Present vs. Future Losses from a 100-year Flood: A Case Study of Grand Isle, Louisiana

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Abstract

Louisiana is among the most vulnerable places on Earth to coastal flooding, for many reasons. Tropical-cyclone-induced storm surge, shoreline erosion accelerated by eustatic sea level rise, tidal influences, minimization of river sediment nourishment due to the presence of levees, and land subsidence caused by compaction of marsh lands and underground resource extraction all contribute to the flood hazard. In addition, increasing frequency and intensity of natural hazards under climate change scenarios are expected to exacerbate the coastal flood risk. Many studies focus on flood risk assessment and mitigation strategies both for the present and future, and other research has analyzed future flood risk considering climate change and sea level rise. Yet few studies consider all of these factors in concert. This research represents a comprehensive approach that considers coastal subsidence, eustatic sea level rise, and tropical cyclone storm surge variability under climate change scenarios, to evaluate future flood risk at the individual building level in Grand Isle, Louisiana. Results suggest that on average, the 100-year flood depth will increase by 37 cm at the individual building level in Grand Isle by 2050, with subsidence contributing over 80 percent of this increase. Subsidence is projected to increase structure and content losses by approximately 18 percent above modeled losses at present, while eustatic sea level rise may contribute approximately one percent of additional losses. A 100-year storm surge event amid a "low" scenario of environmental change would increase the structure and content losses at Grand Isle by 68–74 percent of today's value in ten years, 141–149 percent in 25 years, and 346–359 percent in 50 years. Even more menacingly, "high" scenarios of environmental change are expected to increase the 100-year storm surge losses by approximately 85–91 percent of today's value in ten years, 199–218 percent in 25 years, and 407–415 percent in 50 years. Outcomes from this study will fill the gap in the current literature by implementing a more realistic risk assessment model and will direct flood risk managers, property owners, and other stakeholders to build a comprehensive framework to minimize future flood risk in one of the most vulnerable sites in the USA to coastal flooding.

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Introduction

This research represents a comprehensive approach to assessing coastal flood loss that considers the pluvial (i.e., locally-generated, rainfall-induced) flood-related variables of coastal subsidence and eustatic sea level rise, and the tropical-cyclone-induced storm surge flooding, for the present and future under environmental change scenarios which include the effects of subsidence and ESLR. In this analysis, the concept of the 100-year flood event (or flood with a 100-year recurrence interval), which is defined by United States Geological Survey as a flood of such magnitude that it has a one percent annual chance of being equaled or exceeded, is considered. The binomial theorem holds that, for example, a home in the 100-year floodplain has a 26 percent chance of being flooded at least once during a 30-year mortgage and a 50 percent chance of being flooded during the 70-year useful life cycle of a building. This definition of 100-year flood may apply to pluvial or storm surge-generated causes. The specific objective is to evaluate current and future flood loss (due to 100-year pluvial, and in a separate analysis, 100-year storm surge) to building structures and their contents at the individual building level in the town of Grand Isle, Louisiana (Figure 1), one of the most vulnerable areas in the world to coastal flooding.

Study Area

Grand Isle is a town that sits on both the mainland and the only inhabited barrier island in Louisiana (also named Grand Isle, see again Figure 1). Similar to other barrier islands, Grand Isle was formed as waves and the longshore current deposited sediments in a linear fashion, in this case approximately 5,000 years ago as sediment from the Mississippi River was carried westward. Grand Isle is also one of the few areas where present and projected future 100-year storm surge and current 100-year pluvial flood data are available along with the subsidence rate, ESLR, and NOAA sea level rise inundation depth scenarios. A final reason for selecting this study area is that no previous study has focused on present and future flood damage to building structure and contents in Grand Isle while considering the effects of subsidence, ESLR, and tropical cyclone-related storm surge.

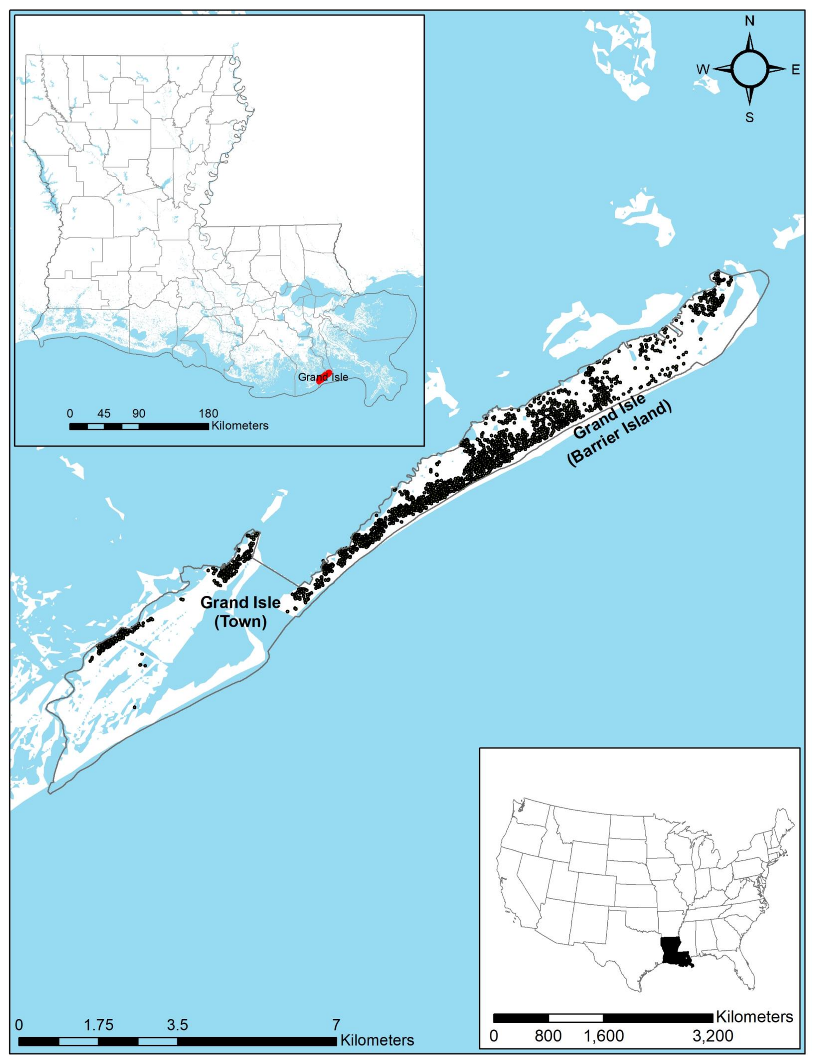

***Figure 1**. Grand Isle (town and barrier island), Louisiana, with dots representing building locations.*

Data

The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's Flood Impact Analysis (HEC-FIA) model is used to calculate the loss from the current 100-year pluvial flood event and (separately) 100-year storm surge event, and to project loss resulting from a future (i.e., in 2050) 100-year flood due to RSLR and (separately) a storm surge event 10, 25, and 50 years after the 2017 baseline. CPRA provides spatially-distributed 100-year storm surge depth grids along Louisiana's coast, for the present and for 10, 25, and 50 years into the future. Each of these projections includes six depths: one each for low, medium, and high scenarios of environmental change (i.e., warming and sea level rise), with and without implementation of mitigation measures described in the Louisiana Coastal Master Plan.

Table 1. Summary of data sources used in this research.

Data	Source	Attribute
Building Information	National Structure Inventory (NSI 2019) 2.0	Occupancy type, replacement value, content value, foundation height, foundation type, and number of stories
Digital Elevation Model (DEM)	National Oceanic and Atmospheric Administration (NOAA 2021b)	Ground elevation (m)
Present 100-year pluvial flood	FEMA (2021) Risk Mapping, Assessment and Planning (Risk MAP) program	3.048 m x 3.048 m depth grid cells in feet
Subsidence Rate	Zou et al. (2016)	mm yr^{-1}
Eustatic Sea Level Rise (ESLR)	National Oceanic and Atmospheric Administration (NOAA 2021b)	Inundation depth (m)
Current and future 100-year storm surge	Coastal Protection and Restoration Authority (CPRA 2017)	Inundation depth (ft)

Methods

For pluvial changes, the current 100-year flood depth at Grand Isle from the Jefferson Parish Risk MAP program flood depth grids is used as the baseline for predicting future flood depths due to these two categories of factors. The mean subsidence rate (mm yr-1) raster files generated by Zou et al. (2016) for coastal Louisiana are used to project the total subsidence from 2017 (i.e., when the flood depth grid was calculated) to 2050. Then, the Grand Isle elevation in 2050 is computed as the value in NOAA (2021b) minus this total subsidence. The decrease in elevation is assumed to be linear over time and will increase the flood depth for buildings in Grand Isle by 2050 at a mean of 1.11 feet, but ranging from 0.63 to 1.25 feet.

The ESLR trend of 9.16 mm yr-1 at Grand Isle as measured by NOAA (2021a) is extrapolated linearly from 2017 (i.e., when the flood depth grid was calculated) for 33 years, to project a ESLR of 302 mm (or ~one foot) by 2050. The flood depth increase attributed to this ESLR increase is calculated using the NOAA (2021b) "sea level rise depth" option for a zero (i.e., for present) and a one-foot (2050 scenario) sea level rise. The inundation depth accompanying this one-foot increase is calculated as the difference between the zero (for present) and one-foot (for 2050) inundation depth. Consequently, the building 100-year flood depth in 2050, considering the effect of ESLR only, is calculated as the sum of the present 100-year flood depth and the increase in inundation depth attributed to ESLR by 2050.

For both present and future 100-year storm surge at Grand Isle, the CPRA (2017) storm surge inundation depth shapefiles are converted to raster files using the "Polygon to Raster" tool in ArcGIS®. All combinations of scenarios are run (i.e., current 100-year storm surge depth, storm surge depth 10 years in the future without action for a low environmental change scenario, 25-year future storm surge without action for a high environmental change scenario, ... 50-year future storm surface with action for a high environmental change scenario). The present and future 100-year storm surge scenarios are used to calculate the structure and content losses in HEC-FIA to determine the economic impact of a future 100-year storm surge in Grand Isle (Figure 2).

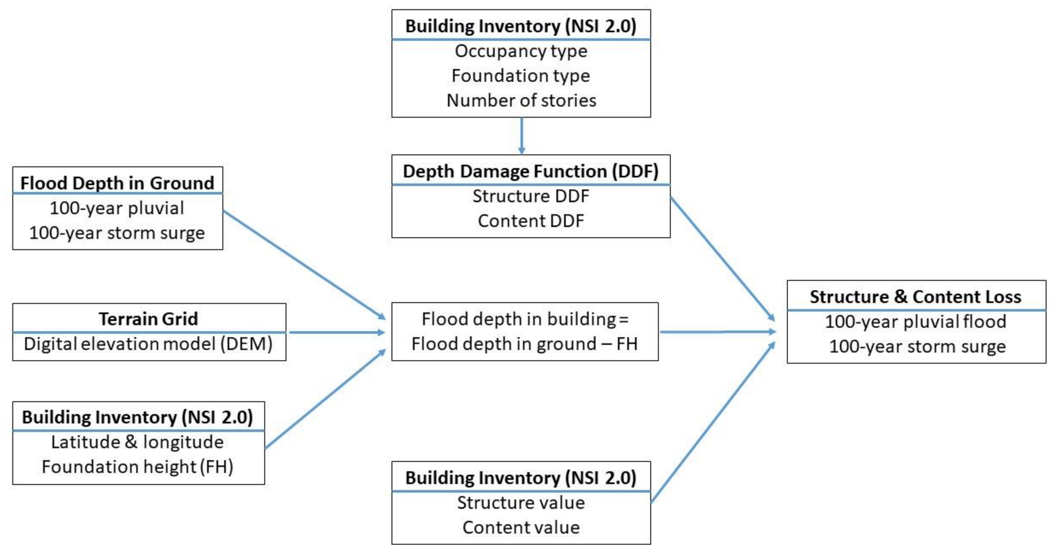

***Figure 2**. HEC-FIA Flood Model.*

Results

A 100-year pluvial flood event in 2017 would produce over $169 million (2020$) in structure and content losses (Figure 3) to the 2,023 structures on Grand Isle, of which 1,897 are residential, 79 are commercial, 21 are industrial, and 26 are public. The mean 100-year pluvial flood depth for all structures on Grand Isle today is 8.95 feet above the ground surfaces, which explains why the structures are all elevated. By 2050, 1.11 feet of additional depth is projected to have been caused by continued subsidence and another 0.24 feet of depth is projected to be due to ESLR, leaving the projected mean 100-year pluvial flood depth for these structures at 10.30 feet. Thus, continued subsidence and ESLR will increase the 2017 pluvial flood depth by 12.4 and 2.7 percent, respectively, by 2050. Continued subsidence to 2050 is projected to increase these losses to over $198 million (2020$), a 17 percent increase, and ESLR would add another 3.1 percent to these losses by 2050. In both cases, losses to structure are and will likely remain greater than losses to content, and the combined total effect of continued subsidence and ESLR will cause over $203 million (2020$) in losses to these buildings by 2050. Nearly 77 percent of these total (structure + content) losses would be to residential structures (Figure 3).

Regarding tropical-cyclone-induced storm surge flooding, the 100-year event that occurs 10, 25, and 50 years into the future will cause greatly magnified total (structure + content) losses at Grand Isle compared to today's loss estimates for all buildings of $59 million (2020$) for structure and content (Figure 4). Interestingly, because the Louisiana Coastal Master Plan (CPRA 2017) prioritizes rebuilding land elsewhere, the losses are estimated to be slightly greater at Grand Isle with implementing the Plan compared to the scenario without Plan implementation (Figure 4). The "low" scenarios of environmental change would increase the storm-surge-induced flood losses at Grand Isle by 68–74 percent in ten years, 141–149 percent in 25 years, and 346–359 percent in 50 years (Figure 4). Even more menacingly, "high" scenarios of environmental change are expected to increase the losses by approximately 85–91 percent in ten years, 199–218 percent in 25 years, and 407–415 percent in 50 years (Figure 4).

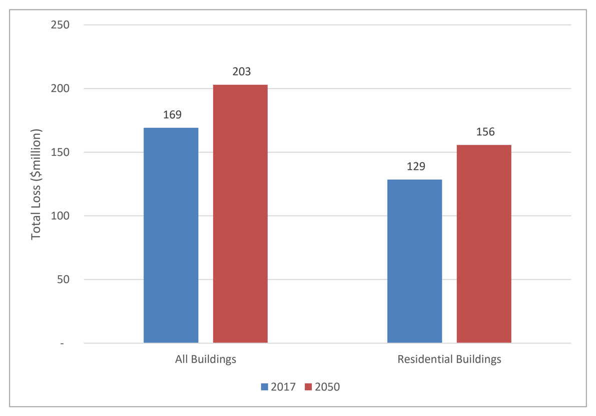

***Figure 3**. Present (2017) and 2050-projected total (structure + content) losses (2020$) for all buildings and for only residential buildings, from 100-year pluvial flood event due to the effects of continued subsidence and eustatic sea level rise, Grand Isle, Louisiana.*

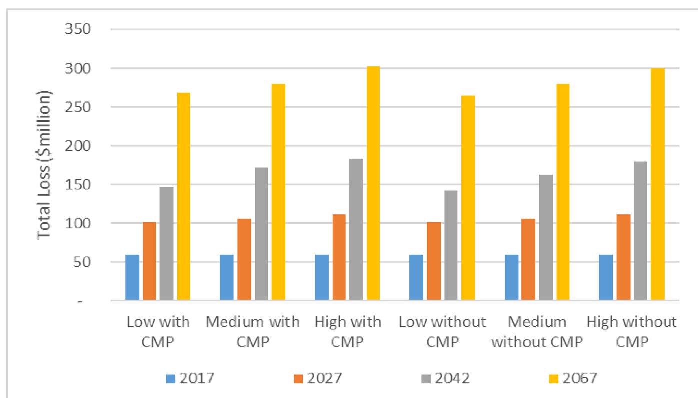

***Figure 4**. Total (structure + content) losses (2020$) for a 100-year storm surge flood event in Grand Isle, Louisiana, with vs. without implementation of the 2017 Louisiana Coastal Master Plan (CMP), and by low, medium, and high scenarios of environmental change, for 2017, 2027, 2042, and 2067.*

Discussion

The nearly $34 million (2020$) in additional damage to all buildings from a 100-year pluvial flood event that can be expected because of the continuing effects of subsidence and ESLR between 2017 and 2050 would represent an extra $23,770 (2020$) for each of the 1,429 permanent residents of Grand Isle in 2017 (U.S. Census Bureau 2021). Thus, the total losses to all buildings are projected at an astounding $142,132 per person (not per household). The 2050 losses from an event of the same magnitude solely to the residential buildings would leave each person (not each household) with $108,922 in damage. An even more sobering story emerges when examining the impact of tropical-cyclone-induced storm surge. In the least severe environmental change scenario with and without implementation of the Louisiana Coastal Master Plan (CPRA 2017), a storm surge in 50 years (i.e., 2067) would inflict $187,786 and $185,133, respectively, per person in losses. Even more ominously, the most severe environmental change scenario with and without implementing the Louisiana Coastal Master Plan (CPRA 2017) would impose losses of $211,443 and $209,646 per person in 2067.

The fact that losses would likely be slightly greater without implementation should certainly not be taken as evidence that Louisiana's Coastal Master Plan (CPRA 2017) should not be implemented. Instead, the direction of resources elsewhere for fortifying Louisiana's coastline in CPRA (2017) may simply be evidence of a triage-based approach to prioritize the areas with the greatest impact per dollar spent. Regardless, however, the overwhelming sentiment is that Grand Isle is worth saving, but this will require individual homeowners to elevate their homes and camps under the assumption that the CPRA Coastal Master Plan will provide little additional mitigating effects for Grand Isle.

According to the binomial distribution, the probability of a 100-year flood occurring in a 33-year period (e.g., between 2017 and 2050) is 28.2 percent, and the 50-years-in-the-future-from-2017 probability of the 100-year storm surge flood is 39.5 percent. In all cases for both the 100-year pluvial flood and the 100-year storm surge, damage to structures exceeds damages to the contents within the structure.

Even more daunting is the fact that these losses do not include those incurred to vehicles including boats, ecosystem structures and functions, recreation, industries (e.g., commercial fisheries, tourism, and mineral extraction), indirect losses (e.g., hotel expenses while a residence is being remodeled, work absences, and emotional/psychological anguish), and the priceless impacts to aesthetic resources for which Grand Isle is renowned. Nor does it include additional damage to structures, contents, or the items listed above from wind or lightning that accompanies the modeled flood-producing storms. Furthermore, it is noteworthy that the losses calculated herein assume no increase in precipitation, even though several sources suggest an increasing frequency of heavy precipitation events, as described previously. Thus, our calculations here likely underestimate the losses.

Conclusion

This analysis estimates loss to building structure and contents from a 100-year pluvial flood event and a 100-year tropical cyclone-induced storm surge event at the iconic resort area of Grand Isle, Louisiana, for the present and for future scenarios. The 100-year pluvial flood event certainly produces formidable flood depths at Grand Isle today – an average of almost 9 feet. However, continued subsidence and ESLR will increase this value by 12.4 and 2.7 percent, respectively, causing over $203 million (2020$) in structure and content damage by 2050, an increase of 20 percent over calculations for the 100-year pluvial flood in 2017. While the 100-year storm-surge flood causes approximately $58,878,948 in structure and content damage today for all buildings in Grand Isle, future increases in flood depths caused by low, medium, and high scenarios of environmental change (CPRA 2017) may produce losses 50 years into the future (i.e., 2067) of between $265 and $300 million. Because mitigation measures are targeted for areas other than Grand Isle, the losses are slightly greater with implementation as compared to without implementation of CPRA (2017). Thus, individual homeowners must elevate their homes and camps under the assumption that the CPRA Coastal Master Plan will provide little additional mitigating effects for Grand Isle. In all cases for both the 100-year pluvial flood and the 100-year storm surge, damage to structures exceeds damage to the contents within the structures. Municipal and parish (county) officials must make all practical efforts to mitigate these losses through effective planning and cooperation to enhance community resilience to the coastal flood hazard. Otherwise, Grand Isle may be destined to a similar fate as another famous Louisiana barrier island resort destination – Isle Dernière – where approximately 200 lost their lives when the island was destroyed and broken into multiple islands by a hurricane in 1856, with its subsequently unpopulated remnants renamed as Isles Dernières.

Similar methods could be used to assess potential risk in any coastal area for which sophisticated flood modeling has been done. Results from such analyses would assist community leaders in planning for the ever-present coastal flood hazard and in educating the public regarding the importance of proactive programs to mitigate the hazard. Such efforts would improve the quality of life and enhance resilience in the densely populated and frequently visited coastal zone.

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