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

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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 the rule affect or involve INFRASTRUCTURE?		Human Welfare Endpoints					
Aspect of infrastructure	**Possible causal pathways**	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-Use Values
Linear infrastructure (e.g., pipelines)	Can block movement of wildlife, reducing opportunities for viewing.	(-)	(-)				
	Can reduce surface flow, lowering water supplies for recreation, drinking, hydropower, and irrigation, and reduce home values.	(-)	(-)	(-)			
Transportation infrastructure (e.g., roads)	Can increase access for and amenities from recreation. 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 and 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 and 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 these.	(-/+)	(-/+)	(-/+)	(-/+)		
	Can remove natural vegetation, harden surfaces, increase flooding, and reduce nature exposure. Nature-based solutions improve infiltration, and reduce flooding and 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 the rule affect or involve WILDLIFE OR RECREATION?		Human Welfare Endpoints					
Aspect of wildlife or recreation	**Possible causal pathways**	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-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)	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, and irrigation, and can reduce home values.	(-)	(-)	(-)			
Transportation infrastructure (e.g., roads)	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 and 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 and 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, and decreasing real estate value. Nature-based solutions improve.	(-/+)	(-/+)	(-/+)	(-/+)		
	Can remove natural vegetation, harden surfaces, increase flooding, and reduce nature exposure. Nature-based solutions improve infiltration, and reduce flooding and stormwater costs.	(-/+)				(-/+)	
	Can damage habitat of species of commercial, recreational or public interest value (e.g., traffic and windows kill animals) or improve habitat (e.g., water treatment wetlands).	(-/+)	(-/+)	(-/+)			(-/+)

Does the rule affect or involve ENERGY PRODUCTION? Human Welfare Endpoints

Aspect of energy production	Possible causal pathways	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-Use Values
Linear infrastructure (e.g., pipelines)	Can block movement of wildlife, reducing opportunities for viewing.		(-)				
	Can reduce surface flow, lowering water supplies for recreation, drinking, hydropower, and irrigation, and reduce 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, and release greenhouse gases. Renewable energy fleets reduce air pollution and greenhouse gases.					(+/-)	
Construction and maintenance	Clearing land and using cement releases greenhouse gases.	(-)	(-)	(-)		(-)	
	Can remove or damage habitat for native pollinators and pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same.	(-/+)		(+/-)			
	Can cause erosion and remove vegetation that cleans water, causing pollution, raising costs and 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, and reduce nature exposure. Nature-based solutions or use of already converted sites can maintain or improve infiltration, and reduce flooding and stormwater costs.	(-/+)			(-/+)	(-/+)	
	Can damage habitat of species of commercial, recreational, or public interest value (e.g., traffic and 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 it 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	Pollutes soil and water, lowering land values, making waters less attractive for recreation, increasing drinking water costs, and damaging species that provide timber and fish products.	(-)	(-)	(-)			
Cooling water	Changes temperature of rivers and oceans, damaging habitat for species of commercial or recreational value or public interest.		(-)	(-)			(-)
Equipment operation, cement	Directly releases 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 the 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**	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-Use Values
Land clearing, harvest, or management	Can remove or damage habitat for native pollinators and pest control species, reducing agriculture productivity and increasing costs. Can incorporate native habitat, boosting same.	(+/-)		(+/-)			
	Can remove native vegetation and release greenhouse gases. Sustainable forestry and restoration can reduce greenhouse gases.	(+/-)	(+/-)	(+/-)		(+/-)	
	Can remove and damage natural vegetation, harden surfaces, and increase flooding. Nature-based solutions improve infiltration and 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 and parks that support physical activity and provide mental health benefits. Incorporation of native habitat can improve.		(+/-)		(+/-)	(+/-)	
	Can cause erosion and remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, and 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 and 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 and 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, and release greenhouse gases. Renewable energy fleets reduce air pollution and 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 and wastes pollute water, reducing recreation opportunities and harming species of public interest. Restorative aquaculture improves water quality.	(+/-)	(+/-)	(+/-)			
	Disease escapes and harms native species of recreational, commercial, or public interest value.		(-)				(-)

Aspect of disaster mitigation or risk reduction	**Possible causal pathways**	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-Use Values
Construction of protective infrastructure	Clearing land and using cement releases greenhouse gases and other air pollutants. Nature-based options sequester greenhouse gases.						
	Can remove or damage habitat for native pollinators and pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same.	(-/+)		(-/+)			
	Can cause erosion and remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, and decreasing real estate value. Nature-based solutions alleviate.	(-/+)	(-/+)	(-/+)			
	Can remove natural vegetation, harden surfaces, increase flooding, and reduce nature exposure. Nature-based solutions improve infiltration, and 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 amenities, and weakening physical and mental health. Restoring greenspace can benefit same.	(-/+)	(-/+)		(-/+)	(-/+)	

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

Aspect of labor or education	Possible causal pathways	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-Use Values
Work environment	Removal of trees and 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, and built vs. natural solutions, changing willingness to pay.	(-/+)	(-/+)	(-/+)			(-/+)
Construction and maintenance of work or education facilities	Clearing land and using cement releases greenhouse gases and other air pollutants. Nature-based options sequester greenhouse gases.	(+/-)	(+/-)	(+/-)		(+/-)	
	Can remove or damage habitat for native pollinators and pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same.	(-/+)		(+/-)			
	Can cause erosion and remove vegetation that cleans water, causing pollution, raising costs, and decreasing real estate value. Nature-based solutions improve.	(-/+)	(-/+)	(-/+)	(-/+)		
	Can remove natural vegetation, harden surfaces, increase flooding, and reduce nature exposure. Nature-based solutions improve infiltration, and reduce flooding and stormwater costs.	(-/+)				(-/+)	
	Can damage habitat of species of commercial, recreational, or public interest value (e.g., traffic and 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.		(-/+)		(-/+)	(-/+)	

Aspect of vehicle fleets	Possible causal pathways	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-Use Values
Construction of parking, storage or transfer facilities	Pavement and impermeable surfaces can increase flooding and stormwater costs. Permeable and nature-based options reduce flooding and costs.						
	Can cause erosion and remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, and decreasing real estate value. Nature-based solutions alleviate.	(-/+)	(-/+)	(-/+)			
	Can remove or damage habitat for native pollinators and pest control species, reducing agriculture productivity or increasing costs and 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 and releases greenhouse gases. Electric vehicle use avoids emissions if electricity is from renewable sources.	(-/+)	(-/+)	(-/+)		(-/+)	

Does the rule affect or involve HOUSING?		Human Welfare Endpoints					
Aspect of housing	**Possible causal pathways**	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-Use Values
Construction of housing	Clearing land for housing facilities and 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 and pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same.	(-/+)		(-/+)			
	Can cause erosion and remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, and decreasing real estate value. Nature-based solutions and redevelopment can alleviate.	(-/+)	(-/+)	(-/+)			
	Can remove natural vegetation, harden surfaces, increase flooding, and reduce nature exposure. Nature-based solutions improve same and redevelopment can avoid impacts.	(-/+)			(-/+)	(-/+)	
	Can damage habitat of species of commercial, recreational, or public interest value or improve habitat. Redevelopment can avoid impacts, and restoring or improving habitat can benefit same.	(-/+)	(-/+)	(-/+)			(-/+)
	Can remove habitat or greenspace, reducing recreation opportunity and 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 and 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, and release greenhouse gases. Renewable energy fleets reduce air pollution and greenhouse gases.	(-/+)	(-/+)	(-/+)	(-/+)	(-/+)	

Does the rule affect or involve WASTE MANAGEMENT?		Human Welfare Endpoints					
Aspect of waste management	**Possible causal pathways**	Amenity Value	Recreation/Leisure	Production	Mental Health	Physical Health	Non-Use Values
Construction of waste management or disposal sites	Clearing land for disposal facilities and 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 and pest control species, reducing agriculture productivity or increasing costs. Can improve native habitat, boosting same.	(-/+)		(-/+)			
	Can cause erosion and remove vegetation that filters water, leading to pollution, limiting water uses, raising costs, and decreasing real estate value. Nature-based solutions can alleviate.	(-/+)	(-/+)	(-/+)			
	Can remove natural vegetation, harden surfaces, increase flooding, and 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 and weakening physical and mental health. Restoring greenspace can benefit same.		(-/+)		(-/+)	(-/+)	
Waste disposal	Combustion of waste can cause air pollution and 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.

How to Build Conceptual Models

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 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 the environment (e.g., more trees help reduce stormwater runoff, improve residents' mental health, and provide habitat corridors for birds).

The process of developing these diagrams is usually iterative, evolving as new perspectives, evidence, and impacts are considered.[1] These diagrams can be used to inform not only the benefit-cost analysis of regulatory alternatives but also the selection of alternatives. See a sample of conceptual models below.

[1] 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*.

For regulatory analysis, building a diagram starts with clarifying regulatory alternatives (e.g., variations in the amount or degree of regulation, such as different pollutant standards). The diagram will illustrate what the selected alternatives 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, interdisciplinary 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.[2]

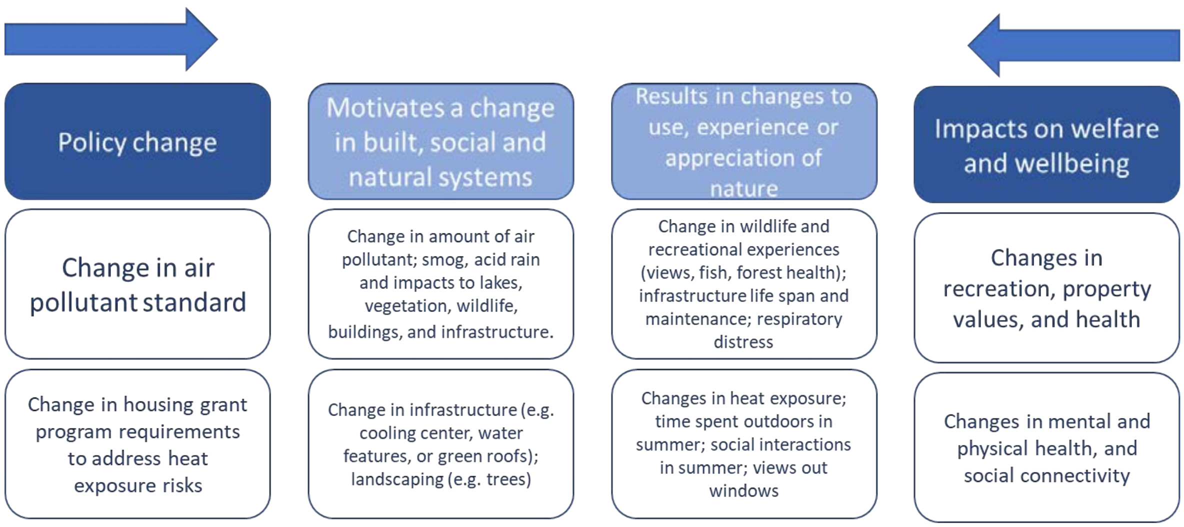
As a conceptual model is developed, it may be necessary to clarify the spatial and temporal scales of effects that should be considered (e.g., immediate effects of pesticide use on crop yields, and longer-term effects on downstream fish and commercial fishing products). If the conceptual diagram is used to design quantitative analysis, it is also useful to identify the metrics that will be estimated. In summary, the steps of building a conceptual model are:

1. Engage experts that can provide relevant information.
2. Identify the policy alternatives and how they will activate change.
3. Identify the expected and likely impacts of the policy alternatives 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) and list the policy's effects.
   - How will the intervention or action affect built systems like infrastructure (e.g., roads, pipelines, dams, and housing)?
   - How will the intervention or action affect social systems like behaviors, markets, or management (e.g., purchases, savings, investment, planning, community engagement, diet, energy use, harvest, or management approaches)?
   - How will the intervention or action affect natural systems (e.g., lands, waters, species, oceans, parks, climate, and nutrient cycles)?
   - How does each of these changes in built, social, and natural systems affect the provision of ecosystem goods and services, and related aspects of human welfare?

[2] 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* (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*.

When developing a model, it is often useful to work from both ends, starting with proposed alternatives and targeted objectives or expected outcomes, then filling in the middle, and then iterating to fill in gaps. Figure A.II-2 shows two examples that illustrate this idea. In the figure, policy alternatives and impacts on welfare are identified, helping to fill in the system changes that connect the two endpoints. Thinking through changes that result from policy can lead to additional impacts that were not planned for or anticipated. Note that these examples are only illustrative and not meant to be comprehensive.

Figure A.II-2. Creating ecosystem services conceptual models by working from both ends.



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 feed back 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[3] or likely magnitude of the effect between two boxes (e.g., 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).

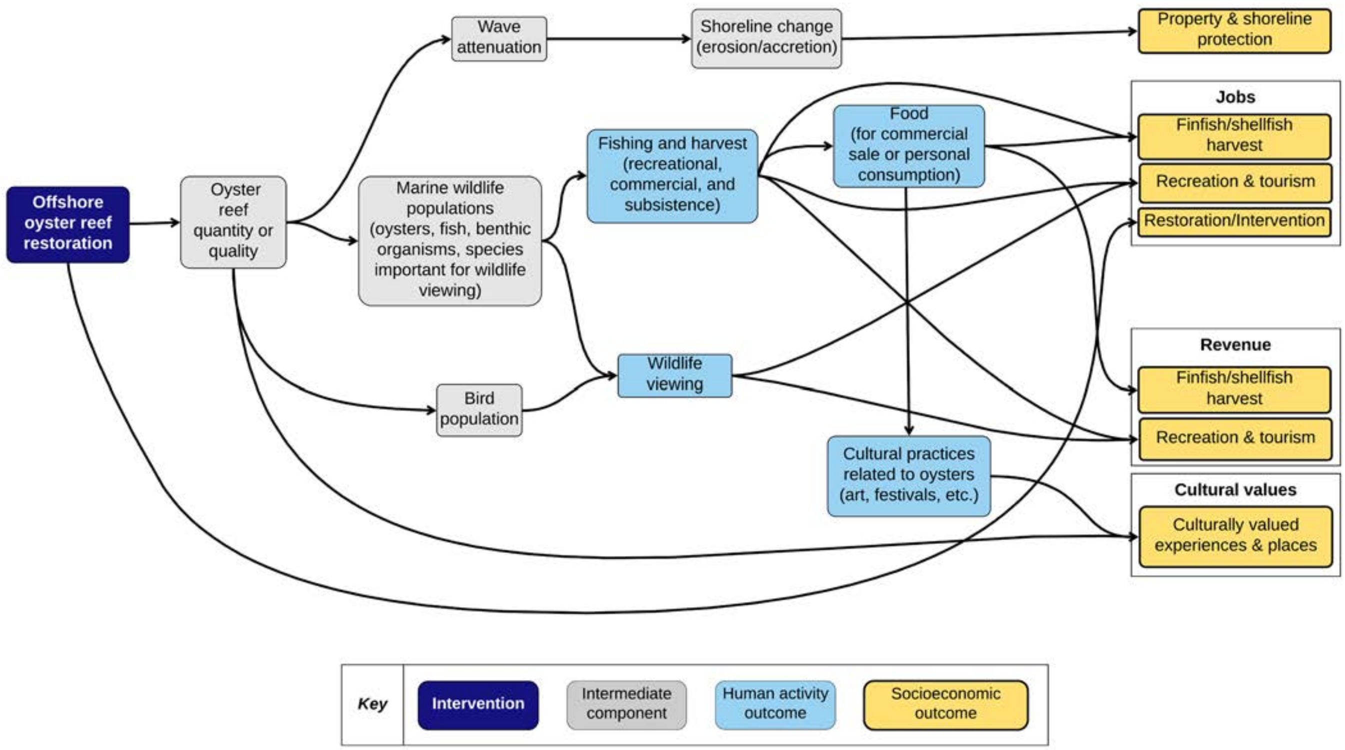
How to Use Conceptual Models to Support BCA

An example of a conceptual models for oyster reef restoration in the Gulf of Mexico shows how conceptual models can be used to think through ecosystem services effects, and identify the critical services that need to be included in the analysis. This example works backwards, starting with the simplified final model.

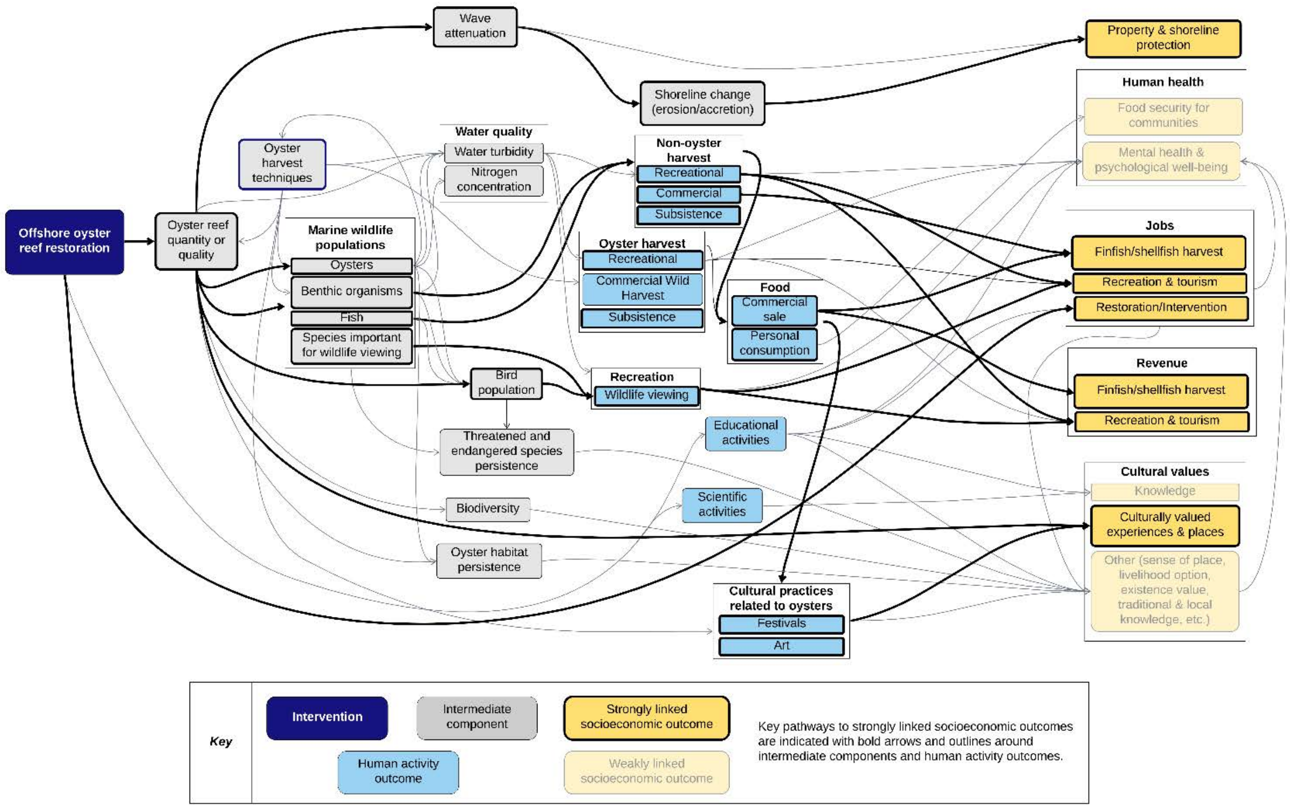
Figure **A.II-3a.** shows a simplified model that includes only the welfare outcomes that are expected to be significantly impacted by an alternative (e.g., a change in permitting rules) that will result in increased off-shore oyster restoration projects.[4] These are the only outcomes that need to be included in the benefit-cost analysis. This simple model was developed by first exploring all the possible outcomes of an increase in aquaculture projects resulting in a more complex version of the model (Figure A.II-3b), which was created from a general model for all types of oyster reef restoration developed for this region (Figure A.II-3c). Then the complex model was simplified based on a review of the science, and expert and local knowledge to identify which effects are likely to be significant. While this study used some different terms than this guidance, it captures similar ideas. This guidance would use the term “amenity value” where the study uses “property and shoreline protection”; and “production” where the study uses “revenue.” The study also includes “jobs” which are resulting in local income, which might be captured as a transfer rather than a benefit under this guidance (see Circular A-4 for more guidance on the challenges of jobs analysis).

[3] 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 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.
[4] Adapted from 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*.

(a) Simplified models for off-shore oyster restoration (complex structure with minimal oyster harvest) in the Gulf of Mexico showing only significant expected welfare Effects.

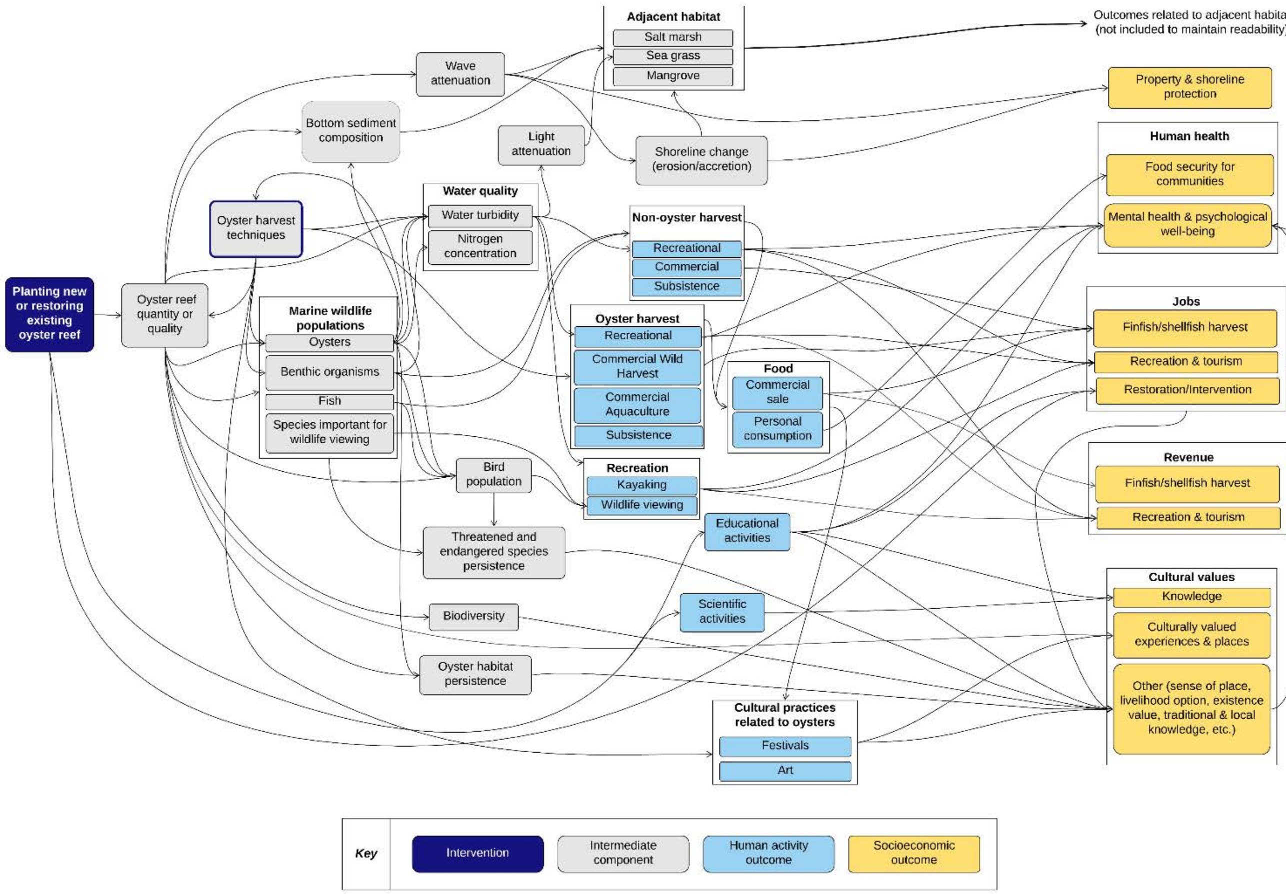


(b) More detailed off-shore oyster restoration model that highlights the most important pathways and outcomes with bold arrows and outlines.[5]



[5] Nicholas Institute for Energy, Environment & Sustainability, *Gulf of Mexico Ecosystem Service Logic Models & Socio-Economic Indicators (GEMS)*, https://nicholasinstitute.duke.edu/project/gems.

(c) General oyster reef restoration model that includes all different types or oyster restoration including reefs for harvest, reefs for habitat creation, intertidal or living shoreline reefs, reef protection, and aquaculture, that was used a starting point. [6]



[6] 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*.

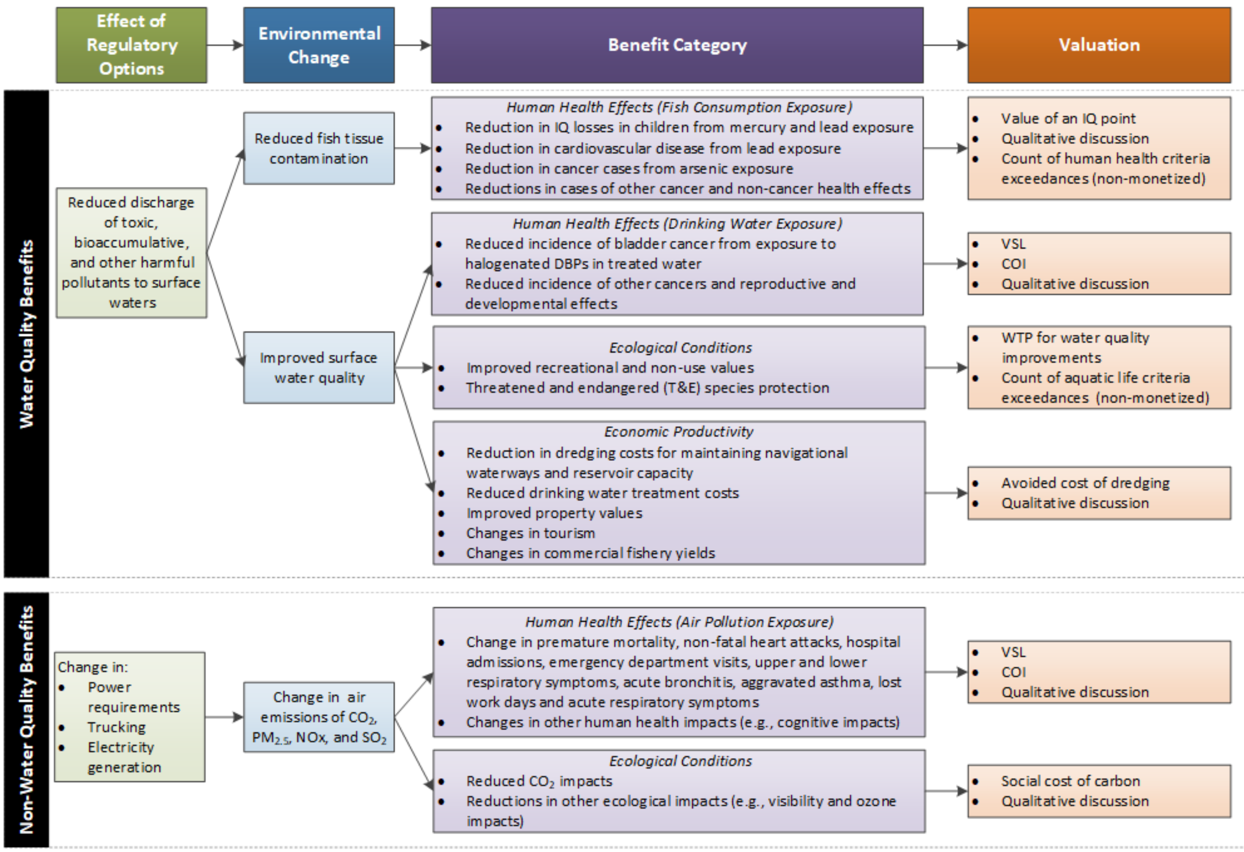
Conceptual models can also be a framework for systematically collecting and organizing evidence used to simplify and identify which outcomes need to be included in an analysis. Relevant evidence can include evidence regarding the hypothesized relationships in the model, factors that may significantly influence an assumed relationship, and information regarding confidence in the evidence. See Table A.II-1 for an example entry in an evidence library.

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).*

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.

Sample conceptual models:

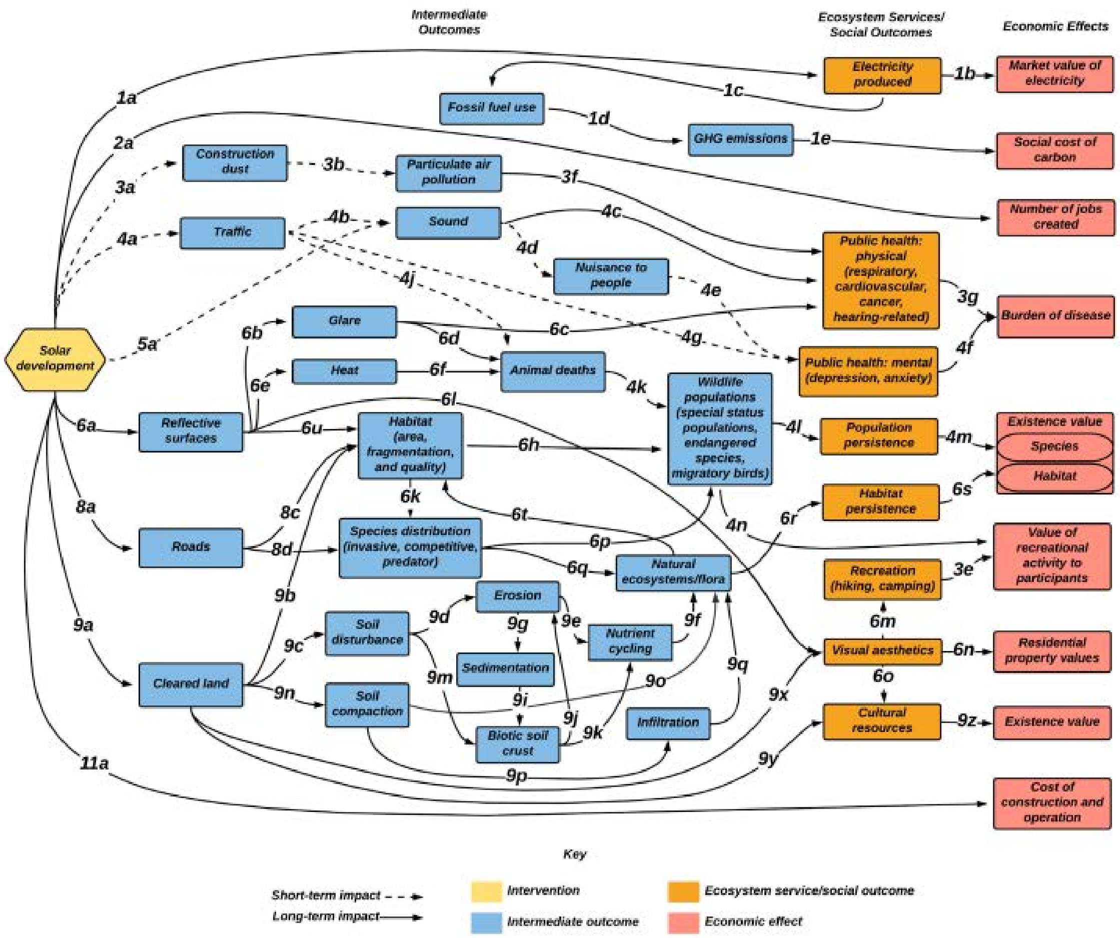
(1) Conceptual model for the Environmental Protection Agency's Benefit and Cost Analysis for Proposed Supplemental Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category.[7] This example only includes benefits, while an analysis following this guidance would include benefits, costs, and transfers, as relevant. This guidance also encourages exploration of expected environmental changes (included here) as well as expected social and built system changes that can affect ecosystem services and associated welfare.



DBP = Disinfection byproducts; WTP = Willingness to Pay; VSL = Value of Statistical Life; COI = Cost of illness

[7] 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 model for solar energy development on Bureau of Land Management (BLM) lands with insignificant effects removed.[8]



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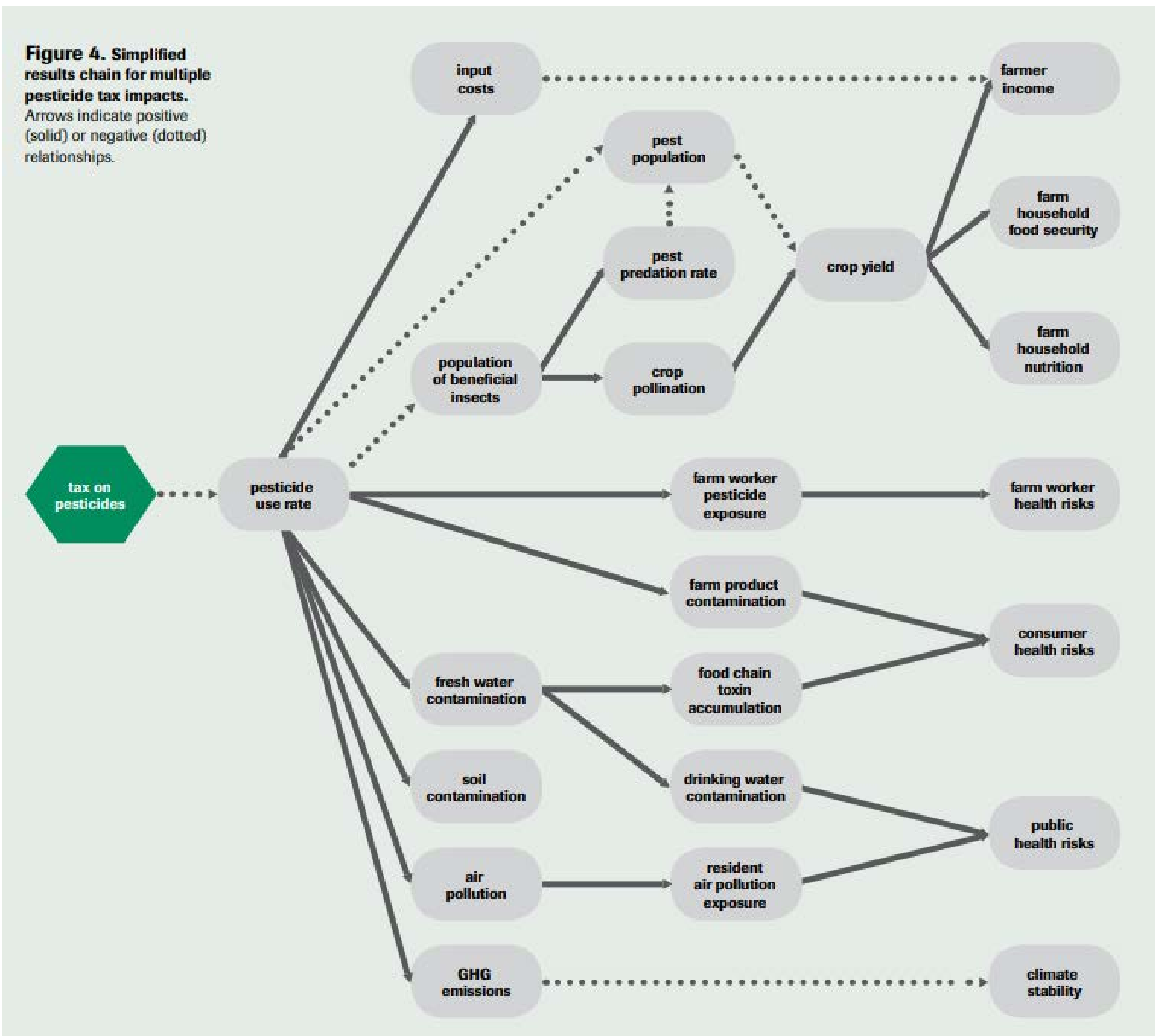
[8] Katie Warnell, Lydia Olander, and Sara Mason, *Ecosystem Services Conceptual Model Application: Bureau of Land Management Solar Energy Development* (National Ecosystem Services Partnership, 2018), https://nicholasinstitute.duke.edu/sites/default/files/publications/escm-application-blm-solar-energy-development-web.pdf.

(3) Conceptual models for pesticide tax impacts (a) and habitat subsidies (b). Arrows indicate the direction of expected effects between the two variables linked by the arrows.[9] 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. This guidance encourages analysts to identify welfare endpoints that are as specific as possible. For example, endpoints such as farm worker health risks are likely too broad to monetize, quantify, or describe in an informative way. Efforts should be made to identify specific health risks.

(a)



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[9] 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)

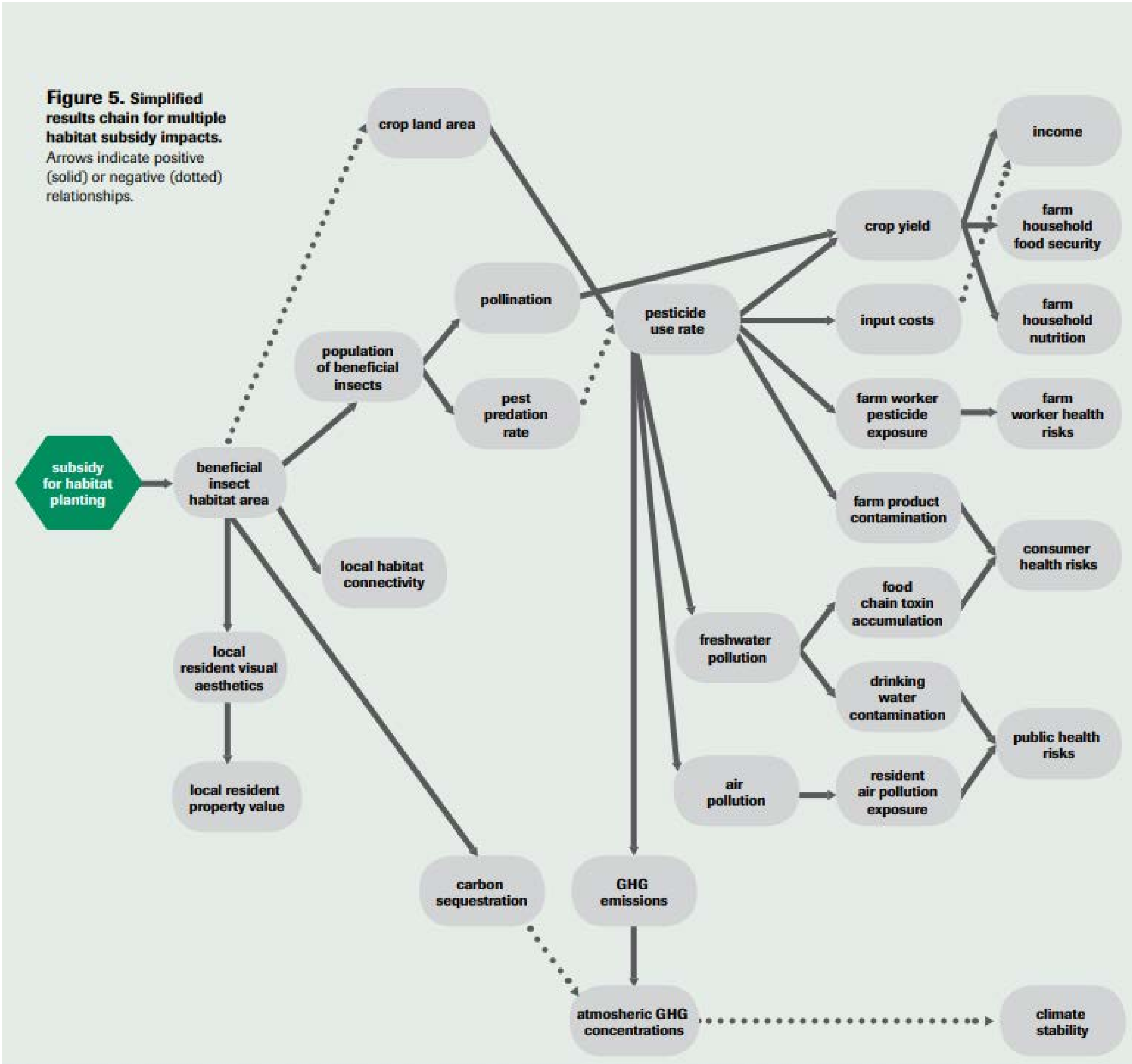

Figure 5. **Simplified results chain for multiple habitat subsidy impacts.** Arrows indicate positive (solid) or negative (dotted) relationships.

(4) Conceptual model regarding natural resources management in Kenya.[10] This example categorizes ecosystem services, goods, and values differently than this guidance suggests. For example, policy alternatives (e.g., PES and carbon offset schemes) are mixed with welfare aspects (e.g., aesthetic value) in the value column. And this guidance considers carbon sequestration to be an ecosystem service that yields multiple welfare benefits.

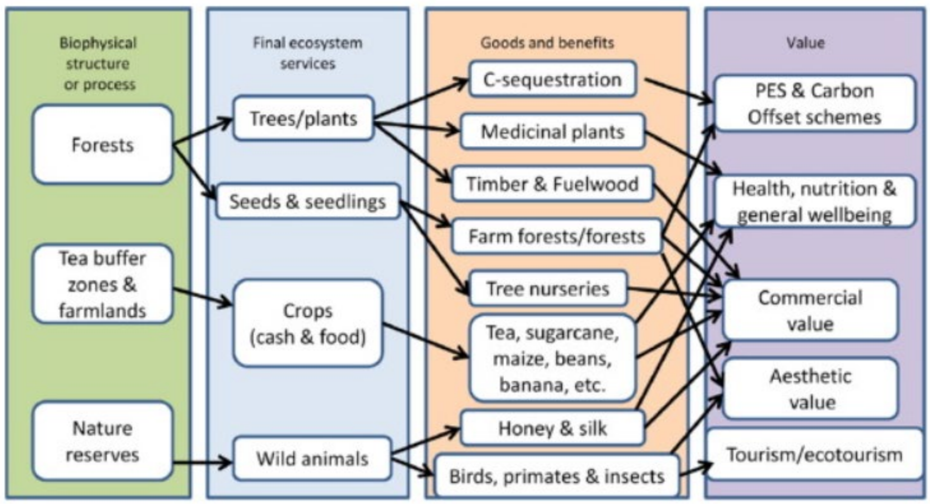

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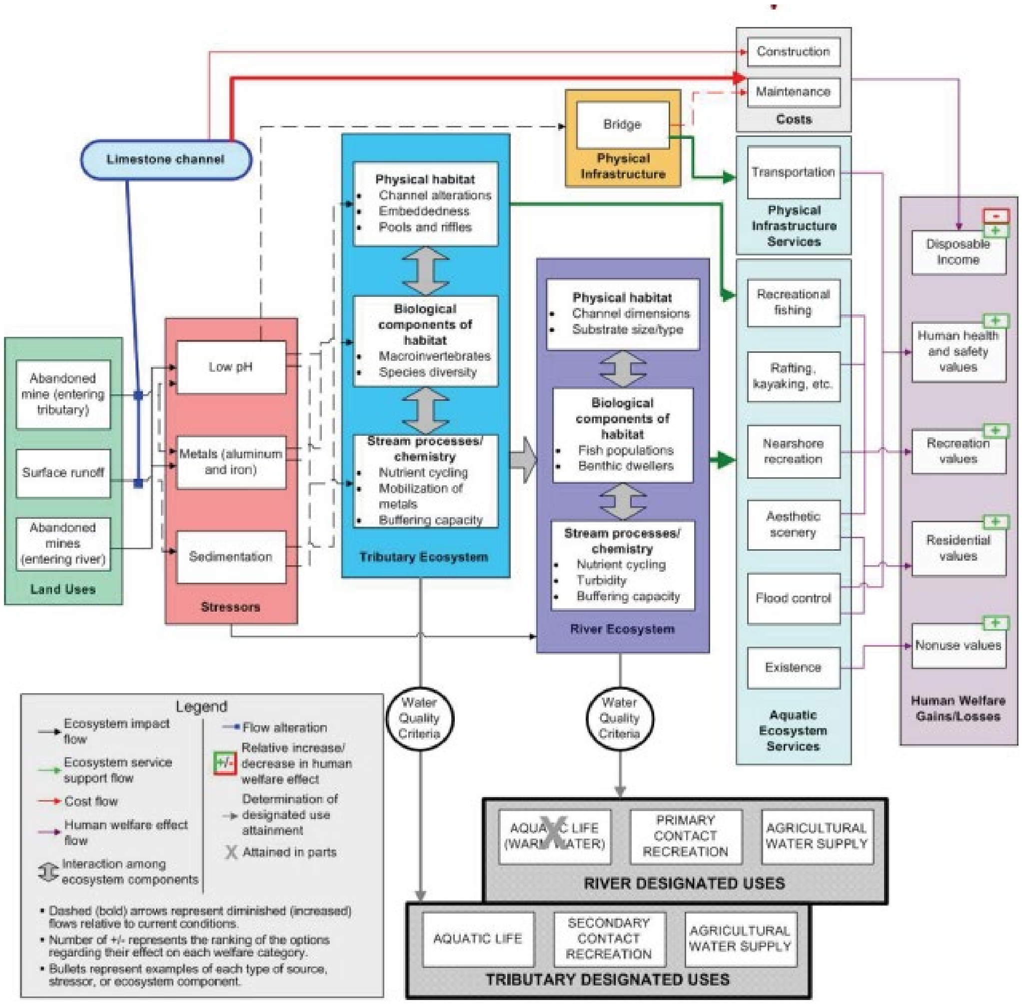
Fig. 2. The cascade redrawn by the case study from the Kakamega Forest Ecosystem, Kenya (CS#24), (source: EU FP7 OpenNESS Project Deliverable 5.1, see Dick and Turkelboom, 2013).

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

(5) Conceptual model regarding creating a limestone channel to mitigate acid mine drainage impacts on a tributary and river.[11] This example follows this guidance quite closely, reflecting natural and built system changes, and using similar welfare categories. This guidance uses the term "amenity value" rather than "residential values."



[11] 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.

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*.

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

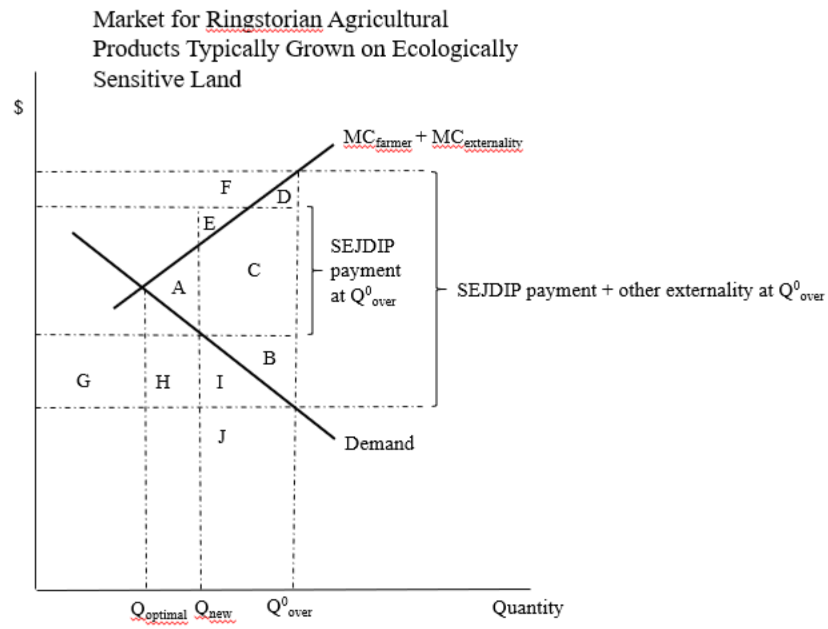
Expansion of the pool of farms that are candidates for the Flora\$ense program would lead, according to IPRA's estimates, to more participating acreage even without any change to the program's budget. IPRA also observes that the SEJ Disaster Insurance Program does not set its premiums to account for 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.[12] 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.[13]

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

[12] 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.

[13] 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.[14]

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).[15] 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 "Presentation of Results and Accounting Statement" in the guidance. See if you can identify problems embedded in the following comments; answers will be provided at the end.[16]]

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

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[14] 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* (Centers for Disease Control and Prevention, 2017), *https://www.cdc.gov/climateandhealth/docs/UseOfCoolingCenters.pdf*.

[15] 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*.

[16] 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.

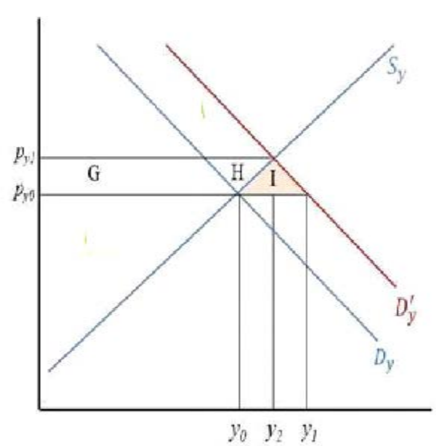
Comment 3:

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 Land-Use/Land-Cover Change

Many ecosystem services considerations can be analyzed using different land-use/land-cover (LULC) scenarios (see the text box *Available resources for ecosystem service analysis* in the main guidance document for more information). Case studies in the ecosystem-service literature highlight the utility of geographic information systems (GIS) for quantifying ecosystem-service changes.[17] These studies typically quantify the provision of different ecosystem services within a region based on the presence, condition, and interactions of particular land-use or land-cover (LULC) types and additional landscape and social features and processes.[18] 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.[19] 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.[20] 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 inform or calibrate models to estimation of changes in some ecosystem services. In many cases, landscapes evolve in ways that can be anticipated, with particular LULC types replacing others in a given region.[21] 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

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[17] 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.

[18] 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. For a recent discussion of the characterization of uncertainty in LULC analyses, see Zander S. Venter et al., "'Uncertainty Audit' for Ecosystem Accounting: Satellite-based Ecosystem Extent is Biased Without Design-based Area Estimation and Accuracy Assessment," *Ecosystem Services*, no. 66 (2024): 101599.

[19] 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*.

[20] 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.

[21] 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.

that will result from selecting a particular scenario.[22] 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).[23]

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 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.

[22] 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.

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