, such inconsistencies risk creating misunderstandings and hinder the standardisation of accounting procedures, as well as the coherence and comparability of results (Vardon et al., 2025). Furthermore, recent studies suggest that even nonmarket valuation methods designed to estimate welfare values may, in some cases, be applicable in ecosystem accounting, as the two value concepts may align under certain circumstances (Femia et al., 2024; Fenichel et al., 2024; Scheufele and Pascoe, 2023).

The second point we would like to emphasize is the effectiveness of the pyramid of methods proposed by the SEEA EA. As noted in section 2.1, the first two methods identified by the SEEA EA as the most appropriate approaches are, in practice, nearly unusable. Several studies, which we excluded from our review, provide economic measures such as water productivity, typically estimated by dividing the GDP of a specific sector or the entire economy by its water use (e.g., Bagstad et al., 2020; DANE, 2024; Gutierrez-Martín et al., 2017). Other estimates, particularly those published by governments (e.g. Australia, Philippines, Zambia) rely on market prices such as water permit grants, water tariffs, or water-related revenues and expenditures (Australian Bureau of Statistics, 2021; Government of the Republic of Zambia, 2020; Philippine Statistic Authority, 2024). However, all these studies are based on the SEEA Water framework (United Nation, 2012). Compared to the SEEA Water, the SEEA EA adopts an ecosystem-based approach, aiming to isolate ecosystems' contributions to the economy. As a result, estimates based on the SEEA Water framework, despite using market-based prices, are often incompatible with the SEEA EA requirements, as they fail to isolate the value of ES.

While our analysis reveals that it is often not possible to find a price for WES that isolates the ecosystem's contribution from other inputs, we find that a significant portion (about 57%) of the studies included in the review value WES using cost-based approaches, such as the replacement cost and avoided damage cost methods. These methods correspond to the SEEA EA category "methods where prices are based on expected expenditures or markets" and are positioned at the base of the pyramid.

These considerations lead us to ask, in conclusion, whether a revision of the pyramid of meta-methods proposed by the SEEA EA is necessary to address these issues.

3. Future research streams

The selection of the most appropriate economic techniques for WES requires not only a review of the literature but also the empirical application in the UK of the proposed valuation methods to draw conclusions on the possibility of and limits posed by each valuation method. UK ONS

(2017, 2023) suggest a number of principles as guidance in the choice of the valuation process, which we have reinterpreted as follows:

- The use of a particular technique should be clearly explained and related to the underlying biophysical assessment process;
- Valuation methods should be transparent, intuitive and replicable;
- Value transfer techniques should be applied with caution.

To support this direction, future work should i) explore the availability and suitability of data for applying each WES valuation method in the UK context, with the aim of recommending the most appropriate approach for each service; ii) identify and document relevant data sources for each method; and iii) provide practical guidance for implementation.

A particularly divisive issue across the approaches is the use of non-market valuation methods, such as stated preference methods, which rely on surveys and questionnaires and are traditionally used to estimate welfare values. These values include consumer surplus and in turn do not conform to the SEEA EA guidelines. Vincent (2015) proposes incorporating non-market valuation directly into the main national accounts. Other scholars propose alternative frameworks to develop a set of satellite accounts where indicators and welfare estimates are presented along exchange values. Among these, Turner et al. (2019) suggest using the Complementary Account Network (CAN) and Di Gennaro et al. (2025) propose a similar flexible approach for reporting environmental and socio-economic values. Similarly, UK ONS (2017, 2023) suggests that in situations where the exchange values cannot be imputed it might be feasible to use welfare values, as proxy for exchange. Obst et al. (2015), instead, stress the need to rely on exchange price that is "the value at which goods, services and assets are exchanged regardless of the prevailing market conditions".

As for most of the Water Ecosystem Services the existence of market is rare, exclusively relying on exchange values, which essentially represent an assumed transaction between an ecosystem asset and an economic unit, might not be a feasible solution. Moreover, the adoption of a broader range of physical and monetary values could serve different purposes other than national accounting, such as policy evaluation, management decisions or advocacy purposes.

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Appendix A

Figure A1. Percentage of the selected studies by typology

This figure presents the distribution of selected studies based on their publication type. Academic papers account for 76% of the reviewed literature, while reports constitute the remaining 24%.

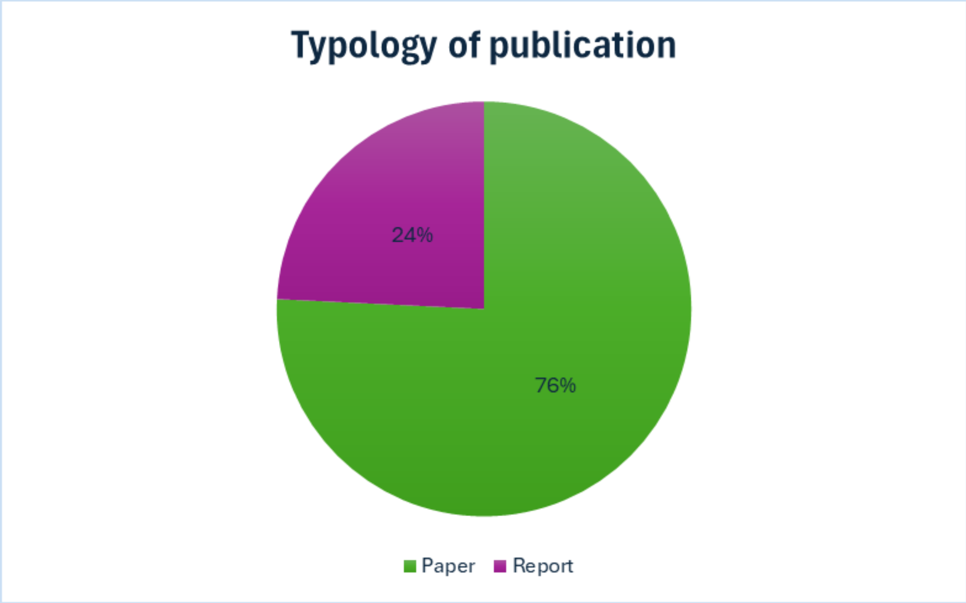

Figure A2. Percentage of studies by macro-category of Water-Related Ecosystem Services (WES)

This figure illustrates the distribution of selected studies across macro-categories of water-related ecosystem services (WES). The systematic literature review identified 43 WES, with 55% classified as provisioning services (e.g., water provisioning), 40% as regulating services (e.g., water purification, flood control), and 5% as cultural services (e.g., water-related recreation).

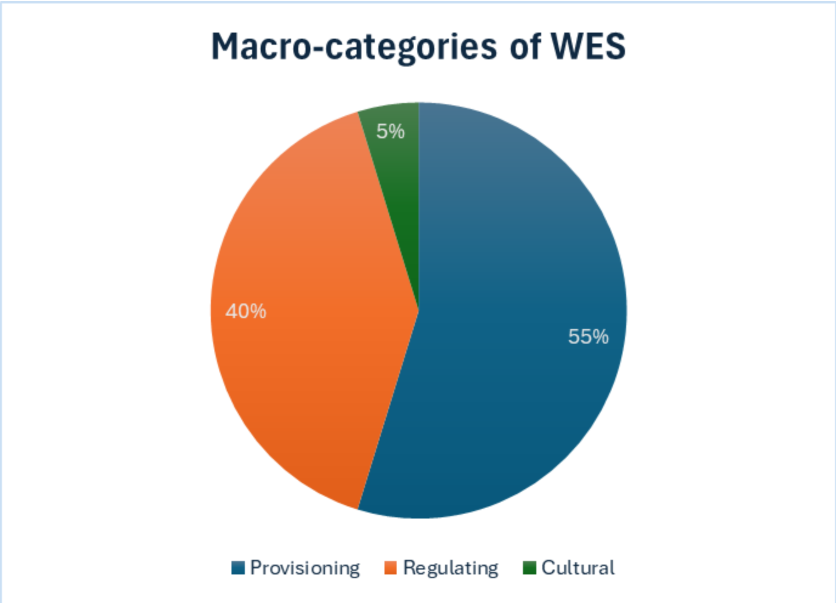

Figure A3. Number of Studies by Continent

This figure presents the geographical distribution of the selected studies across continents. A total of 16 studies are based in Europe, followed by 5 studies in Africa, 5 in Asia, 4 in America, and 3 in Australia.

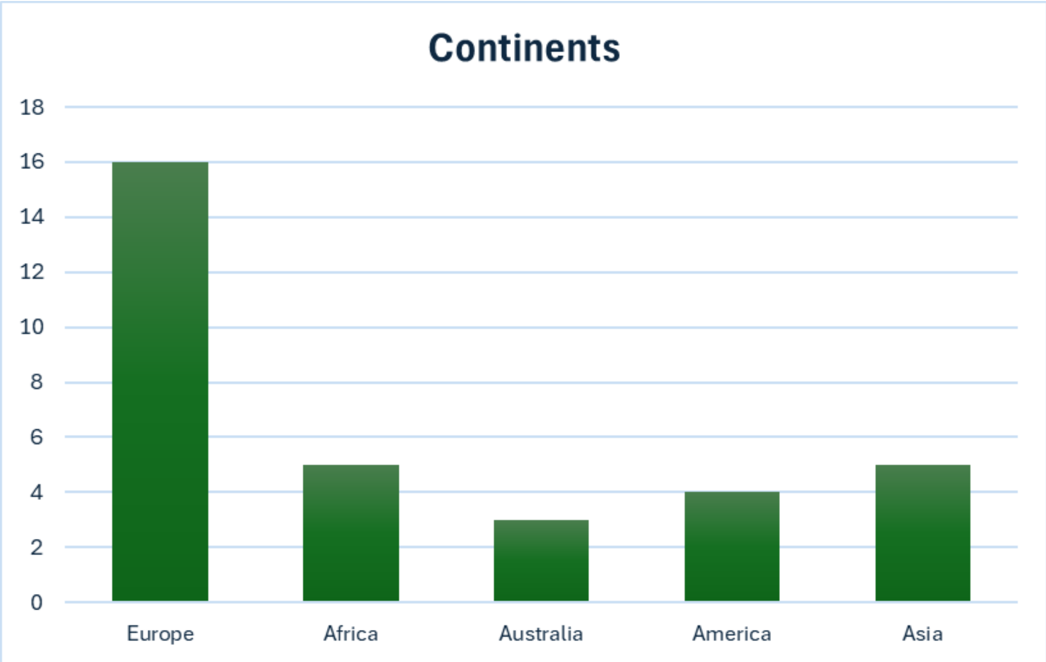

Figure A4. Percentage of SEEA valuation method levels employed in the selected studies

This figure presents the distribution of WES across the levels of valuation methods recommended by the SEEA (as shown by the pyramid in Figure 1). Specifically, 11% of the valuations apply Level 1 methods (where the price is directly observable, see discussion in section 2.1), none correspond to Level 2 (where the price is obtained from markets for similar goods and services), 29% fall under Level 3 (where the price is embodied in market transactions), 4% employ Level 4 methods (where the price is based on revealed expenditures in related goods and services), 47% belong to Level 5 methods (where the price is based on expected expenditures or markets), and 9% belong Level 6 methods (other valuation approaches).

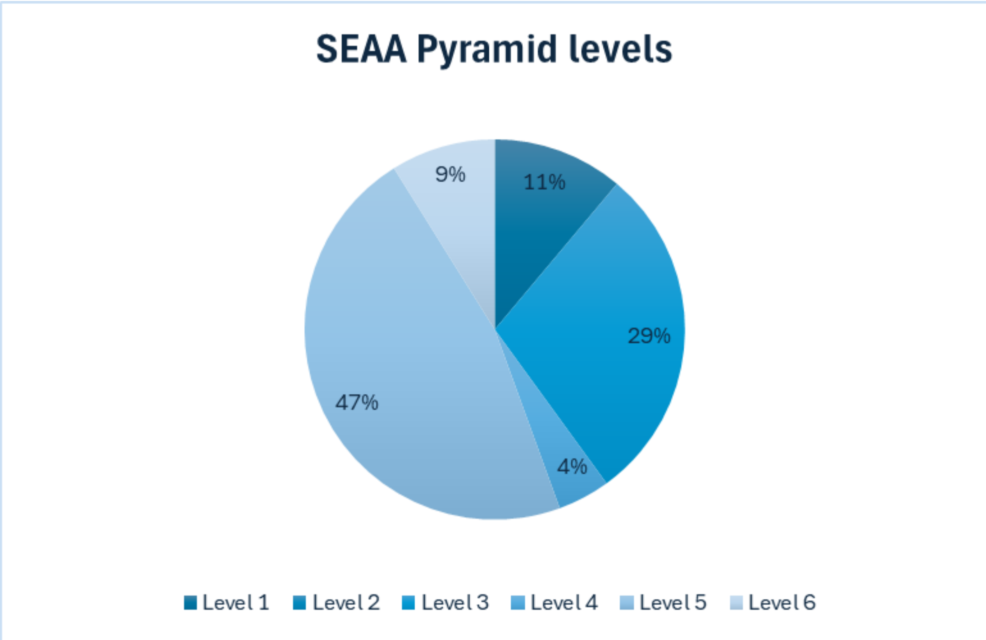

Figure A5. Number of valuation techniques employed in the selected studies

This figure presents the frequency of different valuation methods applied in the selected studies. Specifically, 9 studies employ the Resource Rent and Residual Value method, 4 use the Productivity Change method, 1 applies the Travel Cost method, 1 adopts the Averting Behaviour approach, 14 utilize the Replacement Cost method, 5 apply the Avoided Damage Cost method, and 1 study employs the Simulated Exchange Value method.

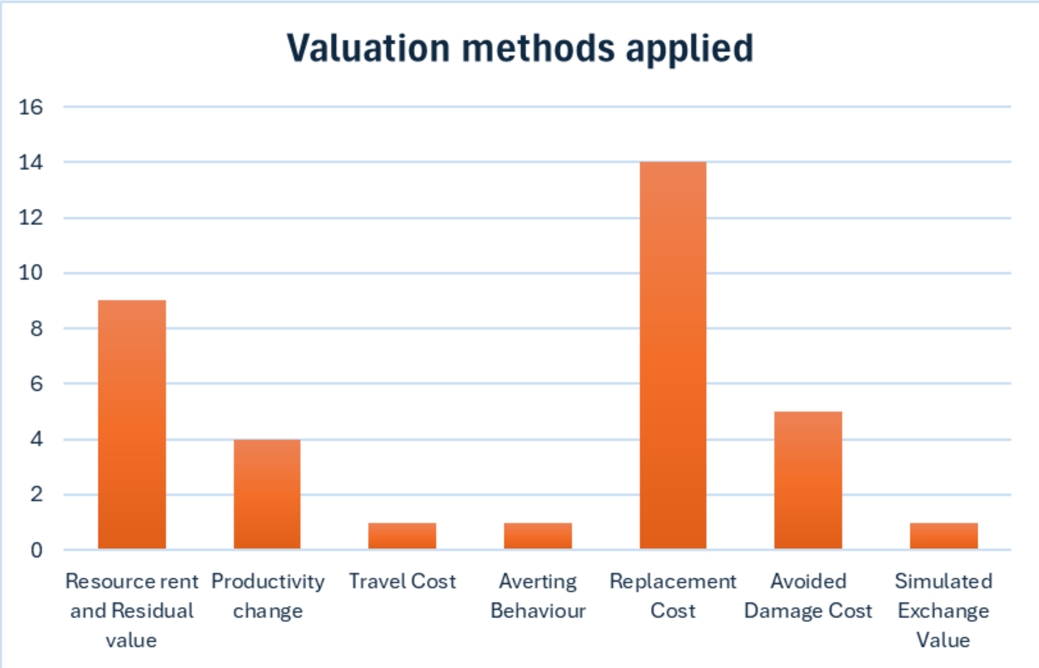

Table A1. Table listing the authors, study titles, and DOI or links to the reports of the studies analysed in the systematic literature review.

Author(s)	Title	DOI or link
Edens and Graveland (2014)	Experimental valuation of Dutch water resources according to SNA and SEEA	https://doi.org/10.1016/j.wre.2014.10.003
Office of National Statistics (2024)	UK natural capital accounts methodology guide: 2024	UK natural capital accounts methodology guide: 2024 - Office for National Statistics
Lankia et al. (2023)	Piloting accounts for recreational ecosystem services: Quality, use, and monetary value of freshwaters in Finland	https://doi.org/10.1016/j.wre.2022.100215
Koko et al. (2021)	Valuing ecosystem services: stakeholders' perceptions and monetary values of ecosystem services in the Kilombero wetland of Tanzania	https://doi.org/10.1080/26395916.2020.1847198
Comisari et al. (2011)	Valuation of water resources and water infrastructure assets	https://seea.un.org/sites/seea.un.org/files/8_32.pdf
Kiprop et al. (2015)	Determining the Economic Value of Irrigation Water in Kerio Valley Basin (Kenya) by Residual Value Method	https://www.researchgate.net/profile/Jonah-Kiprop/publication/342212620_Determining_the_Economic_Value_of_Irrigation_Water_in_Kerio_valley_basin_by_residual_value_methodpdf/data/5ee8f8ca299bf1faac5a0279/Determining-the-Economic-Value-of-Irrigation-Water-in-Kerio-valley-basin-by-residual-value-method.pdf
Berbel et al. (2011)	Value of Irrigation Water in Guadalquivir Basin (Spain) by Residual Value Method	https://doi.org/10.1007/s11269-010-9761-2
Nahuelhual et al. (2007)	VALUING ECOSYSTEM SERVICES OF CHILEAN TEMPERATE RAINFORESTS	https://doi.org/10.1007/s10668-006-9033-8
Bekri et al. (2024)	Ecosystem accounting for water resources at the catchment scale, a case study for the Peloponnisos, Greece	https://doi.org/10.1016/j.ecoser.2023.101586
Rismawati (2024)	Economic Valuation of Water Provisioning Services in the Recharge Area of Ciburial Spring, Bogor Regency	http://dx.doi.org/10.22004/ag.econ.344445
Ouyang et al. (2020)	Using gross ecosystem product (GEP) to value nature in decision making	https://doi.org/10.1073/pnas.1911439117
Grammatikopoulou et al. (2020)	Economic evaluation of green water in cereal crop production: A production function approach	https://doi.org/10.1016/j.wre.2019.100148
Fu et al. (2018)	Payments for Ecosystem Services for watershed water resource allocations	https://doi.org/10.1016/j.jhydrol.2017.11.051
Remme et al. (2015)	Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands	https://doi.org/10.1016/j.ecolecon.2015.02.015
Horlings et al. (2020)	Monetary valuation of ecosystem services for the Netherlands	https://www.cbs.nl/en-gb/background/2020/04/monetary-valuation-of-ecosystem-services-for-the-netherlands
La Notte et al. (2012)	Spatially explicit monetary valuation of water purification services in the Mediterranean bio-geographical region	https://doi.org/10.1080/21513732.2011.645557
La Notte et al. (2017)	Physical and monetary ecosystem service accounts for Europe: A case study for in-stream nitrogen retention	https://doi.org/10.1016/j.ecoser.2016.11.002
Keith et al. (2017)	Ecosystem accounts define explicit and spatial trade-offs for managing natural resources	https://doi.org/10.1038/s41559-017-0309-1
Vardon et al. (2019)	Accounting and valuing the ecosystem services related to water supply in the Central Highlands of Victoria, Australia	https://doi.org/10.1016/j.ecoser.2019.101004
Ashagre et al. (2018)	Integrated modelling for economic valuation of the role of forests and woodlands in drinking water provision to two African cities	https://doi.org/10.1016/j.ecoser.2018.05.004
Gallay et al. (2021)	Monetary Valuation of Flood Protection Ecosystem Service Based on Hydrological Modelling and Avoided Damage Costs. An Example from the Cierny Hron River Basin, Slovakia	https://doi.org/10.3390/w13020198
Díaz-Pinzón et al. (2022)	The Economic Value of Wetlands in Urban Areas: The Benefits in a Developing Country	https://doi.org/10.3390/su14148302
Das et al. (2019)	Valuing water provisioning service of Broadleaf and Chir Pine forests in the Himalayan region	https://doi.org/10.1016/j.forpol.2019.05.017
Piaggio & Siikamäki (2021)	The value of forest water purification ecosystem services in Costa Rica	https://doi.org/10.1016/j.scitotenv.2021.147952
Turpie et al. (2022)	Accounting for ecosystem services and asset value: pilot accounts for KwaZulu-Natal, South Africa	https://doi.org/10.3897/oneeco.7.e86392
NBS (2021)	Ecosystem accounts for China: Report of the NCAVES Project	https://teebweb.org/wp-content/uploads/2022/08/ncaves_-_china_-_country_report_-_final_web_ready.pdf

Broadmeadow et al. (2018)	Valuing flood regulation services of existing forest cover to inform natural capital accounts	https://www.forestresearch.gov.uk/publications/valuing-flood-regulation-services-of-existing-forest-cover-to-inform-natural-capital-accounts/
Horváthová (2022)	Analysis of Drinking Water treatment costs – with an Application to Groundwater Purification Valuation	https://doi.org/10.3897/oneeco.7.e82125
Capriolo et al. (2020)	Biophysical and economic assessment of four ecosystem services for natural capital accounting in Italy	https://doi.org/10.1016/j.ecoser.2020.101207
INEGI (2021)	Ecosystem Accounts of Mexico: Report of the NCAVES project	https://seea.un.org/content/ecosystem-accounts-mexico-report-ncaves-project
WAVES (2021)	Cuenta de ecosistemas de Guatemala	https://www.wavespartnership.org/sites/waves/files/kc/Cuenta-ecosistemas-diagramado-compressed.pdf
Heins et al. (2020)	Ecosystem accounting in the Netherlands	https://doi.org/10.1016/j.ecoser.2020.101118
SANBI & SSA (2021)	Ecosystem accounts for South Africa: Report of the NCAVES Project	https://seea.un.org/sites/seea.un.org/files/files/documents/2022/May/ncaves_-_sth_africa_-_country_report_-_final_web_ready.pdf