Incorporating Alternatives for Ecosystem Services and Equity in Benefit-Cost Analysis (BCA) for Flood Hazard Mitigation

Fahmida Akhter(1), Jerrod Penn(2), Rachelle Sanderson(3), Thomas Douthat(1), Louisiana State University, LA 70803, USA

Introduction

Background: Flood mitigation projects funded by federal funds (e.g., FEMA, USACE, CDBG-MIT/DR) must conduct Benefit-Cost Analyses (BCA) to ensure cost-effectiveness.

- These agencies have developed standardized methodologies and precalculated benefits to calculate the BCA of a project.
- To fully account for the social costs/benefits of the mitigation projects, BCA should include mechanisms to monetize estimates of environmental externalities and social co-benefits, as well as mechanisms to ensure equitable benefit distribution among different communities based on vulnerability.
  - However, only recently have BCA methodologies included ecosystem services (the value at the point of consumption of natural resources), and attempted to include adjustments for vulnerable populations.
  - BCA does not include the negative impacts of ecosystem services and downstream impacts.
  - Equity impacts have proven difficult to standardize and monetize.

Problems

- Projects can have positive or negative effects on downstream risk and ecosystem services and the current tool does not comprehensively monetize these effects.
- The distributional vulnerability of different populations is not considered in traditional flood mitigation BCA based on Annual Average Loss (AAL).

Relevance: In the past 24 months, two major federal directives have redefined federal policy regarding BCA and mitigation project evaluation.

- Justice40 is a directive that explains how certain federal investments might be made toward a goal that 40 percent of the overall benefits of such investments flow to disadvantaged communities.
- the Nature-based Solutions Roadmap explains how to protect, sustainably manage or restore natural or modified ecosystems as solutions to societal challenges.

Approach: Here we will use logic models to assess how the current BCA tool incorporates these externalities as well as how to include negative externalities and downstream impacts.

- A logic model can help elucidate conceptual pathways to explain the relationship in which different ecosystem services are related to different flood mitigation projects in a watershed (Olander et. al., 2021).
- They have been used in Ecosystem Services Logic Models (ESLMs) as habitat restoration, hydrological reconnection, recreational enhancement, and water quality improvement projects and the ways they can contribute to social and economic well-being. Here we take a similar approach to model different ways to incorporate externality and equity into BCA tools and methodologies.

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Ecosystem Services and Externalities

Different flood mitigation projects could be associated with positive or negative externalities (i.e., the uncompensated environmental impacts due to flood mitigation projects) based on their types and locations (**Table 1**), but the extent that they are incorporated can make the BCA tools more complicated and costly to any practical decision making contexts. **Figure 1**, provides a summary of the numerous ecosystem services which should be taken into account during a flood mitigation project. Externalities can be defined by three broad categories: ecosystem services, ecosystem functions, and downstream impacts. Each of these is a facet of externality impact or trade-offs in what we measure or compare the benefits and costs of a project (Miller et. al., 2023). A BCA tool that can fully monetize this model should be able to measure final ecosystem services, mediated through project impact on watershed function, and the location and distribution of the impacts. While these factors should be considered in instrument design, tradeoffs in complexity, usability, and cost should be considered when designing practical tools for programmatic decision-making.

Frameworks 1, 2, and 3 consider three approaches based on these considerations and tradeoffs. **Framework 1** represents a benefit transfer based on the final values of different land use types. **Framework 2** represents a model based on *Fuctional-index* (i.e., Hydrogeomorphic (HGM)) which provides a numerical score based on wetland functions but it doesn't incorporate any downstream impacts. **Framework 3** represents a *Model-Integrated* approach that, might address Hydraulics and Hydrology (H&H) and water quality impacts in a watershed which will incorporate the downstream impacts spatially.

Project Externalities

Project Type	Environmental Impacts	Downstream Impacts (Needs Spatial or Model Data)	Distributional Effects (Needs Spatial or project data)
Floodplain Restoration and Preservation	Positive	Positive	Negative
Flood Storage	Positive	Negative	
Stormwater Management - Gray Infrastructure	Positive/ Negative	Negative	Negative
Stormwater Management - Green Infrastructure	Positive	Positive	Positive/ Negative

Table 1: Positive and negative impacts of environmental externalities based on project types

Ecosystem Services

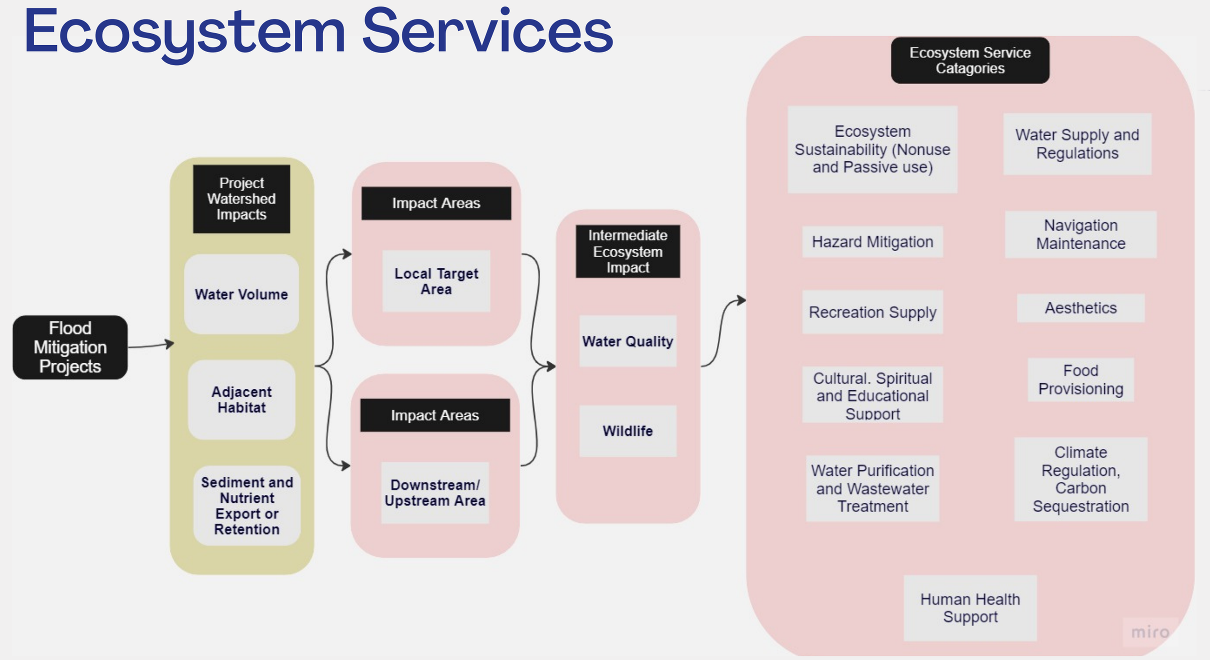
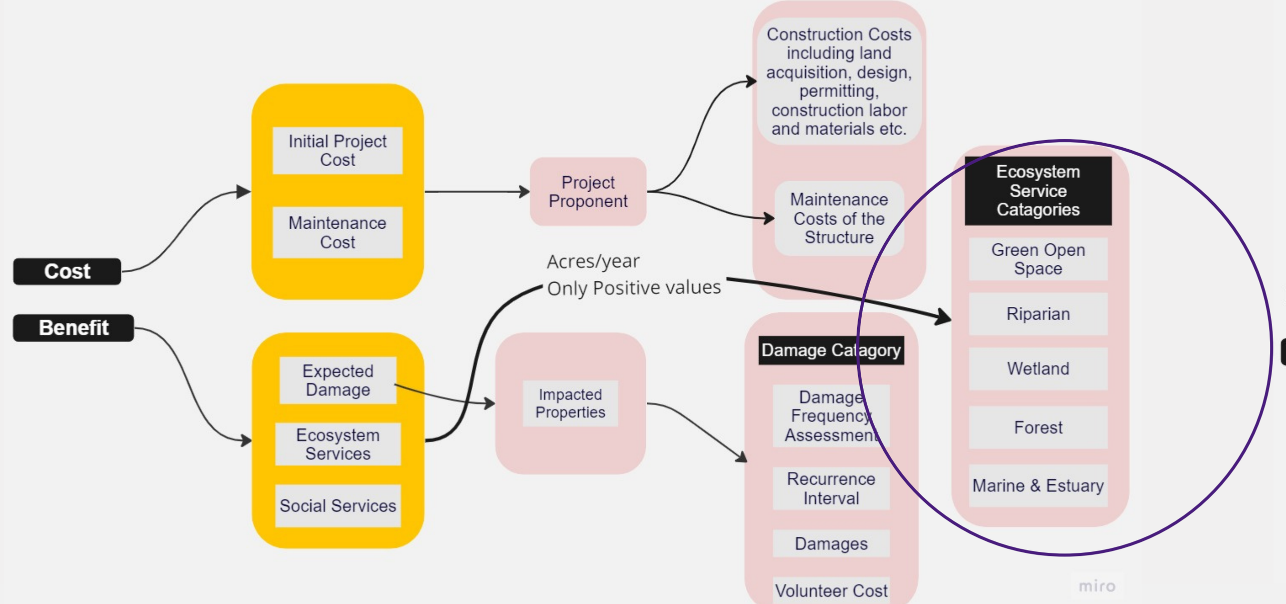


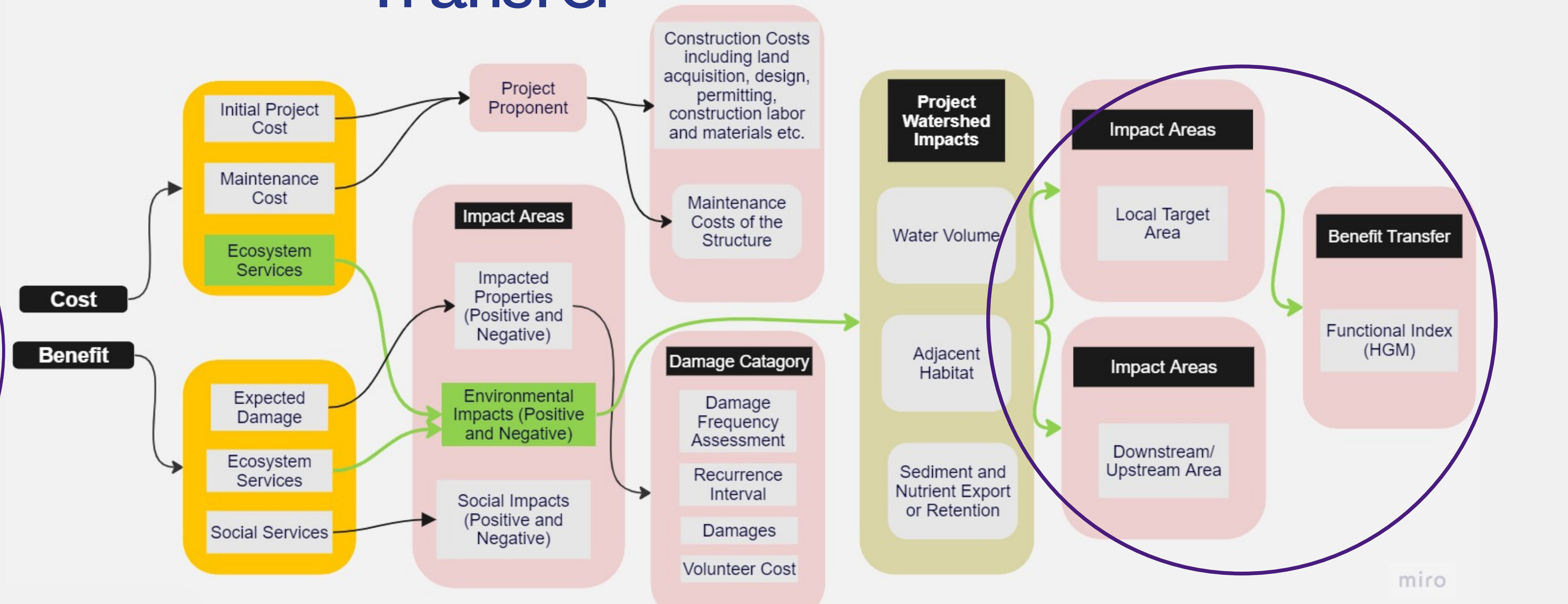
Figure 1: Final Ecosystem Services modified by the project watershed impacts (Wainger et.al., 2023) which will address local target area and downstream impacts based on different watershed impacts.

Framework 1: Acres/year Benefit Transfer



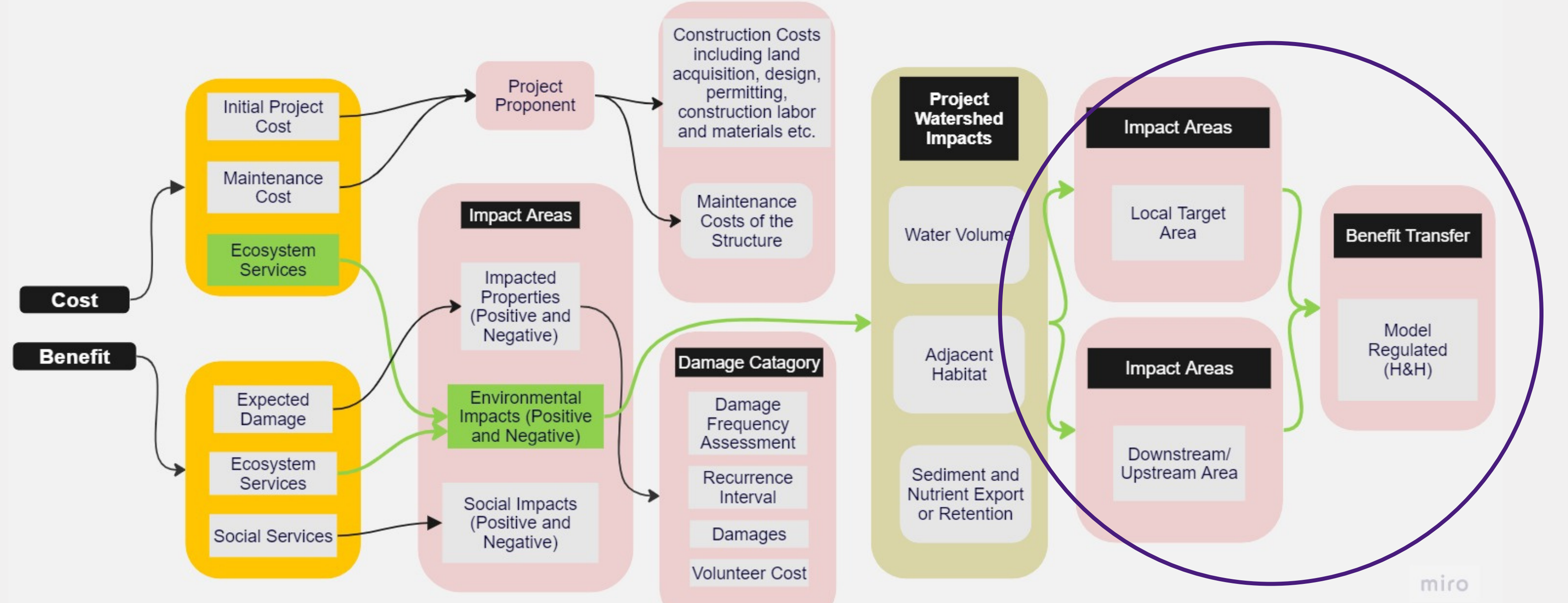
Framework 1: The BCA Framework for FEMA BCA toolkit 6.0, which only considers positive ecosystem services and benefit transfer by Acres/year. For example, FEMA BCA Toolkit 6.0 considers ecosystem services based on the five different land cover categories by Acres/year (Framework 1). Recent changes to the FEMA BCA tool include nine (9) landcover categories instead of five (5). It doesn't take into account the downstream impacts or who and where the beneficiaries are. It cannot account for ecosystem function gain or loss that would impact resources in the watershed, but it is the easiest to calculate.

Framework 2: Functional Index Benefit Transfer



Framework 2: This BCA Framework considers both positive and negative ecosystem services and benefit transfer by functional index(s) e.g., Hydrogeomorphic model (HGM). It will define the habitat, water quality, and hydrologic functions of a wetland. However, it doesn't incorporate social co-benefits or distributional impacts as it lacks to include the scaler impacts at the watershed level.

Framework 3: Model Integrated Benefit Transfer



Framework 3: This conceptual BCA Framework considers both positive and negative ecosystem services (e.g., water surface elevations; sediment processes; modeling of watershed catchment processes, flood hydrograph development, water quality parameters, etc.) and benefits transferred by Model integration (e.g., HECRAS and water quality). It does take into account the scaler impacts at the watershed level.

Equity

The majority of flood mitigation project evaluations place a strong emphasis on property value and local match, which is problematic for those with low and moderate incomes (LMI) (Douthat et. al., 2023). For Example, FEMA is introducing an alternative cost-effectiveness methodology based on a discount rate (3%) and at the same time, it addresses the distributional impact by introducing the Justice40 initiative. If one individual has to depend on their own income only (self-protection) then they will have to pay for the entire amount of Annual Average Loss (AAL). This will also affect the tenure status (renter/owner) of the residents as well as their income level. According to the marginal utility of income, $10,000 damage or AAL would impact low-income households disproportionately compared to high-income households (Figure 2). Here the social flood vulnerability for that individual will be the consumption loss (paid for AAL) divided by household income (Framework 4). Later the recovery will also depend on how much one is willing to pay in a flood event. The risk premium, which is directly related to social vulnerability, is defined as the fraction of household income lost due to a flood event (Kind et. al. 2020).

Affiliation

(1) LSU College of the Coast and Environment - Department of Environmental Sciences - Douthat-Environmental Governance and Planning Lab; Contacts: fakhte1@lsu.edu; tdouthat1@lsu.edu
(2) LSU Ag. Center - Agricultural Economics and Agribusiness
(3) Institute for Sustainable Communities - formerly Planning Director, Capitol Regional Planning Commission

Marginal Utility of Income

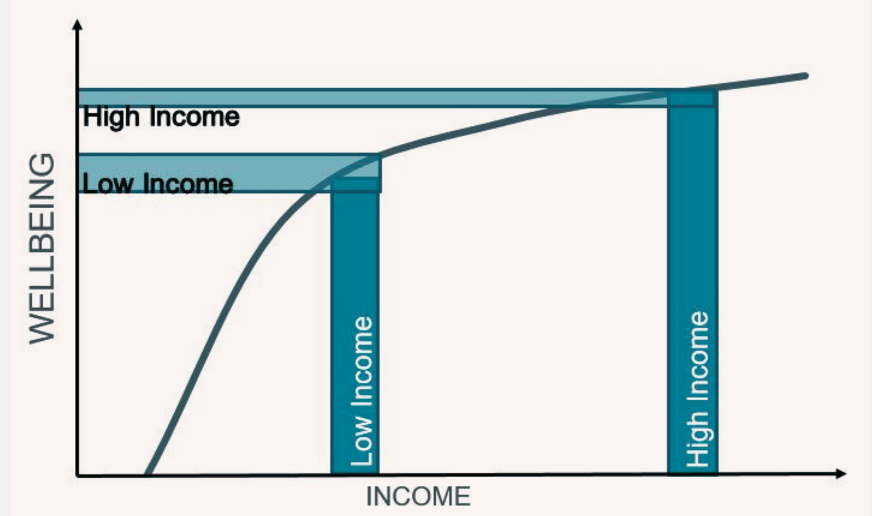
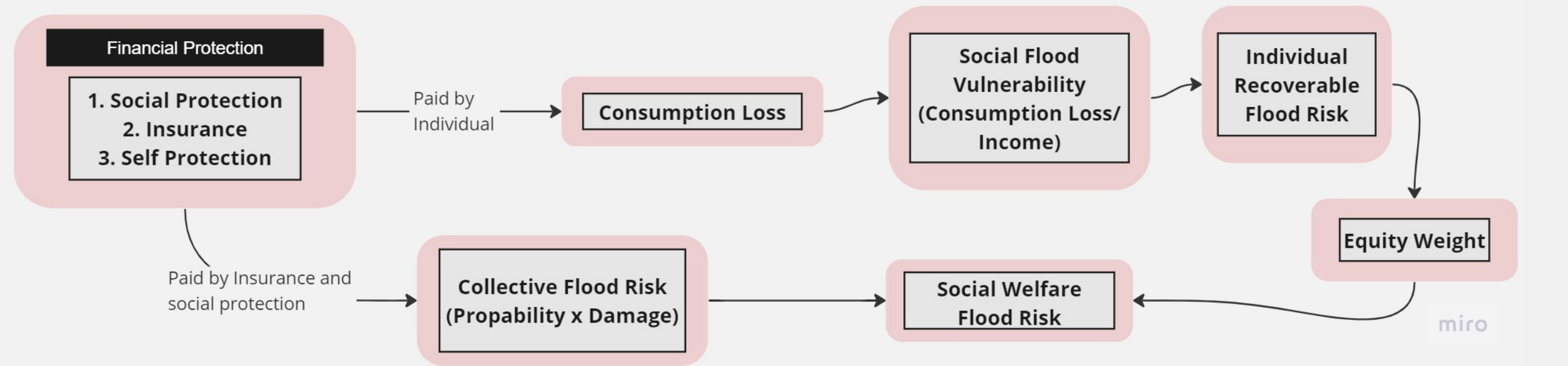


Figure 2: This graph illustrates how a person with a monthly salary of $10,000 would experience greater well-being with a $100 increase in income compared to a person with a $100,000 monthly income. Similarly, the AAL will have different impacts on different income groups, which similar structural damages having disparate economic welfare effects.

Equity (Conceptual Framework)



Framework 4: Equity weighted Social Welfare Flood Risk

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