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Incorporation of Ecosystem Services Values in the Integrated Management of Irish Freshwater Resources: ESManage

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Government of Ireland

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Incorporation of Ecosystem Services Values in the Integrated Management of Irish Freshwater Resources: ESManage

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Prepared for the Environmental Protection Agency

by

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Cover image: Courtesy of Michael Bruen.

DISCLAIMER

This report is based on research carried out/data from January 2015 to January 2019. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The ESManage project tested an eight-step methodological framework to help embed ecosystem services and the ecosystem services approach into policy and decision-making for the sustainable management of water resources, as required by the Water Framework Directive (WFD). It involved identification of relevant freshwater ecosystem services, prediction of how they change when management measures are implemented and economic valuation of those changes. The focus of the research was on ecosystem services from rivers, engaging stakeholders in three case study catchments to explore the ecosystem services derived from these very different rivers and undertake economic valuation of the benefits that people obtain from enhancements to ecosystem services in those rivers.

Modelling, using both a hydrological and a nutrient load apportionment model, was used to quantify changes in flows and inputs of pollutants (nutrients and sediment) associated with the alternative catchment management scenarios (e.g. intensification, extensification and riparian measures such as tree planting), whereas Bayesian belief network modelling was used to predict the resulting changes in ecological responses and their effects on selected ecosystem services (e.g. clean water, angling, wildlife). The focus was on managing diffuse pollution from agriculture, assuming unchanged inputs from domestic septic tanks and point sources, e.g. wastewater treatment plants, that also contribute to water quality problems in the study catchments. The intensification scenarios considered potentially pro rata changes in nitrogen, phosphorus and sediment inputs assumed to arise from an increase in stocking density, whereas extensification related to the corresponding effects as a result of reductions in stocking density.

The “choice experiment” valuation technique was then used to quantify the economic benefits that people obtained from enhancements to river ecosystem services. In addition, data were collected on the cost of wastewater treatment to demonstrate the benefits of natural regulating ecosystem services.

Outputs and Key Findings

The project carried out a review of the ecosystem services approach and an integrated modelling approach to assess changes in river ecosystem services in response to management interventions. The flexible framework also allows additional catchments and management options to be easily added and future information on ecosystem responses to change to be incorporated.

In terms of the economic value of changes in ecosystem services, people in Ireland, on average, valued most highly enhancements to river wildlife, such as birds and invertebrates (average willingness to pay was estimated at between €54 and €68 per household per year), followed by improvements to water quality to remove algal blooms and scum (€48–59) and reductions in the health risk (gastrointestinal infections) from rivers (€45–59). Creating more natural bankside vegetation and enhancing salmon and trout numbers for angling were also valued by the general public. However, values differed where participants belonged to specific interest groups. A second choice experiment with local and visiting anglers in the Moy catchment demonstrated the high value that anglers place on core angling characteristics, such as fish size and catch number, and also on good water quality. Summing across the five river services, it is estimated that, on average, Irish people would be willing to pay between €214 and €250 per household per year to meet the EU WFD targets in rivers. When aggregated to the Irish population, meeting the EU WFD targets for rivers would generate around €389 million of benefits.

The management option most highly valued was riparian management (willingness to pay of between €85 and €108 per household per year). The extensification scenario was valued broadly at one-third that of the riparian management scenario. The intensification scenario resulted in benefit losses of between €55 and €36 per household per year. Note that in the intensification scenario, a standard level of intensification (a 50% increase in dominant livestock numbers) was assumed across all three catchments; however, this level of increase is unlikely to be achieved in the Dodder catchment. Aggregation of these household values to the catchment level suggests that the riparian management policy would generate between €7.76 million and €2.44 million per year of river service benefits. Aggregating across the entire population of Ireland, it was estimated that a policy to implement riparian management would generate ecosystem services worth €160 million per year, whereas extensification would generate ecosystem services worth €43 million per year. Land use intensification would lead to an ecosystem services loss of €73 million per year. These estimates should be considered conservative as they reflect only the five key river services; there are likely to be additional benefits associated with the other river services not investigated.

This project provides a series of recommendations for policy and practice.

1 Background and ESManage Objectives

Human societies have recognised for several millennia that the environment and nature provide benefits, either directly or indirectly (Lele *et al*., 2013). The more recent concept of human benefits from the environment and nature emerged in the 1970s and was initially described as “environmental services” (Wilson and Matthews, 1970). Later, Westman (1977) discussed the value of the benefits that ecosystems provide to human society, which he termed “nature’s services”. He further explained that the effects of development and physical change that humanity impose on ecosystems could potentially be calculated in order to inform society, thus influencing policy and management decisions to mitigate ecosystem degradation. This concept took on the guise of “ecosystem services” in the early to mid-1980s as ideas and understanding evolved (e.g. Ehrlich and Ehrlich, 1981; Ehrlich and Mooney, 1983) and in the mid- to late 1990s it slowly emerged as a potential framework for valuing and protecting ecosystems and their biodiversity (e.g. Costanza *et al*., 1997). This, in turn, resulted in the integration of the formerly separate disciplines of economics and ecology, and allows investigation of relationships between economies and natural environments (Costanza, 1991; Braat and de Groot, 2012).

Today, freshwaters are under ever-increasing pressures from human activities and related climate change. The report by the World Wide Fund for Nature highlights the alarming decline in freshwater biodiversity at a rate higher than in marine or terrestrial systems (WWF, 2018). The 2019 Intergovernmental Science–Policy Platform for Biodiversity and Ecosystem Services (IPBES, 2019) report also highlights that inland waters and other freshwater ecosystems show the highest rate of species loss. With this comes the potential to impact the many interconnected benefits that are derived from freshwater ecosystems. This challenges us to adopt a more holistic evaluation and management of water resources that take into account a wider suite of benefits.

The overall objective of the ESManage project was to harness the knowledge and tools required to embed an appreciation of ecosystem services and the ecosystem services approach into policy and decision-making for sustainable management of water resources, as required by the Water Framework Directive (WFD).

Specific objectives were to:

1. review the concept of ecosystem services in the context of freshwaters and provision of water-related services;
2. provide a synthesis of current knowledge on the Irish freshwater resource capital, services derived, pressures on physico-chemical conditions and biological components, water supply sources, demands, infrastructure and governance structures, and knowledge gaps with particular reference to those issues that compromise ecosystem services delivery;
3. identify, simulate and analyse the most important and feasible water resources management scenarios from the perspective of physical/chemical water quality and to combine these with the linkages to ecosystem conditions developed in objective 4 to produce information that allows objective 5 to determine the value of the services they either deliver or impact on;
4. advance understanding of the linkages between biological components/ecosystem services of freshwaters and various drivers, based on data analyses and new data, to link pressures and drivers leading to biological degradation that may impact on ecosystem services delivery;
5. estimate the economic impact of future changes to the provision of key aquatic ecosystem services in Irish rivers;
6. recommend how the ecosystem services approach can best be embedded into policy and decision-making for sustainable management of water resources;

7. publish a literature review (Feeley *et al*., 2016) and short synthesis (Feeley *et al*., 2017a), compiled by the project team, to address objective 1, and thus only a short synthesis of key concepts and literature is presented here (a glossary of terms is included at the end of this report).

1.1 What Are Ecosystem Services?

Ecosystem services are commonly defined as "the benefits people obtain from ecosystems" or "the contributions that ecosystems make to human well-being*"* after the Millennium Ecosystem Assessment (MEA, 2005) and the Common International Classification of Ecosystem Services (CICES) report (Haines-Young and Potschin, 2013), respectively.

The Common International Classification of Ecosystem Services (Haines-Young and Potschin, 2013) refers to "final" ecosystem services to make the distinction from "intermediate" services and hence avoid double counting in valuation exercises. These services are "final" in that they are the outputs of ecosystems (whether natural, semi-natural or highly modified) that most directly affect the well-being of people (Figure 1.1). The underlying ecosystem functions, processes and structures that generate them are called supporting or intermediate services. Thus, there is general consensus that there should be a distinction between "final" ecosystem services and supporting or "intermediate" services. This distinction is well illustrated in the ecosystem service cascade framework of Potschin and Haines-Young (2011) (and modified by COWI A/S, 2014 – see Figure 1.1) to highlight the position of the CICES (2016) classification and the "production boundary" between social and economic systems and the environment. Further details are given in Feeley *et al*. (2016, 2017a). A glossary of terms is included at the end of this report.

1.2 The ESManage Methodological Framework

To address its objectives, ESManage adopted an eight-step methodological framework that covered identification of, prediction of change in and valuation of freshwater ecosystem services (Figure 1.2).

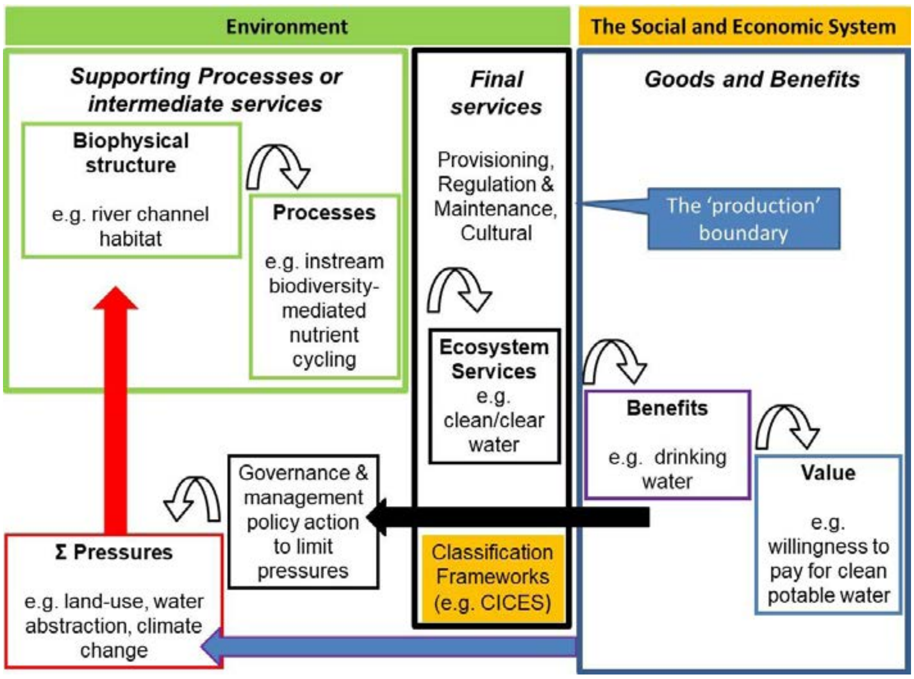

Figure 1.1. The ecosystems cascade model, which highlights the role of supporting processes and intermediate services on the delivery of final services and the goods and benefits humans derive from the environment. Source: modified after Potschin and Haines-Young (2011) and COWI A/S (2014). Ecosystem services are among a range of other catchment services. These comprise the components of natural capital that give rise to ecosystems, geosystems and human/social capital and their associated services (Daly, 2015; see also Figure 1.2).

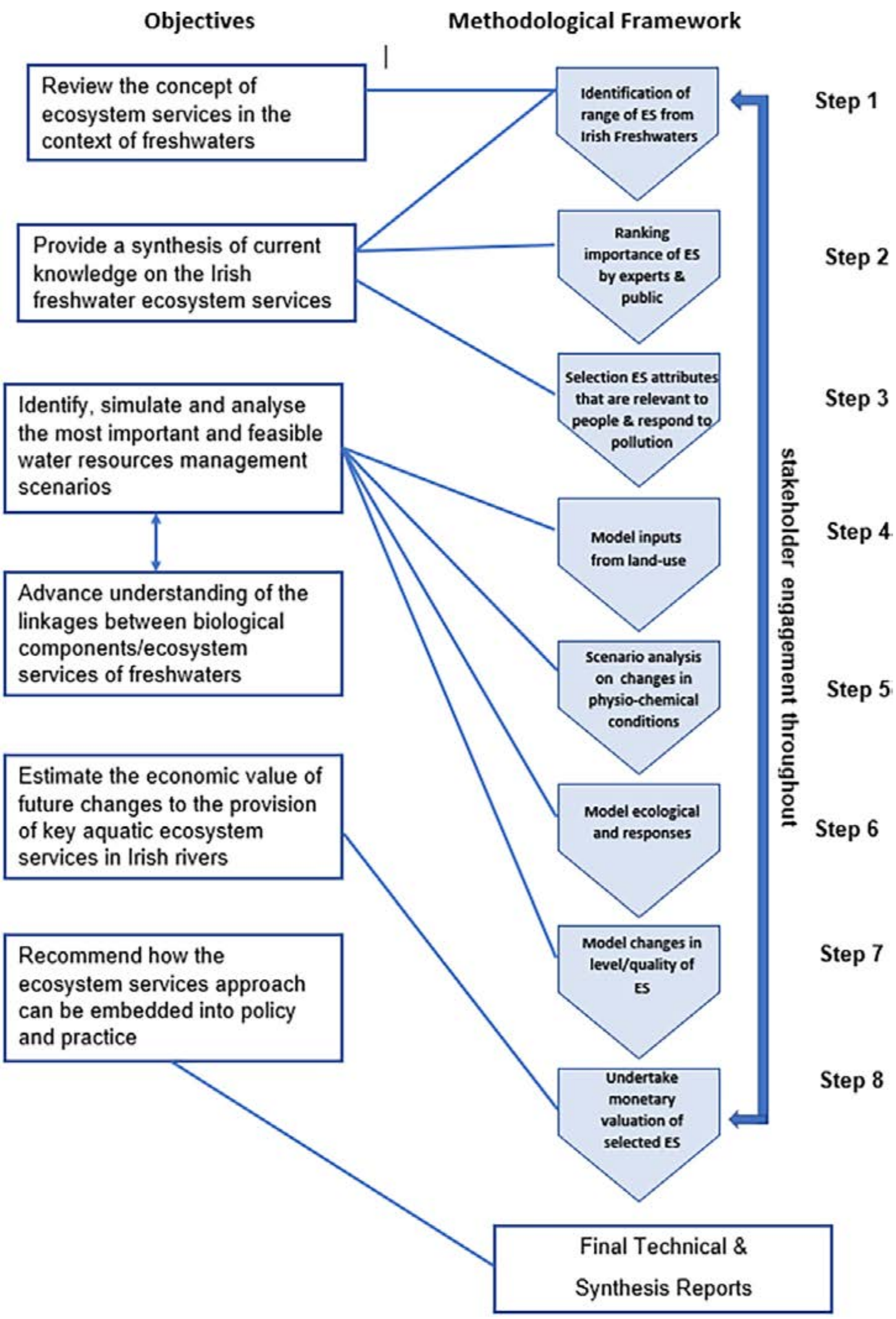

Figure 1.2. Methodological framework for linking management options with their effects on flow regime, and inputs of pollutants (nutrients and sediment), the resulting chemical and physical water quality (focus on nutrients and sediment) and responses in the ecological processes/elements that support the chosen ecosystem services and which thus result in changes in the services being valued. ES, ecosystem services.

Using CICES, we documented the range of ecosystem services derived from Ireland's freshwaters (step 1), followed by an evaluation and ranking of their relative importance (step 2). We then focused attention on rivers (engaging stakeholders in three case study catchments: Dodder, Suir and Moy) and explored (1) the services derived from these rivers and (2) whether or not people benefit from and value those services. Attributes of the ecosystem services that are most relevant to people, represent the quality of the services and respond to changes in pollutant inputs were identified (step 3). Hydrological modelling (step 4 – Chapter 4) was used to quantify changes in flow and inputs of pollutants (nutrients and sediment) associated with the alternative management scenarios (e.g. intensification, extensification and riparian measures, such as tree planting) while Bayesian belief network modelling (Chapter 5) was used to describe the changes in physico-chemical conditions (step 5 – scenario analysis), ecological responses (step 6) and the resulting change in selected ecosystem services (e.g. clean water, angling, river wildlife) (step 7). The focus was on managing diffuse pollution from agriculture, assuming unchanged inputs from domestic septic tanks and point sources, e.g. wastewater treatment plants, that also contribute to water quality problems in the study catchments. The intensification scenarios considered potentially pro rata changes in nitrogen, phosphorus and sediment inputs assumed to arise from an increase in stocking density, whereas extensification related to the corresponding effects as a result of reductions in stocking density. Economic valuation (step 8) of the benefits that people obtain from enhancements to river services was performed using the environmental economic "choice experiment" technique. This survey-based approach involved asking 469 river users in the three catchments a series of "choice tasks" in which alternative scenarios for the future levels of river services were described, along with the cost of providing these services. This analysis produced values for ecosystem service benefits associated with meeting the EU WFD targets. We draw on the modelling work (steps 5–7) and the valuation work (step 8) to provide estimates of the ecosystem service benefits associated with our three catchment management scenarios: intensification, extensification and riparian management. We engaged with stakeholders throughout the project, and to facilitate communication a short synthesis of the ecosystem services literature was produced at the commencement of the project (Feeley *et al*., 2017a). Some additional valuation work was included on wastewater treatment. We conclude this report with recommendations on how the ecosystem services approach can best be embedded into policy and decision-making for sustainable management of water resources. We also highlight gaps that need to be addressed to enable application of the ecosystem concept.

2 Ecosystem Services Identification, Ranking of Their Importance and Attribute Selection (Steps 1–3)

2.1 Identification of Ecosystem Services from Irish Freshwaters (Step 1)

A workshop with freshwater scientists and other stakeholder organisations was held in August 2015 to document the range of ecosystem services associated with Irish freshwaters and how alternative future land use and other pressures and management responses might impact on their delivery. Using the output from the workshop and information derived from reports and published papers, tables based on the CICES framework were constructed, listing all of the potential provisioning, regulating and maintenance, and cultural ecosystem services that may be provided by freshwaters (rivers, lakes, groundwaters and hyporheic zones, wetlands and artificial/heavily modified) in Ireland. A detailed review of Irish freshwater resources in the context of ecosystem services was subsequently published (Feeley *et al.*, 2017b). Only key details relevant to the assessment framework are presented here.

Provisioning services include water for drinking and non-drinking purposes (irrigation, cleaning, agricultural and industrial use) and for the provision of food (e.g. fish). *Regulating and maintenance services* incorporate those that both directly (e.g. waste assimilation, pathogen control) and indirectly (e.g. regulation of decomposition, climate and flows) sustain environmental quality. These provide for water quality and quantity by, for example, removing excess nutrients or moderating water flow (Lautenbach *et al.*, 2012). Climate regulation, through carbon and oxygen cycling processes, maintains air quality, which influences the greenhouse effect and thereby regulates climate at both local and global scales (de Groot *et al.*, 2002). *Cultural services* include tangible recreational uses (e.g. kayaking, fishing and walking along a river) and contribute to less tangible benefits, such as aesthetic or spiritual benefits, as well as providing educational value. Tangible uses in Ireland, for example extensive recreational freshwater fisheries (game, pike and coarse angling), depend on less obvious aspects, such as good habitat and good visual appearance (TDI, 2013). The delivery of freshwater ecosystem services and related benefits is highly dependent on their location within the catchment and the service in question (Maltby and Ormerod, 2011). For example, the supply of water in Ireland at present is principally associated with rivers and lakes (71%) and to a lesser extent with groundwater (29%) (Bullock and O'Shea, 2013). In contrast, wetlands play little or no role in the direct supply of water for consumption in Ireland, but do offer a wide range of services, including groundwater recharge for subsequent abstraction (Maltby and Ormerod, 2011) and treatment of wastewater runoff (Mustafa *et al.*, 2009).

2.2 Relative Importance of Ecosystem Services (Step 2)

Using information provided by experts in the August 2015 workshop and from various reports we rated the relative importance of each service based on the scale of benefits (i.e. level of use) and spatial scale (whether or not the benefits in question are available at scales, from national to local level). The tables are available in Feeley *et al.* (2017b). In terms of provisioning services, water for drinking and non-drinking purposes received the highest rating. With the exception of pest control and climate regulation, regulating and maintenance services were rated of high importance by the experts. With a few exceptions, most of the cultural services were considered to be of high importance, particularly those associated with lakes and rivers.

The analysis from this point onwards was focused on rivers. The aforementioned list of potential ecosystem services from rivers was presented to the public in a series of pilot workshops held within the three case study river catchments. Participants were asked about how they interact with Irish rivers, their perception of the quality of water in rivers and which ecosystem services are important to them. In terms of their perception of water quality, 30% of participants indicated that they considered water quality to be good, while 47% thought it was moderate.

Table 2.1 reports which ecosystem services were rated by the general public as important. Key services included “Bankside activities (e.g. hiking, walking and dog walking)” (14%), “Habitats for plant and animal nursery” (13%), “Pleasure from knowing rivers and river wildlife exist” (12%), “Wildlife watching” (11.3%) and “Leisure fishing and angling” (11.3%).

Based on the findings of these focus groups, it was concluded that the following services were likely to generate the greatest well-being gains under the various catchment management scenarios (discussed in section 3.2): water quality, water health, bankside vegetation, river wildlife and angling. These five services were selected for further investigation and they in particular formed the basis of the choice experiment valuation exercise (step 8).

2.3 River Ecosystem Services Likely to Respond to Management Interventions

A further exercise focused on rivers was carried out in consultation with the Environmental Protection Agency (EPA) to identify the ecosystem services most likely to respond to management interventions targeting improvements in water quality (extensification vs intensification of agriculture, reduction in nutrient/sediment inputs, riparian zone management). The likely response was rated high to low based on the definitions in Table 2.2. Services that were ranked at high importance and which received a high or medium response rating included water for drinking and other purposes, assimilation of wastes, mediation of flows, maintenance of physical, chemical and biological conditions, and all of the cultural services. Full details and tables are available in the final technical report (Kelly-Quinn *et al*., 2019).

2.4 Selection of Ecosystem Services Attributes (Step 3)

A key task was the selection of attributes of the aforementioned services that would show a response to catchment management scenarios and are relevant to the general public. Those selected are listed in Table 2.3 and discussed in greater detail in Kelly-Quinn *et al*. (2019).

Table 2.1. List and ranking of ecosystem services that the workshop participants considered to be most important to them

Response options	%
Provisioning	
Fish for consumption	8.6
Drinking water	2.6
Energy source	1.7
Water for other purposes (e.g. irrigation, livestock)	0.8
Regulating and maintenance	
Habitats for plant and animal nursery	13.0
Control of waterborne fish diseases	5.2
Flood protection	5.2
Water purification	3.4
Erosion control	2.6
Control of waterborne human diseases	0.8
Carbon storage	0.8
Cultural	
Bankside activities (e.g. hiking, walking, dog walking)	14.0
Pleasure from knowing rivers and river wildlife exist	12.0
Wildlife watching	11.3
Leisure fishing and angling	11.3
Water sports (e.g. swimming, boating, kayaking)	6.0

Table 2.2. Definitions of the response of ecosystem services and associated goods and benefits to selected management interventions in Irish freshwater ecosystems

Response category	Definition
High	The response of the service will be significant in terms of meeting relevant policy (e.g. WFD) goals. Includes both positive and negative responses
Medium	The response of the service will be noticeable but not significant in terms of meeting relevant policy (e.g. WFD) goals. Includes both positive and negative responses
Low	The response of the service will not be noticeable or significant in terms of meeting relevant policy (e.g. WFD) goals. Includes both positive and negative responses

Table 2.3. List of ecosystem services and attributes used to illustrate change as a result of management interventions

Service	Attribute
Water quality	Presence/absence of scum and filamentous algae
Water health	Risk of gastrointestinal infections
Habitat	Vegetated (non-agricultural use) riparian buffer
Wildlife	Numbers of mayfly species and numbers of dippers, kingfishers and otters
Angling	Density of “catchable”-sized trout (>25 cm) and salmon (adults) found in the rivers[a]

[a] Inland Fisheries Ireland’s national, WFD monitoring single pass data (2008–2015) on the number of trout and salmon per m^2 in “high alkalinity waters” (the dominant water body type in the test catchments) across the range of river water quality conditions. Only trout in the Dodder upstream of Donnybrook on account of the presence of barriers.

2.4.1 Case study catchments

Three case study catchments (Dodder, Suir and Moy) were chosen for the valuation exercise (Figure 2.1). They were chosen to represent a highly urban catchment (River Dodder), a typical agricultural catchment (River Suir) and a catchment with strong tourism activities (River Moy), particularly related to angling.

River Dodder

The Dodder catchment, covering an area of 121 km^2, is in County Dublin, on the east coast of Ireland. The main river is 28 km long and the whole stream network is 151 km long (OPW, n.d.) and is connected to the River Liffey near its mouth. The catchment is largely urbanised with 61% of its land covered by artificial surfaces (urban fabric, industrial areas and artificial vegetated areas). A further 18% of the catchment is dedicated to agriculture (mostly pasture), 11% is inland wetlands and 5% is covered by forests (EPA, 2012). In 2011, this urban catchment has a total population of 305,956 inhabitants or 90,551 households (CSO, 2012a). The catchment soils consist of 53% miscellaneous soils; the catchment further consists of well-drained material (13% deep, 9% shallow), shallow lithosolic or podzolic soils (12%) and peat (9%). The geology is mostly composed of granites (48%), limestones (38%) and metasediments (14%).

River Suir

The Suir catchment is in the south-east of Ireland, almost exclusively in County Tipperary. The main channel is 88 km long and its entire stream network is 1588 km long (OPW, n.d.). Only the upper part of the River Suir is considered for the study catchment in order to avoid a tidal influence that extends as far as Carrick-on-Suir. However, the only hydrometric gauge with sufficient discharge data for hydrological modelling was at Cahir Park; therefore, the catchment studied was for this gauge. The catchment is 1586 km^2 in area and the land cover is primarily agricultural (73% pasture and 6% arable), 6% is covered with forests and 6% consists of wetlands and 5% of scrubs (EPA, 2012). The population in the catchment is 191,406 inhabitants or 22,924 households (CSO, 2012a). Soils are dominated by deep soil (50% well-drained/poorly drained), shallow well-drained soils (9%), peats (5%) and alluviums (5%). The geology is primarily limestones (56%) and sandstones (23%), with a further 10% consisting of metasediments and volcanics.

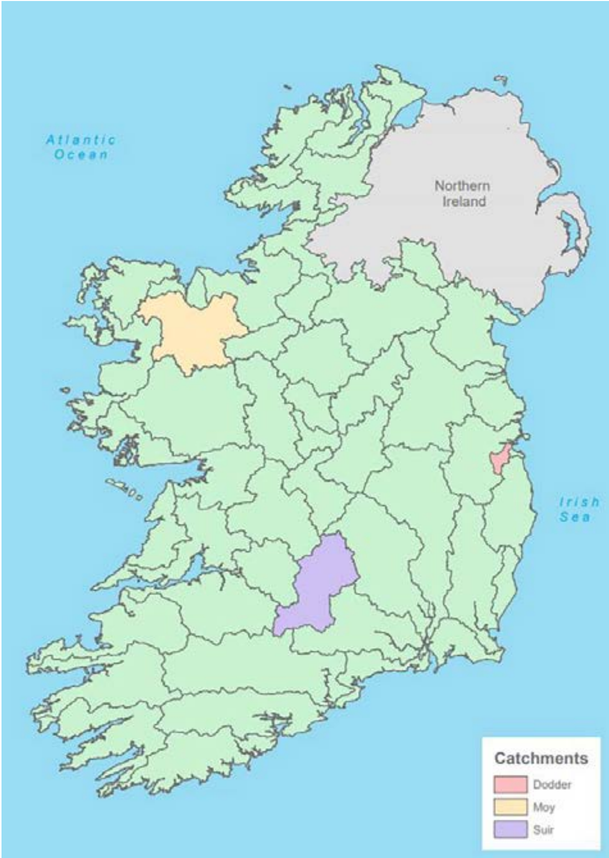

Figure 2.1. Location of the three study catchments.

River Moy

The Moy catchment is located in County Mayo, in the west of the country. The main river length is 90 km but, with its dense network of tributaries, the whole network is 2683 km long (OPW, n.d.). The Moy river estuary flows into the North Atlantic Ocean in Ballina. The catchment is 2201 km^2. It features two major lakes: Lough Conn (47 km^2) and Lough Culin (10 km^2). The main land cover is pasture (51%) and inland wetlands (27%) (EPA, 2012). The remainder is a mixture of heterogeneous agricultural areas, forests and scrubs. The overall population in the catchment is 83,153 inhabitants or 22,924 households (CSO, 2012a). The soil is dominated by peat (34%), deep poorly drained soils (24%) and deep well-drained soils (20%). The geology is dominated by limestones (50%) and a mixture of shales/limestones (7%), quartzites/gneisses/schists (13%), sandstones/shales/limestones (9%), granites/igneous intrusive rocks (7%) and sandstones (10%).

3 Modelling Pollutant Inputs from Land Use/Land Use Change (Steps 4 and 5)

In order to predict the changes in water quality taking into account different catchment management scenarios, an integrated modelling approach using both a hydrological model and a nutrient export model was applied to predict the concentrations of ammonia, nitrate and phosphate in the three study rivers. Three different catchment management scenarios were compared and a sensitivity analysis of the water quality predictions was carried out for each scenario.

3.1 Selection of the Models for Hydrology and Nutrient Export

A review of the suitability of models to use in the context of ecosystem services assessment was carried out as part of this project (Hallouin *et al*., 2018) and a summary of the findings is presented in the final technical report of the project (Kelly-Quinn *et al*., 2019). The two models used were the hydrological model SMART (Soil Moisture Accounting and Routing for Transport), which has been proven to perform well in predicting the hydrological response of Irish catchments, and the Source Load Apportionment Model (SLAM), which predicts the annual catchment export in N and P as well as the contribution of each sector of activities to these exports. These two models have been specifically developed for Irish catchments; therefore, they are expected to produce more accurate predictions than generic ecosystem services models or other bespoke modelling approaches using models neither specifically tailored nor calibrated for Irish conditions.

3.2 Definition of the Management Scenarios

Three very different catchment management scenarios were analysed: two diverging scenarios in terms of the evolution of livestock density in the catchment (agricultural intensification, agricultural extensification) and a scenario considering a remediation measure to prevent nutrients from being discharged into the river (riparian management). The focus was on diffuse pollution from agriculture, although point sources, e.g. from wastewater treatment plants, also contribute to water quality problems in the study catchments.

3.2.1 Scenarios on livestock management

Modelling changes in livestock density requires knowledge about the current conditions in the study catchments. O'Boyle *et al*. (2017) used data from the census of agriculture in 2010 (CSO, 2012b) to determine the stocking density (i.e. livestock units per hectare – LU/ha) in the Blackwater catchment, from the numbers of animals raised in the catchment and the stocking rates associated with each type of animal. The same methodology was used here to determine the baseline stocking density in the three study catchments. However, in addition to dairy cows and cattle, sheep are also included in the stocking density because they are important in the Moy and the Dodder.

Agricultural intensification

The scenario of agricultural intensification corresponds to a managed increase in the livestock density in the catchment. To determine the likely magnitude of change in livestock density, information on the current livestock numbers in Irish catchments is required. Intensification is explored by increasing the number of animals for the dominant animal raised in each study catchment by 50%, i.e. dairy cows in the Suir and sheep in the Moy and the Dodder. Three different levels of increase in the animal numbers are considered as a means of sensitivity analysis on the water quality results; these are +10%, +30% and +50% (Table 3.1).

Agricultural extensification

Agricultural extensification is the opposite of intensification and corresponds to a decrease in the livestock density in the catchment. As a result, extensification is explored by decreasing the number of animals for the dominant animal raised in each study catchment. Two levels (–10% and –20%) of decrease

Table 3.1. Predicted nitrate, ammonia and orthophosphate concentrations in the rivers for each combination of catchment and scenario

Catchment	Baseline	Intensification (+10%)	Intensification (+30%)	Intensification (+50%)	Extensification (–10%)	Extensification (–20%)	Riparian management (50% eff.)	Riparian management (100% eff.)
Nitrate (mg/L N)								
Dodder	**0.671**	0.693	0.738	**0.783**	0.649	**0.626**	**0.555**	0.439
Moy	**0.193**	0.195	0.200	**0.204**	0.191	**0.189**	**0.144**	0.094
Suir	**1.894**	1.934	2.013	**2.093**	1.855	**1.815**	**1.380**	0.867
Ammonia (mg/L N)								
Dodder	**0.0552**	0.0570	0.0607	**0.0644**	0.0534	**0.0515**	**0.0440**	0.0329
Moy	**0.0149**	0.0150	0.0154	**0.0157**	0.0147	**0.0145**	**0.0104**	0.0060
Suir	**0.0371**	0.0379	0.0394	**0.0410**	0.0363	**0.0355**	**0.0253**	0.0136
Orthophosphate (mg/L P)								
Dodder	**0.0316**	0.0318	0.0322	**0.0326**	0.0314	**0.0312**	**0.0306**	0.0297
Moy	**0.0071**	0.0072	0.0073	**0.0074**	0.0070	**0.0070**	**0.0063**	0.0054
Suir	**0.0110**	0.0111	0.0114	**0.0117**	0.0109	**0.0107**	**0.0098**	0.0086

Notes: The meaning of the colours of the dots is provided in Table 3.2. The columns in bold are those used for the Bayesian belief network in the following section.

in the animal numbers were considered as a means of sensitivity analysis on the water quality results.

3.2.2 Scenario on riparian management

The scenario of riparian management corresponds to the introduction of vegetated buffer strips along the riverbanks to retain some of the nutrient runoff on the land and to prevent it from reaching the river. The most up-to-date knowledge on the efficiency of buffer strips to trap nutrient runoff estimates reductions of up to 60% in nitrate, 70% in ammonia and 30% in P (Cost Action 15206, 2019, unpublished literature review). Moreover, the sediment retention efficiency can be expected to go up to 50% (Newell Price, 2011). During the development of the bankside vegetation, these maximum efficiency values may not be achieved and the actual result will depend on many factors, some of which are catchment specific. Because, with the resources and data available, we cannot give specific values for each catchment, we instead perform a sensitivity analysis to (1) indicate the sensitivity of the valuations to the effect of riparian management and (2) to put upper and lower limits on the change in ecosystem values that can be achieved. Therefore, two levels of efficiency were considered in the sensitivity analysis on the water quality results, 50% efficiency and 100% efficiency, and these are compared with a baseline of no riparian management.

3.3 Use of the Nutrient Export Model to Determine Inputs from Land Use (Step 4)

SLAM is a nutrient modelling framework specifically developed for Irish catchments. It uses the current understanding of hydrogeological flow pathways along which nutrients are transported through Irish catchments. In addition, it makes use of the most detailed and up-to-date data about nutrient management in Irish catchments (Mockler *et al.*, 2017). SLAM considers both diffuse and point sources of pollution, including diffuse agricultural sources (arable, pasture, peatlands, forestry), diffuse urban sources and atmospheric deposition as well as direct point discharges (industry, urban wastewater and septic tank systems). The model estimates nutrient retention in the catchment and nutrient attenuation in lakes to predict average annual nutrient exports for all catchments in Ireland.

For the three study catchments, SLAM determines the annual average loads of total N and total P exported from each. The total exports and the load apportionment from the model are illustrated in Figure 3.1 for each catchment separately. The main sources of N export are pasture and diffuse urban runoff for the Dodder and pasture for the Suir and the Moy. Regarding P, the Dodder's export is dominated by urban runoff, while the sources for the Suir and the Moy are more diverse, with pasture as the main contributor, but they also have contributions from different point sources.

These annual loads are used for the baseline conditions in each catchment. Then, the effects of the different management scenarios on nutrient exports were applied to the relevant nutrient sources as given by SLAM: the percentage changes in livestock density owing to the scenarios on livestock management are applied to the nutrient loads corresponding to pasture only, while the percentage of nutrients trapped by buffer strips owing to the riparian management scenario are applied to the nutrient loads corresponding to pasture, arable, peat and forestry. All other sources of nutrients are unchanged between the baseline and the different management scenarios.

3.4 Use of the Hydrological Model and the Nutrient Export Model to Predict Changes in Water Quality (Step 5)

To determine nutrient concentrations in the river at the outlet of each study catchment, the predictions from the hydrological model and the nutrient export model were combined. The SMART hydrological model is used to predict the long-term average annual discharge (m^3/year) for the period 1990–2016, and SLAM and the three management scenarios are used to predict the average annual nutrient export (t/year) for the baseline and the three management scenarios. By combining the annual discharge (in units of water volume per year) and the relevant annual nutrient exports (in units of mass per year), a representative (average) concentration (in units of mass per unit volume, converted to an appropriate unit – mg/L) of total N and total P is determined in each study river for the baseline and each management scenario.

In order to relate these predictions to the impacts on the ecology in the river, using the Bayesian

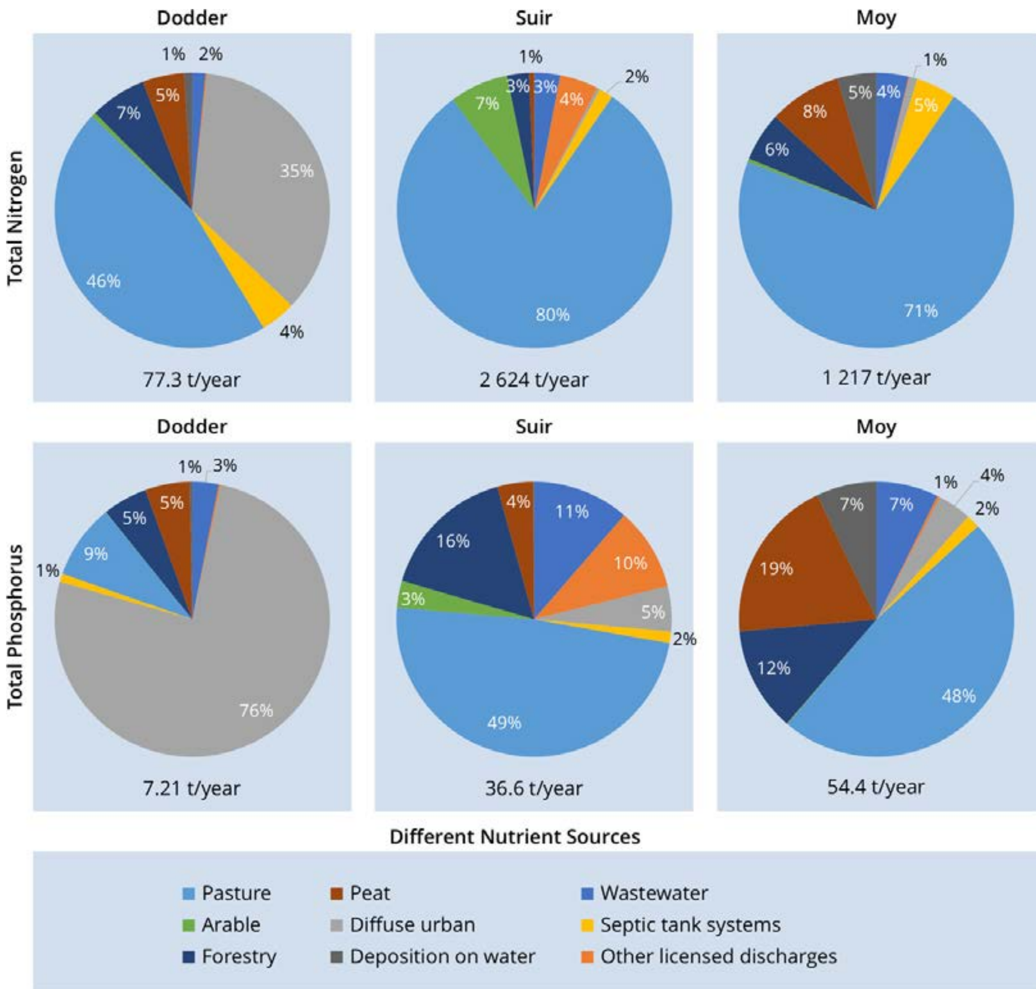

Figure 3.1. Nutrient export and load apportionment determined with SLAM in the study catchments.

Table 3.2. Definition of the thresholds for the three categories of concentration: high, medium and low

Nutrient	• High	• Medium	• Low
Nitrate	C > 2.0 mg/L N	0.8 mg/L < C < 2.0 mg/L N	C < 0.8 mg/L N
Ammonia	C > 0.065 mg/L N	0.040 mg/L < C < 0.065 mg/L N	C < 0.040 mg/L N
Orthophosphate	C > 0.035 mg/L P	0.025 mg/L < C < 0.035 mg/L P	C < 0.025 mg/L P

belief network (BBN) model, concentrations of ammonia, nitrate and orthophosphate are also required. Water quality monitoring data for the period 2015–2018 were used to determine the average proportions of total N as ammonia, total N as nitrate and total P as orthophosphate. These proportions allow the concentrations of ammonia, nitrate and orthophosphate to be calculated from the total N and total P exports predicted as described previously. Table 3.1 summarises the water quality predictions for the baseline conditions and each of the three management scenarios in the three study rivers. These results can be compared with the threshold conditions shown in Table 3.2 to define the categories used as the input in the ecological modelling component (BBN) detailed in the next chapter.

4 Modelling Ecological Responses and Changes in the Levels of Benefits (Steps 6 and 7)

4.1 Model Selection

While there are many, well-proven, models of the hydrological response of catchments and of the variation of physical water quality parameters, modelling the biological responses to complex water quality changes, e.g. of macroinvertebrates, fish, birds or mammals, is challenging and in its infancy. Although a large number of empirical data and field observations exist, extracting usable sub-models from these is difficult and has been done for only a limited number of specific interactions. Despite this modelling lacuna, this project required a model of biological response to simulate the effects of management decisions on ecology. BBNs are a class of models able to fill this gap.

4.1.1 Bayesian belief networks

A BBN is built on a graphical conceptual representation of the important variables and interactions between them required in a model. It consists of a collection of nodes, representing model states, connected by links showing the influence of each node on others in the network. Network models are widely used to represent many different technical, social and biological phenomena, for instance internet traffic, social network linkages, transport (aeroplane, boat, road) systems, food chains and protein interactions. In classical network models, each link denotes an interaction between the nodes it connects. For practical simulations, the strength and direction of the interactions must be specified and these are combined at each node, typically in equations developed empirically from analysing experimental data or field observations. However, for complex sets of interactions, with many nodes influencing many others, such equations become very complex and, for many situations, have not yet been developed. In the absence of proven equations, expert knowledge can be used to help define both the network structure and the strength of the interactions between nodes, expressed as conditional probabilities. This knowledge can be represented in conditional probability tables, which contain the relative probabilities (here expressed as percentages) of a particular level of the output variable occurring for every possible combination of the input variables. Some examples are provided in the next section.

4.2 A Bayesian Belief Network for ESManage

A network diagram was constructed for each service and then combined into a single network model. Each was reviewed by domain experts, fisheries and aquatic scientists, at a series of workshops where they also helped populate the underlying conditional probability tables.

The probability table for a given node describes the probabilities of each possible outcome for that node from every combination of the variables linking into the node. Take for example the “quality of trout angling (good, medium or poor)”, which can be influenced by both trout density and condition as illustrated in Table 4.1.

For practical reasons, i.e. to keep the dimensions of the probability tables to a manageable size, a maximum of four levels per variable was typically allowed and three levels were used where appropriate. In addition, if more than four factors influenced a single quantity, then some intermediate variables, each influenced by four or fewer factors, were sought. Although this increases the number of conditional probability tables to be populated, each is of a size that is more easily managed, in soliciting expert knowledge, to maintain consistency.

The final form of the combined BBN model for ESManage is shown in Figure 4.1. On the left-hand side are two boxes (highlighted in the coloured oval shapes) that can accept user input. One box allows the user to choose the catchment to be analysed. Currently, there are three catchment options – the project study catchments, namely Suir, Moy and Dodder – but there would be little additional difficulty in adding more catchments. The second box allows the user to select from a list of management strategies. In the current version, there are four options (no

Table 4.1. Conditional probabilities for quality of trout angling

Trout condition	Trout density	Conditional probability (%) of quality of trout angling		
		Good	Medium	Poor
Good	High	100	0	0
Good	Moderate	50	30	20
Good	Low	25	50	25
Moderate	High	50	30	20
Moderate	Moderate	25	50	25
Moderate	Low	20	40	40
Poor	High	25	50	25
Poor	Moderate	20	40	40
Poor	Low	0	0	100

change, riparian management, intensification and extensification).

On the right-hand side of the figure there are five output boxes that show the effect of the choice of catchment and management strategy on the chosen ecosystem services. Two boxes show the effect on wildlife (via the surrogates dipper density and mayfly richness). Water quality is also represented by two boxes: algal scum and human health risk (i.e. from pathogens). Cultural services are represented by a single box, related to angling quality, which depends on both trout and salmon angling quality.

4.2.1 Uncertainty analysis

Many of the conditional probability tables were filled in by multiple groups in the workshops and the average of the table values from each group was taken for the final BBN. In addition, the coefficient of variation (i.e. the standard deviation divided by the mean value) was calculated for each value where multiple tables were completed and these indicated whether or not there was general agreement or divergence between groups. An example is in Table 4.2 for dissolved oxygen. The values are colour coded, with the higher values in darker red and the lower values in darker green. For instance, the value with a dark red background, for the case of medium water temperatures, high biochemical oxygen demand (BOD) and high eutrophication, the coefficient of variation for the probability of medium dissolved oxygen is 2.36, indicating large differences between the groups for the effect of this combination of factors. In contrast, the coefficient of variation for low dissolved oxygen when the water temperature is high, the BOD is low and the eutrophication risk is high is 0.05; this is shown in a green background, indicating substantial agreement between the groups for the effect of this combination of factors. In this table most of the uncertainty is for the combinations that give high dissolved oxygen and general agreement for the conditions causing low dissolved oxygen.

4.3 Effect of Management Scenarios

To estimate the effect of each management scenario, an "expected value" for each ecosystem service was calculated from the conditional probabilities for each level of the service for a baseline "no change" scenario. The corresponding expected value was then calculated for each of the management scenarios and for each catchment separately. The effect of each management scenario in each catchment was then estimated by subtracting its expected value for each ecosystem services from the corresponding baseline value. For instance, the effect of each management scenario on mayfly richness for each catchment is shown in Table 4.3. The changes are shown as absolute differences and as percentages of the baseline value. It shows that riparian management in the Moy is predicted to lead to a 35.9% increase in mayfly richness. Table 4.4 shows the corresponding values for filamentous algae. In both tables the direction and magnitudes of the predicted changes for each management scenario seem plausible. Table 4.5 summarises the estimates for dippers and Table 4.6 for the angling service.

These estimates of the changes in ecosystem services resulting from the management scenarios were used in an economic analysis of the value/cost of the predicted changes.

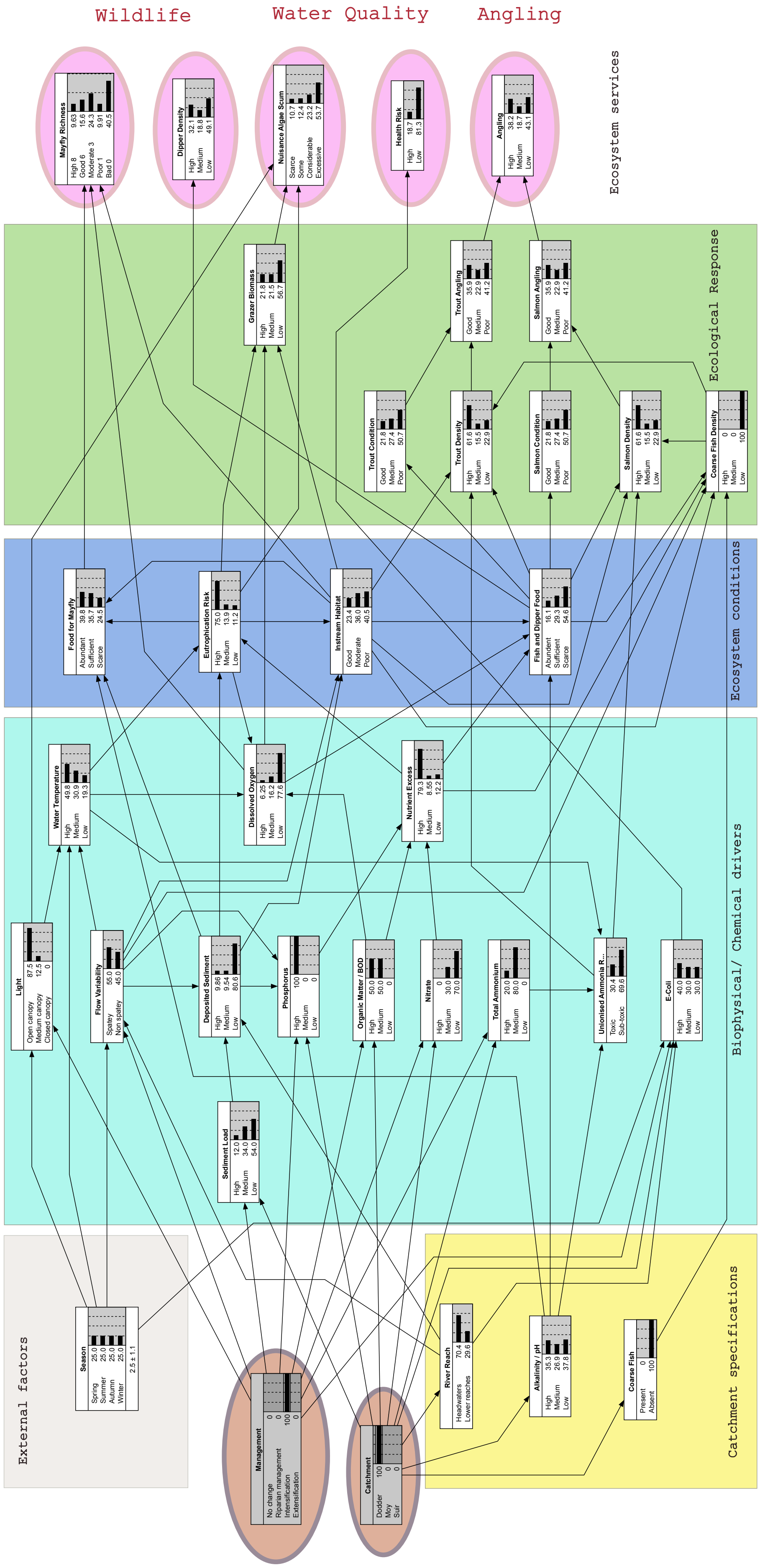

Figure 4.1. Structure of the final ESManage BBN model.

Table 4.2. Coefficients of variation for conditional probabilities for dissolved oxygen

Water temperature	BOD	Eutrophication	Dissolved oxygen		
			High	Medium	Low
High	High	High	0.00	0.00	0.00
High	High	Medium	1.41	1.41	0.04
High	High	Low	1.41	1.41	0.00
High	Medium	High	1.41	0.47	0.09
High	Medium	Medium	0.00	0.24	0.00
High	Medium	Low	0.16	0.13	0.00
High	Low	High	1.41	0.18	0.05
High	Low	Medium	0.00	0.57	0.16
High	Low	Low	0.00	0.57	0.47
Medium	High	High	1.41	2.36	0.00
Medium	High	Medium	1.41	1.41	0.00
Medium	High	Low	1.41	1.01	0.09
Medium	Medium	High	1.41	0.57	0.20
Medium	Medium	Medium	0.20	0.00	0.07
Medium	Medium	Low	0.28	0.33	0.08
Medium	Low	High	1.41	0.16	0.05
Medium	Low	Medium	0.00	0.28	0.20
Medium	Low	Low	0.08	0.85	1.41
Low	High	High	1.41	0.94	0.04
Low	High	Medium	1.41	0.71	0.09
Low	High	Low	0.00	0.88	0.20
Low	Medium	High	0.85	0.79	0.33
Low	Medium	Medium	0.00	0.35	0.14
Low	Medium	Low	0.47	0.18	0.47
Low	Low	High	1.41	0.39	0.16
Low	Low	Medium	0.08	0.11	0.28
Low	Low	Low	0.00	0.00	0.00

Table 4.3. Effect of management scenarios on mayfly richness for each catchment

Catchment	Management option	Water quality (mayfly richness)					Score	Absolute change	Relative change (%)
		High (8)	Good (6)	Moderate (3)	Poor (1)	Bad (0)			
Dodder	No change	13.8	16.1	23.6	9.64	36.6	2.87		
	Riparian management	22.0	16.3	22.6	9.14	29.9	3.51	0.63	22.0
	Intensification	9.99	15.6	24.2	9.92	40.2	2.56	–0.31	–10.9
	Extensification	17.4	16.0	23.1	9.22	34.3	3.14	0.26	9.1
Moy	No change	20.4	15.8	22.1	9.36	32.2	3.34		
	Riparian management	38.1	14.5	18.0	7.6	21.7	4.53	1.20	35.9
	Intensification	13.2	15.8	23.5	10.0	37.5	2.81	–0.53	–15.8
	Extensification	29.4	15.1	20.0	8.3	27.2	3.94	0.60	18.1
Suir	No change	19.0	15.5	22.2	9.35	33.9	3.21		
	Riparian management	34.5	14.8	18.9	7.97	23.7	4.29	1.09	33.8
	Intensification	12.3	15.1	23.3	9.73	39.5	2.69	–0.52	–16.3
	Extensification	25.6	15.2	20.8	8.61	29.8	3.67	0.46	14.4

Table 4.4. Effect of management scenarios on filamentous algae for each catchment

Catchment	Management option	Algal cover (%[a])				Score	Absolute change	Relative change (%)
		Scarce (97.5)	Some (87.5)	Considerable (64)	Excessive (20)			
Dodder	No change	13.2	14.2	22.9	49.7	49.89		
	Riparian management	19.1	15.9	23.0	42.0	55.66	5.76	11.6
	Intensification	11.0	12.7	23.2	53.1	47.31	–2.59	–5.2
	Extensification	14.8	14.8	22.6	47.8	51.40	1.51	3.0
Moy	No change	18.4	18.1	21.9	41.5	56.09		
	Riparian management	28.7	22.1	20.4	28.8	66.14	10.04	17.9
	Intensification	14.1	15.4	22.7	47.7	51.29	–4.80	–8.6
	Extensification	23.0	20.0	20.8	36.1	60.46	4.36	7.8
Suir	No change	18.2	18.1	22.0	41.8	56.02		
	Riparian management	27.1	21.4	20.8	30.7	64.60	8.58	15.3
	Intensification	13.8	15.1	22.7	48.5	50.90	–5.13	–9.2
	Extensification	21.3	19.3	21.3	38.1	58.91	2.88	5.1

[a]Score is area clear of algae (%).

Table 4.5. Effect of management scenarios on dipper density for each catchment

Catchment	Management option	Water quality (dipper abundance)			Score	Absolute change	Relative change (%)
		High (2)	Medium (1)	Low (0)			
Dodder	No change	36.4	19.2	44.4	0.92		
	Riparian management	41.4	19.5	39.1	1.02	0.10	11.2
	Intensification	32.9	18.9	48.2	0.85	–0.07	–7.9
	Extensification	38.6	19.3	42.1	0.97	0.04	4.9
Moy	No change	54.1	20.3	25.6	1.29		
	Riparian management	63.8	18.8	17.4	1.46	0.18	13.9
	Intensification	48.9	20.8	30.4	1.19	–0.10	–7.7
	Extensification	59.1	19.5	21.4	1.38	0.09	7.2
Suir	No change	50.8	20.1	29.1	1.22		
	Riparian management	59.5	19.2	21.2	1.38	0.17	13.6
	Intensification	45.1	20.3	34.7	1.11	–0.11	–9.2
	Extensification	54.7	19.7	25.6	1.29	0.07	6.1

Table 4.6. Effect of management interventions on angling

Catchment	Management option	Angling (number of catchable fish)			Score	Absolute change	Relative change (%)
		High (5)	Medium (2)	Low (1)			
Dodder	No change	41.8	18.5	39.8	2.86		
	Riparian management	46.5	17.9	35.6	3.04	0.18	6.3
	Intensification	38.7	18.7	42.6	2.74	–0.12	–4.3
	Extensification	43.2	18.2	38.6	2.91	0.05	1.8
Moy	No change	40.6	18.1	41.2	2.80		
	Riparian management	47.8	17.9	34.3	3.09	0.29	10.2
	Intensification	37.6	18.0	44.4	2.68	–0.12	–4.3
	Extensification	43.7	18.1	38.1	2.93	0.12	4.4
Suir	No change	38.4	18.1	43.5	2.72		
	Riparian management	45.6	17.9	36.5	3.00	0.29	10.5
	Intensification	34.9	17.9	47.2	2.58	–0.14	–5.2
	Extensification	40.9	18.1	40.9	2.82	0.10	3.6

5 Evaluation of the Economic Benefits Associated with Enhancements to River Ecosystem Services (Step 8)

5.1 Approach

This chapter describes the approach used to assess the economic value of changes to river ecosystem services associated with policy options targeted at meeting Ireland's WFD commitments. A review of alternative approaches to valuing freshwater services is provided in Kelly-Quinn *et al*. (2019). Key approaches are summarised in Box 5.1. Based on this review, we conclude that the choice experiment method is the most appropriate technique for this study. Details of choice experiment theory are given in Kelly-Quinn *et al*. (2019).

The choice experiment methodology was used to value changes to river ecosystem services under alternative river policy scenarios. Choice experiments are a stated preference survey technique that requires survey respondents to complete a series of choice tasks (see Figure 5.1). Each choice task comprises (usually) three hypothetical policy options: two options relating to alternative policy scenarios and a third option relating to a baseline scenario. Each policy option is described in terms of a bundle of environmental attributes and a cost attribute, where the levels of the environmental attributes reflect predicted policy outcomes. Respondents are required to trade off alternative bundles of attributes which are varied by means of an underlying statistical design. The process of making these successive choices can be used to reveal the effect that any one attribute level has on the probability of choice, to which a monetary value can be estimated effected by the inclusion of a cost attribute.

In our study, these attributes related to five river ecosystem services (water quality, water health, buffer strip (habitat), wildlife and angling). The changes to river services evaluated in the choice experiment reflected a change from the current situation to one in which river services were enhanced to a level that would meet the EU WFD "satisfactory" standards. In addition, we also evaluated, as previously mentioned, three river catchment policy scenarios: intensification, extensification and riparian zone management.

A total of 469 people were interviewed for the choice experiment study. Of these, 350 were asked about

Box 5.1. Methods for primary valuation

- *Market prices*: used to assess the value of services that have direct market value. Predominantly, market prices are available only for provisioning services such as the market price of fish.
- *Costs-based approaches* (replacements costs, damage costs avoided and production functions): these approaches assess value through the costs of providing the services elsewhere in the economy, for example reduced costs of flood damage or expenditures on the costs of alternative flood management infrastructure.
- *Revealed preferences* (travel cost method and hedonic pricing): used where the values that people derive from freshwater services are revealed by their behaviour in related markets. For example, the travel cost method can use the cost (expenditures and time) of travel to a river as a means to determine the recreational value of that river, while the hedonic pricing method uses evidence of house price premiums to measure how much people are willing to pay for the amenity benefits of properties close to, for example, a river.
- *Stated preferences* (contingent valuation and choice experiments): use surveys to ask people directly about their willingness to pay (WTP, or willingness to accept compensation) for the services that are delivered by freshwater ecosystems. One advantage of the choice experiment method is that it allows the attributes of environmental good to be valued.

Further details can be found in Eftec (2006) and Christie *et al*. (2008).

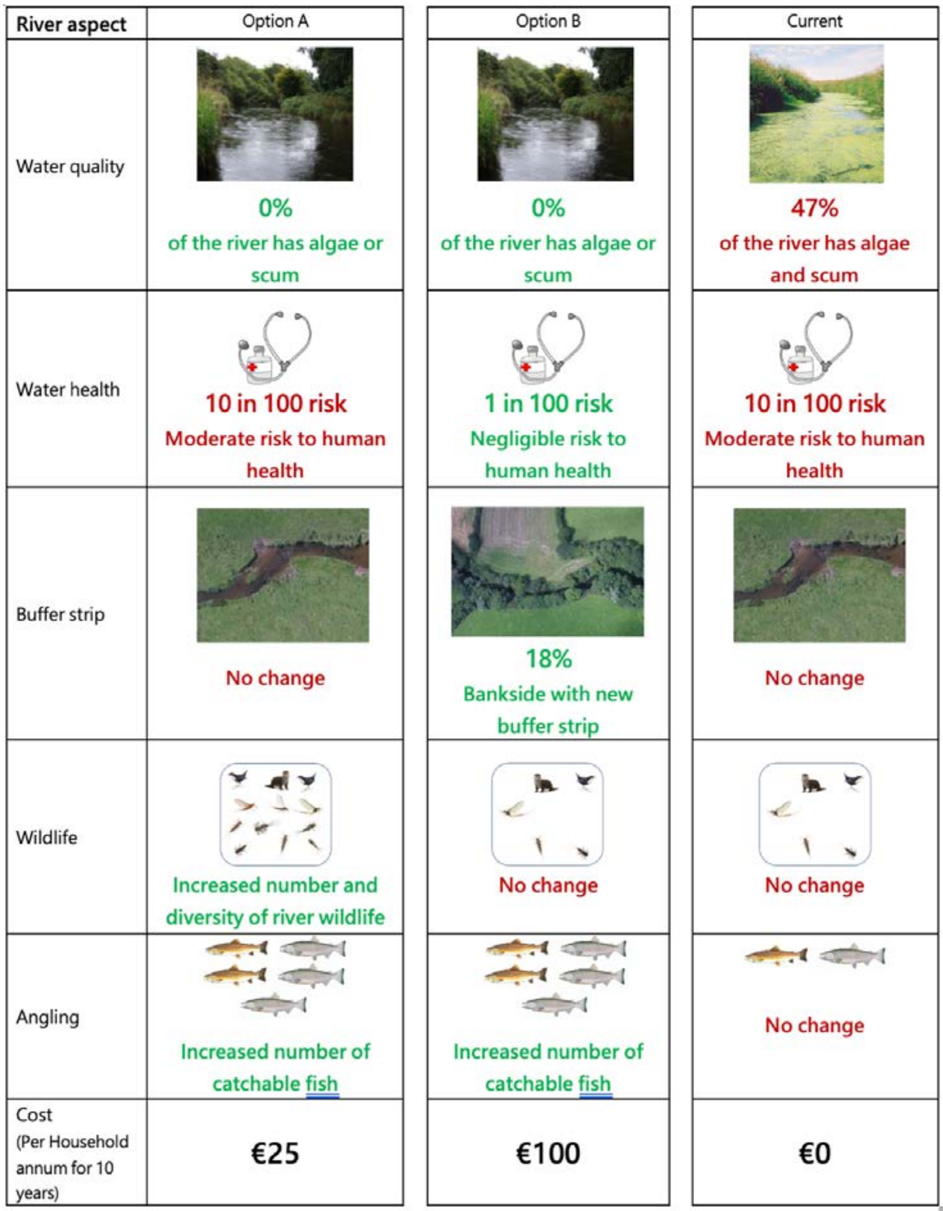

Figure 5.1. Example of a typical choice experiment choice task (from the River Moy).

their values for improvements to river services at three rivers: 118 people at the Dodder, 111 at the Moy and 121 at the Suir. A further 119 people were asked about their values for improvements to river services across all Irish rivers; 55 and 64 people were interviewed in Dublin and Galway, respectively. During the interviews, respondents were asked about their interactions with the case study rivers and were then asked to complete a series of choice tasks. An example of a typical choice task is provided in Figure 5.1. The choice experiment data were analysed using a conditional logit model to generate WTP values for changes to the river services (further details are provided in Kelly-Quinn *et al*., 2019).

5.2 Valuation of the Ecosystem Service Benefits Associated with Achieving the EU WFD Targets

Survey respondents were, on average, willing to pay the most to improve river wildlife (average WTP was between €54 and €68 per household per year to improve wildlife in the Moy and the Dodder) (Table 5.1). The next highest valued services were improved water quality (€48 for the Moy and the Dodder and €59 for the Suir) and improved water health (€45 for the Moy and the Dodder and €59 for the Suir). Lowest values were found for improved buffer strip (i.e. planting trees on pasture next to the river) and improved angling. Summing across these river services, it is estimated

Table 5.1. Economic value of river services by river (€ per household per year)

River service	Dodder (€)	Moy (€)	Suir (€)	Galway and Dublin, all rivers[a] (€)
Improved water quality	48.3	48.5	59.1	56.8
Improved water health	45.5	45.2	59.6	50.9
Improved buffer strip	41.2	36.7	36.8	42.3
Improved wildlife	68.3	54.8	65.9	69.1
Improved angling	19.2	28.8	28.8	25.3
All services	223	214	250	244
All services (lower bound)	189	164	203	195
All services (upper bound)	257	263	298	294

[a]The "All rivers" survey was based on interviews held in Dublin and Galway.

that, on average, Irish people would be willing to pay between €214 and €250 per household per year to meet the EU WFD targets. An aggregate value was also estimated by multiplying the per household values with the number of households living in that catchment. Achieving the EU WFD targets were estimated to generate aggregate benefits of between €20.2 million per year in the River Dodder and just under €6 million in the Rivers Moy and Suir.

Unfortunately, we did not have detailed enough evidence to systematically aggregate our findings across all river catchments in Ireland. However, as an illustration of the potential benefits that could be achieved by implementing the WFD across Ireland, we took the mean value per household per year by averaging across our three case study rivers (€229 per household per year) and multiplied this by the number of households in Ireland (€1.7 million households). Based on this analysis, we estimate that achieving the WFD targets across Ireland could generate €390 million in benefits from enhanced river services.

5.3 Valuation of River Catchment Enhancement Policy Scenarios

Our evaluation of the benefits associated with the three river catchment management policy scenarios (intensification, extensification and riparian management) involved two stages. The first involved an assessment of the extent to which the different management scenarios would impact the delivery of the different river services. For this assessment, we developed a BBN model (described in Chapter 4) that linked the three management scenarios to changes to the delivery of river services. The second stage involved scaling the values of river services (elicited in the choice experiment) to the levels of change in services provision under the management scenarios (as predicted in the BBN model).

Based on this analysis, the management option most highly valued was the riparian management option, which was valued at €107 per household per year on the River Suir, €90 on the Moy and €85 on the Dodder (Table 5.2). The river service benefits associated with the extensification scenario were broadly one-third those of the riparian management scenario. The intensification scenario resulted in negative values for all of the river services, with a total loss in welfare of €55 per household per year in the Suir and €36 per household per year in the Dodder. Note that in the intensification scenario a standard level of intensification (a 50% increase in the dominant livestock numbers) was assumed across all three catchments; however, this level of increase is unlikely to be achieved in the Dodder catchment. In addition, the Dodder's smaller size and greater heterogeneity means it has a larger modelling uncertainty than the other study catchments, so the value for the Dodder catchment should be considered an upper bound estimate. It should, however, be noted that the values reported in Table 5.2 should be considered conservative estimates of the values of river services in that they include only five river services (albeit the most important ones); other potential river services are not considered in this analysis.

The values reported in Table 5.2 relate to values per household. The final stage of the analysis is to estimate the total value across all people affected by the change. In our research, we assume that the affected population are people who live in the river catchment. Thus, our aggregate value was estimated by multiplying the per household values with the

Table 5.2. Value of changes in river services (€ per household per year) by river and management option

Catchment	Management	Improved water quality (€)	Improved water health (€)	Improved buffer strip (€)	Improved wildlife (€)	Improved angling (€)	All river services (€)
Dodder	Riparian management	4.80	27.30	41.20	8.92	3.48	85.70
	Intensification	–2.15	–26.39	0.00	– 5.17	–2.36	–36.08
	Extensification	1.26	13.51	0.00	3.78	1.00	19.55
Moy	Riparian management	10.36	27.12	36.70	13.10	2.76	90.04
	Intensification	–4.96	–26.22	0.00	–6.32	–1.15	–38.65
	Extensification	4.50	13.42	0.00	6.66	1.19	25.77
Suir	Riparian management	18.10	35.76	36.80	14.38	2.75	107.79
	Intensification	–10.82	–34.57	0.00	–8.00	–1.36	–54.75
	Extensification	6.09	17.69	0.00	6.23	0.95	30.97

number of households living in that catchment (again we note that this is likely to be a conservative estimate, as people living outside the catchment may also have values for the river). The riparian management policy was found to generate €7.76 million per year of river service benefits in the Dodder catchment and €2.47 million in the Suir catchment and €2.44 million in the Moy catchment (Table 5.3). In contrast, intensification of land use and the resultant deterioration in river services would result in welfare losses of €3.27 million per year in the Dodder catchment, €1.26 million in the Suir and €1.05 million in the Moy (Table 5.3).

As stated previously, we did not have detailed enough evidence to systematically aggregate our findings across all river catchments in Ireland. However, as an illustration of the potential benefits that could be achieved by implementing the three catchment scenarios across Ireland, we take the mean value per household per year from across our three case study rivers and multiply this by the number of households in Ireland (Table 5.4). Based on this analysis, riparian management has the potential to generate €160 million per year, while extensification would provide €43 million per year. Intensification would result in a loss in welfare of €73 million per year (Table 5.4). The upper and lower bound estimates were estimated using the highest and lowest per household value, respectively, from our case study river.

5.4 Assessment of Angler Values for River Ecosystem Services

In addition to the choice experiment survey of public users of rivers, a further survey was carried out with anglers in the Moy catchment. A choice experiment approach was again used; prior to this 15 semi-structured interviews were conducted with anglers, mostly experienced club members and gillies (fishing guides) (results are given in the ESManage Final Technical Report).

Questionnaires were posted to around 200 anglers and 78 were returned, giving a response rate of 39%. In the event, only members of the East Mayo Angling Club were surveyed as co-operation from other clubs or beats on the river was not forthcoming. This does mean that respondents were mostly thinking about salmon when answering the questions (i.e. rather than trout), as this club has rights to the faster upper reaches of the river. However, around 10% of the sample is composed of visitors from Northern Ireland or Great Britain and a handful of visitors are from continental Europe.

The choice task received by each angler consisted of six "choice sets". These required anglers to choose between two sets of three fishing scenarios containing the four attributes of (1) fish size (weight), (2) fish number, (3) water quality and (4) trip price, each presented at one of three levels as listed below (see example in Figure 5.2). The definition of trip price is restricted to the cost of a day's fishing, i.e. a fishing permit:

- largest fish size: 3 lb, 5 lb, 9 lb;
- number of fish per day: one every 2 days, two, four;
- water quality: moderate, good, excellent;
- trip price: €25 per day/€100 per week, €40 per day/€150 per week, €50 per day/€190 per week.

Table 5.3. Total value of changes in river services (€ million per year) by river and management option

Catchment	Households living in the catchment	Management	Value per household (€ per household per year)	Aggregate value (million € per year)
Dodder	90,551	Riparian management	85.70	7.76
		Intensification	–36.08	–3.27
		Extensification	19.55	1.77
Moy	27,122	Riparian management	90.04	2.44
		Intensification	–38.65	–1.05
		Extensification	25.77	0.70
Suir	22,924	Riparian management	107.79	2.47
		Intensification	–54.75	1.26
		Extensification	30.97	0.71

Table 5.4. Illustrative estimates of the value of river services from catchment management options applied across Ireland

Management	Mean value across our three rivers (€ per household per year)	Number of households in Ireland	Aggregate value of river services across Ireland (million € per year)	Aggregate value of river services across Ireland: lower bound (million € per year)	Aggregate value of river services across Ireland: upper bound (million € per year)
Riparian management	94.51	1,702,289	160.88	145.89	183.49
Intensification	–43.16	1,702,289	–73.47	–65.79	–93.20
Extensification	25.43	1,702,289	43.29	33.28	52.72

Q. **Which alternative angling trip do you prefer?**

	TRIP A	**TRIP B**	**TRIP C**
Largest salmon for the trip	3lb	5lb	9lb
Number of all-sizes of fish caught per trip	4	2	4
Water quality	Good	Excellent	Moderate
Trip price	€25 per day	€25 per day	€40 per day
I prefer:	☐	☐	☐
My second choice would be	☐	☐	☐

Figure 5.2. An example of the choices given to the anglers.

Cumulatively, the returns provide evidence of the marginal value that anglers place on each attribute level. This can be interpreted as the relative influence that each attribute level has on the angler's choice of trip A, B or C.

Of the attributes, there is a natural relationship between water quality and catch, as salmonids do not linger in stretches of poorer water quality. Typically, poor water quality is not a feature of the Moy, although anglers claim it to be bad in the vicinity of some wastewater outlets. Price (trip cost) was included to further force a trade-off and to provide a monetary value of WTP.

To provide realism and account for different groups of anglers, the first three choice sets were defined as being trips for "small fish and grilse (single-sea-winter salmon)" and contained the two lower levels of fish size and trip price and the two higher levels of number. The second three trips were defined as being for "larger fish and springers (multi-sea-winter salmon)" and contained the two higher levels of weight and trip price and the lower level of number.

5.5 Survey Results

A return of 78 questionnaires is about the smallest sample that can be analysed and does not easily permit division into subsamples of different types of anglers (e.g. by level of experience, visiting or trout anglers). However, there is good variability in the sample, as anglers are very mixed in their beliefs and in what they value about a day's fishing.

Prior to the choice experiment section of the questionnaire, only 8% of anglers had said that their main preference was to "catch a large fish". In the choice experiment, however, the value placed on the highest fish size (9 lb) was very high relative to other attributes, indicating that this attribute level is much preferred compared with a baseline and has a big influence on the angler's choice of trip, i.e. a 9 lb fish was far more likely to be preferred than a larger number of 3 lb fish. There was also evidence of a preference for large fish among those who prefer to fish in February/March, when springers may be present (i.e. large multi-sea-winter salmon that have spent more time at sea feeding). A large catch of fish (four) and water quality (excellent) were also rated highly, with values of equivalent size to one another. A moderate catch (two) was only valued slightly. While water quality (good) had a negative value relative to the higher quality (excellent), this value was still higher than for water quality (moderate).

Overall, the result suggests that anglers' preferences for fish size and water quality do vary, with the variation being much greater and slightly more significant for water quality. The source of variation could not be attributed to any one characteristic of individual anglers aside from their expressed preferences and possibly income. A larger sample size, and the inclusion of clubs downriver, would probably reveal more variation in preferences.

In terms of WTP for a day trip (normally €50), this is estimated to increase to €128.14 where there is the prospect of catching a fish weighing 9 lb. It increases to €66.10 where there is a prospect of catching four fish per day and to €61.69 where water quality can be described as excellent.

5.6 Relevance to Ecosystem Services

The relative coefficient values can be compared with those from the broader stakeholder workshops. Angling is a final ecosystem service and primarily a cultural service, given that any salmon caught above the daily bag limit must be returned to the river through tag quotas and catch-and-release programmes. Water quality is a result of the balance of pollution and the effect of regulating ecosystem services. The value placed on water quality indicates its relative importance. This value is supported by the results of an earlier question in the angler questionnaire which found that 65% of anglers thought it was worth paying extra for high water quality, although most would appear to have opted for large fish size or a good catch number when forced by the choice experiment to trade higher water quality against these other characteristics. Nevertheless, the value placed on water quality was trumped by fish size or number for only 4% of anglers.

5.7 Wastewater Treatment Costs

Aquatic ecosystems have the capacity to self-clean, as nutrients are consumed by microfauna, and harmful pollutants and bacteria are assimilated by other fauna and flora. The objective behind the examination of wastewater treatment costs was to determine a "surrogate value", i.e. an equivalent public good value, for a corresponding reduction in nutrients and other pollutants to levels that can be assimilated by the aquatic ecosystem to achieve a sufficiently high quality of water. The value of the ecosystem service is effectively the cost avoided of further wastewater treatment to achieve this same high water quality.

Detailed EPA data are available for larger wastewater treatment plants. The performance of wastewater treatment plants is measured by the difference in BOD, N and P between the influent flow into the plant and the effluent. Figures were obtained from Irish Water in 2015 for the removal of these pollutants at different levels of treatment. Data on nutrient reductions and corresponding costs were analysed, for eight successively higher levels of treatment from baseline secondary to higher tertiary. Primary treatment begins with a lowering of levels of BOD and suspended solids, but it is only once tertiary treatment is installed that significant reductions occur in N, P and organophosphate. Estimates were made of the cost per kilogram of reducing these pollutants for wastewater treatment plants of different sizes, which operated for six population equivalent bands corresponding to settlements with successively higher levels of population. The data, from 2016, were based on a modest number of samples and represented preliminary data, but demonstrate a method that could provide more accurate estimates if informed by the more detailed data currently being collected by the water utility.

The cost data consisted of capital cost (CAPEX) data and treatment operating cost (OPEX) data for the eight successive levels of treatment for the six population equivalent bands between 50 and 50,000. As with pollutants, these data were preliminary sample data and do not always show consistent increases in cost with higher levels of treatment. Nevertheless, if the anomalies are smoothed out, it is possible to arrive at estimates of the additional OPEX per kilogram for increases in treatment where reductions in pollutants occur. These costs reduce proportionally for each size band.

It is possible to combine the actual or predicted physical reductions in N and P and the cost data for these same pollutants to determine the cost of treatment for most communities of more than 150 people in the Moy and Suir catchments (and for the Boyne, which was also examined). Smaller non-listed communities are assumed to be served by private septic tanks for which domestic waste would be managed by soil (rather than water) ecosystem services. The cost of treatment for the listed communities indicates what is spent to avoid undue pollution of the receiving waters, although for larger agglomerations the level of treatment is predetermined by legislation. Additional treatment costs are avoided, as the river is already able to provide a natural regulating ecosystem service that assimilates some of the sewage waste. This can mean that an urban area is able to get by with a lower level of wastewater treatment than might be needed elsewhere. The costs avoided by not having to operate at the next higher level of treatment are given by the last two columns of Table 5.5 and provide an indication of the value of the ecosystem service. These savings do not apply to those agglomerations which have already invested in the highest tertiary treatment, i.e. 3NP, as here no cost is avoided.

Table 5.5. Current costs of wastewater treatment and the additional annual OPEX in the absence of the ecosystem service

Catchment	Current OPEX (€)		Cost avoided of next-level treatment (€)	
	N	P	N	P
Moy	794,699	1,176,222	122,712	581,317
Suir	1,258,538	1,101,340	421,968	904,085
Boyne	1,939,930	1,834,222	283,543	1,263,520

6 General Conclusions and Recommendations

ESManage sets out to gather the information needed to embed the ecosystem services approach into policy and practice for sustainable management of freshwater resources as required by the WFD. The literature review and synthesis introduced the project to stakeholders and these were an integral part of the methodological framework adopted. While there are hundreds of studies dealing with various aspects of ecosystem services, few other studies have looked at these in the context of the WFD objectives. We adopted an eight-step methodological framework to address objectives 2–5, outlined in Chapter 1. We started with identification of the full range of ecosystem services derived from Irish freshwaters and concluded with the economic valuation of a number of ecosystem services associated with rivers. The final objective, to produce recommendations for policy, is dealt with here.

6.1 Selection of Ecosystem Services for Valuation

It is clearly impractical to value all ecosystem services, but we can, as undertaken in this project (Chapter 2), select those that represent a range of key benefits to people and, in terms of the WFD, respond to water quality change. The results of the workshops with the general public highlight the importance of cultural services and represent a way to connect people to freshwater resources and their protection.

Key message

Cultural services should be included as a key component of ecosystem services assessments.

It quickly became clear to the ESManage team that there are few datasets that enable linkages to be made between water quality and final ecosystem services and that there are multiple attributes that represent the quality of any one service.

Key message

To fully operationalise the ecosystem services approach, data are required on the quality and quantity/levels of key final ecosystem services. Related to this is the need to carefully select those ecosystem services attributes that best respond to changes in water quality and, at the same time, are meaningful to the general public and policymakers.

Incorporating regulating and maintenance services for valuation poses a particular challenge both in terms of data availability to describe linkages to water quality but also because they do not have the same “visibility” as provisioning and cultural services.

Key message

The range of ecosystem services should be extended to include important regulating and maintenance services such as water purification and decomposition of organic detritus.

In the interim, the cost of potable and wastewater treatment could provide a useful surrogate value for the benefit of aquatic regulating ecosystem services. The ESManage team did not have access to sufficient data on water treatment costs to provide a robust economic value.

6.2 Linking Pressures/Stressors to Ecosystem Services

A key challenge for the ESManage team, and similar projects, was making the links between stressor (P, N and sediment) inputs, impacts on aquatic ecology and the final ecosystem services. This is related, in part, to the aforementioned data deficits but also to the paucity of scientifically validated relationships for many of these linkages. We addressed this issue by using

BBNs to capture and use the knowledge and experience of experts for the unknown or poorly understood scientific relationships. The BBN used here reflects the information available to the project team at the time of writing. In the future, as more knowledge and data become available, the BBN can be modified to reflect the new information.

Key message

The methodological framework and BBN model are a key output of the project. The BBN can be used as a foundation for future work in this area and in other catchments.

A complicating factor in the development of models such as BBN is that freshwaters are seldom impacted by only a single stressor and more often multiple stressors interact (e.g. in additive, antagonistic, synergistic ways) to affect biodiversity, ecosystem function and ecosystem services. The result depends on the types and levels of the stressors, community structure/functions, ecosystem services providers, type of service and the period between stressor events (Jackson *et al*., 2016), which challenges the prediction of effects on ecosystem services. In their recent quantitative meta-analysis of 88 scientific publications dealing with 286 paired stressor effects in freshwater ecosystems, Jackson *et al.* (2016) showed that 56% of the combined effects were antagonistic, while only 28% were synergistic and 19% additive. While the BBN captures the experts' conceptualisation of the multi-stressor effects, these experts have not been exposed to all possible combinations (or levels) of stressors, so their knowledge is limited.

Key message

The links in the ESManage BBN models need to be strengthened over time as empirical data become available quantifying responses of ecosystem functions and services to multiple stressors. Within this context it is equally important that metrics, particularly those related to ecosystem function, are carefully chosen to capture the cumulative response to various combinations of stressors (Craig *et al*., 2017).

Despite the empirical data limitations, the BBN modelling provided a means to link catchment inputs to changes in the selected ecosystem services. BBN models are typically used in these types of situations where physically based models and data for their calibration either are not available or cannot be easily implemented. They allow expert knowledge and intuition, as well as available data, to be incorporated into the modelling system. Such knowledge informs both the structure of the BBN and the numbers in its conditional probability tables. In ESManage, this knowledge was acquired through an experts workshop and a follow-up series of focused meetings with specific domain experts. Experts can differ in their opinions, and ESManage attempted to capture such disagreement as well as where the experts concurred. This was done by dividing the experts into relatively small groups and collecting conditional probability tables for the same situations from each group, allowing indices of agreement/disagreement to be calculated. This information could be used to target any future workshops or further development of the BBN model to address areas of high uncertainty.

A further challenge of BBN modelling is to reduce the uncertainty in the conditional probability tables by seeking parsimony in the network structure while still capturing the key interactions and processes in the system. In practice, reducing the number of nodes and linkages (where possible) simplifies the process of populating the probability tables. Kuhnert and Hayes (2019) recommend that BBNs should undergo rigorous development in workshops with a range of experts, as was done by ESManage.

6.3 Economic Analysis

The economic analysis utilised the choice experiment method to value the ecosystem service benefits that would be generated (1) from achieving the EU WFD targets and (2) from three different river catchment management scenarios. In both cases, the valuation was based on the value of five river services, which were selected as the most likely to be enhanced as a result of catchment management and which were considered important to people. The five services evaluated were water quality, water health, buffer strip (habitat), wildlife and angling. Survey respondents most highly valued improvements to river wildlife (average WTP was between €54 and €68 per household per year to improve wildlife in the Moy and Dodder), water quality (€48 for the Moy and Dodder and €59 for the Suir) and water health (€45 for the Moy and Dodder and €59 for the Suir; see Table 5.1). Taking these river services into account, it is estimated that, on average, Irish people would be willing to pay between €214 and €250 per household per year to meet the EU WFD targets. When aggregated to the Irish population, meeting the EU WFD targets would generate around €389 million in benefits. We also investigated values for three catchment management scenarios. The management option most highly valued was the riparian management option (€107.79 per household per year on the river Suir, €90.04 on the Moy and €85 on the Dodder). The extensification scenario was broadly one-third that of the riparian management scenario. The Intensification scenario resulted in welfare losses of €55 per household per year in the Suir and €36 per household per year in the Dodder. Note that in the intensification scenario a standard level of intensification (a 50% increase in livestock numbers) was assumed across all three catchments; however, this level of increase is unlikely to be achieved in the Dodder catchment. In addition, the Dodder's smaller size and greater heterogeneity means it has a larger modelling uncertainty than the other study catchments, so the value for the Dodder catchment should be considered an upper bound estimate. Aggregating across the population of Ireland, it was estimated that a policy to implement riparian management would generate €107 million per year, while extensification would generate €43 million per year. Land use intensification would lead to a welfare loss of €66 million per year. It should be noted that these values should be considered conservative estimates of the welfare benefits associated with enhancing river water quality in that the values only reflect the five key river services benefits and that there are likely to be additional benefits associated with the other river services not investigated. At the catchment level, we are confident that the reported values are an accurate reflection of people's values for enhancement to river water quality. However, the approach that we used to aggregate the values of river services across Ireland as a whole (i.e. averaging across our three catchments and multiplying this by the number of households) was rather crude and therefore these values should only be used as an indicative value of the national benefits.

Key message

Further research is needed to refine our approach to the aggregation of river benefits across all rivers in Ireland. Such approach may be centred around value transfer methods that account for the environmental and water quality attributes of Irish rivers, as well as the socio-economic and demographic characteristics of people living in the river catchments.

The recently established IPBES re-conceptualises the ecosystem services framework to one of "nature's contribution to people" (NCP), where NCP goes beyond monetary, instrumental values of ecosystem services to also include the notion of nature's gifts (social and cultural values) to human beings, linking objective or scientific knowledge to indigenous and local knowledge of local environments and socio-ecological systems. ESManage explored the values placed on cultural ecosystem services and the role of specialist knowledge of interest groups, such as anglers, who can have a particular insight into local ecological conditions and how these are changing over time. Our research thus does not effectively capture the social and cultural values of NCP from Irish rivers.

Key message

Further research based on the IPBES conceptual framework will help explore the additional benefits associated with local knowledge of nature's benefits derived from Irish rivers.

6.4 Integration of the Ecosystem Services Approach into Policy and Practice

The project produced a demonstration structure (Figure 6.1) for linking current EPA catchment management tools, such as the Catchment Management Tool (CMT), SMART and SLAM, and hydrology and water quality datasets with ecosystem services using a BBN model. The structure incorporates (1) modelling tools, (2) technical Information sources (mainly measured data) and

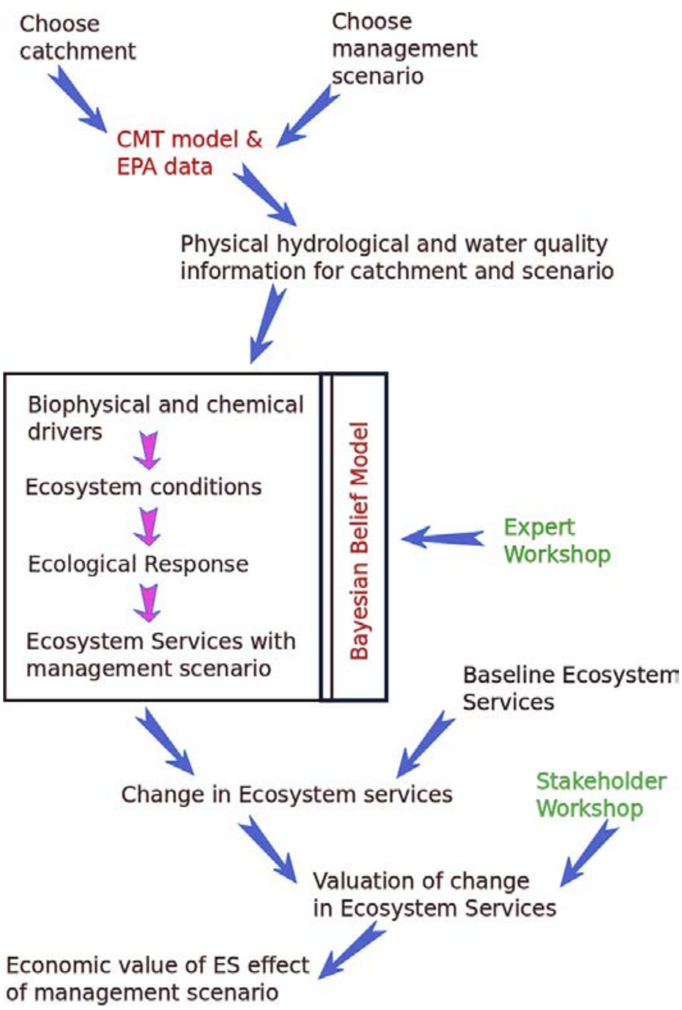

Figure 6.1. Structure for linking current EPA catchment management tools, such as the CMT, SMART and SLAM, and hydrology and water quality datasets with ecosystem services using a BBN model.

(3) opinions and preferences from stakeholders and experts (elicited during workshops); it is also interdisciplinary. The sequence illustrated in Figure 6.1 shows how several different tools and sources of information may be combined to produce the inputs required for ecosystem service considerations to be incorporated into policy formulation and catchment management. The structure allows managers and policymakers to estimate the value of changes in such services produced by several management options at their disposal. The structure also allows additional catchments and management options to be easily added and future information on ecosystems responses to change to be incorporated.

While a limited number of services were addressed in the ESManage project, there is clearly the potential to expand the range that is relevant to respond to water quality change and ideally, as mentioned, regulating and maintenance services should be included. In the interim, as previously mentioned, cultural ecosystem services (wildlife, bankside conditions, angling) were among those most highly ranked by the general public and present an opportunity to best reconnect people to water and the importance of water quality.

Key message

The benefits derived from cultural services need to be better represented in economic analyses related to WFD measures.

One of the drawbacks of the ecosystem services approach as noted by Grizzetti *et al*. (2016) is the challenge of communicating and building an understanding of the concept. They concluded that most of the knowledge needs relating to operationalising the ecosystem services approach concern (1) concepts (i.e. explanation of the approach), (2) guidelines on how to apply the approach (methodologies) and (3) valuation methods. The ESManage synthesis report takes on board these observations in an attempt to facilitate streamlining of the ecosystem services approach into water management and policy.

It is widely recognised that we must better engage citizens if we are to address water pollution in Ireland to meet the requirements of the WFD and at the same time protect aquatic biodiversity and the benefits provided by freshwaters that we depend on for domestic, leisure and economic activities. The ecosystem services concept has the potential to strengthen water resources protection/management decisions because it shows the links between the effects of land use and other activities on the quantity and quality of the benefits that are derived from water. It has been defined as “a way of understanding the complex relationship between nature and humans to support decision-making with the aim of reversing the declining status of ecosystems and promoting sustainable use/management/conservation of resources*”* (Martin-Ortega *et al*., 2018). As mentioned in the introduction, demonstrating that reducing pollution protects drinking water and provides other benefits is easier to appreciate and justify than the WFD policy goal of “achieving good status”. Furthermore, the ecosystem services approach should enable a more comprehensive evaluation of the benefits and costs of actions or measures (e.g. through a cost–benefit analysis) to improve water quality, and thereby help justify the costs of protection and restoration. The approach also provides a useful tool by which to understand the trade-offs between different policy impacts, and it therefore provides evidence to better design policy mechanisms that target those options that generate the greatest welfare benefits. It is a “stakeholder-driven concept” and it complements the initiatives and measures in the River Basin Management Plan 2018–2021. These include the newly created Local Authority Waters Programme, which includes the Waters and Communities Office and the Catchment Assessment Team, both operating from 13 different local authority centres across the country, and provides opportunities to raise awareness, discover the local causes of water pollution, activate engagement of local communities and identify measures in consultation with land owners, industry and other stakeholders that can reduce pollution inputs to local rivers. In addition to this the Agricultural Sustainability Support and Advisory Programme, funded by the Department of Housing, Planning and Local Government, the Department of Agriculture, Food and the Marine and the dairy co-ops, will be implemented by 30 advisors. These will work under Teagasc and the dairy co-ops on a one-to-one basis with farmers to bring about behavioural change through improved agricultural practices in areas which have identified pressures on water bodies. As proposed in the River Basin Management Plan 2018–2021, local authorities have put in place support and advisory teams to carry out scientific assessments and to drive the implementation of mitigation measures at the local level. The above illustrates that there is a policy demand for better evidence on the impacts and benefits of alternative management options to enhance the quality of water in Ireland’s rivers. Decision-makers may use the findings from this research to provide evidence to justify and design existing or new policies to enhance water quality or to improve design.

Key message

The concept of ecosystem services should be embedded in communication in the aforementioned initiatives with stakeholders and the general public to illustrate the benefits of improved water quality.

The finding of this research should be used to support existing water protection measures and to help design new policies that target those ecosystem services that generate the greatest welfare gains.

By understanding not only the nature and significance of the benefits, but also the beneficiaries of these services, there is also potentially the opportunity to leverage private sector contributions to water quality improvements through, for example, systems of payments for ecosystem services.

The concept of ecosystem services is an integral part of the natural capital framework and natural capital accounting.

6.5 Where To from Here?

Although there has been sustained ecosystem services research activity on freshwaters, there are still considerable knowledge gaps and challenges that need to be addressed before the approach can be widely incorporated into water resources management. Key challenges identified during the ESManage project and from the literature review include the following: (1) incorporating an understanding of the impact of multiple stressors on ecosystem services to develop/ strengthen models on these linkages; (2) in response to IPBES, incorporating valuation of nature's gifts from rivers as conceptualised in NCP; and (3) developing decision-support tools that inform how ecosystem services/NCP change in response to multiple stressors and management interventions.

The conceptual framework used in ESManage was based on The Economics of Ecosystems and Biodiversity (TEEB) framework (TEEB, 2010a). In the past few years, the academic and policy debate has moved beyond the TEEB approach to explore the wider conceptualisation of values and valuation (Kenter *et al*., 2015; Costanza *et al*., 2017; Braat, 2018). Diaz *et al*. (2015) argue that the valuation of nature should go beyond the valuation of instrumental values (nature's benefits to humans), to also include relational values (the importance of nature to foster desirable relationship between people and nature) and intrinsic values (the value of nature itself). Kenter *et al*. (2015) also recognised transcendental values (i.e. guiding principles that transcend specific situations), contextual values (i.e. values that are dependent on an object of value and hence context) and value indicator (i.e. a measure of the importance of something, which may be expressed in monetary or non-monetary terms). The current debate now recognises this plurality of values of nature (Pascual *et al*., 2017). Furthermore, Diaz *et al*. (2015) showed that different stakeholders will hold different values, and therefore it will be important to ensure that the values held by all stakeholders are accounted for in policy decisions. This argument is further supported by Jacob (2016) and Martin-Lopez *et al*. (2014), who call for an "integrated valuation" that captures the plurality of values and worldviews in a coherent and operational assessment framework. Kenter *et al*. (2016) proposed the "Deliberative Value Formation" approach, grounded in social-psychological theory, which can help understand how people "translate" transcendental values and worldviews to more specific contextual values, which effectively integrates social learning and plural knowledge and values in valuation and decision-making.

The IPBES captures many of these conceptual developments (Pascual *et al*., 2017; IPBES, 2018), and argues that different types of values should be considered in decision-making. It thus aims to move the conceptualisation of ecosystem service values beyond the TEEB instrumental (monetary) valuation, to one that embraces different disciplines and knowledge systems in the co-construction of evidence on the state of the world's biodiversity and the benefits it provides to people (Diaz *et al*., 2015). In doing so, the IPBES conceptual framework reframes ecosystem services values to NCP (IPBES, 2018). The IPBES definition of NCP embodies both the (western) scientific concept of ecosystem goods and services, and the notion of nature's gifts from indigenous and local knowledge systems. Within the IPBES framework, nature's contributions are assessed from two complementary perspectives (Diaz *et al*., 2015): one generalising in nature and the other context specific. The generalising perspective includes 18 "contributions", organised into three partly overlapping groups: regulating, material and non-material contributions (which respectively map onto the Millennium Ecosystem Assessment (MEA, 2005) regulation and maintenance, provisioning and cultural services). The context-specific perspective includes geographical and cultural aspects of indigenous and local knowledge systems. These contributions enhance people's quality of life; which can be measured through instrumental and relational values (Figure 6.2).

The IPBES conceptual framework thus aims to extend, through the conceptualisations of NCP, the way that assessments of the value of nature are undertaken.

ESManage has been successful in capturing the economic (instrumental) values of river ecosystem service; however, it did not address the wider conceptualisations of value proposed by IPBES. These gaps will be addressed by the recently initiated ESDecide project funded by the EPA.

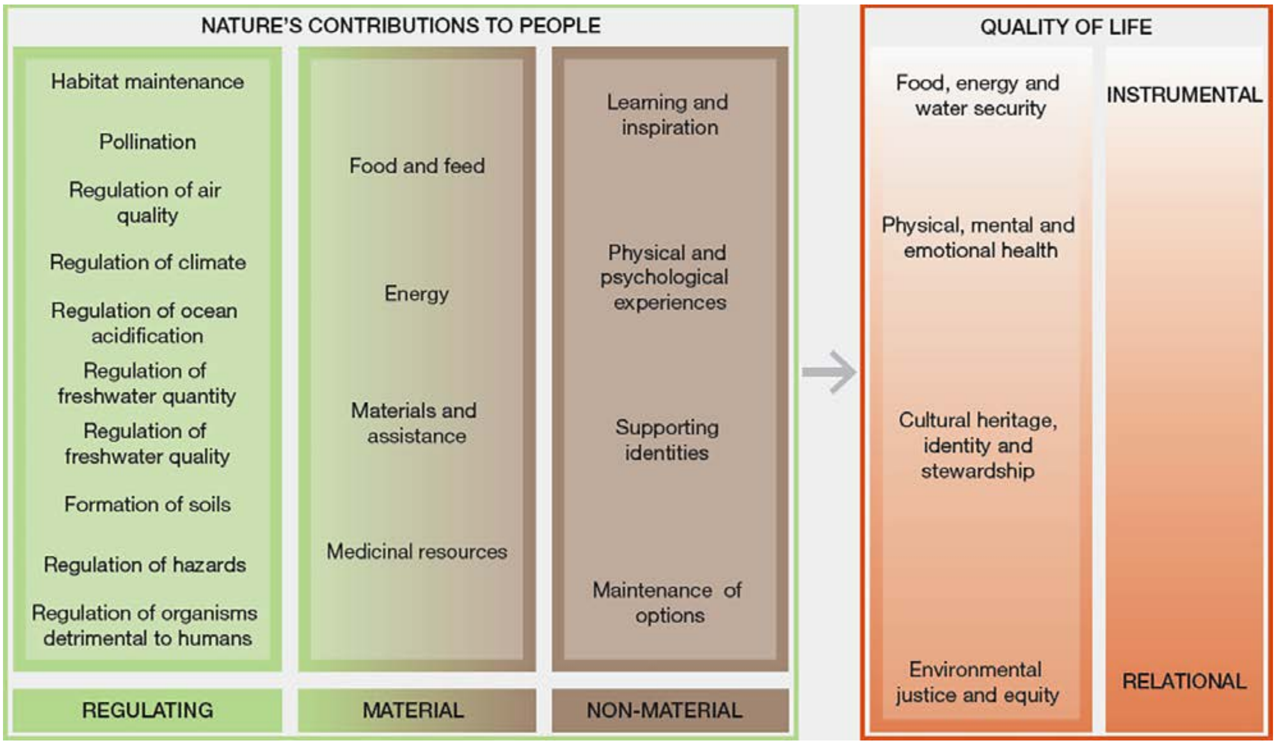

Figure 6.2. Nature's contributions to people and their relation to quality of life in terms of instrumental and relational values. The grading of green and brown colours indicates whether nature's contributions to people are associated more with natural (green) or with cultural (brown) systems. Source: IPBES (2018).

6.6 Summary of Key Recommendations

6.6.1 Recommendations for policy and practice

- Embed the ecosystem services approach in communication and activities undertaken by the Local Authority Waters Programme and the Agricultural Sustainability Support and Advisory Programme to illustrate the benefits to people of improved water quality.
- Adopt the methodological framework developed by ESManage to investigate changes to ecosystem services and associated goods and benefits in response to management interventions.
- Extend the use of BBN model to other catchments.
- Include cultural services as a key component in ecosystem services assessments.
- Strengthen and expand collection of relevant data on ecosystem services and associated goods and benefits.
- A number of guiding principles for the integration of ecosystems and their services into decision-making has been highlighted in the 2019 European Commission Working Document (EC, 2019). Among the eight principles, key actions include prioritising measures that improve ecosystem condition while contributing to well-being and prosperity for net social gain, addressing the net inter-dependences and trade-offs, tackling potential negative impacts and applying the precautionary principle to protect ecosystem condition and resilience, and delivery of ecosystem services.

6.6.2 Recommendations for future research

- Increase the range of ecosystem services in the modelling and assessment framework, particularly to cover regulating services.
- Strengthen the links in ESManage BBN models over time as empirical data become available quantifying responses of ecosystem functions

and services to multiple stressors. Within this context it is equally important that metrics, particularly those related to ecosystem function, are carefully chosen to capture the cumulative response to various combinations of stressors. The aforementioned EC (2019) Working Document highlights the need to strengthen our understanding of the links between ecosystem condition and the quality and maintenance of the ecosystem services provided.

- Refine the approach to the aggregation of river benefits across all rivers in Ireland. Such approach may be centred around value transfer methods that account for the environmental and water quality attributes of Irish rivers, as well as the socio-economic and demographic characteristics of people living in the river catchments.
- Undertake research based on the IPBES conceptual framework, to explore the additional benefits associated with nature’s gifts derived from Irish rivers.
- Build decision-support systems to move beyond the conceptual framework to mainstream ecosystem services into public and private decision-making processes.

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Abbreviations

BBN	Bayesian belief network
BOD	Biochemical oxygen demand
CICES	Common International Classification of Ecosystem Services
CMT	Catchment Management Tool
EPA	Environmental Protection Agency
IPBES	Intergovernmental Science–Policy Platform for Biodiversity and Ecosystem Services
NCP	Nature's contribution to people
OPEX	Operating cost
SLAM	Source Load Apportionment Model
SMART	Soil Moisture Accounting and Routing for Transport (model)
TEEB	The Economics of Ecosystems and Biodiversity
WFD	Water Framework Directive
WTP	Willingness to pay

Glossary

Note: definitions may have been adapted or amalgamated from cited sources to provide further clarity.

Asset(s)	See “Natural capital”.
Beneficiaries	The interests of individuals and organisations (e.g. households, associations, societies and companies) that “drive active or passive consumption and/or appreciation of ecosystem services resulting in an impact (positive or negative) on their welfare” (Harrington *et al*., 2010; Nahlik *et al*., 2012; Landers and Nahlik, 2013).
Benefit	In this context, used as a general term to denote the many ways that human well-being is enhanced through the processes and functions of ecosystems via ecosystem services, or something that directly impacts on the welfare of people, such as more or better drinking water or a more satisfying fishing trip (Fisher *et al*., 2009; Mace *et al*., 2012). Benefits may be economic, social or health benefits (UK NEA, 2011a). However, it must be noted that “services” are not “benefits” (Boyd and Banzhaf, 2007).
Biodiversity	Also described as “biological diversity”, this is “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and between ecosystems” (Convention on Biological Diversity, 2004; TEEB, 2010b).
DPSIR (drivers, pressure, state, impact and response)	The causal framework for describing the interactions between society and the environment.
Driver	“Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem” (MEA, 2005; Harrington *et al*., 2010; TEEB, 2010b).
Ecological process	An interaction among organisms; ecological processes frequently regulate the dynamics of ecosystems and the structure and dynamics of biological communities (Mace *et al*., 2012).
Ecological stability	See “Ecosystem health”.
Ecosystem	“A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit” (MEA, 2005; TEEB, 2010b).
Ecosystem approach	“a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way” (Convention on Biological Diversity, 2004).
Ecosystem function	“A subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services” (TEEB, 2010b).
Ecosystem goods	The things from ecosystems that people value through experience, use or consumption, whether that value is expressed in economic, social or personal terms. Note that the use of this term here goes well beyond a narrow definition of goods simply as physical items bought and sold in markets, and includes objects that have no market price (e.g. outdoor recreation) (UK NEA, 2011a).

Ecosystem health	A "healthy ecosystem is one that is sustainable – that is, it has the ability to maintain its structure (organization) and function (vigor) over time in the face of external stress (resilience)" (Costanza and Mageau, 1999).
Ecosystem process	"Any changes in the stocks and/or flows of materials in an ecosystem, resulting from interactions among organisms and with their physical–chemical environment" (Mace *et al*., 2012).
Ecosystem service	"The benefits people obtain from ecosystems" (MEA 2005). It can also be defined as an "activity or function of an ecosystem that provides benefit (or occasionally disbenefit) to humanity and its economies" (e.g. Boyd and Banzhaf, 2007; Mace *et al*., 2012).
Ecosystem services approach	see "Ecosystem services framework".
Ecosystem services framework	The "ecosystem services framework" (also referred to as the "ecosystem services approach") focuses on understanding how biodiversity, natural systems and the linkages between ecosystem components and processes lead directly or indirectly to human welfare benefits.
Evolutionary process	A process leading to changes in gene frequencies in populations and ultimately potentially the appearance of new species or intraspecific taxa (Mace *et al*., 2012).
Final ecosystem service	An ecosystem service (whether natural, semi-natural or highly modified) that directly underpins or delivers a good to humanity and improves well-being. A fundamental characteristic is that ecosystem services retain a connection to the underlying ecosystem functions, processes and structures that generate them (Boyd and Banzhaf, 2007; UK NEA, 2011a; Mace *et al*., 2012; Haines-Young and Potschin, 2013).
Flow	Transfer of materials in an ecosystem from stocks and between pools, forms or states (Mace *et al*., 2012).
Human well-being	See "Well-being".
Indicator	Information based on measured data used to represent a particular attribute, characteristic or property of a system (MEA, 2005).
Intermediate service	A service that is not directly consumed by people but which supports or underpins the output of other services (Haines-Young and Potschin, 2009).
Natural capital	"The stock of natural assets that provide society with renewable and non-renewable resources and a flow of ecosystem services, the latter being the benefits that ecosystems provide to people. It includes abiotic assets, e.g. fossil fuels, minerals, metals, and biotic assets, e.g. ecosystems that provide a flow of ecosystem services. The biotic component of natural capital is defined as ecosystem capital" (EC, 2013).
Pressure	A stress or negative effect on the environment caused by human activities (e.g. excess organic pollution) or natural events (e.g. drought).
Regime	"The set of system states within a stable landscape/catchment" (Folke *et al*., 2010).
Regime shift	"A change in a system state from one regime or stable state to another" (Folke *et al*., 2010).

Resilience (of ecosystem)	Capacity of an ecosystem to recover from and tolerate a disturbance to its structure and function without collapsing or changing status (Walker and Salt, 2006; Folke *et al*., 2010; Harrington *et al*., 2010; TEEB, 2010b).
Service providing areas	A catchment or defined area that includes the sum of biodiversity and its traits (i.e. the biotic components of the ecosystem) required to deliver a given ecosystem service, as well as the physical or abiotic ecosystem components (Vandewalle *et al*., 2009; Syrbe and Walz, 2012).
Stakeholder	A person, group or organisation that has a stake in or is affected by the outcome of a particular activity or policy (Harrington *et al*., 2010; TEEB, 2010b).
Stock	"The amount of a material or components in a given pool, form or state in an ecosystem that provide for services" (Mace *et al*., 2012).
Threshold	"Boundaries in space and time in changeable systems that separate alternative stable states (i.e. dynamic regimes) which shift toward different attractors" (e.g Briske *et al*., 2010; Folke *et al*., 2010).
Trade-offs	"Management choices that intentionally or otherwise change the type, magnitude, and relative mix of services provided by ecosystems" (TEEB, 2010b).
Value	The size of the well-being improvement delivered to humans through the provision of good(s) (Mace *et al*., 2012).
Well-being	That which arises from adequate access to the basic materials for a good life needed to sustain freedom of choice and action, health, good social relations, security, peace of mind and spiritual experience. The state of well-being is dependent on the aggregated output of ecosystem goods and benefits, the provision of which can change the status of well-being (TEEB, 2010b; Haines-Young and Potschin, 2013).

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Incorporation of Ecosystem Services Values in the Integrated Management of Irish Freshwater Resources: ESManage

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epaResearch

Climate - Water - Sustainability

Identifying pressures • Informing policy • Developing solutions

Identifying Pressures

The ESManage project tested a methodological framework to help embed ecosystem services and the ecosystem services approach into policy and decision-making for sustainable management of water resources, as required by the Water Framework Directive. The eight-step framework involved identification of the relevant freshwater ecosystem services, prediction of how they change when management measures are implemented and valuation of that change. The focus of the research was on ecosystem services from rivers, engaging stakeholders in three case study catchments (Dodder, Suir and Moy) to explore the services derived from these very different rivers and undertake economic valuation of the benefits that people obtain from enhancements to ecosystem services in those rivers. In terms of impacts on ecosystem services, the key management scenarios investigated involved changes in diffuse pollution from agriculture, assuming unchanged inputs from domestic septic tanks and point sources, e.g. wastewater treatment plants, that also contribute to water quality problems in the study catchments.

Informing Policy

The project framework can be extended to incorporate a wider range of ecosystem services into decision-making relating to the management of freshwaters and protection of associated ecosystem services. In particular, workshops with scientists, stakeholder organisations and the general public highlighted the importance of cultural services to citizens, and therefore these should be a key component in ecosystem services assessments. The economic valuation provides data that can be incorporated into policy and management decisions. The project produced a series of recommendations for policy and practice.

Developing Solutions

The project demonstrated a structure for linking current Environmental Protection Agency catchment management tools, such as the Catchment Management Tool (CMT), Soil Moisture Accounting and Routing for Transport (SMART) model and Source Load Apportionment Model (SLAM), and hydrology and water quality datasets with ecosystem services using a Bayesian Belief Network model. This framework allows managers and policymakers to estimate the value of changes in such services produced by the management options at their disposal. The flexible framework also allows for additional catchments and management options to be added, and for future information on ecosystem responses to change to be incorporated.

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