Linking water quality and well-being for improved assessment and valuation of ecosystem services

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Despite broad recognition of the value of the goods and services provided by nature, existing tools for assessing and valuing ecosystem services often fall short of the needs and expectations of decision makers. Here we address one of the most important missing components in the current ecosystem services toolbox: a comprehensive and generalizable framework for describing and valuing water quality-related services. Water quality is often misrepresented as a final ecosystem service. We argue that it is actually an important contributor to many different services, from recreation to human health. We present a valuation approach for water quality-related services that is sensitive to different actions that affect water quality, identifies aquatic endpoints where the consequences of changing water quality on human well-being are realized, and recognizes the unique groups of beneficiaries affected by those changes. We describe the multiple biophysical and economic pathways that link actions to changes in water quality-related ecosystem goods and services and provide guidance to researchers interested in valuing these changes. Finally, we present a valuation template that integrates biophysical and economic models, links actions to changes in service provision and value estimates, and considers multiple sources of water quality-related ecosystem service values without double counting.

One of the fundamental challenges of mainstreaming ecosystem services into decision making involves linking ecosystem processes with changes in human well-being (1). This is especially true for water quality-related ecosystem goods and services. Water quality is highly valued by the public, and information on water quality values is increasingly demanded by decision makers. However, there is no generalizable framework for linking changes in water quality to changes in multiple ecosystem goods and services. This is problematic because limiting ecosystem service assessments to those services with direct use value and market prices systematically undervalues ecosystem services and fails to achieve a full accounting of all of the environmental and economic tradeoffs associated with decisions.

Valuing water quality changes is particularly challenging relative to other ecosystem goods and services. Changing water quality affects many aspects of human well-being, and benefits and/or costs accrue to different groups of beneficiaries at varying spatial and temporal scales. This complexity contrasts with other ecosystem services, such as carbon sequestration, for which emissions are aggregated into a global atmospheric pool. Each unit increase in carbon emissions results in a more or less constant loss in value (i.e., costs associated with climate change). By contrast, each unit improvement in water quality may affect only a local area, the value of which varies widely with spatial context and may have strongly diminishing marginal benefits (e.g., additional reductions in nutrient pollution entering a clean lake generate minimal new benefits, and those benefits are further influenced by the condition and proximity to substitute lakes). Further, actions today can affect water quality far into the future, with the consequent challenge of predicting future values.

High uncertainty and lack of appropriate data to populate biophysical and economic models are also barriers to comprehensive water quality valuation. Water quality affects people through numerous pathways, from drinking water to recreation to commercial fisheries. The consequences of decisions on the provision of water quality-related ecosystem services are often separated by space and time, modified by variation in baseline conditions, and characterized by nonlinearities and thresholds (2). The value of ecosystem services, especially for cultural and aesthetic values, is also likely to be highly uncertain.

Previous work has made progress in identifying sources of water quality value and in developing nonmarket approaches to valuation, but most water quality valuation tools fall short of the needs and expectations of decision makers (3). First, few water quality valuation assessments account for the multiple costs and/or benefits of water quality-related changes. Recent assessments of the water quality impacts of bioenergy policy in the United States (e.g., refs. 4 and 5) focus solely on the contribution of fertilizer-derived nitrogen to hypoxia in the Gulf of Mexico, neglecting other potential consequences for drinking water treatment costs, human health, and diminished recreational opportunities. Failure to consider all of the water quality-related consequences for well-being can lead to a serious underestimate of the true value of changes in ecosystem services associated with a given action or decision.

A second shortcoming of existing work on water quality valuation, and ecosystem services research in general, is that valuation assessments often are not linked with changes in management, land use, or other actions that lead to water quality change (1). Assessments of the total costs of eutrophication (e.g., ref. 6) or the total value of ecosystem services from an ecosystem or land cover type (e.g., refs. 7 and 8) do little to help a decision maker trying to assess the consequences of alternative actions. The value attributable to conserving wetlands for improved sediment retention, for example, needs to be assessed relative to a specified alternative land cover or management action (i.e., draining wetlands for agriculture or urban development). Decision makers need models that are sensitive to the variation in local ecological conditions that affect the provision of ecosystem services, as well as to variation in local social and economic conditions that affect the value of ecosystem services to beneficiaries. By failing to link valuation estimates with specific actions and subsequent changes in human well-being, researchers also risk double-counting of value (9).

Finally, economic models for valuing water quality-related ecosystem services are often poorly integrated with ecological and

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hydrologic models. Biophysical and economic models are typically developed in isolation, without consideration of how the outputs of one model may feed into the next, making it challenging to integrate models and data. For example, the water quality metrics most commonly measured by scientists are not well connected with attributes the public actually values (e.g., people value the extent to which they can safely use and enjoy a lake; they do not directly value the concentration of phosphorus in the lake). Similarly, many economic models require inputs that are very different from the outputs of standard water quality models.

Framework for Water Quality Valuation. We propose a unique framework for the assessment and valuation of water quality-related services that addresses many of the shortcomings of existing work. Our approach is comprehensive, integrates biophysical and economic research, is sensitive to alternative land use or management decisions, and avoids double-counting of costs or benefits. To maximize the potential utility for decision making, the framework links actions to a measured or modeled change in water quality and then to changes in the value of ecosystem goods and services (Fig. 1).

Biophysical models inform the linkage between actions or changes on the landscape and a change in water quality (Fig. 1*A*) as measured by changes in nutrient concentrations, sediment loading, or inputs of toxins or other chemicals. Models focusing on the characterization of changes in water quality include continuous daily time step models, such as the Soil and Water Assessment Tool (10), and less complex models, such as the Integrated Valuation of Ecosystem Services and Tradeoffs (11). These models have been used to estimate the water quality consequences of future land use scenarios (12) or the effectiveness of conservation policies (13). Outputs from the biophysical models may be expressed in terms of nutrient retention across a landscape or in loadings to specific aquatic endpoints.

The second step in our framework (Fig. 1*B*) links changes in water quality to changes in the provision of ecosystem goods and services that directly affect human well-being. Lack of appropriate models or data to describe this link often limits the potential to successfully integrate biophysical and economic models. Ideally, biophysical models would translate water quality changes to valued goods and services, such as changes in catch per unit effort of fishes, frequency of beach closures, or the toxicity of harmful algal blooms. However, many of these relationships are either poorly understood, difficult to generalize, or we lack the data to quantify the relationships. Specificity is also an important part of this linkage: water quality affects many different aspects of human well-being, so a change in one water quality constituent may affect different beneficiaries at varying spatial and temporal scales.

The final linkage in the framework (Fig. 1*C*) connects changes in ecosystem goods and services to changes in values. There are numerous approaches used by economists to place an economic value on water quality-related ecosystem services (14–17). In brief, economists can ask respondents directly how much they would be willing to pay for a given improvement in water quality (stated preference methods). Alternately, economists can indirectly estimate the value of changes in water quality through observations of human behavior, such as willingness to drive longer distances to visit areas of higher water quality or willingness to pay for property neighboring waters of higher quality (revealed preference methods). Other approaches include estimating the costs avoided by improving water quality (e.g., sediment dredging, drinking water treatment), or the costs associated with increased health risks due to contact or consumption of unsafe water. Some caution is needed in applying these cost-based approaches, to ensure that they represent measures of value (18). In addition, valuation methods typically generate estimates of value held by people today given current conditions and not a dynamic assessment of values of changes in the flow of ecosystem services through time. Reviews of economic approaches to water quality valuation are provided by Wilson and Carpenter (19), Brauman et al. (20), Olmstead (21), and Griffiths et al. (3).

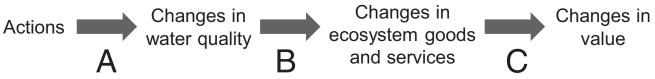

Fig. 1. Framework for linking actions to values for water quality-related ecosystem services.

Delineating the Multiple Ecosystem Services Associated with Water Quality. Defining water quality as multiple biophysical metrics that may influence the provision of many different "final" ecosystem services is critical for comprehensive valuation (9). In Fig. 2 we chart the potential interactions between changes in water quality and multiple ecosystem services. A single action that affects water quality may cause a change in another attribute, such as water clarity, or have a direct effect on the provision of various ecosystem services that affect different groups of beneficiaries. Fig. 2 builds the on the general framework introduced by the Millennium Ecosystem Assessment (22) that links ecosystem services to constituents of well-being, while adding specificity for water quality-related services.

Few water quality-related services are affected by just one action, and many services in combination cause changes in value (Fig. 2). For example, the value of lake fishing is affected by changes in fish abundance and species composition but may also be influenced by water clarity and/or the prevalence of toxins that lead to fish consumption advisories. Fish abundance, in turn, is driven by changes in phosphorus and is influenced by nitrogen, temperature, sediments, toxins, and interactions with other organisms. There may also be feedbacks among services such that a change in the provision of one service affects the provision of another service (e.g., a change in lake fishing may also affect the value of boating).

Fig. 2 also illustrates how a single change in one water quality constituent can affect multiple ecosystem services and numerous sources of value. Changes in nitrate loading are most commonly associated with changes in the extent and duration of coastal hypoxia and with the health risks of methemoglobinemia, often called blue-baby syndrome (23, 24). However, changes in nitrate can also affect the prevalence of water-borne disease-causing organisms, and even low levels of nitrate in drinking water can lead to increased health risks (25). Therefore, the total value associated with a change in the quality of drinking water includes both the cost of removing nitrate from drinking water and any loss in value associated with increased health risks from consuming water with nitrate levels that are high but below the drinking water standard. Additional negative commercial or recreational consequences associated with hypoxia or harmful algal blooms would add to the lost value attributable to a single action (e.g., increased nitrogen fertilizer added upstream).

Template for the Assessment and Valuation of Water Quality-Related Services. On the basis of the services and interactions mapped in Fig. 2, we present a template for integrated biophysical and economic modeling for comprehensive water quality valuation. For each constituent of water quality change (nitrogen, phosphorus, sediment, etc.), the template identifies the water quality attribute most commonly valued by people, the endpoint and beneficiaries to be measured or modeled, and appropriate economic valuation approaches (Fig. 3). Researchers interested in assessing water quality-related services and economic values can use the template to identify model requirements, key data needs, and existing

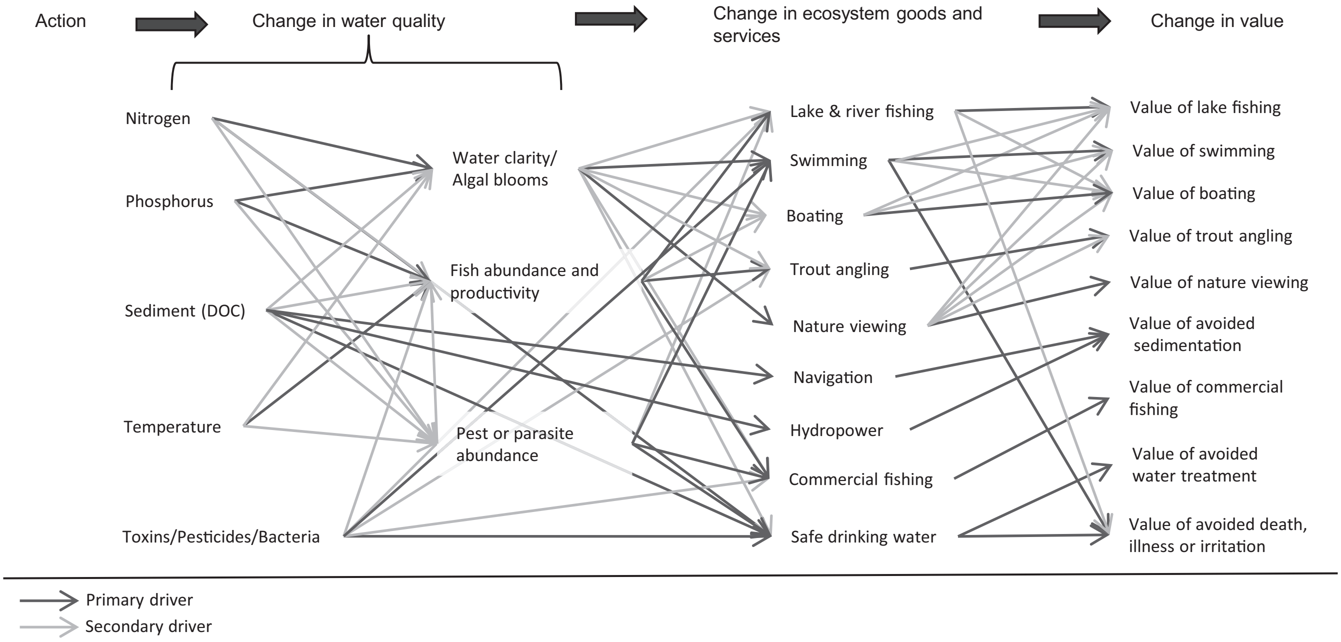

Fig. 2. Relationships between water quality change, multiple ecosystem goods and services, and associated changes in values. Actions considered in the far left column include changing land use or land management as well as other drivers of water quality change, such as climate change, invasive species, and atmospheric deposition. Connections between columns are classified as primary or secondary, according to expert opinion. Although not representative of all possible water quality changes, pathways, and effects on well-being, the figure highlights the most important and often-measured services.

tools and approaches for water quality valuation. There are five steps to using the template.

Step 1: Identify actions and beneficiaries of interest. Land use and land management decisions, as well as factors such as climate change and invasive species, have the potential to affect the source and transport of many different types of water quality constituents or contaminants. Identifying the beneficiaries of interest and then working backward to determine the appropriate biophysical parameters that have the greatest potential to affect those groups provides focus for research efforts and can ensure that subsequent work captures the most important drivers and ecosystem service consequences. Alternatively, if water quality information is available from previous monitoring or modeling, then the template can be used to identify all of the potential services affected by a change in a given nutrient or pollutant. One goal of the template is to draw attention to all of the constituents, endpoints, beneficiaries, and ecosystem goods and services related to changes in water quality. Therefore, an approach that considers both upstream drivers and downstream beneficiaries will generate the most comprehensive valuation.

Step 2: Identify shared inputs/outputs of biophysical and economic models. After selecting the key actions and ecosystem service changes, the next step is to identify the inputs and outputs that need to be included in a set of integrated biophysical and economic models. In Fig. 3 we use the term "valued attribute" to describe the aspect of water quality that can be measured or modeled in biophysical assessments and directly affects human well-being. For the service of clean drinking water, the valued attribute is the concentration of the nutrient or contaminant for which increased health risks are associated with increased exposure to nitrate or toxins. For other services, an additional biophysical model may be needed to translate the driver of water quality change into the valued attribute. For example, stream temperature has been identified as a principal driver of the distribution and abundance of trout (26, 27). Here, a functional relationship is needed to translate changes in stream temperature into changes in either the size and abundance of trout populations or the area of suitable habitat for each species. Warming water temperatures may also alter species composition, shifting angling value from that based on cold-water species to warm-water species (28). In some cases, there may be alternative choices of the valued attribute, and what should be chosen depends on biophysical understanding, links to human well-being, and data availability.

Step 3: Select appropriate biophysical models. Applying the template requires the user to identify an appropriate biophysical model to capture the effects of an action on the valued attribute at a defined endpoint. Watershed water quality models estimate how changing land use or management resulting from alternative policies or future scenarios will affect nitrogen and phosphorus loading to downstream endpoints. To use these models in our framework, nutrient outputs need to be linked to a valued attribute from Fig. 3, such as changes in water clarity. Comprehensive valuation of water quality may require different biophysical models for each water quality constituent. For example, a groundwater model could be used for services associated with nitrate contamination of drinking water wells, and a basin-scale water quality model could be used to route nutrients downstream to predict consequences for coastal regions. Differing spatial and temporal lags for each service mean it is important to consider how the concentration of any given constituent changes across space and through time (29).

Step 4: Select appropriate economic models. In addition to identifying an appropriate biophysical model, applying the framework requires linking valued attributes at particular endpoints with economic models that measure the value of these attributes to specific beneficiaries. For example, changes in the concentration of nitrate in groundwater affect human well-being where wells supply drinking water to residents. Economic models can be used to compare the well-being of people before and after a change in water quality. These models predict how changes in nitrate concentrations at drinking water sources will affect behavior, such as prompting the installation of treatment systems by municipal water treatment facilities or the purchase of bottled water by well owners. Although these costs can be used as proxies for economic values, it is important to distinguish the costs incurred through

	Biophysical Modeling			Economic Modeling	
Ecosystem Service	**Change in Constituent**	**Endpoint**	**Change in Valued Attribute**	**Beneficiaries**	**Valuation Approach**
Lake recreation	P and/or N	Lakes	Water clarity	Lake recreationists Lakeshore property owners	Recreational demand model Willingness to pay for recreation Hedonic pricing
Clean drinking water	N	Sourcewater treatment facilities	[Nitrate] above 10ppm	Treatment facility & taxpayers	Avoided treatment costs for nitrate
Clean drinking water	N	Groundwater	[Nitrate] above 10ppm	Well owners	Avoidance costs (bottled water) Remediation costs (treatment) Replacement costs (new well)
Clean drinking water	N	Drinking water (surface or groundwater)	[Nitrate]	Consumers, particularly at-risk subpopulations	Increased risk of disease * value of statistical life/health Avoidance costs
Commercial fisheries	N	Bays, estuaries, coasts	Fish and shellfish productivity	Fish and shellfish industry and consumers	Fishery rents Value per unit fish/shellfish
Coastal recreation	N	Ocean beaches and coasts	Extent, frequency, or intensity of algal blooms	Coastal recreationists	Willingness to pay for recreation Recreational demand model
Safe contact water	N and/or P	Swimming beaches	Prevalence of aquatic pests and parasites	Swimmers	Avoidance costs Irritation/health costs
Coldwater angling	Stream temperature	Coldwater streams	Trout abundance or habitat area	Anglers	Willingness to pay per fish or per unit area habitat Recreational demand model
Hydropower production and navigation	Sediment	Reservoirs, lakes, harbors, ports, channels	Amount of sediment	Taxpayers, commercial, navigation interests	Avoided costs (dredging)
Safe drinking water	Sediment Dissolved organic carbon (DOC)	Source water treatment facilities	[DOC]	Treatment facility & taxpayers	Avoided treatment costs (DOC can react with chlorine to form suspected carcinogens)
Safe drinking water	Toxins, bacteria, or other contaminants	Drinking water (surface or groundwater)	[toxin]	Consumers	Increased risk of disease * value of statistical life/health Avoidance behavior costs
Safe contact water	Toxins, bacteria, or other contaminants	Swimming areas	[toxin]	Swimmers	Increased risk of disease * value of statistical life/health Avoidance costs
Safe consumption fish and shellfish	Toxins, bacteria, or other contaminants	Recreational or commercial fishing endpoints	[toxin]	Consumers	Increased risk of disease * value of statistical life/health
Non-use value	Unspecified	All aquatic endpoints	Existence or bequest value	Non-users	Willingness to pay for existence or bequest value

Fig. 3. Template for water quality valuation based on integrated biophysical and economic models. Each row in the table represents a water quality change that affects an endpoint and groups of beneficiaries in a unique way, such that there is no overlap in value. Value estimates generated by each row in the template can be summed for an estimate of the value generated or lost by a given action or scenario. For some service estimates (e.g., lake recreation), users will need to select a single valuation tool (e.g., hedonic model or recreation demand model) listed in the cell to avoid double-counting value because there may be overlap in the groups of beneficiaries if multiple approaches are applied to the same water quality change (e.g., lakeshore property owners may also be lake recreationists). The examples given in the template are not meant to be a complete enumeration of all services but rather are provided as illustrative examples of the steps involved in an integrated approach.

avoidance activities (the price of a new treatment system) from the true value associated with access to clean drinking water (difficult to measure but likely of much greater value).

Economic models should measure change in value in terms of a common monetary metric. Where the valued attribute is a market good such as fish or shellfish, valuation is fairly straightforward. However, most water quality-related ecosystem services are not directly associated with market goods, so values must be estimated using nonmarket valuation techniques. Both market and nonmarket values are context dependent; they are influenced by the physical, economic, and regulatory settings in which the valuation takes place, as well as on social or cultural norms. For example, the amount that a user is willing to pay to engage in a recreational activity such as swimming varies by income level as well as by the availability of substitute recreational opportunities (30). There is also variability in perceptions of the way water quality affects the suitability or desirability of recreation in different locations. Surveys of water recreationists in Minnesota, for example, have found that the level of lake water clarity users rate as "suitable for swimming" ranges from just 0.5 m to at least 2.0 m, depending on the baseline water quality of the region (31).

Step 5: Consider existing models and data sources. Although there are few examples of integrated, comprehensive analyses of ecosystem services related to water quality, there is a wealth of useful information with which to build such an assessment. In *SI Text* we have assembled a comprehensive literature review of water quality valuation studies, added relevant biophysical models and case studies, and linked these references to each row in the valuation template presented in Fig. 3. In some cases, existing work is sufficient to translate biophysical outputs to changes in service provision and value. However, few generalizable models linking actions to changes in value exist for water quality-related services. In many instances, researchers will have to collect new data in their region of interest or make assumptions about how to adapt existing models developed in other contexts. Recent work has advanced the practice of value transfer by developing valuation relationships that can be parameterized by the user with local data (e.g., refs. 16 and 32).

Discussion

There are many challenges associated with implementing an integrated modeling approach that links actions to changes in the values of water quality-related services. Current understanding of the biophysical dynamics that link actions to changes in valued attributes is incomplete at best, and there is also uncertainty surrounding economic value estimates for changes in environmental amenities. Despite these challenges, decision-makers are still called upon to make decisions about land use and resource management. Below we highlight biophysical and economic uncertainties related to water quality valuation and then describe how our framework can help to identify and address these challenges.

Challenges Linking Changes in Water Quality to Changes in Human Well-Being. There are some services, such as the effects of increased nutrient loading on commercial fish and shellfish productivity, for which uncertainties in the biophysical relationships make it difficult to reliably model changes in the valued attribute. In coastal areas, nitrogen loading has been linked with the spatial extent and intensity of hypoxia, shifting the timing of commercial fishing seasons and altering the size distribution of catches (33, 34). Quantifying the effects of nitrogen loading on commercial fishing is difficult because other stressors, such as overfishing and climate change, also affect fish populations (35). Furthermore, improving water quality in ways that increase fishery productivity may generate little net benefits if the fishery itself is poorly managed (36). With the exception of a few well-studied systems (e.g., ref. 37), there are no generalizable models that predict how a unit change in nutrient loading will affect fish or shellfish harvesting. Similar limitations apply to the relationship between harmful algal blooms and nutrient loading to coastal systems (38). There are documented statistical relationships between nutrient loading and harmful algal blooms (39, 40). However, other physical and biological mechanisms likely modify responses to nutrient loadings (38). In addition, there is no consensus on how to model changes in the recreation or commercial values according to the frequency, toxicity, extent, or duration of a harmful bloom. Lack of ability to tie actions to changes in ecosystems and to changes in valued attributes is a major limitation in assessing a number of ecosystem services.

Challenges Linking Changes in Ecosystem Goods and Services to Changes in Value. In some cases biophysical relationships are well understood, but the economic tools used to link biophysical changes to human well-being are not generalizable or are not straightforward in their application or interpretation. Required inputs for predictive economic models vary depending on the ecosystem service measured (recreation vs. a marketed good, such as fish), but common inputs include information on income, population, and distance between users and resources valued (e.g., lakes), in addition to water quality metrics. One common limitation of economic models that estimate changes in recreational value associated with changing water quality is that water quality inputs to the model are in the form of subjective water quality scales in lieu of quantitative biophysical metrics. These model inputs commonly take the form of compound metrics that combine several variables in a water quality index (e.g., ref. 41) or use descriptive terms such as swimmable, fishable, or boatable to characterize water quality (e.g., ref. 42), or stated preference surveys in which respondents rate water quality on a five-point scale (e.g., ref, 43). Although widely used, these approaches provide no clear link between biophysical data on water quality and the qualitative scale used in the economic study. Descriptive indices can also make it difficult to generalize model results across different geographical regions or demographic groups where there is variation in public perceptions of what constitutes clean water (31).

Finally, there are nonuse values such as the intrinsic value of intact food webs or the cultural values associated with the existence of species or habitats that are difficult to quantify using economic tools. Some estimates suggest that these nonuse values make up a significant portion of total value (44, 45). However, apart from stated preference surveys there are limited economic approaches to approximate these values, which are likely to be highly contextual and localized.

Even for situations in which there are robust biophysical and economic data, valuation following our framework is time-consuming and requires careful consideration of modeling assumptions and the propagation of uncertainty throughout the pathway from action to value. Still, our framework represents an improvement over existing "total value" approaches to ecosystem service valuation that tend to mask potential sources of uncertainty and make it difficult to assess confidence bounds on estimates of value. Using our template, researchers can identify exactly where uncertainty might be greatest and conduct sensitivity analyses to explore the effects of uncertainty on valuation estimates all along the pathway from action to change in value. This allows for transparent explanations of sources of uncertainty and can identify key gaps for future research investment. Our approach also allows users to track the distributional consequences of actions by identifying the unique sources of value that accrue to various individuals or groups of beneficiaries.

Examples of Integrated Models for Water Quality Valuation. There are a few examples of integrated biophysical and economic models for the valuation of water quality that fit our proposed framework and can serve as models for future work. Egan et al. (46) coupled water quality monitoring data from lakes across Iowa with survey data on household characteristics and trip information to develop a recreational demand model that predicts lake use and willingness to pay as a function of changing water clarity. Huang and Smith (37) developed a spatially explicit bioeconomic model that predicts how changing levels of nitrogen pollution affect the ecological drivers of hypoxia. They linked this biophysical model with an economic model of the commercial blue crab fishery in the Nuese River Estuary. Their work was used to predict how changes in nutrient loading in the watershed could affect fishery rents in the estuary. These two examples demonstrate that valuation of water quality is both robust and feasible when ecological and economic relationships are considered simultaneously in model development and parameterization. Neither model was meant to be generalizable to other regions or applications, but with additional research there is potential to build more integrated models such as these and create new models for improved benefits transfer following our valuation template.

Future work on water quality valuation should begin by improving integration of existing models where there is general agreement on the valued attribute and endpoint. Biophysical models of changing water quality can be fed into economic tools listed in Fig. 3 to estimate the net present values of modeled changes in water quality. Ideally, information is needed not just on current values but on changes in the stream of benefits into the future. Doing so would allow researchers to use dynamic optimization approaches to identify the set of action that would maximize the value of water quality-related services over time.

Conclusion

Managers are under increasing pressure to adopt practices to reduce the negative consequences of agriculture, grazing, timber harvesting, and other management practices on water quality. Information on the value of water quality improvements is needed to evaluate the return on investment in conservation practices as well as to inform policies or payment programs that compensate land owners for benefits generated by their actions. Water quality assessments would be more meaningful to the public if modeled changes were presented not just as concentrations of nitrogen or phosphorus but also in terms of risks to drinking water contamination, reduced fish and shellfish catches, or diminished recreational opportunities. To date there has been a lack of methods to inform decision makers on how their actions would affect these valuable services.

We have addressed this gap by introducing a generalizable framework for the assessment and valuation of water quality services. This article describes the multiple biophysical and economic pathways that link actions to changes in water quality-related ecosystem goods and services. Our template overcomes many of the shortcomings of existing approaches by integrating biophysical and economic models, basing value estimates on marginal changes in service provision, and accounting for multiple sources of value without double-counting.

Information on the provision and value of ecosystem services is increasingly informing payment for ecosystem services schemes and ecosystem service markets across the globe (47). Decisions such as weighing the relative consequences of agricultural extensification vs. intensification are highly sensitive to the value placed on water quality changes. It is critical that water quality-related services are not left out of research that informs these new markets and decisions. Our framework allows researchers to improve decision making now by using existing models and data presented in the valuation template, while also encouraging future research that targets gaps in our understanding of the biophysical and economic drivers of changes in water quality-related values.

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