Journal of Ocean and Coastal Economics

Volume 4
Issue 1 *General Papers*

Article 3

June 2017

Economic Evaluation of Coastal Land Loss in Louisiana

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Recommended Citation

Barnes, Stephen R.; Bond, Craig; Burger, Nicholas; Anania, Kate; Strong, Aaron; Weilant, Sarah; and Virgets, Stephanie (2017) "Economic Evaluation of Coastal Land Loss in Louisiana," *Journal of Ocean and Coastal Economics*: Vol. 4: Iss. 1, Article 3.
DOI: https://doi.org/10.15351/2373-8456.1062

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Economic Evaluation of Coastal Land Loss in Louisiana

Acknowledgments

Preparation of this article was supported by Louisiana's Coastal Protection and Restoration Authority. Charles Sutcliffe in the Governor's Office of Coastal Activities provided invaluable advice and guidance throughout the project. The authors also thank members of the CPRA staff and Steering Committee for their important contributions to the study scoping and feedback. We thank all those who provided data and expert opinion, including Jim Mitchell, Chris Fillastre, and Virginia Burton from Louisiana Department of Transportation and Development; David Dismukes and Greg Upton from the Louisiana State University Center for Energy Studies; Raymond Berthelot from the Louisiana Office of State Parks; Sean Duffy of the Big River Coalition; and members of the Coastal Protection and Restoration Authority working on the Mississippi River Hydrodynamic and Delta Management Study. The authors also thank David R. Johnson and Rachel Costello for their vital support and research assistance with RAND's CLARA model. The support staff of the LSU Economics & Policy Research Group deserves additional thanks for their work in this process. The team was instrumental in shaping and carrying out the analysis for this study. We would also like to thank our external reviewers for making this a better report.

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1. INTRODUCTION

From 1932 to 2010, Louisiana lost approximately 1,880 square miles of land. By 2060, future projections suggest that another 1,750 square miles may be at risk, including conversion to open water and associated shoreline retreat (U.S. Geological Survey, 2011; CPRA, 2012). These processes are driven by many natural environmental changes, including global sea level rise and more gradual subsidence, coupled with human-driven changes such as dredging, channelization, industrial development, agricultural drainage, and oil and gas extraction (Turner, 1990). Up to 80% of Louisiana's coastal wetlands may be lost by the turn of the century (Farber, 1996).

Land loss in coastal Louisiana is expected to have economic effects. In particular, both capital stocks and flows of economic activity in the region are likely to be affected, along with disruption of the trade flows of goods, services, and people through the region. In addition, land loss will reduce the overall quantity of coastal wetlands, which buffer storm surges and provide other ecosystem services. These wetlands, in conjunction with complementary man-made storm protection structures (e.g., levees), help reduce damage to highly developed areas further inland. While the damage caused by Hurricanes Katrina and Rita in 2005 has resulted in enhanced man-made protection since 2005, the land loss has continued, serving to decrease the efficacy of this capital and increasing the risk of damage and disruption from the land loss process.

This study quantifies the economic assets and activity that is at risk from the process of land loss in coastal Louisiana in a future without restoration and protection efforts to minimize or mitigate land loss (a "future without action"). This work builds on previous studies (e.g., CPRA 2012) and draws heavily on existing coastal modeling (Fischbach, et al., 2012), though we use different estimates of establishments, economic activity, and capital stocks in the region.

The basis for this analysis is today's economic landscape and maps of projected land loss and storm-related flooding from the 2012 Coastal Master Plan. We take the existing stocks and their spatial structure as the result of past decisions, and generally we do not account for future adaptive dynamic behaviors of residents, firms, and governments in response to the land loss process. Any mitigation response, from hardening of infrastructure to relocation, is not considered, which is consistent with the notion of a "future without action." As such, results should be interpreted as the "footprint" of economic activity at risk, rather than a forecast of the future.

Our primary focus is on the *incremental* change in damages (for stocks) and disruptions (for flows of economic activity and ecosystem services) that result from land loss. We assume that capital stocks (such as residential and non-residential fixed capital stocks and infrastructure related to transportation) can be impacted either directly (e.g., when the asset is currently located in an area expected to be converted from land to water) or through increased flooding due to land loss and the resulting reduction in storm protection services. We assume that annual flows of economic activity (e.g., wage payments and employment) can similarly be impacted in these two ways by land loss.

This article is structured as follows. In Section 2, we provide background on land loss in Louisiana and review our overall approach to assessing economic effects of land loss. Sections 3 and 4 present our evaluation of assets and activity directly at risk from land loss. Sections 5 and 6 present our evaluation of the effects of incremental storm damage. The final section notes study limitations and concludes.

2. BACKGROUND

From a theoretical perspective, the cost of land loss in a future without action is the difference in total welfare from a world in which land loss does not happen and a world in which it does (and no actions are taken to stop it). Both paths are theoretical in nature, will depend on many assumptions about adaptive responses and future states of nature, and are unobservable from the present. To isolate the effects of land loss without confounding it with additional assumptions, the basis for this analysis is the existing economic landscape and maps of land loss and storm surge projections from the 2012 Coastal Master Plan. That is, we estimate the effects of projected land loss on *current*, rather than *future*, economic activity.

We chose this approach for several reasons. First, future economic development paths are highly uncertain. While a 50-year time horizon may not be especially long in geophysical terms, a 50-year projection reaches beyond any widely accepted economic forecast. Historically, the coastal Louisiana region has experienced a long-run trend of positive population and economic growth (most recently driven by large industrial expansions fueled by low-cost and abundant natural gas), and the state's long-run employment forecast to 2024 shows such trends continuing for years to come. In the context of disaster management, an effective restoration and protection program would encourage additional people and firms to relocate to coastal Louisiana. However, a future without action in which individuals, firms, and governments invest little in mitigating action against potential threats from land loss, in conjunction with unpredictable storm events, could result in a very different development path for coastal Louisiana, possibly including depopulation and economic decline.

Second, even if one or more assumptions for future growth in the region could be agreed upon, the spatial and industry-level distribution of that growth across the region (including supporting infrastructure and patterns of trade) in the presence of land loss and random storm events would skew many of the results. To concentrate attention on the services provided by coastal land, we extrapolate away from future dynamics of the coastal region's economy.

Third, this approach minimizes the need for assumptions about adaptive behaviors on behalf of individual economic actors or the public sector. Rational households or firms will make mitigation or relocation decisions regarding responses to land loss based on their own preferences, available opportunities, and their own constraints. We do not model this behavior, as ours is a static, rather than dynamic, approach. If households or firms can respond to environmental changes through mitigating actions at their current location, or moving to a new location, estimates of the costs of land loss would certainly change.

Finally, we believe that fixing the current economic system provides insight into the likely causal effects of land loss on damage and disruptions without confounding future economic conditions. By overlaying the current economic system, which is well-known, with the projected loss of land, we essentially keep "all else constant" in our analysis. This avoids confounding the damage associated with land loss with forecasts of future economic development. On a proportional basis, however, one can interpret our results as valid if one were to assume that the coastal economy grows at a constant rate. Alternatively, one can think of these results representing the present value of future costs if the economy grows at a rate equal to the discount rate.

Within this context, we estimate the effects of land loss and resultant increase in flooding and storm damage on man-made capital stocks and the flows of economic activity that are supported by those stocks. We quantify the effects of land loss as the value of stocks or economic flows that are at risk of damage or disruption due to the conversion of land to water. Stocks or flows that are near predicted land loss are assumed to be directly at risk. Calculated effects of increased storm damage are primarily focused on the change in flooding resulting from the degradation of storm protection services due to the loss of land relative to current conditions. While these estimates are indicative of the order of magnitudes of damage that the various land loss projections might entail, the analysis does not include every potential type of capital stock damage or economic flow disruption, nor does it consider any general equilibrium effects, such as reactions by individuals or firms to changes in the environment or economy.

We generally restrict our results to reporting the total value at risk from land loss for private economic activity. Our estimates provide a broad perspective on estimated capital stock and flows at risk from coastal land loss, without focusing on impacts to specific subsectors of the economy or specific areas within coastal Louisiana.[1]

2.1 Land Loss Projections

The land loss projections (2010 base year) rely on environmental scenarios that are defined over two sets of environmental conditions representing scientific uncertainty over key parameters including sea level rise, rates of subsidence, storm intensity and frequency, Mississippi River discharge and nutrient concentration, evapotranspiration, and marsh collapse threshold. In the 2012 Coastal Master Plan, a comprehensive geophysical modeling effort considered a plausible range of change in each of these key parameters and arrived at two benchmarks for maps and discussion: one set of moderate assumptions near the

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[1] For the purposes of this study, we define coastal Louisiana as the following parishes: Acadia, Ascension, Assumption, Calcasieu, Cameron, Iberia, Iberville, Jefferson, Jefferson Davis, Lafayette, Lafourche, Livingston, Orleans, Plaquemines, St. Bernard, St. Charles, St. James, St. John the Baptist, St. Martin, St. Mary, St. Tammany, Tangipahoa, Terrebonne, and Vermilion. These 24 parishes are projected to have at least some land loss in at least one of the environmental scenarios and time horizons considered in our analysis.

lower end of the range that corresponds to relatively less land loss, and a set of less optimistic assumptions near the higher end of the range that corresponds to relatively more land loss. Each set of assumptions lays out a plausible environmental scenario and are referred to as the "moderate scenario" and "less optimistic scenario," respectively. For instance, in the parameter of sea level rise, a plausible range of 0.12 to 0.65m over 50 years was considered. In the moderate scenario, sea level rise was assumed to be .27m over 50 years; in the less optimistic scenario, sea level rise was pegged at .45m over 50 years. The less optimistic scenario also assumes increased subsidence, higher storm intensity and frequency, and marsh conditions that are more susceptible to loss. Land loss is projected under each set of environmental conditions for 25- and 50-year time horizons.[2]

2.2 Stocks and Flows at Risk

For the analysis, we group capital stocks and activities into the following categories:

Stocks of Physical Capital

- Non-residential structures and inventory
- Residential structures and contents
- Network Infrastructure (roads, rail, pipelines, and waterways)

Flows of Economic Activity

- Commodity and trade flows
- Economic activity at risk of disruption directly through land loss

Where sufficient data or models exist on the processes that relate land loss to economic effects, we report the economic effects. This is the case for most of the non-network infrastructure capital stocks and many of the economic flows. In other cases, such as network infrastructure, the linkages between land loss and economic effects are complicated by a lack of data, potential behavioral adaptation, or other factors. In these cases, we typically report either the physical

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[2] For more information on environmental modeling conditions, see the 2012 Coastal Master Plan Appendix C.

drivers of damage or current levels of economic activity at risk, or qualitatively discuss the potential effects. We do not discuss disruptions to natural capital or the services that such capital provides.

The economic impacts of land loss are calculated for both the stocks of physical capital and the flows of economic activity. We estimate the total value of a stock or flow that is at risk—a term that reflects the uncertainty over damage—from being abandoned, damaged, disrupted, or destroyed by the loss of land, based on the land loss projections. For an at-risk stock, such as a residential building, we estimate the value of the structure. For an at-risk flow, such as employment or wages, we characterize disruptions by measuring the at-risk activity on an annual basis. There may be activities that could be replaced or relocated to other areas in less than a year while other activities may uniquely benefit from their current location and may take more than a year to become fully reestablished elsewhere, or the loss may be permanent.

The second component of this analysis looks at incremental damage from the increased risk of flooding driven by land loss in a future without action. Much of the land that will be lost over the next 25 to 50 years is wetlands. A valuable characteristic of wetlands is their ability to slow down or reduce effects of storm surge (see, e.g., Kawabe and Oka, 1996; Tovilla-Hernandez et al., 2001, Johnston, et al. 2002; Wilson and Farber, undated; Costanza, et al. 2008). As such, the storm protection services from coastal land are a predominant ecosystem service with relatively well-defined links to the rest of the economic system.

2.3 Case Study Storms

The 2012 Coastal Master Plan analysis modeled coastal flooding on 40 individual storms following the ten tracks shown in Figure 1 under baseline, moderate, and less optimistic scenario conditions (2012 Coastal Master Plan, Appendix D-24, 2012). Four storms per track were modeled which varied by wind and pressure field, resulting in maximum values for storm surge, wave height, and wave period, as well as hydrographs that describe the evolution of the storm surge process (2012 Coastal Master Plan, Appendix D-24, 2012). To illustrate the potential impacts of degraded storm protection on flooding in Louisiana, we chose two representative storms to analyze: one eastern track (E2) and one western track (W2) storm. The chosen storms had the third-highest wind speed and third-lowest pressure of the storms along each track.

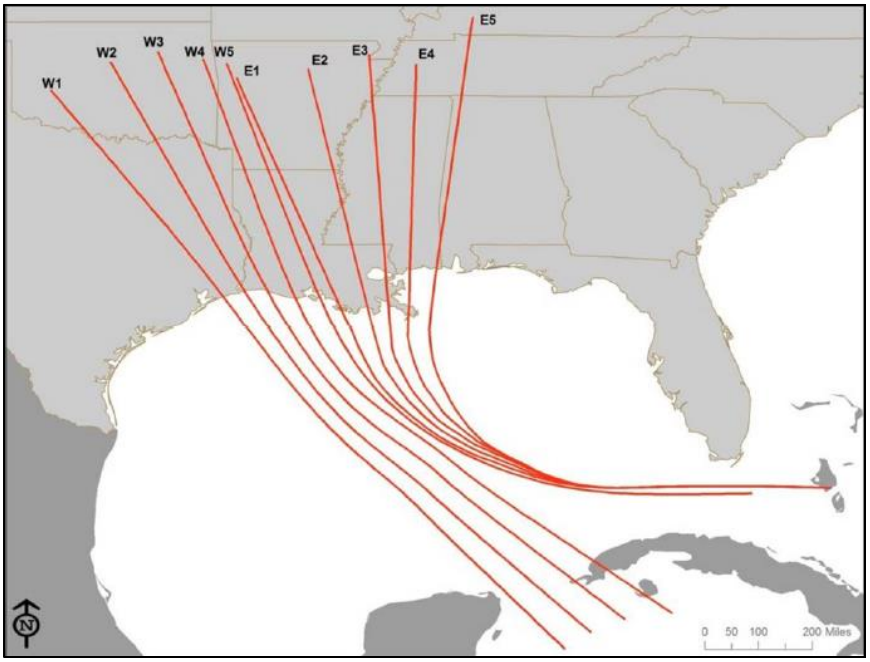

Figure 1. Storm tracks used in the 2012 Coastal Master Plan modeling (Arcadis 2012)

In addition, we modeled the impacts of the "100-year" flood depths, which correspond to the flood depth levels associated with a 1% chance of being reached each year. Given the evolution of the land loss process, the flood depths associated with this probability are scenario-dependent for each time horizon, and found via probabilistic simulation of possible storms over a representative set (see the "Flood Modeling" subsection). Unlike the other two case studies, this case does not fix a particular storm's track and intensity over the land loss projections, but rather fixes the 1% probability and varies the flood depths in accordance with the land loss projections. For the sake of exposition, we refer to this case as the "100-year storm."[3]

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[3] The chosen storms along each track have wind speed of 57.8 meters per second (or approximately 130 miles per hour), pressure of 900 millibars, landfall winds of 46.7 meters per second (or approximately 105 miles per hour), landfall pressure of 918 millibars, pressure scale radius of 21.8 nautical miles, and forward velocity of 11 knots (see Table 3 in 2012 Coastal Master Plan Appendix D-24, p. 15).

The three case-study storm events are thus defined by:

1. **Storm 18 (Eastern Track Storm):** This case-study storm has an eastern (E2) track. Storm parameters are fixed with respect to land loss projections.
2. **Storm 218 (Western Track Storm):** This case-study storm has a western (W2) track. Storm parameters are fixed with respect to land loss projections.
3. **The 100-year storm**: Estimate of flooding expected to recur with a 1% probability each year, commonly referred to as the 100-year flood. Storm is not fixed with respect to land loss projections; rather, probability of flooding is fixed at 1%.

2.4 Flood Modeling

We use the Coastal Louisiana Risk Assessment (CLARA) model to translate the ADCIRC storm modeling developed by Arcadis into maximum flood depths (Fischbach, et al., 2012).[4] CLARA uses the ADCIRC results and statistical techniques to generate a suite of "synthetic storms" and uses these in conjunction with probability distributions over the suite to model the expected annual damage of storm activity in each modeled land-loss projection. These projections take man-made infrastructure for storm surge protection (e.g., ring levees) into account and model flooding via a "bathtub" model at the census block level.[5,6] Because CLARA models surge protection infrastructure failures as a stochastic process, we assume flooding from each storm is equal to the median flood depth across a full Monte Carlo simulation of protective infrastructure failures based on default CLARA assumptions.

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[4] CLARA is a constantly-evolving modeling tool incorporating new techniques and data as they become available. CPRA requested that the study team use the version of the CLARA model used for the 2012 Coastal Master Plan effort.

[5] The study area contains 35,556 census blocks overall.

[6] The baseline storm protection systems were those in place as of 2012 in accordance with CLARA current condition assumptions (Fischbach, et al., 2012). In CLARA, protection infrastructure failure is probabilistic; for simplicity in this report, failure rates are assumed at the median for each scenario.

3. EFFECTS OF LAND LOSS

We first estimate the economic assets and activity that reside on land that may be lost in a future without action, and this section describes the methodological approach and data sources. The analysis of direct impact of land loss follows four basic steps:

1. **Identify land loss.** We use map-based data from CPRA that indicates land that is at high risk of loss in the future.
2. **Identify locations of physical capital stock and activity.** Business activity and capital stock is not distributed evenly across the coast but is concentrated along relatively high ridges of land. Therefore, we identify the most geographically granular and reliable source of geospatial data for each type of asset or activity. In general, point, path, or footprint level data are used rather than aggregated regions or blocks.
3. **Determine which capital stock and activities are at risk.** The geospatial data is used in conjunction with the land loss maps prepared by CPRA to identify structures and activity at risk from land loss.
4. **Screen Results.** To avoid overstating the effect of land loss on economic activity, we allow for a modest degree of private mitigating action. In cases where a business or capital asset is on land estimated to be lost, but the surrounding area is not significantly impacted, we assume that modest private mitigation actions will prevent losses.

Where the extent of potential damage to capital stock or disruption of activities attributable to land loss cannot be quantified, as in the case of river navigation, we report totals from the coastal region and offer only a qualitative discussion.

3.1 Non-residential Capital Stock

To analyze non-residential structures, we evaluated and compared several datasets for locations of businesses and other sources of economic activity to assess the accuracy of the data as well as the usefulness for this effort given the degree of geographic detail available.[7] We use the Info-USA database, which provides the most accurate data on business activity. These data include information on the location of private businesses, government agencies, and the self-employed, geocoded by its physical address. The data also include number of employees, annual sales volume, and square footage of the facility.

Because the geocoded addresses are one-dimensional points located on a road, we had to approximate the location of the facility in relation to the road. We define an approximate establishment area as the land surrounding the geocoded address within 90 meters of the road and on the same side of the road as the address.[8] We consider establishments to be directly at risk from land loss if the approximate establishment area intersects with the land loss map so that at least a portion of the establishment area lies within the area of predicted land loss. We assume that private mitigating actions will prevent losses if less than 5% of the area within a quarter mile of that establishment is lost.

Replacement costs come from Table 14.1 in the Federal Emergency Management Agency's HAZUS-MH model documentation (FEMA 2000-current), which provides cost estimates per square foot by class of structure and is updated to 2012 dollars using the GDP price deflator. HAZUS-MH is a multi-hazard loss estimation methodology and tool used to predict damage for earthquakes and floods.

3.2 Residential Capital Stock

There is no readily available, coast-wide georeferenced database available for the analysis of residential structures at risk. To estimate a spatial inventory of residential stocks, we use a methodology based on combining two data sources: the 2010 American Community Survey (ACS) five-year housing structure

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[7] County Business Patterns (U.S. Census Bureau), Quarterly Census of Employment and Wages (U.S. Department of Labor), OnTheMap (U.S. Census Bureau), HAZUS-MH (FEMA), Dun & Bradstreet (commercial dataset), and Info-USA (commercial dataset)

[8] As a sensitivity test, we also analyzed 30 meters and 60 meters. Visual inspection in select areas of the number of buildings captured within each of these radii led us to select 90 meters as a preferred range that captured most businesses without adding a significant amount of erroneous overlap with the land loss map. Meters are the standard unit of distance in GIS software applications.

estimates from the U.S. Census Bureau, and the 2012 LANDscan population estimates. The former provides census-tract level estimates of housing stocks by building type and occupancy status, as well as average occupancy rates. The latter provides geospatial estimates of population distribution at a sub-tract level (more specifically, in cells of 100x100 meters), which can then be used to aggregate into sub-tract geographies.

To estimate spatially-specific residential housing stock estimates, we calculate the average value of stocks per person by census tract from the ACS data using Census estimates of occupancy, owner-occupied housing value, average rents (for rented property), and estimated vacancy. These tract-level estimates are then multiplied by estimated population from the LANDscan data to obtain 100 by100 meter estimates of the value of housing stock in the study region.

To estimate the value of residential stocks at risk from direct land loss, we overlaid land loss maps onto the LANDscan data to identify cells predicted to be affected by the land loss process. For each affected cell, the proportion of cell lost is calculated, and this proportion is multiplied by the estimated residential stock value for that cell to obtain the estimate of the residential housing stock at risk. Values were updated to 2013 using the GDP price deflator.[9]

This approach implicitly assumes a uniform distribution of housing within each LANDscan cell. If, as expected, land loss is negatively correlated with elevation, and the value of residential housing stocks is positively correlated with elevation (i.e., housing stocks tend to be on higher ground), then the measure of housing structures at risk will be overestimated.[10]

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[9] A second method in which buffer areas around roads were calculated for each Census Block used by the CLARA model, and all housing was assumed to lie within these buffers, was tested by the study team. This methodology also assumes a uniform distribution of housing stocks within the buffer zones. For 30 meter and 90-meter buffer zones, the total calculated at-risk stock percentages were 0.32% and 0.52% for the less optimistic scenario at 50 years. The method using the LANDscan data resulted in an estimate of 0.29% of total estimated stock in affected regions. Given a lack of empirical data on the proper width of the buffer zone and the specificity of the spatial distribution of the estimates, we chose to use the LANDscan methodology.

[10] However, it should offer an improvement over assuming a uniform distribution of structures within an entire census block or tract via the inclusion of spatially-explicit population information.

3.3 Network Infrastructure

For network infrastructure, we calculate the miles of infrastructure in the predicted area of land loss for each projection for roads, rail, and pipelines. For roads and rail, we also estimate replacement costs. For pipelines, it is less obvious what the exact effect of land loss will be. Although we can calculate the miles of pipelines newly exposed to the elements and more vulnerable to cracking and maintenance problems, there is a lack of literature on expected damage caused by exposed pipelines. Therefore, we cannot estimate what these additional costs will be so we only display miles of pipeline exposed and do not quantify future costs.

Finally, we do not specifically articulate damage to communications infrastructure (such as telephone or cable lines) given significant uncertainty about the degree to which land loss will directly or indirectly affect these capital stocks. However, as many of these lines will likely follow the rights-of-way associated with roads and rail, the estimates of miles affected presented for these capital stock may provide a proxy estimate for the extent of this type of infrastructure that is at risk.

Miles lost and replacement cost for roads and highways are based on data from the Louisiana Department of Transportation & Development (LADOTD). Data on rail infrastructure was sourced from the National Transportation Atlas Database (NTAD) 2014, published by the U.S. Department of Transportation's Bureau of Transportation Statistics. Replacement costs were sourced from HAZUS-MH. Pipeline infrastructure data was sourced from the LSU Center for Energy Studies and valuation data from the Center for Energy Studies.

3.4 Economic Activity

Using data from Info-USA and the selection method described for selecting non-residential structures at risk, we report the employment and sales volume of all establishments affected by land loss to estimate total employment and sales at risk directly from land loss under the four land loss projections. A second source of data, County Business Patterns (CBP), is used to estimate wages for lost jobs in this area. The average annual salary by parish from CBP is multiplied by total employment affected by land loss in that parish to estimate at-risk wages in the affected area.

4. LAND LOSS RESULTS

This section presents the results for non-residential, residential, and network infrastructure capital stocks directly at-risk from the land loss process. We conclude the section with the results for economic activity at-risk from land loss.

4.1 Residential and non-residential assets

Table 1 shows that total replacement costs for non-residential structures for establishments at risk lay between $1.5 billion and $2.2 billion, depending on the scenario and time horizon. Furthermore, between 800 and 1,200 establishments are directly at risk due to land loss. In terms of both number of establishments and total replacement costs under both scenarios, the effect over time is non-linear, in that the number/cost for the first 25 years of the planning horizon is greater than the additional number/cost for the second 25 years.

Table 1. Non-Residential Structures at Risk from Land Loss

Environmental Scenario	Time Horizon	Establishments	Total Replacement Costs ($ millions)
Moderate	25 year	810	$1,500
Moderate	50 year	960	$1,800
Less Optimistic	25 year	970	$1,800
Less Optimistic	50 year	1,200	$2,200

Source: Uses HAZUS-MH square footage by business class unless it contradicts InfoUSA square footage data, in which case endpoints of InfoUSA square footage class most consistent with HAZUS-MH square footage is used. Replacement costs from HAZUS-MH documentation (Table 14.1) and updated to 2012 using the GDP price deflator from BEA. All monetary values presented in 2012 dollars.

The largest industries in the affected area include Retail Trade, Construction, Transportation and Warehousing, Accommodation and Food Services, and Other Services. Compared to the entire coastal region, this area has a relatively larger number of businesses in the Construction, Transportation and Warehousing industries and a relatively smaller number of businesses in the Professional, Scientific, and Technical Services and Health Care and Social Assistance industries. Most of these businesses are small, with an average of 10 employees.

Table 2 shows that total replacement costs for residential structures at risk are between $310 million and $510 million. Total estimated baseline residential stocks for the state of Louisiana are approximately $255 billion (approximately 1.9 million housing units), suggesting that between 0.1 and 0.2% of the value of the state's fixed residential structures are at-risk from land loss.[11] As with non-residential structures, most of the at-risk housing stock is threatened in the first 25 years for each environmental scenario. Comparing these results with non-residential structures, the value of establishment structures directly at risk are estimated to be approximately 4.5 to 5 times that of housing structures.

Table 2. Residential Structures at Risk from Land Loss

Environmental Scenario	Time Horizon	**Number of Structures**	Total Replacement Costs ($ millions)
Moderate	25 year	2,100	$310
Moderate	50 year	2,500	$360
Less Optimistic	25 year	2,700	$380
Less Optimistic	50 year	3,700	$510

Source: Authors' calculation based on per-person estimates of residential housing stock values from the U.S. Census American Community Survey and spatial distribution of nighttime population levels from LANDscan. All results presented in 2012 dollars.

4.2 Network Infrastructure

As in Table 3, at the low end, 190 miles of roads are at risk under the moderate scenario at the end of 25 years with an estimated replacement cost of $220 million.[12] At the high end, 580 miles are at risk under the less optimistic scenario

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[11] Due to the lack of geospatial residential structure information, the estimated number of structures is based on average housing stock per resident at the Census Block level and the number of structures reported in the American Community Survey. If there are differences in average values for those properties at-risk due to land loss relative to the rest of the census block, then the structure count will be biased.

[12] There are of course economic flows that are enabled by network infrastructure, but assessing the substitutability of those flows to other network infrastructure is beyond the scope of this study. Any economic losses associated with switching to alternative networks are not included in this study.

at 50 - years with an estimated replacement cost of $700 million. We use replacement cost to value these roads; however, some of these losses are permanent losses, or may require a bridge or elevated highway to repair the roadway completely, which may involve a greater cost than replacing a ground-level highway. As such, these replacement costs should be considered a lower bound.

Table 3. Roads at Risk from Land Loss

Environmental Scenario	Time Horizon	Miles Lost	Replacement Cost ($ millions)
Moderate	25 year	190	$220
Moderate	50 year	280	$320
Less Optimistic	25 year	300	$340
Less Optimistic	50 year	580	$700

Source: Based on road distribution type and repair/replacement cost information obtained from LADOTD. All monetary values presented in 2012 dollars.

Two areas of land loss near heavily traveled and strategic highways (Louisiana Highway 1 between Golden Meadow and Leeville, and I-10 near New Orleans before the Twin Spans over Lake Pontchartrain) could make critical roadways particularly vulnerable to land loss over the next 25 to 50 years leading to more widespread effects than are considered here.

Rail losses are much smaller than road losses because there are fewer miles of railway track in the state. Table 4 displays miles of track lost and replacement value of the track. The replacement cost of rail infrastructure at risk from land loss is between $28 million and $48 million depending on the land loss projection.

Louisiana’s coast has a vast network of pipelines, almost entirely privately owned, that have been built over many decades to support offshore oil and gas activity as well as the Louisiana Offshore Oil Port (LOOP). In a future without action, some pipelines not designed to be in open water will become exposed. These pipelines will be more vulnerable to damage from vessels and scouring by wave action, which will create a need for more maintenance, repair or replacement. Damage to these pipelines could not only result in environmental damage, but also create disruptions to the oil and gas-related businesses that rely on this critical infrastructure.

Table 4. Rail at Risk of Land Loss

Environmental Scenario	Time Horizon	Miles of Track	Replacement Costs ($millions)
Moderate	25 year	11	$28
Moderate	50 year	14	$33
Less Optimistic	25 year	15	$36
Less Optimistic	50 year	20	$48

Source: Based on infrastructure inventory data from NTAD2014 and replacement estimates from HAZUS-MH. All monetary values presented in 2012 dollars.

We did not identify any reliable studies that quantify the increased vulnerability from exposure; instead, we measure the number of miles of pipeline that will be exposed in a future without action and present those results in Table 5. The number of miles of pipeline exposed by land loss is detailed by pipeline commodity and by pipeline size; the larger the pipeline, the greater the flow of commodities through it. For comparison, there are approximately 46,500 miles of pipeline in Louisiana, so the estimates in Table 5 range from 1% to 3.5% of total pipeline mileage in the state.

Table 5. Miles of Pipeline Exposed by Coastal Land Loss

	Moderate, 25 Year	**Moderate, 50 Year**	**Less Optimistic, 25 Year**	**Less Optimistic, 50 Year**
Commodity				
Natural Gas	360	570	570	1,100
Crude Oil	140	240	200	360
LPG/NGL	87	120	110	170
Petrochemical	14	17	19	43
Refined Products	12	18	14	24
Other	2	3	2	3
Diameter (inches)				
Less than 20	400	630	600	1,100
20 - 36	210	320	310	600
More than 40	6	9	9	25
Total Miles of Pipeline	610	960	910	1,700

Source: Based on infrastructure inventory data from the LSU Center for Energy Studies and valuation data from the Center for Energy Studies.

To further characterize the potential damage associated with increased pipeline exposure, we investigated oil spill notifications from the U.S. Coast Guard's National Response Center (NRC). Between 1990 and 2012, there were 1,565 spill notifications in the 24 coastal parishes that are the focus of this study. When reported to the NRC, many of these incidents are identified as being caused by corrosion, a result of aging infrastructure reaching the end of its useful life. However, there were 58 spill notifications between 1990 and 2012 that were attributed to exposure or a storm-related event, and on average each was associated with less than one barrel of oil spilled.[13] In a future without action, the existing pipeline network will become increasingly exposed and pipeline-related spills are likely to increase. However, the lack of data quantifying the probability of such a disruption prevents us from formally estimating these effects.

4.3 Economic Activity

Info-USA data include estimates of the number of employees and sales volume at each establishment in the database. We use these data in conjunction with the at-risk businesses identified for each land loss projection to determine the employment and sales volume directly at risk from coastal land loss. Should all or a portion of these businesses relocate out of the region or state due to the threat of land loss, these losses can be interpreted as permanent, because the jobs and output are permanently removed from the regional economy.[14] Government establishments and public institutions are not included in the data.

Table 6 summarizes total establishments, employment, and sales volume of the businesses on land that is expected to be lost. Employment directly at risk from land loss is between 0.8% and 1.1% of total coastal employment, with

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[13] Specific causes for these pipeline-related spill notifications include vessels hitting a pipeline or pipe movement caused by a storm, including eleven notifications associated with Hurricane Katrina damage.

[14] The decision to mitigate or relocate a business due to the threat of land loss is a micro-level decision that will depend on individual preferences, the extent of the threat, and other financial, economic, and environmental factors. The count of business establishments identified as "at risk", as well as their employment and sales, is an upper bound on the direct losses that could be attributable to the land loss process.

between $2.4 billion and $3.1 billion of sales (approximately 1% of total coastal sales) at risk.

Table 7 provides estimates of wages from jobs directly at risk, in terms of annual payroll. Between $410 million and $580 million of annual payroll is directly at risk from coastal land loss.

Table 6. Economic Activity at Risk: Establishments and Sales Volume

Environmental Scenario	Time Horizon	Establishments	Sales Volume ($ billions)
Moderate	25 year	810	$2.4
Moderate	50 year	960	$2.6
Less Optimistic	25 year	970	$2.6
Less Optimistic	50 year	1,200	$3.1

Source: Based on Info-USA data for business establishments. Sales volume is defined as the total value of output from establishments. Government institutions are not included in sales figures. All monetary values presented in 2012 dollars.

Table 7. Economic Activity at Risk: Employment and Annual Payroll

Environmental Scenario	Time Horizon	Employment	Annual Payroll ($ millions)
Moderate	25 year	8,800	$410
Moderate	50 year	9,700	$450
Less Optimistic	25 year	9,800	$460
Less Optimistic	50 year	12,200	$580

Source: Based in Info-USA data for business establishments and County Business Patterns for wages. Government institutions are not included in sales figures. All monetary values presented in 2012 dollars.

5. EFFECTS OF STORM DAMAGE

We calculate increased storm damage from land loss in a future without action for both stocks and flows based on the predicted flood depths and timing of economic disruptions, both of which are outputs of the CLARA model. For capital stocks, we use default, structure-specific depth-damage curves in CLARA (unless otherwise indicated) to compute proportional damage to the stock and associated replacement costs. For economic flows, disruption times are used to estimate lost sales and wages. The analysis of the increased storm damage follows the following steps:

Estimate Flood Depths. As described in the previous subsection.

Identify locations of capital stock and activity. The census block of each stock or flow is calculated to remain consistent with the flooding output. The data used for each group of capital stock or activity is discussed in detail in the appropriate subsections of Section 3.

Calculate damage or value of disruption. Conditional on estimated flood depth at the location of each stock or flow, the depth-damage curves or disruption times are used to estimate the effect of flooding.

Because our focus is on the economic consequences of environmental changes, we report the *increase* in storm damage relative to expected baseline flooding under current conditions. Therefore, all results presented in storm damage sections represent the damage in a future without action less the damage from an identical storm using current land conditions.

These estimates represent potential short-term losses. Affected capital stocks and activities may not close permanently, but they may need repairs or experience temporary business interruptions. Storm damage can also cause more lasting or even permanent losses if damage or disruption is severe enough to cause some businesses to fail to reopen. We report damages related to capital stocks and those related to economic activity, like the land loss analysis. However, disruptions to economic activity can be significantly reduced with additional capital-related expenditures to allow businesses to operate at a temporary location while the primary location is being repaired or rebuilt. Because of the interdependency of capital-related costs and activity-related costs of storms, we discuss the two types of damage together in laying out the methodology for estimating costs. Flood model data is drawn from the CLARA model.

The method for calculating storm damage follows an adjusted HAZUS-MH approach. HAZUS-MH measures "direct economic losses" – the cost of repair and replacement of damaged and destroyed buildings, the cost of damage to building contents, and losses of building inventories. HAZUS-MH also estimates "indirect economic costs," which are losses related to the length of time the facility is non-operational. The four indirect economic costs calculated by

HAZUS-MH are business disruption losses (a measure of the loss of services or sales), wage loss, relocation expense (the cost to move operations to a temporary location while the usual building is being repaired, which we will henceforth term “temporary location cost”), and rental income loss to business owners.[15] We supplement HAZUS-MH with Louisiana-specific data, which allows us to select only the most reliable damage estimates from HAZUS-MH and to minimize the potential for double counting.

5.1 Capital Stocks

The value of non-residential structures is estimated from the square footage of businesses in the Info-USA database and the HAZUS-MH estimates of degree of damage associated with a given flood depth for each business. The value of residential structures by census block was estimated using information from the 2010 ACS and 2012 LANDScan population data as described in the data and methods section above. We use this information in conjunction with depth-damage curves and distributions of structure and foundation types in the CLARA model, as well as estimates on residence contents, to estimate flood damage from each of the three storms under the four land-loss projections (see Fischbach, et al. 2012 for more details on CLARA assumptions).[16]

5.2 Network Infrastructure

For network infrastructure, we estimate damage and replacement costs from flooding of roads and rail. Like direct land loss, the exact cost of flooding on pipelines is not measured, though the length of pipelines flooded is calculated.

Storm damage typically leads to disruptions in business activity, which can range from short-term closures to business failure. Losses associated with business interruption depend on the length of time a facility takes to repair.[17] To calculate business interruption losses, we use information from FEMA’s HAZUS-

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[15] Post-storm clean-up costs can also be estimated using the HAZUS-MH methodology.

[16] The storm damage estimates are based on improved levee and other infrastructure, as described in Fischbach et al. (2012), but the model allows for infrastructure failure.

[17] Some of these losses may be offset by private insurance for business interruption claims, which we do not consider.

MH modeling methodology and tool, embedded within the CLARA model, to identify repair time based on industry type and amount of damage as the "loss of function" time -- the amount of time it takes a business to assess damage, make decisions, find alternate locations for temporary operations while the business is repaired, and restart operations in a temporary location. We call this period while the business is non-operational "Time A" in the schematic in Figure 2. For the rest of the time the building is being repaired, "Time B," we assume the business operates in a temporary location.

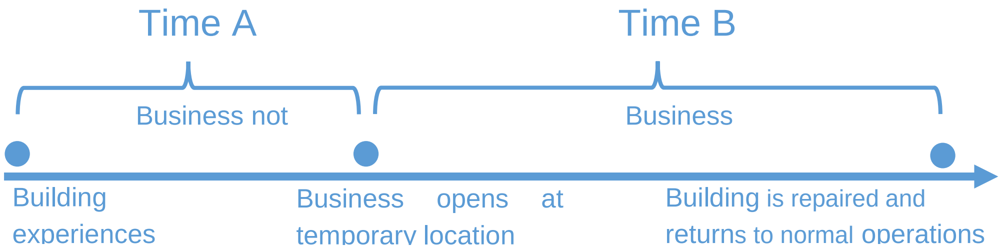

Figure 2. Schematic representation of business recovery after a storm

To calculate income losses in sales and wages, we assume the business earns 0 sales/wages during Time A and 100% of sales/wages, plus a recapture factor, during Time B. The recapture factor represents a percentage of sales during the period of loss that can be made up by working overtime or extra shifts once full operation is resumed in Time B. The default recapture factor varies by industry, ranging from 51% to 98%. For example, retail trade has a recapture factor of 87% while heavy industrial has a recapture factor of 98%.[18]

We extract estimates of Time A for each business class from HAZUS-MH. According to the technical manual, default HAZUS-MH recapture factors are only applicable for approximately 3 months. Since the median length of Time A for all damaged businesses in all cases is 5.4 months due to the severity of damage in the three storm cases, we present a range for sales and income losses that assumes on the low end that default recapture factors apply across all of Time A and on the high end that recapture factors are 0. Considering the length of time it will take most businesses to reopen, we believe that actual recapture factors will

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[18] The additional costs of paying employees overtime, or accelerated depreciation from running equipment at higher than normal rates, are not considered, suggesting that the true costs of disruptions would be understated when using the default recapture factors.

be minimal. Estimated lost sales and wages for each damaged establishment are calculated as the sales (wages) lost during Time A minus any recapture.[19]

To reduce lost economic activity, businesses facing extended repair or rebuilding times will attempt to find a temporary location, incurring capital-related costs to secure that location. HAZUS-MH assumes that it will be possible for businesses to operate at a rented temporary location while original buildings are being repaired. We use the default parameters for disruption costs, the cost of moving to a temporary location and operating there, and rental costs per square foot for the temporary location.

Rental income losses are only incurred during Time B by building owners that rent to other businesses. When the building used by a non-owner-occupied business is damaged, the business stops paying rent to the building owners while the business is being repaired. Rental income losses are calculated based on the average percentage of non-owner-occupied businesses in the HAZUS-MH inventory, average rental costs per square foot by industry, calculated default formulas for temporary location costs and disruption costs by industry, and the calculated Time B.

In potentially catastrophic events like the case-study storms with widespread damage over a large area, it may not be possible for every business to find a temporary location. In particular, the manufacturing sector may have difficulty finding temporary locations due to large equipment and training costs. There may also be a crowding effect that will extend time A or B or both. Some establishments may leave the area, moving to neighboring cities and states. There will likely be delays in the reconstruction and repair of buildings. Finally, because of the loss of their facilities and displacement of customers, workers and suppliers, some businesses may face additional challenges in reopening after a storm. This possibility is explored further in the section on business survival. Given these additional considerations, the primary results presented here should be considered conservative estimates of business interruption costs.

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[19] Analysis of the agricultural sector showed that sales were underrepresented in InfoUSA, so agricultural sales were supplemented with crop data from the National Agricultural Statistical Service (NASS).

5.3 Business Survival

After a catastrophic storm event like the three storms used in this analysis, some businesses and organizations impacted by the storm may not reopen. In past natural disasters, the federal government has spent billions of dollars to assist in rebuilding and implemented programs to minimize business failures. While storms can affect businesses in many ways, the hypothetical storms considered in this study can be used to investigate how increased flooding in a future without action would impact the probability of business failure after a storm.

Two recent studies examined flooding and business failure associated with Hurricanes Katrina and Rita. Lam, Arenas, Pace, LeSage, and Campanella (2012) focuses on businesses located in Orleans Parish before Hurricanes Katrina and Rita and reports results from a follow-up survey roughly two years after the storms to determine whether businesses had reopened. Lam et al. found that approximately 12.4% of firms had not reopened within the first 26 months following the storm. A working paper by Craioveanu and Terrell (2010) uses state administrative data from the unemployment insurance tax system to investigate business failure and found 38.5% of Orleans Parish businesses had not reopened within two years of the storm, indicating impacts that are larger than those found by Lam et al.

We use the estimates from Lam et al. to examine the effects of increased storm damage in a future without action. The study used a Bayesian spatial probit model to assess the effects flood and firm characteristics on firm survival. Flood depth was the most important factor in predicting reopening probabilities. We use the marginal effects of flooding on the probability of reopening after a storm from Lam et al. (2012) to estimate the number of establishments that would remain closed two years after each of the storm cases considered.

6. STORM DAMAGE RESULTS

This section reports the increased damage in a future without action across multiple storms and land loss projections. We report the net, or increased, effect that land loss has on overall regional storm damage.

6.1 Non-Residential and Residential Structures

Table 8 reports the increased cost of storm damage to non-residential and residential structures under each of the land loss projections. The results for the eastern track storm under the less optimistic scenario show substantial additional storm-related damage to the capital stock compared to other land loss and storm track combinations. The estimated damages from the eastern track storm under the less optimistic scenario are higher for the 50-year time horizon than for the 25-year horizon. Unlike most of the other cases, storm protection infrastructure failures are predicted around New Orleans in this case due to increased pressure from greater storm surge associated with long-term land loss. Given the density of the fixed capital stock and economic activity in that city, substantially more structures and businesses are affected.

Table 8. Increased Storm Damage to Non-Residential and Residential Structures

Storm	Environmental Scenario	Time Horizon	Damage to Non-Residential Structures ($ billions)	Damage to Residences ($ billions)
Eastern	Moderate	25 year	$4.7	$3.9
	Moderate	50 year	$7.2	$6.0
	Less Optimistic	25 year	$6.4	$5.1
	Less Optimistic	50 year	$71.0	$61.0
100 Year	Moderate	25 year	$9.2	$6.1
	Moderate	50 year	$14.0	$9.0
	Less Optimistic	25 year	$13.0	$8.5
	Less Optimistic	50 year	$33.0	$27.0
Western	Moderate	25 year	$8.2	$4.8
	Moderate	50 year	$13.0	$7.5
	Less Optimistic	25 year	$12.0	$7.5
	Less Optimistic	50 year	$26.0	$13.0

Source: Authors' calculations from CLARA flood modeling, the InfoUSA establishment database, per-person estimates of residential housing stock values from the U.S. Census American Community Survey, and spatial distribution of nighttime population levels from LANDscan. Note: All results presented in 2012 dollars.

Depending on the storm and land loss projection, increased damage to private and public establishment buildings and inventory at the 50-year time horizon ranges from $7 billion for the moderate land loss eastern track storm to $72 billion for the less optimistic eastern track storm. Commercial damages make up 64% to 74% of the baseline costs from which this damage is estimated, while industrial business costs make up 22% and 31% of the baseline. The remainder of damage to non-residential structures is from public and agricultural structures.

Our estimates for increased storm damage for residential structures closely follows the non-residential structures estimates. Under current conditions, the western track storm causes approximately $6.4 billion in damage, the storm associated with 100-year flooding causes $7.8 billion, and the eastern track storm causes $7.5 billion. Increased storm damage at 25 years ranges from $4 billion to $9 billion depending on the storm and land loss projection. Extending the land loss projection to 50 years increases the expected damage under both environmental scenarios for each storm, but it does so much more for the 100-year storm and eastern track storm under the less optimistic scenario. The total damage under this scenario is 42.4% of the total value of the study area's fixed structures and their contents.

6.2 Network Infrastructure

Results showing replacement costs to damaged roads and rail relative to current conditions are shown in Table 9. Damage to road and rail infrastructure is a relatively small fraction of total overall damage to structures, with increased rail damage from the eastern track storm in the less optimistic scenario at 50 years estimated to be approximately $140 million and road damage just under $500 million, as compared to total structure, inventory and contents damage of approximately $134 billion. Patterns of damage are generally consistent with the structural estimates across storms, although the infrastructure failures that lead to the flooding of New Orleans in the worst case considered do not affect network infrastructure to the same degree, due to a lack of density of vulnerable road and rail in the city.

Table 9. Increased Storm Damage to Roads and Rail and Flooded Pipelines

Storm	Environmental Scenario	Time Horizon	Damage to Rail ($ millions)	Damage to Roads ($millions)	Length Flooded (Miles)
Eastern	Moderate	25 year	$40	$100	470
	Moderate	50 year	$40	$150	1,500
	Less Optimistic	25 year	$40	$140	1,100
	Less Optimistic	50 year	$140	$500	2,300
100 Year	Moderate	25 year	$40	$140	770
	Moderate	50 year	$60	$210	1,200
	Less Optimistic	25 year	$60	$200	1,200
	Less Optimistic	50 year	$130	$380	1,900
Western	Moderate	25 year	$30	$110	590
	Moderate	50 year	$50	$170	920
	Less Optimistic	25 year	$50	$170	950
	Less Optimistic	50 year	$110	$310	1,600

Source: Author’s calculations. Note: All results are presented in 2012 dollars. Pipeline inventory data from the LSU Center for Energy Studies and valuation data from the Center for Energy Studies.

Pipelines experiencing flooding are more vulnerable to cracks and ruptures. Exactly to what degree they are affected cannot be determined based on existing research, but the length of potential flooded pipeline is detailed in Table 9. Some of the most important pipelines in Louisiana are those carrying crude oil or natural gas to refineries and processing centers and refined products like gasoline to other parts of the nation. After a major storm, it is common for major pipelines to shut down or reduce capacity for days or even weeks resulting in substantial impacts to the nation, which we do not quantify here.

6.3 Temporary Relocation Costs

Table 10 reports the temporary relocation costs in each case. These costs are relatively small compared to the primary damage to capital stock estimates, but they still range from $260 million for the eastern track storm under moderate conditions at 25 years to $3.9 billion for the same storm under less optimistic conditions at 50 years.[20] While these costs are directly related to a firm's ability to reduce businesses activity losses, we do not include these figures in total capital-related costs from increased storm damage to ensure that our preferred estimate of activity losses with zero recapture do not overstate total costs.

Table 10. Temporary Location Costs from Increased Storm Damage

Storm	Environmental Scenario	Time Horizon	Temporary Location Costs ($ millions)
Eastern	Moderate	25 year	$260
	Moderate	50 year	$380
	Less Optimistic	25 year	$350
	Less Optimistic	50 year	$3,910
100-Year	Moderate	25 year	$470
	Moderate	50 year	$700
	Less Optimistic	25 year	$660
	Less Optimistic	50 year	$2,800
Western	Moderate	25 year	$400
	Moderate	50 year	$620
	Less Optimistic	25 year	$620
	Less Optimistic	50 year	$1,280

Source: Based on Info-USA data for business establishments and HAZUS-MH rental costs. Note: All results presented in 2012 dollars.

6.4 Economic Activity

Table 11 reports the incremental number of damaged establishments and the incremental number of workers that are employed at these damaged establishments, and there are large differences across storms and land loss scenarios. For example, less optimistic environmental conditions result in 8,000 additional establishments flooded and nearly 90,000 additional employees affected at the 100-year flood level relative to the moderate scenario in 50 years, while the flooding of New Orleans with the eastern storm increases the number of impacted establishments by 24,000 and workers by just over 290,000 in the less

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[20] Rental rates can fluctuate dramatically after a storm in areas within close proximity to the impacted area and we do not attempt to model changes to the rental market.

optimistic scenario. Differences are less dramatic for the western track storm due to both density and elevation considerations.

Table 11. Establishments and Workers Affected by Increased Storm Damage

Storm	Environmental Scenario	Time Horizon	Establishments	Workers
Eastern	Moderate	25 year	1,600	20,000
	Moderate	50 year	2,400	29,000
	Less Optimistic	25 year	2,100	27,000
	Less Optimistic	50 year	26,000	320,000
100-Year	Moderate	25 year	3,100	32,000
	Moderate	50 year	4,800	51,000
	Less Optimistic	25 year	4,500	46,000
	Less Optimistic	50 year	13,000	140,000
Western	Moderate	25 year	2,500	30,000
	Moderate	50 year	4,200	49,000
	Less Optimistic	25 year	4,000	49,000
	Less Optimistic	50 year	9,000	100,000

Source: Based on Info-USA data for business establishments. Government institutions are not included in sales figures. All monetary values presented in 2012 dollars.

Disruption duration affects costs, and business can only recapture some losses. Table 12 reports a range of lost wages and sales for a “low-end” damage estimate and a 0% recapture factor at the high-end of the damage estimates, which is our preferred approach because of the extended length of time most businesses will be non-operational.

Table 12. Lost Economic Activity from Increased Storm Damage

Storm	Environmental Scenario	Time Horizon	Lost Wages ($ millions)		Lost Sales ($ millions)	
			Default Recapture Factor	0 Recapture Factor	Default Recapture Factor	0 Recapture Factor
Eastern	Moderate	25 year	$140	$530	$340	$1,900
	Moderate	50 year	$210	$740	$510	$2,600
	Less Optimistic	25 year	$190	$690	$450	$2,400
	Less Optimistic	50 year	$1,800	$6,400	$4,600	$23,000
100-Year	Moderate	25 year	$200	$920	$510	$3,200
	Moderate	50 year	$360	$1,500	$920	$5,300
	Less Optimistic	25 year	$320	$1,300	$820	$4,900
	Less Optimistic	50 year	$900	$3,300	$2,400	$12,000
Western	Moderate	25 year	$140	$710	$430	$3,100
	Moderate	50 year	$250	$1,100	$730	$4,500
	Less Optimistic	25 year	$250	$1,200	$700	$4,600
	Less Optimistic	50 year	$650	$2,500	$1,700	$9,100

Source: Based on Info-USA data for business establishments, County Business Pattern Wages, and HAZUS-MH recapture factors. Government institutions are not included in sales figures. All monetary values presented in 2012 dollars.

6.5 Lost Rental Income

Table 13 reports the lost rental income in each case. Rental income losses may be larger than given estimates if property owners are delayed in securing contracts to repair building damage or locating new tenants after periods of extended disruptions. Lost rental income is relatively small compared to the primary business disruption costs, but they still range from $100 million for the eastern track storm under moderate conditions at 25 years to $1.9 billion for the same storm under less optimistic conditions at 50 years. Because we do not attempt to model changes to the rental market, we present these estimates for reference, but do not include them in totals for disruptions to economic activity.

Table 13. Lost Rental Income from Increased Storm Damage

Storm	Environmental Scenario	Time Horizon	Rental Income Lost ($ millions)
Eastern	Moderate	25 year	$100
	Moderate	50 year	$160
	Less Optimistic	25 year	$140
	Less Optimistic	50 year	$1,900
100-Year	Moderate	25 year	$200
	Moderate	50 year	$320
	Less Optimistic	25 year	$300
	Less Optimistic	50 year	$880
Western	Moderate	25 year	$170
	Moderate	50 year	$290
	Less Optimistic	25 year	$280
	Less Optimistic	50 year	$600

Source: Based on Info-USA data for business establishments and HAZUS-MH rental costs. Note: All results presented in 2012 dollars.

6.6 Business Survival

The marginal effects of flooding on the probability a firm would reopen after a storm are used to estimate the number of establishments that would remain closed two years after the flooding associated with each case considered in this analysis. Results depicting increased storm damage for each case are provided in Table 14 The number of establishments estimated to remain closed two years after a major storm ranges from 282 establishments in the eastern storm with the moderate environmental scenario at 25 years to 3,417 establishments in the eastern storm with the less optimistic environmental scenario at 50 years. These estimates correspond with approximately 3,000 to 39,000 jobs.

Table 14. Increase in Establishments Remaining Closed Two Years After Major Storm

Storm	Environmental Scenario	Time Horizon	Number of Establishments
Eastern	Moderate	25 year	280
	Moderate	50 year	410
	Less Optimistic	25 year	360
	Less Optimistic	50 year	3,400
100-Year	Moderate	25 year	440
	Moderate	50 year	670
	Less Optimistic	25 year	690
	Less Optimistic	50 year	1,500
Western	Moderate	25 year	300
	Moderate	50 year	480
	Less Optimistic	25 year	480
	Less Optimistic	50 year	1,000

Source: Based on Info-USA data for business establishments and HAZUS-MH rental costs. Note: All results presented in 2012 dollars.

7. CONCLUSIONS

We estimate that replacement costs associated with capital stock at risk from direct land loss range from approximately $2.1 billion to $3.5 billion under the environmental scenarios and time horizons considered (Table 15). The economic activity directly at risk in coastal Louisiana ranges from $2.4 billion to $3.1 billion in annual output. At-risk establishments in the less optimistic scenario at the end of 50 years are roughly 0.7 percent of all establishments statewide and reflect a similar share of economic output.

Table 15. Capital Stock and Activity at Risk to Land Loss Summary Table

		Replacement Costs of Capital Stock				*Economic Activity*
Environmental Scenario	Time Horizon	Non-Residential ($ millions)	Residential ($ millions)	Network Infrastructure ($ millions)	Total ($ millions)	Lost Annual Output ($ billions)
Moderate	25 year	$1,500	$310	$248	$2,058	$2.4
Moderate	50 year	$1,800	$360	$353	$2,513	$2.6
Less Optimistic	25 year	$1,800	$380	$376	$2,556	$2.6
Less Optimistic	50 year	$2,200	$510	$748	$3,458	$3.1

Increased storm damage to capital stocks ranges from $8.7 to $133 billion across our storm case studies (Table 16). Contributing to those estimates is damage to non-residential structures ranging from $4.7 billion for the eastern track storm in the moderate scenario at 25 years to $71 billion for the same storm track in the less optimistic scenario at 50 years. Damage estimates for residential structures range from $3.9 billion to $61 billion for the same storm cases, with network infrastructure costs ranging from $140 million to $640 million (Table 16). Economic activity will also face more substantial disruptions by storms in a future without action. Our preferred estimates imply that lost activity from businesses directly facing additional damage ranges from $1.9 billion to $23 billion in lost sales across the storm case studies; for example, the eastern track storm in the less optimistic scenario at 50 years is estimated to increase damage for approximately 26,000 establishments employing 320,000 workers, resulting in $6.4 billion of lost wages and $23 billion of lost sales (Table 16). The estimated number of businesses potentially facing long-term closure due to increased storm damage ranges from about 280 to 3,400 across the storm case studies.

Table 16. Eastern Storm Damage Summary Table

		Replacement Costs of Capital Stock				*Economic Activity*
Environmental Scenario	Time Horizon	Non-Residential ($ billions)	Residential ($ billions)	Network Infrastructure ($ millions)	Total ($ billions)	Lost Sales ($ billions)
Moderate	25 year	$4.7	$3.9	$140	$8.7	$1.9
Moderate	50 year	$7.2	$6.0	$190	$13.4	$2.6
Less Optimistic	25 year	$6.4	$5.1	$180	$11.7	$2.4
Less Optimistic	50 year	$71.0	$61.0	$640	$132.6	$23.0

Lastly, Tables 17 and 18 show the increased storm damage to capital stock and economic activity lost from the 100-year storm and the western storm case studies.

Table 17. 100-Year Storm Damage Summary Table

		Replacement Costs of Capital Stock				*Economic Activity*
Environmental Scenario	Time Horizon	Non-Residential ($ billions)	Residential ($ billions)	Network Infrastructure ($ millions)	Total ($ billions)	Lost Sales ($ billions)
Moderate	25 year	$9.2	$6.1	$180	$15.5	$3.2
Moderate	50 year	$14.0	$9.0	$270	$23.3	$5.3
Less Optimistic	25 year	$13.0	$8.5	$260	$21.8	$4.9
Less Optimistic	50 year	$33.0	$27.0	$510	$60.5	$12.0

Table 18. Western Storm Damage Summary Table

		Replacement Costs of Capital Stock				*Economic Activity*
Environmental Scenario	Time Horizon	Non-Residential ($ billions)	Residential ($ billions)	Network Infrastructure ($ millions)	Total ($ billions)	Lost Sales ($ billions)
Moderate	25 year	$8.2	$4.8	$140	$13.1	$3.1
Moderate	50 year	$13.0	$7.5	$220	$20.7	$4.5
Less Optimistic	25 year	$12.0	$7.5	$220	$19.7	$4.6
Less Optimistic	50 year	$26.0	$13.0	$420	$39.4	$9.1

Our goal was to provide comprehensive, policy-relevant estimates of the cost of coastal land loss in Louisiana, but we acknowledge a range of limitations to our analysis and final estimates. First, we do not attempt to project how the distribution of economic assets and activity in Louisiana would change over the 25- and 50- year horizons of our study period, although we know that current conditions will not persist into the future. We assume *no change in capital stock* to avoid the large degree of uncertainty in the level and distribution of future economic development across coastal Louisiana and to abstract away from feedbacks between land loss and economic development. This approach lets us more fully isolate and illustrate the differential impact of land loss on the economy.

Second, our methodology uses static models to estimate the effects of land loss on major categories of economic assets and activity. This has the advantages of being both tractable and easily understood, but it also greatly simplifies reality by not considering dynamic economic processes and behaviors, including feedback between the geophysical process of land loss and the economic system. We make assumptions that limit the potential for individual economic actors taking actions to reduce damage due to land loss. For example, individual homeowners can take action to harden their homes. Businesses at direct risk from land loss can choose to relocate further inland or invest to protect critical asset. Government organizations can opt to undertake projects to further protect areas viewed as particularly at risk.[21] We interpret a "future without action" as one in which such behaviors are generally assumed away, though it seems unlikely that this assumption holds in practice.

The estimates of potential costs presented in this report are limited to two categories of effects: 1) the capital stock and activity at risk of land loss; and 2) the expected increase in storm damage from a loss of storm surge protection. While we believe that these categories are the largest components of the overall costs of land loss, they are not comprehensive. There are potential effects of land loss that will affect economic activity that are not explicitly valued in this report (e.g., non-protective ecosystem services and navigability of the Mississippi River). The major characteristics of these excluded effects are that either a) there is great uncertainty in the physical relationship between land loss and the asset or service being valued; b) there is uncertainty about the marginal values associated with the asset or service being valued; or c) both. Many of these values may be non-market in nature. For example, the value of supporting ecosystem services is derived from a suite of potentially market and non-market final ecosystem services. There may also be existence, option, and bequest values associated with coastal Louisiana as a unique cultural place in the American landscape. Future research would help clarify the potential effects of land loss by reducing the uncertainty over these elements.

In some cases, we underestimate the capital stock at risk of damage or loss due to data or methodological limitations. For example, we estimate increased damage to roads and rail infrastructure, but did not calculate the monetary costs for bridges and pipelines. Significant bridge damage could occur because of collisions with vessels or debris propelled by storm surge, but there does not appear to be a practical way of attributing a differential in this risk to the process of land loss.

Finally, we consider uncertainty in this analysis through the variations implicit in the land loss scenarios and time horizons and through three representative storm events. In some cases, we also provide estimates over a varying parameter space. While this approach provides some indication of the differences in costs of land loss across various futures, it does not capture all uncertainty associated with

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[21] See the *2012 Coastal Master Plan* for an evaluation of the benefits of particular suites of such protection projects

the future. Our approach is meant to help illustrate the variation in potential magnitudes across certain futures and events. We remind readers that there will be some future years in which no major storm events impact coastal Louisiana, but there may also be years with multiple severe events like the 2005 hurricane season.

Future work could account for changes in the location and scale of economic activity over time, including how the economy is likely to respond through feedback mechanisms, thus incorporating likely mitigating behaviors. Industry-specific case studies, especially focused on substitutability in supply chains and transportation modes, could lend additional insight into the likely effects of land loss on specific sectors.

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