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LETTER

Flood damage reduction benefits and costs in Louisiana’s 2017 Coastal Master Plan

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Abstract

The State of Louisiana faces a substantial planning challenge in addressing the joint problems of rapid coastal land loss and storm surge flood risk, exacerbated by rising sea levels and land subsidence. To address these twin challenges, Louisiana has developed a series of coastwide master plans that include substantial investments in coastal restoration and hurricane flood risk reduction, with the most recent update in 2017 that includes about $50 billion in projects to be implemented over 50 years (approximately 2016–2065). This research builds on the integrated modeling analysis conducted in support of Louisiana’s 2017 Coastal Master Plan. We use the Coastal Louisiana Risk Assessment (CLARA) model to project coastal flood damage over time under different scenarios, either in a future without action or with the master plan implemented according to its intended schedule. Analysis results suggest positive, notable benefits from risk reduction investments over a range of assumptions about future conditions and economic considerations. We estimate a 50-year net economic benefit from master plan risk reduction investments of $39.6 to $59.8 billion (benefit-cost ratios of 3.0 to 4.1) across several future scenarios with a 3% assumed discount rate, for instance. Scenarios with higher sea level rise (SLR) and coastal subsidence rates generally yield greater net economic benefit from flood risk reduction investments. Net benefit from risk reduction investments is negative only with the highest discount rate assumption (7%) and if costs are somewhat higher than initially estimated for structural or nonstructural projects. In general, implementing the master plan could yield considerable net economic benefit from damage reduction investment for coastal Louisiana in many plausible future scenarios if implemented as planned.

1. Introduction

The State of Louisiana faces a substantial planning challenge in addressing the joint problems of massive coastal land loss and storm surge flood risk, exacerbated by rising sea levels and land subsidence (Peyronnin et al 2013). While recent pluvial events have resulted in severe flooding and damage to Baton Rouge and other inland communities (Wang et al 2016), the state’s coastal zone has been impacted by 43 tropical cyclones since 1950, 18 of which had a central pressure of 985 mb or less at landfall (Landsea et al 2018). To address the twin challenges of coastal storm surge and land loss, the state initiated a long-term integrated master planning process after Hurricanes Katrina and Rita in 2005, led by the newly created Coastal Protection and Restoration Authority (CPRA) (Coastal Protection and Restoration Authority of Louisiana 2007). This process mandates the

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development and maintenance of a comprehensive coastwide master plan; the most recent version is Louisiana’s 2017 Comprehensive Master Plan for a Sustainable Coast, a 50-year plan guiding approximately $50 billion in current and future coastal investments (Coastal Protection and Restoration Authority of Louisiana 2017b).

Louisiana’s 2017 Coastal Master Plan was developed using best-available science regarding the coastal landscape and ecosystem processes, and current and future vulnerability to coastal flood risk. Coastal flood risk reduction and restoration benefits were estimated using a series of integrated systems models, originally developed for the 2012 analysis and subsequently improved for 2017 (Peyronnin et al 2013, Coastal Protection and Restoration Authority of Louisiana 2017a, Meselhe et al 2017a). Projects were selected for the master plan through a participatory stakeholder process supported by comparisons of estimated benefits with investment costs in different scenarios over a 50-year (2015–2065) timeframe, with a focus on (1) minimizing coastal land loss or maximizing land retention, measured as coastal land area (acres); and (2) minimizing flood risk, measured as expected annual damage (EAD, in dollars) (Groves et al 2012, Groves and Sharon 2013, Groves et al 2017).

CPRA also developed a range of other decision criteria to guide project selection or serve as constraints, working in partnership with local planners and stakeholders, but these criteria were not used to directly rank the proposed projects and instead were used to constrain the final project selection in some cases (Groves et al 2014, Reed et al 2017). Barnes et al (2017) recently estimated the economic impact of coastal land loss for Louisiana, but the economic benefits of coastal land building were not formally assessed in the 2017 master plan. As a result, the analysis relied on the cost-effectiveness of land building (cost per acre saved/restored over 50 years) and flood damage reduction (cost per dollar of EAD reduced in 2065) as the primary decision criteria. However, a traditional benefit-cost analysis was not employed.

In this article, we extend the analysis initially conducted by a large, multi-institution research team in support of Louisiana’s 2017 Coastal Master Plan to develop estimates of the net economic benefit from large-scale risk reduction project investments. Risk reduction investments in the master plan include structural risk reduction projects (e.g., levees, floodwalls, flood gates, and pumps) and nonstructural investments focused on hardening of individual assets (e.g., elevation-in-place, floodproofing) or voluntary acquisition and removal from the floodplain. We also present estimates of the net present value of direct flood damage reduction from the master plan as a whole, including ecosystem restoration projects not explicitly formulated to reduce risk.

2. Methods

We estimated risk reduction benefits using the Coastal Louisiana Risk Assessment (CLARA) model, originally developed at the RAND Corporation, a non-profit research organization, in support of Louisiana’s 2012 Coastal Master Plan (Fischbach et al 2012b, Johnson et al 2013, Fischbach et al 2017a). CLARA estimates flood depth and damage exceedance probability curves under a range of assumptions about environmental conditions and protection system configurations. CLARA builds on previous studies of flood risk in Louisiana—in particular, the Louisiana Coastal Protection and Restoration study (US Army Corps of Engineers 2009) and the Interagency Performance Taskforce project (Interagency Performance Evaluation Taskforce 2009)—and other models, notably the Hazards US Multi-Hazard (Hazus-MH) model developed and maintained by the Federal Emergency Management Agency (FEMA) (Federal Emergency Management Agency 2009). CLARA’s damage module estimates EAD from storm surge-based flooding, under snapshots of current and future conditions, and with and without implementation of projects from the master plan. Here, we provide a concise overview of relevant model details; see the supplemental annex to this article, as well as Fischbach et al (2012a), Johnson et al (2013), Fischbach et al (2017a), for a more complete description of CLARA methods and validation.

2.1. The CLARA model

Flood depths and damage are calculated in grid cells that span the coastal region of Louisiana, forming a mixed-resolution grid with a minimum resolution of 1 km². More densely populated areas have higher resolution, such that each census block is represented by at least one grid cell (Fischbach et al 2017b). The CLARA model is configured to estimate damage under scenarios reflecting different geophysical conditions (e.g., sea level rise [SLR], storm frequency) and socioeconomic assumptions (e.g., changes in future assets on the coast).

2.1.1. Flood depths

CLARA estimates the probability distribution of flood depths based on simulations of ‘synthetic storm’ events with minimum central pressures ranging from 975 to 900 mb, representing tropical cyclones from approximately Category 1 to Category 5 on the Saffir–Simpson scale. The particular storms evaluated were chosen based on their ability to produce estimates of flood depth exceedances coastwide that are similar to those
produced by a larger corpus of 446 storms developed by the US Army Corps of Engineers for analysis by FEMA (Fischbach et al 2016). A Monte Carlo simulation of processes such as surge/wave overtopping and levee failures is employed to generate a frequency distribution of flood depths associated with each storm. This is then combined with estimates of the relative likelihood of each storm to produce an empirical cumulative distribution function, based on a modified version of the Joint Probability Method with Optimal Sampling (JPM-OS) (Resio 2007, Toro et al 2010, Fischbach et al 2012a).

2.1.2. Direct economic damage
Damage is calculated as a deterministic function of flood depths and the quantity, type, and value of assets in each grid cell, based primarily on Hazus-MH methodology. This includes direct economic losses such as damage to structures (and their contents), vehicles, agricultural crops, and roads; it also includes quantities like lost wages and displacement costs during a reconstruction period. It does not, however, consider the value of loss of life or macroeconomic spillovers (e.g., impacts of reduced refinery capacity on gross domestic product) or other indirect economic impacts from flooding. Losses are expressed in constant 2015 US dollars.

Flood depth and damage exceedances are calculated at 22 return periods ranging from the 5-year to 2000-year values. We calculate EAD at each model grid point; values reported here are aggregated over all asset types and spatially to 54 ‘risk regions’ spanning the coast (Coastal Protection and Restoration Authority of Louisiana 2017b). Risk regions are primarily defined using parish boundaries, with parishes being split into multiple risk regions by federally accredited flood protection systems (e.g., levees, floodwalls) and/or by major bodies of water (e.g., the Mississippi and Atchafalaya rivers). Conditions, and consequently EAD, change over time as a result of factors like SLR, land subsidence, changes to hurricane characteristics, and economic growth, as described in the Experimental Design section.

Reported damage figures reflect replacement or repair cost estimates, assuming that assets are generally replaced after a flood event, either locally or elsewhere (Johnson et al 2013). This is consistent with the National Flood Insurance Program, which pays out actual replacement costs for policies on residential dwellings that cover up to at least 80% of the replacement cost. Given the relatively old building stock in the region, reporting only depreciated exposure values could substantially underestimate the real economic costs associated with reconstruction.

2.2. Modeling change over time in future scenarios
For the 2017 master plan, we estimated EAD associated with current conditions (2015) and three future time periods: 10, 25 and 50 years from the current baseline (2025, 2040, and 2065, respectively). To better estimate how risk changes over time, we constructed flood depth exceedance curves for every year from 2015 to 2065 by linearly interpolating the depth exceedances at each return period between the time periods explicitly modeled. We then ran the damage model on an annual basis to produce a time series of how EAD changes in response to changing flood depth distributions and changes to the value of exposed assets as the coastal population changes (also modeled using interpolation between time periods).

Although linear changes to flood depth exceedances are a simplifying assumption, the resulting damage still displays nonlinear behavior. Depth-damage curves, the functions relating flood depths to the proportion of an asset’s value that is damaged, are not linear (Federal Emergency Management Agency 2005, 2009). Nor is the relationship between storm surge elevation and overtopping rates (the rate at which water flows over a levee or floodwall when surge or waves exceed the barrier height) (van der Meer 2002). Further, risk in the intervening years will change dramatically as the master plan’s structural protection projects are implemented.

2.2.1. Implementation of Louisiana’s 2017 coastal master plan
The master plan prioritizes recommended projects into three implementation periods (Years 1–10, 11–30, and 31–50). The master plan team separately defined durations and costs for each project, including engineering and design, construction, and operations and maintenance phases (McMann et al 2017). This prior analysis assumed

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6 92 storms were used to inform the distribution of flood depths in the current conditions baseline, while 60 were used for future scenarios. This resulted in response surfaces spanning 168 and 120 synthetic storms being run through CLARA in current and future scenarios, respectively.

7 In areas enclosed by protection systems, flood depths are also influenced by rainfall and the total volume of water removed from the system by pumping stations (where applicable).

8 EAD can be interpreted as the average amount of damage that would occur over many years facing the same underlying conditions. In practice, some areas may go years without experiencing flooding, while others may see multiple flood events in successive years.
the costs of each phase of a project are incurred uniformly throughout the phase’s duration; cumulative undiscounted cash flows of project costs are broken out by project type in figure 1. The master plan also made the conservative assumption that projects have no impact on flood depth distributions until the construction phase is completed. Consistent with this approach, we adopt a 50-year planning horizon ending in 2065 when considering both costs and benefits. Given the long lifetime of structural risk reduction infrastructure, this represents a conservative assumption that may underestimate the true net present value (NPV) of the master plan. This is due to the fact that substantial benefits may continue to accrue beyond the planning horizon, while continuing operations and maintenance costs associated with the master plan projects are a minor expense compared to the costs, borne before 2065, of design and construction.

As part of the master plan analysis, we modeled a series of landscapes with combinations of structural risk reduction projects implemented that are sufficiently far apart geospatially for their impacts on storm surge and waves to be considered independent. We also ran a landscape that included all recommended structural risk reduction projects but excluded all coastal restoration projects. These model runs, compared to a set of Future Without Action (FWOA) landscapes, allowed us to identify each project’s ‘zone of influence,’ the set of grid points whose flood depth distributions are altered by implementing the project. To generate the series of flood depth distributions over time, we switch each grid point from the FWOA flood depths to the ‘Future with Master Plan’ depths in the first year after the construction phase ends on a structural risk reduction project that impacts the grid point.9

2.3. Experimental design
As years pass, flood risk changes. The underlying storm hazard may change with differences in future hurricane frequency or intensity (Emanuel 2005, Landsea et al 2006, Bender et al 2010, Hill and Lackmann 2011, Grinsted et al 2013). Vulnerability can increase as the coastal landscape is reshaped by SLR, natural land subsidence, erosion, sediment deposition, and anthropogenic changes (Barras et al 2003, Meehl et al 2005). Economic development impacts the quantity and value of exposed assets, and the provision of structural protection measures may cause shifts in development patterns (Montz 2000, Burby 2006, Kahan et al 2006, Olshansky 2006).

To account for this uncertainty, we examined the benefits of the master plan in several future scenarios over a 50-year planning horizon. The Low, Medium, and High ‘environmental scenarios’ defined in the master plan study were adopted to represent a range of plausible assumptions about future local SLR, land subsidence, and changes to the average intensity and frequency of Atlantic cyclones (Meselhe et al 2017b). Land subsidence rates vary throughout the coastal zone, so the values given in table 1 correspond to percentiles within a range representing uncertainty in future rates at each spatial location within the study region. Other flood risk scenario uncertainties considered in the master plan analysis are shown at nominal values based on prior sensitivity.

9 We note that this may not represent true changes in flood depth distributions in areas where multiple structural risk reduction projects interact hydrodynamically.
Table 1. Summary of modeled scenario uncertainties (changes over 50 Years).

| Environmental Uncertainty | Low Scenario | Medium Scenario | High Scenario |
|---------------------------|--------------|-----------------|--------------|
| Eustatic SLR              | 0.43 m       | 0.63 m          | 0.83 m       |
| Subsidence (varies spatially⁴) | 20% of range | 20% of range    | 50% of range |
| Average storm intensity   | +10%         | +12.5%          | +15%         |
| Overall storm frequency   | −28%         | −14%            | +0%          |

⁴ Subsidence rates range from 0 to 35 mm yr⁻¹ across 17 geographical regions in coastal Louisiana. Specific rates selected vary by region (Reed and Yuill 2017).

analysis (Fischbach et al 2017a).¹⁰ A summary of the relevant uncertain parameters applied here is provided in table 1 (Meselhe et al 2017b).

These scenarios represent a convenience sample of scenarios available for analysis of a range of future conditions. We agree with the perspective of Stainforth et al (2007), that scenario ensembles such as this are necessarily only a ‘lower bound on the maximum range of uncertainty’ (Stainforth et al 2007). One can imagine alternative future conditions that could produce impacts outside of the range of what is presented here; the master plan’s scenarios only represent an attempt to assess its impacts over a subset of plausible future conditions.

2.3.1. Discounting

The choice of an appropriate discount rate for large capital projects for climate change adaptation and catastrophe risk management is contentious. Ermolieva et al (2012) argue that any typical discount rate is tantamount to evaluating benefits over a finite time horizon of only a few decades, rendering it impossible to properly evaluate the impacts of protection against very low-frequency events. The US Army Corps of Engineers provides guidance recommending a 2.875% federal discount rate for Corps projects in Fiscal Year 2018; this recommended rate has declined significantly in recent years, from a peak of 8.875% in 1990 (US Army Corps of Engineers 2012). A growing body of literature argues for the use of a discount rate that varies over time (Arrow et al 2014), but this continues to be a hotly-debated research area due to the degree of subjectivity involved (Burke et al 2016). Federal agencies in the United States do not provide standardized guidance, with multiple rules arguably relevant to the master plan recommending rates ranging from 0.6% to 7% (US Army Corps of Engineers 2012, US Office of Management and Budget 2003a, 2003b, Lavappa and Kneifel 2018). To address this issue, we ran all benefit-cost calculations with multiple discount rates (0%, 1%, 3%, and 7%). Rather than advocating for any particular rate, this serves as a sensitivity analysis. In addition, we have identified the rate in each environmental scenario at which the NPV of the master plan is zero (i.e., the internal rate of return).

3. Results

Figure 2 depicts flood depths with a 1% annual exceedance probability (AEP) in Year 50 of a FWOA (left pane) and estimated flood depth reduction (right pane) with all projects implemented for the Medium (top row) and High (bottom row) scenarios. In the right pane, green shades indicate areas where flood depth is reduced; tan shades, alternately, show areas in which depths increase with the master plan implemented.

Results show that many areas of coastal Louisiana could see depths in excess of 5 m with a 1% AEP, especially in the High scenario. Master plan reductions of this flooding by 1–5 m for many populated areas in the southeast and central coast. Some of this reduction can be attributed to coastal restoration projects. For example, no levees are proposed in the master plan for the southwest portion of the state (Cameron and Calcasieu parishes), so all flood depth reduction in this region can be attributed to marsh creation, ridge restoration, and other restoration project types. In addition, some areas—typically those seaward of new levee alignments—experience increased flood depths of 1–2 m when compared with a FWOA.

Figure 3 shows how flood depths translate to EAD over a 50-year time series for the Louisiana coast. Figures show undiscounted EAD by year (billions of 2015 $) in the Low, Medium, and High environmental scenarios. The colored line represents the median value, while the shaded gray band shows the estimated 10th to 90th

¹⁰ This paper presents results using CLARA’s IPET Low fragility scenario and Historic economic growth scenario. Results from the 2017 Master Plan indicated that risk reduction did not substantially vary across the economic growth scenarios modeled. The IPET Low fragility scenario is a middle-of-the-road scenario that was typically used when communicating the 2017 Master Plan results. Other than a ‘No Fragility’ scenario that assumes system failures would never occur, it produces the lowest probabilities of system failure among the fragility curves implemented in CLARA. As such, it represents a conservative fragility scenario, in the sense that other scenarios would typically produce greater risk reduction and therefore greater benefit-cost ratios. Refer to Fischbach et al (2017a) for more detail on assumptions and implementation underpinning these scenarios.
In the FWOA, EAD climbs steadily throughout the first 30 years, with a steeper trend beginning after 2045 that is largely attributable to the accelerating rate of SLR in the Medium and High scenarios.

Analysis of flood depth exceedances suggests that after 2045, surge and wave exceedances reach levels that start to induce a greater likelihood of system failures in protection systems designed to protect against contemporary 100-year events, resulting in a sudden uptick in expected annual damage. With the master plan

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**Figure 2.** Coastal flood depths in a future without action (left) and depth reduction with the master plan implemented (right). Results represent the median flood depth or depth reduction estimated at the 100-year return period (1% annual exceedance probability [AEP]), for a Year 50 future condition in the Medium (top) and High (bottom) environmental scenarios.

**Figure 3.** EAD over time in a future without action or with the master plan implemented, in the Low (top), Medium (middle), and High (bottom) scenarios. Lines show median EAD estimates, while shading shows CLARA estimates of parametric uncertainty (10th to 90th percentile).
implemented on its recommended schedule, EAD remains relatively flat from now until that same time period around the year 2045. EAD accelerates more rapidly from this point forward in the High scenario compared to the Low or Medium scenario even with plan projects implemented.

In summarizing the NPV of the planned investments, we begin by presenting coastwide risk reduction benefits and costs only associated with the master plan’s structural and nonstructural protection projects. We then consider the benefits and costs from the master plan as a whole, including coastal restoration benefits and costs. While restoration projects do have risk reduction benefits through various mechanisms for attenuating incoming storm surge and waves, their risk reduction benefits were not maximized, as restoration projects were selected based on their impacts on the Plan’s other decision criteria. For example, other master plan modeling efforts tracked the impact of projects on suitable habitat for 14 different animal species, including brown and white shrimp, oysters, Gulf menhaden, and spotted seatrout, as well as other considerations such as navigation and flood protection of historic properties (Meselhe et al. 2017a).

Table 2 summarizes the present value of reductions in EAD (EAD Delta), present value of costs, coastwide net present value (NPV), and benefit-cost ratio (BCR) of the master plan under each of the three environmental scenarios, with and without restoration projects included, and under each discount rate. Note that results for the Low scenario are only shown for the full master plan, as an alternative future with the Low environmental conditions and restoration projects excluded was not evaluated as part of the 2017 master plan modeling effort.

These results show that discounted benefits exceed costs across most scenarios modeled when assuming the master plan’s best estimates of project costs. In fact, even if the costs associated with restoration projects are included, NPV is negative—corresponding to a BCR below 1.0—only in the Low and Medium scenarios when combined with a 7% discount rate. As expected, the return on investment in risk reduction is greater in cases where the baseline risk without the master plan is larger (e.g., in the High scenario). Because EAD in the FWOA case increases over time, during the last two decades of the planning horizon in particular, and project costs are heavily front-loaded during the construction phase as compared to operations and maintenance, the NPV and BCR are greater when adopting a smaller discount rate.

Including restoration projects as part of the analysis roughly doubles the undiscounted cost of the master plan. However, we see in Table 2 that the restoration projects do also provide some additional benefits in terms of risk reduction. For example, in the undiscounted, High scenario case, restoration projects add $25.6 billion in costs but provide an additional risk reduction benefit over 50 years of $20 billion in present value terms, nearly paying for themselves. Using a high discount rate, however, nearly wipes out this effect. At a 7% discount rate, the present value of costs goes up by $10.8 billion when including restoration projects, but the additional risk reduction benefit they provide in the High scenario is only $1.4 billion in present value terms. A small number of restoration projects located near populated areas may be responsible for a large portion of this risk reduction (Environmental Defense Fund and Qualified Ventures 2018). However, we emphasize that risk reduction benefits estimated by CLARA include only direct economic losses and do not account for the value of ecosystem services provided by restoration projects and associated with maintaining the current state of coastal wetlands.

We also calculated the internal rate of return (IRR)—defined as the discount rate at which NPV would equal 0—for each alignment and scenario (Table 3). This additional calculation confirms that the net benefit is neutral.

### Table 2. Coastwide benefit-cost analysis summary (billions of discounted 2015$).

| Future Scenario | 2017 Master Plan (No Restoration) | 2017 Master Plan (Including Restoration) |
|-----------------|-----------------------------------|------------------------------------------|
|                 | 0%  | 1%  | 3%  | 7%  | 0%  | 1%  | 3%  | 7%  |
| Low EAD Delta   | —   | —   | —   | —   | 103.0 | 75.0 | 41.7 | 15.6 |
| Total Cost      | —   | —   | —   | —   | 50.8  | 44.8 | 36.2 | 26.2 |
| NPV             | —   | —   | —   | —   | 32.2  | 30.2 | 3.5  | −10.5|
| BCR             | —   | —   | 1.7 | —   | 2.0   | 1.7  | 1.2  | 0.6  |
| Medium EAD Delta| 153.9 | 109.9 | 58.9 | 20.6 | 158.5 | 113.1 | 60.4 | 20.9 |
| Total Cost      | 25.2 | 22.8 | 19.3 | 15.4 | 50.8  | 44.8 | 36.2 | 26.2 |
| NPV             | 128.7 | 87.2 | 39.6 | 5.2  | 107.7 | 68.3 | 24.2 | −5.2 |
| BCR             | 6.1  | 4.8  | 3.0  | 1.3  | 3.1   | 2.5  | 1.7  | 0.8  |
| High EAD Delta  | 210.9 | 149.8 | 79.1 | 26.7 | 230.9 | 163.1 | 85.2 | 28.1 |
| Total Cost      | 25.2 | 22.8 | 19.3 | 15.4 | 50.8  | 44.8 | 36.2 | 26.2 |
| NPV             | 185.7 | 127.0 | 59.8 | 11.3 | 180.1 | 118.3 | 49.0 | 1.9  |
| BCR             | 8.4  | 6.6  | 4.1  | 1.7  | 4.5   | 3.6  | 2.4  | 1.1  |
to positive for relatively high discount rates, with the exception of the entire master plan (including restoration projects) under the Low scenario (IRR of 3.8%).

Next, we take a closer look at how the benefits accrue over time. Figure 4 shows the NPV of the master plan, with and without restoration projects, as costs and benefits accrue from 2015 to 2065. As with most investments with high upfront costs and benefits that accrue over the long-term, NPV is initially negative and then increases in later decades. This shows that the payback period of the planned investments is approximately 20 years, if the future resembles the High scenario and restoration projects are excluded, and decision-makers adopt a small discount rate of 1%–3%. The payback period becomes longer in the low or medium future scenarios, or when using a higher discount rate.

Finally, we examine the net value of the master plan accounting for cost uncertainty associated with risk reduction projects. Because uncertainty related to the design, construction, or operations and maintenance costs of engineered projects was not directly estimated in the master plan analysis, we use simple cost multipliers to support preliminary exploration. Structural risk reduction projects are assumed to have a best-estimate cost of $19.2 billion (undiscounted), while the best estimate of nonstructural costs is $6 billion; as such, the economic results are more sensitive to uncertainty in structural project costs.

Table 4 shows the NPV and BCR of the 2017 master plan investments if structural and nonstructural risk reduction costs turn out to be equal to their best estimates, 50%, or 100% greater than initially estimated. For simplicity, we exclude restoration projects from these results.

Table 4 shows that, when considering structural and nonstructural risk reduction costs only, the investments would fail to break even only with a 7% assumed discount rate and in scenarios where structural project costs are

Table 3. Estimated internal rate of return (%).

| Future Scenario | 2017 Master Plan (No Restoration) | 2017 Master Plan (Including Restoration) |
|-----------------|-----------------------------------|------------------------------------------|
| Low             | —                                 | 3.8                                      |
| Medium          | 8.6                               | 5.7                                      |
| High            | 10.1                              | 7.4                                      |

Figure 4. Net present value of master plan benefits over time (2015 to 2065).
50% (Medium scenario) or 100% (High scenario) greater than initial estimates. While we did not conduct a threshold analysis to identify the frontier of cost multipliers and discount rates that result in the policy breaking even, our results suggest that the master plan’s risk reduction projects are generally economically justified unless costs substantially exceed planners’ best estimates or if a discount rate much greater than the U.S. Army Corps of Engineers’ prescribed rate is adopted.

Figure 5 illustrates how the Plan’s risk reduction benefits are distributed geographically, using the previously mentioned risk region polygons defined by parish boundaries, protection system centerlines, and major rivers. Results correspond to a 3% discount rate with all projects, including restoration efforts. While the specific present values of EAD reduction vary by scenario and by discount rate, the geospatial pattern is consistent.
Figure 5 summarizes changes in EAD associated with changes to flood depths at all return periods, convolved with the value of exposed assets in each risk region.

The majority of risk reduction is concentrated in parishes southwest of New Orleans, and St. Tammany Parish on the north shore of Lake Pontchartrain. The former is predominantly attributable to the ‘Morganza to the Gulf’ and ‘Larose to Golden Meadow’ projects, although nonstructural projects are also recommended in some of these areas. The latter is primarily due to the Lake Pontchartrain Barrier and Slidell Ring Levees projects (Fischbach et al. 2017c). Increased risk in some regions is attributable to the induced surge on the seaward side of protection elements, as previously noted in figure 2. However, the greatest increase in risk from the plan is projected to occur on the west bank of the Mississippi River in the Greater New Orleans area. This stems from induced surge where the Upper Barataria Risk Reduction project ties into the New Orleans Hurricane & Storm Damage Risk Reduction System (HSDRRS), suggesting that planners could ameliorate the increase in risk by increasing HSDRRS levee heights in tandem with the Upper Barataria project implementation. Due to interactions between projects, and the fact that many projects impact multiple risk regions, it is difficult to estimate the NPV of the plan at a regional level by allocating project costs across risk regions.

4. Discussion and limitations

This research provides initial estimates of the net economic benefit from risk reduction investments in the master plan. However, the results presented here rest on several important assumptions, and this work does not comprehensively address the full range of potential benefits from risk reduction investments or costs.

In general, the economic benefits from risk reduction investments presented in this analysis likely underestimate the true benefit. First, benefits might be undercounted by estimating direct damage and immediate post-disaster damage from Category 1 and higher hurricanes only. Considering a wider range of potential flood events (e.g., tropical storms, extratropical events, tidal flooding) could suggest greater benefits from risk reduction and coastal restoration investments. We also do not estimate the indirect economic benefits from risk reduction investments, including effects on regional or national economic output, employment, or related factors. In addition, risk reduction benefits also exclude some categories of critical infrastructure due to the lack of available valuation or depth-damage estimates for these categories during the 2017 analysis. Finally, assumptions made as part of the master plan analysis, including an arbitrary cutoff of benefits in 2065 and relatively late implementation of large-scale risk reduction projects—which pushes benefits further into the future—will tend to yield lower estimates of discounted benefits.

By contrast, there are other potential sources of bias towards high net benefit estimates. For instance, this research used structure replacement costs versus depreciated asset values, and the potential disbenefits (costs) imposed by structural protection infrastructure are not monetized. We also do not take into account other societal costs associated with implementation of the master plan risk reduction projects, such as opportunity costs. In addition, cost estimates for risk reduction projects could be understated, though we addressed this to an extent through sensitivity analysis.

This research also does not address all future scenario uncertainty potentially relevant to future flood risk in coastal Louisiana. For example, changes to the number or distribution of residents living on the coast were considered in the master plan analysis (Fischbach et al. 2017b) but omitted here because the variation across scenarios did not meaningfully affect plan development in 2017. In addition, changes in land use along the coast could affect future coastal flood hazards but were not directly considered in this analysis.

5. Conclusions

This research was built on the integrated simulation modeling analysis conducted in support of Louisiana’s 2017 Coastal Master Plan. We projected coastal flood damage over time in a future without action and with the master plan implemented according to its proposed schedule and use the resulting benefit and costs to estimate a stream of discounted net economic benefits over 50 years (through 2065). Analysis results suggested positive, notable benefits from risk reduction investments over a range of assumptions about future conditions and economic considerations, including different assumed discount rates. A more adverse environmental scenario with higher SLR and coastal subsidence rates yielded greater net economic benefit from flood risk reduction investments. In general, this research showed that implementing the master plan could yield considerable net economic benefit from damage reduction investments for coastal Louisiana in many plausible futures if implemented as planned.
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