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: August 2023

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I. Introduction

Preparing benefit-cost analyses consistent with Office of Management and Budget (OMB) Circulars A-4 or A-94 often involves analyzing ecosystem services. This guidance uses the term ecosystem services to encompass all relevant contributions to human welfare from the environment or ecosystems. The United Nations defines ecosystem services as "the contributions of ecosystems to the benefits that are used in economic and other human activity."[1] However, 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. This document, "Guidance for Assessing Changes in Environmental and Ecosystem Services in Benefit-Cost Analysis," describes best practices for analyzing the incremental or marginal 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.

Considering ecosystem services, broadly defined, in benefit-cost analyses helps agencies understand relevant tradeoffs or complementarities among different ecosystem services and with other costs and benefits. It also helps agencies avoid situations in which the value of specific ecosystem services are implicitly given no weight or disproportionate weight in an analysis.[2] 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.

The principles and guidelines herein are generally applicable to benefit-cost analyses that are consistent with both OMB Circular A-4 and A-94. 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

[1] 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*. This definition has also been used for national-level statistical applications, for instance, in the United Kingdom. U.K. Office for National Statistics, *England Natural Capital Accounts: 2023* (2023), *https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/englandnaturalcapitalaccounts/2023*. Under that narrower SEEA-EA 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 and separated from ecosystem services in this narrower sense. The SEEA-EA definition also excludes human contributions to the value of marketed commodities, including those resulting from ecosystem service flows. Valuing the ecosystem service flow may, nevertheless, require consideration of the output. 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. However, precise classifications like this are less relevant for purposes of benefit-cost analysis than for other applications, such as accounting.

[2] This approach is also consistent with different "ecosystem service" typologies that have been advanced over the years, ranging from the commonly used "supporting, provisioning, regulating, cultural service" typology in Millennium Ecosystem Assessment (MA), *Ecosystems and Human Well-being: Synthesis* (Island Press, 2005), to more process-based typologies that distinguish between various intermediate and final services in, for instance, Brendan Fisher and R. Kerry Turner, "Ecosystem Services: Classification for Valuation." *Biological Conservation* 141, no. 5 (2008): 1167-1169. This guidance does not require the use of these typologies, nor does it preclude it. This guidance does, however, direct readers to focus on final services where relevant in order to avoid double-counting.

to the analogous part of that circular. For example, where this document references the Circular A-4 section "Discount Rates," readers performing analyses consistent with Circular A-94 should refer to the Circular A-94 section "Discount Rate Policy."

In developing this guidance, OMB, in collaboration with the Office of Science and Technology Policy, developed a draft that was subject to interagency review. This draft will go through a process of public comment and peer review. OMB is grateful for feedback from interagency stakeholders, and looks forward to feedback from public commenters and peer reviewers. OMB itself is solely responsible for the final content of this guidance.

Some agencies have already developed internal guidance for valuing ecosystem services in their own benefit-cost analyses.[3] This guidance represents OMB's recommended best practices for such analyses in regulatory impact analyses (RIAs). Insofar as this guidance conflicts with any internal guidance, agencies should consult with OMB.

This guidance elaborates on material presented in Circulars A-4 and A-94. It does not impose any requirements on agencies. As these circulars note, agencies should generally attend to the trade-off between the benefits and costs of more analysis by focusing attention on only important potential effects. Not all actions will have substantial effects on ecosystem services. Moreover, agencies should always refer to their operative statutory authorities and, if their authorities are inconsistent with the proposed Guidance, should defer to the relevant statute.

II. <u>What are ecosystem services?</u>

This guidance provides specific direction on the analysis of environmental and ecosystem services, herein called *ecosystem services*. As discussed above, for 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.[4] The ways that ecosystem services relate to markets vary, and include cases in which ecosystem services contribute to goods and services that are bought and sold in markets (e.g., timber and seafood); are bundled with other goods that are bought and sold (e.g., pollinated crops); or are public goods, provided without monetary transactions that reflect their monetary value (e.g., wetlands reducing flood risk or storing

[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* (2013), *https://www.iwr.usace.army.mil/portals/70/docs/iwrreports/egs_policy_review_2013-r-07.pdf*; Emily Weidner et al., *Integrating Ecosystem Services into National Forest Service Policy and Operations* (2017), *https://www.fs.usda.gov/pnw/pubs/pnw_gtr943.pdf*.

[4] 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, 2003), 7.

water used for drinking).[5] RIAs should include analyses of ways in which regulatory changes affect human welfare through ecosystem-service changes (see Section III).[6]

Natural assets. Closely related to ecosystem services is the concept of natural assets (also referred to as natural capital). As defined in the *National Strategy to Develop Statistics for Environmental-Economic Decisions*, natural assets are durable physical or biological elements of nature that persist through time and contribute to current or future economic production, human enjoyment, or other services people value. Natural capital is distinguished from ecosystem services in that natural capital is a stock (e.g., the acreage of a specific type of ecosystem) and ecosystem services are flows of natural goods and services from that stock that influence human welfare.[7] Both stocks (quantities of natural capital) and flows (quantities of ecosystem services) can change over time. Natural assets are valued through the net present value of the goods or services they provide.[8] 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 (natural assets) that protect inland areas from storm surge (ecosystem service), or the ability of wildlife (natural asset) to support commercial, subsistence, or recreational hunting and angling (ecosystem services).

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

As Circular A-4 recognizes, benefit-cost analyses of regulations focus on expected changes in human welfare. There are many aspects of human welfare that can be affected by changes in ecosystem services. Some changes may result in positive impacts to human welfare, some may result in negative impacts, and some may result in transfers (e.g., offsetting increases and decreases in welfare for different groups of people). Welfare effects from changes in ecosystem services have historically been underrepresented in RIAs. This section reviews some of the most commonly considered ways in which ecosystem-service changes can affect human welfare, although it is not exhaustive. Some of these welfare effects potentially overlap, and agencies should avoid double-counting impacts. Also note that

[5] As an example of explicit market transactions incorporating ecosystem services, paid pollinator services can increase the value of a farm's agricultural produce or reduce the farm's cost of producing. Ecosystem services often occur without formal market transactions. Adding green vegetated spaces can improve air quality and provide shade, improving health outcomes and worker productivity; these health and worker-productivity benefits are, in many cases, not directly traded in markets. As discussed below, note that ecosystem services can increase or decrease welfare. For example, deer can provide recreational hunting services that benefit society, but deer can also cause vehicle collisions. Daniel Rondeau, "Along the Way Back from the Brink," *Journal of Environmental Economics and Management* 42, no. 2 (2001): 156-182. Note that, under the narrower definition of ecosystem services referenced in footnote 1, ecosystem services can only increase welfare, but this guidance widens the scope to welfare-decreasing effects.

[6] 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.

[7] 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).

[8] 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 ed. (Elsevier, 2018), 85-142; Partha Dasgupta, *Human Well-Being and the Natural Environment* (Oxford University Press, 2001).

some of these effects reflect stocks, and others reflect flows. Generally, one should conduct benefit-cost analysis of a given ecosystem-service effect using flows or stocks, but not both.[9] When combining such measurements, as discussed further in Section VI, Step 4 below, take extra caution and use your best professional judgment to avoid double-counting. Section VI also provides other recommended steps for systematically considering ecosystem services in analyses and identifies complexities that agencies may need to address.

Changes in mental health and physical health and safety can be connected to changes in aspects of the environment, often called environmental determinants of disease.[10] Polluted air can cause or exacerbate respiratory and other severe diseases, and polluted water can cause or exacerbate several illnesses. Pest control provided by birds, snakes, and other pest predators can improve health and safety by reducing exposure to diseases carried by pests.[11] 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. 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. Access to wooded areas or parks can increase physical activity and improve physical health,[12] and exposure to natural spaces can improve mental health.[13]

Changes in property value can be tied to ecosystem services.[14] Soil improvements, soil nutrient cycling by microbes, pollination, and pest control provided by native species on or near farms can increase farmland asset values. Healthy aquatic systems can raise nearby home asset values while unhealthy aquatic systems, polluted by excess nutrient runoff, nitrogen or sulfur deposition, or affected by other drivers, can make water bodies less attractive for recreation or to home buyers.[15] Coastal habitats can dampen storm surge and protect homes and infrastructure, reducing damage and losses.[16] Conditions in

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[9] Flows are streams of benefits that occur continuously in time (similar to "revenues"), whereas stocks are assets that are stable over time (similar to "capital"). In general, many stock variables (e.g., forests) generate flows of value (e.g., absorbing carbon dioxide), and the projected flow of value coming from a stock variable is a key determinant of the value of a stock variable. Note that, in practice, flow variables are rarely measured continuously, but rather over short fixed periods of time, such as a flow that occurred over a year. Future welfare changes may be measured as future flows or as changes to capital stocks. However, to avoid double-counting, if a stock produces a flow of value, calculated changes in welfare should only include the value of the stock or the value of the flow, but not both.

[10] Joshua Graff Zivin and Matthew Neidell, "Environment, Health, and Human Capital," *Journal of Economic Literature* 51, no. 3 (2013): 689-730.

[11] 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 Rime and Risk of Lyme: A Case of Ecosystem Service Income and Substitution Effects," *Environmental and Resource Economics* 70, no. 3 (2017): 631-650.

[12] 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.

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

[14] 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.

[15] 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.

[16] Edward B. Barbier et al., "The Value of Estuarine and Coastal Ecosystem Services," *Ecological Monographs* 81, no. 2 (2011): 169-193.

forest ecosystems influence timber asset values and the value of standing timber on a property. 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.[17]

Changes in the production of goods and services are also tied to ecosystem services. Changes in the natural capital within the environment can alter production of fish, trees, or other resources that can be harvested for sale in a market or used for personal consumption. Wild pollinators or pest control species (e.g., butterflies, bees, birds, or natural pest enemies[18] such as parasitoids or spiders) can increase farms' profitability.[19] Changes in water quality can alter fish production and the desirability of fishing.[20] 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.[21] Changes in the supply or quality of water can affect its many uses and users. These changes in service provision are often reflected in natural capital valuation changes. Note that a change in the value of a particular natural capital asset may result from multiple service changes. Note also that ecosystem service changes may comprise a mix of costs, benefits, and transfers. For example, increases in deer populations may enhance recreation opportunities while also increasing vehicle collisions.[22]

Changes in outdoor recreation, leisure, and other important forms of nature access and experiences are tied to ecosystem services. The types of experiences available and the quality of those 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.[23] Notably, 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 highlighted in several other paragraphs in this section.

Changes in non-use value can 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, among other things, bequest and existence values. It is common for individuals to forgo consumption or to expend resources to ensure that natural assets—for example, a forest—are available for use by an individuals' descendants (i.e., bequest value). Similarly, individuals

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[17] 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.

[18] Animal and Plant Health Inspection Service, *Biological Control Program* (last modified December 14, 2022), *https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/biological-control-program*.

[19] 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.

[20] D. Matthew Massey, Stephen Newbold, and Brad Gentner, "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.

[21] Alaska Department of Fish and Game, *Subsistence in Alaska*, *https://www.adfg.alaska.gov/index.cfm?adfg=subsistence.main*.

[22] Daniel Rondeau and Jon M. Conrad, "Managing Urban Deer," *American Journal of Agricultural Economics* 85, no. 1 (2003): 266-281.

[23] 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*, *https://www.fws.gov/program/national-survey-fishing-hunting-and-wildlife-associated-recreation-fhwar*.

may simply value knowing that the natural asset—like that forest—exists, even if there are no plans for any current or future uses (i.e., existence value).[24]

Changes in culturally valued experiences, such as the opportunity for fulfilling a way of life (e.g., being able to lead a subsistence way of life) or spiritual connection and uses—including, but not limited to, for many Tribal Nations and indigenous communities—stem from changes to ecosystem services.[25] 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").

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[24] These 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 (and not double-counted; see Section VI below); how agencies categorize edge cases is often less relevant.

Individuals are sometimes willing to forgo other benefits, such as lower product prices, in order to secure public ecosystem services. However, market failures can prevent individuals from doing so. Regulation can help correct some of these market failures.

Economists often categorize benefits as non-use values when an individual forgoes current benefits by not consuming a good or service in the current period. Daniel J. Phaneuf and Till Requate, *A Course in Environmental Economics: Theory, Policy, and Practice* (Cambridge University Press, 2017): 575-576; Robert J. Johnston et al., "Contemporary Guidance for Stated Preference Studies," *Journal of the Association of Environmental and Resource Economists* 4, no. 2 (2017): 319-405. Such services constitute contributions to welfare, and therefore should be considered in benefit-cost analysis. John V. Krutilla, "Conservation Reconsidered," *The American Economic Review* 57, no. 4 (1967): 777-786. Valuing these services presents some analytical challenges; for instance, these services may be used with some probability in the future, and the reasons for forgoing current consumption may include bequest values or contributions to one's reputation, which may be categorized as "use." However, motivations for the tradeoff are generally not important; the main thing that matters is that people are willing to make the tradeoff and bear the opportunity cost.

Regardless, the flow of services likely depends on the condition and availability of nature, in that people are willing to give up their time or other resources to protect and maintain special places, wildlife, or other natural features. Many economic studies have estimated that households value environmental amenities regardless of whether they are active users. See, for example, Tim Haab, Lynne Y. Lewis, and John Whitehead, "State of the Art of Contingent Valuation," *Oxford Research Encyclopedia of Environmental Science* (2020), https://doi.org/10.1093/acrefore/9780199389414.013.450. In cases of passive-use or non-use values, services can still be generated even during periods of human inaction. If a period of inaction is open-ended, such as delaying the harvest of a forest in perpetuity, these may be observationally equivalent to non-use value. Richard Hartman, "The Harvesting Decision When a Standing Forest Has Value," *Economic Inquiry* 14, no. 1 (1976): 52-58. In such cases, the passive use-value may provide only a lower bound to the non-use value. In other cases, the recipients of benefits may not have the ability to take management actions for institutional, scientific, or feasibility reasons.

[25] 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.

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, because carbon and nitrogen are cycled through ecosystems.

Moreover, when greenhouse gases are emitted, they can cause a range of harms. These harms—to ecosystems and otherwise—are often assigned 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 a 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 the value of other ecosystem services. In practice, because of data and modeling limitations, which prevent full representation of harmful climate impacts, estimates of the SC-GHG are a partial accounting of climate change 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.[26] Take care to avoid double-counting values that are already counted in the SC-GHG estimates you use (see Section VI for more on double-counting).

IV. Does your rule involve ecosystem services?

Table 1 offers examples of connections between common rule topics and some ecosystem services that could be affected. Table 1 is designed to stimulate thinking about how rules can affect ecosystem services, even when the rule does not target ecosystem changes. More details connecting the objects of regulations with ecosystem services can be found in Appendices I and II.

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

If your rule could affect or involve…	Then a sample (i.e., non-exhaustive) list of ecosystem services affected could include…
Infrastructure	Water quality maintenance for drinking, transportation, energy production, or recreation; flood risk reduction for property protection; wildlife or places for recreation or culturally valued experiences; wild populations', places', or features' existence
Natural resources (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; wild populations', places', or features' existence
Vehicle fleets or production	Air quality for physical health; greenhouse gas effects on various services

[26] For more information, see, for example, Interagency Working Group on Social Cost of Greenhouse Gases, U.S. Government, *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* (2021), https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

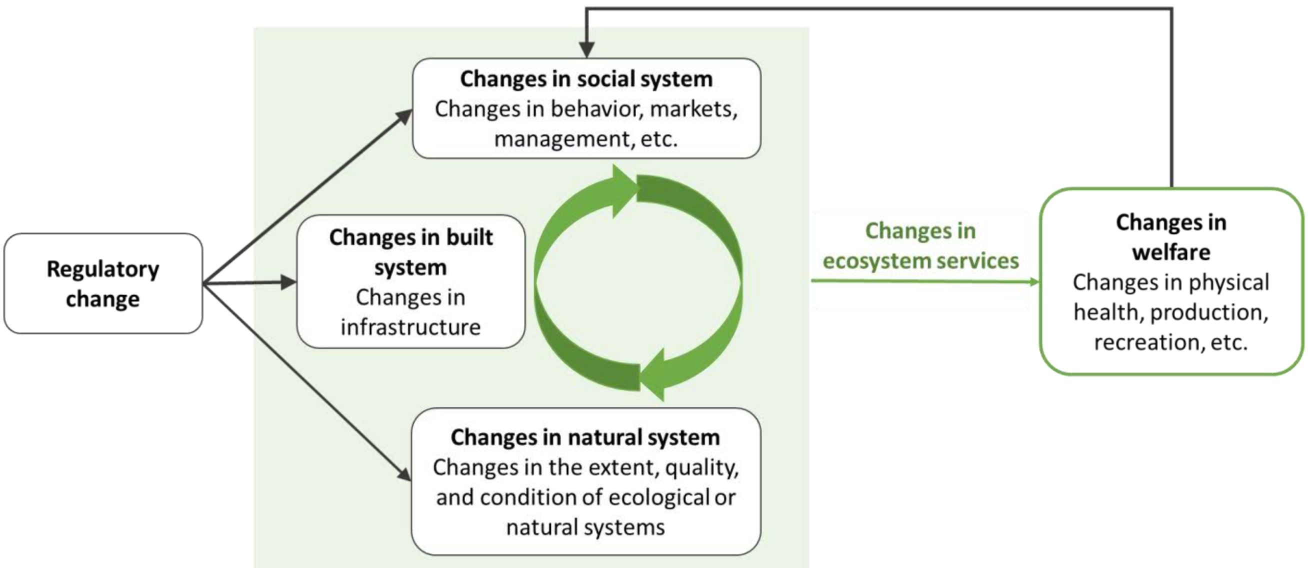
If your rule could affect or involve…	Then a sample (i.e., non-exhaustive) list of ecosystem services involved could include…
Energy (e.g., management, frameworks, standards)	Air quality for physical health; greenhouse gas effects on various services; wild populations', places', or features' existence; water supply for real estate value, recreation opportunities, or energy production
Community or economic development	Wildfire risk reduction for property protection; air cooling for reducing energy use; exposure to nature for mental health; productivity for crops (via pollination)
Agriculture (including aquaculture)	Water quality maintenance for drinking; productivity for timber, fish, crops or other products; greenhouse gas effects on various services; wildlife or places for recreation or culturally valued experiences; wild populations', places', or features' existence
Waste management	Greenhouse gas effects on various services; water quality maintenance for drinking; wildlife or places for recreation or culturally valued experiences
Disaster mitigation or risk reduction	Flood risk reduction for property protection; wildfire risk reduction for physical health; wildlife or places for recreation or culturally valued experiences; wild populations', places', or features' existence
Labor or education	Air quality for worker productivity, exposure to nature for mental health or worker productivity
Housing	Flood risk reduction for property protection; air cooling for reducing energy use; water quality maintenance for drinking; wildlife and places for recreation or culturally valued experiences; nature for aesthetics in viewsheds
Culturally, spiritually, or historically important buildings, geographic features, artifacts, etc.	Wild populations', places', or features' existence; 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
Health	Air quality for worker productivity; exposure to nature for mental health; wildfire risk reduction for physical health; wildlife or places for recreation

V. How might regulatory changes affect ecosystem services?

Analyses should focus on the changes in the provision of ecosystem services between the baseline (what would happen absent the regulatory action that is being assessed[27]) and the proposed regulatory alternatives. Figure 1 illustrates how such changes might manifest.

[27] For a deeper discussion of baselines, see the Circular A-4 section "Developing an Analytic Baseline."

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). Regulations can also affect ecosystem services by altering the built system, which includes built capital (middle pathway), affecting physical access to benefits (e.g., roads that provide access for recreation; dams that create reservoirs and reduce downstream access to water supplies). Regulations can also affect ecosystem services by altering the social system (top pathway), which includes the ways in which people experience, value, pay for, or act on ecosystem services (e.g., market prices, legal constraints on access, or preferences changed through education). Any regulation may affect several of these pathways and their interactions (central arrows).*



The value of an ecosystem service is influenced by changes in the amount and quality of service provided, the ability of people to access the service (physically and institutionally), the availability of substitute or complementary ecosystem or built goods or services, and people's preferences for a given amount or quality of that service. Therefore, the amount and importance of changes in ecosystem services caused by a regulation are a function of how the regulation changes the natural system, the built system, or the social system. Changes in the natural system affect the supply of an ecosystem service through the extent or quality of ecosystem elements, processes, or functions. Changes in the built system can alter how many and which people have access to ecosystem services, and how difficult or costly that access is to obtain. Changes in the social system can also alter how many and which people have access to ecosystem services (by changing rights or norms related to access) and how much value people attribute to those services, or how much it costs to access them. As emphasized by the central circular arrows, changes in one of these three systems can yield changes in other systems, sometimes resulting in feedback effects.[28] All of these changes, alone or in combination, can affect human welfare that is associated with ecosystem services. To emphasize, a regulation need not directly affect the natural system to cause a change in ecosystem services; there are multiple pathways for change.

[28] 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. It also changes the social system by altering how much different populations visit and value the area.

As Figure 1 indicates, ecosystem-service dynamics can be complicated, especially where multiple ecosystem services and feedback cycles interact. However, following decades of research and application, many ecosystem-service dynamics are now well understood.[29] The following sections give examples of how regulatory-driven changes in each system can affect ecosystem services.

Changes in the natural system

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.[30] Changes in hydrology that affect groundwater supplies and inflow to reservoirs often alter availability of irrigation water, affecting agricultural production.[31] 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, and recreational opportunities.

Biogeochemical processes in wetlands and other habitats help 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 human welfare, including physical health (e.g., heat stress, water-borne diseases, exposure to toxic algal blooms, and respiratory disease from air pollution), real estate values (e.g., higher values for homes near less polluted water bodies), and recreation opportunities and income from recreation- and tourism-related companies (e.g., beach, lake, or recreational fishing spot closures yielding less time and money spent on recreating; poor air quality days yielding fewer tourists to the affected area). As additional examples of effects through market transactions, water pollution can also increase the cost of producing drinking

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[29] For example, searching for "ecosystem services" in Google Scholar returns more than 800,000 studies published since the Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: Synthesis* (Island Press, 2005). See also Department for Environment, Food and Rural Affairs, *An Introductory Guide to Valuing Ecosystem Services* (2007), https://ec.europa.eu/environment/nature/biodiversity/economics/pdf/valuing_ecosystems.pdf; United Nations Environment Programme, *Guidance Manual on Valuation and Accounting of Ecosystem Services for Small Island Developing States* (2014), https://www.cbd.int/financial/monterreytradetech/unep-valuation-sids.pdf; Luke Brander, *Guidance Manual on Value Transfer Methods for Ecosystem Services* (2013), https://www.gwp.org/globalassets/global/toolbox/references/guidance-manual-on-value-transfer-methods-for-ecosystem-services-unep-2013.pdf; National Academy of Sciences, *Special Feature: Nature as Capital PNAS 100th Anniversary* (2015), https://www.pnas.org/topic/123.

[30] 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.

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

water,[32] energy (e.g., suspended sediments can settle in hydropower reservoirs and damage 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, and sport fishing), 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 and 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).

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 climate change. Climate change, in turn, affects these variables, resulting in feedback loops. Alterations to the global climate system cause myriad social impacts, many of which are captured by estimates of the social cost of greenhouse gases.

Changes in the built system

Constructing, operating, maintaining, or removing infrastructure can change access to ecosystem services, even when the natural system does not change. Building roads, trails, boat ramps, or other infrastructure can increase access to (and potentially crowding of) recreation areas, improve access for fire management, increase the presence of trash from visitors, change soil erosion patterns, or increase access to natural products (e.g., fish, timber, or products used for cultural purposes). 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. These changes can alter demand by making services accessible, which can affect prices and distribution of use by changing the cost of accessing the service. It can also change whether a market can support new buyers and sellers. Energy infrastructure can harness services such as wind energy or hydropower. Energy may be available for harvest in the natural system, but it does not provide an energy service—i.e., it is not accessible—until infrastructure is built to capture it for human use. Infrastructure can also reduce or eliminate access to ecosystem services. Dams that produce electricity 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, reducing the water treatment processes needed for drinking water. Upgrading a water treatment plant could lower demand for those ecosystem services by

[32] 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.

replacing them with economic services. This would not affect the value of other ecosystem services that these natural assets provide, such as hiking or recreational boating opportunities.

Constructing buildings can increase or decrease some ecosystem services, depending on whether the construction incorporates (i.e., 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 people and property more prone to coastal flood risks. Designing buildings to keep or improve the same habitats can increase welfare by giving more people access to ecosystem service benefits. Construction may also reduce ecosystem services by harming habitats, blocking viewsheds, reducing surface permeability (which increases flooding and may increase air temperatures), or by increasing crowding in natural areas, such that they are less enjoyable for many individuals.

Changes in the social system

Social rules and norms can influence demand for, and therefore the value of, ecosystem services. For example, social norms that value outdoor recreation (e.g., because of a policy aimed at attracting visitors to national parks) could lead to higher willingness to pay for natural assets that enable such recreation, but increased recreational use can also physically degrade those assets more quickly. Changing dietary preferences (e.g., because of changes in dietary trends or nutrition guidelines) may affect demand for certain ingredients that derive from natural assets or that interact with natural assets (e.g., wild caught fish or intensive farming requiring trees to be cut down). 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 nearby natural assets). Changing demographics can influence these social rules and norms.

Human behavior can influence demand for, supply of, and access to—and therefore the value of—ecosystem services. Regulations can influence behavior directly; as a simple example, closing a park to off-road vehicles would lead to fewer people driving such vehicles in that park. Regulations can also influence behavior related to ecosystem services less directly; for example, closing a road to vehicles to preserve certain natural assets may lead to more vehicles on a substitute 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.[33]

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 amenity 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 are imposed. They also change who can afford, for example, trips or equipment to visit certain natural areas, thereby influencing demand for those areas.

[33] 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.

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. These interventions affect people's willingness to pay for a service without necessarily directly affecting the natural system providing the service. Other types of campaigns that seek to encourage outdoor activities may result in congestion in previously underused public lands, which can reduce each user's enjoyment.

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.

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 your 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, irrigation canals	Changes in preference for water uses; changes in rules that affect access or costs (water rights, fees, or prices port taxes, access fees)	Water supply for real estate value	Property value
				Water supply for recreation opportunities	Recreation and other leisure
				Water supply for recreation income	Production
				Water supply for drinking	Production
				Water supply for energy production (hydropower)	Production
				Water supply for agriculture (irrigation)	Production
				Water supply for transportation (shipping, cargo)	Production
				Water supply for industrial uses	Production

If your 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 quality	Changes to water quality in rivers, lakes, ocean; 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, discharge pipes	Changes in preferences for water quality; changes in rules, norms or behaviors that affect quality (e.g., pollution standards, beach closures) or costs (e.g., fines, cost of dredging or treating polluted water)	Water quality maintenance for physical health	Physical health
				Water quality maintenance for real estate value	Property value
				Water quality maintenance for recreation opportunities	Recreation and other leisure
				Water quality maintenance for recreation income	Production
				Water quality maintenance for drinking	Production
				Water quality maintenance for energy production	Production
				Water quality maintenance for transportation	Production
				Water quality maintenance for industrial uses	Production
Flooding	Changes in flood intensity or flood frequency; changes in habitats that buffer flood risks (e.g., forests, marshes, wetlands, corals, 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, crop and timber management changes)	Changes in preferences for flood protection; changes in flood-related rules, norms, or behaviors that affect property or product values (e.g., crops, timber), flood risk reduction or damage costs (e.g., insurance rates, construction costs), health care costs	Flood risk reduction for physical health	Physical health
				Flood risk reduction for property protection (avoided damages)	Non-use value, production, or property value
				Water quality maintenance for drinking	Production
				Water quality maintenance for physical health	Physical health

If your 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		
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, norms or behaviors that affect property values, product values, fire risk reduction or damage costs, health care costs	Wildfire risk reduction for physical health	Physical health or property value
				Wildfire risk reduction for property protection (avoided damages)	Non-use value, production, or property value
Wildlife conservation	Changes in species populations, species or habitat productivity, 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, residential facilities to natural areas (e.g., building near natural areas)	Changes in awareness of or preference for species, places or features existence; changes in rules, norms, or behaviors that affect prices for accessing natural areas, health care costs, property values	Wildlife, places for recreation (birds, fish, game, lakes, beaches, etc.)	Recreation and other leisure
				Wildlife, places for recreation income (birds, fish, game, lakes, beaches, etc.)	Production
				Wild populations, places or features existence	Non-use value
				Nature exposure for mental health	Mental health
				Nature for aesthetics in viewsheds	Property value
				Productivity for timber, fish, crops, or other products	Production
				Wildlife, places for culturally valued experiences	Non-use value

If your 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 preference for certain levels of air quality or temperatures; changes in rules, norms or behaviors that set acceptable levels of air quality, affect prices for air filtration or air-cooling equipment, or change frequency of behaviors that cause emissions (e.g., plowing fields, driving)	Air quality for physical health	Physical health
				Air cooling for physical health	Physical health
				Air cooling for reducing energy use (avoided costs)	Production
				Air quality for real estate value	Property value
				Air quality for recreational opportunities	Recreation and other leisure
				Air quality for worker productivity	Production
Greenhouse gas emissions	Changes in species, habitats, climate conditions, or biogeochemical processes that affect greenhouse gas stocks and flows (e.g., carbon storage, sequestration)	Changes in energy infrastructure that alter the energy mix (e.g., hydropower, coal facilities), changes in transportation infrastructure that affect emissions, changes in equipment or facilities (e.g., engines, power generators, filters) that affect emissions	Changes in preferences for certain energy mix, transport modes, or levels of greenhouse gas emissions; changes in rules, norms or behaviors that set acceptable levels of emissions, or behaviors that cause emissions	Various	Various

VI. What are recommended steps for considering and assessing ecosystem services?

This guidance provides five recommended steps that agencies can follow to identify and assess important effects on ecosystem services, including regulatory alternatives' obvious effects and any additional effects.[34] As the agency learns about the implications of a regulatory alternative from additional research or from stakeholder engagement (e.g., Tribal consultations or public comments), additional clarity may emerge that can inform what to include in the analysis and how best to summarize the effects, requiring refinement of work done in earlier steps. These steps are iterative, and some steps should be repeated as more information is gathered about ecosystem-service impacts.

> **Step 1.** Ensure that the scope (i.e., time and spatial scale) of the analysis is sufficiently broad to reflect important ecosystem services in the baseline and across alternatives.
>
> **Step 2.** Describe the links between regulatory alternatives and likely changes to ecosystem services, and preliminarily determine which ecosystem services should be included in the analysis.
>
> **Step 3.** To the extent feasible and appropriate, monetize, quantify, or qualitatively describe the important effects of the regulatory alternatives on ecosystem services, and address uncertainty.
>
> **Step 4.** Aggregate estimated ecosystem-service changes and report them in a table, along with other benefits, costs, and transfers.
>
> **Step 5.** Incorporate monetized, quantified, and qualitatively described ecosystem-service benefits and costs into a narrative describing all benefits, costs, and transfers.

More details on each step follow.[35]

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At times, agencies will have a clear idea of which ecosystem services their rules plausibly implicate. In that case, starting with Step 1 is most appropriate. At other times, agencies may not know how their rules could affect ecosystem services. In that case, starting with Step 2 and identifying such services may

[34] Circular A-4 generally uses the term "important" to signify when a change is sufficiently consequential to merit inclusion in an analysis.

[35] These steps broadly align with prior OMB guidance that identifies nine steps for completing RIAs: (1) describe the need for the regulatory action; (2) define the baseline; (3) set the timeframe of analysis; (4) identify a range of regulatory alternatives; (5) identify the consequences of regulatory alternatives; (6) quantify and monetize the benefits and costs; (7) discount future benefits and costs; (8) evaluate non-quantified and non-monetized benefits and costs; and (9) characterize uncertainty in benefits, costs, and net benefits. Office of Management and Budget, *Regulatory Impact Analysis: A Primer* (2011), https://www.whitehouse.gov/wp-content/uploads/legacy_drupal_files/omb/inforeg/inforeg/regpol/circular-a-4_regulatory-impact-analysis-a-primer.pdf. Steps 1 to 4 of the prior guidance are presumably done before analyzing ecosystem service effects, and they are then refined per Step 1 of this guidance. Step 5 of the prior guidance is done during Step 2 of this guidance. Steps 6 to 8 of the prior guidance are done during Step 3 of this guidance. And Step 9 of the prior guidance is done during Steps 4 and 5 of this guidance.

be more appropriate. Either way, note that this process is iterative, and agencies may wish to return to Step 1 after completing Step 2.

Step 1. Ensure that the scope (i.e., time and spatial scale) of the analysis is sufficiently broad to reflect important ecosystem services in the baseline and across alternatives.

As an initial step, review evidence to determine if a regulatory action is likely to have a large effect on any ecosystem services. That can also help determine if there are important distributional effects or alterations of existing inequalities, as discussed in Step 2 below.

Analysts should use appropriate baselines and regulatory alternatives that reflect ecosystem-service considerations. Baselines are generally not static; following the Circular A-4 section "Developing a Baseline," baselines should reflect a reasonable forecast of relevant system dynamics absent the rule.[36] These can be baseline changes in the natural, built, or social systems that affect ecosystem services. Accounting for how these systems might interact is important for correctly calculating the effect of a rule on the value of ecosystem services.

The scope of the analysis includes its spatial scale, which can be determined by the "extent of the market"[37] or ecosystem "serviceshed." "Extent of the market" does not require explicit monetary transactions but is defined by the extent of welfare effects.[38] This extent may be different for different services; for instance, the extent of people who enjoy hiking in a forest may be different from the extent of people who benefit from its water-filtration services. Those who derive non-use value from knowing a forest exists and is healthy may be different still. To help determine each relevant market extent, a "serviceshed" captures the area in which a specific ecosystem service accrues to a specific group of people. The boundaries are defined by the area that supports the biophysical production of the service, by relevant physical and institutional determinants of access to the service, and by the location of people creating demand for the service that is physically supplied in that area.[39] Mapping the natural assets that provide ecosystem services, and where people access the services, can help identify relevant service dynamics, including possible tradeoffs among different ecosystem services resulting from an action (see Appendix IV).[40] In some cases, it may be appropriate to enlarge the spatial scale of the analysis to include an ecosystem service and to capture alternatives' benefits or costs. For example, the analysis of a rule that will improve downstream water-quality by reducing pollution should take into

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[36] 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 (2020): 232-244.

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

[38] Confusing the physical extent of ecosystem impacts with the physical extent of welfare effects can lead to very different benefit and cost measures. Wiktor Adamowicz et al., "Assessing Ecological Infrastructure Investments," *Proceedings of the National Academy of Sciences* 116, no. 12 (2019): 5254-5261.

[39] 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.

[40] For example, 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.

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. When in doubt, a broader spatial scope is preferable, though challenges related to aggregation and resolution merit attention.[41]

It is important that the analytical timeline selected for analysis is not arbitrarily short or driven by any one specific flow of benefits and costs. This is because the effects of changes in some ecosystem services may take longer to be realized than other costs or benefits of a rule.[42] The benefits and costs associated with changes to ecosystems may not be experienced immediately, or the change in services may be persistent through time. Accounting for likely changes in ecosystem services in the future is important in assessing an alternative's certainty-equivalent benefits and costs, including how future changes may affect current asset valuations. For example, future expected production and option value may influence current property value; the value of forest land may depend on its future timber production potential or the potential cost of accessing that timber. Or, for example, consider rules in which a nature-based solution is compared with more conventional "built" (i.e., non-nature-based) approaches. For those rules, extending the timeframe for assessing costs and benefits might be advisable because the built approach may last a shorter time than the nature-based approach. For instance, the built approach might deliver more immediate benefits but be structurally sound for only 20 years, whereas the nature-based approach might deliver benefits for 50 years. In that case, the analytical timeframe should be extended to 50 years for all alternatives. During this time, the cost of reconstructing the built system, assuming that is the relevant alternative, would occur twice in that time frame, in years 20 and 40. Consistent with the guidance in the Circular A-4 section "Scope of Analysis," to the extent feasible, your analytic timeframe should be long enough to incorporate all important effects of each alternative. Note that exogenous future events may also be important considerations when selecting a time horizon. For example, specific ecosystem services provide benefits relative to extreme wildfire, storm, or flooding events that will occur with some frequency over particular time horizons. Agencies should also refer to the Circular A-4 section "Treatment of Uncertainty" and "Step 3d. Account for uncertainty" in this guidance.

As noted in that Circular A-4 section on uncertainty, specifying key analytical assumptions is important. When analyzing ecosystem services, certain kinds of assumptions are frequently influential. First, because 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 (e.g., Federal, State, Local, Tribal, and Territorial), it is important to clarify how related regulations are expected to affect that asset and how that influences the baseline(s) and each proposed alternative. Second, the frequency and severity of low-probability, high-cost events such as severe wildfires can influence ecosystem services' values, and may differ between the baseline(s) and

[41] As Circular A-4 notes, clear presentation of benefits and costs is important. This principle is especially relevant in cases in which distance attenuates ecosystem service effects. Issues involving significant digits and modifiable areal units can lead to challenges related to spatial scale and scope. Use professional judgment and be transparent about assumptions of this nature.

[42] 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.

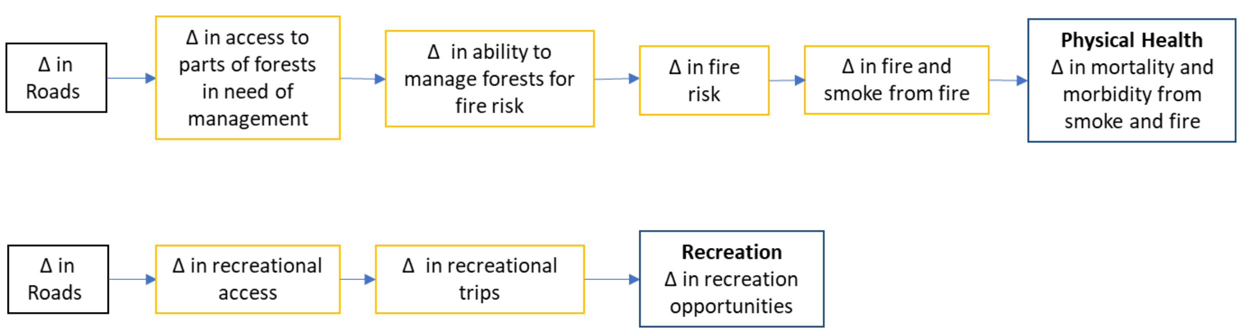
proposed alternatives. Be especially attentive to, and transparently report, assumptions on these topics for the baseline and each alternative.

At this step (and others), pause to consider whether additional alternatives merit formal assessment,[43] given the evidence you have gathered, including evidence related to the role of natural assets or environmental conditions. Agencies may identify ecosystem service-based (or nature-based) regulatory alternatives that would 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 improving community resilience to increased heat risks from climate change 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.

Step 2. Describe the links between regulatory alternatives and likely changes to ecosystem services, and preliminarily determine which ecosystem services should be included in the analysis.

Identify and describe how regulatory alternatives are expected to affect natural, social, and built systems and related ecosystem services (as outlined in 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 and Appendix II for conceptual model examples). Consider the likely ways that the alternatives are expected, based on reliable evidence, to affect ecosystem services. 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, and the additional effect of enabling workers to slow the pace of fishing activities, improving worker safety.[44]

Figure 2. Hypothetical pathway from a regulatory change that affects roads to ecosystem-service costs and benefits. *For more extensive examples, see Appendix II. Note that the symbol Δ, or delta, indicates a relative change. 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.*



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[43] The Circular A-4 section "Evaluation of Alternatives" urges the assessment of a meaningful range of policy options, including at least two that differ from the approach being proposed or finalized—specifically, at least one that "achieves additional benefits (and presumably costs more)" and one "that costs less (and presumably generates fewer benefits)." As you gather evidence and the analysis more generally progresses, the insights gained may prompt ideas for how to comply with this guidance regarding assessment of alternatives within RIAs.

[44] 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.

Questions to consider. When describing links between 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?
- 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, housing, 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 value; 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.
- Appendix I for examples of logic descriptions linking rule types to likely ecosystem service changes, and Appendix II to see examples in conceptual models.
- Appendix II for details on developing conceptual models.

Identify evidence for each expected change in ecosystem services that is relevant to the region, timeline, and context of the rule alternatives, and evaluate the strength and credibility of evidence for the potential changes that are identified. Evidence can inform whether a relationship exists in the pathway between a regulatory change, a change in built, social, or natural systems, and the expected change in ecosystem services (e.g., boxes in Figure 2); what the direction and magnitude of that relationship is; how consistent and predictable the relationship is; and whether the information can be generalized from a particular place or study to the context of the regulatory alternatives under consideration. Types of usable evidence can include experimental or observational research studies from a variety of disciplines, meta-analysis or synthesis studies, tools, models, expert opinion, and Indigenous Knowledge.[45]

Use the assessment of evidence to iterate and improve the understanding and description of system changes and effects on ecosystem services. It is often helpful for transparency and organization to synthesize evidence in a conceptual diagram showing all the pathways described from the regulatory changes to the ecosystem-service endpoints. See Appendix II for examples of how evidence can be organized with conceptual diagrams.

Identify the groups of people likely to experience expected changes in ecosystem services. Agencies can start this assessment by mapping possible ecosystem changes and comparing these maps with Census data and information on the location of historically underserved communities (Appendix IV). The Environmental Protection Agency's EJ Screen (*https://www.epa.gov/ejscreen*), the Council on Environmental Quality's Climate and Economic Justice Screening Tool (*https://screeningtool.geoplatform.gov*), and related tools can assist with this process. Note that the spatial extent of the serviceshed for a given ecosystem service is often broader than the spatial extent of the ecosystem or natural assets that gives rise to the service. Information from regional planning activities (e.g., forest plans) and sector analyses (e.g., tourism, agriculture) can help delineate the serviceshed. If any potentially affected groups are underserved communities, or if there could be a shift in inequities due to changes in an ecosystem service caused by an alternative, those services are important to include in the analysis. Refer to the Circular A-4 section "Distributional Effects" for how to identify and account for differential effects on different affected populations.

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 irreversible (e.g., through death, one-way land conversion, or a large fixed cost)?[46]
- Are the expected changes likely to further or hinder the agency's statutory purpose or any other regulatory purpose?

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

If there is evidence that little to no change would occur in a pathway (i.e., evidence that an alternative will result in little to no change in the built, social, or natural system), then the pathway may be excluded from the analysis. If there is evidence of a change, but little or no evidence on the direction or

[45] 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*.

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

magnitude of change, consult the Circular A-4 section "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. However, if there is little evidence or other reasons to expect that a pathway exists at all, use appropriate professional judgment, which may result in the pathway being excluded from further analysis. For the sake of transparency, explain the reasoning behind any decisions to exclude an identified pathway from further analysis.

As previously noted, this process can be iterative. Some of the potential effects on the provision of ecosystem services and human welfare identified initially will turn out not to be important to analyze. In other cases, new important effects will be identified during evidence assessment, and pathways may be added to the analysis.

Step 3. To the extent feasible and appropriate, monetize, quantify, or qualitatively describe the important effects of the regulatory alternatives on ecosystem services, and address uncertainty.

Incremental changes in benefits, costs, and transfers related to ecosystem services should be (in order of preference) monetized if feasible, and if not, quantified if feasible, and if not, described qualitatively to the same extent as other benefits and costs, as discussed in Circular A-4.[47] Analysts often start with qualitative assessment, then move to quantitative, and then monetize when possible. Qualitative descriptions may be useful even for effects that are also monetized or quantified. Resources and data exist that may be useful in monetizing or quantifying ecosystem-service provision from baseline conditions (e.g., EnviroAtlas,[48] reviews of ecosystem services relevant data and models by the National Ecosystem Services Partnership, [49] and the system of Federal natural capital accounts and environmental-economic statistics[50]). If the rule is expected to result in land-use changes, geospatial models can be used to estimate service changes (see Appendix IV). When relevant baseline information or data are not available, the 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. Figure 3

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[47] See the Circular A-4 section "Developing Benefit and Cost Estimates" for a fuller discussion of and considerations for developing these estimates.

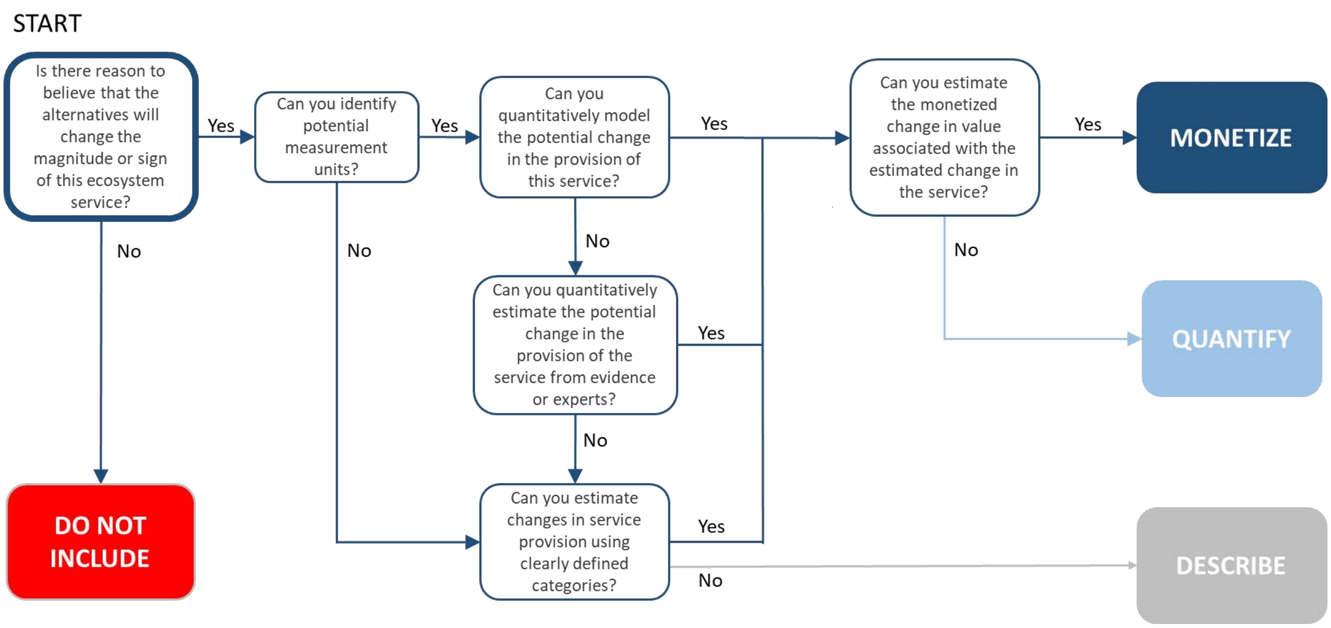
[48] Environmental Protection Agency, *EnviroAtlas*, *https://www.epa.gov/enviroatlas*.

[49] 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 and Working Lands in the United States: Dataset Evaluation and Readiness Assessment* (2022), *https://hdl.handle.net/10161/26601*.

[50] 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 Accounts 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, "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."

reflects the guidelines in Circular A-4 by illustrating a set of questions that can be asked for each service to help determine whether it should be monetized, quantified, or described qualitatively.

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



As noted in Circular A-4, for changes that are difficult to monetize or quantify, it is often helpful to state what would be needed to monetize or quantify the change to help identify analytical gaps and to rectify them in the future. Consider unbundling effects if that would facilitate monetizing or quantifying at least part of the total effect. For example, rules related to transmission lines might influence fire risk, habitat, and property value, and these changes might be easier to quantify separately. As discussed further in Step 4 below, be attentive to the risk of double-counting certain effects when aggregating these separate values.

As feasible and appropriate, analyses of ecosystem services should capture both (i) the change in the magnitude of costs and benefits, which can be driven by changes in the supply of services, demand for or use of services, or changes in the serviceshed or market size ("extent of the market"); and (ii) changes in how costs and benefits are distributed. This would include changes in the magnitude and quality of the services enhanced or diminished for a particular community, as well as relative changes across communities. Because many regulatory alternatives cause both positive and negative changes in ecosystem services, analyzing both is important. Other aspects that can be important to analyze include the ways in which alternatives shift how a service is provided (e.g., moving from providing a service artificially to relying on nature, or moving from one natural asset to another), as well as interactions between different natural assets and ecosystem services.

Often, the process of attempting to monetize or quantify regulatory impacts leads to new insights and improves regulatory design, whether or not monetization or quantification is ultimately achieved. After completing this section, consider whether the baseline, alternatives, timelines, ecosystem services considered, or other aspects of the analysis need to be adjusted. A brief statement summarizing any changes made during this iterative learning process may be helpful in your final analysis.

Step 3a. Monetize

Changes in ecosystem services can be monetized using a range of standard analytical methods.[51] The Circular A-4 section "Developing Benefit and Cost Estimates" provides substantial direction with respect to monetization methods relevant for ecosystem services. Valuation should capture the degree to which proposed regulatory alternatives are expected to change ecosystem services relative to baseline conditions. There is no need to value the *entirety* of an ecosystem-service flow; only the expected *change* in the service(s) caused by the alternatives under consideration. Estimating the "total value" of an ecosystem service is unneeded. For example, the total monetary value of *all* freshwater in the world is ill defined, and some economists would argue it is infinite.[52] But no single regulatory action is likely to jeopardize the entirety 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, suppose a policy would degrade water quality in a water body. There is no need to estimate the water body's full value, or the value of the services it would offer if it were theoretically "pristine." Rather, only the incremental decline in water quality that might occur as a result of a regulatory alternative merits valuation in the applications covered by this guidance.

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, obtaining measures of marginal value requires an analytical approach beyond observing direct market transactions. If market transactions do not reveal the marginal value, then 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 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.[53] Models and data for monetizing ecosystem services through these methods are available in many cases. In some cases, monetizing ecosystem services may be as simple as adding an additional parameter to other equations or calculations. 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 a single parameter in the existing flood model to reflect

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[51] 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 Science+Business Media, 2nd ed., 2017): 1-26; Daniel J. Phaneuf and Till Requate, *A Course in Environmental Economics: Theory, Policy, and Practice* (Cambridge University Press, 2017).

[52] 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.

[53] 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.

natural vegetation could represent the ecosystem service-change pathway and provide an efficient way to monetize the service. In cases in which 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.[54]

For more information on these sorts of valuation methods, see the Circular A-4 section "Developing Benefit and Cost Estimates."

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 value these ecosystem services:
Revealed preference/indirect use	Water supply for recreation income, real estate value, drinking, energy production, and agriculture
	Water quality maintenance for real estate 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 real estate 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 existence
	Air quality for recreation opportunities
Revealed or stated preference or health utility	Water quality maintenance for non-fatal physical health risks
	Wildfire risk reduction for non-fatal physical health risks
	Pest control for non-fatal physical health risks
	Nature exposure for non-fatal mental health risks
	Flood risk reduction for non-fatal physical health risks
	Air quality or cooling for non-fatal physical health risks
Value of statistical life or value of statistical life years	Wildfire risk reduction for fatality
	Flood risk reduction for fatality
	Air quality or cooling for fatality
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 often help facilitate monetization. These approaches may use market data, revealed

[54] Agencies and academic groups have developed a variety of ecosystem service models that make these connections. For examples, 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.

non-market behavior, stated-preference methods, or stated-behavior methods. When such methods are used, they should account for the fact that many ecosystem-service values are location specific and hard to apply to other locations, which means the marginal value in one location can be different from the marginal value in a different location. Also, there can be a high amount of spatial variation in the supply of services, physical and institutional access to services, or demand and preference for services. Monetization models should reflect this spatial variation, when feasible and appropriate. For example, the degree to which a rule affecting land cover (e.g., vegetation) will create benefits or costs for energy production by affecting water supply will depend on the hydrology of the areas affected (supply), where hydropower facilities are located (physical access), the rules guiding their operation (institutional aspects), and how much energy is demanded in the affected area (which depends, in part, on population size, energy use behaviors, and energy prices).

Analysts considering how best to monetize particular services should first look for existing data that may be relevant to the question at hand, including market and non-market data. Take, for example, an action potentially affecting the area covered by a wetland (i.e., wetland extent). A recent analysis of National Flood Insurance Program (NFIP) payments from 2001 to 2016 found that each acre of wetland loss increases NFIP claims by over $700 per year on average, and this annual increase may exceed $3,000 per acre in developed watersheds.[55] This study highlights the potential importance of the flood risk mitigation service that may be lost if wetland acres are lost. Note that adapting these NFIP-derived values for use in benefit-cost analysis may further require understanding the extent to which individuals would pay to avoid these costs. Multiple studies report household willingness to pay (WTP) for wetland protection, and most of these reported values are <$1 per acre.[56] Ex ante WTP estimates are different than ex post NFIP claim estimates due to differences in the number of households affected, quality and quantity of wetland affected, and other contributing factors.[57] Transfer effects should also be considered and modeled in an impact analysis, in addition to incremental costs and benefits.[58] Given these considerations, both the available stated preference values and the observed damage costs might be useful for informing benefit-cost analyses for rules involving wetlands, but analysts should evaluate their appropriateness for a given context and avoid double-counting.

For a discussion on the choice between using stated or revealed preference methods, see the Circular A-4 Section “Appropriate Use of Stated Preference Methods.” A WTP valuation should explicitly specify the benefits that respondents should be considering in their estimates. Many past stated-preference studies

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

[56] Klaus Moeltner et al., “Waters of the United States: Upgrading Wetland Valuation Via Benefit Transfer,” *Ecological Economics* 164 (2019): 106336.

[57] Moreover, depending on how many households each wetland is protecting, a low WTP per household could be consistent with large value per acre.

[58] Due to off-site (including downstream) externalities, the amount of wetland conversion may be expected to exceed the social optimum. As illustrated in Appendix III(a) for a hypothetical case, this scenario could be visualized with a market diagram featuring a deadweight loss wedge to the right of the intersection of the marginal cost curve (including both off-site costs and producers’ internalized costs) and the demand curve. Please note that categorization of impacts could differ substantially from what was just outlined if a pre-existing subsidy occurred alongside a pre-existing *positive* externality, a pre-existing negative externality occurred alongside a pre-existing net *tax*, or if a regulation-induced change in subsidy *rates* were calculated without behavior change (in this case, wetland conversion) included as part of the overall estimation. Further guidance on modeling welfare effects may be found in Richard E. Just, Darrell L. Hueth, and Andrew Schmitz, *The Welfare Economics of Public Policy: A Practical Approach to Project and Policy Evaluation* (Edward Elgar, 2004).

have not specified which services were being considered, or they have assumed that responses reflected all possible services from an ecosystem (e.g., a wetland). In the latter case, estimates theoretically represent the incremental value to society from an incremental change in the habitat area. Results from past wetland stated-preference studies vary considerably—from as much as $85 per acre in one case to less than $0.01 per acre in others.[59] Because survey respondents are sometimes asked to value goods and services that are not traded directly in the market, their elicited responses may suffer from many deficiencies that are noted in the economics literature. Household respondents may not know the full extent of the ecosystem services that they currently derive from wetlands or they may not know how to monetize values. In cases in which the survey instruments do not describe all of a wetland's attributes or the services of interest, the valuations provided by households may be lower than if such information were provided and understood. If both revealed-preference and stated-preference studies that are directly applicable to regulatory analysis are available, you should consider both kinds of evidence and compare the findings when feasible. If the results diverge significantly, you should, when feasible, compare the overall quality of the two bodies of evidence. Other things equal, revealed preference data is preferable to stated preference data because revealed preference data are based on actual decisions, where market participants enjoy or suffer the consequences of their decisions. This is not generally the case for respondents in stated preference surveys, where respondents may not have similar incentives to offer thoughtful responses that are consistent with their preferences or may be likely to bias their responses. However, it is generally appropriate to—all else equal—give less credence to a lower-quality revealed preference study than a higher-quality stated-preference study (e.g., when a stated preference study is better targeted at valuing the particular good being analyzed than a revealed preference study). In cases in which data gaps exist that can be filled only by novel stated preference-studies conducted by the agency, and the agency chooses to conduct such studies, the agency should pay careful attention to survey design and design instruments to minimize bias and accurately capture the specific, relevant ecosystem-service value(s).

When change in value relative to the baseline is possible to monetize 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, as discussed in Step 3d of this guidance and in the Circular A-4 section "Treatment of Uncertainty." If available information is insufficient to develop monetized estimates, consider using expert elicitation, as discussed in the Circular A-4 section "Quantitative Analysis of Uncertainty."

Future benefits and costs should be discounted appropriately according to the Circular A-4 section "Discount Rates."

As described in detail in the Circular A-4 section "Benefit-Transfer Methods," it is not always possible to collect timely, case-specific data on revealed preference or stated preference to support regulatory analysis. For ecosystem-service benefits and costs—as with other benefits and costs—benefit-transfer methods may be used to help with monetization. Consider best practices for this method. Values should be appropriate for use in the new circumstance, and reference appropriate benefit-transfer

[59] Klaus Moeltner et al., "Waters of the United States: Upgrading Wetland Valuation Via Benefit Transfer," *Ecological Economics* 164 (2019): 106336. Note that other values for "wetlands" exist in the literature. See, for example, Robert Costanza et al., "Changes in the Global Value of Ecosystem Services," *Global Environmental Change* 26 (2014): 152-158. But many of these numbers are difficult to substantiate absent more information about valuation methods.

methodologies.[60] Consider whether meta-analyses may help aggregate and synthesize benefit-transfer methods and estimates for particular ecosystem services. As that Circular A-4 section states, benefit-function transfer (i.e., transferring the entire demand function) is generally preferred to benefit-point transfer (i.e., adopting a single point estimate) because it more robustly accounts for natural, built, and social system characteristics of the resource of interest. However, benefit-point transfer may be preferable in the rare cases in which the study and policy sites are very similar.[61] In the ecosystem-service literature, there are many examples of simplified benefit-function transfer studies that estimate a change in habitat acres and use a per-area estimate of a value for one or more services to monetize benefits and costs. However, the limitations of this approach have been widely documented.[62] 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. Continuing the beach example, moving from 0 to 10 acres of beach would likely provide more marginal recreation value than moving from 100 to 110 acres. In addition, as already noted, values generated by WTP studies may also vary due to context-specific aspects of the study design, including any survey instruments. For these reasons, area-based benefit transfer may not be a robust method for benefit transfer in ecosystem-service analysis for an RIA. Many more reliable function transfer studies and models are available and may represent more accurate estimates of ecosystem-service costs and benefits. Analysts should be strongly attentive to the risks of creating a misleading analysis when using an area-based benefit-transfer approach.

As already indicated in the discussion about wetland values above, there is a difference between assessing the marginal value of *an ecosystem*, as an asset, and valuing the change in *the services the ecosystem provides*.[63] The two are connected in that the marginal value of an ecosystem, as an asset, is the net present value of the change in the services, appropriately accounting for all changes that occur as the result of an exogenous change in the quantity or quality of the ecosystem. However, this is seldom the relevant framing for benefit-cost analysis as such analyses rarely deal with the value of an entire ecosystem. For example, a regulation is unlikely to risk eliminating an entire forest; it would more likely change, for example, the character or extent of the forest and thus some subset of the services the forest provides.

There are multiple reasons to exercise caution in incorporating the total value of an ecosystem into an analysis of ecosystem services. First, there is often no reason to expect a one-to-one relationship between ecosystems and ecosystem services. Many ecosystems provide multiple services and many

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[60] Examples include: 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," in *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.

[61] 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.

[62] 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.

[63] Eli P. Fenichel et al., "Measuring the Value of Groundwater and Other Forms of Natural Capital," *Proceedings of the National Academy of Sciences* 113, no. 9 (2016): 2382-2387.

ecosystem services require multiple inputs. Second, it is possible to assess the marginal value of an ecosystem, as an asset, holding the service relationships constant under the status quo. The question of marginal value relates to a change in a quantity (or quality) measure of the ecosystem under the status quo. In benefit-cost analysis, however, the mechanism by which the service flows are changing—the alternative rule—matters. Third, the change in service flows for benefit-cost analysis should be a welfare measure, not simply any marginal value or price that is not connected to welfare. Pay special heed to these complications, and consult with OMB as appropriate to identify a workable strategy for your analysis.

Step 3b. Quantify

For ecosystem-service effects that cannot be monetized, effects should be quantified in changes to other physical or behavioral units to the extent possible—e.g., changes in kilowatt-hours of energy production lost due to reservoir sedimentation, lost aquaculture yield due to water pollution, agricultural yield attributable to pollination, or number of people visiting recreational sites (e.g., beaches or parks). 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 (physical or legal) to those benefits. Physical units, without additional information relevant to changes in human welfare, are less-preferred units for quantification. That said, quantification in physical units—especially when accompanied with a robust qualitative discussion of likely welfare changes—remains much preferred to no quantification when at least this level of presentation is feasible.

Many models exist that can be used to quantify effects of changes in ecosystem services on welfare.[64] If predictive models (statistical or mechanistic) are not available or sufficient to develop quantitative

[64] Agencies and academic groups have developed a variety of ecosystem service models. For lists of 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*; Council on Environmental Quality, Office of Science and Technology Policy, and Office of Domestic Climate Policy, *Nature-Based Solutions Resource Guide* (2022), *https://www.whitehouse.gov/wp-content/uploads/2022/11/Nature-Based-Solutions-Resource-Guide-2022.pdf*. Additional information and links to ecosystem models can be found in the Environmental Protection Agency's Ecosystem Services Model Library and on pages maintained by the U.S. Geological Survey and the U.S. Forest Service. 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/*. Several non-Federal entities also curate lists of available resources, including the National Ecosystem Services Partnership. National Ecosystem Services Partnership, *Federal Resource Management and Ecosystem Services Guidebook: Resources* (n.d.), *https://nespguidebook.com/resources/*.

estimates, consider using expert elicitation, as discussed in the Circular A-4 section "Quantitative Analysis of Uncertainty."

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, overall water quality in rivers) is not directly relevant to an RIA.

Metrics should be cardinal measures if monetizing, but can be cardinal or ordinal if quantifying. Analysts should ensure that the numeric ranks of any index used for monetization maintain cardinal measurement in a way that preserves a one-to-one relationship with welfare. Consider a water quality index that comprises bacterial count, harmful aquatic parasite count, and chlorophyll concentration. This index might be useful for certain scientific questions. However, if a 1% increase in any of these factors increases the index by 1%, but the cost of a 1% increase in parasite count is much greater than the cost of a 1% increase in the other two factors, using the index will not provide a consistent measure of welfare changes from rules that affect it. In general, the inability to identify units may be an indication that the service has not been clearly defined.

It is helpful to report all ecosystem-service changes that have been quantified or monetized, even if they are later deemed inconsequential. Doing so provides transparency and a more comprehensive understanding of expected changes, and it reduces the likelihood of concerns about services that are not analyzed. Such reporting may also be useful for future analyses.

When there are quantified but unmonetized ecosystem services, consider doing a breakeven analysis, as noted in the Circular A-4 section "The Need for Analysis of Proposed Regulatory Actions." It may be possible to ask whether the breakeven value of the services could plausibly affect the outcome of the analysis, including the comparison of regulatory alternatives.

Step 3c. Describe

Per the Circular A-4 section "Benefits and Costs that are Difficult to Quantify," 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. Omission of information provides incomplete information about regulatory actions' impacts, and it can potentially bias the results of benefit-cost analysis. As noted in that Circular A-4 section, 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, as outlined in that Circular A-4 section.

In some cases, you may be able to apply "threshold"/"break-even" and "screening"/"order-of-magnitude" analyses to help decide whether unmonetized and unquantified effects are likely to change policy preference rankings, consistent with the Circular A-4 section "Quantitative Analysis of Uncertainty."

Step 3d. Account for uncertainty

Given the high degree of uncertainty present in analyses of some ecosystem services, it is especially important in this context to consult the Circular A-4 section, "Treatment of Uncertainty." Important tools for considering uncertainty are real option value analysis, Monte Carlo analysis, and the calculation of certainty-equivalent valuations, as described in that section.[65]

One common source of uncertainty in ecosystem-service measurement is the challenge of modifiable areal units. This is a phenomenon in which parameter estimates, including marginal values, can depend on the pattern and scale of aggregation because the geographic boundaries useful for analysis are often drawn in ways unrelated to the underlying processes.[66] Because benefits and costs from ecosystem services accrue to individuals, but may be reported at the group level, often grouped over specific geographies, care should be used in justifying how benefits, costs, and transfers are aggregated. As discussed in Step 1, it is important to select an appropriate spatial scale for the analysis.

Another source of uncertainty common in valuing ecosystem services is the degree to which benefits or costs in one area are offset by behavior change in the same or different areas, including internationally. 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 the above guidance on uncertainty and transparently state assumptions of this type.

Step 4. Aggregate estimated ecosystem-service changes and report them in a table, along with other benefits, costs, and transfers.

Benefits and costs that have been monetized should each be summed (after discounting to present value), and then costs should be subtracted from benefits to compute monetized net benefits. 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.[67] The change in value of different services, or the change in value of different assets (i.e., natural capital), often can be estimated using multiple methods. These methods can implicitly or explicitly define the considered services or affected groups differently. And some methods may count only part of the value a service provides.

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[68] and thus beach width. One could use a travel cost method (i.e., how much people pay to travel to beaches of different

[65] 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.
[66] For more information, see David W. S. Wong, "The Modifiable Areal Unit Problem (MAUP)," in *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.
[67] 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.
[68] Beach nourishment refers to adding sand to a beach.

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 user groups' valuations. Travelers and home buyers may value the same service differently, in which case summing the hedonic and travel cost values would not constitute double-counting.

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 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.[69] 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.[70] 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. A more meaningful value would be just the change in farm gate value, assuming that includes the full change in value of water as an input to crop production.[71]

As a "rationality check," ensure that the value of intermediate services (e.g., water supply as an input to production) does 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.[72]

Another "rationality check" could involve confirming that changes in the value of capital, including natural capital, balance with income- or production-related net benefits. Often, benefit-cost analyses

[69] The discount rate implicit in the market may not be the same as discussed in the Circular A-4 section "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.
[70] "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.
[71] Just the change in water value could also be meaningful, but the change in farm gate value is more likely to be easily measurable.
[72] 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.

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 "rationality check" highlights that changes in capital value—for example, changes in the value of *ecosystems*—should not be added to net benefits associated with income and production—for example, changes in the value of *ecosystem services*.[73]

Additionally, consider which effects are offsetting benefits or costs and whether you are analyzing them as transfers, referring to the Circular A-4 section "Consistent Treatment of Transfers in Your Estimates of Regulatory Impacts." Rules that involve ecosystem services may include transfers. For example, rules that increase green space may also create jobs tending to that green space. 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.

To capture ecosystem services' welfare effects accurately, it can be important to differentiate between (i) values that represent *total* willingness to pay (or accept) for the specific change in the service being considered and (ii) those that represent *marginal* willingness to pay (or accept) for such changes. A total value can be directly included in the schedule of benefits for the year in which it occurs. A marginal value is more complex; it is often not as straightforward as multiplying the "pre-rule" price people are willing to pay (or accept) for a service by the "pre-rule" quantity of the service, then doing the same for "post-rule" price and quantity, then differencing the two. That approach can produce a biased estimate of the change in welfare. For marginal values, the best approach is to model a full demand curve for the service, as Fenichel and Hashida (2019) describe in the context of natural asset valuation.[74] That demand curve can be used to approximate how changes to a service affect monetized welfare. If that is not feasible—for instance, due to data constraints—then other approximations are available.[75]

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[73] For examples of this type of double-counting, see Appendix III, especially section III(a) and Public Comments 2 and 3 in section III(b).

[74] Eli P. Fenichel and Yukiko Hashida, "Choices and the Value of Natural Capital," *Oxford Review of Economic Policy* 35, no. 1 (2019): 120–137. See especially Section II and Figure 1. This should properly be a Hicksian demand curve rather than a Marshallian one. For discussion of the theoretical reasons underlying this principle, see Robert D. Willig, "Consumer's Surplus Without Apology," *The American Economic Review* 66, no. 4 (1976): 589-597; 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, 2003).

[75] $P_1*Q_1 – P_2*Q_2$ (i.e., the price at one time times the quantity at that time, minus those at later times) does not represent a welfare measure such as consumer surplus; instead, consumer surplus change can be approximated by valuing the quantity change at appropriate average prices (i.e., appropriately averaging P_1 and P_2) and multiplying the result by the difference between P_1 and P_2. Arnold C. Harberger, "Three Basic Postulates for Applied Welfare Economics: An Interpretive Essay," *Journal of Economic Literature* 9, no. 3 (1971): 785-797. Given general properties of demand curves, geometric means tend to have lower approximation error than arithmetic means. Walter E. Diewert, "Exact and Superlative Welfare Change Indicators," *Economic Inquiry* 30, no. 4 (1992): 565-582.

Report impacts according to the guidelines in the Circular A-4 section "Accounting Statement," alongside and on the same terms as other benefits and costs.[76] Also analyze and report the distribution of benefits and costs across different populations consistent with the Circular A-4 section "Distributional Effects."

Step 5. Incorporate monetized, quantified, and qualitatively described ecosystem-service benefits and costs into a narrative describing all benefits, costs, and transfers.

The last step is to put everything together into one presentation of net benefits, as noted in the Circular A-4 section "Accounting Statement." Explain your logic for each pathway of change for each ecosystem service in a clear descriptive narrative. Incorporate monetized values of services, quantified estimates of changes in or contributions to human welfare, and implications for affected communities (including which populations are likely to experience effects of these changes in ecosystem services). The narrative should include all costs and benefits, including all services analyzed: those monetized, quantified, and qualitatively described. For transparency, the narrative should also include a description of services that were dropped from the analysis because they were not deemed sufficiently important 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. See Appendix II for guidance on development of conceptual diagrams and Appendix III for case-study examples.

Existing methods and research for quantifying and monetizing ecosystem services may not always be sufficient to quantify and monetize as many ecosystem services as would be optimal. In order to accelerate learning and improvement over time, agencies should, where feasible, describe important research gaps. These descriptions should include (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 (value function).

VII. Conclusion

This guidance is the first to assist Federal agencies specifically 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 an opportunity for future updates, as appropriate.

[76] In addition to reporting monetized and quantified costs and benefits in the benefit cost table, it is sometimes useful to report ecosystem service costs and benefits in categories that align with a standardized U.S. government coding system such as 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* (2022), https://www.epa.gov/eco-research/national-ecosystem-services-classification-system-nescs-plus.

Appendix I: Types of Rules with Potential Effects on Ecosystem Services and Causal Pathways

This Appendix gives additional, though not comprehensive, lists of possible causal pathways from different types of rules to potential changes in ecosystem services. It also gives short explanations for how each rule type might cause each specific ecosystem-service change. The tables indicate whether a rule is likely to increase (+) or decrease (-) the noted ecosystem service, or whether specifications within the rule could cause either increases or decreases in the service (+/-). These tables do not replace creating conceptual diagrams but can be a useful guide for doing so. Many rule types have the potential to affect multiple ecosystem services. A subset of such rule types is considered here:

- Infrastructure
- Wildlife or recreation
- Energy production
- Agriculture or commercial harvest
- Disaster mitigation or risk reduction
- Public health or health care
- Labor or education
- Vehicle fleets
- Housing
- Waste management

Some agency rulemakings may relate to more than one of these listed rule types. In those cases, reviewing all relevant tables can be helpful. Other rule types not listed here but likely to have some ecosystem service effects include rules affecting contaminated site cleanup, financial assistance, trade, fees, royalties, quotas, or credits, among others.

Does your rule affect or involve INFRASTRUCTURE?		Human Welfare Endpoints					
Aspect of infrastructure	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Linear infrastructure (e.g., pipelines, roads)	Can block movement of wildlife, reducing opportunities for viewing		(-)				
	Can reduce surface flow, lowering water supplies for recreation, drinking, hydropower, irrigation, and reducing home values	(-)	(-)	(-)			
Roads	Can increase access for other activities that damage environment, causing multiple indirect losses	(-)	(-)	(-)			(-)
Transportation infrastructure	Can increase amenities for recreation; increase access to nature. Sustainable activity levels create benefits, overuse creates harms		(+/-)		(+/-)	(+/-)	
	Fossil fuel emissions pollute air, contributing to respiratory disease, release greenhouse gases. Renewable energy fleets reduce air pollution, greenhouse gases					(+/-)	(+/-)
Buildings, boat launches, ports	Can increase amenities for recreation; increase access to nature. Sustainable activity levels create benefits, overuse creates harms		(+/-)		(+/-)		
Construction and maintenance	Clearing land, using cement releases greenhouse gases and other air pollutants. Nature-based options sequester greenhouse gases	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same	(-/+)		(+/-)			(+/-)
	Can cause erosion, remove vegetation that cleans water, causing pollution, raising costs, decreasing real estate value. Nature-based solutions improve	(-/+)	(-/+)	(-/+)	(-/+)		
	Can remove natural vegetation, harden surfaces, increase flooding, reduce nature exposure. Nature-based solutions improve infiltration, reduce flooding, stormwater costs	(-/+)				(-/+)	(-/+)
	Can damage habitat of species of commercial, recreational or public interest value (e.g., traffic, windows kill animals) or improve habitat (e.g., water treatment wetlands)	(-/+)	(-/+)	(-/+)			(-/+)

Does your rule affect or involve WILDLIFE OR RECREATION?		Human Welfare Endpoints					
Aspect of wildlife or recreation	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Species management	Removal, relocation, or reduction of native species (e.g., through habitat loss, hunting, fishing, etc.) can disrupt food webs, causing declines in populations of other species of commercial, recreational, or public-interest value. Sustainable management can improve same	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
	Removal, relocation, or reduction of native species (e.g., through habitat loss, hunting, fishing, etc.) or introduction of non-native species can change populations and disease dynamics, increasing disease risk. Sustainable management can reduce risks		(+/-)		(+/-)	(+/-)	
	Removal, relocation, or reduction of native species (e.g., through habitat loss, hunting, fishing, etc.) can reduce pollinators or native pest control, reducing crop yields or increasing costs. Increased native populations can improve same	(+/-)		(+/-)			
	Change in species populations can change access to species of commercial, recreational, or public interest value	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
Recreation or tourism access or activity levels (e.g., catch limits, area restrictions)	Intensive uses (e.g., off-road vehicles, harvest, or high tourism) can damage habitat, stress species, and reduce populations with commercial, recreational, or public-interest value. Sustainable use maintains same	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
	Increasing access can increase non-native species or novel disease vector introductions, disrupting native species populations of commercial, recreational, or public-interest value. Limiting access can decrease same	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
Linear infrastructure (e.g., pipelines, roads)	Can block movement of wildlife, reducing opportunities for viewing or enjoyment. Well-designed can increase connectivity		(+/-)				(+/-)
	Can reduce surface flow, lowering water supplies for wildlife (including aquatic wildlife), as well as for recreation, drinking, hydropower, irrigation, and reducing home values	(-)	(-)	(-)			
Transportation infrastructure (e.g., roads, ports)	Can increase access for other activities that damage environment, causing multiple indirect losses	(-)	(-)	(-)			(-)
	Can increase amenities for recreation or tourism; increase access to nature. Sustainable activity levels create benefits, overuse creates harms		(+/-)		(+/-)	(+/-)	
	Can increase wildlife-vehicle collisions, reducing populations of commercial, recreational, or public interest value. Improved road siting or wildlife crossings can improve same		(+/-)	(+/-)			(+/-)
	Fossil fuel emissions from visitors to an area pollute air, contributing to respiratory disease, and release greenhouse gases. Transportation alternatives or reduced demand reduce air pollution, greenhouse gases					(+/-)	(+/-)
Construction and maintenance	Clearing land for recreation or tourism facilities or using cement releases greenhouse gases and other air pollutants. Nature-based options sequester greenhouse gases	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)

(e.g., recreational facilities)	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same	(-/+)		(+/-)			(+/-)
	Can cause erosion, remove vegetation that cleans water, causing pollution, raising costs, decreasing real estate value. Nature-based solutions improve	(-/+)	(-/+)	(-/+)	(-/+)		
	Can remove natural vegetation, harden surfaces, increase flooding, reduce nature exposure. Nature-based solutions improve infiltration, reduce flooding, stormwater costs	(-/+)				(-/+)	(-/+)
	Can damage habitat of species of commercial, recreational or public interest value (e.g., traffic, windows kill animals) or improve habitat (e.g., water treatment wetlands)	(-/+)	(-/+)	(-/+)			(-/+)

Does your rule affect or involve ENERGY PRODUCTION?		Human Welfare Endpoints					
Aspect of energy production	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Linear infrastructure (e.g., pipelines, roads)	Can block movement of wildlife, reducing opportunities for viewing		(-)				
	Can reduce surface flow, lowering water supplies for recreation, drinking, hydropower, irrigation, and reducing home values	(-)	(-)	(-)			
Roads	Can increase access for other activities that damage environment, causing multiple indirect losses	(-)	(-)	(-)			(-)
	Fossil fuel emissions pollute air, contributing to respiratory disease, release greenhouse gases. Renewable energy fleets reduce air pollution, greenhouse gases					(+/-)	(+/-)
Construction and maintenance	Clearing land, using cement releases greenhouse gases	(-)	(-)	(-)		(-)	(-)
	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same	(-/+)		(+/-)			(+/-)
	Can cause erosion, remove vegetation that cleans water, causing pollution, raising costs, decreasing real estate value. Nature-based solutions or use of converted sites can maintain or improve	(-/+)	(-/+)	(-/+)			
Medical waste	Can remove natural vegetation, harden surfaces, increase flooding, reduce nature exposure. Nature-based solutions or use of already converted sites can maintain or improve infiltration, reduce flooding, stormwater costs	(-/+)			(-/+)	(-/+)	(-/+)
	Can damage habitat of species of commercial, recreational or public interest value (e.g., traffic, windows kill animals) or maintain or improve habitat (e.g., water treatment wetlands; develop on already-converted sites like roofs, closed mines, etc.)	(-/+)	(-/+)	(-/+)			(-/+)
Fossil fuel extraction	Can directly release greenhouse gases (e.g., methane) and contributes to burning of fossil fuels that release greenhouse gases	(-)	(-)	(-)		(-)	(-)
	Contributes to fossil fuel burning that causes particulate air pollution, causing sickness and death			(-)		(-)	
Renewable energy development	If replaces fossil fuel use, avoids air pollution, saving lives and improving health; and reduces greenhouse gas emissions			(+)		(+)	
	Hydropower water use can constrain other water uses; Some management practices can reduce conflicts	(+/-)	(+/-)	(+/-)			(-)
Mine tailings, other wastes	Pollute soil, water, lower land values, making waters less attractive for recreation, increasing drinking water costs, damage species that provide timber, fish products	(-)	(-)	(-)			(-)
Cooling water	Changes temperature of rivers, ocean, damaging habitat for species of commercial or recreational value or public interest		(-)	(-)			(-)
Equipment operation, cement	Directly release greenhouse gases	(-)	(-)	(-)		(-)	(-)

Energy infrastructure	Can harm species of commercial, recreational or public interest value (e.g., dams harm fish; windmills harm birds) or provide habitat (e.g., structures provide marine habitat)		(-)	(-)			(-)

Does your rule affect or involve AGRICULTURE OR COMMERCIAL HARVEST (e.g., crops, livestock, timber, fish)?

		Human Welfare Endpoints					
Aspect of agriculture or commercial harvest	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Land clearing, harvest, or management	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity, increasing costs. Can incorporate native habitat, boosting same	(+/-)		(+/-)			
	Can remove native vegetation and release greenhouse gases. Sustainable forestry, restoration can reduce greenhouse gases	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
	Can remove, damage natural vegetation, harden surfaces, increase flooding. Nature-based solutions improve infiltration, reduce flooding and stormwater costs					(+/-)	(+/-)
	Can damage habitat of species of commercial, recreational or public interest value. Sustainable practices, native plants and habitat can improve species	(+/-)	(+/-)	(+/-)			(+/-)
	Can damage or remove natural areas, parks that support physical activity and provide mental health benefits. Incorporation of native habitat can improve		(+/-)		(+/-)	(+/-)	
	Can cause erosion, remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, decreasing real estate value. Nature-based solutions alleviate	(+/-)	(+/-)	(+/-)			
	Can remove individuals or habitat, destabilizing populations of species of commercial, recreational or public interest value. Sustainable practices, population management can improve	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
Chemical use	Fertilizer production releases greenhouse gases and other air pollutants, affecting respiratory health, and climate change	(-)	(-)	(-)		(-)	(-)
	Pesticide use can harm native pollinators, pest control species, reducing agriculture productivity or increasing costs	(-)		(-)			
	Intensive fertilizer application can cause water pollution, limiting other uses or increasing costs, and reducing real estate values	(-)	(-)	(-)			(-)
Intensive livestock facilities	Livestock emit greenhouse gases and other air pollutants. Some feeds reduce, but don't eliminate some gases	(-)	(-)	(-)		(-)	(-)
	Runoff and deposition from emissions can cause water pollution, limiting other uses or increasing costs, and reducing real estate values. Nature-based options (e.g., treatment wetlands) alleviate	(+/-)	(+/-)	(+/-)			
Equipment use	Emissions pollute air, contributing to respiratory disease, release greenhouse gases. Renewable energy fleets reduce air pollution, greenhouse gases	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
	Soil disturbance can cause air pollution, contributing to respiratory disease, and releasing disease vectors (e.g., Valley Fever). Not tilling the soil can improve same					(+/-)	
Irrigation	Intensive irrigation water use constrains other water uses; Growing lower water demand crops in dry regions and other options to reduce use reduces conflicts	(+/-)	(+/-)	(+/-)			(+/-)

Aquaculture	Feed, wastes pollute water, reducing recreation opportunities and harming species of public interest. Restorative aquaculture improves water quality	(+/-)	(+/-)	(+/-)			(+/-)
	Disease escapes, harms native species of recreational, commercial or public interest value		(-)				(-)

Does your rule affect or involve DISASTER MITIGATION OR RISK REDUCTION?		Human Welfare Endpoints					
Aspect of disaster mitigation or risk reduction	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
	Clearing land, using cement releases greenhouse gases and other air pollutants. Nature-based options sequester greenhouse gases	(-/+)	(-/+)	(-/+)		(-/+)	(-/+)
	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same	(-/+)		(-/+)			
	Can cause erosion, remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, decreasing real estate value. Nature-based solutions alleviate	(-/+)	(-/+)	(-/+)			
Construction of protective infrastructure	Can remove natural vegetation, harden surfaces, increase flooding, reduce nature exposure. Nature-based solutions improve infiltration, reduce flooding and stormwater costs	(-/+)			(-/+)	(-/+)	(-/+)
	Can damage habitat of species of commercial, recreational or public interest value (e.g., dams for flood control) or improve habitat (e.g., wetlands for flood control)		(-/+)	(-/+)			(-/+)
	Water impoundment to reduce floods can conflict with or promote other water uses	(-/+)	(-/+)	(-/+)			(-/+)
	Can remove habitat or greenspace, reducing recreation opportunity or property value, weakening physical and mental health. Restoring greenspace can benefit same	(-/+)	(-/+)		(-/+)	(-/+)	

Does your rule affect or involve PUBLIC HEALTH OR HEALTH CARE?		Human Welfare Endpoints					
Aspect of public health or health care	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Care facility siting and landscaping	Green or blue views can improve mental health, shorten recovery times				(+)	(+)	
Greenspace	Creation of safe greenspaces provide opportunities for recreation, create healthy living environment with physical and mental health benefits, increase adjacent property value	(+)			(+)	(+)	
Health care facility construction and maintenance	Clearing land, using cement, fossil fuel energy releases greenhouse gases and other air pollutants. Renewable energy sources, nature-based options reduce climate impacts	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same	(-/+)		(+/-)			(+/-)
	Can cause erosion, remove vegetation that cleans water, causing pollution, raising costs, decreasing real estate value. Nature-based solutions improve	(-/+)	(-/+)	(-/+)			
	Can remove natural vegetation, harden surfaces, increase flooding, reduce nature exposure. Nature-based solutions improve infiltration, reduce flooding, stormwater costs	(-/+)			(-/+)	(-/+)	(-/+)
	Can damage habitat of species of commercial, recreational or public interest value (e.g., traffic, windows kill animals) or improve habitat (e.g., water treatment wetlands)	(-/+)	(-/+)	(-/+)			(-/+)
Medical waste	Disposal of waste can damage habitat or species of commercial, recreational or public interest value. Reducing medical waste can improve same.		(-/+)				(-/+)
	Combustion of medical waste can cause air pollution, release greenhouse gases	(-)	(-)	(-)	(-)	(-)	(-)

Does your rule affect or involve LABOR OR EDUCATION?		Human Welfare Endpoints					
Aspect of labor or education	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Work environment	Removal of trees, vegetation can increase heat stress, lowering physical health and worker productivity. Nature-based improvements increase			(-/+)		(-/+)	
	Lack of views or green or blue (water) spaces from work setting impair cognitive function and worker productivity. Creation of views improve same			(-/+)	(-/+)		(-/+)
Education content	Teaching or training can encourage or discourage preferences for nature, time outdoors, sustainable products, healthy diets, built vs. natural solutions, changing willingness to pay	(-/+)	(-/+)	(-/+)			(-/+)
Construction and maintenance of work or education facilities	Clearing land, using cement releases greenhouse gases and other air pollutants. Nature-based options sequester greenhouse gases	(+/-)	(+/-)	(+/-)		(+/-)	(+/-)
	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same	(-/+)		(+/-)			(+/-)
	Can cause erosion, remove vegetation that cleans water, causing pollution, raising costs, decreasing real estate value. Nature-based solutions improve	(-/+)	(-/+)	(-/+)	(-/+)		
	Can remove natural vegetation, harden surfaces, increase flooding, reduce nature exposure. Nature-based solutions improve infiltration, reduce flooding, stormwater costs	(-/+)				(-/+)	(-/+)
	Can damage habitat of species of commercial, recreational or public interest value (e.g., traffic, windows kill animals) or improve habitat (e.g., water treatment wetlands)	(-/+)	(-/+)	(-/+)			(-/+)
Time use	Worker and education policies increase/decrease time people have for recreation, and ability to receive related health benefits		(-/+)		(-/+)	(-/+)	

Does your rule affect or involve VEHICLE FLEETS?		Human Welfare Endpoints					
Aspect of vehicle fleets	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Construction of parking, storage or transfer facilities	Pavement, impermeable surfaces can increase flooding, stormwater costs. Permeable and nature-based options reduce flooding, costs	(-/+)				(-/+)	(-/+)
	Can cause erosion, remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, decreasing real estate value. Nature-based solutions alleviate	(-/+)	(-/+)	(-/+)			
	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs; harming species of commercial or public interest; nature-based options improve same	(-/+)		(-/+)			(-/+)
	Can remove or damage habitats, features, places or species of recreational, commercial or public interest; nature-based options improve same		(-/+)	(-/+)			(-/+)
	Can remove natural vegetation, releasing greenhouse gases and other air pollutants; nature-based options improve same	(-/+)	(-/+)	(-/+)		(-/+)	(-/+)
Fleet fuel source	Fossil fuel use causes air pollution, releases greenhouse gases. Electric vehicle use avoids emissions if electricity is from renewable sources	(-/+)	(-/+)	(-/+)		(-/+)	(-/+)

Does your rule affect or involve HOUSING?		Human Welfare Endpoints					
Aspect of housing	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Construction of housing	Clearing land for housing facilities, using cement releases greenhouse gases and other air pollutants. Using sites without natural habitat (e.g., redeveloping previously developed areas) and using alternative materials avoids some emissions	(-/+)	(-/+)	(-/+)		(-/+)	(-/+)
	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same	(-/+)		(-/+)			
	Can cause erosion, remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, decreasing real estate value. Nature-based solutions, redevelopment can alleviate	(-/+)	(-/+)	(-/+)			(-/+)
	Can remove natural vegetation, harden surfaces, increase flooding, reducing nature exposure. Nature-based solutions improve same, redevelopment can avoid impacts	(-/+)			(-/+)	(-/+)	(-/+)
	Can damage habitat of species of commercial, recreational or public interest value or improve habitat. Redevelopment can avoid impacts, restoring or improving habitat can benefit same	(-/+)	(-/+)	(-/+)			(-/+)
	Can remove habitat or greenspace, reducing recreation opportunity, weakening physical and mental health. Restoring greenspace can benefit same		(-/+)		(-/+)	(-/+)	
Landscaping irrigation	Irrigation water use constrains other water uses; drought tolerant landscaping in dry regions reduces conflicts	(-/+)	(-/+)	(-/+)			
Landscaping chemical use	Pesticide use can harm native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can harm species of commercial value or public interest	(-)	(-)	(-)			(-)
	Intensive fertilizer application can cause water pollution, limiting other uses or increasing costs, harming species of commercial value or public interest, and reducing real estate values	(-)	(-)	(-)			(-)
Construction equipment use	Emissions pollute air, contributing to respiratory disease, release greenhouse gases. Renewable energy fleets reduce air pollution, greenhouse gases	(-/+)	(-/+)	(-/+)	(-/+)	(-/+)	(-/+)

Does your rule affect or involve WASTE MANAGEMENT?		Human Welfare Endpoints					
Aspect of waste management	Possible causal pathways	Property Value	Recreation/Leisure	Production	Mental Health	Physical Health	Passive Use Values
Construction of waste management or disposal sites	Clearing land for disposal facilities, using cement releases greenhouse gases and other air pollutants. Using degraded sites and alternative materials avoids some emissions	(-/+)	(-/+)	(-/+)		(-/+)	(-/+)
	Can remove or damage habitat for native pollinators, pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same	(-/+)		(-/+)			
	Can cause erosion, remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, decreasing real estate value. Nature-based solutions can alleviate	(-/+)	(-/+)	(-/+)			
	Can remove natural vegetation, harden surfaces, increase flooding, reduce nature exposure. Nature-based solutions can improve same	(-/+)			(-/+)	(-/+)	(-/+)
	Can damage habitat of species of commercial, recreational or public interest value or improve habitat	(-/+)	(-/+)	(-/+)			(-/+)
	Can remove habitat or greenspace, reducing recreation opportunity, weakening physical and mental health. Restoring greenspace can benefit same		(-/+)		(-/+)	(-/+)	
Waste disposal	Combustion of waste can cause air pollution, release greenhouse gases	(-)	(-)	(-)	(-)	(-)	(-)
	Leakage or runoff from disposal sites can damage habitat or species of commercial, recreational, or public interest value	(-)	(-)	(-)			(-)

Appendix II: Advice on Conceptual Models

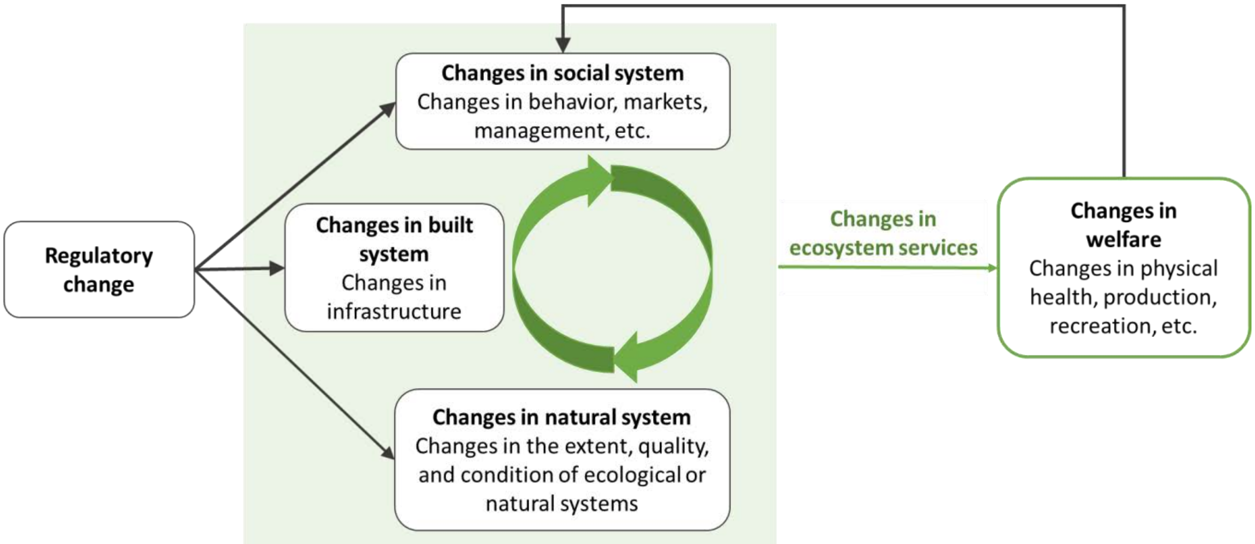
Conceptual diagrams (variously called conceptual models, logic models, results chains, Forrester diagrams, or theories of change) are used by a range of disciplines to identify a logical and ordered sequence of effects, illustrating how a system responds to interventions, actions, stressors, or perturbations.

Using conceptual diagrams can be helpful for:

- Providing a transparent and systemic way to capture the target and non-target impacts of a policy, including both positive and negative impacts;
- Providing a systemic framework for collecting evidence and talking to experts and stakeholders regarding expected impacts and for quantifying or monetizing impacts, as well as for articulating a strong narrative description;
- Testing assumptions about the relationship and pathways of change from a policy intervention to the social and economic impacts;
- Thinking about who is impacted, and how, for each of the different impacts identified;
- Aligning agency experts and OMB examiners about what the agency considered in a policy decision; or
- Organizing information to use in other decision support tools such as estimation models, options matrices, or others.

In a policy context, conceptual diagrams usually start with a policy intervention or action that targets a change in behavior, markets, management, or infrastructure (e.g., requiring public housing in areas that reach temperature above 95°F in summer to have cooling features, cooling centers, portable cooling units, or vegetative cover (i.e., shade trees) sufficient to reduce extreme heat impacts). This then results in targeted changes to behavior, markets, management, and infrastructure (e.g., number of public housing areas with cooling features or a change in tree planting and maintenance for these facilities) and additional changes (e.g., demand for and construction of cooling centers and cooling units, changing production and prices; or number of landscaping jobs). These are expected to result in targeted changes in welfare (e.g., reduced morbidity and mortality from heat for residents), as well as numerous additional effects (both positive and negative), some of which are mediated through their impact on nature or the environment (e.g., more trees help reduce stormwater runoff, improve residents' mental health, and provide habitat corridors for birds) (Figure A.II-1).

Figure A.II-1. Structure of conceptual models. *This matches Figure 1 in the guidance above.*



The process of developing these diagrams is usually iterative, evolving as new perspectives, evidence, and impacts are considered.[77] These diagrams can be used to inform not only the benefit-cost analysis of regulatory alternatives but also the selection of alternatives. See examples of conceptual models below.

For regulatory analysis, building a diagram starts with clarifying a regulatory intervention or set of similar regulatory interventions (e.g., variations in the amount or degree of regulation, such as different pollutant standards). The diagram will illustrate what the selected intervention(s) will change in the social, built, and natural systems. Similar regulatory alternatives can usually all be captured by a single diagram because the system changes are similar. If regulatory alternatives effect substantially different system changes, then multiple conceptual diagrams may be needed.

The development of conceptual diagrams can benefit from multiple perspectives. Where possible, it is helpful to include resource managers with experience with the system, as well as research scientists who can consider implications outside the scope of current management. It is also helpful to include policy analysts or decision makers who can clarify objectives and alternatives and make adjustments as needed. Where possible, develop a model using scoping sessions or participatory workshops where these experts work together to draft out the model. In some cases, as feasible and appropriate, it can also be valuable to engage potentially impacted stakeholders and communities.[78]

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[77] There are numerous resources describing how to develop conceptual models, including: Lydia Olander et al., *Building Ecosystem Services Conceptual Models* (National Ecosystem Services Partnership Conceptual Model Series No. 1., 2018), https://nicholasinstitute.duke.edu/conceptual-model-series; Marion Potschin-Young et al., "Understanding the Role of Conceptual Frameworks: Reading the Ecosystem Services Cascade," *Ecosystem Services* 29, part C (2018): 428-440; Caroline Stem and Marco Flores, *Using Results Chains to Depict Theories of Change in USAID Biodiversity Programming* (United States Agency for International Development, 2016), https://pdf.usaid.gov/pdf_docs/PA00M8MW.pdf.

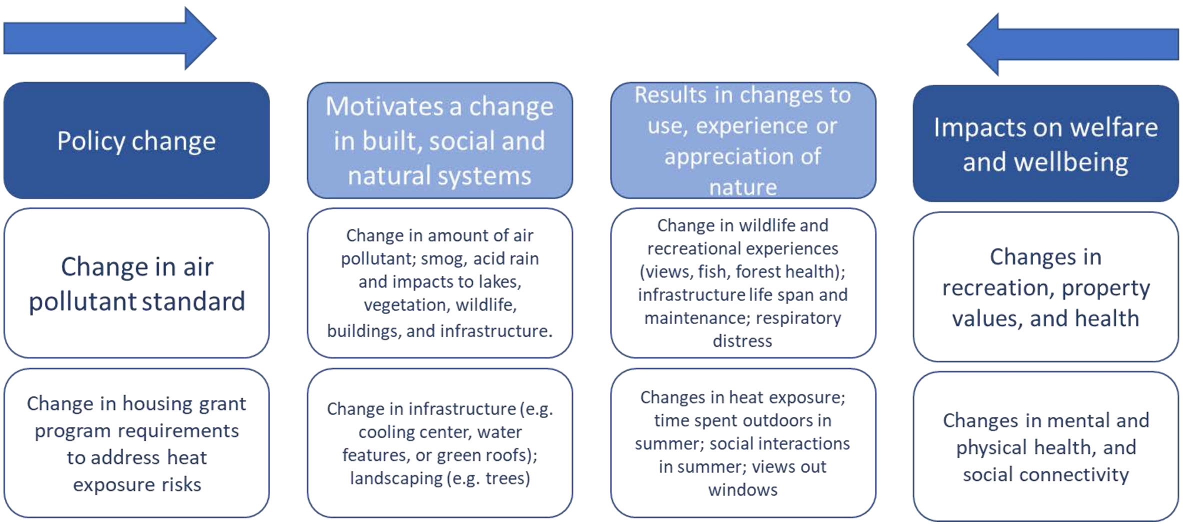
[78] Existing resources or case studies that can be used as models for designing working sessions to develop or adapt conceptual models include: Mark Reed, "Stakeholder Participation for Environmental Management: A Literature Review," *Biological Conservation* 141, no. 10: 2417-2431; Sara Mason, Rachel Karasik, and Lydia Olander, *Workshop Guide: Using Facilitation Techniques to Integrate Ecosystem Services into Coastal Management Decisions*

As a conceptual model is developed, it may be necessary to clarify the spatial scale and time scale of effects that should be considered given the types of effects expected (e.g., immediate effects of pesticide use on crop yields, and longer-term effects on downstream fish and commercial fishing revenue). When developing a model, it is often useful to work from both ends, starting with the intervention (proposed alternatives) and targeted objectives or expected outcomes, then filling in the middle, and then iterating to fill in gaps. If the conceptual diagram is used to design quantitative analysis, it is also useful to identify what metrics will be estimated.

1. Start with a process of asking what you know and who has the expertise to provide the information.
2. Begin drafting a conceptual model by articulating your intervention and how it will activate change.
3. Then identify the expected and likely impacts of the policy alternative and group them into a common set of categories.
4. To do this, consider a series of nested questions (to think through the changes in the built, social and natural systems—Figure A.II-1) and list the policy's effects.
    - How does the intervention or action affect built systems like infrastructure (roads, pipelines, dams, housing, etc.)?
    - How does the intervention or action affect social systems like behaviors, markets, or management (purchases, savings, investment, planning, community engagement, diet, energy use, harvest or management approaches, etc.)?
    - How does the intervention or action affect natural systems (lands, waters, species, oceans, parks, climate, nutrient cycles, etc.)?
    - And how does each of these changes in built, social, and natural systems affect the provision of ecosystem goods and services, impacting human welfare?
5. Then fill in the middle by thinking about the logic chain or pathway that links the effects of the rule to the final impacts on welfare (income, health, etc.) and include any significant steps along the way.

(Nicholas Institute for Environmental Policy Studies, 2019), *https://hdl.handle.net/10161/26482*; Lydia Olander et al., "Exploring the Use of Ecosystem Services Conceptual Models to Account for the Benefits of Public Lands: An Example from National Forest Planning in the United States," *Forests* 12, no. 3 (2021): 267; Nicholas Institute for Energy, Environment & Sustainability, *Use Cases - Forest Systems*, *https://nicholasinstitute.duke.edu/project/ecosystem-services-toolkit-for-natural-resource-management/forest/use-cases*.

Figure A.II-2. Creating ecosystem services conceptual models by working from both ends. *Two examples that illustrate the intervention (policy alternatives) and the impacts (ecosystem services and other impacts on welfare and wellbeing) that can be identified before filling in the system changes that connect the two in the middle. Thinking through changes that result from the policy can lead to additional impacts that were not planned for or anticipated. The examples are illustrative and not fully developed.*



Conceptual models usually include:

- Arrows that point to likely or hypothesized causes and effects; and
- Boxes representing attributes that are changed by the policy and are specific enough to be measured (e.g., change in the number of coastal roads, change in evacuation capacity, or change in the number of affordable housing complexes with cooling centers or tree cover).
    - Attributes in these boxes usually do not include direction (increase/positive or decrease/negative); they just indicate a "change in X," either for clarity or because the direction is not certain.

There are a number of other features these models can also include for clarity, such as:

- Positive or negative feedback loops to show how impacts feedback on the system;
- Information about the assumptions made and in some cases the evidence available about the relationships they represent, which would be associated with each arrow;
- List of external but critical driving factors that could change outcomes (e.g., climate change, population changes, or innovation), and, if helpful, an indication of how they impact the outcomes in the diagram;
- Faded out pathways for those that are not consequential, but are good to show for transparency to indicate that they were considered (note that pathways should not be faded out simply because they cannot be fully quantified or monetized); or
- Different types of arrows (e.g., different widths, or dotted/dashed versus solid arrows) to indicate the strength of evidence[79] or likely magnitude of the effect between two boxes (e.g.,

[79] Strength of evidence can be evaluated in many different ways. Please see the following references for some relevant examples: Lydia Olander et al., *Building Ecosystem Services Conceptual Models* (National Ecosystem Services Partnership Conceptual Model Series No. 1., 2018), *https://nicholasinstitute.duke.edu/conceptual-model-series*; Heather Tallis et al., *Bridge Collaborative Practitioner's Guide: Principles and Guidance for Cross-Sector*

how much evidence there is that building a road will result in temporary increases in sedimentation that will impact local water treatment cost, or how large the sediment impact is likely to be on cost of water treatment).

Conceptual models can also be a framework for systematically collecting and organizing evidence used as the foundation of a regulatory analysis. This can include evidence regarding the hypothesized relationships in the model, factors that may significantly influence an assumed relationship, and information regarding confidence in the evidence. See Table A.II-1 for an example entry in an evidence library, and see also the references associated with the conceptual model examples (1) and (2) below, which include full evidence libraries.

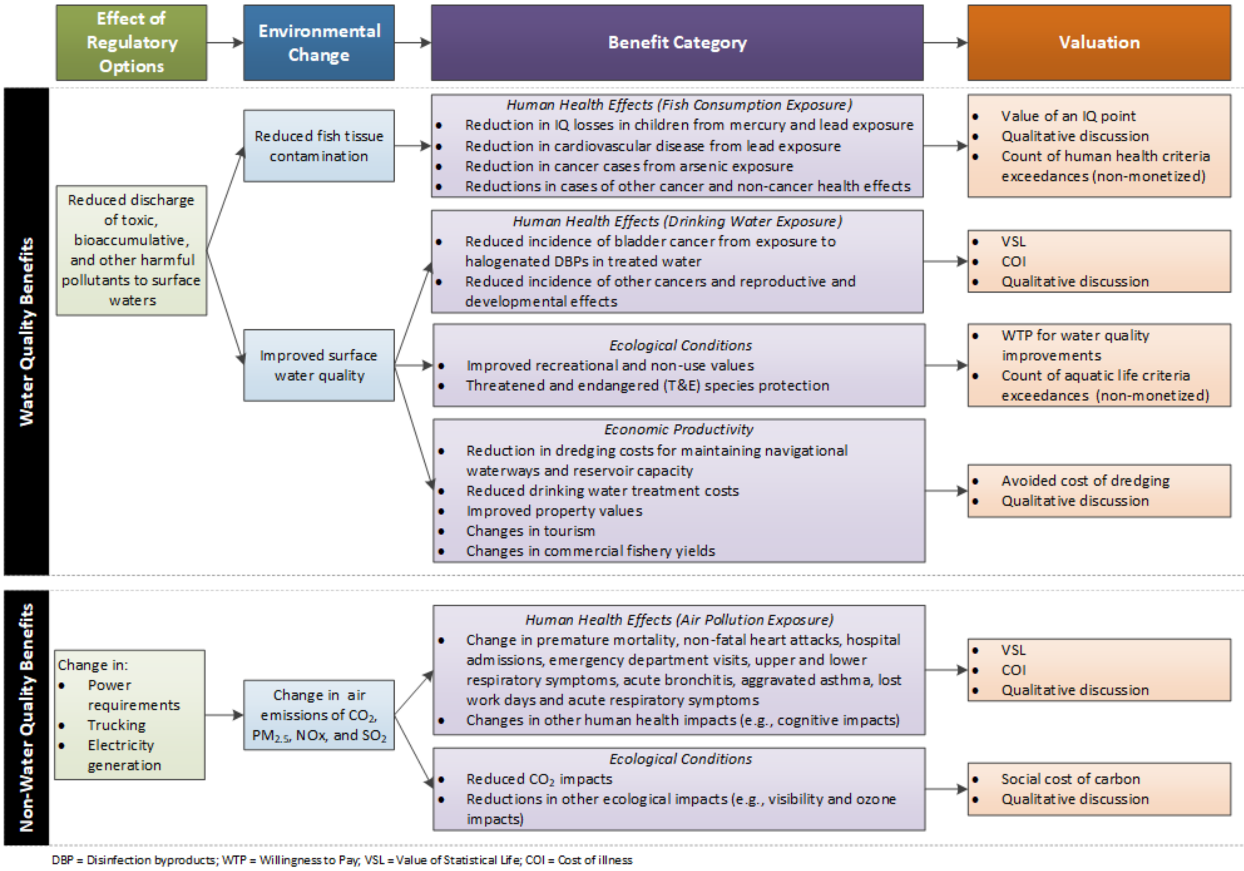
Table A.II-1. Illustrative evidence library entry. *This entry describes the link between solar energy development and water use for solar energy installation on Bureau of Land Management Lands (from: Warnell, Olander, and Mason 2018—see example conceptual model 1 below and associated reference).*

Evidence element	Example from solar energy development conceptual model
Link ID	10a: Solar energy development >> Water use
Description of relationship	Photovoltaic solar plants consume 11–226 gallons of water per MWh of electricity produced. This consumption includes water used to manufacture photovoltaic panels and for dust suppression during construction.
Summary of evidence	One meta-analysis harmonized lifecycle water consumption estimates for photovoltaic power plants and found the water consumption values listed above. It included 23 estimates of upstream (raw materials, manufacturing, construction, and transportation) and downstream (decommissioning) water consumption for crystalline silicon panels and 9 estimates of water consumption during operation.
Strength of evidence	Fair: The meta-analysis of water consumption by solar energy facilities was constrained by the number of studies available, and the included water consumption estimates ranged over an order of magnitude. This analysis did not account for site-specific factors including climate that may influence water consumption.
Other factors	The amount of water required for manufacturing photovoltaic panels varies by specific panel technology; for example, cadmium telluride panels require less water to produce than crystalline silicon panels.
Sources	Meldrum, J., S. Nettles-Anderson, G. Heath, and J. Macknick. 2013. "Life Cycle Water Use for Electricity Generation: A Review and Harmonization of Literature Estimates." *Environmental Research Letters* 8. stacks.iop.org/ERL/8/015031. Sinha, P. 2013. "Life Cycle Materials and Water Management for CdTe Photovoltaics." *Solar Energy Materials and Solar Cells* 119: 271–275. https://doi.org/10.1016/j.solmat.2013.08.022.

Action Planning and Evidence Evaluation (The Nature Conservancy, 2017), *https://hdl.handle.net/10161/26486*; Heather Tallis et al., "Aligning Evidence Generation and Use Across Health, Development, and Environment," *Current Opinion in Environmental Sustainability* 39 (2019): 81-93.

Example conceptual models:

(1) Conceptual model for the Environmental Protection Agency's Benefit and Cost Analysis for Proposed Supplemental Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category.[80]

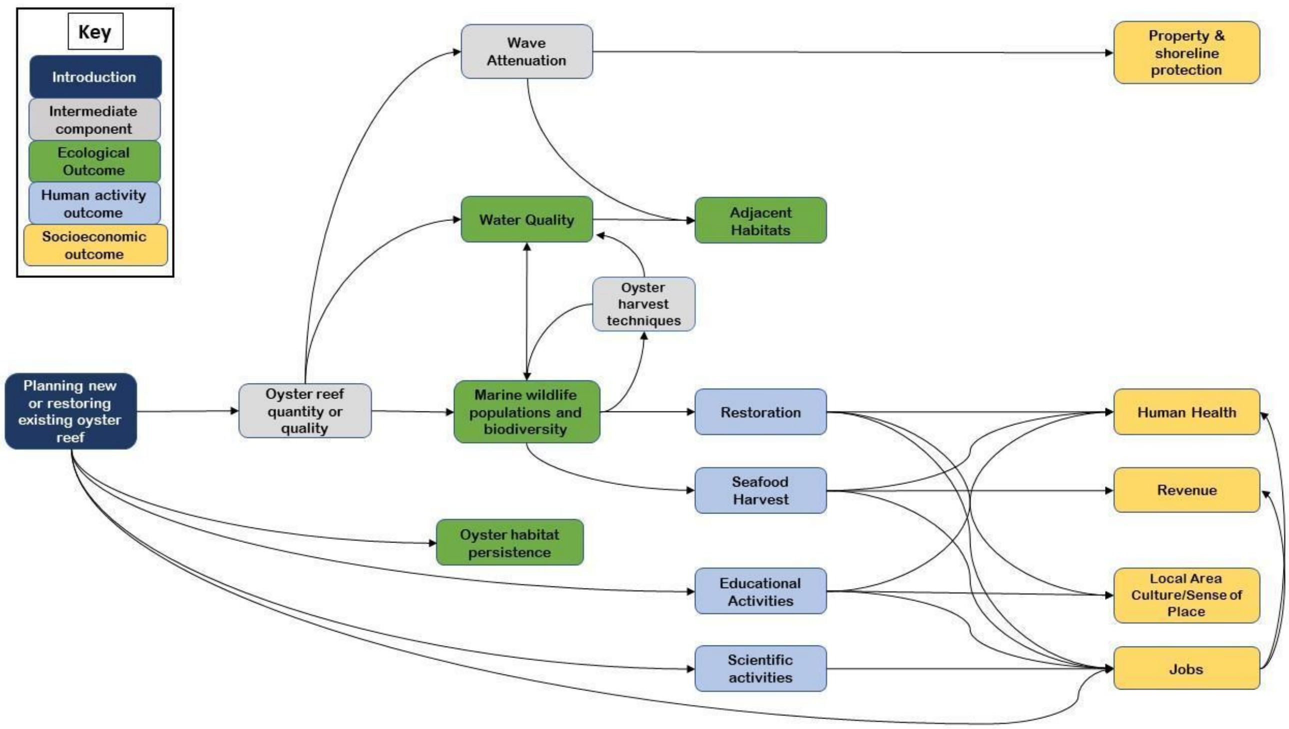


[80] Environmental Protection Agency, *Benefit and Cost Analysis for Proposed Supplemental Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (2023), https://www.epa.gov/system/files/documents/2023-03/steam-electric-benefit-cost-analysis_proposed_feb-2023.pdf.

(2) Conceptual models for oyster reef restoration in the Gulf of Mexico.

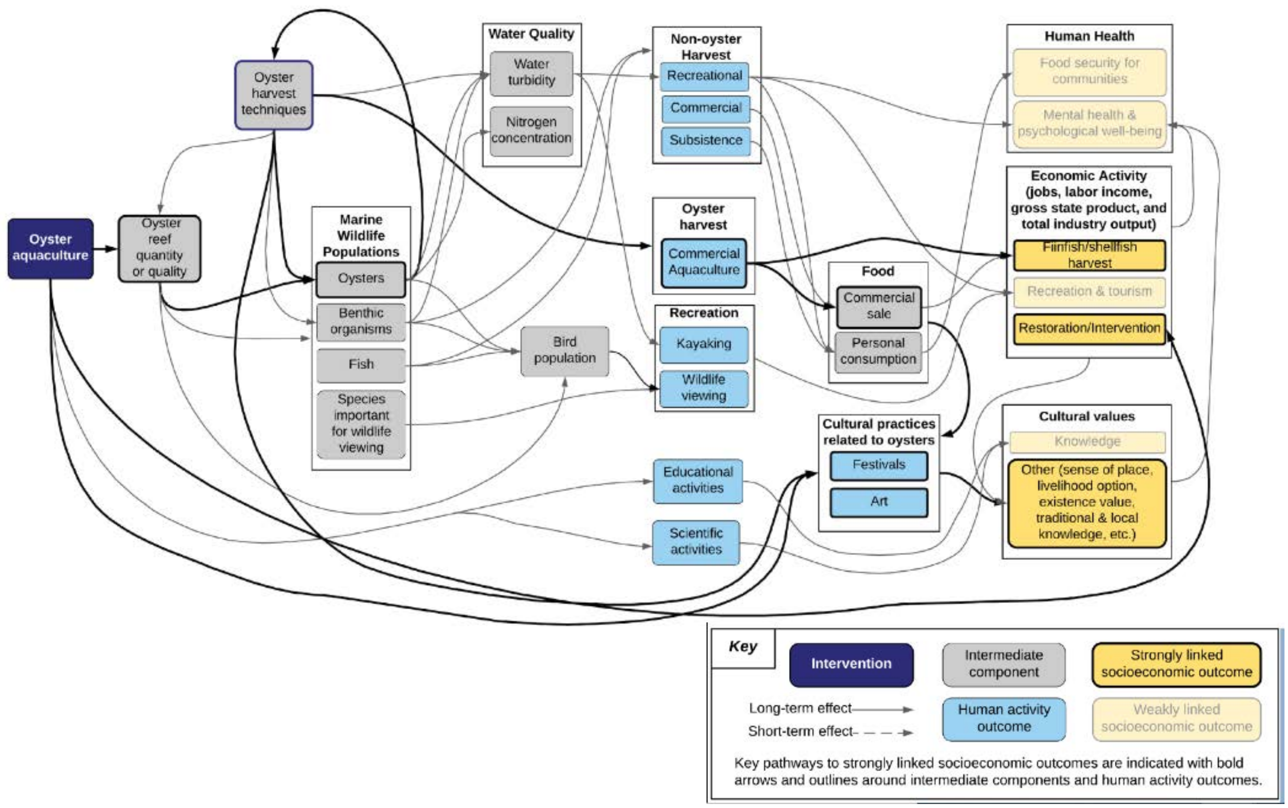
a) A simplified version of the general oyster reef restoration model shown in figure (a) used for communication purposes.[81]
b) Conceptual model for aquaculture in the Gulf of Mexico that highlights the most important pathways and outcomes with bold arrows and outlines.[82]
c) A general model that includes all different types or restoration approaches including subtidal reefs for harvest, subtidal reefs for habitat creation, intertidal or living shoreline reefs, reef protection, and aquaculture.[83]

(a)



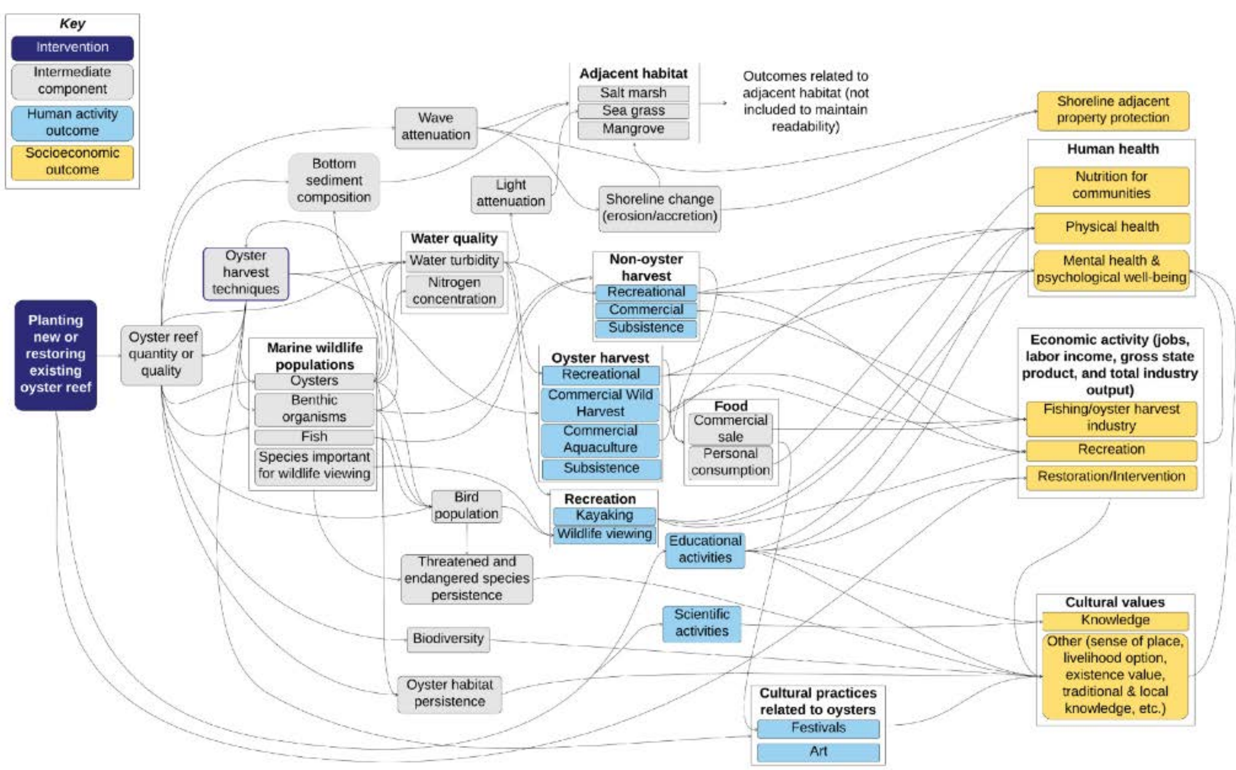
[81] Nicholas Institute for Energy, Environment & Sustainability, *Using Ecosystem Services in Outreach - Coastal Systems*, https://nicholasinstitute.duke.edu/project/ecosystem-services-toolkit-for-natural-resource-management/coastal/outreach.
[82] Nicholas Institute for Energy, Environment & Sustainability, *Gulf of Mexico Ecosystem Service Logic Models & Socio-Economic Indicators (GEMS)*, https://nicholasinstitute.duke.edu/project/gems.
[83] Katie Warnell et al., *Evidence Library for Oyster Reef Restoration in the Gulf of Mexico* (National Ecosystem Services Partnership, 2020), https://nicholasinstitute.duke.edu/sites/default/files/publications/GEMS-Evidence-Library_0.pdf.

(b)



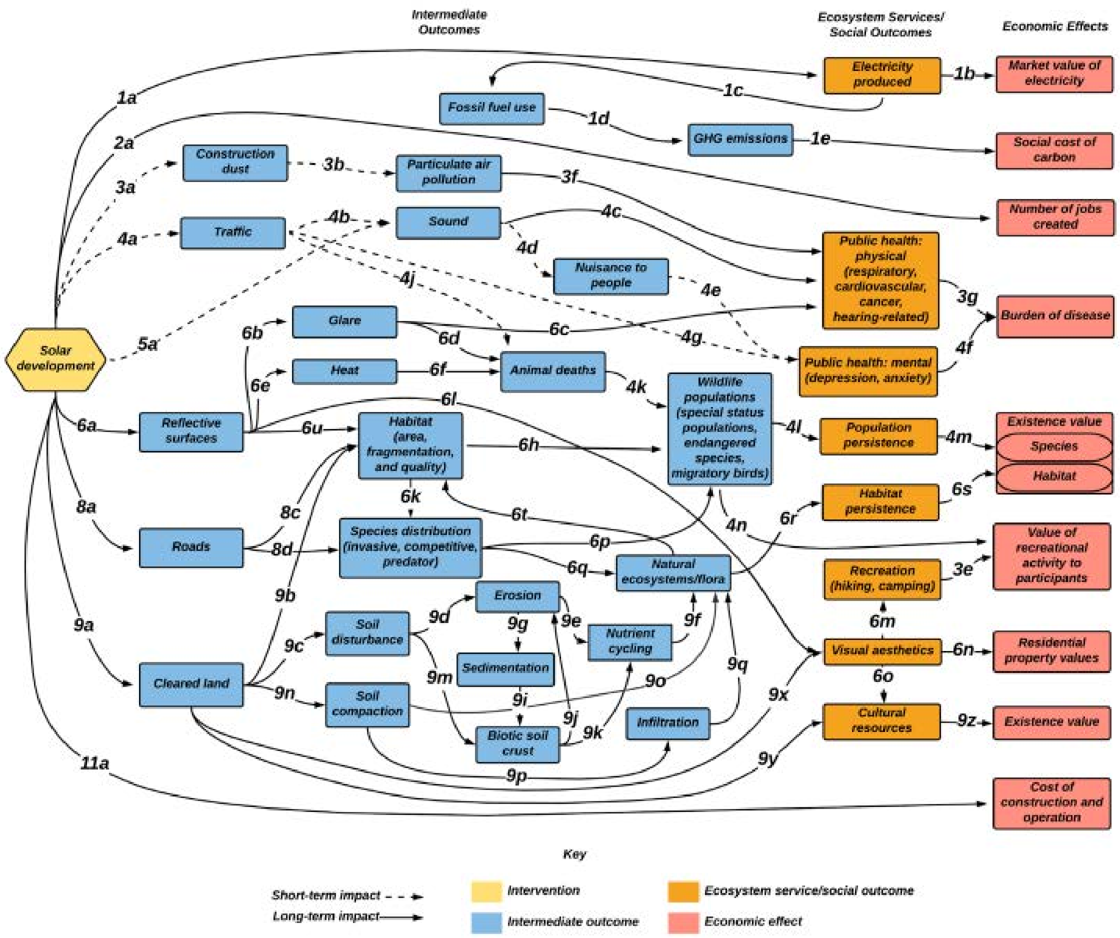
Oyster aquaculture
Oyster reef quantity or quality
Oyster harvest techniques
Marine Wildlife Populations
Oysters
Benthic organisms
Fish
Species important for wildlife viewing
Water Quality
Water turbidity
Nitrogen concentration
Bird population
Non-oyster Harvest
Recreational
Commercial
Subsistence
Oyster harvest
Commercial Aquaculture
Recreation
Kayaking
Wildlife viewing
Educational activities
Scientific activities
Food
Commercial sale
Personal consumption
Cultural practices related to oysters
Festivals
Art
Human Health
Food security for communities
Mental health & psychological well-being
Economic Activity (jobs, labor income, gross state product, and total industry output)
Finfish/shellfish harvest
Recreation & tourism
Restoration/Intervention
Cultural values
Knowledge
Other (sense of place, livelihood option, existence value, traditional & local knowledge, etc.)
Key
Intervention
Intermediate component
Strongly linked socioeconomic outcome
Long-term effect
Short-term effect
Human activity outcome
Weakly linked socioeconomic outcome
Key pathways to strongly linked socioeconomic outcomes are indicated with bold arrows and outlines around intermediate components and human activity outcomes.

(c)



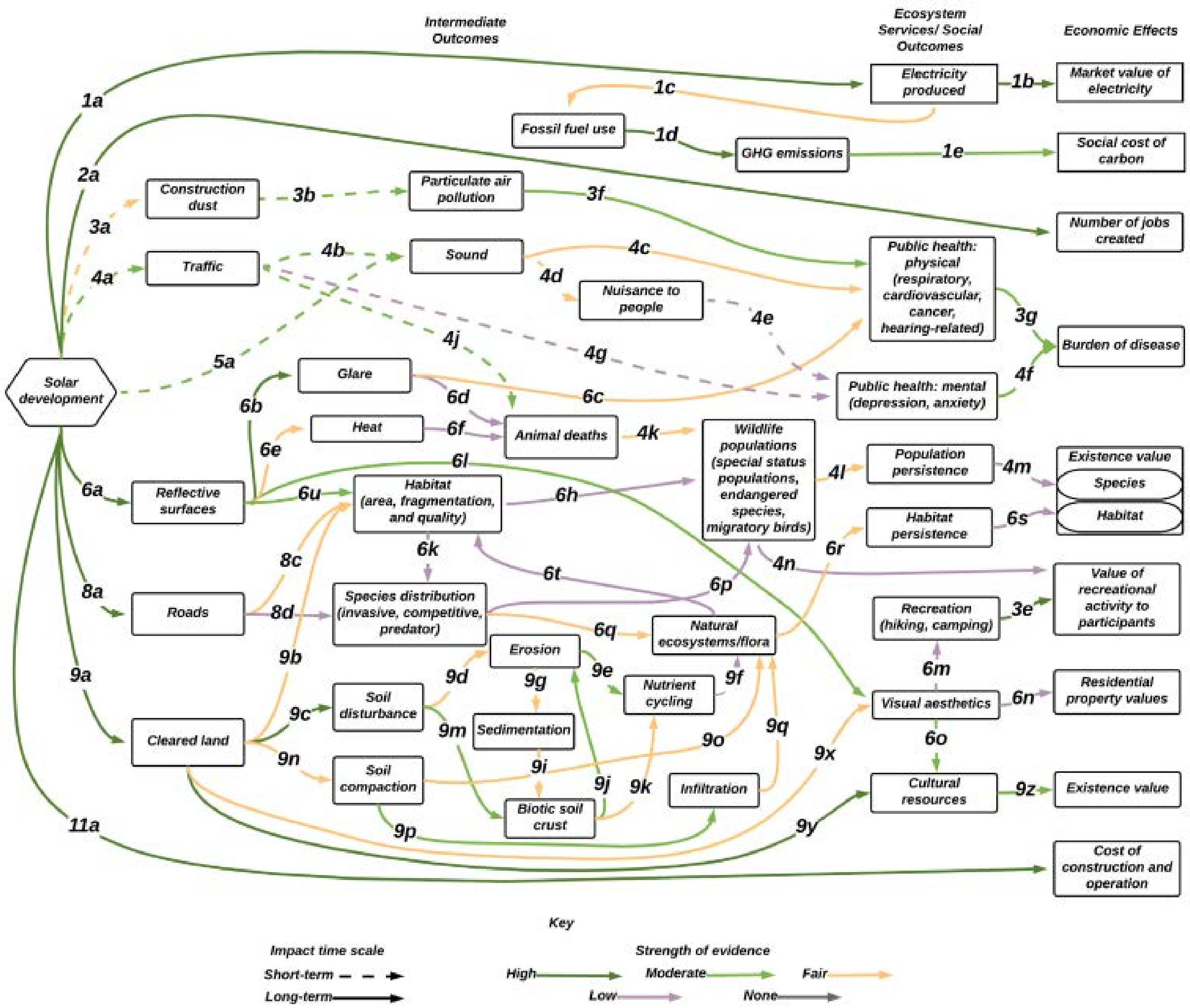
Key
Intervention
Intermediate component
Human activity outcome
Socioeconomic outcome
Planting new or restoring existing oyster reef
Oyster reef quantity or quality
Oyster harvest techniques
Bottom sediment composition
Wave attenuation
Light attenuation
Adjacent habitat
Salt marsh
Sea grass
Mangrove
Outcomes related to adjacent habitat (not included to maintain readability)
Shoreline change (erosion/accretion)
Water quality
Water turbidity
Nitrogen concentration
Marine wildlife populations
Oysters
Benthic organisms
Fish
Species important for wildlife viewing
Bird population
Threatened and endangered species persistence
Biodiversity
Oyster habitat persistence
Non-oyster harvest
Recreational
Commercial
Subsistence
Oyster harvest
Recreational
Commercial Wild Harvest
Commercial Aquaculture
Subsistence
Food
Commercial sale
Personal consumption
Recreation
Kayaking
Wildlife viewing
Educational activities
Scientific activities
Cultural practices related to oysters
Festivals
Art
Shoreline adjacent property protection
Human health
Nutrition for communities
Physical health
Mental health & psychological well-being
Economic activity (jobs, labor income, gross state product, and total industry output)
Fishing/oyster harvest industry
Recreation
Restoration/Intervention
Cultural values
Knowledge
Other (sense of place, livelihood option, existence value, traditional & local knowledge, etc.)

(3) Conceptual model for solar energy development on Bureau of Land Management (BLM) lands with insignificant effects removed (a) and a version with arrows indicating strength of evidence (b).[84]



[84] Katie Warnell, Lydia Olander, and Sara Mason, *Ecosystem Services Conceptual Model Application: Bureau of Land Management Solar Energy Development* (National Ecosystem Services Partnership, 2018), https://nicholasinstitute.duke.edu/sites/default/files/publications/escm-application-blm-solar-energy-development-web.pdf.

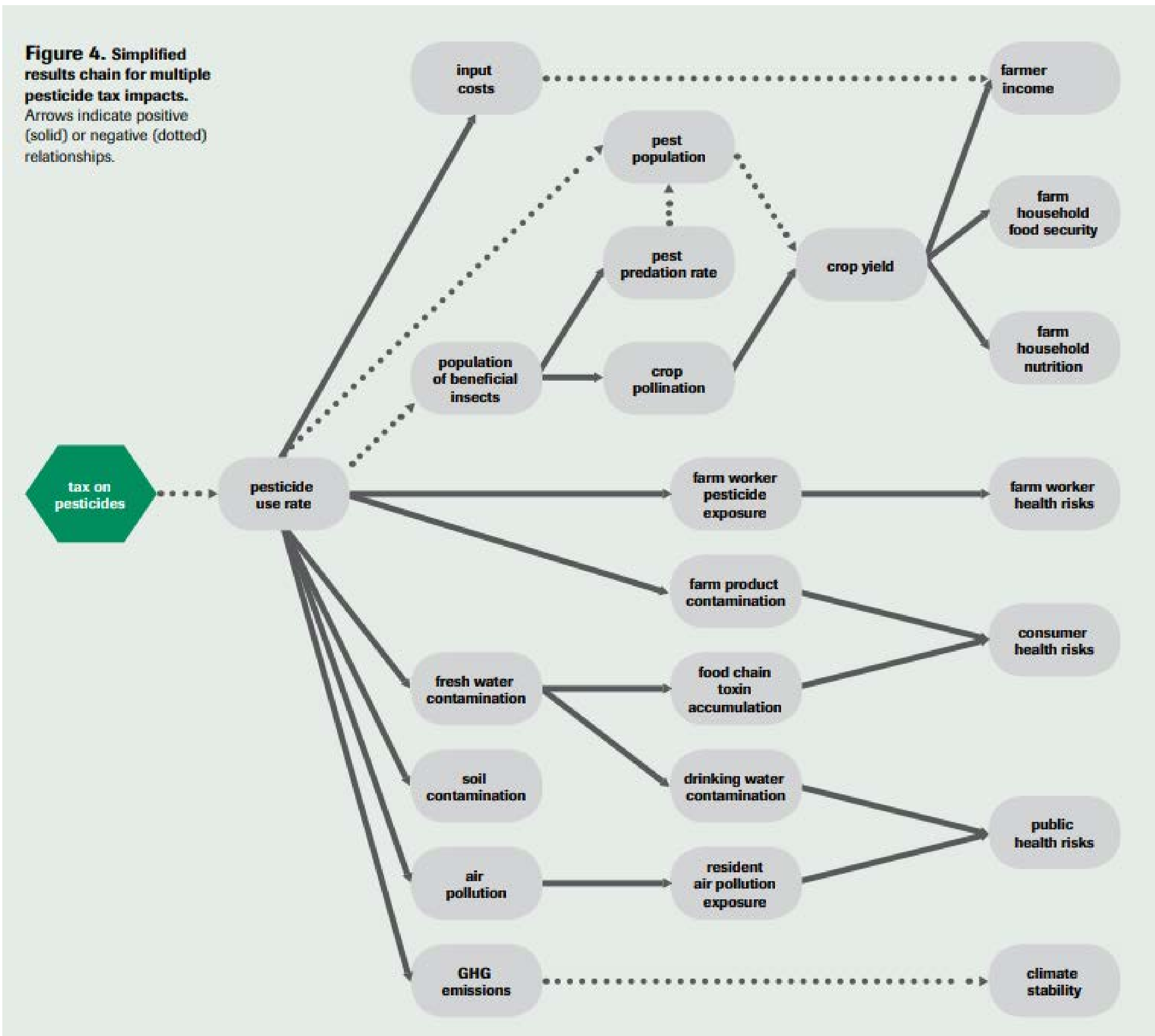
(b)


Intermediate Outcomes
Ecosystem Services/ Social Outcomes
Economic Effects
Solar development
Electricity produced
Market value of electricity
Fossil fuel use
GHG emissions
Social cost of carbon
Number of jobs created
Construction dust
Particulate air pollution
Traffic
Sound
Nuisance to people
Public health: physical (respiratory, cardiovascular, cancer, hearing-related)
Burden of disease
Public health: mental (depression, anxiety)
Glare
Heat
Animal deaths
Wildlife populations (special status populations, endangered species, migratory birds)
Population persistence
Existence value
Species
Habitat
Habitat persistence
Reflective surfaces
Habitat (area, fragmentation, and quality)
Roads
Species distribution (invasive, competitive, predator)
Natural ecosystems/flora
Value of recreational activity to participants
Recreation (hiking, camping)
Erosion
Nutrient cycling
Soil disturbance
Sedimentation
Visual aesthetics
Residential property values
Cleared land
Soil compaction
Biotic soil crust
Infiltration
Cultural resources
Existence value
Cost of construction and operation
1a 1b 1c 1d 1e 2a 3a 3b 3e 3f 3g 4a 4b 4c 4d 4e 4f 4g 4j 4k 4l 4m 4n 5a 6a 6b 6c 6d 6e 6f 6h 6k 6l 6m 6n 6o 6p 6q 6r 6s 6t 6u 8a 8c 8d 9a 9b 9c 9d 9e 9f 9g 9i 9j 9k 9m 9n 9o 9p 9q 9x 9y 9z 11a
Key
Impact time scale
Short-term
Long-term
Strength of evidence
High
Moderate
Fair
Low
None

(4) Conceptual models for pesticide tax impacts (a) and habitat subsidies (b). Arrows indicate direct (solid) and inverse (dotted) relationships between the two variables linked by the arrows.[85]

a. For example, the dotted arrow between "tax on pesticides" and "pesticide use rate" suggests that, as taxes on pesticides increase, pesticide use decreases. The solid arrow between "pesticide use rate" and "fresh water contamination" suggests that, as pesticide use increases, fresh water contamination also increases. Those relationships jointly suggest that as taxes on pesticides increase, fresh water contamination decreases.

(a)



[85] Heather Tallis et al., *Bridge Collaborative Practitioner's Guide: Principles and Guidance for Cross-Sector Action Planning and Evidence Evaluation* (The Nature Conservancy, 2017), https://hdl.handle.net/10161/26486.

(b)

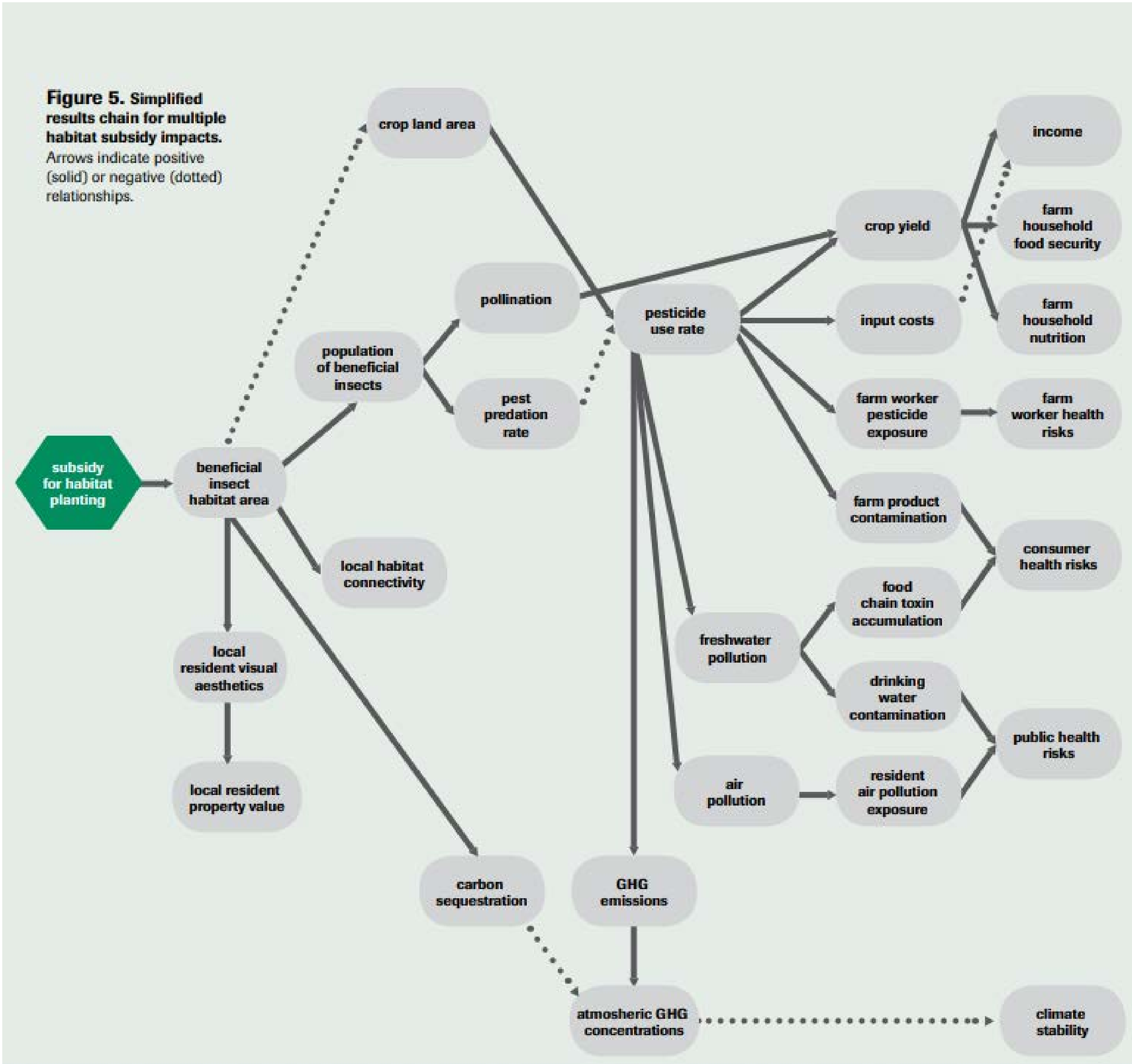


Figure 5. Simplified results chain for multiple habitat subsidy impacts.
Arrows indicate positive (solid) or negative (dotted) relationships.
subsidy for habitat planting
beneficial insect habitat area
crop land area
population of beneficial insects
pollination
pest predation rate
local habitat connectivity
local resident visual aesthetics
local resident property value
carbon sequestration
GHG emissions
atmosheric GHG concentrations
climate stability
pesticide use rate
crop yield
input costs
farm worker pesticide exposure
farm product contamination
food chain toxin accumulation
drinking water contamination
freshwater pollution
air pollution
resident air pollution exposure
income
farm household food security
farm household nutrition
farm worker health risks
consumer health risks
public health risks

(5) Conceptual model regarding natural resources management in Kenya.[86]

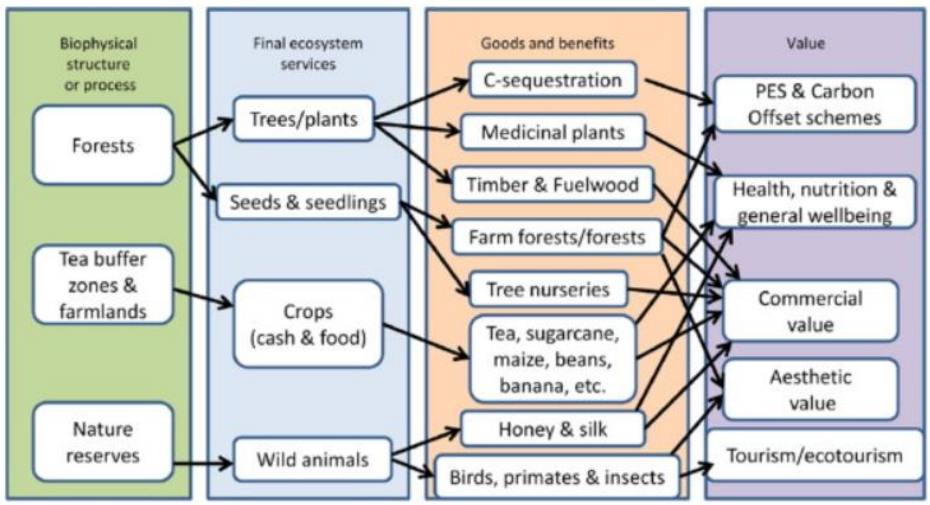
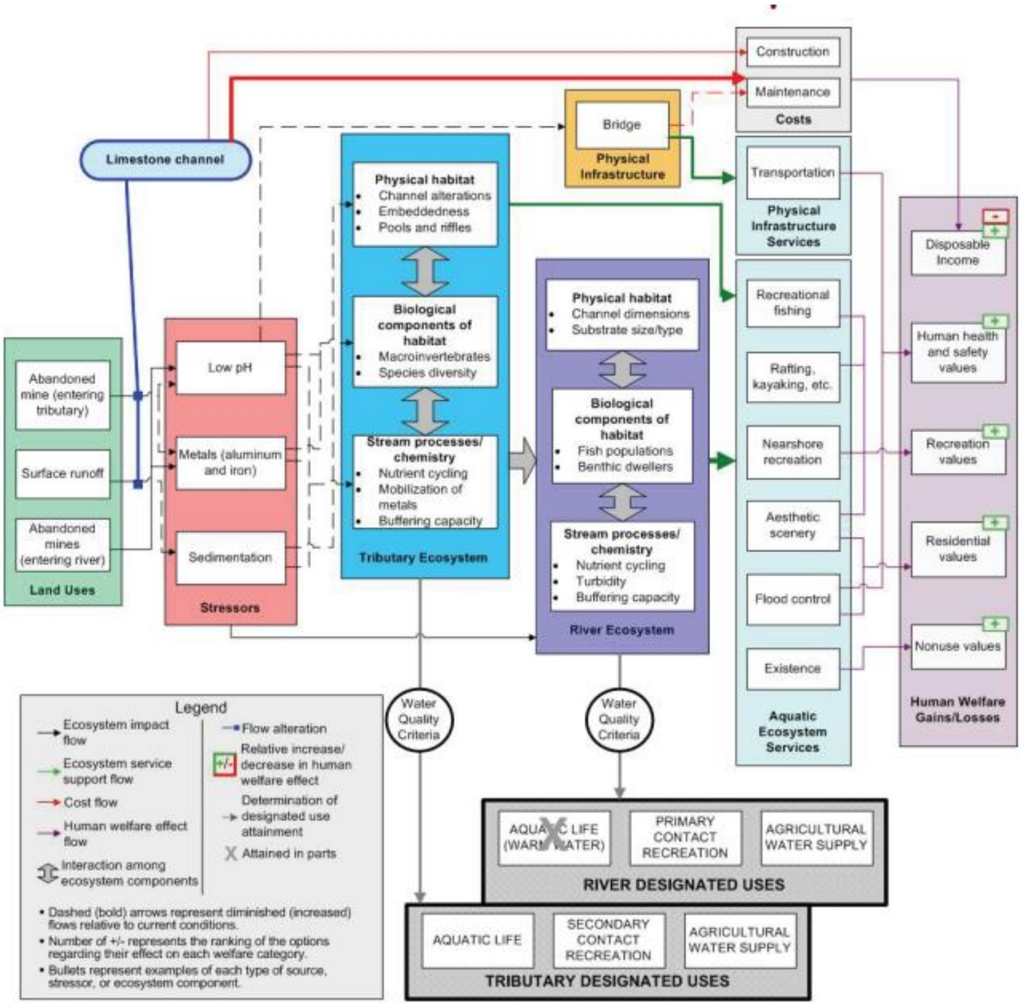


Fig. 2. The cascade redrawn by the case study from the Kakamega Forest Ecosystem, Kenya (CS#24), (source: EU FP7 OpenNESS Project Deliverable 5.1, see Dick and Turkelboom, 2013).

[86] Marion Potschin-Young et al., "Understanding the Role of Conceptual Frameworks: Reading the Ecosystem Services Cascade," *Ecosystem Services* 29, part C (2018): 428-440.

(6) Conceptual model regarding creating a limestone channel to mitigate acid mine drainage impacts on a tributary and river.[87]



Useful References:

Sara Mason, Rachel Karasik, and Lydia Olander, *Workshop Guide: Using Facilitation Techniques to Integrate Ecosystem Services into Coastal Management Decisions* (Nicholas Institute for Environmental Policy Studies, 2019), https://hdl.handle.net/10161/26482 [Reference includes example workshop agendas and worksheets].

Lydia Olander et al., *Building Ecosystem Services Conceptual Models* (National Ecosystem Services Partnership Conceptual Model Series No. 1., 2018), https://nicholasinstitute.duke.edu/conceptual-model-series.

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[87] Environmental Protection Agency, *A Framework Incorporating Community Preferences in Use Attainment and Related Water Quality Decision-Making* (2010): Figure 3-6, https://nepis.epa.gov/Exe/ZyPDF.cgi/P100U1LA.PDF?Dockey=P100U1LA.PDF.

Jiangxiao Qiu et al., “Evidence-Based Causal Chains for Linking Health, Development, and Conservation Actions,” *BioScience* 68, no.3 (2018): 182-193.

Heather Tallis et al., “Aligning Evidence Generation and Use Across Health, Development, and Environment,” *Current Opinion in Environmental Sustainability* 39 (2019): 81-93.

Carl Walters, *Adaptive Management of Renewable Resources* (Macmillan Publishing, 1986).

Appendix III: Avoiding Potential Accounting Pitfalls—Hypothetical Examples

This appendix consists of two hypothetical example scenarios that are designed to help you better understand how to analyze ecosystem services in practice.

III(a) Hypothetical #1: Clarifying Land Titles

Suppose the Republic of Ringstoria's Inheritance Property Restoration Administration (IPRA) implements, through regulation, a program that helps resolve unclear land ownership by farmers (where some of the lack of clarity is attributable to past discriminatory practices by the Ringstorian government). Addressing lack of clear title to land could generate benefits through multiple channels. For starters, farmers whose property titles become clear would experience enhanced incentives and opportunities (e.g., due to greater access to credit markets) to upgrade equipment and production practices on their farms; IPRA estimates that affected farms would generate an additional $11 million in profit annually. Moreover, lack of clear title can be a barrier to participation in Ringstorian programs that address negative environmental externalities, including one that pays farmers to replace agricultural production with native cover on ecologically sensitive land (Flora$ense); the baseline situation harms ecosystem services because participation in the program is artificially limited to a relatively small pool of candidate farms. As of an early stage in the development of its property title regulation and accompanying analysis, IPRA is preliminarily able to estimate:

- how much the Flora$ense pool would increase as a result of the lending title clarity program; and
- downstream effects in two Ringstorian territories where there is no agricultural production and thus no eligibility for Flora$ense:
    - in the territory called Northwest Jurrilsburg, a $7 million ecosystem services benefit per year, and
    - in the territory called Southeast Jurrilsburg, a $5 million transfer per year, associated with reduced flood-insurance payments under the Southeast Jurrilsburg Disaster Insurance Program (SEJDIP).

Benefits of Hypothetical Program to Clarify Property Titles (Preliminary Estimates)

	Year 1	Year 2	…	Year 40
Farmer Profits	$11M	$11M	…	$11M
Ecosystems Services in Northwest Jurrilsburg (Downstream Territory)	$7M	$7M	…	$7M
Total	$18M	$18M	…	$18M

Further analysis allows IPRA to also estimate a $400 million *net* increase in property values across the mainland of Ringstoria (including watersheds that are characterized by expanded Flora$ense activity *and* watersheds characterized by less such activity as program spending shifts across farms). Although both the $400 million and $11 million estimates are informative, they should not be added together because they (or subtotals within them) represent two manifestations of the same phenomenon; in other words, increased profitability of farmland that remains in production and increased farmer internalization of ecosystem-service benefits due to on-farm conservation practices are reflected in the $11 million profit effect and are also components of what raises (by $400 million) the value of property that includes the farms, so summing both types of estimates would constitute double-counting.

Benefits of Hypothetical Program to Clarify Property Titles (Later Estimates)

	Year 1	Year 2	…	Year 40
Mainland Ecosystem Services and Farmer Profits	$400M	$0M	…	$0M
Ecosystems Services in Northwest Jurrilsburg (Downstream Territory)	$7M	$7M	…	$7M
Total	$407M	$7M	…	$7M

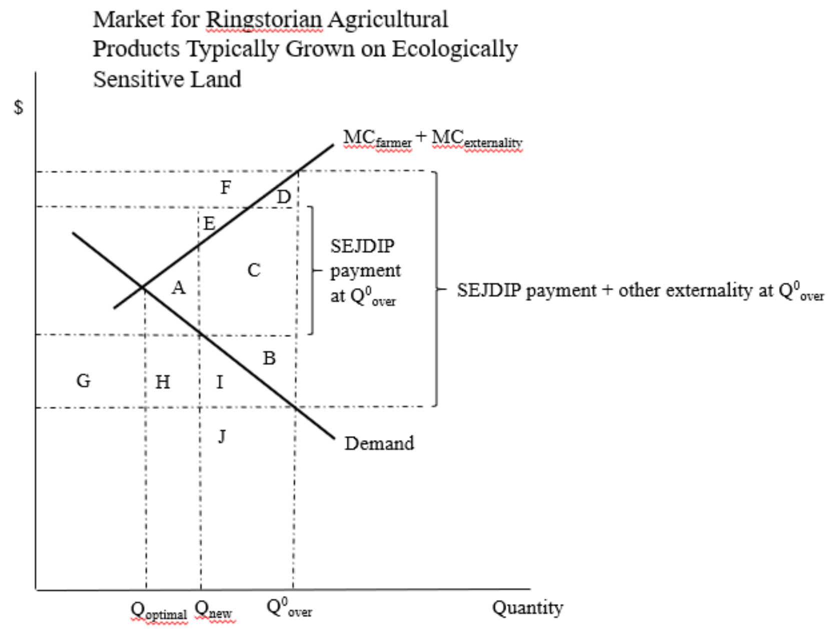
Expansion of the pool of farms that are candidates for the Flora$ense program would lead, according to IPRA's estimates, to more participating acreage even without any change to the program's budget. IPRA also observes that the SEJ Disaster Insurance Program does not set its premiums to account for downstream effects; instead, its actuarial models capture only expected losses on farmers' own property. Accordingly, refinements to IPRA's regulatory analysis include modeling of marginal effects using the figure below. It depicts a market for the types of agricultural products that Ringstorian farmers typically grow on ecologically sensitive land; along with consumer demand, the diagram includes a marginal cost (MC) curve that encompasses both farmer costs and downstream externalities. Due to these externalities, the amount of agricultural production (Q^0_{over}) is expected to exceed the social optimum ($Q_{optimal}$). The regulation-induced reduction of agricultural production on ecologically sensitive land would decrease the size of the deadweight loss wedge, from A+B+C+D to A, for an overall societal gain of B+C+D. Of this gain, C accrues to the taxpayers who are now funding less-extensive SEJDIP payments (noted above to be $5 million per year), while B+D is most intuitively thought of as accruing to individuals who now experience reduced off-site externalities that are not captured by the $5 million SEJDIP flood estimates.[88] As a result of the analytic refinements, IPRA staff now recognize that the $5 million effect that they have been able to quantify belongs in the benefits category for the regulatory analysis, rather than the transfer category, where it appeared in the preliminary accounting.[89]

Benefits of Hypothetical Program to Clarify Property Titles (Even Later Estimates)

	Year 1	Year 2	…	Year 40
Mainland Ecosystem Services and Farmer Profits	$400M	$0M	…	$0M
Ecosystems Services in Northwest Jurrilsburg (Downstream Territory)	$7M	$7M	…	$7M
Ecosystems Services in Southeast Jurrilsburg (Downstream Territory)	$5M	$5M	…	$5M
Total	$412M	$12M	…	$12M

[88] It is possible, depending on the mechanism whereby the regulation decreases agricultural production, that some form of value pass-through occurs, in which case at least a portion of these benefits ultimately accrue to direct participants in the market.

[89] Shifts of value among Ringstorian consumers, farmers, taxpayers, and individuals experiencing off-site externalities—associated with areas E, F, G, H, I and potentially a subset of J—would depend on the details of the regulatory mechanism, the SEJDIP actuarial model, and other market conditions, which would in turn affect agricultural prices.



III(b) Hypothetical #2: Housing Grant Programs and Urban Ecosystem Services

The Ringstorian Housing and Neighborhood Administration (RHNA) operates a grant program in which funds may be used to improve living and environmental conditions for low- and moderate-income households. Recipients are local governments or provinces.

Although the program's governing regulation does not anticipate green infrastructure as a substitute for built infrastructure, there are multiple possible avenues to allocate funds for this purpose:

- Housing: rehabilitation of residential, low-income rental or homeowner housing, including energy improvements and water efficiency improvements; activities that support new housing construction such as acquisition, clearance, site improvements, and street improvements.
- Public facilities: acquisition, construction, reconstruction, rehabilitation, or installation of public improvements or public facilities. "Public improvements" include, but are not limited to, improvements to streets, sidewalks, water and sewer lines, and parks.

Operating and maintenance expenses (of public facilities, improvements, and services) are ineligible. However, green infrastructure projects are not normally a once-and-done type of activity; they usually require periodic maintenance to continue providing their intended goods and services. Ongoing costs of bringing the project to the benefits-generation stage would need to be authorized by regulatory change.

Grant recipients have up to five years to expend funds. Further regulatory change would be needed to allow for longer-term use of funds for developing and maintaining green infrastructure, and this possibility is explored in the regulatory alternatives discussed below.

Alternative 1: Five-Year Expenditure Requirement

This alternative would feature the program changes described above but would maintain the requirement that funds be spent within five years. With this regulatory alternative, some grantees that are motivated by climate change considerations are expected to newly provide cooling centers that vulnerable residents could use when heat becomes extreme.[90]

Alternative 2: Twenty-Year Expenditure Requirement

This alternative would feature program changes in which grants may be awarded if applicants can point to evidence of community accomplishments likely to be achieved within twenty years. With this regulatory alternative, some grantees are expected to newly install green infrastructure projects, with a particular focus on including tree planting to help cool urban areas and reduce heat extremes (this is an example of a nature-based solution).[91] Trees may need to be replaced from time to time during the twenty-year expenditure period.

Self-test

Prior to proposing changes to the grant program, RHNA receives the comments listed below. ***Should RHNA incorporate this feedback into its regulatory benefit-cost analysis, and, if so, should there be any deviations from the jurisdictions' analytic suggestions?*** [Hint: Review Step 4, on aggregation of benefits and costs, in the above guidance. See if you can identify problems embedded in the following comments; answers will be provided at the end.[92]]

Comment 1:

The city of Arborima states that, if Alternative 2 for the new RHNA rule is finalized and Arborima's grant application is successful in the upcoming award cycle, the funding would be used for a tree-planting program. Citing a credible model that has, among its inputs, a peer-reviewed hedonic housing study, the city estimates a 0.5% increase in home values attributable to new tree coverage that is characterized by the volume, placement, and species mix that Arborima has in mind. The city's housing stock is worth roughly $10 billion, and the average time period between home sales is seven years (and the comment provides enough specificity for these estimates to seem credible). As a result, Arborima suggests that RHNA's RIA should include a benefit line item of $50 million in approximately Year 1, Year 8, Year 15, etc.

Comment 2:

The township of Stumples Cove is downwind from Arborima. Citing a credible model that has, among its inputs, a peer-reviewed hedonic housing study, the township estimates a 0.1% increase in home values attributable to the new tree coverage that its neighboring jurisdiction has in mind; applied to the $20 billion value of Stumples Cove's housing stock yields a $20 million benefit line item for Alternative 2. However, given its downwind position, the township also points out that the increased cost of leaf

[90] Stasia Widerynski et al., *The Use of Cooling Centers to Prevent Heat-Related Illness: Summary of Evidence and Strategies for Implementation* (Climate and Health Technical Report Series, 2017), https://www.cdc.gov/climateandhealth/docs/UseOfCoolingCenters.pdf.

[91] The Trust for Public Land, *The Heat Is on* (2020), *https://www.tpl.org/wp-content/uploads/2020/09/The-Heat-is-on_A-Trust-for-Public-Land_special-report_r1_2.pdf*.

[92] The errors listed in the answer box should be avoided both in RHNA's regulatory analysis and in any benefit-cost analyses conducted by the jurisdictions (e.g., if required as part of their grant applications).

collection and disposal, estimated to be $4 million per year, would be attributable to the regulatory action.

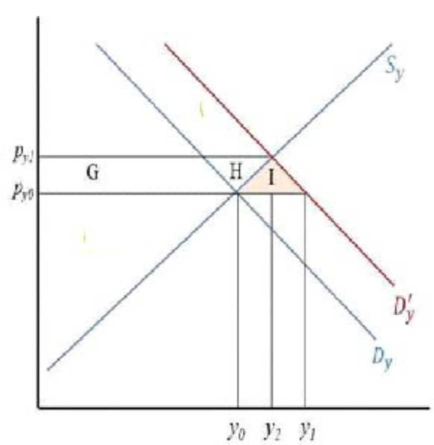
Comment 3:

The village of Boxneau is adjacent to both Arborima and Stumples Cove. Citing the same study as the latter community, Boxneau estimates a 0.1% increase in its own home values attributable to the new tree coverage that Arborima has in mind; applied to the $700 million annual rental value of Boxneau's housing stock yields a $0.7 million annual benefit line item for Alternative 2. Moreover, using a peer-reviewed travel cost model, Boxneau estimates that its residents will spend an additional $5 million per year visiting Arborima's new and improved green spaces. Boxneau notes that summing the $0.7 million and $5 million results would be double-counting, instead suggesting that they be presented as two different methodological contributions to a range of benefits estimates.

Comment 4:

The county of San Cinemato indicates an interest in applying for future program awards. If the application were to succeed, the county would follow a mixed strategy, with existing senior-citizen cooling facilities—which are located near population centers and currently admit individuals age 60 and above during extreme heat events—being newly restricted to residents age 65 and above (to ease overcrowding, which has become a noteworthy concern in light of the COVID-19 pandemic). Meanwhile, new county parks and all-ages cooling facilities would be established in more remote parts of the county. San Cinemato uses a travel cost model to assess the benefits of the new facilities that would come into being but also some costs of its suite of policy changes. More specifically, the county acknowledges that individuals who are currently between the ages of 60 and 64 would newly need to travel to relatively distant cooling centers during extreme heat events. The county estimates that this cost will decline to 80% of its Year 1 amount in Year 2, 60% of its Year 1 amount in Year 3, and so forth, until reaching $0 in Year 6, by which time all current 60- to 64-year-olds will reach age 65 and thus be eligible to resume using the nearby cooling facilities.

Comment 5:



The island community of Isiyiska is near San Cinemato. If San Cinemato expands parks and opens new cooling centers, the island expects its beach resorts to lose business—an effect that is, as Isiyiska notes, omitted from San Cinemato's partial-equilibrium analysis of its own likely experience with Alternative 2.

Isiyiska models its own experience as a decrease in beach-resort demand from D'_y to D_y, with Isiyiska's loss of surplus (combining producer and consumer surplus) represented by the area marked as A+H in the diagram above.

Responses to Comments

Comment 1: Arborima's suggestion contains a stock-flow error. The $50 million estimated benefit would appropriately be included in Year 1 but not in subsequent years.

Comment 2: Stumples Cove does not cite any reason why the cost of leaf collection and disposal would not be captured in the reduced-form estimate of increased property value. In other words, the $20 million estimated benefit implicitly includes a gross increase in property value that exceeds $20 million, *along with* a $4 million annual cost; including the $4 million cost in the regulatory analysis would therefore be a double-counting error.

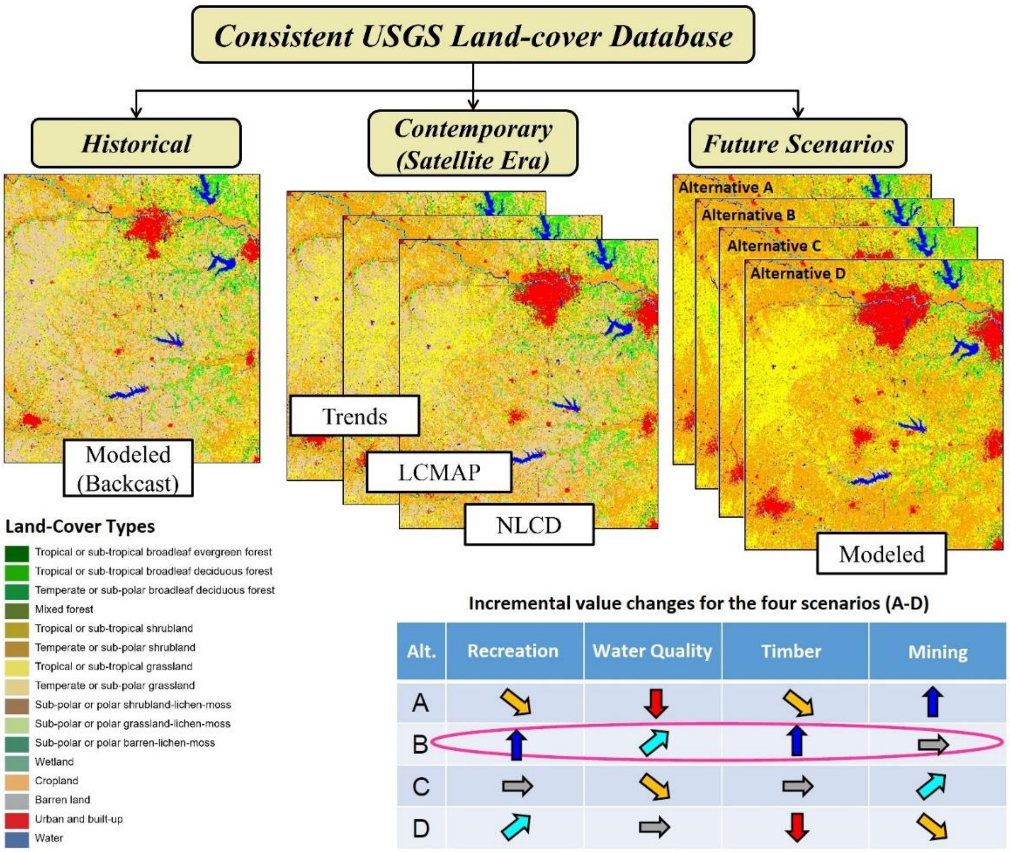
Comment 3: The $5 million estimate provides both a lower bound on Boxneau's residents' willingness-to-pay for the new tree coverage in Arborima *and* an estimate of a new cost attributable to the policy alternative that makes Arborima a more appealing travel destination; considering both aspects of the $5 million amount yields a lower-bound net-benefits estimate of zero. In other words, if $X is the cost estimate that would be appropriately compared with the $0.7 million benefits estimate (or a benefits total for which the $0.7 million amount is an addend), then $X + $5 million is the cost estimate that would be appropriately compared with the $5 million benefits estimate (or a benefits total for which the $5 million amount is an addend). Adding greater detail to the travel cost model would be necessary for it to generate an estimate that would be meaningfully included in a summary range with the $0.7 million benefits estimate generated using the hedonic approach.

Comment 4: Although the cost to *current* 60- to 64-year-olds may reasonably be expected to follow the pattern suggested by San Cinemato (declining to 80% of its Year 1 amount in Year 2, 60% of its Year 1 amount in Year 3, and so forth, until reaching $0 in Year 6), this estimation approach would inappropriately omit costs to individuals who age into the 60- to 64-year range.

Comment 5: Isiyiska consumer surplus effects should be tracked with a visual focus on the pre-shifted demand curve, yielding a consumer surplus gain of G; area A can be ignored because the consumers who have departed from the Isiyiska market have had their welfare effects tracked in the analysis focusing on San Cinemato. Overall, with a consumer surplus gain of G and a producer surplus loss of G+H, there would be an Isiyiska social loss of H. A useful resource in addressing this type of analytic issue would be Richard E. Just, Darrell L. Hueth, and Andrew Schmitz, *The Welfare Analysis of Public Policy* (2004).

Appendix IV: Mapping Ecosystem-Service Endpoints

Figure A.IV-1. Land-use/land-cover scenarios. *Many ecosystem services considerations can be analyzed using different land-use/land-cover (LULC) scenarios. This figure shows the distribution of land cover types in a hypothetical landscape at the present point in time and in four different alternative land-use scenarios at a future point in time, including a baseline scenario. Programs can use process-based models or transfer functions to calculate output levels for different ecosystem services and for other economic activities of interest for each alternative and then identify the alternative that maximizes total value. In this hypothetical example, Alternative B is the net benefit maximizing scenario. This figure is adapted from the U.S. Geological Survey's (USGS) Land Change Monitoring, Assessment, and Projection (LCMAP) program; NLCD refers to the National Land Cover Database.*[93]



Case studies in the ecosystem-service literature highlight the utility of geographic information systems (GIS) for quantifying ecosystem-service changes.[94] These studies typically quantify the provision of different ecosystem services within a region based on the presence, condition, and interactions of

[93] U.S. Geological Survey, *LCMAP Projects Possibilities for Future Land Cover Change* (2019), https://www.usgs.gov/news/lcmap-projects-possibilities-future-land-cover-change. National Land Cover Database (2018), https://www.usgs.gov/centers/eros/science/national-land-cover-database.

[94] For general background on ecosystem service GIS tools, see Ignacio Palomo et al., "Tools for Mapping ecosystem Services," in *Mapping Ecosystem Services*, ed. Benjamin Burkhard and Joachim Maes (Pensoft Publishers, 2017): 70-74. For background on efforts to operationalize ecosystem service assessments using map-based tools, see 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.

particular land-use or land-cover (LULC) types and additional landscape and social features.[95] Different LULC types can represent aspects of socio-ecological systems that interact with each other and with other conditions to provide different services or different amounts of a given service across landscapes.[96] LULC maps, one source of data used in these types of models, can be generated by categorizing (i.e., binning) pixel values in digital (raster) images, such as remotely sensed satellite or aerial photographs. Note, however, that ecosystem services may vary in different locations due to factors not captured by LULC maps alone.[97] The relationship between LULC and service provision can also be non-linear, and can be affected by LULC parcel configuration, parcel connectivity, and other landscape ecology factors, as well as differences in built and social systems that affect servicesheds with respect to human beneficiaries.

Changes in LULC can be one source of information used to estimate changes in some ecosystem services. Landscape image timeseries (e.g., Landsat) allow observers to document such LULC changes over time and contribute to estimation of changes in some ecosystem services. This kind of monitoring also facilitates future scenario projection. In many cases, landscapes evolve in ways that can be anticipated, with particular LULC types replacing others in a given region.[98] Geospatial analysts can use observed trends in landscape timeseries to extrapolate LULC changes into the future under a business-as-usual scenario or under scenarios representing different policy alternatives. After estimating the output levels for different ecosystem services in each of several future scenarios, program analysts can compare the scenario results and quantify potential tradeoffs that will result from selecting a particular scenario (Figure A.IV-1).[99] It is generally useful for agencies to undertake this kind of analysis for actions that codify—or are expected to result in—a specific, spatially explicit LULC scenario (e.g., actions intended to facilitate a specific Land-use or Forest Management Plan outcome). A variety of existing tools facilitate this kind of monitoring, landscape projection, and alternatives analysis, including the Land Change, Monitoring, Assessment, and Projection (LCMAP) products from the U.S. Geological Survey (USGS).[100]

In cases where a regulation is expected to result in LULC changes, but the timing and precise locations of changes are uncertain, agencies can generate and compare possible LULC configurations using geospatial tools. Many regulations fall into this category. Examples include Department of the Interior actions that either increase or decrease stringency for particular land-use permits and Department of Agriculture actions that codify grant programs that incentivize particular land management actions by

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[95] Prominent examples include: 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 (2009): 4-11; Christina M. Kennedy et al., "Bigger is Better: Improved Nature Conservation and Economic Returns from Landscape-Level Mitigation," *Science Advances* 2, no. 7 (2016): e1501021.

[96] For example, the Environmental Protection Agency's EnviroAtlas has data layers created from interactions between LULC, such as percentage of roads buffered by vegetation or acres of pollinated crops with no nearby pollinator habitat. Environmental Protection Agency, *EnviroAtlas* (2023), *https://www.epa.gov/enviroatlas*.

[97] See, for example, Xiaojia Han et al., "Spatiotemporal Evolution of Ecosystem Service Values in an Area Dominated by Vegetation Restoration: Quantification and Mechanisms," *Ecological Indicators* 131 (2021): 108191.

[98] Note, however, that LULC changes may also be non-linear. See Abera Assefa Biratu et al., "Ecosystem Service Valuation Along Landscape Transformation in Central Ethiopia," *Land* 11, no. 4 (2022): 500.

[99] Maximizing one service on the landscape may diminish the provision of others. 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.

[100] USGS LCMAP products are available at: https://www.usgs.gov/special-topics/lcmap.

private landowners. The agency can account for this uncertainty by generating multiple, hypothetical LULC scenarios. Possible LULC changes can be randomly distributed on the landscape or distributed according to clearly specified assumptions, as appropriate. The resulting comparisons provide both order-of-magnitude estimates for possible ecosystem services and information on estimate sensitivities.