GUIDANCE FOR ASSESSING CHANGES IN ENVIRONMENTAL AND ECOSYSTEM SERVICES IN BENEFIT-COST ANALYSIS

Office of Information and Regulatory Affairs

Office of Management and Budget

Published: February 28, 2024

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Introduction

Preparing benefit-cost analyses consistent with Office of Management and Budget (OMB) Circulars A-4 or A-94 often involves analyzing ecosystem services.[1] This document, "Guidance for Assessing Changes in Environmental and Ecosystem Services in Benefit-Cost Analysis," uses the term *ecosystem services* to encompass all relevant contributions to human welfare from the environment or ecosystems. The guidance describes best practices for analyzing changes in these services in the benefit-cost analysis context. For simplicity and clarity of presentation, rather than distinguishing ecosystem-derived benefits from other interrelated environmental effects throughout this document, this guidance uses the term ecosystem services to include all such effects (see *Definitions of Key Concepts*).

Considering ecosystem services, broadly defined, in benefit-cost analyses will help agencies understand relevant tradeoffs or complementarities among different ecosystem services as well as with other costs and benefits. It will also help agencies avoid situations in which certain ecosystem services are implicitly given no weight or disproportionate weight in an analysis. The guidance describes the similarities between ecosystem service effects and other effects of regulation while also outlining some unique considerations when including ecosystem services in an analysis.

This guidance is intended to be fully consistent with Circulars A-4 and A-94, and it is intended to clarify how agencies can apply the principles in those circulars to analyses involving ecosystem services. When regulations alter ecosystem services, these changes can and should be assessed within the same analysis as other costs and benefits, using the same steps, and following general guidance from OMB Circulars A-4 and A-94, when appropriate.[2] This guidance elaborates on material presented in those circulars. In addition, in applying this guidance, agencies should always act consistent with applicable law.

This guidance represents OMB's recommended best practices for ecosystem services analyses in agency benefit-cost analyses. Certain agency programs have contributed significantly to the ecosystem service field over the years, and some agencies have already developed internal guidance for valuing ecosystem services in their own benefit-cost analyses.[3] This guidance is intended to be both generally applicable

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[1] OMB, Circular A-4, *Regulatory Analysis* (Nov. 9, 2023), https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf [hereinafter Circular A-4] and OMB, Circular A-94, *Regulatory Analysis* (Nov. 9, 2023), https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-94.pdf [hereinafter Circular A-94].

[2] For ease of presentation, this guidance mainly references only relevant sections of Circular A-4. Readers performing analyses consistent with Circular A-94 should refer to the analogous part of that circular. For example, where this document references the Circular A-4 section on "Discount Rates," readers performing analyses consistent with Circular A-94 should refer to the Circular A-94 section on "Discount Rate Policy."

[3] See, for example, Tammy Newcomer-Johnson et al., *National Ecosystem Services Classification System (NESCS Plus)* (2020), *https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=350613&Lab=CEMM*; Denise Reed, Lynn Martin, and Janet A. Cushing, "Using Information on Ecosystem Goods and Services in Corps Planning: An Examination of Authorities, Policies, Guidance, and Practices," *Institute for Water Resources* (2013), *https://www.iwr.usace.army.mil/portals/70/docs/iwrreports/egs_policy_review_2013-r-07.pdf*; Emily Wainger and David Ervin, "Synthesis Chapter – The Valuation of Ecosystem Services from Farms and Forests: Informing a systematic approach to quantifying benefits of conservation programs," *The Council on Food, Agriculture and Resource Economics (C-FARE) Report No. 0114-301a* (2017), *https://nespquidebook.com/wp-content/uploads/2018/10/SynthesisChapter-TheValuationofEcosystemServicesfromFarmsandForests.pdf*; Emily Weidner et al., *"Integrating Ecosystem Services Into National Forest Service Policy and Operations," U.S. Department of Agriculture* (2017), *https://www.fs.usda.gov/pnw/pubs/pnw_gtr943.pdf*.

across agencies and consistent with existing, agency-specific documents. Agencies should consult with OMB if questions arise regarding the application of this guidance relative to other guidance related to ecosystem services.

Definitions of Key Concepts

Ecosystem services – contributions to human welfare from the environment or ecosystems.[4]

This document, following Circular A-4, uses a broad definition to encompass all relevant contributions to human welfare from the environment or ecosystems. In contrast, the United Nations defines ecosystem services in some contexts as "the contributions of ecosystems to the benefits that are used in economic and other human activity."[5] Under this narrower conception, *ecosystem services* must derive from an ecosystem, and ecosystems are comprised of biotic constituents and their physical environment. Services that arise solely from the abiotic environment are considered *environmental services* in that context, and separated from ecosystem services. The UN definition also excludes human contributions to the value of marketed commodities, including those resulting from ecosystem service flows.[6]

While precise classifications like this have been used for other applications, such as environmental-economic accounting,[7] they are too narrow for direct incorporation into agency benefit-cost analyses. Changes in ecosystem-derived benefits often result from, relate to, or precipitate changes in other environmental costs and benefits, and all of these effects should be considered in a benefit-cost analysis prepared pursuant to the OMB circulars.

The approach in this guidance is also consistent with different ecosystem service typologies that have been advanced over the years, including the early categories put forward by the Millennium Ecosystem Assessment (supporting, provisioning, regulating, and cultural services),[8] the framework supported by the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (nature's regulating, material, and non-material contributions to people),[9] and the more process-based typologies that distinguish between various intermediate and final services.[10] This guidance does not require the use of these typologies, nor does it preclude it. This guidance does, however, recommend that readers focus on final services, where relevant, to avoid double-counting.

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[4] As defined in Circular A-4, section on "Accounting for the Benefits and Costs from Environmental Services, Ecosystem Services, and Natural Capital."

[5] United Nations, *System of Environmental-Economic Accounting—Ecosystem Accounting* (2021): 27, https://seea.un.org/sites/seea.un.org/files/documents/EA/seea_ea_white_cover_final.pdf.

[6] Gretchen C. Daily et al., "Ecosystem Services in Decision Making: Time to Deliver," *Frontiers in Ecology and the Environment* 7, no. 1 (2009): 21-28. Resulting commodities are sometimes identified as "ecosystem goods"; Gretchen C. Daily et al., "The Value of Nature and the Nature of Value," *Science* 289, no. 5478 (2000): 395-396.

[7] U.K. Office for National Statistics, *England Natural Capital Accounts: 2023* (2023), https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/englandnaturalcapitalaccounts/2023.

[8] Walter V. Reid, "Ecosystems and Human Well-Being: Synthesis," *Millennium Ecosystem Assessment* (Island Press, 2005).

[9] IPBES (2019): *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. S. Díaz et al. (eds.), IPBES Secretariat https://doi.org/10.5281/zenodo.3553579.

[10] Brendan Fisher and R. Kerry Turner, "Ecosystem Services: Classification for Valuation," *Biological Conservation* 141, no. 5 (2008): 1167-1169.

Natural capital (or natural assets) – physical biotic or abiotic natural resources capable of providing—or contributing to—future welfare, potentially through environmental or ecosystem services.[11]

Natural capital is distinguished from ecosystem services in that natural capital is a stock (measure of quantity in a place at a point or period of time) whereas ecosystem services are flows (measures of changes in quantity over time).[12] Natural assets are valued through the net present value of the goods or services they provide. Understanding the link between natural assets and ecosystem services can help clarify analyses and avoid confusion. Common examples of the links between natural assets and ecosystem services include coral reefs, beach and dune systems, or wetlands (types of natural assets) that protect inland areas from storm surge (the protection is an ecosystem service), or the ability of wildlife (natural asset) to support commercial, cultural, subsistence, or recreational hunting and fishing (examples of ecosystem services).

Nature-based solutions – actions to protect, sustainably manage, or restore natural or modified ecosystems to address societal challenges, simultaneously providing benefits for people and the environment.[13]

Nature-based solutions typically provide benefits to people through flows of ecosystem services. For example, an investment in restoring a wetland that is connected to a community's drinking water supply is a nature-based solution if it improves environmental conditions (e.g., restores native species and ecological processes) and enhances the supply or quality of drinking water (e.g., ecosystem services).

[11] As defined in Circular A-4, section on "Accounting for the Benefits and Costs from Environmental Services, Ecosystem Services, and Natural Capital."

[12] Eli P. Fenichel, Joshua Abbott, and Seong Do Yun, "The Nature of Natural Capital and Ecosystem Income," in *Handbook of Environmental Economics*, ed. Partha Dasgupta, Subhrendu K. Pattanayak, and V. Kerry Smith, 4th vol. (Elsevier, 2018): 85-142; Partha Dasgupta, *Human Well-Being and the Natural Environment* (Oxford University Press, 2001).

[13] White House Council on Environmental Quality, White House Office of Science and Technology Policy, White House Domestic Climate Policy Office, "Opportunities to Accelerate Nature-Based Solutions: A Roadmap for Climate Progress, Thriving Nature, Equity, and Prosperity," *Report to the National Climate Task Force* (2022).

Part 1: Guidance Summary

When considering ecosystem services in a regulatory impact analysis (RIA) or benefit-cost analysis of Federal projects, programs, or policies, the same steps can be followed as for other analyses consistent with Circulars A-4 and A-94. Several of the steps of a regulatory analysis as outlined in Circular A-4 are presented below, along with important, specific considerations for the treatment of ecosystem services. More details on each of the steps can be found in *Part 3: Detailed Guidance*.

Scope of the Analysis

For ecosystem services, the *spatial scope for analysis* should capture effects both in areas that generate the ecosystem services and areas where people who gain value from those services are. These areas may not be the same. The *temporal scope of analysis* should be long enough to encompass all the important benefits and costs likely to result from the action. Some changes in ecosystem services play out over long timeframes, which may be accounted for by adopting a temporal scope of analysis long enough to capture those effects.

Developing an Analytic Baseline

As stated in Circular A-4, "The benefits and costs of a regulation are generally measured against a no-action baseline: an analytically reasonable forecast of the way the world would look absent the regulatory action being assessed, including any expected changes to current conditions over time."[14] Ecosystems can change over time due to a variety of factors, including demographic changes and top-down environmental changes. Ecosystem services are also a function of natural, social, and built systems, so relevant aspects of these systems should be included in the baseline and analyses of alternatives.

Alternative Regulatory Approaches

Analyses should assess a meaningful range of policy options, including, when feasible and appropriate, at least two that differ from the approach being proposed or finalized. Circular A-4 recommends that, when feasible and appropriate, agencies should analyze alternatives that achieve additional benefits or that cost less.[15] When doing so, consider developing alternatives that generate additional ecosystem services.

Assessing Benefits, Costs, and Transfers

Analyses should discuss the anticipated benefits, costs, and transfers of the regulatory options, including the option eventually selected as well as reasonable alternatives. Many of the same methods and considerations involved in assessing other benefits and costs apply here, and relevant general guidance should be consulted.[16]

[14] Circular A-4 at 11.
[15] Circular A-4 at 21.
[16] E.g., Circular A-4 and Circular A-94.

Analyses should also describe how each option is expected to cause the anticipated ecosystem service effects. Focus should be given to regulatory changes that are likely to have meaningful effects on ecosystem services, important distributional effects, or which are at least partially irreplaceable or irreversible (e.g., through death, one-way land conversion, or large fixed costs). Some of the ecosystem service effects identified in initial exploration may not be meaningful enough to include.

Accounting for the effects of a regulatory change on ecosystem services is important for accurate accounting of the costs and benefits of alternative policy options. When examining these effects, note that ecosystem service changes can also result from interactions between different aspects of social, natural, or built systems. A multidisciplinary approach may be the most effective when thinking through these effects.

As stated in Circulars A-4 and A-94, agencies should typically consider the costs and benefits of conducting more complex analysis.[17] Attention should generally be provided in proportion to the importance of potential effects. At the same time, not all actions will have substantial effects on ecosystem services.

Ecosystem service changes can be monetized using the same revealed and stated preference methods used for other costs and benefits. Circular A-4's section on "Developing Benefit and Cost Estimates" contains a helpful discussion of developing these estimates. When using estimates from published research, particular attention is needed to ensure that the ecosystem service effects that were valued are of the same type as those being valued in the policy analysis.

Valuation should capture the degree to which proposed regulatory alternatives are expected to change ecosystem services relative to baseline conditions. There is not generally a need to value the entirety of an ecosystem-service flow. Instead, only the expected value of changes in ecosystem services caused by the alternatives under consideration needs to be assessed. Estimating the "total value" of an ecosystem service—rather than the marginal effect of the regulatory alternative—is not generally needed for this kind of analysis.

An ecological production function approach—which links changes in natural, built, and social systems to ecosystem service changes and subsequent welfare changes—can be useful to link changes in ecosystem conditions to changes in the provision of ecosystem services. The endpoint of an ecological production function analysis should be goods and services denominated in units that can be monetized using standard revealed and stated-preference methods.

When using benefit-transfer methods, apply function transfers when possible and follow best practices. While best practices for using these methods in ecosystem service valuation are well established, close scrutiny is needed in choosing studies for policy analysis. A common concern arising with benefit-transfer methods is that area-based estimates of ecosystem service values may be poorly matched to new locations. This limitation should generally be avoided by using point or function transfer approaches instead.

[17] See Circular A-4 section on "Developing a Regulatory Analysis" or Circular A-94 at 8 stating that "Agencies should strive to achieve a balance between conducting the most comprehensive analysis possible and considering the resources required by both Federal agencies and external applicants to perform the analysis."

When monetization is not feasible, changes in ecosystem services should be quantified (if feasible) or described qualitatively (if quantification is not feasible). Quantification and qualitative description should focus on effects that contribute to changes in human welfare and should ideally be expressed in terms of welfare change rather than in terms of a change in other aspects of the natural, built, or social systems.

Distributional Effects

Ecosystem service benefits and costs may be distributed unevenly in space, among groups, or over time, resulting in regulatory impacts falling on different individuals or different groups of individuals. Quantitative or qualitative distributional analysis can help illustrate these effects. Analysis should pay close attention to localized effects, including health or other impacts on overburdened communities. For example, hunting, fishing, and gathering wild plants and animals can be important means for obtaining locally sourced foods—which can be especially important for populations that include subsistence hunters or gatherers—and can also have important cultural value.

Treatment of Uncertainty

When uncertainty is high, agencies should use probability distributions, plausible ranges, and sensitivity analyses to effectively compare regulatory alternatives. The precise ecosystem service consequences of regulatory options are often uncertain. Lower-probability, high-cost events—such as extreme wildfires or coastal storms—often have the highest uncertainty. Analyzing the effects of a regulation on these events requires estimating event frequency and intensity under both baseline and regulatory conditions.

Presentation of Results and Accounting Statement

Benefits, costs, and transfers related to ecosystem services should be reported with other effects, and in the same manner as other effects. That is, the analysis should report benefit and cost estimates for ecosystem services within the following three categories, in order of preference: monetized; quantified, but not monetized; and unquantified (or qualitative). A description of unquantified ecosystem service effects should be included, as appropriate, and ecosystem service effects that have been monetized should each be summed along with other effects (after discounting to present value), and then costs should be subtracted from benefits to compute one comprehensive estimate of monetized net benefits.

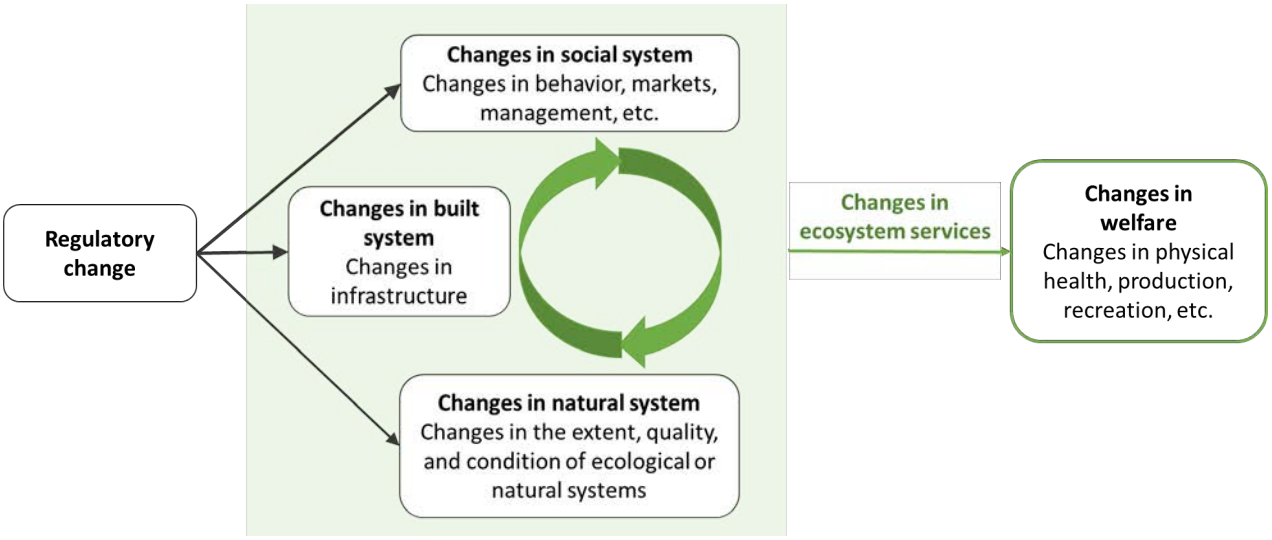
Part 2: Background

What are ecosystem services and how do they relate to regulatory analysis?

This guidance provides specific direction on the analysis of ecosystem services. As discussed above, for the purposes of this guidance, ecosystem services are contributions to human welfare from the environment or ecosystems. In the context of ecosystem services, contributions to welfare refers to market and nonmarket goods and services deriving from the environment—for example health, visual amenities, and opportunities for outdoor recreation—that, based on individuals' own assessments, make these individuals better or worse off.[18]

Ecosystem services changes usually stem from changes in natural, built, and social systems. As a result, changes to any of those systems caused by regulation can affect ecosystem services. Figure 1 shows how regulatory changes can affect ecosystem services via changes to natural, built, and social systems. Effects on one of these systems can also cause iterative effects on another system. At a further level of complexity, there can be feedbacks across social, built, and natural systems.

Figure 1. Pathways through which regulatory changes could affect the provision of ecosystem services. *Regulatory changes can affect ecosystem services by affecting nature itself, including natural capital (the bottom pathway in this Figure), the built system (middle pathway), and the social system (top pathway). Any regulation may affect several of these pathways and their interactions including possible feedback effects and iterative effects across the pathways (central, circular arrows).*



Regulation can directly affect natural systems (bottom pathway in Figure 1) by, for example, changing air or water pollution levels. Changes in the built system (middle pathway in Figure 1), including to built capital such as roads that provide access for recreation or dams that create reservoirs and reduce downstream access to water supplies, can alter which people have access to ecosystem services, as well as the difficulty or cost of that access. Changes in the social system (top pathway in Figure 1), such as the introduction of outdoor recreation permits or other legal or economic constraints, can also alter which people have access to ecosystem services, how much value people attribute to those services, or

[18] A. Myrick Freeman III, Joseph A. Herriges, and Catherine L. Kling, *The Measurement of Environmental and Resource Values: Theory and Methods*, 3rd ed. (Resources for the Future, 2014): 7.

how much it costs to access them. These systems interact (Figure 1, central, circular arrows), sometimes resulting in feedback effects.[19] These changes, alone or in combination, can affect human welfare.

To emphasize, a regulation need not directly affect the natural system to cause a change in ecosystem services. Many types of rules are likely to have ecosystem service effects, including those that involve infrastructure, natural resources, vehicles, energy, economic development, agriculture, waste management, labor or education, culturally important buildings or places, and health.

Which aspects of human welfare can be affected by ecosystem-service changes?

For agencies less familiar with ecosystem services, this section reviews some ways that ecosystem services can affect human welfare, although it is not exhaustive.

Changes in public health and safety can be connected to changes in aspects of the environment, often called environmental determinants of health.[20] Polluted air and water can cause, contribute to, or exacerbate several illnesses and conditions including chronic respiratory disease, cancer, and neurodevelopmental disorders.[21] Pest control provided by birds, snakes, and other pest predators can improve health and safety by reducing exposure to diseases carried by pests.[22] Healthy forests with low fuel loads can reduce the risk of wildfires, and that can save lives and result in avoided health care costs related to smoke inhalation. Access to wooded areas or parks can increase physical activity and improve physical health,[23] and exposure to natural spaces can improve mental health.[24]

Changes in amenity value can be tied to ecosystem services.[25] Healthy aquatic systems can make nearby communities more attractive (which can be valued through changing property values) while unhealthy aquatic systems—polluted by excess nutrient runoff, nitrogen or sulfur deposition, or

[19] For example, a change in the built system could entail building paved hiking trails that are accessible to more people with limited mobility. That also changes the natural system insofar as those trails change the character of the natural area. The trails would also change the social system by altering how much different populations visit and value the area.

[20] Joshua Graff Zivin and Matthew Neidell, "Environment, Health, and Human Capital," *Journal of Economic Literature* 51, no. 3 (2013): 689-730; Network of the National Library of Medicine, "Environmental Determinants of Health," (retrieved February 16, 2024), *https://www.nnlm.gov/initiatives/edh*.

[21] Susan C. Anenberg et al., "Estimates of the Global Burden of Ambient $PM_{2.5}$, Ozone, and NO_2 on Asthma Incidence and Emergency Room Visits," *Environmental Health Perspectives*, 126, no. 10 (2018): 107004; Shelia Zahm et al., "Carcinogenicity of Perfluorooctanoic Acid (PFOA) and Perfluorooctanesulfonic Acid (PFOS)," *Lancet Oncology* 25, no. 1 (2024): 16-17; Bruce P. Lanphear et al., "Low-level Environmental Lead Exposure and Children's Intellectual Function: An International Pooled Analysis," *Environmental Health Perspectives* 113, no. 7 (2005): 894-899.

[22] Jennifer L. Raynor, Corbett A. Grainger, and Dominic P. Parker, "Wolves Make Roadways Safer, Generating Large Economic Returns to Predator Conservation," *Proceedings of the National Academy of Sciences* 118, no. 22 (2021): e2023251118; Thomas D. Crocker and John Tschirhart, "Ecosystems, Externalities, and Economies," *Environmental and Resource Economics* 2, no. 6 (1992): 551-567; Kevin Berry et al., "The Allocation of Time and Risk of Lyme: A Case of Ecosystem Service Income and Substitution Effects," *Environmental and Resource Economics* 70, no. 3 (2017): 631-650.

[23] Roy P. Remme et al., "An Ecosystem Service Perspective on Urban Nature, Physical Activity, and Health," *Proceedings of the National Academy of Sciences* 118, no. 22 (2021): e2018472118.

[24] Gregory N. Bratman et al., "Nature and Mental Health: An Ecosystem Service Perspective," *Science Advances* 5, no. 7 (2019): eaax0903.

[25] Mitchell R. Livy and H. Allen Klaiber, "Maintaining Public Goods: The Capitalized Value of Local Park Renovations," *Land Economics* 92, no. 1 (2016): 96-116.

affected by other drivers—can make the same communities less appealing.[26] Healthy coastal habitats can dampen storm surge and protect homes and infrastructure, reducing damage and losses.[27] Changes in access to green space, rarified views, or land productivity (e.g., for crops or timber) can also affect the value of land and structures such as houses and buildings.[28]

Changes in the production of goods and services are also tied to ecosystem services. Changes in the environment can alter production of resources that can be harvested for sale in a market or used for personal consumption. Conditions in forest ecosystems influence the value of standing timber on a property. Soil improvements as well as the presence of wild pollinators or pest control species (e.g., butterflies, bees, birds, or natural pest enemies[29] such as parasitoids or spiders) can increase farms' profitability.[30] Changes in water quality can alter fish production and the desirability of fishing.[31] Wild-harvested products (e.g., deer meat, seal skins, or native plants) can be important sources of food, clothing, and other natural materials for a variety of uses.[32] Changes in the supply or quality of water can affect a variety of uses and users. Some ecosystem services affect the production of public goods which lack monetary transactions that reflect their monetary value (e.g., clean air).[33]

Changes in outdoor recreation, leisure, and other important forms of nature access and experiences are tied to ecosystem services. The types and quality of experiences can be significantly affected by changes in water quality, forest health, natural views, and populations of species available for hunting, fishing, and viewing. For example, outdoor recreation—including hunting, fishing, hiking, swimming, boating, camping, playing, and wildlife viewing—are important forms of leisure that many people value.[34] While activities like hunting and fishing may be recreational for some, for others these activities may be important to support a livelihood, nutritional and health needs, a subsistence way of life, or culturally valued experiences, as throughout this section.

Changes in non-use value can also result from ecosystem services changes. These are values generated without the beneficiary taking action. As noted in the Circular A-4 section "Indirect Uses of Market Data," these values include bequest and existence values. People often forgo consumption or preserve

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[26] David Wolf, Sathya Gopalakrishnan, and H. Allen Klaiber, "Staying Afloat: The Effect of Algae Contamination on Lake Erie Housing Prices," *American Journal of Agricultural Economics* 104, no. 5 (2022): 1701-1723.
[27] Edward B. Barbier et al., "The Value of Estuarine and Coastal Ecosystem Services," *Ecological Monographs* 81, no. 2 (2011): 169-193.
[28] H. Allen Klaiber and Daniel Phaneuf, "Valuing Open Space in a Residential Sorting Model of the Twin Cities," *Journal of Environmental Economics and Management* 60, no. 2 (2010): 57-77.
[29] Animal and Plant Health Inspection Service, *Biological Control Program* (last modified January 2, 2022), https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/biological-control-program.
[30] Dale T. Manning and Amy Ando, "Ecosystem Services and Land Rental Markets: Producer Costs of Bat Population Crashes," *Journal of the Association of Environmental and Resource Economists* 9, no. 6 (2022): 1235-1277.
[31] D. Matthew Massey et al., "Valuing Water Quality Changes Using a Bioeconomic Model of a Coastal Recreational Fishery," *Journal of Environmental Economics and Management* 52, no. 1 (2006): 482-500.
[32] Alaska Department of Fish and Game, *Subsistence in Alaska*, https://www.adfg.alaska.gov/index.cfm?adfg=subsistence.main.
[33] For example, adding green vegetated spaces can improve air quality and provide shade, improving public health outcomes, particularly for communities facing multi-source impacts, as well as improve worker productivity. These health and worker-productivity benefits may not be directly traded in markets.
[34] Daniel J. Phaneuf and V. Kerry Smith, "Recreation Demand Models," in *Handbook of Environmental Economics*, ed. Karl-Göran Mäler and Jeffrey R. Vincent, 2nd vol. (Elsevier, 2005): 671-761; U.S. Fish & Wildlife Service, *National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (FHWAR)*, https://www.fws.gov/program/national-survey-fishing-hunting-and-wildlife-associated-recreation-fhwar.

resources to ensure that natural assets—for example, a forest—are available for use by an individuals' descendants (bequest value). Similarly, individuals may simply value knowing that the natural asset exists, even if there are no plans for any current or future uses (existence value).[35]

Changes in culturally valued experiences, such as the opportunity for fulfilling a way of life (e.g., subsistence living) or spiritual connection and uses can stem from changes to ecosystem services.[36] Cultural values can be important for Tribal Nations, Indigenous Peoples, and many other communities. When certain types of cultural values are cited as ecosystem services in ways that cannot be changed or assessed incrementally, then the analysis may need to address such questions qualitatively (see the Circular A-4 section "Benefits and Costs that Are Difficult to Quantify").

Greenhouse gases. Many regulations affect greenhouse gas emissions, so understanding the relationship between greenhouse gases and ecosystem services is important. Environmental changes can affect greenhouse gas concentrations through carbon and nitrogen cycles.

When greenhouse gases are emitted, they can cause a range of harms. These harms are often reported collectively by assigning a monetary value using the social cost of greenhouse gases (SC-GHG). The SC-GHG is the monetary value of the net harm to society from emitting an additional metric ton of that GHG to the atmosphere in a given year. The SC-GHG, therefore, also reflects the societal net benefit of reducing emissions of the GHG by a metric ton. In principle, the SC-GHG includes the monetary value of all climate change impacts (both negative and positive), including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk, changes in the frequency and severity of natural disasters, disruption of energy systems, risk of conflict, environmentally-driven migration, and changes to the value of other ecosystem services. In practice, estimates of the SC-GHG are typically only a partial accounting of climate change impacts because data and modeling limitations prevent full representation of harmful climate impacts. When appropriate and feasible, agencies should apply the best available estimates of the SC-GHG when valuing changes in greenhouse gas emissions resulting from ecosystem service impacts of a rule.

[35] The definitions of use and non-use value, and the boundaries between them, are imprecise. As a general matter, most important for purposes of benefit-cost analyses is ensuring that each relevant value is captured; how agencies categorize edge cases is often less relevant. See Circular A-4 at 34 for more discussion of how to measure non-use values.

[36] Some things that people commonly consider cultural values have been described in other categories. For example, recreation and leisure have strong cultural dimensions. Existence value and aesthetics are also considered cultural values in some frameworks. As mentioned above, these categories are meant as illustrative examples of ways in which ecosystem services affect welfare, and not as definitive or non-overlapping categories.

Part 3: Detailed Guidance

This section provides details on the recommended steps for considering and assessing ecosystem services that are summarized in *Part 1*: *Guidance Summary*. The following guidance addresses how ecosystem service effects can be embedded in the core steps of regulatory analysis, following the same general steps and topics discussed in Circular A-4. As is true for other effects, the process may be iterative and steps can be revisited. Further examples of how to incorporate ecosystem services into economic analysis can be found in the appendices to this guidance.

- Scope of the Analysis
- Developing an Analytic Baseline
- Alternative Regulatory Approaches
- Assessing Benefits and Costs
- Distributional Effects
- Treatment of Uncertainty
- Presentation of Results and Accounting Statement

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Scope of the Analysis

Spatial Scope of Analysis: Circular A-4 notes that, in many circumstances analysis should focus on effects that are experienced by citizens and residents of the United States, and in some cases, noncitizens residing abroad. This holds for effects from ecosystem service changes. For ecosystem services, the spatial scope for analysis may need to be adjusted to capture both the area where people are affected (sometimes called "the extent of the market"[37]) and the areas that generate the ecosystem services.

The scope may be different for different services produced in the same area; for instance, the people who enjoy hiking in a forest may be different from the people who benefit from its water-filtration services. Assessing effects of a regulation that significantly changed these services would require a spatial scope that captures the forest and both sets of people. In determining the spatial scope of analysis, the "serviceshed" concept may be useful. A serviceshed captures the area that supports the biophysical production of the service, the physical and institutional aspects that determine access to the service (e.g., roads, water pipelines, laws), and the groups of people creating demand for the service.[38]

For example, the analysis of a rule that will improve downstream water-quality by reducing pollution should take into account the full spatial scale over which those water quality benefits and costs are realized. This means considering benefits and costs to individuals making use of the affected watershed (e.g., including water that may be piped to people living far away), including the degree to which local effects may be offset or mitigated elsewhere.

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[37] V. Kerry Smith, "Nonmarket Valuation of Environmental Resources: An Interpretive Appraisal," *Land Economics* 69, no. 1 (1993): 1-26.

[38] James Boyd and Spencer Banzhaf, "What Are Ecosystem Services? The Need for Standardized Environmental Accounting Units," *Ecological Economics* 63, no. 2-3 (2007): 616-626; Heather Tallis and Stephen Polasky, "Mapping and Valuing Ecosystem Services as an Approach for Conservation and Natural-Resource Management," *Annals of the New York Academy of Sciences* 1162, no. 1 (2009): 265-283.

Temporal Scope of Analysis: The timeframe of analysis should include a period long enough to encompass all the important benefits and costs likely to result from the action and their alternatives. When including ecosystem services in regulatory analysis, the temporal scope may require adjustment because the effects of some changes in ecosystems play out over longer timeframes.[39] For example, a rule that protects property or communities from sea level rise through infrastructure (e.g., sea walls) may yield benefits over a 20-year period, whereas an alternative that supports infrastructure and coastal marsh restoration may yield benefits over a 50-year period, thereby requiring an analytic timeline long enough to accommodate both of these alternatives. Accounting for likely changes in ecosystem services in the future is important in assessing an alternative's benefits and costs, including how future changes may affect current asset valuations.

Developing an Analytic Baseline

Analysis should follow Circular A-4 by generally measuring the benefits and costs of a regulation against a no-action baseline. Such a baseline is an analytically reasonable forecast of the way the world would look absent the regulatory action being assessed, including any expected changes to current conditions over time. Such a forecast focuses on the issues or phenomena relevant to the effects of the regulation. Ecosystem services are a function of natural, social, and built systems, so relevant dynamics of these systems should be included in the analytic baseline and alternatives. Baselines are generally not static. Reasonable forecasts of relevant system dynamics related to ecosystem service changes are likely to include demographic changes (e.g., that may affect the extent of the market),[40] top-down drivers of change (e.g., that may affect supply of ecosystem services and vulnerability of beneficiaries), and land or aquatic use changes (separate from those driven by the proposed alternatives). Resources and data exist that may be useful in establishing or projecting ecosystem-service provision from baseline conditions (e.g., EnviroAtlas,[41] reviews of ecosystem services relevant data and models by the National Ecosystem Services Partnership, [42] EPA's NESCS Plus Webtool,[43] the system of Federal natural capital accounts, and environmental-economic statistics[44]). When relevant baseline information or data are not available, the

[39] Consistent with guidance in Circular A-4, analytical time horizons should generally not be terminated before the likely signs and relative rankings of policy alternatives in terms of net benefits stop changing.

[40] For example, Hunt et al. show that background human demographic changes can influence demand for ecosystem services. Len M. Hunt et al., "The Influence of Human Population Change and Aquatic Invasive Species Establishment on Future Recreational Fishing Activities to the Canadian Portion of the Laurentian Great Lakes," *Canadian Journal of Fisheries and Aquatic Sciences* 78, no. 3 (2021): 232-244.

[41] Environmental Protection Agency, *EnviroAtlas*, *https://www.epa.gov/enviroatlas*.

[42] For a fuller collection of ecological and social data and models available for quantifying ecosystem service contributions, see Lydia Olander et al., *Data and Modeling Infrastructure for National Integration of Ecosystem Services into Decision Making: Expert Summaries* (2017), *https://hdl.handle.net/10161/26485*; Katie Warnell, Sara Mason, and Lydia Olander, *Tracking the Benefits of Natural & Working Lands in the United States: Dataset Evaluation and Readiness Assessment* (2022), *https://hdl.handle.net/10161/26601*.

[43] NESCS Plus is a classification system for final ecosystem services; see Environmental Protection Agency, *National Ecosystem Services Classification System (NESCS) Plus*, *https://www.epa.gov/eco-research/national-ecosystem-services-classification-system-nescs-plus*.

[44] Office of Science and Technology Policy, Office of Management and Budget, and Department of Commerce, *National Strategy to Develop Statistics for Environmental-Economic Decisions: A U.S. System of Natural Capital Accounting and Associated Environmental-Economic Statistics* (2023), *https://www.whitehouse.gov/wp-content/uploads/2023/01/Natural-Capital-Accounting-Strategy-final.pdf*. On page 66, this National Strategy notes,

models used for evaluating alternatives can often be applied to establish baseline conditions to provide a relevant comparison, as model input data (e.g., biophysical or social conditions) may be more readily available than directly observed ecosystem-service data.

Alternative Regulatory Approaches

The analysis should assess a meaningful range of policy options, including, when feasible and appropriate, at least two that differ from the approach being proposed or finalized.[45] This is an important step for considering whether an alternative that affects ecosystem services could provide greater benefits or lower costs.

The analysis can consider whether an alternative that involves a nature-based solution[46], or a hybrid alternative (combining conventional "gray" or "built" approaches with nature-based "blue" or "green" approaches) would result in higher net benefits, given ecosystem service effects. These kinds of alternatives may achieve the same regulatory objectives at lower cost or with greater durability or resilience, or provide additional benefits at little to no additional cost.

For example, an alternative for reducing the risk of heat stress for communities may include greening housing developments or cities, since trees and other vegetation can cool the living environment and reduce health risks and air conditioning costs in warm climates. Similarly, an alternative for a regulation aimed at increasing infrastructure longevity under extreme conditions could incorporate green infrastructure options where appropriate. Such inclusions may be relevant for many other analyses, including for housing, transportation, health and other regulations (see Table 2).

Assessing Benefits and Costs

The regulatory analysis should discuss the anticipated benefits and costs of the selected regulatory option and reasonable alternatives.[47] The analysis should describe how the action is expected to cause the anticipated ecosystem service effects along with other effects, including obvious and additional effects. The presentation of results should integrate ecosystem service effects into lists and discussions of other effects—they do not require a separate or different approach to reporting. As with other effects, ecosystem service effects should be (in order of preference) monetized, quantified, or described. They can then be reported directly with other effects that are treated similarly. When the distribution of benefits and costs is analyzed, ecosystem service effects should be included, as relevant.

"National accounting data typically cannot be directly integrated into benefit-cost analyses. Crosswalks are needed to make them applicable, and this expert group should develop those." It thus calls for OMB to "convene an expert group to develop the necessary crosswalk between valuation in the context of benefit-cost analysis and national accounting by 2025."

[45] Circular A-4 section on "Alternative Regulatory Approaches."

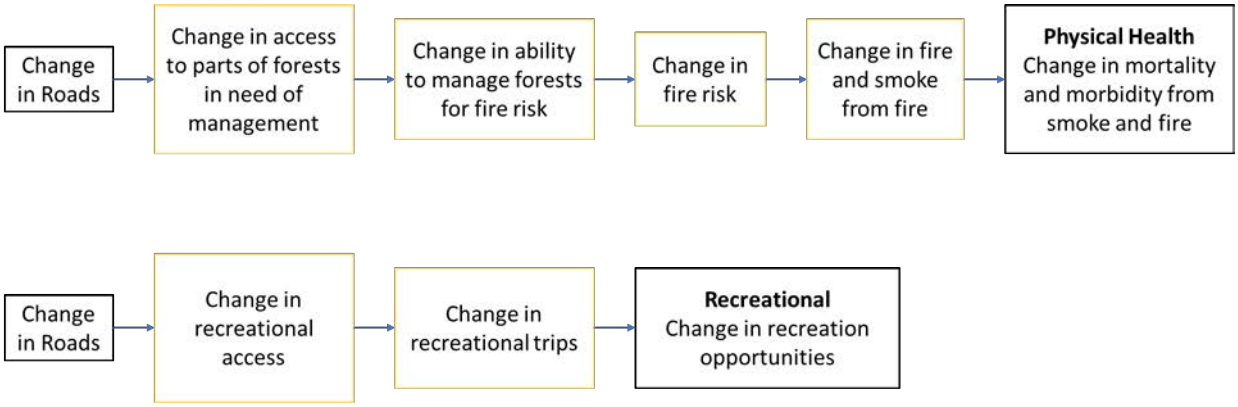
[46] White House Council on Environmental Quality, White House Office of Science and Technology Policy, White House Domestic Climate Policy Office, *Opportunities to Accelerate Nature-Based Solutions: A Roadmap for Climate Progress, Thriving Nature, Equity, and Prosperity. A Report to the National Climate Task Force* (2022), *https://www.whitehouse.gov/wp-content/uploads/2022/11/Nature-Based-Solutions-Roadmap.pdf*.

[47] Circular A-4 section on "Assessing Benefits and Costs."

Identifying Ecosystem Service Effects

Identify and describe how regulatory alternatives are expected to affect natural, social, and built systems and related ecosystem services (Figure 1). These pathways can be described in narrative form, with a conceptual model (e.g., box-and-arrow diagram), or both (see Figure 2 for an example). Capture relevant pathways leading to additional benefits and costs along with direct effects. For example, regulating a fishery with catch shares has the direct effect of preventing overfishing, thereby affecting the value of ecosystem services related to commercial fishing, with the additional effect of enabling workers to slow the pace of fishing activities, improving worker safety.[48]

Figure 2. Hypothetical pathway from a regulatory change that affects roads to ecosystem-service costs and benefits. *Note that these are just two illustrative sample pathways. Changes in roads, along with other changes listed in these pathways, can produce other effects not listed here.*



Because ecosystem services are links between multiple parts of integrated systems, thinking through their changes often require a multidisciplinary approach. Most analysts are trained in some aspects of these systems and not others, so the box below includes questions that may help identify which ecosystem services may be affected. For analysts less familiar with the ways that regulations can affect ecosystem services, Table 1 offers some examples for common rule types.

If answering the box's questions is challenging, the additional discussion in this section provides more narrative examples of how regulations can affect ecosystem services through natural, built, and social systems. Following decades of research and application, many ecosystem-service dynamics are now well understood.[49] The examples here may help stimulate thinking about how rules can affect ecosystem services, even when the rule does not target ecosystem changes.

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[48] Lisa Pfeiffer and Trevor Gratz, "The Effect of Rights-Based Fisheries Management on Risk Taking and Fishing Safety," *Proceedings of the National Academy of Sciences* 113, no. 10 (2016): 2615-2620.

[49] See, e.g., Walter V. Reid, "Ecosystems and Human Well-Being: Synthesis," *Millennium Ecosystem Assessment* (Island Press, 2005); Department for Environment, Food and Rural Affairs, *An Introductory Guide to Valuing Ecosystem Services* (2011), https://ec.europa.eu/environment/nature/biodiversity/economics/pdf/valuing_ecosystems.pdf; Paulo A.L.D. Nunes et al., Guidance Manual on Valuation and Accounting of Ecosystem Services for Small Island Developing States, UNEP, Ecosystem Services Economics Unit, Division of Environmental Policy Implementation (2014),

Questions to consider. When describing links between regulatory alternatives and ecosystem service changes, it may be useful to ask questions such as:

- Could changes from the rule change the production of goods or services that people sell in the market? *For example, could the regulation of a chemical affect managed or wild pollinator populations, altering producers' choices to purchase commercial pollination services or rely on wild pollination, the production of fruits or nuts, or both; or could it affect pest populations, altering crop yields?*
- Could changes from the rule lead people to reallocate time or money in order to maintain desirable conditions or services? *For example, could a regulation influence green space and affect air quality, altering disease risk; or could it incentivize people to visit a green space such that the space degrades more quickly from wear and tear?*
- Could changes from a rule affect people's ability to access goods and services for themselves? *For example, could a regulation increase road construction in a remote area, enabling new opportunities for fee-less outdoor recreation; or could it cut off wild animals' migratory paths, reducing wildlife viewing opportunities; or, could that regulation reduce opportunities for citizens of Tribal Nations to obtain culturally necessary natural products?*
- Could changes from a rule affect the cost of producing goods and services or the prices producers might gain from goods and services*? For example, could a regulation change food, building material, real estate, tourism, or other prices, thus changing the monetary value of timber, fish, water, or other natural assets; or could it reduce the costs of replacing ecosystem services, such as by making access to commercial pollinators, pesticides, or water filters cheaper?*
- Could changes from a rule affect the extent of the market for one or more ecosystem service(s)? *For example, could a rule creating roadless areas limit the extent of the market for some ecosystem services (e.g., places for recreation) or expand the market for others (e.g., existence value); or could a rule creating water infrastructure extend the market for some ecosystem services (e.g., water supply for drinking) and limit the market for others (e.g., water supply for real estate amenities; or wildlife or places for recreation)?*

For additional resources, consult:

- Table 2 for examples of how different general types of ecosystem services map to a common set of welfare changes.
- Text box "Available resources for ecosystem service analysis."

https://www.cbd.int/financial/monterreytradetech/unep-valuation-sids.pdf; Luke Brander, "Guidance Manual on Value Transfer Methods for Ecosystem Services," United Nations Environment Programme (2013), *https://www.gwp.org/globalassets/global/toolbox/references/guidance-manual-on-value-transfer-methods-for-ecosystem-services-unep-2013.pdf*; Proceedings of the National Academy of Sciences, *Special Feature: Nature as Capital PNAS 100th Anniversary* (2015), *https://www.pnas.org/topic/123*.

Table 1 Examples of the targets of rules and the types of ecosystem service effects they may alter. *Expected impacts from a rule may be beneficial or adverse. This list is not exhaustive. Table 2 shows how specific ecosystem services link to human welfare.*

If the rule could affect or involve…	Then a sample (i.e., non exhaustive) list of ecosystem service effects could include…
Agriculture (including aquaculture)	Water quality maintenance for drinking; productivity for timber, fish, crops, or other products; greenhouse gas effects on various services; food and air quality for public health; wildlife or places for recreation or culturally valued experiences; existence of wildlife and plant populations, places, or features
Community or economic development	Wildfire risk reduction for property protection; energy use and effects associated with changing energy use; exposure to nature for public health; productivity for crops (via pollination)
Culturally, spiritually, or historically important buildings, geographic features, artifacts, etc.	Existence of wildlife and plant populations, places, or features; productivity for timber, fish, or other wildlife products; nature for aesthetics in viewsheds; Tribal communities' ability to access sacred sites and engage in cultural practices
Disaster mitigation or risk reduction	Flood risk reduction for public health and property protection; wildfire risk reduction for public health; wildlife or places for recreation or culturally valued experiences; existence of wildlife and plant populations, places, or features
Energy development or production (e.g., management, frameworks, standards)	Air quality for public health; greenhouse gas and local air pollution effects on various services; existence of wildlife and plant populations, places, or features; water supply (both quantity and quality), recreation opportunities
Infrastructure (e.g., road construction or maintenance, flood levees, housing development)	Water quality maintenance for drinking, air quality related to transportation, energy production, or recreation; flood risk reduction for property protection; wildlife or places for recreation or culturally valued experiences; existence of wildlife and plant populations, places, or features
Natural resources management (e.g., forests, minerals, wildlife), including access to them	Biological resource productivity for timber, fish, crops, or other products; greenhouse gas effects on various services; wildlife or places for recreation or culturally valued experiences; existence of wildlife and plant populations, places, or features
Vehicle fleets or production	Air quality for public health; greenhouse gas effects on various services
Waste management	Greenhouse gas effects on various services; water quality maintenance for drinking; air quality for public health; waste production management for public health; wildlife or places for recreation or culturally valued experiences

Examples of Changes in Natural Systems That Affect Welfare Through Ecosystem Services

Changes in the water cycle affect the timing and quantity of water in rivers, lakes, and estuaries, with ramifications for water use. Variation in the amount of water in rivers and lakes is known to affect real estate values, as homeowners pay a premium to see a full lake or reservoir. [50] Changes in hydrology that affect groundwater supplies and inflow to reservoirs often alter availability of irrigation water, affecting agricultural production. [51] Similarly, fluctuations in surface and groundwater flows can alter the supply of water for drinking, hydropower production, or water-based recreation. Those fluctuations can also affect the amount of water remaining in rivers that provide aquatic habitat to plants, animals, and fungi.

Forest health, wildlife populations, and ecosystem conditions affect how much timber is available for harvest; how much yield agricultural fields, rangelands, or pastures produce; and how many and which species of plants, animals, or fungi are available and viable for commercial, recreational, subsistence, or cultural uses. In addition to natural resource management, changes in habitats and biodiversity through land use change or pollution, climate conditions, biogeochemical cycles, migration, predator-prey relationships, plant-pollinator relationships, and other dynamics can alter the condition of all of these natural assets and the services they provide. In urban environments, changes to these types of natural systems often affect property value, heating and cooling costs, health, and recreational opportunities.

Biogeochemical processes in wetlands and other habitats influence the quality of air, lands, and waters that can be harmed by direct discharges of pollutants into the environment. This harm can be exacerbated by removal of natural vegetation, aquatic organisms, and soil microbes that filter some contaminants (e.g., excess nutrients and sediments). Pollution affects many aspects of welfare, including health (e.g., heat stress, water-borne diseases, exposure to toxic algal blooms, asthma, cancer , and other disease from air and water pollution), real estate values (e.g., higher home values near less polluted water bodies), and recreation opportunities and income from recreation- and tourism-related companies (e.g., beach, lake, or recreational fishing closures yielding less time and money spent on recreating; poor air quality yielding fewer tourists to affected area). Water pollution can also increase the cost of producing drinking water,[52] energy (e.g., suspended sediments can damage hydropower machinery), and shipping (e.g., high sediment loads can increase dredging costs).

Changes to plants, animals, fungi, and microbes, and the extent and quality of their habitats can also alter ecosystem services. For example, people often seek out recreational activities to engage with certain animals (e.g., birdwatching, wildlife viewing, hunting, angling), and changes in the populations of those animals can affect recreational opportunities, tourism opportunities, and recreation- and tourism-derived income. Some plants and animals are of particular commercial value (e.g., salmon, Douglas fir), so changes in populations and habitats can alter economic production. Still other species (e.g., monarch butterflies), habitats, or places are of special social or cultural interest, and people want to ensure they continue to exist for current and future generations (i.e., they have existence value or bequest value). Activities which affect the spread of invasive species can impact resource productivity and may have broader ecosystem effects (for example, by displacing non-invasive species or increasing the risk of a high-intensity forest fire).

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[50] Melissa A. Boyle and Katherine A. Kiel, "A Survey of House Price Hedonic Studies of the Impact of Environmental Externalities," *Journal of Real Estate Literature* 9, no. 2 (2001): 117-144.

[51] Peter Folger et al., *The Federal Role in Groundwater Supply*, Congressional Research Service R45259 (updated May 22, 2020), *https://crsreports.congress.gov/product/pdf/R/R45259*.

[52] James I. Price and Matthew T. Heberling, "The Effects of Source Water Quality on Drinking Water Treatment Costs: A Review and Synthesis of Empirical Literature," *Ecological Economics* 151 (2018): 195-209.

Changes in atmospheric greenhouse gas concentrations can result from changes in the natural climate-regulating system, including habitat extent, land use, habitat quality, species populations, biogeochemical processes, and soil conditions. This includes changes in carbon storage and sequestration. These changes in greenhouse gas concentrations can affect the timing and intensity of climate change. Alterations to the global climate system cause myriad social impacts, many of which are captured by estimates of the social cost of greenhouse gases.

Examples of Changes in Built Systems That Affect Welfare Through Ecosystem Services

Constructing, operating, maintaining, or removing infrastructure can change access to ecosystem services, even when the natural system itself does not change significantly. For example, building roads, trails, boat ramps, or other infrastructure can increase access to recreation areas, improve access for fire management, increase the presence of trash and traffic pollution from visitors, change soil erosion patterns, or increase access to natural products (e.g., fish, timber, or products used for cultural purposes). These changes can alter demand by making services more accessible, which can affect prices and distribution of use. The changes can also affect whether a market can support new buyers and sellers. For example, pipes are often constructed to connect drinking water to homes, increasing access or changing the cost of access to raw water supplies for drinking water. Relatedly, upgrading pipes can alter the amount of heavy metals entering soil or groundwater. Energy infrastructure can also harness services such as wind energy or hydropower. Energy may be available in the natural system, but it is not accessible as an energy service until infrastructure is built to capture it for human use. Infrastructure can also impede or eliminate access to ecosystem services. Dams can block fish passage or cut off access for recreational, commercial, or cultural uses. Linear infrastructure (e.g., roads, pipelines, or train tracks) can disrupt water movement in wetlands or rivers, thereby reducing or eliminating access to water-related services. Infrastructure can also disrupt wildlife movement and populations, and introduce predators and pests.

Built infrastructure can also replace certain uses of ecosystem services. For instance, forests, wetlands, and other natural assets can purify water. Upgrading a water treatment plant could lower demand for those ecosystem services by replacing them with economic services. It is important to note that other services provided by those natural assets, such as hiking or recreational boating opportunities, might be unaffected.

Constructing buildings can increase or decrease some ecosystem services, depending on whether the construction restores, protects, or converts ecosystems. For example, removing mangroves, coral reefs, dunes or other coastal habitats during construction can make the new construction and surrounding communities more prone to coastal flood risks. Designing buildings to preserve or improve habitats can increase overall welfare by giving people more access to ecosystem service benefits. Conversely, construction may also reduce ecosystem services by increasing pollution, harming habitats, blocking viewsheds, reducing surface permeability (which increases flooding and may increase air temperatures), or by increasing crowding in natural areas.

Examples of Changes in Social Systems That Affect Welfare Through Ecosystem Services

Human behavior can influence demand for, supply of, and access to ecosystem services. Regulations can influence behavior directly. For example, closing a park to off-road vehicles would lead to fewer people driving such vehicles in that park while a policy to promote national parks could lead to more outdoor recreation. Regulations can also influence behavior related to ecosystem services indirectly. For

example, closing a road to vehicles may lead to more vehicles on another road, which could affect natural assets near that road. Similarly, closing one area to fishing can lead to increased bycatch of other species in other areas as fishers are displaced and change which species they target. [53] Physical conflict (e.g., wars) can adversely affect ecosystem services in the area of the conflict, and at times outside the area (e.g., through weapons testing that harms public health or through conflict-induced migration).

Economic changes and policies can influence the value of ecosystem services. For example, subsidizing or taxing goods used for outdoor recreation can influence demand for those goods, in turn changing the value of that recreation. Policies that affect commodity markets can affect prices for extracted and harvested products, such as agricultural goods and timber. Policies that increase household discretionary income or encourage migration (such as remote work or extended broadband capacity) may result in greater permanent or temporary consumption of natural resources in areas where these changes occur. They could also change who can afford trips or equipment to visit certain natural areas, thereby influencing demand for those areas.

Education, campaigns, or programs can affect the salience of information and ease or cost of acquiring information about ecosystem services, altering how much people value a given amount of those services. For example, many conservation campaigns aim to increase awareness of endangered species and increase the population that holds an existence value for those species. See Circular A-4 section on "Informational Approaches to Regulation and Nudges" for further information and caveats about analysis of information-based interventions.

Table 2 provides illustrative examples of how some regulatory changes cause changes to natural, built, and social systems, which in turn flow through ecosystem services to cause changes in human welfare. As shown in Figure 1, these changes can sometimes affect each other (e.g., changes in water quality might also affect wildlife and plant habitats).

[53] Joshua K. Abbott and Alan C. Haynie, "What Are We Protecting? Fisher Behavior and the Unintended Consequences of Spatial Closures as a Fishery Management Tool," *Ecological Applications* 22, no. 3 (2012): 762-777.

Table 2. Examples of how different biophysical changes and human welfare changes are linked through common ecosystem services. *This is not comprehensive and focuses on some commonly affected services.*

If the regulation may affect…	Then possible system changes may include…			And affected ecosystem services may include…	Which may yield human welfare changes through changes to…
	Natural system changes	Built system changes	Social system changes		
Water quantity or access	Changes in water quantity in rivers, lakes, ocean; changes in habitat, species, or conditions that affect hydrological processes	Changes in infrastructure that affect access, like dams, pipelines, or irrigation canals	Changes in water uses; changes in rules that affect access or costs (water rights or fees; port taxes; or access fees)	Water supply for real estate value	Amenity value
				Water supply for recreation opportunities	Recreation and other leisure
				Water supply for recreation income	Products
				Water supply for drinking	Products
				Water supply for energy production (hydropower)	Products
				Water supply for agriculture (irrigation)	Products
				Water supply for transportation (shipping, cargo)	Products
				Water supply for industrial uses	Products
Water quality	Changes to water quality in rivers, lakes, or oceans; changes in biophysical processes that affect water quality; changes in habitat or species composition that affect water quality	Changes in infrastructure that affect water quality like treatment plants or discharge pipes	Changes in rules or behaviors that affect quality (e.g., pollution standards or beach closures) or costs (e.g., fines or cost of dredging or treating polluted water)	Water quality maintenance for public health	Public health
				Water quality maintenance for real estate value	Amenity value
				Water quality maintenance for recreation opportunities	Recreation and other leisure
				Water quality maintenance for recreation income	Products
				Water quality maintenance for drinking	Products
				Water quality maintenance for energy production	Products
				Water quality maintenance for transportation	Products
				Water quality maintenance for industrial uses	Products

If the regulation may affect…	Then possible system changes may include…			And affected ecosystem services may include…	Which may yield human welfare changes through changes to…
	Natural system changes	Built system changes	Social system changes		
Flooding	Changes in flood intensity or flood frequency; changes in habitats that buffer flood risks (e.g., forests, marshes, wetlands, corals or mangroves)	Changes in infrastructure that affect flood risk like flood gates, levees, or the amount or value of property in flood risk zones (e.g., building or property enhancement or crop and timber management changes)	Changes in flood-related rules or behaviors that affect property or product values (e.g., crops or timber), flood risk reduction or damage costs (e.g., insurance rates or construction costs), or health care costs	Flood risk reduction for public health	Public health
				Flood risk reduction for property protection (avoided damages)	Products, or amenity value
				Water quality maintenance for drinking	Products
				Water quality maintenance for public health	Public health
Wildfires	Changes in climate conditions, habitats or biophysical processes that affect forest condition, fire frequency, or fire intensity	Changes in infrastructure that affect access for fire management (e.g., roads) or the amount or value of property in fire risk zones	Changes in rules or behaviors that affect amenities, product values, fire risk reduction, damage costs, or health care costs	Wildfire risk reduction for public health	Public health or amenity value
				Wildfire risk reduction for property protection (avoided damages)	Products, or amenity value
Wildlife and plant habitat	Changes in species populations, species or habitat productivity, or habitat extent or condition that affect wildlife or places of interest	Changes in infrastructure that affect access for management or recreational activities (including congestion effects); changes that affect proximity of work settings, health care facilities, or residential facilities to natural areas (e.g., building near natural areas)	Changes in awareness of species, places or features existence; changes in rules or behaviors that affect prices for accessing natural areas, health care costs, or amenities	Wildlife and plants, places for recreation (birds, fish, game, lakes, beaches, etc.)	Recreation and other leisure
				Wildlife and plants, places for recreation income (birds, fish, game, lakes, beaches, etc.)	Products
				Existence of wildlife and plant populations, places, or features	Non-use value
				Nature exposure for public health	Public health
				Nature for aesthetics in viewsheds	Amenity value
				Productivity for timber, fish, crops, or other products	Products
				Wildlife and plants, places for culturally valued experiences	Cultural value

If the regulation may affect…	Then possible system changes may include…			And affected ecosystem services may include…	Which may yield human welfare changes through changes to…
	Natural system changes	Built system changes	Social system changes		
Air quality	Changes in air quality (e.g., particulate matter); changes in air temperature; changes in vegetation that affect air quality or temperature	Changes in transportation infrastructure or vehicle designs that affect emissions; changes in industrial infrastructure that affect emissions; changes in facilities that change access to air filtration or cooling equipment	Changes in rules or behaviors that set acceptable levels of air quality, affect prices for air filtration or energy use, or change frequency of behaviors that cause emissions (e.g., plowing fields or driving)	Air quality for public health	Public health
				Air cooling for public health	Public health
				Air cooling for reducing energy use (avoided costs)	Products
				Air quality for real estate value	Amenity value
				Air quality for recreational opportunities	Recreation and other leisure
				Air quality for worker productivity	Products
Greenhouse gas emissions	Changes in species, habitats, climate conditions, or biogeochemical processes that affect greenhouse gas stocks and flows (e.g., carbon storage or sequestration)	Changes in energy infrastructure that alter the energy mix (e.g., hydropower or coal facilities), changes in transportation infrastructure that affect emissions, changes in equipment or facilities that affect emissions (e.g., engines, power generators, filters)	Changes in rules or behaviors that set acceptable levels of emissions, or behaviors that cause emissions	Potentially all of the above	Potentially all of the above

Focusing the Analysis

Some of the ecosystem service effects identified in initial exploration may not be important or practical to include. Use the following questions as heuristics to help assess which service changes are likely to be sufficiently important for further analysis:

- Is the proposed regulatory change likely to have a meaningful effect on the ecosystem service or populations affected by it?
- Are the expected changes likely to have important distributional effects or alter existing inequalities?
- Are the expected changes likely to be at least partially irreplaceable or irreversible (e.g., through death, one-way land conversion, or a large fixed cost)?[54]

To help answer these questions, consult relevant evidence, which can include experimental or observational research studies from a variety of disciplines, meta-analysis or synthesis studies, tools, models, expert opinion, and Indigenous Knowledge.[55]

Evidence from these sources can inform whether a relationship exists between a regulatory change, ecosystem services and welfare outcomes (e.g., boxes in Figure 2). Evidence can also clarify the direction and magnitude of that relationship and whether the information can be generalized from a particular place or study to the particular regulatory alternatives under consideration. It may be helpful for transparency and organization to synthesize evidence in a conceptual diagram showing the pathways described from the regulatory changes to the human welfare endpoints, as in Figure 2.

If the answer is "yes" to any of the questions above, analysts should consider including the pathway and expected change in the RIA when feasible and appropriate.

If there is evidence that an expected effect is unlikely to occur under the specific regulation being proposed, that effect may be excluded from the analysis. If there is evidence of a change, but little or no evidence on the direction or magnitude of change, consult the Circular A-4 section on "Treatment of Uncertainty." Take care to distinguish uncertainty *in whether an effect exists* from uncertainty *in the effect's precise magnitude*. An uncertain magnitude does not suggest that the best estimate of the magnitude is zero. Many ecosystem-service changes are important and worth including in an analysis despite uncertain magnitudes with appropriate caveats. For the sake of transparency, explain the reasoning behind any decisions to exclude an identified pathway from further analysis.

Appropriate Use of Monetization Methods

Costs and benefits caused by ecosystem service changes can be monetized, or otherwise assessed, using the same revealed and stated preference methods used for other costs and benefits.[56] There are some

[54] For a fuller discussion of irreversibility in decision making, see Avinash K. Dixit and Robert S. Pindyck, *Investment Under Uncertainty* (Princeton University Press, 1994).

[55] For more on incorporating Indigenous Knowledge into regulatory processes, see Office of Science and Technology Policy and Council on Environmental Quality, *Guidance for Federal Departments and Agencies on Indigenous Knowledge* (2022), https://www.whitehouse.gov/wp-content/uploads/2022/12/OSTP-CEQ-IK-Guidance.pdf.

[56] Kathleen Segerson, "Valuing Environmental Goods and Services: An Economic Perspective," in Patricia A. Champ, Kevin J. Boyle, and Thomas C. Brown, eds., *A Primer on Nonmarket Valuation* (Springer, Dordecht, 2017): 1-26;

common considerations to make and pitfalls to avoid in applying these methods to ecosystem service changes.

Do not assume that monetization is impossible. As with other costs, benefits or transfers, incremental changes in ecosystem service effects on welfare should be (in order of preference) monetized, quantified, or described qualitatively.[57] Analysts less familiar with ecosystem service analysis may assume that costs and benefits that are not experienced through markets cannot be monetized. Figure 3 reflects the guidelines in Circular A-4 in a set of questions that can be asked to help determine whether an effect should be monetized, quantified, or described qualitatively. If it is challenging to answer the questions in Figure 3, or if all ecosystem service effects should be described qualitatively, it can be helpful to revisit logic models or expert discussions to make sure each effect is sufficiently specified. For example, if a proposed rule will affect forest health, but the potential measurement unit is unclear, that is likely because "forest health" is capturing multiple changes in a vague concept that is difficult to analyze. Working through how forest changes are likely to affect specific aspects of welfare may reveal costs and benefits that can be quantified or monetized. For example, specification may reveal that proposed changes in forests are likely to cause increased fire risk to health and benefits associated with increased access for recreation. Unbundling these expected effects can provide further clarity on what can be monetized, quantified or described.

Focus on *marginal* (not *total*) costs, benefits, and transfers. Valuation should capture the degree to which proposed regulatory alternatives are expected to change ecosystem services relative to baseline conditions. There is not generally a need to value the *entirety* of an ecosystem-service flow; only the expected *change* in the service(s) caused by the alternatives under consideration. For example, some economists would argue the total monetary value of *all* freshwater in the world is infinite.[58] No single regulatory action is likely to jeopardize all of the world's freshwater supply. Rather, regulatory decision making might affect the supply or quality of some finite quantity of water whose specific uses can be monetized for benefit-cost analysis. For instance, a policy that would degrade water quality in a water body would not require estimation of the water body's full value, or the value of the services it would offer if it were theoretically "pristine." Rather, under the principles of this guidance, valuation would only be needed for the incremental change in water quality that might occur as a result of each regulatory alternative.

Markets reveal the marginal value of some ecosystem services, making such services relatively straightforward to monetize (Table 3). In other cases, ecosystems directly provide services to individuals and households without market intermediaries. In these cases, indirect uses of market data may be applicable for monetization (Table 3). For example, several ecosystem services are inputs to goods or services that are traded in markets (e.g., services in Table 2 linked to production), so implicit (shadow) prices can be estimated. Health models estimate future changes in fatal and non-fatal health and safety risks, and environmental aspects that affect health can be built into these models. Hedonic pricing

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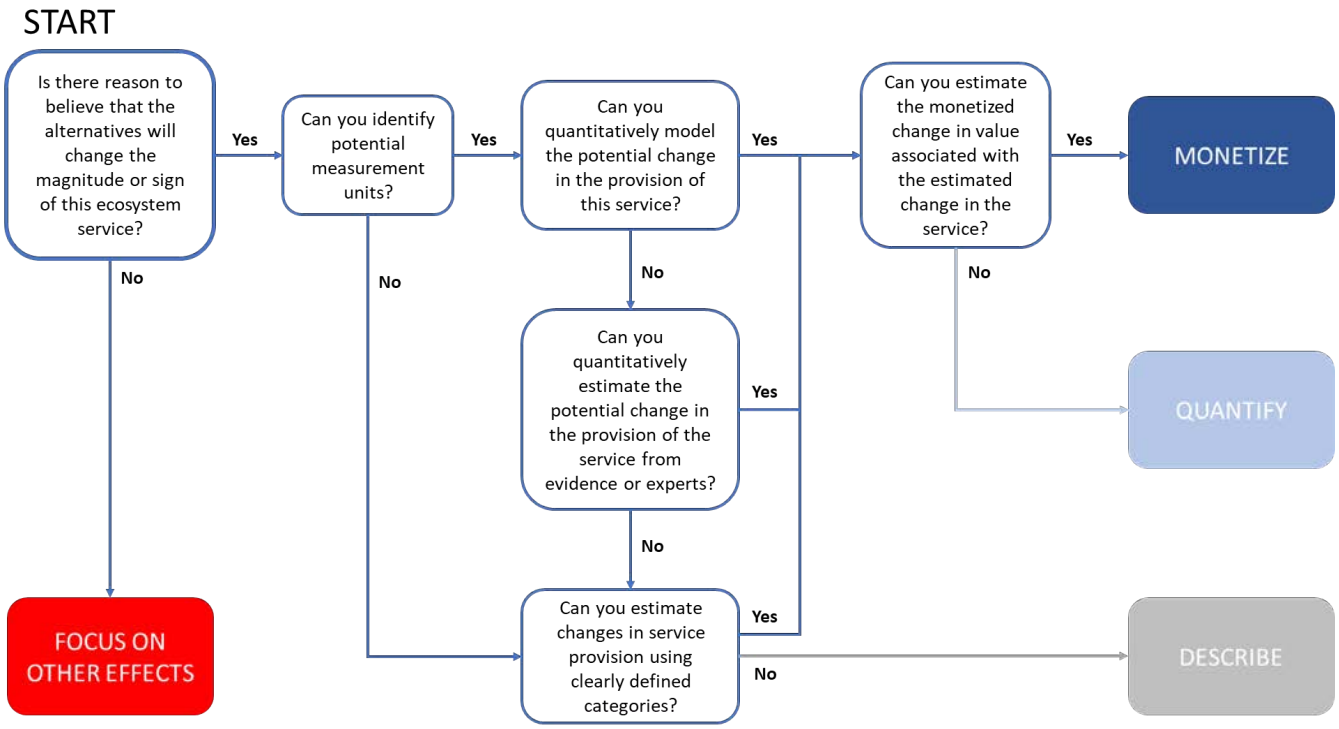
Daniel J. Phaneuf and Till Requate, *A Course in Environmental Economics: Theory, Policy, and Practice* (Cambridge University Press, 2017).

[57] See Circular A-4 section on "Developing Benefit and Cost Estimates" for a deeper discussion of, and considerations for, developing these estimates.

[58] For example, Toman argued that attempts to value the world's total ecosystem services can result only in "a serious underestimate of infinity." Michael Toman, "Why Not to Calculate the Value of the World's Ecosystem Services and Natural Capital," *Ecological Economics* 25, no. 1 (1998): 58.

methods are frequently used to understand how ecosystems services or natural assets capitalize into other goods that bundle many services, such as real estate value.[59]

Figure 3. Decision tree. *This decision tree is intended to aid decisions on whether to monetize, quantify, or qualitatively describe an ecosystem-service effect.*



Models and data for monetizing ecosystem services through these methods are available in many cases. Monetizing ecosystem services may also be possible within an existing model. For example, an agency may already be using a flood risk model to estimate property damages, but that model may not capture the way that natural vegetation affects flood risk. Altering the existing flood model to reflect natural vegetation could represent the ecosystem service-change pathway and provide an efficient way to monetize the service. Care should be taken to ensure that such a change maintains the logic of the model. When existing monetization models for human welfare changes cannot be adapted to capture the ecosystem service, models focused on ecosystem services may be able to estimate the change in services.[60]

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[59] Kelly C. Bishop et al., "Best Practices for Using Hedonic Property Value Models to Measure Willingness to Pay for Environmental Quality," *Review of Environmental Economics and Policy* 14, no. 2 (2020): 260-281; David Wolf and H. Allen Klaiber, "Willingness to Pay in Hedonic Pricing Models," *Oxford Research Encyclopedia of Economics and Finance* (2021), https://doi.org/10.1093/acrefore/9780190625979.013.583.

[60] Agencies and academic groups have developed a variety of ecosystem service models that make these connections. For examples, see Erik Nelson et al., "Modeling Multiple Ecosystem Services, Biodiversity Conservation, Commodity Production, and Tradeoffs at Landscape Scales," *Frontiers in Ecology and the Environment* 7, no. 1: 4-11; Lydia Olander et al., "Data and Modeling Infrastructure for National Integration of

Table 3. Valuation methods and estimates relevant to ecosystem services. *Please note that this table presents illustrative examples of valuation methods and estimates rather than a comprehensive list.*

These valuation methods and estimates*…	May be applicable to ecosystem services valued through…
Revealed preference/indirect use	Water supply for recreation income, amenity value, drinking, energy production, and agriculture
	Water quality maintenance for amenity value, drinking, and energy production
	Wildfire risk reduction for timber production and property protection
	Pollination for farmland value and crop productivity
	Pest control for crop productivity
	Nature for aesthetics in viewsheds; wildlife, places for recreation income, and recreation opportunities
	Flood risk reduction for property protection
	Air quality for amenity value
Revealed preference/direct use	Productivity for timber, fish, crops, or other products
Stated preference	Water quality maintenance for recreation opportunities
	Wildlife, places, or features for recreation opportunities, or non-use value
	Air quality for recreation opportunities
Revealed or stated preference or health utility	Water quality maintenance for non-fatal health risks
	Wildfire risk reduction for non-fatal health risks
	Pest control for non-fatal health risks
	Nature exposure for non-fatal health risks
	Flood risk reduction for non-fatal health risks
	Air quality or cooling for non-fatal health risks
Revealed and stated preferences (Value of statistical life)	Wildfire risk reduction for mortality risk
	Flood risk reduction for mortality risk
	Air quality or cooling for mortality risk
Social cost of greenhouse gases	Greenhouse gas effects on various services

* See Circular A-4 for more detail on these methods and estimates.

When ecosystem services produce goods that are not traded in markets, indirect monetization approaches can be relevant. These approaches may use market data, revealed non-market behavior, or stated-preference methods. When such methods are used, they should account for the fact that many ecosystem-service values are unique or location specific and therefore cannot be applied or are hard to apply to other locations, which means the marginal value in one location can be substantially different from the marginal value in a different location.

A feature of monetizing ecosystem service changes is the interdisciplinary nature of the analyses. Models using any monetization approach need to reflect the connections between the natural, social and built environment, and many models capture only a subset of those connections. Ecological production function models have partly closed this gap, and have applied both direct and indirect

Ecosystem Services into Decision Making: Expert Summaries," *National Ecosystem Services Partnership* (2017), *https://nicholasinstitute.duke.edu/sites/default/files/publications/nesp_wp_16-02_0.pdf*.

monetization approaches.[61] These production functions link changes in natural, built, and social systems to ecosystem service and welfare changes. For example, a production function modeling approach was applied to estimate the current total value of coral reefs for flood risk reduction for property protection, finding that U.S. coral reefs result in multiple effects including "[a]voided flooding to more than 18,180 people" and "[a]voided direct flooding damages of more than $825 million to more than 5,694 buildings." [62] This multidisciplinary analytical approach could be applied to new policy or program alternatives to estimate the marginal change in these ecosystem services.

Benefit-transfer methods may be useful when transferring results of studies. It is not always possible to collect timely, case-specific data to support regulatory analysis.[63] Benefit-transfer methods can be used to transfer estimates of the same type of effects as the ones included in the analysis. When transferring estimates for using in an ecosystem service valuation, particular attention is needed to ensure that the ecosystem service effects that were valued in the study are the same type of effects as those being valued in the policy analysis. Some past studies have assumed that responses reflected all possible services from an ecosystem (e.g., a wetland). Not all services will necessarily be relevant to the analysis, and in these cases, the use of estimates of the value of all possible services should not be used. For example, a valuation of the cost of losing recreation access to half a wetland's area should not be used to estimate the value of losing drinking water benefits from the same magnitude of area loss elsewhere. If the services being valued are unclear, the study should not be used.

Best practices for using these methods in ecosystem service valuation are well established.[64] In general, benefit transfer based on meta-analysis is preferred to benefit-function transfer (i.e., transferring the entire demand function rather than just a point estimate), and benefit-function transfer is generally preferred to unit transfer. But each approach might have appropriate applications.[65] Studies chosen for policy analysis should follow these best practices.

A common misuse of benefit-transfer methods has been to apply area-based estimates (a type of unit value transfer) of ecosystem service values to policy sites that are poorly matched to study sites. This

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[61] National Research Council. 2005. *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*. Washington, DC: The National Academies Press. https://doi.org/10.17226/11139**;** Edward B. Barbier "Valuing Ecosystem Services as Productive Inputs," *Economic Policy* 22, no. 49 (2007): 177-229; Heather Tallis and Stephen Polasky, "Mapping and Valuing Ecosystem Services as an Approach for Conservation and Natural-Resource Management," *Annals of the New York Academy of Sciences* 1162, no. 1 (2009): 265-283; Peter Kareiva et al., *Natural Capital: Theory and Practice of Mapping Ecosystem Services* (Oxford University Press, 2013).

[62] C.D. Storlazzi et al., "Rigorously Valuing the Role of U.S. Coral Reefs in Coastal Hazard Risk Reduction," U.S. Geological Survey Open-File Report 2019–1027, 42 (2019): 1, https://doi.org/10.3133/ofr20191027.

[63] See Circular A-4 section on "Benefit-Transfer Methods."

[64] Examples include: Environmental Protection Agency, "Guidelines for Preparing Economic Analyses," (2010): 7-44–7-50; Robert J. Johnston et al., "Guidance to Enhance the Validity and Credibility of Environmental Benefit Transfers," *Environmental and Resource Economics* 79, no. 3 (2021): 575-624; Robert J. Johnston and Lisa A. Wainger, "Benefit Transfer for Ecosystem Service Valuation: An Introduction to Theory and Methods," *Benefit Transfer of Environmental and Resource Values: A Guide for Researchers and Practitioners*, ed. Robert J. Johnston et al. (Springer, 2015): 237-273; Stephen Newbold et al., "Benefit Transfer Challenges: Perspectives from U.S. Practitioners," *Environmental and Resource Economics* 69, no. 3 (2018): 467-481.

[65] See Circular A-4 section on "Benefit Transfer Methods"; see also, Environmental Protection Agency, "Guidelines for Preparing Economic Analyses," (2010): 7-44–7-50.

limitation to the approach has been widely documented.[66] The effect of an area change on a given ecosystem service can seldom be translated directly between contexts. For example, how much marginal recreational value is added by creating or preserving an acre of beach depends on factors like how many acres of beaches already exist nearby, as well as how accessible, crowded, and high-quality the relevant beaches are. Area changes are often nonlinearly related to changes in ecosystem-service costs or benefits, and estimates reported or transferred on the basis of area alone often miss important variation in values.[67] Continuing the beach example, moving from 0 to 10 acres of beach would likely provide a higher recreation value per acre than moving from 10,000 to 10,010 acres. The same type of ecosystem can also provide different services from place to place, depending on the context of the social and built system. For example, an acre of forest may be used for recreational hunting in one area and for timber harvest in another. These values are not interchangeable, and using an area-based value transfer may inappropriately assume that they are. In addition, as already noted, values generated by stated preference studies may also vary due to context-specific aspects of the study design, including any survey instruments. For these reasons, area-based benefit transfer is seldom a robust method for benefit transfer in ecosystem-service analysis for a benefit-cost analysis.

Make sure that effects are categorized appropriately. Existing ecosystem service research does not always group ecosystem service effects into costs, benefits, and transfers. A common misstep in the benefit-cost analysis context is to report jobs created as a benefit. When an economy is at full employment, each job created is offset by a job that is vacated, and in such circumstances new jobs could therefore be considered transfers (in that case, from the person who lost a job to the person who gained a job). When payments to or from the government are involved, be especially attentive to whether that payment constitutes a benefit, cost, or transfer. For example, changes in hunting or fishing permit fees may be transfers. Payments by the National Flood Insurance Program might also constitute transfers.[68] It is also common for the literature to report changes in income as ecosystem service benefits or costs. These effects are relevant, but should be reported in terms of the appropriate form of production rather than as income. For example, a study may report how an increase in a fish stock leads to higher commercial landings and increased fishery profits as well as lower prices for consumers.

[66] See, for example, Mark L. Plummer, "Assessing Benefit Transfer for the Valuation of Ecosystem Services," *Frontiers in Ecology and the Environment* 7, no. 1 (2009): 38-45; Stephen Newbold et al., "Benefit Transfer Challenges: Perspectives from U.S. Practitioners," *Environmental and Resource Economics* 69, no. 3 (2018): 467-481.

[67] For more information, see David W. S. Wong, "The Modifiable Areal Unit Problem (MAUP)," *WorldMinds: Geographical Perspectives on 100 Problems* (Springer, 2004): 571-575; Adrienne Grêt-Regamey et al., "On the Effects of Scale for Ecosystem Service Mapping," *PLoS ONE* 9, no. 12 (2014): e112601.

[68] Charles A. Taylor and Hannah Druckenmiller, "Wetlands, Flooding, and the Clean Water Act," *American Economic Review* 112, no. 4 (2022): 1334-1363.

Additional Benefits and Costs

As with other effects, the analysis of ecosystem service effects should look beyond the obvious benefits and costs of the regulation and consider any important additional benefits or costs, when feasible.[69] Analysts may be most familiar with the additional costs that federal actions can create through losses in ecosystem services. For example, construction of new buildings or other infrastructure that aims to deliver new low-income housing or secure transportation options may be done by clearing habitat or degrading ecosystems. Those construction impacts can create additional costs by removing the flood risk reduction, carbon sequestration, or recreational use opportunities that the habitat provided. These additional costs should be considered.

It is equally important to consider additional benefits and transfers. For example, the same construction—designed differently—could create ecosystem service benefits or reduce the loss of ecosystem service benefits. Siting new construction on already degraded areas, and using construction options like green roofs, restored wetlands for stormwater management, and native vegetation for localized cooling could create such additional benefits. The ecosystem conversion might also reduce the frequency of particular diseases (e.g., heat stroke or malaria).

Methods for Treating Non-Monetized Benefits and Costs

For ecosystem-service effects that cannot be monetized, effects should be quantified in changes to other physical or behavioral units to the extent possible.[70] Examples of relevant units for quantifying ecosystem service effects that reflect both physical changes and impacts to human welfare include change in the number of days people can visit a culturally important site, percent change in the likelihood of each birdwatcher seeing a rare bird species at an important site, change in expected number of weeks when subsistence fishers catch enough to meet weekly needs, and change in the number of days of exposure to wildfire smoke each year.

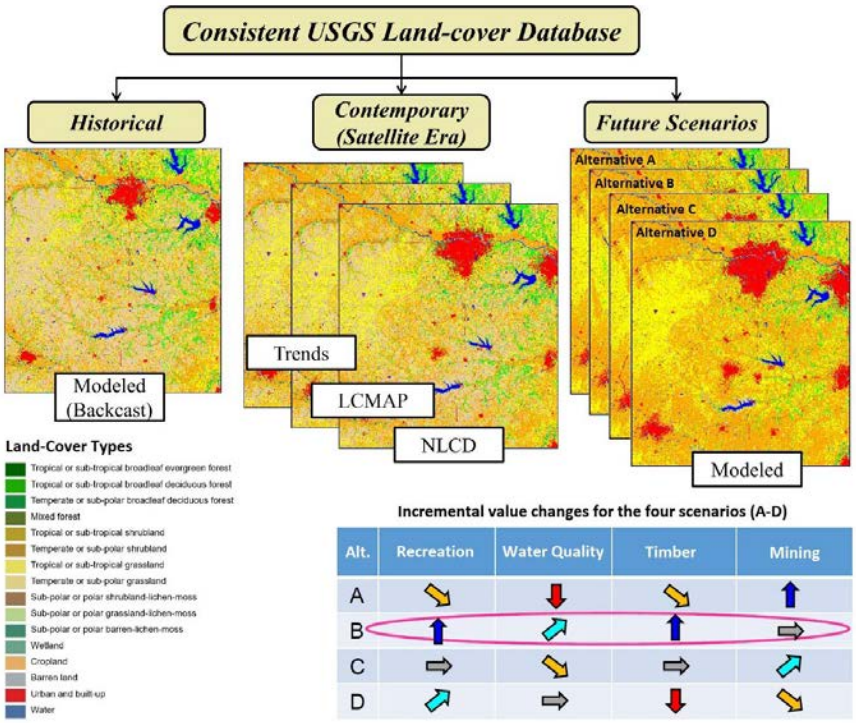
Many models exist that can be used to quantify effects of changes in ecosystem services on welfare (see "Available resources for ecosystem service analysis" box). If predictive models (statistical or mechanistic) are not available or sufficient to develop quantitative estimates, consider using expert elicitation, as discussed in the Circular A-4 section on "Quantitative Analysis of Uncertainty."

Quantification should focus on effects that contribute to changes in human welfare (Figure 2) and so should ideally be in non-monetary terms of welfare change (e.g., life years, product volumes, or time spent engaging in a culturally or spiritually valued experience) rather than quantities of change in other aspects of the natural (e.g., area of habitat or volume of water), built (e.g., miles of road or number of power facilities), or social (e.g., number of places where access to a service is allowed or prices on products) systems. Quantities that reflect changes in the physical realm (e.g., miles of river with clean water, number of wild animals, distance from people to parks, number of recreation amenities, amount of a culturally important species present, or number of clean air days) without connecting to ecosystem-service beneficiaries do not account for how many people have access to those benefits and a robust qualitative discussion of likely welfare changes remains preferred to no quantification.

[69] Circular A-4 section on "Additional Benefits and Costs."
[70] Lydia P. Olander, "Benefit Relevant Indicators: Ecosystem Services Measures that Link Ecological and Social Outcomes," *Ecological Indicators* 85 (2018): 1262-1272, https://doi.org/10.1016/j.ecolind.2017.12.001.

Available resources for ecosystem service analysis

Agencies and academic groups have developed a variety of models to assist with the identification and analysis of ecosystem services, including the recently launched ARIES for SEEA Explorer, which uses 'machine reasoning' to build custom ecosystem service models using relevant publicly available data (available at: https://aries.integratedmodelling.org/aries-for-seea-explorer/). Many ecosystem services considerations can be analyzed using different land-use/land-cover (LULC) scenarios. The U.S. Geological Survey's (USGS) Land Change Monitoring, Assessment, and Projection (LCMAP) program is a useful tool for analyzing these scenarios (see figure below).



For lists of other available resources, see:

- Lydia Olander et al., *Data and Modeling Infrastructure for National Integration of Ecosystem Services into Decision Making: Expert Summaries* (2017), https://nicholasinstitute.duke.edu/sites/default/files/publications/nesp_wp_16-02_0.pdf.
- National Ecosystem Services Partnership, *Federal Resource Management and Ecosystem Services Guidebook: Resources* (n.d.), https://nespguidebook.com/resources/.

Additional information on ecosystem models can be found on pages maintained by federal agencies:

- Environmental Protection Agency, *EcoService Models Library (ESML)* (n.d.), https://esml.epa.gov/; United States Geological Survey, *Ecosystem Services* (n.d.), https://www.usgs.gov/programs/climate-research-and-development-program/science/science-topics/ecosystem-services;
- Geosciences and Environmental Change Science Center, *Ecosystem Services Assessment and Valuation* (2017), https://www.usgs.gov/centers/geosciences-and-environmental-change-science-center/science/ecosystem-services-assessment;
- United States Forest Service, *Ecosystem Services* (n.d.), https://www.fs.usda.gov/ecosystemservices/.

As with monetization, quantification should focus only on the marginal change in ecosystem services likely to be caused by the regulatory alternatives. Reporting only total stocks (e.g., total acres of forest, total carbon stocks, total number of fish in a population, or overall water quality in rivers) may be relevant to the analysis, but data focusing on the anticipated changes to such stocks may be important for a benefit-cost analysis.

When there are quantified but unmonetized ecosystem services, consider doing a breakeven analysis, as noted in the Circular A-4 section on "The Need for Analysis of Proposed Regulatory Actions." It may be possible to determine what the unit value of the service would have to be in order for net benefits to be positive, including under different regulatory alternatives.

If costs, benefits, and transfers cannot be monetized or quantified, then they should be described qualitatively, as specifically and with as much detail as possible.[71] Omission of information can potentially bias the results of benefit-cost analysis. The changes in described services should be presented in a summary table, and professional judgment should be used to incorporate them into the overall analysis, including how they affect preference rankings of the policy alternatives under consideration. Described effects should be given the same analytic weight as similarly important monetized or quantified effects.

Distributional Effects

As with other effects, ecosystem service benefits and costs of a regulation may be distributed unevenly across space, time, or people. Distributional analysis can help illustrate these effects.[72] As possible ecosystem service effects are identified, it can help with distributional analysis to also identify the locations or groups of people likely to experience expected changes in ecosystem services. Existing resources, such as Census data, regional plans (e.g., forest, transportation, disaster response, or community development plans) and sector analyses (e.g., tourism, agriculture, energy) can be useful in this process, along with public input or community engagement, where appropriate. Other agency resources can help identify if any likely affected populations or communities are affected by environmental or health impacts,[73] or are overburdened or disadvantaged.[74]

When performing a distributional analysis on ecosystem service changes, the concept of a serviceshed can again be helpful.[75] Changes in some ecosystem services are more likely to have distributional effects than others. For example, greenhouse gas mitigation gains or losses have similar effects on the global atmosphere regardless of where the change occurs (because the atmosphere is relatively well-mixed). Thus, the location where ecosystem services affect greenhouse gas emissions will not have a substantial distributional component (though the impacts of climate change themselves could still have important distributional consequences). However, some services are more locally produced and should be evaluated locally, including other air pollutants that are emitted by sources that also emit greenhouse

[71] See Circular A-4 section on "Benefits and Costs that Are Difficult to Quantify or Monetize."
[72] Circular A-4 section on "Distributional Effects."
[73] See, e.g., Environmental Protection Agency, "EJ Screen: Environmental Justice Screening and Mapping Tool," *https://www.epa.gov/ejscreen*.
[74] See Council on Environmental Quality, "Climate and Economic Justice Screening Tool," *https://screeningtool.geoplatform.gov*.
[75] Lisa Mandle et al., "Who Loses? Tracking Ecosystem Service Redistribution from Road Development and Mitigation in the Peruvian Amazon," *Frontiers in Ecology and the Environment* 13, no. 6 (2015): 309-315.

gases or the coastal flood risk reduction benefits from coral reefs. A regulation that affects where coral reefs are likely to be (e.g., through restoration or damages) will affect some communities more than others, and so may be well-informed by a distributional analysis. Ecosystem service changes can have distributional effects by changing where ecosystem services are supplied, or changing where or how people have access to these benefits.[76]

Treatment of Uncertainty

As with other effects, the precise ecosystem service benefits and costs of agency actions are not generally known for certain, as there may be uncertainty about the incidence, magnitude, location, or probability of the effects.[77] However, reasonable estimates of such uncertain consequences can often be developed. An effect of a regulation should not be excluded from a regulatory analysis simply because of uncertainty.

Important tools for considering uncertainty are real option value analysis, Monte Carlo analysis, and the calculation of certainty-equivalent valuations.[78] Ecosystem services that are related to lower-probability, high-cost events, such as extreme wildfires or coastal storms, may have particular uncertainty. Analyzing effects on these services requires understanding the frequency and intensity of these events under both the baseline and regulatory alternatives. Both elements can be highly uncertain. For example, land use changes or climate change may affect the ecosystem even in the absence of agency action. When change in value relative to the baseline is monetizable but uncertain, then report probability distributions or plausible ranges and sensitivity analyses to help show whether the uncertainty is likely to change the relative ranking of regulatory alternatives.[79] If available information is insufficient to develop monetized estimates, consider using expert elicitation.[80]

One source of uncertainty common in valuing ecosystem services is the degree to which benefits or costs in one area are offset by behavioral changes in the same or different areas. For example, routing a highway around a natural feature could avoid directly damaging that feature. But it may cause drivers to drive more on other roads, which could harm the ecosystems near those roads. The degree of these effects may be difficult to predict, so carefully apply guidance on uncertainty and transparently state assumptions of this type.

It is useful to state other key assumptions as well. When analyzing ecosystem services, it is important to specify the regulatory context being considered. Natural assets are often subject to regulation under multiple sources of authority (e.g., a water body may be regulated under both the Clean Water Act and the Safe Drinking Water Act), and under multiple levels of government, so it is important to clarify how

[76] Maria Brück et al., "Broadening the Scope of Ecosystem Services Research: Disaggregation as a Powerful Concept for Sustainable Natural Resource Management," *Ecosystem Services* 53 (2022): 101399.
[77] Circular A-4 section on "Treatment of Uncertainty."
[78] See also chapter 11, "Dealing with Uncertainty: Expected Values, Sensitivity Analysis, and the Value of Information," and chapter 12, "Risk, Option Price, and Option Value," in Anthony E. Boardman et al., *Cost-Benefit Analysis: Concepts and Practice*, 5th ed. (Cambridge University Press, 2018); Perrine Hamel and Benjamin P. Bryant, "Uncertainty Assessment in Ecosystem Services Analyses: Seven Challenges and Practical Responses," *Ecosystem Services* 24 (2017): 1-15.
[79] Circular A-4 section on "Treatment of Uncertainty."
[80] Circular A-4 section on "Quantitative Analysis of Uncertainty."

related regulations are expected to affect that asset and how that influences the baseline(s) and each proposed alternative.

Presentation of Results and Accounting Statement

Benefits, costs, transfers, and distributional effects related to ecosystem services should be reported alongside, and in the same manner as, other effects. That is, benefit and cost estimates should be reported within the following three categories: monetized; quantified, but not monetized; and unquantified. No separate or adjusted reporting for ecosystem services is needed, and they should be directly integrated into the reporting of all other effects.[81]

Ecosystem service effects that have been monetized should each be summed along with other effects with appropriate discounting, and then costs should be subtracted from benefits to compute one comprehensive estimate of monetized net benefits. As with other effects, analysts should be careful to avoid double-counting (i.e., capturing the same value more than once) and undercounting (i.e., not capturing a value, or a part of the value). This can be challenging with imputed benefits or imputed costs, which are common with some ecosystem services.[82]

There are three forms of potential double-counting that agencies may need to address for ecosystem services. These arise because many current ecosystem-service valuation methods are associated with changes in underlying natural capital rather than the services experienced by beneficiaries.

First, changes in natural capital may change the value of multiple services, but these services may not be measured completely separately. Consider a rule that influences beach nourishment[83] and thus beach width. One could use a travel cost method (i.e., how much people pay to travel to beaches of different widths) to estimate the change in the value of recreational services from changes in the width of beaches. One could also estimate a hedonic pricing function, which reveals the change in value of home prices with respect to change in beach recreation access. But those home prices may also reflect the value of other services, such as storm protection and viewsheds. Individual studies are not always clear about these interconnections. In some cases, summing the hedonic and travel cost values would double-count some portion of the recreational value. However, the hedonic pricing approach and travel cost approach may appropriately capture the different services depending on how the studies are structured. Please consult OMB when combining different valuation techniques to estimate changes in total ecosystem services attributable to policy alternatives.

Second, using that same example, the two valuation methods should be treated differently in summarizing costs and benefits. The travel-cost model measures the value for a flow of services. People travel to beaches year after year. Each visit provides distinct value. This year-by-year value can be added

[81] In addition to reporting monetized and quantified costs and benefits in the benefit cost table, it is sometimes useful to report ecosystem service effects in categories that align with a standardized U.S. government coding system such as the North American Industry Classification System (NAICS). For example, the Environmental Protection Agency developed the National Ecosystem Services Classification System Plus, which integrates NAICS codes. Environmental Protection Agency, *National Ecosystem Services Classification System (NESCS) Plus (2002), https://www.epa.gov/eco-research/national-ecosystem-services-classification-system-nescs-plus.*

[82] Challenges can also arise with ensuring that qualitative portions of an analysis avoid implying the separate existence of effects that are actually implicitly included in monetized estimates.

[83] Beach nourishment refers to adding sand to a beach.

to a schedule of future benefits and costs without much complication or adjustment. Conversely, for an asset measure, such as in the home-based hedonic pricing example, the estimated contribution of the beach width to home prices provides a baseline capitalization value. The correct quantities to add to the benefit and cost schedules are related to the changes in that capitalization value. Such values should be added as a one-time value as if they have already incorporated the flow of future benefits, implicitly already having been discounted to net present value by the market.[84] However, changes to these assets' values may be incorporated year-by-year if there are future changes to the natural asset.

Third, including the values of processes that occur along the causal chain from a system change to a welfare outcome (e.g., valuing an intermediate service and the associated final service) can lead to double-counting. For example, some quantity of water may be a valuable input into crop production. It may be possible to break out the value of that water from the "farm gate" value of crops.[85] That is useful in many analyses, but adding the change in farm gate value and the change in water value would not be analytically appropriate in an RIA context, because it counts the contribution of water twice, both as and input and its contribution to value-added for an output. A measure that does not double count would be just the change in farm gate value, once it includes the full change in value of water as an input to crop production.[86]

As one possible check, ensure that only the value of welfare changes is reported, not changes in inputs (sometimes called intermediate services, e.g., water supply as an input to production). If intermediate values are calculated as part of analysis (but not reported), they can be used to check that intermediate values do not exceed the value of final services (e.g., the value of that production). For example, suppose (for simplicity of discussion) that some quantity of water and soil organic matter provide only one service: serving as inputs into crop production. In that case, the value of simultaneous increases in water and soil organic matter for crop production cannot exceed the value of crop production.[87] Note that this check on the results relies on efficient markets, which might not be valid in all contexts. Therefore, it is not definitive.

Another useful check could involve confirming that changes in the value of capital, including natural capital, balance with production-related net benefits. Often, benefit-cost analyses deal with changes in flows rather than changes in stocks—or, in this context, the value of ecosystem services rather than changes in the values of ecosystems or natural capital. This check highlights that changes in capital value—for example, changes in the value of *ecosystems*—should not be added to net benefits associated with production—for example, changes in the value of *ecosystem services*.

In addition to a table integrating monetized and quantified ecosystem service effects with other effects, it is important to include a descriptive summary of all effects. Explain the logic for expected changes and

[84] The discount rate implicit in the market may not be the same as discussed in the Circular A-4 section on "Discount Rates." If they diverge, consider whether adjustments to the value estimate or discount rate are appropriate, and be transparent about any such divergences. If unsure, consult with OIRA.

[85] "Farm gate" value of a crop is the total value of the crop less the costs of selling the crop, such as transportation and marketing expenses.

[86] Just the change in water value could also be meaningful, but the change in farm gate value is more likely to be easily measurable.

[87] It may be the case that water and soil organic matter also provides non-crop-related services (i.e., the simplifying assumption of providing only one service is relaxed). In that case, the values of changes in water and soil organic matter could not exceed the sum of the change in crop production and those other services.

implications for affected communities (including which populations are likely to experience effects). The narrative should include all costs and benefits, including all effects monetized, quantified, and qualitatively described. Published studies provide examples of ways that ecosystem services evaluated in various terms can be discussed together in terms of comparing alternatives. For example, an analysis of land use options in Hawaii reported how various alternatives are expected to perform in terms of water quality maintenance (relative change reported), greenhouse gas emission changes (in quantitative terms), and agricultural production (in monetary terms).[88] For transparency, the narrative should also include a description of ecosystem service effects that were dropped from the analysis and an explanation of the logic behind that decision.

When possible, it may be helpful to include a summary conceptual diagram showing the pathways from regulatory alternatives to ecosystem service changes in welfare through alterations of the natural system, built system, or social system, and their interactions.

In order to accelerate learning and improvement over time, agencies should, where feasible, describe important research gaps including: (i) a brief description of the type of study or data that would be necessary to quantify ecosystem service effects, and (ii) a brief description of the type of study or data that would be necessary to monetize the welfare changes associated with changes in services.

Conclusion

This guidance is intended to help all Federal agencies in developing their RIAs, policy, and program alternatives to include ecosystem services. As understanding and the published literature in the field of ecosystem services continues to evolve and grow, there may be opportunities for future updates.

[88] Joshua H. Goldstein et al., "Integrating Ecosystem-Service Tradeoffs into Land-Use Decisions," *Proceedings of the National Academy of Sciences* 109, no. 19 (2012): 7565-7570.