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Climate Change Adaptation Case Study: Benefit-Cost Analysis of Coastal Flooding Hazard Mitigation

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Abstract
The damage Hurricane Sandy caused had far-reaching repercussions up and down the East Coast of the United States. Vast coastal flooding accompanied the storm, inundating homes, businesses, and utility and emergency facilities. Since the storm, projects to mitigate similar future floods have been scrutinized. Such projects not only need to keep out floodwaters but also be designed to withstand the effect that climate change might have on rising sea levels and increased flood risk.

In this study, we develop an economic model to assess the costs and benefits of a berm (sea wall) to mitigate the effects of flooding from a large storm. We account for the lifecycle costs of the project, which include those for the upfront construction of the berm, ongoing maintenance, land acquisition, and wetland and recreation zone construction. Benefits of the project include avoided fatalities, avoided residential and commercial damages, avoided utility and municipal damages, recreational and health benefits, avoided debris removal expenses, and avoided loss of function of key transportation and commercial infrastructure located in the area. Our estimate of the beneficial effects of the berm includes ecosystem services from wetlands and health benefits to the surrounding community from a park and nature system constructed along the berm.

To account for the effects of climate change and verify that the project will maintain its effectiveness over the long term, we allow the risk of flooding to increase over time. Over our 50-year time horizon, we double the risk of 100- and 500-year flood events to account for the effects of sea level rise on coastal flooding. Based on the economic analysis, the project is highly cost beneficial over its 50-year timeframe. This analysis demonstrates that climate change adaptation investments can be cost beneficial even though they mitigate the impacts of low-probability, high-consequence events.

1. INTRODUCTION

Hurricanes and tropical storms cause significant flooding and storm surge events in coastal, estuarine, and riverine communities. These storms cause substantial damages to homes, businesses, communities, and the environment. Designing and implementing resiliency measures to mitigate these damages is of upmost importance; these decisions, however, cannot be made assuming a static environment. Planning for these resiliency measures needs to include an assessment of climate change impacts to maintain their long-term effectiveness.

Analysis of the costs and benefits of climate adaptation and hazard mitigation measures are critical to decision-making. Climate resilience analysis captures the costs of constructing an adaptation project, while benefits stem from the reduction in expected weather-related damages. This information can be combined into quantitative metrics for the adaptation alternatives under consideration to facilitate comparisons and support project selection.

With the increasing threat of future extreme weather events due to climate change, the evaluation of associated costs is essential for effective long-term planning of infrastructure projects. Although it has challenges, benefit-cost analysis provides a framework to support climate change decision-making and adaptation planning (Sussman et al., 2014a; Sussman et al., 2014b; Neumann et al., 2014; and Neumann et al., 2015).

Benefit-cost analysis for use in evaluating adaptation decisions is evolving, as reflected in the literature (Li et al., 2014). This study illustrates the use of readily available tools and data in a benefit-cost analysis framework to support the decision-making process for a large-scale flood mitigation project.

The focus of this study is on Bergen County, New Jersey, which was devastated by Hurricane Sandy. This study examines the potential costs and benefits of constructing an 8.2-mile berm (i.e., earthen wall) along the Hackensack River to protect the adjacent communities from storm surges. The analysis estimates the incremental costs and benefits of the berm relative to a baseline in which the berm and ancillary components (collectively, “the project”) are not constructed.

This study uses data from a variety of sources to estimate the costs and benefits of the project over a 50-year analytical period, although the berm is anticipated to provide benefits beyond that period. The primary project costs include costs for berm construction, administration and contingencies, wetlands construction, recreation zone construction, and land acquisition, while the primary benefits include avoided residential and commercial damages.

When feasible, the analysis uses or estimates quantitative and monetary values for the expected impacts of the project. When monetary estimates or input parameters were not available due to data limitations, the analysis estimates quantitative impacts using a combination of credible and geography-specific quantitative data sources. Some quantitative impacts were not sufficiently reliable for inclusion in the decision-making metrics—the net present value (NPV) and the benefit-cost ratio (BCR). As applicable, this study presents a qualitative discussion of those impacts.

The analysis relies on the Federal Emergency Management Agency's (FEMA) Benefit-Cost Analysis (BCA) Tool in estimating the majority of the benefits of the project resulting from a reduction in the consequences of the flooding, such as residential and commercial damages.

This study demonstrates that the project is cost beneficial when evaluated over a 50-year timeframe. The analysis estimates net present values of $331.3 million and $1,241.4 million (at 7- and 3-percent discounting, respectively). The analysis also estimates benefit-cost ratios of 2.09 and 4.39 (at 7 and 3 percent, respectively). The breakeven points, where the benefits are equal to the costs, occur 8 and 11 years after the completion of construction (at 3 and 7 percent, respectively), demonstrating that the project is cost beneficial relatively early in the project's useful life.

2. METHODS

2.1. Approach

This study focuses on the estimation of two key economic payoff evaluation metrics—the NPV and the BCR. The NPV is the difference between the discounted total benefits and the discounted total costs. A positive NPV indicates that the adaptation measure is cost beneficial and will pay for itself over time. The BCR is a numeric ratio that expresses the discounted total benefits relative to its discounted total costs. A BCR equal to or greater than 1 indicates that the benefits of the adaptation measure are equal to or greater than its costs. Although NPV and BCR yield very similar information, this study analyzes the value of the proposed flood protection project using both methods. The BCR provides a useful tool for comparing multiple alternatives or projects, but it does not provide a sense of the economic magnitude. NPV, on the other hand, yields the overall magnitude of the project value in dollars. Additionally, some agencies and decision makers tend to favor the NPV metric, while others use the BCR.

This analysis estimates the incremental costs and benefits of the project relative to a baseline in which the project is not implemented. The analysis has the

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following objectives to ensure that the economic payoff evaluation is sufficiently rigorous and based on sound economic fundamentals:

- Account for lifecycle costs, which are all recurring and one-time costs over the lifetime of the project. Lifecycle costs include construction, operations and maintenance, and upgrade costs.
- Capture private and social benefits. Private benefits include avoided residential and vehicle damage, while social benefits include avoided loss of function for utilities or fire services.
- Account for climate change by incorporating the effects of sea level rise. To do so, the analysis adjusts the estimates by the probability of the various storms types (e.g., 100-year flood, 500-year flood), thus estimating the impacts based on the expected value.
- Account for environmental impacts to the extent possible.

Section 4.2 discusses the methodological limitations.

2.2. Study Area

Located in the northeastern part of New Jersey, the geographic area subject to this study includes South Hackensack, Teterboro, Little Ferry, Moonachie, Carlstadt, and East Rutherford, which comprise the Meadowlands Region in Bergen County, New Jersey. The Meadowlands Region experienced catastrophic damage from Hurricane Sandy in 2012 and contains more than 12,900 housing units, 6,500 businesses, critical infrastructure, and Superfund (sensitive environmental) sites. In addition, the area includes significant vulnerable populations.

Figure 1 displays the study area. To the north, the study area is bounded by Interstate I-80; the Hackensack River provides a natural boundary to the east. State Routes 3 and 17 bound the area to the south and west, respectively. The area contains several economically important points of interest, including the MetLife Sports Complex (which houses the MetLife Stadium that is home to the New York Giants and New York Jets National Football League teams); Teterboro Airport; and American Dream Meadowlands, a large retail and entertainment complex located directly southeast of the MetLife Sports Complex (it is not labeled on the map because it is under construction as of the time of this study).

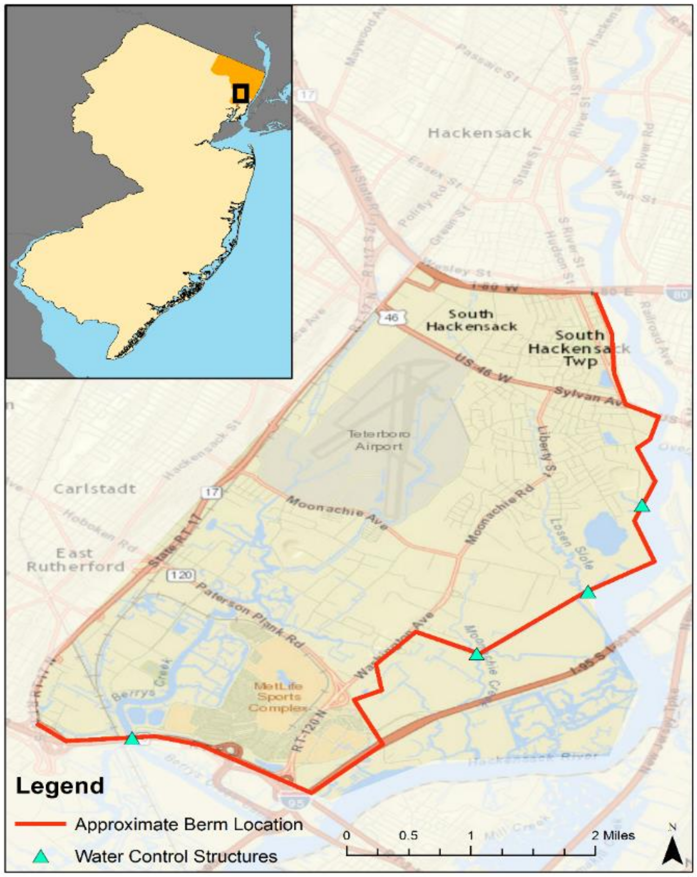

Figure 1. Map of the study area and the approximate berm location[1]

2.3. Approach to Quantification

When feasible, this study uses monetary estimates of the expected impacts of the proposed project. When monetary estimates were not available due to data limitations, the analysis estimates quantitative impacts using a combination of credible and geography-specific quantitative data sources.

In some cases, sufficiently applicable or credible quantitative data relevant to the project were not available. In those cases, this study uses quantitative factors

[1] The approximate berm location appears on the map in red, while the water control structures such as the tide gates are represented by blue triangles.

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(e.g., scaling factors) to estimate the impact on the total study area using estimates from nearby localities or recent quantitative studies on hazard mitigation. This approach of adapting estimates from existing studies to a new context (in this case, the study area) is a form of "benefit transfer," a method recognized by the U.S. Office of Management and Budget (OMB) for obtaining monetary estimates when direct values are not available.[2] This study prioritizes the use of original estimates from similar localities or community characteristics when adapting these values to the study area.

Some of the estimated quantitative impacts were not sufficiently reliable for inclusion in the NPV or BCR. For example, this study seeks to estimate the positive impacts of the project on tourism in the study area; however, tourism data were not available at the level of individual boroughs. Due to data limitations, however, the analysis is unable to account for the spatial distribution of tourism across the study area. For impacts such as these, this study presents the quantitative results and notes their exclusion from the NPV and BCR calculations. This exclusion ensures that the benefits of the project are calculated rigorously while avoiding underestimating the costs of the project.

Finally, some impacts simply do not occur with sufficient frequency to yield reliable results. In such cases, this study uses anecdotal data to inform the analysis, such as data based on the experience following Hurricane Sandy. Although these anecdotal data are informative from an analytical standpoint regarding the directionality or the impact, the analysis excludes them from the NPV and BCR calculations for two reasons. To use those data reliably, the analysis would need to disentangle flood-related damages from non-flood-related damages because the proposed project will prevent only the former; this disaggregation is not possible for most estimates due to data limitations. Second, relying on damages from Hurricane Sandy is analytically tenuous because it was a singular event. For impacts such as these, this study presents a qualitative discussion and, if available, anecdotal evidence, noting the directionality of the resulting impact based on economic theory.

Figure 2 presents the impacts included in the economic payoff metrics, the impacts quantified but not included in the economic payoff evaluation metrics, and the impacts discussed qualitatively.

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[2] OMB oversees the quality of federal agency programs and policies and issues guidance to standardize analyses. For benefit-cost analysis, OMB has issued Circular A-4 and Circular A-94, which describe appropriate discounting techniques (7 percent as the primary rate and 3 percent as an alternative for projects or regulations with long-term impacts). This analysis follows the OMB guidelines for BCA.

Impacts Quantified and Included in the Economic Payoff Metrics	Impacts Quantified but Not Included in the Economic Payoff Metrics	Impacts Discussed Qualitatively
• Avoided Residential Damages • Avoided Commercial Damages • Recreational Benefits • Health Benefits • Avoided Landmark Damages • Wetland Ecosystem Benefits • Avoided Utility Damages • Avoided Fatalities • Avoided Debris Removal • Avoided Municipal Damages	• Increased Property Values • Increased Tax Revenues • Avoided Tourism Damages • Mental Health Benefits	• Enhanced Remediation Efforts • Reduced Runoff • Reduced Vehicle Emissions • Improved Wetland Habitat • New Greenways and Open Space • Decreased Insurance Premiums • Reduced Combined-Sewer Overflows

Figure 2. Analysis of impacts

This study uses publicly available damage estimates for 100- and 500-year floods affecting the communities of South Hackensack, Teterboro, Little Ferry, Moonachie, and Carlstadt. This study refers to these communities collectively as "the pilot area." The geographic scope also includes the Borough of East Rutherford. This study refers to the total area protected by the proposed hazard mitigation project as "the protected area." Analogous estimates for the additional protected area (i.e., East Rutherford) were not publicly available. Instead, the analysis applies a scaling approach to estimate the damages to East Rutherford using damage estimates for the pilot area. To estimate the damages for East Rutherford, the analysis converts the pilot area damage estimates to damage-per-area parameters (i.e., dollars per acre) and multiplies those parameters by the total acreage—by land use type—in East Rutherford (see Appendix A for more information).

2.4. FEMA Benefit-Cost Analysis Tool

FEMA maintains a BCA tool for conducting benefit-cost analyses supporting Hazard Mitigation Assistance grant applications. The tool contains methods for estimating benefits of the most common benefit categories for buildings (e.g., building damage, displacement, and loss of function), utilities (e.g., electricity, water supply, and waste water treatment), and services (e.g., fire services and police services). Several modules comprise the FEMA BCA tool to estimate expected damages from natural disasters, such as floods, hurricanes, tornados, and earthquakes. This study uses the tool's Damage Frequency Assessment (DFA) module to estimate the benefits resulting from reduction in flooding due to the project. The DFA module is commonly used to estimate the benefits of large-scale hazard mitigation projects.[3] Section 4.2 discusses the limitations of the FEMA BCA tool.

3. RESULTS

This study compares the incremental costs and benefits of the project against the baseline—that is, the costs and benefits without the construction of the project. The analysis covers 50 years (2016 through 2065) to ensure it captures all major costs and benefits expected to accrue over the useful life of the project. When summarizing the costs and benefits, this study presents 50-year averages to estimate the typical annual effects and 50-year discounted totals to summarize the present value of the overall effects. All impacts are in constant dollars, and monetized costs and benefits are discounted to capture the time value of money because benefits and costs are worth more if they are experienced sooner.

3.1. Economic Analysis

The following impacts are included in the calculation of the NPV and BCR: lifecycle costs, which include the cost to construct the berm and the recreation band, the maintenance cost of the berm, the land acquisition cost, and the wetland construction and mitigation cost; resiliency benefits, which include avoided residential and commercial structural damage, avoided commercial lost revenue, avoided fatalities, avoided displacement, and avoided utility and municipal damages; environmental value, which includes the benefits of newly constructed wetlands; and social value, which includes the recreational and health benefits of newly constructed parks along the recreation band.

3.1.1. Lifecycle Costs

Lifecycle costs of the project include berm construction, recreation area construction, land acquisition and easement, berm operation and maintenance, and wetland mitigation. These costs result from a bottom-up estimation approach in which individual project components are estimated by an engineer and are combined to calculate total project costs. The study assumes the berm construction

[3] Unlike the Flood module in the FEMA BCA tool, the DFA module does not require detailed data for each individual structure in the geographic area protected by the hazard mitigation project.

phase will require approximately two years. Total undiscounted costs for the project are presented in Table 1.

Table 1. Costs of the Project (Undiscounted)

Impacts	Cost (Millions)	Percent of Total
Berm Construction	$173.2	45.1%
Recreation Zone Construction	$27.2	7.1%
Wetland Construction	$29.1	7.6%
Land Acquisition	$25.0	6.5%
Administration and Design	$84.2	21.9%
Contingency	$45.0	11.7%
Annual Berm Maintenance	$0.5	0.1%
Total	$384.2	100%

In addition to the construction costs of the 8.2-mile berm, there are costs for constructing the recreation band and wetland mitigation. The project includes a recreation band along the length of the berm including a bike path, boat access ramps, and landscaping features aimed at beautifying the area and encouraging outdoor activities in the community. Although every effort will be made to avoid impacts to the wetlands during the construction of the project, some wetland area will be disturbed or destroyed. To mitigate this impact, replacement wetlands will be constructed that will replace and expand the wetland area to compensate for the loss of resource value. No costs associated with financing (e.g., debt service) are included in the lifecycle costs of the project.

This study assumes that easements will be obtained voluntarily, implying that no monetary transaction will take place to account for homeowner inconvenience or property use restrictions. Negotiations with landowners over easements could result in additional costs or realignment of the berm and associated public access and ecological restoration, or other government measures to ensure access to the properties. The total construction cost (including the physical construction, recreation band construction, wetland construction, and land acquisition) is estimated at $254.5 million.

The cost of administrative oversight and design is estimated to be an additional one-third of the construction costs and is estimated at $84.2 million. An additional contingency value of 15 percent is used to account for uncertainty in the cost estimates, resulting in an estimated value of $45.0 million. Finally, the annual cost of berm operation and maintenance is estimated to be $0.5 million over the 50-year useful life of the berm.

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In total, lifecycle costs amount to an average annual value of $10.65 million over the 50-year analysis time period. Applying a discount rate of 7 percent, the total cost is estimated at $467.3 million over the useful life of the project.

There are potential impacts that are not considered in this analysis due to the uncertainty of their magnitude. For example, the construction of the berm and wetlands will disturb land that may currently provide ecosystem services, which would result in a loss of wetlands relative to the baseline. A loss of wetlands would represent a cost of the project because wetlands provide ecosystem services. This study does not measure this potential cost; a biological survey of the proposed site of the berm would be necessary to measure the net change in wetlands resulting from the proposed berm.

There are potential impacts outside the study area that are not considered in the analysis. The floodwaters that would inundate the area without the construction of the proposed berm will now be displaced by the berm into adjacent areas, thus raising floodwaters in potentially susceptible areas. Estimating these effects are also beyond the scope of this study. We expect that any increase in flood height elsewhere, and therefore any additional damages, to be minimal given the relatively small area over which this increase would occur.

3.1.2. Resiliency Value

Damages caused by Superstorm Sandy placed an immense strain on Bergen County and the State of New Jersey. The New Jersey Governor's Office estimated a total cost of $35 billion in direct damages from Superstorm Sandy (Mantell, 2013). Damages to Bergen County alone were estimated at $29 million (U.S. Department of Commerce, 2013). In New Jersey, residents filed 70,787 National Flood Insurance Program claims due to damages caused by Superstorm Sandy, which totaled approximately $3.1 billion (Huffington Post 2013). This value, however, underestimates total damages because 69 percent of low- and moderate-income households did not carry homeowners insurance, and 90 percent had no flood insurance (Halpin, 2013).

Furthermore, Superstorm Sandy caused nearly 19,000 small businesses to sustain damages totaling $250,000 or more, resulting in $8.3 billion in total losses to New Jersey businesses (1 percent of the 2012 Gross State Product) (U.S. Department of Commerce 2013).

In Bergen County alone, estimated lost wages as a result of Superstorm Sandy were valued at more than $75.5 million (Halpin, 2013). The project is expected to increase resiliency, protecting the region from future and repeat disasters such as Superstorm Sandy. The project will also reduce the damages from repeated riverine flooding as the berm will protect some vulnerable riverine areas from flooding. In addition, improved water conveyance infrastructure and pumping stations will shorten the amount of time water remains at riverine flood levels.

The construction of the 14-foot berm will increase resiliency to future catastrophic flooding events. The project will prevent both 100- and 500-year floodwaters from inundating the area, which FEMA assumes will have total flood heights of 9 feet and 11 feet, respectively (Massachusetts Institute of Technology 2014).[4] The berm will reduce risk to private property, fatalities, displacement of residents, and damages to energy and water infrastructure. A breakdown of these benefits is presented in Table 2.

Table 2. Resiliency Benefits of the Project (Undiscounted)

Avoidance of …	**Resiliency Benefits (Millions)**	**Percent of Total**
Residential Damages	$2,720.0	79.8%
Commercial Damages	$473.6	13.9%
American Dream Meadowlands Damages	$122.4	3.6%
Utility Damages	$43.0	1.3%
Teterboro Airport Damages	$33.4	1.0%
Fatalities	$9.0	0.3%
Debris Removal	$6.0	0.2%
MetLife Stadium Damages	$1.1	0.03%

The largest benefits, representing more than 90 percent of the undiscounted benefits, stem from avoided residential and commercial damages. These damages include structural damages and commercial losses estimated using the scaling approach discussed above (see Appendix A for details), and residential displacement estimated using data from the U.S. Census (2010) and inundation estimates from the Bergen County Jurisdiction Mitigation Plan. We extrapolate total displacement using displacement days estimated by FEMA and per diem

[4] This study assumes that the 100-year flood level will be 9 feet, which includes an 8-foot storm surge with 1-foot waves. The 500-year flood level is assumed to be 11 feet, which includes a 10-foot storm surge with 1-foot waves. These assumptions are based on publicly available information from the MIT Rebuild by Design New Meadowlands study.

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lodging and meal rates, specific to Bergen County from the U.S. General Services Administration (2015).[5]

The remaining 6 percent of the benefits are the benefits to American Dream Mall, Teterboro Airport, and MetLife Stadium and avoided utility damages, fatalities, debris removal, and municipal damages. The American Dream Meadowlands Mall is expected to open partially in 2016 with full occupancy by summer 2017 (Verdon, 2014). As benefits of the project begin to accrue after the two-year construction phase, this study assumes that the mall will be completed at approximately the same time. Avoided damage estimates for the New Meadowlands Mall are based on the estimated size of the completed mall (Brennan, 2014).[6] The resulting values reflect lost revenue of the mall during 100- and 500-year floods. This study uses commercial losses per acre to estimate the avoided commercial damages of the unfinished mall based on the estimated commercial footprint of the mall upon completion (see Appendix A for details).

Reduced floodwater inundation also will prevent fatalities in the protected area; the analysis monetizes this benefit using the FEMA-suggested value of a statistical life ($6.6 million in 2014 dollars) (Federal Aviation Administration, 2008).[7]

The project also will yield benefits in avoided damages and outages to local utilities, including electricity, water supply, and wastewater treatment. With floodwaters not breaching the berm, these services should remain largely unaffected. The project also will prevent the loss of function of municipal services and avoid lost revenues of Teterboro Airport, MetLife Stadium, and American Dream Meadowlands Mall. This study assumes a three-day shutdown of the airport and the MetLife Stadium to estimate loss of function.

Finally, the project is expected to prevent cleanup costs caused when floodwaters, carrying debris, wash through. The berm will prevent floodwaters

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[5] Displacement days, which are calculated using the FEMA Depth Damage Function, vary based on the height of the floodwaters. Nine-foot and eleven-foot floods result in 405 and 495 displacement days, respectively.

[6] Estimated revenue loss includes only commercial space and does not include lost tourism revenue expected from a proposed water and amusement park. For this reason, expected avoided damages to the American Dream Mall should be viewed as a conservative estimate that seeks to avoid overestimating the benefits of the project.

[7] The study assumes the value of a statistical life to be $5.8 million (in 2012 dollars) from the Federal Aviation Administration, converted to 2014 dollars using the Consumer Price Index.

from inundating the protected service area, which will avoid debris removal costs. This study uses publicly available data to estimate debris removal costs.

In total, the project will mitigate property and commercial damages; fatalities; displacement of residents; damages to energy and water infrastructure to Teterboro Airport, MetLife Stadium, and American Dream Mall; and debris removal costs. These benefits amount to an average annual value of $68.2 million over the 50-year analysis period. Applying a discount rate of 7 percent, the total discounted resiliency benefits value is estimated at $693.6 million over the lifetime of the project.

3.1.3. Environmental Value

The construction of the berm will have environmental impacts on the surrounding area. During the construction phase, there will be intermittent wetland construction, including the drainage and paving of wetlands in the direct path of the project, and the creation of new wetlands to mitigate the acres lost to construction of the project.

The enhanced wetland areas will improve local air quality and have a positive impact on climate change by absorbing harmful pollutants and carbon dioxide from the atmosphere, which are then stored in the plant biomass or the surrounding soil. Additionally, wetlands help contain storm water runoff and reduce peak flows during rain events by trapping water. Wetlands also provide waste treatment services by removing nitrogen and phosphorous from waterways and storing these nutrients, which helps prevent detrimental impacts to waterways, such as algal blooms. Finally, the wetlands will provide prime habitat for a variety of species. This habitat not only benefits the species that make the wetlands a habitat, but also will serve as a cultural and recreational amenity for the surrounding community.

This study uses the value of ecosystem services of an acre of wetlands from a New Jersey Department of Environmental Protection report (State of New Jersey, 2007). The total benefit from wetland ecosystem services is presented in Table 3. The project is expected to have a negligible impact on energy use, noise levels, and the urban heat-island effect.

Table 3. Environmental Benefits of the Project (Undiscounted)

Benefit from…	Benefit (Millions)
Wetland Ecosystem Service	$36.6
Energy Use	Negligible
Noise Level	Negligible
Urban Heat-Island Effect	Negligible

3.1.4. Social Value

The project will affect the community positively by reducing risks to human life, property damage, and displacement that occur from flood events. The project will reduce community and household hardships caused by storm damage and repeated flooding. In Moonachie and Little Ferry, for example, 25 percent of residents whose homes were damaged during Superstorm Sandy experienced emotional distress even three years after the storm, and one in eight residents exhibited signs of post-traumatic stress disorder (Washburn, 2015). This study quantifies the estimated mental health treatment costs and lost productivity using monetary estimates per person extrapolated from national data from the U.S. Department of Housing and Urban Development (2015). This emotional strain results in an estimated treatment cost of $2.1 million per year and $7.4 million in estimated lost productivity. Although the berm is not expected to mitigate widespread hurricane destruction, reduced flood damage will alleviate human suffering caused by repetitive flooding and catastrophic environmental events.

The benefits for low- and moderate-income households are difficult to quantify. The project will serve a low- and moderate-income population that comprises 41.8 percent of the total population of the protected service area. The benefits of the project will apply directly to those who live in the immediate area and will positively impact low- and moderate-income households in the region. Housing prices can be expected to increase as a result of lower flood risks and the addition of the natural amenity created by the restored wetlands and the recreation band along the length of the berm. Homebuyers and lenders place a higher value on homes in areas of reduced flood risk, which should result in increases in local property values (Bin et al., 2006). According to the Trust for Public Land (2009), properties adjacent to parks increase in value about 5 percent due to the amenity value of the parks.

Similarly, the health benefits of the new recreational zones will apply directly to all residents in the area, including low- and moderate-income households. The recreational benefit, including a per-user health and visitor recreational benefit, is estimated by multiplying the population in each area by per-person monetary value of health and recreation benefits (Trust for Public Land, 2009). This yields an average annual benefit of $7.1 million. Applying a discount rate of 7 percent, the total discounted impact is estimated at $95.2 million over the lifetime of the project. The fraction of this estimate that applies directly to low- and moderate-income persons and households is unclear; nevertheless, the benefits should be widely distributed across the resident population. The total social benefits of the project are presented in Table 4.

Table 4. Social Benefits of the Project (Undiscounted)

Benefit from…	Total Undiscounted Benefit (Millions)
Mental Health	$12.9
Health and Recreation	$356.1

3.1.5. Economic Revitalization

Economic revitalization can materialize in many ways, including through the construction of new residential, commercial, or industrial buildings; the development or redevelopment of neighborhoods and districts; or as renewed investor confidence in historically risk-prone areas. For the area protected by the project, where Superstorm Sandy caused catastrophic structural damage and human suffering, the economic revitalization generated by the project will be substantial. The direct, avoided physical damages to structures and property and the prevented human suffering from displacement and fatalities are obvious benefits, but many benefits are indirect or not immediately apparent. Impacts on tourism, residential and commercial property values, tax revenues, and insurance premiums, for example, are important components that contribute to the economic revitalization of the region protected by the project. This section presents a discussion of those potential benefits.

3.1.5.1. Tourism

The impact of Superstorm Sandy on tourism in the State of New Jersey was substantial. The U.S. Department of Commerce (2013) estimated that, in the third quarter of 2013 alone, New Jersey lost approximately $950 million in direct tourism spending. These losses were distributed across the subsectors of the tourism industry, including accommodations ($287.2 million), food services and drinking establishments ($217 million), retail ($46.8 million), recreation ($106.5 million), air transportation ($30.1 million), and other transportation and support activities ($141.0 million).

Tourism data were not available at the individual borough level. Therefore, this study attempts to estimate the avoided damages to tourism from the project based on the disaggregation of tourism estimates for the various jurisdictions in Bergen County. During this disaggregation process, it was not possible to account for tourism hotspots; thus, the study assumes an equal distribution of tourism impacts across the study area. The total annual value of tourism in the protected service area is estimated at $121.6 million based on total area. Although the extent to which the project would directly protect the tourism industry is unclear, the effects could be substantial, as demonstrated by Superstorm Sandy.

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Beyond immediate tourism impacts, American Dream Mall is expected to increase tourism in the area. The 66-acre complex will support its own water and theme park and an indoor ski slope. With space for over 400 vendors and restaurants, the mall is expected to become a major regional tourism draw. The berm will protect this new retail space and prevent closures to the mall and the surrounding area. This added protection likely will increase investor confidence and enhance interest in reserving retail space. Through the avoided damages to American Dream Mall, the neighboring MetLife Stadium, and the additional avoided lost tourism revenue, the berm is expected to affect economic revitalization positively.

Due to uncertainty around the estimation of the benefits to tourism, the impacts to tourism are not included in the NPV or BCR of the project. The values presented are limited to helping frame the potential scope of the additional tourism benefits.

3.1.5.2. Property Values

The project will have a positive impact on property values due to the flood risk reduction coupled with new natural and recreational amenities. This study estimates the increase in property values due to the recreation band using the methodology outlined by Trust for Public Land (2009). This study uses an analogous approach to estimate increases due to reduced flood risk. Across the protected service area, this study estimates property values will increase by $546.3 million as a result of the reduced risk and the recreation band. This increase will result in increased tax revenues, described below.

Separately, the project will prevent decreases in property values due to storm damage. After Superstorm Sandy, the price of properties near the coast dropped considerably. Over time, the volatility of price fluctuations settled, but the average property value in coastal New Jersey still declined by approximately 2 percent (Trif, 2013). Future storms and flooding in the region could result in additional decreases in property values in the absence of the berm.

3.1.5.3. Tax Revenues

The reduced risk of flooding and the recreation band are expected to increase property values and the associated tax revenues. The project likely will encourage further investment in these communities and enhance the revitalization of the area. Across the entire protected service area, annual property taxes are estimated to increase by $17.6 million as a result of the reduced risk and the recreation band. This study estimates the changes to annual tax revenues by measuring the change in property values as described above and multiplying by the municipal specific property tax rates.

3.1.5.4. Insurance Premiums

As a direct result of Superstorm Sandy, insurance premium rates increased. Single-family homes and condominium units experienced an additional surcharge of $25, while multifamily homes and non-residential buildings experienced an analogous surcharge of $250 (NJ Spotlight, 2015). The construction of the berm will reduce the risk associated with 100- and 500-year flood events, which will reduce insurance premiums. This decrease will result in higher disposable incomes of households in the areas protected by the berm, and this, in turn, will result in increased economic activity in the area.

3.2. Qualitative Benefits

This section presents a qualitative discussion of the benefits of the project for factors that were not possible to quantify or monetize appropriately.

3.2.1. Combined-Sewer Overflows

During Superstorm Sandy, the Bergen County Utilities Authority was inundated by the 8.5-foot storm surge, which resulted in the shutdown of sewage treatment operations. This shutdown led to the release of hundreds of thousands of gallons of untreated sewage into the Hackensack River. Sewage releases put the community and wildlife populations at risk for exposure to disease and contamination. The release of untreated sewage increases the toxicity of floodwaters. As the floodwaters retreat, high levels of pollutants and toxins in bodies of water and waterways remain, leading to the death of fish and other animals, as the contaminated habitats cannot support life.

Additionally, pathogens released into the water supply can have lingering health impacts. Viruses, bacteria, and parasites are released by wastewater overflows. Consumption of contaminated water or the recreational use of contaminated waterways can result in a variety of illnesses. As such, beach closures are common after sewer overflows as a preventive measure.

In 2008, the U.S. Environmental Protection Agency estimated the cost of reducing New Jersey's risk for combined sewer overflows at $9.3 billion (Chelser, 2014). Although the project does not include replacement components for the aging system, its construction will prevent floodwaters from inundating sewage plants, allowing planners to focus on controlling additional rainwater and runoff volume.

3.3. Summary of Economic Analysis

Table 5 presents the costs and benefits of the project and the NPV and BCR calculations. Over the 50-year time horizon, the largest cost of the project is the construction cost of the berm at $3.46 million per year. The next largest cost is the administration and contingency costs for the construction at $2.64 million per year, followed by wetland construction ($0.58 million per year), recreation zone construction ($0.54 million per year), annual berm maintenance ($0.52 million per year), and land acquisition ($0.50 million per year).

Table 5. *Berm Project Costs and Benefits.*[8]

Impacts	Average Annual Impact (Millions)	50-year Total Discounted Impact (Millions)	
		7-Percent Discounting	3-Percent Discounting
Costs			
Berm Construction	$3.46	$167.53	$170.67
Annual Berm Maintenance	$0.52	$7.67	$13.77
Recreation Zone Construction	$0.54	$26.33	$26.83
Administration and Contingency	$2.64	$127.60	$129.99
Land Acquisition	$0.50	$24.18	$24.64
Wetland Construction	$0.58	$28.15	$28.68
Benefits			
Avoided Residential Damages	$54.40	$551.38	$1,221.33
Avoided Commercial Damages	$9.47	$91.76	$208.57
Avoided Casualties	$0.18	$1.83	$4.04
Avoided Utility Damages	$0.86	$7.72	$18.35
Avoided Municipal Damages	$0.00	$0.01	$0.01
Avoided Teterboro Airport Damages	$0.67	$6.78	$14.99
Avoided MetLife Stadium Damages	$0.02	$0.22	$0.50
Avoided American Dream Mall Damages	$2.45	$32.72	$62.56
Wetland Ecosystem Services	$0.76	$9.78	$18.69
Recreational and Health Benefits	$7.12	$95.19	$181.96
Avoided Debris Removal	$0.12	$1.21	$2.69
Total Costs	**$8.25**	**$381.46**	**$394.57**

[8] Construction costs are realized in the first two years; although an annual equivalent is shown in the second column, construction costs are discounted for the construction period only.

Impacts	Average Annual Impact (Millions)	50-year Total Discounted Impact (Millions)	
		7-Percent Discounting	3-Percent Discounting
Benefits			
Total Benefits	**$76.05**	**$798.60**	**$1,733.70**
Net Present Value (NPV) [Total Benefits − Total Costs]	**$65.40**	**$331.30**	**$1,241.37**
Benefit-Cost Ratio (BCR) [Total Benefits / Total Costs]		**2.09**	**4.39**

Note: Totals might not sum due to rounding.

Figure 3 presents the total benefits with 7-percent discounting. The largest benefits, comprising more than 92 percent of the total benefits, are the avoided residential damages ($551.4 million, 69.0 percent), recreational and health benefits ($95.2 million, 11.9 percent), and avoided commercial damages ($91.2 million, 11.5 percent).

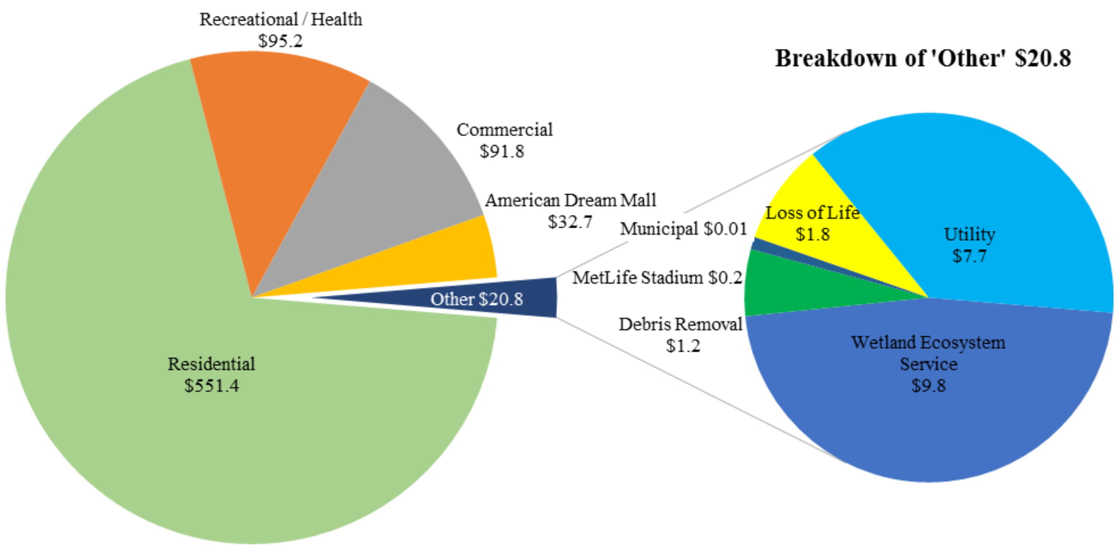

Figure 3. Breakdown of total benefits (at 7-percent discounting, million dollars)

Figure 4 presents the net benefits over time. It shows at what point the project breaks even, or when the cumulative discounted benefits equal cumulative discounted costs. The negative slopes of the lines in the early years represent the construction phase when most of the costs are accrued, but before the benefits begin to accrue. As the construction period ends and the benefits begin to accrue, the slopes turn positive. The cumulative net present values cross the breakeven line in 2029 and 2026 (at 7-percent and 3-percent discounting, respectively). After that point, the project gains additional benefit beyond the costs of construction. A kink point occurs halfway through the analysis period, which represents when the flooding risk rates are doubled, resulting in higher avoided damages after that point; we use flooding risk rates as a proxy for the impacts of sea level rise (Massachusetts Institute of Technology, 2014).

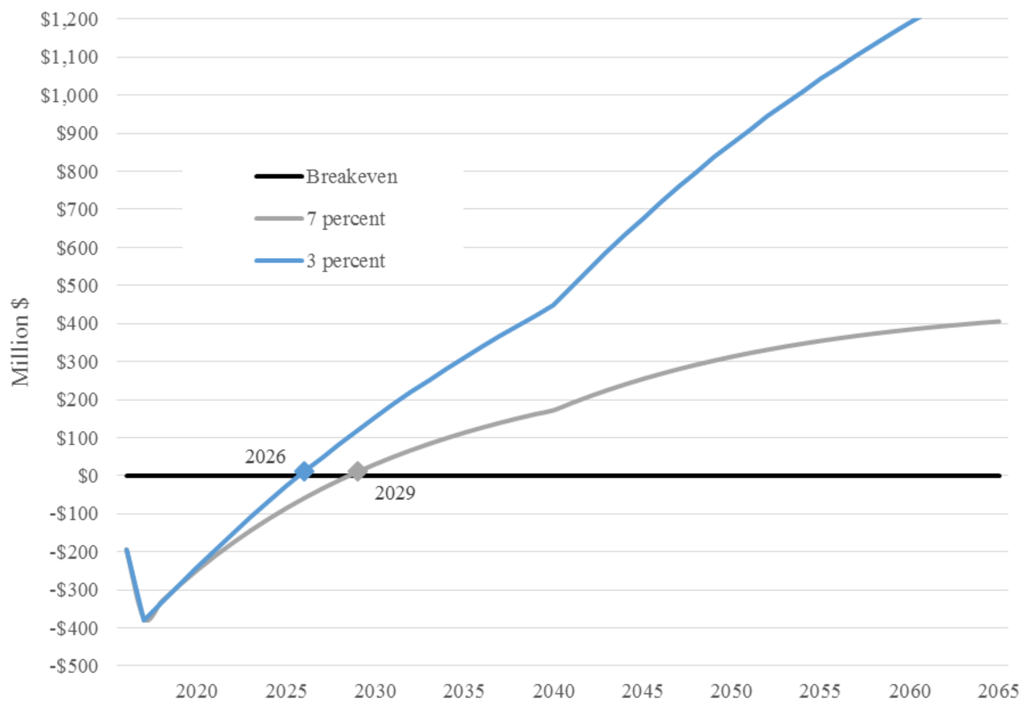

Figure 4. Cumulative net present value

These results demonstrate several conclusions about the project. First, Figure 4 demonstrates how steady increases in cumulative net present value over time increase the cost-effectiveness of the project as additional future damages are avoided. The slope of the line increases after the kink point due to the increased risk of sea level rise, which increases the benefits associated with avoided damages. If sea level rise is greater (smaller) than forecasted, the benefits of the project will be greater (smaller) than estimated. Similarly, more (less) frequent storms than those forecasted would increase (decrease) the benefits and the cost-effectiveness of the project. The project is designed with several feet of freeboard, or protected vertical space above the high water level. Therefore, the damages caused by an increase in seal level beyond that forecasted would still be mitigated by the project.

Secondly, the results indicate that even if delays or other factors that increase the budget over the assumed 15 percent contingency occur, the project will remain cost-effective. The breakeven points occur early in the useful life of the project, and any additional construction costs would simply transpose the lines downwards, thus pushing the breakeven points further out into the analysis timeline. Except for significant unforeseen construction costs of nearly $400 million—which would more than double the total costs—the project would remain cost-effective even with 3 percent discounting.

4. CONCLUSION

This section presents a discussion of the implications (including a sensitivity analysis) and limitations of this case study and possibilities for future research.

4.1. Implications

This study uses data from a variety of publicly available sources to conduct a cost-benefit analysis of implementing a climate adaption measure in Bergen County, New Jersey, to protect a region devastated by Hurricane Sandy. Based on the economic analysis, the project is highly cost beneficial over its 50-year timeframe. This analysis demonstrates that climate change adaptation investments can be cost beneficial even though they mitigate the impacts of low-probability, high-consequence events.

The primary implication of this case study pertains to the importance of protecting residents and business operations from coastal flooding, especially areas vulnerable to storm surge. The avoided residential and commercial damages comprise the majority of the benefits of the proposed berm. The total discounted avoided residential and commercial damages sum to $551.4 million and $91.8 million with 7-percent discounting, which amounts to approximately 70 percent and 12 percent of the total benefits, respectively.

As a sensitivity analysis, the study repeated the breakeven analysis with all costs included but only the avoided residential and commercial damages as benefits. In this scenario, we assume no prevented environmental damages, no health benefits, no loss of utilities or emergency services, and no damages to the airport or stadium. Under that alternative scenario, only 36 percent and 61 percent of the residential and commercial damages need to be prevented for the project to be cost beneficial (at 3- and 7-percent discounting, respectively). If commercial damages are also excluded—leaving only avoided residential damages as benefits—the berm is cost beneficial if it prevents 71 percent of the residential damages. These alternative scenarios further support the long-term benefits of the flood mitigation investment and demonstrate that protecting residential infrastructure and commercial business operations are of paramount importance.

4.2. Limitations

This case study reveals several limitations of the methodology. Flood events such as 100- and 500-year floods are low-probability, high-consequence events that cause catastrophic destruction to the regions they impact. Because of their rare occurrence, the historical data on which analyses can be conducted are limited. These limitations make estimates based on these data uncertain and constrain their use in other analytical contexts.

The FEMA BCA tool is useful for estimating the costs and benefits of hazard mitigation alternatives and is widely used in applications for Hazard Mitigation Assistance grants. The tool, however, has several limitations. One of the tool's greatest strengths—and arguably its greatest limitation—is its reliance on micro-level data. The FEMA BCA tool can model damages to individual structures based on flood levels using depth-damage functions encoded into the model. However, structure-level data such as basement types, first-floor elevations, and structure types, are necessary inputs. Obtaining such specific information across an entire community can be difficult; obtaining such data across several communities is both expensive and time consuming. This study relied on scaling damages from a previous study and used the FEMA BCA tool to estimate annualized benefits rather than attempting to model the damages at the individual structure level. Such a work-around is one way to alleviate the tool's rigidness at the macro level. We would like to see the model be able to accommodate larger scale, macro-level analyses with greater flexibility as the tool continues to evolve.

The encoded data in the FEMA BCA tool is used to standardize analyses and obtain results that are comparable across studies—namely, FEMA Hazard Mitigation Assistance grants. These data, however, are often criticized for being outdated or rigid. The FEMA BCA tool uses internal depth-damage functions to estimate structure-specific damages based on user inputs. The internal depth-damage functions are standardized and do not fit every situation. The FEMA BCA tool allows for custom depth-damage functions to be used, but these data place the burden on the user to supply the information. Similar limitations apply to other encoded data, such as per diem lodging rates for residential displacement or estimates of loss of function of utilities. These preset values allow the user to develop estimates quickly but also shoehorn results. While the user can manually change the inputs, it would be useful for the tool to provide more clarity on the encoded data and potentially provide a series of acceptable alternatives for different values rather than for only one option.

The study was not able to fully ground-truth the FEMA model to the study area because of a lack of available data. The study relies on the values encoded into the tool and does not supplement the tool with other forms of data. Nevertheless, the general magnitude of the estimates is comparable to that in the MIT Rebuild by Design New Meadowlands study. The Rebuild by Design study did not use the FEMA BCA tool yet yields comparable results across the regions where the two studies overlap.

One challenge of analyzing low-probability, high-consequence events is that because they occur rarely, the sample sizes for many required input data are very small. Another challenge of low-probability, high-consequence events pertains to geographic applicability. This case study sought data that was specific to the protected service area. In cases where data relevant to the protected service area were not available, the study uses benefit transfer methods to estimate those parameters using data from similar events in other geographic locations. A common challenge encountered in benefit-transfer analysis, however, is the requirement that the estimate from the existing study be closely applicable to the new area. The challenge comes from identifying data from existing studies with geographic areas that are representative of the new area. In particular, remote areas with idiosyncratic features pose unique analytical challenges due to their lack of comparability with geographic areas that have experienced disaster events.

This case study estimates the costs and benefits of the proposed berm project as designed but does not estimate other potential design, engineering, or natural alternatives. Alternative structural designs—variations on the size, width, length, or mix of natural and gray infrastructure—could prove equally or more cost-beneficial, but such assessments are beyond the scope of this study.

FEMA guidance lists several flood-proofing alternatives to barriers. These alternatives include drainage improvements, wet flood proofing (uninhabited portions of structure resistant to damage and allowed to flood), dry flood proofing (sealing structures to prevent water from entering), structure elevation, and relocation or acquisition out of the floodplain. Many of these alternatives are included as potential mitigation measures in the FEMA BCA tool; these alternatives, however, are not considered in this study.

Another limitation of the case study is the assumption that the area and its population and infrastructure will remain relatively stable over the next 50 years. For example, the methodology assumes that the residential housing stock and its aggregate value will remain relatively stable over the period. Although historical data and established analytical methodologies exist that could be used to forecast

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changes over time in the residential housing stock and its value, forecasting 50-year changes in each input parameter is speculative due to the length of the forecasting time horizon and is outside the scope of this case study.

A final limitation of this study is the estimation of project benefits based on 100- and 500-year storm events. The project likely will prevent damages from more frequent, but less damaging, storms. For example, damages from 50- or 75-year storms might result in significant damages in the absence of the project, but the analysis does not account for these benefits. Sufficient data to measure a wider variety of storms were not available, but these benefits would only increase the NPV and BCR, as the costs remain unchanged. Therefore, the results of the analysis should be viewed as a lower bound of the NPVs and BCRs; the total benefits of the project could be greater.

4.3. Areas for Future Research

Further research should be performed to apply benefit-cost analysis techniques and the BCA tool to other climate change adaptation contexts. Such research would demonstrate the applicability of the tool in other contexts and identify additional limitations and areas for improvement.

Another area of future research is the expansion of the database of disaster events. This study relied heavily on analyses specific to the study area. When data relevant to the study area were not available, the study estimated benefits using a benefit-transfer methodology. As discussed above, a common challenge encountered in benefit-transfer contexts is identifying data from an existing study that has a geographic area that is relatively representative of the new area. By compiling a comprehensive database of disaster events and related economic parameters, the identification of the most relevant and applicable parameters would be more efficient and effective, yielding more accurate and reliable forecasts.

Future research also could account for a wider variety of storms in the estimation of the cost effectiveness of projects. This case study accounted only for benefits of the project that result from the prevented damages of 100- and 500-year storms. The project could prevent additional damages from more frequent but less damaging storms. The data were not available to measure the benefits from a wider variety of storms, but future research could capture a more complete picture of the cost effectiveness of projects by accounting for prevented damages for a greater variety of storm events.

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