Louisiana Silver Jackets

Spatial and Temporal Variations in Exposure and Sensitivity to Coastal Flooding Resulting from a 100-Year Storm Event

East St. Mary Parish and Lower Lafourche Parish, Louisiana

Prepared for:

JESCO Environmental

Prepared By:

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List of Acronyms

Acronym	Term
C-CAP	Coastal Change Analysis Program
CLARA	Coastal Louisiana Risk Assessment
CPRA	Coastal Protection and Restoration Authority
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GIWW	Gulf Intracoastal Waterway
LDWF	Louisiana Department of Wildlife and Fisheries
LSU	Louisiana State University
NOAA	National Oceanic and Atmospheric Administration
TNC	The Nature Conservancy
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
ULL	University of Louisiana at Lafayette

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Executive Summary

Low-lying communities along the Louisiana coast are particularly vulnerable to storm surge-related flood hazards. This study compares the vulnerability of a number of communities in two coastal Louisiana regions, each with unique physical and social vulnerabilities, Lower Lafourche Parish and East St. Mary Parish. Variations in community exposure and sensitivity to storm surge was assessed through a combined analysis of social vulnerability, exposure of critical and essential facilities to coastal flooding, and elevation of critical structures above flood levels. Flood hazards were adapted from the Coastal Louisiana Risk Assessment (CLARA) model methodology and qualification of community exposure and sensitivity was conducted through analysis of varying socioeconomic attributes indicative of societal vulnerability.

The resulting analysis shows that communities in each of the two study areas become increasingly vulnerable to storm surge flooding through time due in large part to the high number of critical and essential facilities located in flood-prone locations. In both study areas, analysis indicates a relatively low risk to critical and essential infrastructure resulting from a 100-year storm occurring under current conditions. However, under future conditions, levels of risk dramatically increase for all classes of developed land and associated critical and essential facilities. This increase is especially notable in the Lower Lafourche Parish study area, which is anticipated to be nearly completely flooded by a 100-Year storm in 50 years. An indication of enhanced community vulnerability is associated with the inundation of critical and essential facilities that primarily serve vulnerable populations.

In several communities, relative vulnerability is primarily attributed to a community's high inherent sensitivity to coastal flooding, meaning that assets located in flood-prone areas represent a large percentage of the community's total assets. For example, the sole emergency operations center located in Lower Lafourche Parish is located in an area projected to flood above 3 ft. Despite this facility being elevated above the projected inundation level, the facility could be potentially isolated from the surrounding community during coastal storm events.

It is important to note that the results of this research showing reduced vulnerability to storm surge and coastal flooding in certain locations does not mean that the region is safe from either riverine flooding or flooding caused by extreme rainfall events. Based on geospatial analysis of socially vulnerable populations, critical and essential facilities, and developed land distribution, the following conclusions can be drawn for the two study areas assessed:

- Under current conditions, both study areas are not projected to experience drastic amounts of significant flooding, defined as 3 ft. or more of inundation, from a 100-year storm event. Areas that are projected to experience flooding are either immediately adjacent to waterways or located outside of protection levees.
- For both study areas, the greatest flood risk occurs over the period occurring between 25 and 50 years in the future. During this time, communities within storm protection levees are projected to experience 3 ft. or more of flooding during a 100-year storm, particularly in Lower Lafourche Parish and the communities of East St. Mary Parish, east of the Atchafalaya River.

- Critical and essential facilities in both study areas are well protected from coastal flood hazards under current conditions. Under a scenario of moderate environmental change, between Year 25 and Year 50, both study areas experience a significant jump in the number of at-risk critical and essential facilities.
- Both study areas have large elderly populations, individuals above the age of 65, greater than the statewide average. Individuals in this population group may have difficulty during evacuation operations due in part to health concerns and potential mobility limitations.
- The racial diversity of both study areas is noticeably lower than that of the State of Louisiana.
- Under current conditions, no single minority group was found to be more sensitive to flood hazards arising from a 100-year storm event in East St. Mary Parish, while the Asian population of Lower Lafourche Parish was found to be sensitive to such a storm event. In Lower Lafourche Parish, Hispanic populations see an increase in flood susceptibility in Year 25, but by Year 50, nearly all the land in Lower Lafourche Parish experiences significant flooding along with the entire population of the study area, regardless of social vulnerability.

Introduction

Coastal Louisiana is experiencing a globally high rate of wetland loss due in part to a combination of sea level rise, subsidence, saltwater intrusion, and reduced sediment input. Between 1932 and 2010, coastal Louisiana lost over 1,800 square miles of land and is predicted to lose another 1,200 to 4,100 square miles over the next 50 years (Couvillion et al., 2011; CPRA, 2017). As coastal land is lost, communities become increasingly vulnerable to storm surge, coastal flooding, tropical weather events, hurricanes, storms, and frontal systems. Residents living in this changing environment will be forced to either adapt or relocate away from high risk areas. Those who choose to remain, or who lack the financial resources to relocate, may face additional economic threats as rising insurance rates and accessibility to mortgages could potentially make living in coastal areas unaffordable (Dalbom et al., 2014; Hemmerling et al., 2016).

The purpose of this research is to assess and describe geographic variations in community vulnerability to storm surge under both current and future environmental conditions. Community vulnerability is defined here as the attributes of a human-environmental system that increases the potential for hazard-related losses or reduced performance and is primarily determined by how communities occupy and use hazard-prone land (Wood et al., 2007a). Vulnerability is characterized in this research by the exposure and sensitivity of several societal assets, including developed land, socially vulnerable residential populations, and critical and essential facilities, to storm surge resulting from a 100-year tropical storm event. This research utilized modeled storm surge data derived for Louisiana's 2017 Coastal Master Plan. Future flood depths from storm surge are estimated at 10, 25, and 50 years from now under a medium environmental change scenario if no further actions are taken to reduce risks. The medium environmental scenario projects a 2.07 ft. increase in sea level and a land-loss estimate of 2,254 square miles over the next 50 years (CPRA, 2017).

The ability of communities to adapt to changing environmental conditions and rebound from coastal hazard events is dependent on both the social vulnerability of residents and how quickly essential services can be restored. The restoration of essential services is a key aspect of community resilience. This research identifies critical and essential facilities that are currently exposed to varying levels of coastal flooding and storm surges within coastal communities as well as those that are projected to be exposed to such flooding in the future. Certain facilities are important for short-term response and long-term recovery of a community following a flood event. Critical facilities are those considered important for short-term response operations and include those used for public safety purposes (civil-defense facilities, fire stations, national-security facilities, police stations, and radio and television stations), medical services (ambulances, hospitals, outpatient-care centers, and physician offices), and infrastructure maintenance (electric, public-works, natural-gas, waste-water, and water and sewer facilities) (Wood et al., 2007a). Essential facilities are those considered important for long-term recovery. Two classes of essential facilities are examined here. The first includes those facilities that provide basic necessities for residents (banks and credit unions, gas stations, and grocery stores) or serve government functions (courts and legal offices, government offices, international-affairs offices, and U.S. Post Offices) (Frazier et al., 2010). The ability of communities to adapt to changing environmental conditions and rebound from coastal hazard events is dependent on how quickly these essential services can be restored. The second includes those facilities that provide reliable care and services for children, including schools, libraries, and day care centers. After the basic needs such as food and shelter are met, it then becomes necessary to restore these types of social infrastructure.

The State of Louisiana has developed a Flood Risk and Resilience Program that highlights areas where structures could be elevated or floodproofed, as well as areas where flood depth may force residents to considered moving to higher ground (Clipp et al., 2016). The exposure of residents and facilities to coastal flood hazards varies spatially, even within the same broad geographical regions. Golden Meadow, for example, located in Lower Lafourche Parish, is different from Morgan City, located within the delta of the Atchafalaya River, despite that fact that both communities are located within the Mississippi River Delta Plain. Both Morgan City and Golden Meadow have roughly the same hurricane return periods (Keim et al., 2007; Trepanier et al., 2015), but their levels of risk are vastly different due to the combined effects of anthropogenic changes to sediment supply and river flow, subsidence, and sea-level rise (Twilley et al., 2016). Morgan City, close to an active river channel with two growing deltas, is protected by a ring levee designed to protect the city from riverine flooding. Golden Meadow, located on Bayou Lafourche, which has been largely disconnected from the Mississippi River by the construction of locks, levees, and other water control structures, is surrounded by a levee system intended to protect the interior communities from storm surge and coastal flooding.

Methods and Data

This study assesses geographic variations in community exposure to current and future coastal flood risks in two communities in coastal Louisiana, the Larose to Golden Meadow corridor in Lower Lafourche Parish and Morgan City and surrounding communities in East St. Mary Parish. Future environmental scenarios are used to predict when facilities might be expected to be impacted by coastal flooding and establish a set of adaptive action timelines. These timelines indicate critical thresholds, such as when a facility is projected to fall below the 1% annual chance storm surge height (e.g., less frequency then a 100-year storm event). This information can be used by state and local government officials as well as facility managers to prioritize the development of nonstructural adaptation measures for critical and essential facilities and infrastructure, including developing individual mitigation measures, floodproofing, raising structure elevations, and facility relocation. Community exposure is described by the amount and relative percentage of societal assets experiencing 3 ft. or more of flooding during a 100-year storm event. As outlined in the 2017 Coastal Master Plan, assets inundated above 3 ft. are considered at risk and require structural elevation efforts to increase flood resiliency. Non-elevated assets inundated above 3 ft. require extensive time and capital-intensive remediation efforts after a flood event. Variations in community exposure are calculated using geographic information system (GIS) tools and do not represent engineering-based loss estimates for any particular community or facility.

Societal-asset calculations focus on the amount and percentage of developed land, socially vulnerable residential populations, critical facilities, and essential facilities located within modeled flood zones under several future scenarios. These assets are utilized because they represent key components of coastal vulnerability and resilience. Socially vulnerable populations often lack the social and financial capital to effectively respond to and recover from hazards events. Similarly, the vulnerability of critical and essential facilities to these events is directly related to the capability of communities to respond during the event and to recover afterwards. Finally, these assets are determined in part because U.S. jurisdictions are encouraged to collect similar data as they develop state and local mitigation plans (Wood, 2008).

Data used in this analysis include:

Land cover – based on the distribution of developed land and determined by using the low-, medium-, and high-intensity developed classes, defined below, of the 2010 National Land Cover Database, which was compiled by the NOAA Coastal Change Analysis Program;

Residents – based on block-level population counts compiled for the 2010 U.S. Census; and

Critical and essential facilities – based on the 2006 InfoUSA Employer Database, a proprietary business database that identifies location, number of employees, total sales volume, and the North American Industry Classification System code.

The primary purpose of this population exposure study is to support preparedness and education efforts; therefore, it does not include analysis of direct or indirect economic losses to individuals, businesses, or communities. This analysis is intended to help community members, facility managers, and local, state, and federal policymakers prioritize where and when nonstructural protection plans should be implemented in order to lessen future damages to critical facilities and infrastructure from coastal hazards such as land loss, sea level rise, and coastal storm surge. The data inventory and adaptation timelines developed for this study can be continuously updated as conditions on the ground change, allowing officials to measure the progress of nonstructural implementation plans and determine where limited financial resources could best be utilized. Such nonstructural adaptation approaches can effectively reduce the vulnerability of at-risk populations and critical and essential facilities to coastal flood hazards and reduce the likelihood that facilities exposed to flood hazards will realize adverse social and economic consequences.

LAND-COVER DATA

Describing patterns of land cover and human development is an important component of an exposure assessment in predicted hazard zones (Diefenbach et al., 2015; Frazier et al., 2010; Wood, 2008; Wood et al., 2013). Land cover information for the Louisiana coast was determined using NOAA's 2010 Coastal Change Analysis Program (C-CAP) data, which is produced at a 30 m spatial resolution. With a base scale of 1:100,000 for mapping applications and accuracy standards of 85%, C-CAP data are used to identify regional landscape patterns and not individual features (Wood, 2009). To assess variations in community exposure to coastal flood hazards, this study focuses on three classes of developed land in the C-CAP data:

High-intensity developed pixels – which contain more than 80% impervious surfaces, contain little or no vegetation, and typically represent heavily built-up urban centers, large buildings, and abundant paved surfaces, such as runways and interstate highways;

Medium-intensity developed pixels – which contain 50-79% impervious surfaces, are a mix of constructed and vegetated surfaces, and typically represent single-family housing units and associated outbuildings; and

Low-intensity developed pixels – which contain 21-49% impervious surfaces and are similar to medium-intensity developed pixels with the addition of roads and associated trees (Wood et al., 2013).

To assess overall community exposure and sensitivity to coastal flood hazards, this study calculates the amount and percentage of at least 20% area developed land that is anticipated to flood under several coastal storm scenarios, under both current and future landscape conditions. Comparing landscape compositions at the regional scale provides insight into the relationship between developed areas and predicted hazards within communities (Wood et al., 2007b). However, this information does not directly translate to economic loss potential of any specific asset within a modeled grid cell, as developed classes denote the amount of impervious surfaces within a grid cell but not the density of development. Therefore, land classified as developed includes a wide range of impervious surfaces, including interstates, highways, parks, residential homes, and commercial parks. Nevertheless, research has shown that community vulnerability increases with greater amounts and percentages of developed land located in hazard zones (Wood, 2009).

POPULATION DATA

Although all individuals occupying flood-prone locations have the potential to be impacted by coastal storm events, demographic factors can amplify the potential for losses and create varying recovery times (Wood et al., 2007). Social impacts of hazard exposure often fall disproportionately on society's most vulnerable populations, including minorities, children, the elderly, and the single parent households. In broad terms, social vulnerability refers to the inherent characteristics of a person or group that influences their capacity to anticipate, cope with, resist, or recover from the impact of a hazard (Wisner et al., 2004). Inherent social vulnerability can lead to adverse or positive responses to hazards events and is influenced by the following characteristics (Jepson & Colburn, 2013):

- Pre-event socioeconomic structures of the community that may create or negate the potential for harm;
- Susceptibility to harm, powerlessness, and marginality of physical, natural and social systems; and
- Patterns of differential access to resources

Vulnerability is a function of local socioeconomic conditions and the nature of the hazard to which the human population is exposed (Adger et al., 2004). While overall vulnerability is dependent upon exposure to specific hazards, social vulnerability represents the inherent characteristics of a community or population group that influence how it is able to respond to and recover from any number of hazards events. Many factors contribute to the ability of communities to respond adaptively to changing conditions and these factors can be represented by any number of indicator variables. Indicator variables are either quantitative or qualitative measures derived from observations that simplify the reality of complex situations (Cutter et al., 2010).

To determine the number and type of residents vulnerable to current and future flood events, this research uses block level population counts and demographic data from the 2010 U.S. Census. Although vulnerability varies at the individual level, the block is the most practical unit that can be reliably quantified and is regularly utilized by local officials and public agencies. Although additional socioeconomic data are available for larger census units, such as the census block group and census tract, block level data most closely corresponds with the scale of the flood data used in this research. Population and demographic variables analyzed in this research include the following characteristics:

- Total population
- Hispanic or Latino population
- White alone
- Black or African American alone
- Native American alone
- Asian alone
- Median age
- Population less than 5 years in age
- Population more than 65 years in age
- Female population
- Households
- Renter-occupied houses
- Female-headed households with children

Previous research has examined the relationship between social vulnerability and coastal storm events, identifying structural weaknesses of certain populations that highlight their specific vulnerabilities (Table 1). Because the root causes of these vulnerabilities (lack of financial resources, special medical needs, political disempowerment, etc.) are independent of any specific hazard, they can be adapted and considered across a range of hazardous events. In the case of coastal storms and other acute onset events, issues related to immediate evacuation are important. In the case of gradual onset events, such as coastal land loss and sea level rise, immediate evacuation may not be needed. Rather, issues related to population relocation become important. The same structural weaknesses of the vulnerable populations exist, regardless of the type of hazard or the speed of onset. Note that this research assumes that current demographic rates will remain consistent over the 50-year timeframe encompassed by the flood risk analysis.

Table 1. Social vulnerability factors and their implications during and after coastal storm events (adapted from Dunning & Durden, 2011).

Vulnerability Factor	Response During Event	Recovery
Elderly/very young	Greater difficulties in evacuation, increased health and safety issues, potential for higher loss of life	May lack ability to rebound
Single parent/female-headed households	Lack of resources and special needs relative to child care may complicate evacuation	Lack of resources may hinder ability to recover
Minorities	Lack of influence to protect interests, politically disempowered	Lack of influence to protect interests, lack of connections to centers of power or influence
Occupants of mobile homes/renters	Occupy more vulnerable housing	Potential displacement with higher rent

CRITICAL AND ESSENTIAL FACILITIES DATA

Community resilience is a measure of the sustained ability of a community to utilize available resources to respond to, withstand, and recover from hazard events and other adverse situations (Acosta et al., 2017). Certain facilities are considered critical for short-term response and others are considered essential for long-term recovery of a community following a disaster (Wood, 2007; Wood et al., 2007a). For the purposes of this study, critical facilities are defined as those considered important for short-term response operations while essential facilities are defined as those considered important for long-term recovery of the community. Critical facilities include those used for public safety purposes, medical services, and infrastructure maintenance while essential facilities include those that provide for basic necessities or serve government functions (Wood, 2007). The facilities identified[1] for this study include:

- Critical Facilities
    - Hospitals
    - Outpatient Care Centers
    - Physician Offices
    - Fire Stations
    - Police Stations
    - Electric Companies
    - Gas Companies
    - Radio and TV Broadcasting
    - Water and Sewage Companies
- Essential Facilities
    - Banks and Credit Unions
    - Gas Stations
    - Government Offices
    - Retail Grocers
    - Day Care Centers
    - Schools
    - Libraries

Determining Elevation of Critical and Essential Facilities

Elevation of structures in flood-prone areas is a key defense to coastal flooding during storm events. Elevated facilities experience significantly decreased downtime after a flood event and are better able to assist in ongoing emergency response. The cost of elevating a facility is high, but the benefits associated with elevation far outweigh the costs associated with renovating a flooded facility. Determination of facility elevation requires a comprehensive research methodology ranging from application of remote sensing to research of online documentation conducted in conjunction with field visits. Remote sensing methods that can be utilized to determine facility elevation include commercial products such as Google Earth and Google Street View. Subsequent to application of remote sensing data, online documentation

[1] Critical and essential facilities were identified by the 8-digit North American Industry Classification System code for each business in the 2014 Dun & Bradstreet employer database.

helps fill in data gaps associated with incomprehensive sensor coverage. Online hosted pictures of facilities prove to be a valuable source of information regarding facilities undocumented by remote sensing activities. Field work, primarily travel to the study area to photograph unknown facilities, helps fill in data gaps associated with construction completed outside the temporal bounds of remote sensing efforts. The applicability of remote sensing is hindered by the availability of data and the temporal range it covers. Address matching used to determine correct facility location requires several data sources to ensure accuracy and is wholly dependent on the comprehensive nature of the research conducted and the spatial precision of the original dataset. Estimates regarding the elevation of a facility can only be completed after the location of a facility has been correctly determined.

Determination of facility elevation is accomplished primarily through photogrammetric analysis conducted on ground level images taken of the facility in question. One method of quantifying the elevation of a facility can be accomplished through comparison of the height of a facility with the height of known objects located in the frame. These known objects can include vehicles, vegetation, and even people. For example, a semi-trailer parked adjacent to a facility can be used to estimate the elevation of the facility by comparing the height differential between the roof of the trailer and the base floor of the elevated structure. Whether an elevated facility gets inundated is strictly dependent on the benchmarks outlined in the modeling environment. In the case where a water level of 3 ft. is selected as the inundation criteria, a facility that elevated to 12 ft. would not be considered flooded unless the modeled grid cell in which the facility resides is inundated to 15 ft. This additive effect reinforces the obvious notion that elevated facilities are much less likely to flood than adjacent non-elevated facilities. Elevated facilities that can remain operational during an inundation event further increase a community's ability to provide critical services to those residents affected. These services, in conjunction with uninterrupted emergency management, allow for a quicker macro-scale recovery.

Figure 1 depicts a ground level view of gas station and marina in Leeville, Louisiana. Immediately adjacent to the facility is a domestic tractor trailer with the roof of the semi-trailer extending slightly higher than the base of the second story. The average height of a domestic semi-trailer is estimated between 13.5 and 14 ft. As the second story of the structure sits roughly 10% lower than the roof of the semi-trailer a conservative estimate of this facility's elevation would be 90% of the average determined elevation of the semi-trailer or the product of 0.9 and 13.5 ft. As such, the elevation of this structure is estimated at 12 ft.

Figure 1. Gas station and marina in Leeville, Louisiana (image courtesy of Google).

Figure 2 shows a government facility located in Port Fourchon, Louisiana under construction in September 2013. As previously described, vehicles can be used to estimate the elevation of this facility given the absence of known data. Pictured in the foreground to the left of the structure is an eleventh-generation Ford F-150 pickup truck. The documented height of this series F-150 ranges between 73.5 and 76 in. depending on drivetrain and cab type. Although it appears slightly lifted, a conservative estimate puts the height of this particular vehicle at 74 in. Being in the foreground of the picture, the truck will seem larger to the observer when compared to the structure behind it. Using the distance measuring tool native to Google Earth a ratio can be formulated between the distance from the observer (southbound lane of LA-3090) to the edge of the parking lot (where the truck is parked) and the distance between the observer and the edge of the building. This parameter is estimated at 0.8. The inverse of this relationship depicts how many times larger the truck in the foreground appears when compared to an identical vehicle parked directly adjacent to the building. As such, any estimate of the building's height using the truck in the foreground as a reference would have to be multiplied by a factor of 1.25 to account for this offset. From the image, two of these trucks would fit neatly underneath the raised facility. Rounding this number up for simplicity results in a height of 150 inches or 12.5 ft. Accounting for the offset requires finding the product between the aforementioned inverse distance ratio and this calculated height. The product of these parameters gives an estimated height of 15.625 ft. When conducting rough photogrammetric analysis such as this it is always prudent to provide a conservative estimate rather than an aggressive one. As such, the elevation of this particular government facility is estimated at 15 ft.

Figure 2. Government facility in Port Fourchon, Louisiana (image courtesy of Google).

Figure 3 depicts a Louisiana Department of Transportation and Development facility in Leeville, Louisiana. Determination of the elevation of this facility requires a combination of known reference points located in the frame. Assuming the water visible in the foreground is set as the baseline datum, the elevation of the toll booth can be determined using an amalgam of the average heights of surrounding vegetation, marsh fill, and vehicles. This snapshot was captured in the Fall of 2013 and the brown vegetation visible is smooth cordgrass, *Spartina alterniflora*, with an average height ranging between 3 and 5 ft. The cordgrass terminates at the marsh fill underlying the facility in question. Visible between the smooth cordgrass and the beginning of the marsh fill is a strip of unidentifiable green vegetation. Photogrammetric analysis is often limited by imagery resolution and the average height of an expressly unidentified strip of vegetation cannot be used as criteria for evaluation. As such, it is necessary to rely on a rough estimate of the height of this material by comparing it with the average height of the adjacent cordgrass. At the center of the frame, the block of vegetation, cordgrass and other vegetation extends from the surface of the open water to a point at the bottom of the chassis of the boom crane. Roughly one third of this vegetation block is composed of the unidentified vegetation with the remainder being smooth cordgrass. Assuming the cordgrass has an average height of 4 ft. the entire section of vegetation will have a height of 6 ft. The unidentified vegetation extends past the base of the marsh fill and overlaps the wheels on the boom crane. This is illustrative that the total height of the unidentified vegetation is greater than the height of the marsh fill. A competing ground level view (not pictured) taken about 100 ft. to the right of Figure 3 shows that the elevation of the marsh fill coincides with the midpoint of the unidentified strip of vegetation. So, of the 2 ft. of unidentified vegetation, only half contributes to the elevation estimate of the marsh fill. The sum of this value and the average height of smooth cordgrass is a reasonable estimate for the elevation of the marsh fill above the assigned datum. This value is calculated at 5 ft. The dark vehicle adjacent to the structure, parked to the right of the crane from the observer's perspective, is a third-generation Ford Explorer with a documented height of 71.4 in. Numeric precision, insofar as significant figures, is not useful when conducting rough analysis such as this and it is prudent to provide a whole number. This value is set at 6 ft. The partially obscured vehicle driving up to the facility is an eighth-generation GMC or Chevy Suburban. More important than the total height of this vehicle is the height of the obscured portion. This measurement can be related to the average height of the dividing barriers between the lanes leading to and from the facility in question. By comparing with other images of the vehicle in question, it is estimated that roughly half of the vehicle's total height is obscured by the divider. Assuming an average height between 69 and 76 in. for the model in question, the height of the obscured portion is estimated at 3 ft. It is necessary to also provide an estimate of the height of the concrete divider directly above the roofline of the crane adjacent vehicle. This value, when subtracted from the height of the obscured portion of the vehicle on the roadway, adjusts the estimated height of the crane adjacent vehicle to the estimated height of the roadway. As this vehicle is slightly offset from the divider this parameter is estimated at 2 ft. The difference between these values estimates how much lower the actual roadway is in comparison to the height of the crane adjacent vehicle. This value is calculated as 1 ft. As such, the estimated elevation of this facility is the sum of the heights of the marsh fill and the crane adjacent vehicle, as well as the height differential between this vehicle and the actual roadway. The elevation of this facility is estimated at 10 ft.

Figure 3. Louisiana Department of Transportation and Development facility in Leeville, Louisiana.

ASSESSING COMMUNITY VULNERABILITY TO COASTAL FLOODING

Flood depths were derived for the State of Louisiana's 2017 Coastal Master Plan by a team of researchers at the RAND Corporation using the CLARA model, a quantitative simulation model of storm surge flood risk that estimates flood depth exceedances: the probabilities of observing, in a given year, flood depths equal to or greater than estimated values. CLARA generates synthetic storms, simulates the flooding caused by these storms, and uses the resulting flood depths to estimate exceedance probabilities and other statistical measures of risk (Pollard et al., 2016). The geospatial unit of analysis for the CLARA model combines 2010 census block centroids with a grid of regularly spaced points, allowing the model to better estimate community vulnerability. CLARA models variability in future storm frequency and average intensity of storms to explore the differential impacts at each of these points under a range of future scenarios.

This research analyzes the number of societal assets projected to experience coastal flooding of greater than 3 ft. under the 2017 Coastal Master Plan medium scenario. Under the medium scenario, eustatic (global) sea level is anticipated to increase by 2.07 ft. over the 50-year model period, with an acceleration in the latter half of the period, while the effects of ongoing subsidence are estimated to reduce elevation anywhere from 0 to 0.75 in. per year, depending on spatial location. Finally, under the medium scenario, the CLARA model estimates that overall storm frequency will decline by 14% while storm intensity will increase by 12.5% (Meselhe et al., 2016). To assess variations in hazard-prone locations and community sensitivity to coastal flooding, this research used outputs of the CLARA model, land use data, demographic data, and point level facility data to map the number of assets within various flood zones and then calculated the percentage of each facility class and vulnerable population group projected to flood under various scenarios. This process was used to determine the vulnerability of societal assets under current conditions as well as 10, 25, and 50 years into the future. Assets are defined in this research as the residential population of the study area and the critical and essential facilities that this population depends upon to provide services before, during, and after a flood event.

Community vulnerability to coastal flooding considers both exposure and sensitivity to flood hazards. Exposure is based on the total amount of an asset within the flood zones while sensitivity is defined as the relative impact of losses to an entire community, calculated by dividing the amount of an asset in the flood zone by the total amount of that asset in the study area. In the case of residential exposure, sensitivity is measured by comparing the percentage of each vulnerable population group in the flood zone to the percentage of that same group in the total study area while sensitivity of critical and essential facilities is measured by comparing the total count of facilities in the flood zone to the overall number of facilities in the study area. The results of this assessment are then verified using odds ratios, a nonparametric statistic that derives the odds of each societal asset located in a flood zone relative to the number of assets found outside that flood zone. Some communities may have a high number of assets in a flood zone, resulting in a high level of exposure, but this number may represent a low percentage of the total assets in the community, resulting in a low level of sensitivity. This analysis does not examine direct or indirect economic losses to individuals, businesses, or communities. Rather, this vulnerability assessment is designed to help community members, facility managers, and policymakers prioritize where and when protection plans should be implemented to lessen future damages from coastal flood hazards.

This study focuses on two regions of coastal Louisiana – Morgan City surrounding communities in East St. Mary Parish and Lower Lafourche Parish from Larose to Golden Meadow (Figure 4). These two areas were selected for a number of reasons. First, both locations can be classified as commercial-industrial complexes that are also prominent service and supply centers for the offshore and Outer Continental Shelf oil industry (Austin et al., 2002). Oil and gas extraction and related activities – water transportation, fabrication, shipbuilding and repair – are primary sources of employment in both regions. Both also have extensive networks of offshore infrastructure, including fabrication yards, shipyards, support bases, and terminals (Austin et al., 2002; Hemmerling & Colten, 2004). Offshore oil and gas extraction and processing industries, like other natural resource-reliant industries, are largely immovable, often relying on infrastructure sited in close proximity to the resource itself. Such immovable industries require an active workforce that often resides within commuting distance. Thus, both study areas have a large concentration of residents within them, many of which are reliant upon employment in coastal industries. Due to the number of coastal residents and their proximity to the Gulf of Mexico, both areas are also surrounded by floodwalls, levees, and other forms of structural protection.

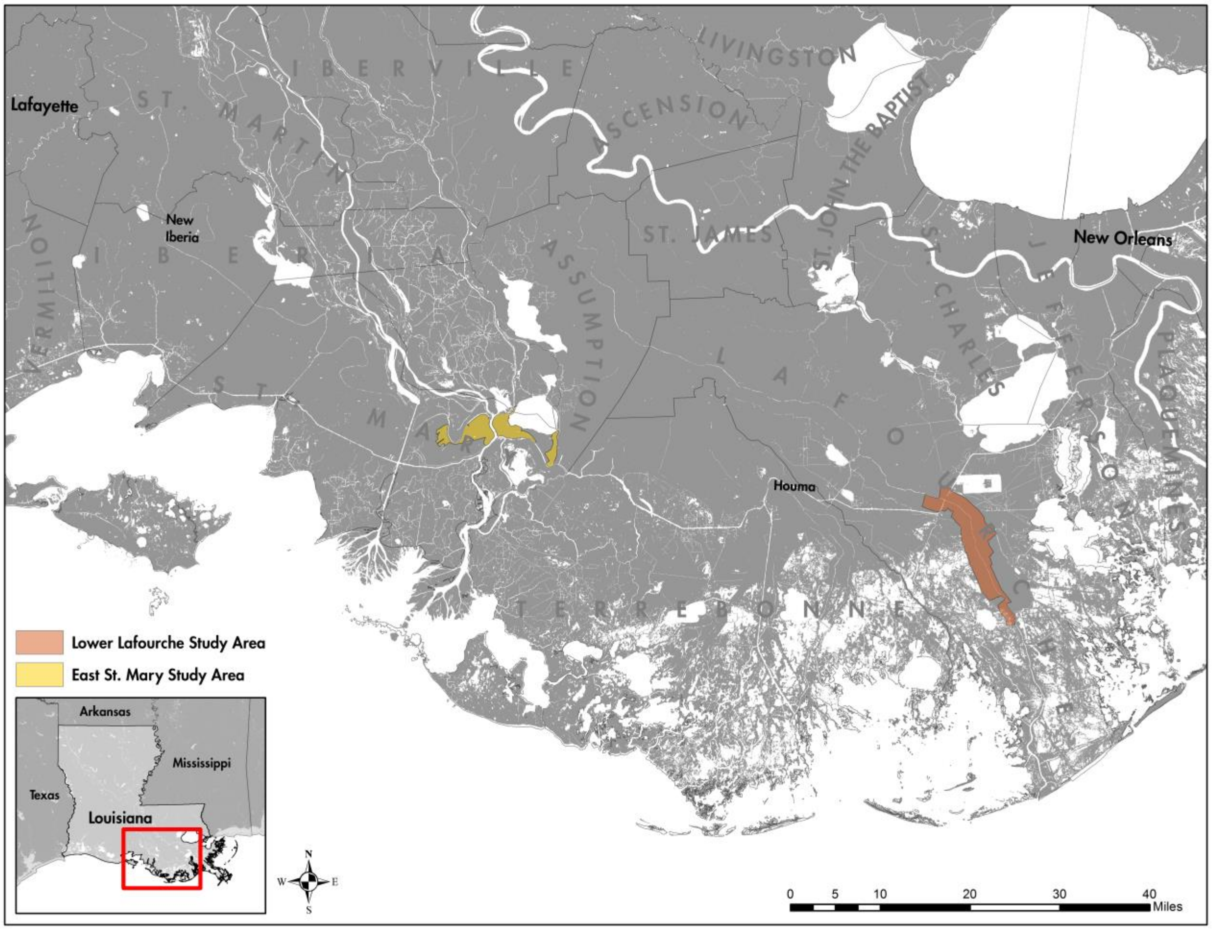

Figure 4. Regional Overview of Lower Lafourche and East St. Mary Parish Study Areas.

Case Study: East St. Mary Parish

BACKGROUND

St. Mary Parish is in the central region of the Louisiana coast. This area initially built out as part of the Maringouin delta formation roughly 7,500 to 5,000 years ago. From approximately 5,000 to 500 years ago the region entered a period of deltaic decline. Toward the end of this timeframe, a portion of the Mississippi River diverted down the Atchafalaya River and began to accrete land, moving this coastal region from submergence back to reoccupation (Blum & Roberts, 2012). Today, the quantity of river water and associated land building sediment that forms the Wax Lake and Atchafalaya deltas is controlled by the Old River Control Structure, located where the Mississippi and Atchafalaya rivers divide (Allison et al., 2012). Much of the central Louisiana coast, including St. Mary Parish, is a region with lower erosion rates and higher sedimentation rates due to land building at the Wax Lake Delta. The region also experiences high levels of river flooding due in part to increased relative sea level rise in this area (Penland & Ramsey, 1990).

Almost 55,000 residents live in St. Mary Parish. Morgan City, with a total 2010 population of just over 12,000 residents, is the largest city in the parish. To the east of Morgan City is the unincorporated community of Amelia (2,400 residents, nearly a quarter of which are Vietnamese). Berwick, across the Atchafalaya River from Morgan City, has a population of around 5,000 residents. Patterson (6,100 residents) at the confluence of Bayou Teche and the Atchafalaya River, and the unincorporated residential area of Bayou Vista (4,600 residents) are the additional communities that, together, comprise "East St. Mary Parish" (Figure 5). Calumet Cut, a man-made overflow outlet from the Atchafalaya system to the Gulf, marks the border – to the west is extensive sugar cane farmland (Austin et al., 2002). The Morgan City Harbor and Terminal District is home to approximately 175 privately owned facilities and primarily serves the inland and offshore oil and gas production industry. The parish is home to a sizable African American population (32.5%) and relatively small Asian (1.7%) and Native American (1.8%) populations. In addition, 5.3% of the parish population is Hispanic. In total, nearly 40% of the parish population is minority. Furthermore, for the parish as a whole, 21.8% of the population is below the U.S. Census Bureau's definition of poverty. These numbers are above the Louisiana state average, signifying a high level of social vulnerability in the region (Figures 6-13).

St. Mary Parish has historically been heavily impacted by tropical storms and hurricanes. In 1992, Hurricane Andrew, the second costliest hurricane in U.S. history behind only Hurricane Katrina, made landfall approximately 23 miles west-southwest of Morgan City, heavily damaging property, agricultural crops, and fisheries. Over the last quarter of the twentieth century, residents of the parish filed $6.9 million in National Flood Insurance Program flood loss claims with Morgan City alone accounting for $1.1 million of these claims (Laska et al., 2005). Even though St. Mary Parish was not directly in the paths of either Hurricane Katrina or Hurricane Rita, most of St. Mary Parish south of Highway 90 was submerged (Roth, 2010). The commercial fisheries infrastructure also experienced a high level of economic damage from the two storms. The loss of infrastructure and revenue (estimated over a five-year period) to seafood dealers in St. Mary Parish was approximately $9.1 million. The discounted losses due to damaged fishing vessels in the parish was estimated at an additional $2 million dollars (Erlambang, 2007). In total, from 1960 to 2003, when at least 11 tropical systems affected coastal Louisiana, St. Mary

Parish suffered more property losses from tropical storms and hurricanes than any other parish in Louisiana, totaling approximately $177.7 million (Cutter et al., 2006).

To protect residents against both storm surge and river flooding, a number of protection projects have been constructed in and around East St. Mary Parish. State projects planned and monitored by CPRA in St. Mary Parish can be divided into proposed and completed protection. One project completed by the state was the Franklin floodgate and pump station which was put in place to protect against storm surge and rain runoff. A proposed project is the Morgan City and St. Mary flood protection which includes improvements to two and a half miles of the current system. The final proposed protection is the St. Mary backwater flooding project where six miles of levee will be improved that are part of the larger Morgan City flood protection system (CPRA, 2012).

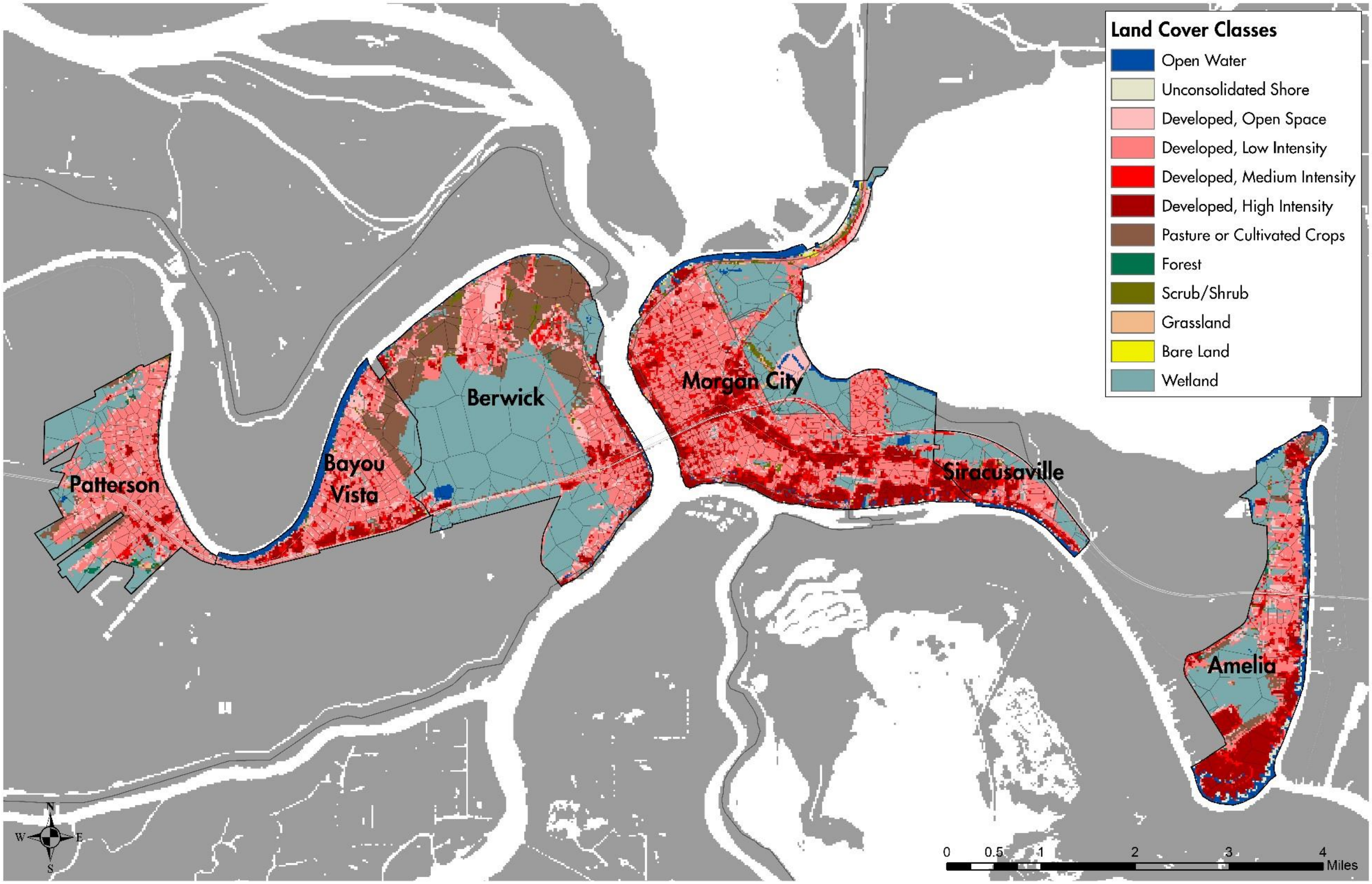

Figure 5. Land Cover Classification of East St. Mary Parish.

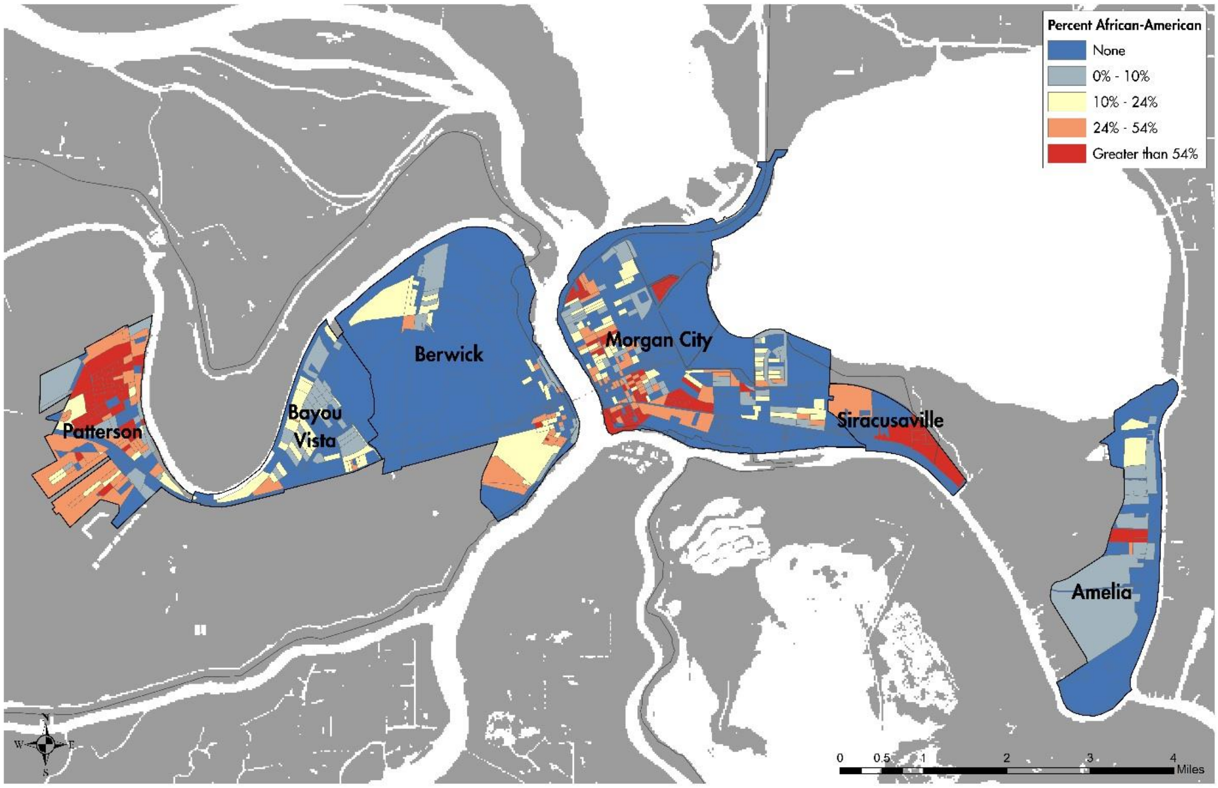

Figure 6. Percent African American Population in East St. Mary Parish.

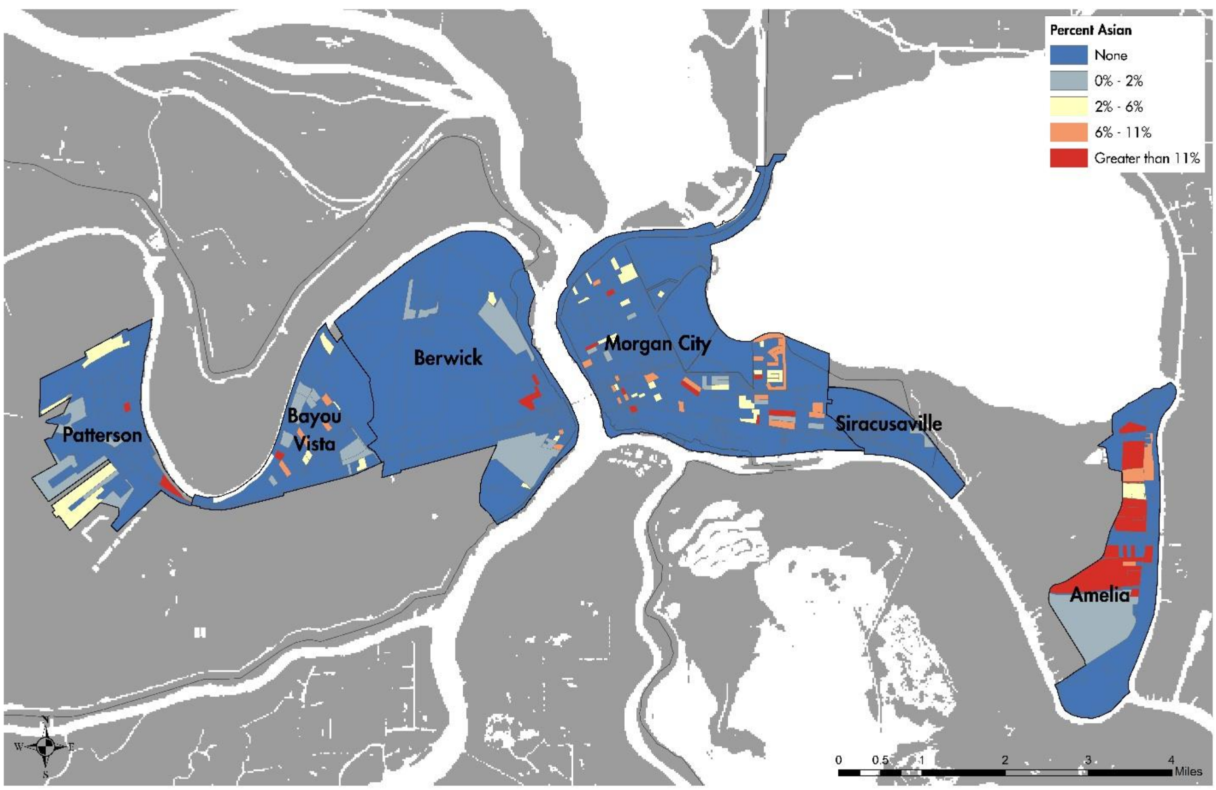

Figure 7. Percent Asian Population in East St. Mary Parish.

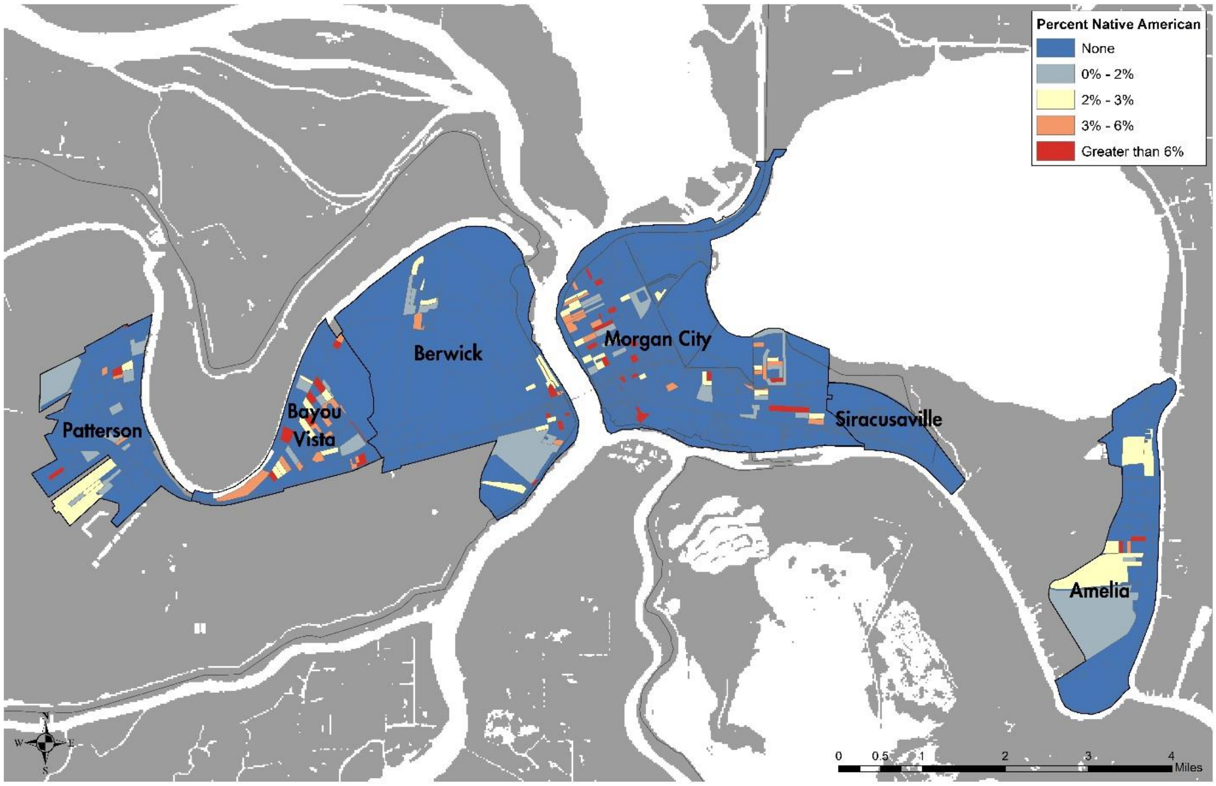

Figure 8. Percent Native American Population in East St. Mary Parish.

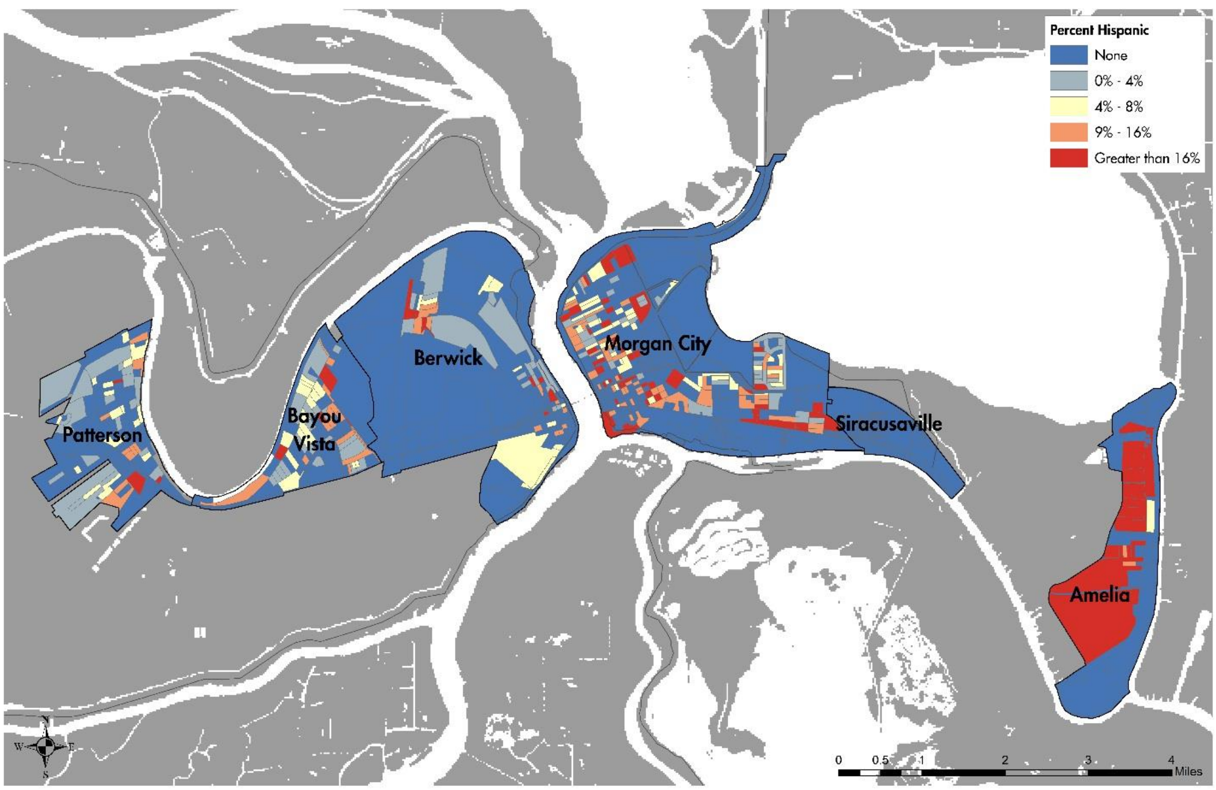

Figure 9. Percent Hispanic Population in East St. Mary Parish.

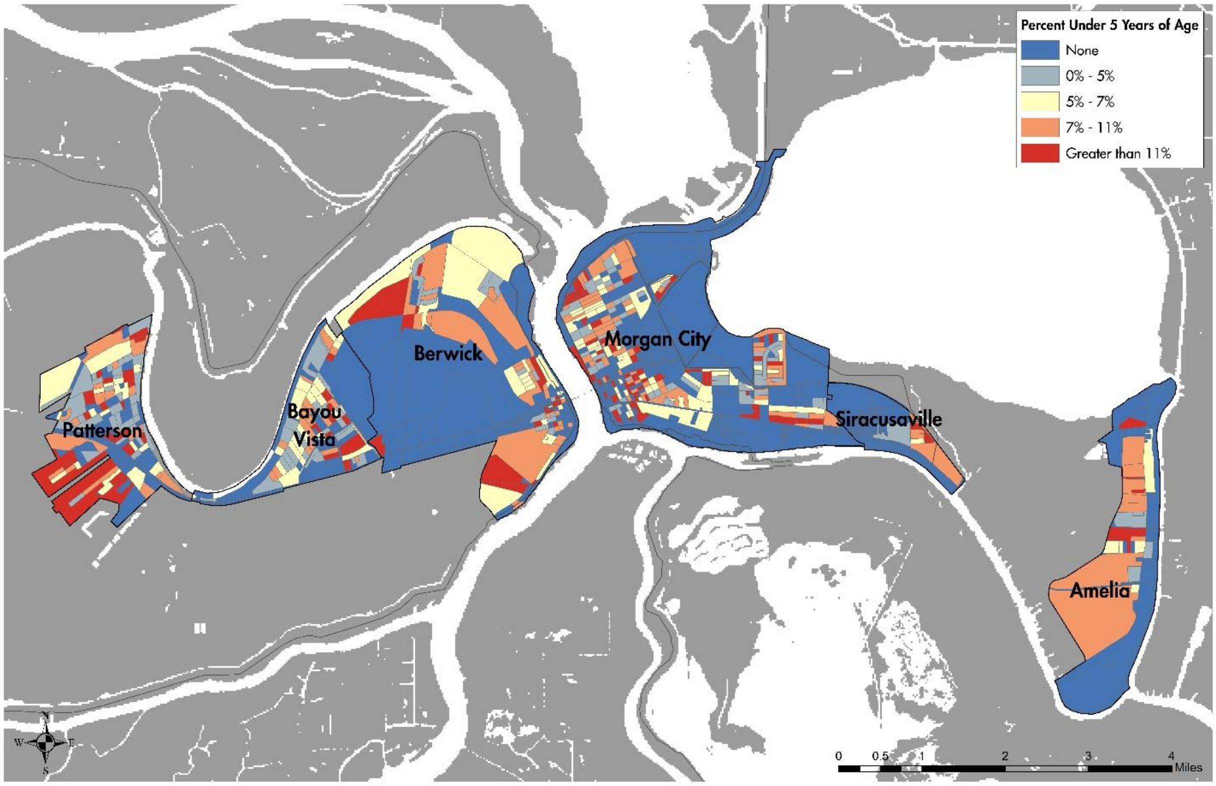

Figure 10. Percent of Population Under 5 Years of Age in East St. Mary Parish.

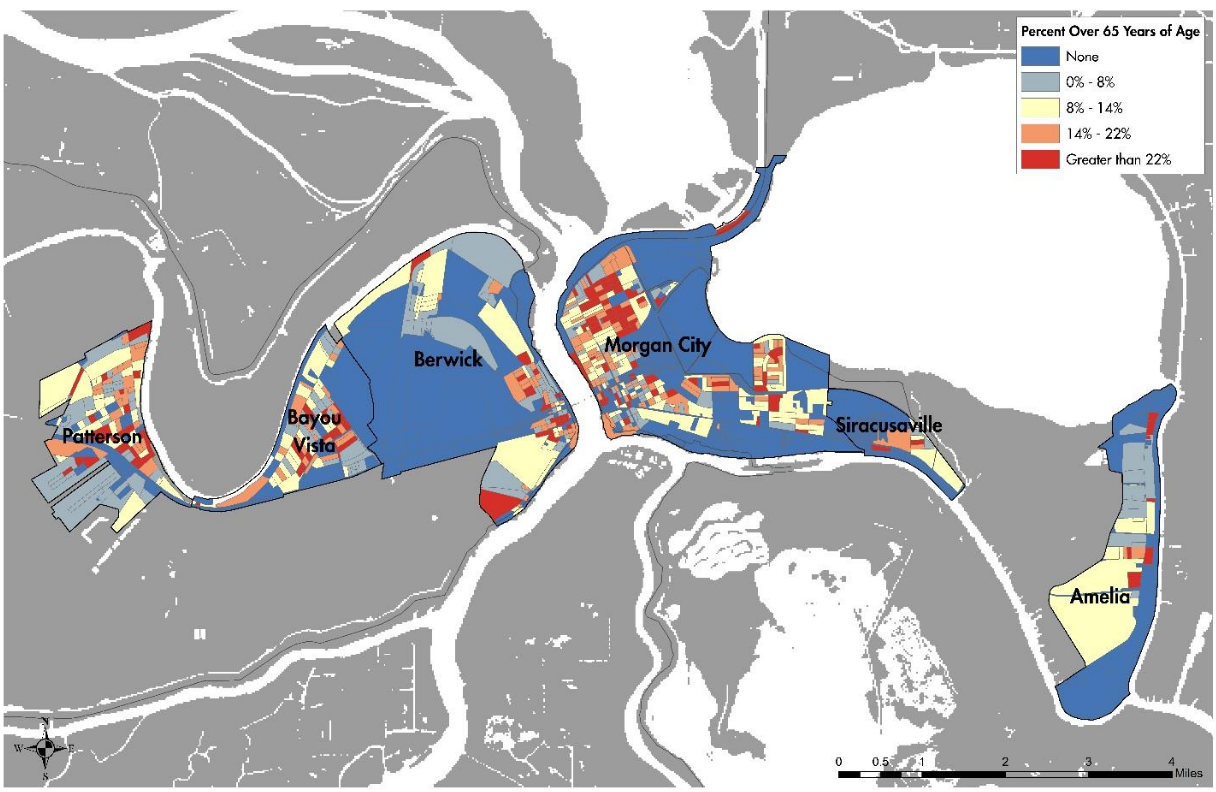

Figure 11. Percent of Population Over 65 Years of Age in East St. Mary Parish.

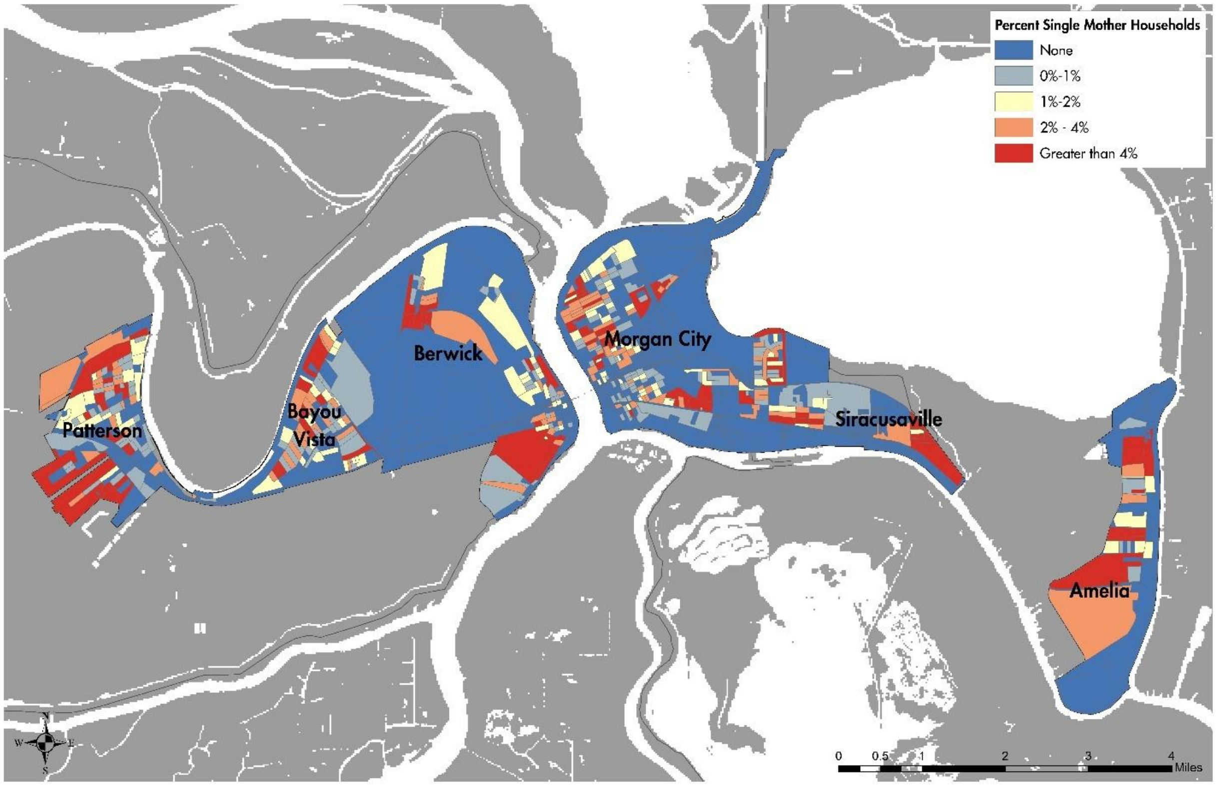

Figure 12. Percent of Single Mother Households in East St. Mary Parish.

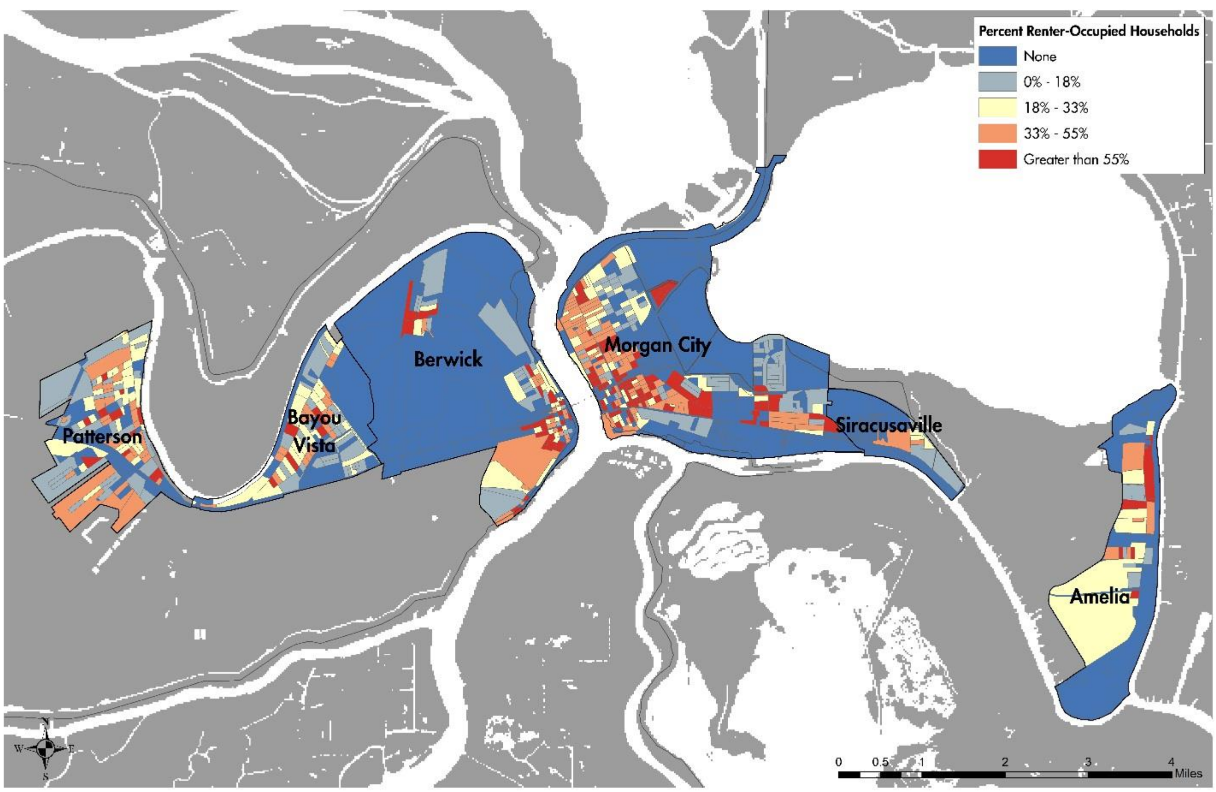

Figure 13. Percent of Renter-Occupied Households in East St. Mary Parish.

RESULTS

Morgan City and the surrounding communities in East St. Mary Parish are considerably more insulated from coastal flood events than other locations within the Louisiana Coastal Zone, including Lower Lafourche Parish. Even if no actions are taken, most of the communities of East St. Mary Parish are not projected to experience coastal flooding from either a 100- or 500-year storm under current conditions (Figure 14 and Figure 15). In fact, under the medium future scenario, these communities are not projected to experience significant coastal flooding until the end of the modeling period, 50 years in the future. It is important to note that the reduction in storm surge and coastal flooding does not mean that the region is safe from either riverine flooding or flooding caused by extreme rainfall events. As recently as 2011, Mississippi River floodwaters were diverted into the Atchafalaya River causing businesses located on the river front in both Morgan City and Berwick to flood. Even communities located farther away from the Atchafalaya River, not protected by levee systems, such as Franklin and Amelia, experienced significant backwater flooding during this event.

Current Conditions

Land Cover

Due to the fact that eastern East St. Mary Parish is largely buffered from the Gulf of Mexico by relatively intact wetlands and much of the developed land is enclosed by a ring levee, the communities of East St. Mary Parish are not anticipated to experience significant levels of flooding from a 100-year storm event under current environmental conditions (Figure 16). Overall, only 3.5% of the total developed land area would be projected to experience more than 3 feet of flooding (Table 2). There are geographical differences in the levels of flooding anticipated across the study area, however, with the Atchafalaya River essentially dividing areas of higher risk from those of lower risk. Communities located west of the Atchafalaya River, including Berwick, Patterson, and Bayou Vista, are considerably less likely to experience coastal storm surges than those located east of the river, including Siracusaville, Amelia, and Morgan City.

It is notable that despite the relatively low levels of overall exposure of developed land to coastal flooding during a 100-year storm, the most densely developed portions of some communities are more sensitive to flood impacts. For example, Berwick and Amelia are projected to see 17.0 and 14.8% of high-intensity developed land, respectively, flood during a 100-year storm under current conditions. This percentage is significantly higher than that of the other communities in the study area.

Residential Population

Results indicate that, while approximately 3.5% of the developed land in the study area would be currently projected to flood under a 100-year storm event, less than one-tenth of one percent of the total population in the study area would experience significant flood impacts (Table 3). This result is indicative of the fact that the projected flooding in the region is anticipated to occur along the area’s waterways, where much of the developed land consists of industrial and commercial development. This is particularly true of the flood zones identified in Berwick and Amelia. Further, when socially vulnerable population groups that are projected to flood are analyzed, the results indicate that none are significantly more likely to reside in the modeled flood zone than outside the flood zone (Figure 17).

Critical and Essential Facilities

Further analysis shows that the developed land projected to flood under current conditions does not include any of the critical or essential facilities that support the local populations, with the exception of two government facilities (Table 4). The first, the Berwick Lock, is operated by the USACE and is adjacent to the lower Atchafalaya River on the west side of Berwick Bay. This lock serves a dual purpose, preventing floodwaters from entering the lower Atchafalaya River and providing a navigation link to lower Bayou Teche. The second government-operated facility projected to flood during a 100-year storm event is the Avoca Island Ferry landing, which provides transportation from Morgan City to a virtually uninhabited private island that is home to several oil and gas operations, cattle operations, and a private hunting club. It is notable that both of these facilities are immediately adjacent to major waterways and are thus at an enhanced level of risk. Additionally, both structures are classified as civil works infrastructure directly tied to the surface elevation of the water and are therefore cannot be elevated above projected flood levels (Figure 18).

It should be noted that these results are specifically related to coastal flooding and coastal storm surge events. This area is considerably more insulated from these types of events than other communities along the coast, particularly those regions experiencing significant land loss. The dominant flood risks in Morgan City and surrounding communities are expected to result from river flooding, particularly in the spring when water levels in the Atchafalaya River begin to rise. In addition to the high river flows anticipated to occur annually in the spring, Mississippi River flow into the Atchafalaya River is also controlled by the Old River Control Structure. Red River flow is entirely captured by the Atchafalaya and is unregulated. The Old River structure controls the proportion of water that flows into the Mississippi and Atchafalaya Rivers. During peak floods, additional structures such as the Morganza Spillway can be opened to relieve pressure on levees along the downstream portion of the Mississippi River in Baton Rouge and New Orleans, diverting water into the Atchafalaya Basin, flooding the swamps and marshes along the entire length of the Atchafalaya River. While Morgan City is largely protected by the levees shielding the populated areas from Lake Palourde, unprotected surrounding communities would be at higher risk of experiencing enhanced river flooding.

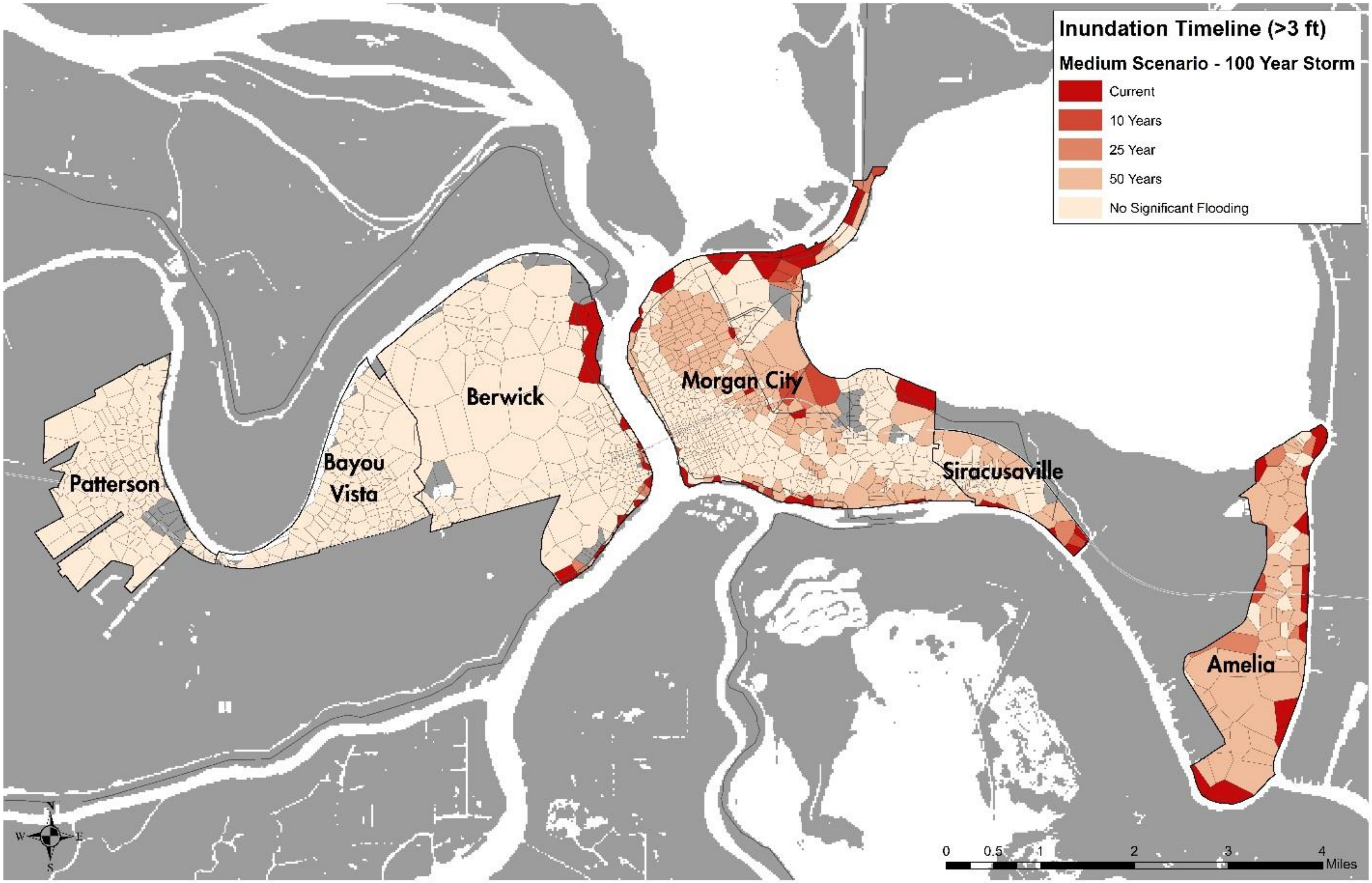

Figure 14. Inundation Timeline for a 100-Year Storm in East St. Mary Parish Study Area (Medium Scenario).

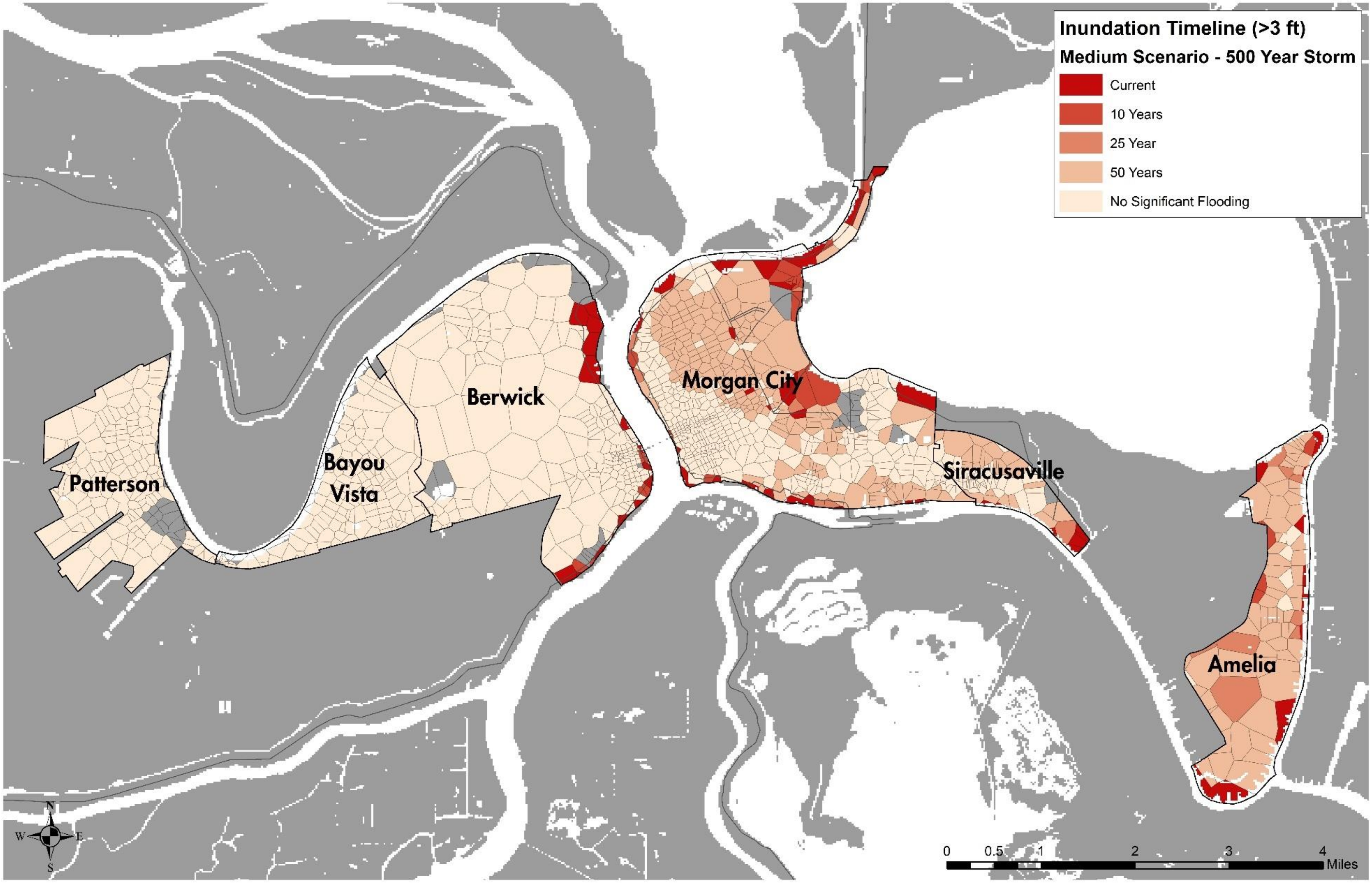

Figure 15. Inundation Timeline for a 500-Year Storm in East St. Mary Parish Study Area (Medium Scenario).

Figure 16. Projected flooding from a 100-Year Storm in East St. Mary Parish Under Current Conditions. Red cells indicated inundation at or above 3 ft.

Table 2. Exposure and Sensitivity of Developed Land to Coastal Flooding from a 100-Year Storm in East St. Mary Parish Under Current Conditions.

Census Designated Place	Low-Intensity Developed			Medium-Intensity Developed			High-Intensity Developed			Total Developed		
	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%
Amelia	10.7	390.7	2.7	11.8	117.9	10	54.5	369	14.8	76.9	877.6	8.8
Bayou Vista	0	561.1	0	0	87.4	0	0	89.8	0	0	738.3	0
Berwick	25.8	647.8	4	6.9	109.4	6.3	16.7	97.9	17	49.4	855.1	5.8
Morgan City	47.6	1446.2	3.3	7.8	512.6	1.5	22	583.6	3.8	77.4	2542.4	3
Patterson	0	729.2	0	0	29.6	0	0	28	0	0	786.8	0
Siracusaville	4	146.1	2.7	2.7	67.2	4	2	92.1	2.2	8.7	305.3	2.8
TOTAL	88.1	3921.3	2.2	29.1	924	3.2	95.2	1260.3	7.6	212.4	6105.6	3.5

Table 3. Exposure and Sensitivity of Socially Vulnerable Population Groups to Coastal Flooding from a 100-Year Storm in East St. Mary Parish Under Current Conditions (Medium Scenario).

Demographic Category	Coastal Flood Zone (Current Conditions)	Study Area Total	Flood Zone Percentage	Study Area Percentage	Sensitivity Rating
Total population	20	30,891	0.1%	n/a	n/a
Hispanic or Latino	0	2,465	0.0%	8.0%	0.00
Race - White	19	20,663	95.0%	66.9%	1.42
Race - Black or African American	1	7,133	5.0%	23.1%	0.22
Race - American Indian	0	351	0.0%	1.1%	0.00
Race - Asian	0	801	0.0%	2.6%	0.00
Population less than 5 years old	0	2,239	0.0%	7.2%	0.00
Population more than 65 years old	2	3,905	10.0%	12.6%	0.79
Total households	10	11,819	0.1%	n/a	n/a
Renter-occupied households	2	4,082	20.0%	34.5%	0.58
Single-mother-occupied households	0	1,335	0.0%	11.3%	0.00

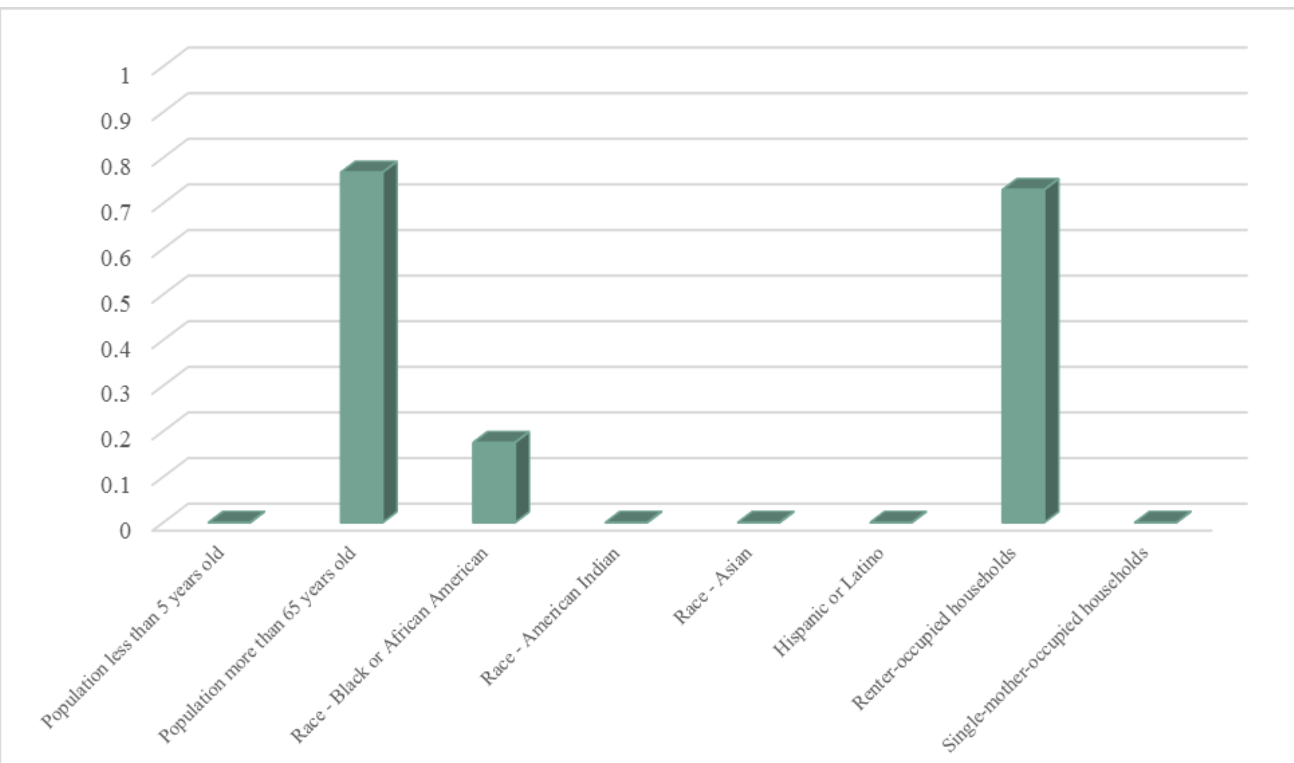

Figure 17. Odds of Exposure to Coastal Flood Events Under Current Conditions for Vulnerable Populations in East St. Mary Parish (Medium Scenario – 100-Year Storm Event).

Table 4. Exposure and Sensitivity of Critical and Essential Facilities to Coastal Flooding from a 100-Year Storm in East St. Mary Parish Under Current Conditions (Medium Scenario).

Critical Facilities	Coastal Flood Zone (Current Conditions)	Study Area Total	Flood Zone Percentage
Hospitals	0	1	0.0%
Outpatient Care Centers	0	8	0.0%
Physician Offices	0	25	0.0%
Fire Stations	0	8	0.0%
Police Stations	0	5	0.0%
Electric Companies	0	3	0.0%
Gas Companies	0	1	0.0%
Radio and TV Broadcasting	0	5	0.0%
Water and Sewerage Companies	0	3	0.0%
Essential Facilities			
Banks and Credit Unions	0	14	0.0%
Gas Stations	0	8	0.0%
Government Facilities	2	49	4.1%
Retail Grocers	0	9	0.0%
Day Care Service	0	6	0.0%
Library	0	4	0.0%
School	0	20	0.0%

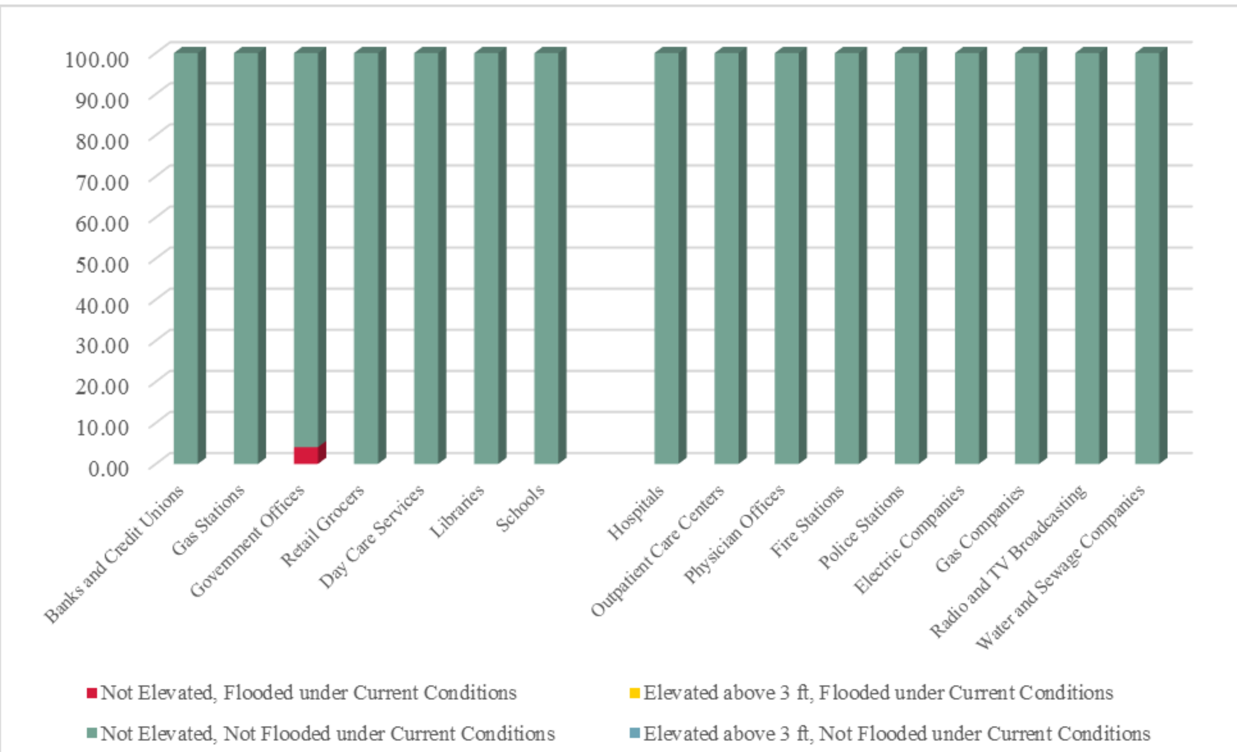

Figure 18. Elevation Dependent Sensitivity of Critical and Essential Facilities Under Current Conditions in East St. Mary Parish Study Area (Medium Scenario – 100-Year Storm Event).

Year 10

Land Cover

The pattern of coastal flooding in East St. Mary Parish is expected to change little over the next decade (Table 5). Under the medium environmental change scenario modeled by the State of Louisiana for the 2017 Coastal Master Plan, the total area of developed land in the study area projected to experience significant flooding is forecast to increase by less than 1%. Similar to the results found under current conditions, the results show a higher sensitivity in Berwick and Amelia at Year 10. Most of the increase in land area flooded is in Siracusaville, Amelia, and Morgan City, the communities located between Lake Palourde, the Avoca Island Cutoff, and the Atchafalaya River (Figure 19). In Morgan City and Siracusaville, the expansion of the flood zone occurs largely in unpopulated wetlands while the greatest expansion in Amelia is along Highway 90, an east-west running roadway that bisects the community.

Residential Population

Similar to the results found when current conditions were modeled, results modeled for 10 years in the future under the medium environmental change scenario indicate that, while approximately 4.2% of the developed land in the study area is currently projected to flood under a 100-year storm event, less than one-tenth of one percent of the total population in the study area would experience significant flood impacts (Table 6). Again, this result is indicative of the fact that the projected flooding in the region is anticipated to occur along the area's waterways, where much of the developed land consists of industrial and commercial development. Some of this exposed developed land is located along highways, most notably Highway 90 in Amelia. Further, when socially vulnerable population groups that are projected to flood are analyzed, the results indicate that none are significantly more likely to reside in the modeled flood zone than to reside outside the flood zone (Figure 20). However, despite the low exposure levels for all population groups, the elderly and residents occupying rental units are more sensitive to coastal flooding, although both groups are still more likely to reside outside of the flood zone than within.

Critical and Essential Facilities

The slight increase in exposure of developed land to coastal flooding over the next decade is not projected to have any additional impacts on critical and essential facilities in the study area. As under current conditions, only two government civil works facilities, one in Berwick and the other in Morgan City, are projected to experience more than 3 ft. of flooding under the medium change scenario (Table 7). Neither of these facilities are elevated above the surface water elevation of the adjacent waterways (Figure 21), making them more vulnerable to coastal storm impacts.

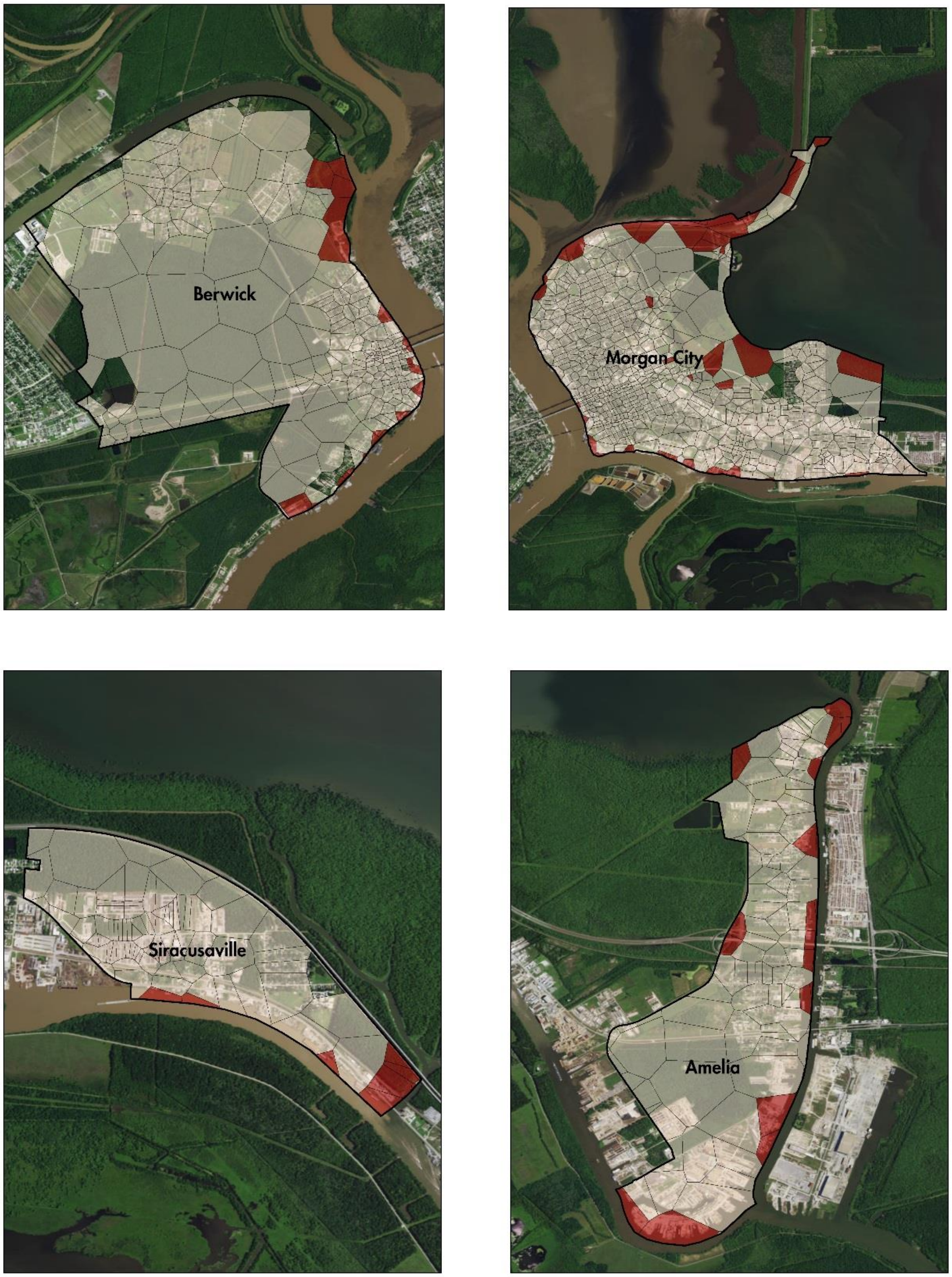

Figure 19. Projected flooding in Year 10 from a 100-Year Storm in East St. Mary Parish. Red cells indicated inundation at or above 3 ft.

Table 5. Exposure and Sensitivity of Developed Land to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 10.

Census Designated Place	Low-Intensity Developed			Medium-Intensity Developed			High-Intensity Developed			Total Developed		
	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%
Amelia	17.3	390.7	4.4	14	117.9	11.9	56.5	369	15.3	87.8	877.6	10
Bayou Vista	0	561.1	0	0	87.4	0	0	89.8	0	0	738.3	0
Berwick	26.9	647.8	4.2	7.3	109.4	6.7	16.9	97.9	17.3	51.2	855.1	6
Morgan City	66.1	1446.2	4.6	10	512.6	2	28	583.6	4.8	104.1	2542.4	4.1
Patterson	0	729.2	0	0	29.6	0	0	28	0	0	786.8	0
Siracusaville	4.9	146.1	3.3	3.6	67.2	5.3	3.3	92.1	3.6	11.8	305.3	3.9
TOTAL	115.2	3921.3	2.9	34.9	924	3.8	104.7	1260.3	8.3	254.9	6105.6	4.2

Table 6. Exposure and Sensitivity of Socially Vulnerable Population Groups to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 10 (Medium Scenario).

Demographic Category	Coastal Flood Zone (Year 10)	Study Area Total	Flood Zone Percentage	Study Area Percentage	Sensitivity Rating
Total population	26	30,891	0.1%	n/a	n/a
Hispanic or Latino	0	2,465	0.0%	8.0%	0.00
Race - White	25	20,663	96.2%	66.9%	1.44
Race - Black or African American	1	7,133	3.8%	23.1%	0.17
Race - American Indian	0	351	0.0%	1.1%	0.00
Race - Asian	0	801	0.0%	2.6%	0.00
Population less than 5 years old	0	2,239	0.0%	7.2%	0.00
Population more than 65 years old	3	3,905	11.5%	12.6%	0.91
Total households	12	11,819	0.1%	n/a	n/a
Renter-occupied households	4	4,082	33.3%	34.5%	0.97
Single-mother-occupied households	0	1,335	0.0%	11.3%	0.00

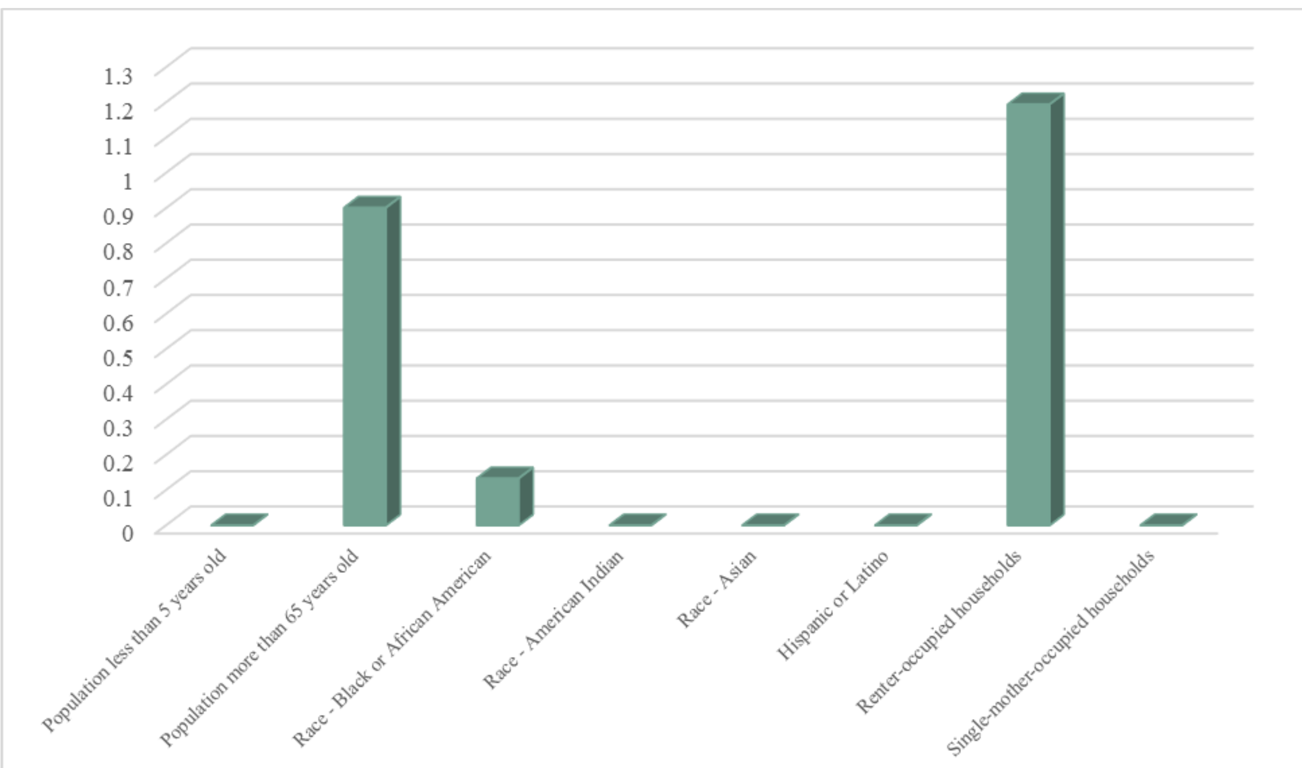

Figure 20. Odds of Exposure to Coastal Flood Events in Year 10 for Vulnerable Populations in East St. Mary Parish Study Area (Medium Scenario – 100-Year Storm Event).

Table 7. Exposure and Sensitivity of Critical and Essential Facilities to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 10 (Medium Scenario).

Critical Facilities	Coastal Flood Zone (Year 10)	Study Area Total	Flood Zone Percentage
Hospitals	0	1	0.0%
Outpatient Care Centers	0	8	0.0%
Physician Offices	0	25	0.0%
Fire Stations	0	8	0.0%
Police Stations	0	5	0.0%
Electric Companies	0	3	0.0%
Gas Companies	0	1	0.0%
Radio and TV Broadcasting	0	5	0.0%
Water and Sewerage Companies	0	3	0.0%
Essential Facilities			
Banks and Credit Unions	0	14	0.0%
Gas Stations	0	8	0.0%
Government Facilities	2	49	4.1%
Retail Grocers	0	9	0.0%
Day Care Service	0	6	0.0%
Library	0	4	0.0%
School	0	20	0.0%

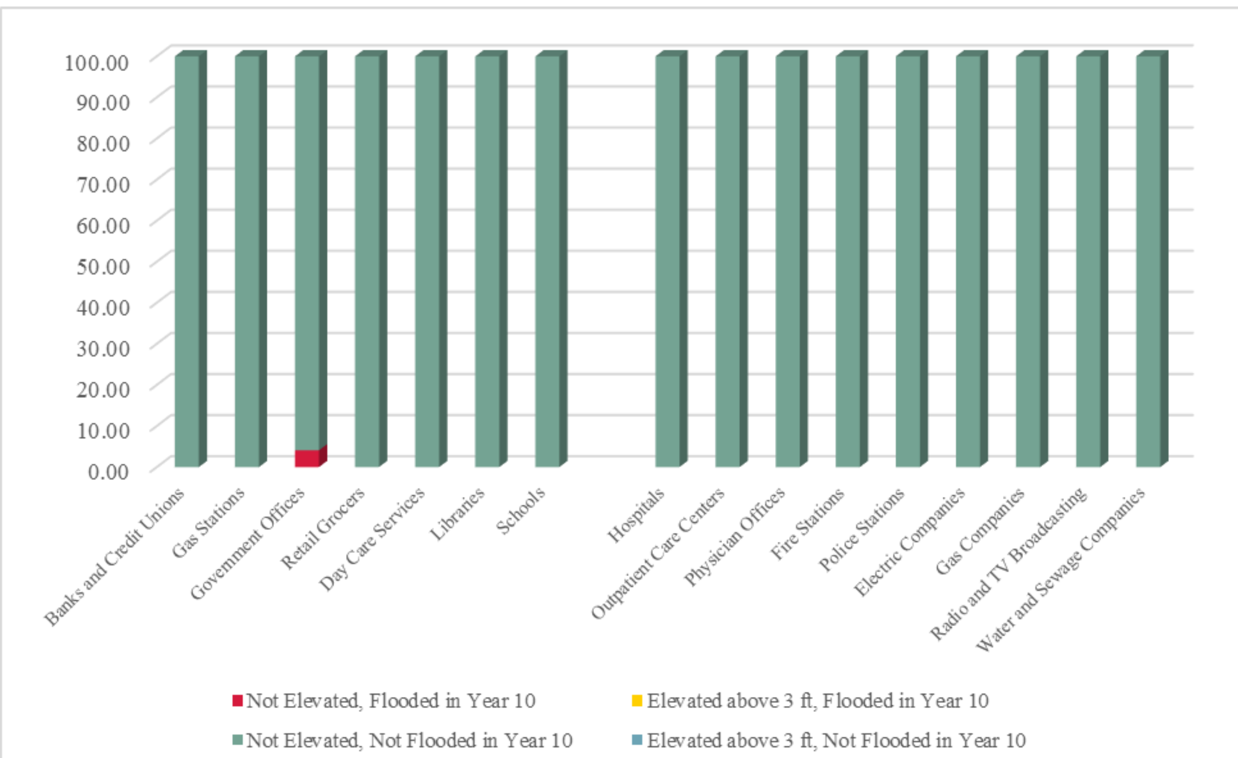

Figure 21. Elevation Dependent Sensitivity of Critical and Essential Facilities in Year 10 in East St. Mary Parish Study Area (Medium Scenario – 100-Year Storm Event).

Year 25

Land Cover

Model results for Year 25 reveal very little substantial changes in the pattern of coastal flooding in East St. Mary Parish compared to Year 10 (Table 8). Under the medium environmental change scenario, the total area of developed land in the study area projected to experience 3 ft. or more of coastal flooding is anticipated to increase from 4.2% to 5.3%. Similar to the results found under current and 10 Year conditions, the greatest increase in flooding is anticipated to occur in Siracusaville, Amelia, and Berwick (Figure 22). In Siracusaville, the expansion of the flood zone occurs largely in the southeastern corner of the community, between Bayou Boeuf and the Ramos Wetlands. Similarly, the greatest expansion in Amelia occurs in and around the forested wetlands, including a large portion within the city limits.

Residential Population

Similar to the results found under current and 10 Year conditions, results modeled 25 years in the future under the medium scenario indicate that, while approximately 5.3% of the developed land in the study area is currently projected to flood under a 100-year storm event, only 1% of the total population in the study area would experience significant flood impacts (Table 9). Again, this result is indicative of the fact that the projected flooding in the region is anticipated to occur along the area's waterways, where much of the developed land consists of industrial and commercial development. However, when socially vulnerable population groups that are projected to flood are analyzed, the results indicate that several are significantly more likely to reside in the modeled flood zone than to reside outside the flood zone (Figure 23). Particularly notable is the large increase in the Asian population, which in Year 25 is 10.2 times more likely to reside in the flood zone than to reside outside the flood zone. Of the total population projected to experience flooding in East St. Mary Parish in 25 years, 20% of these would be Asian, based on current population distributions. While the odds ratios are not as striking, both the Native American (1.5 times more likely) and Hispanic (2.3 times more likely) populations in the region would be more likely to be flooded by a 100-year storm than not. Notably, of the total population projected to flood, over 16% is Hispanic. However, despite the relatively low exposure levels for other vulnerable population groups, several are becoming more sensitive to coastal flooding over time despite the fact that most are still more likely to reside outside of the flood zone than within. Almost 30% of households in the flood zone, for example, are rental units, making this group the most sensitive to a 100-year storm event, despite the fact that this percentage is lower than the percentage found in the study area overall.

Critical and Essential Facilities

The slight increase in exposure of developed land to coastal flooding over the next decade is not expected to have any additional impacts on critical and essential facilities in the study area. The same two government facilities, the Berwick Lock and the Avoca Island Ferry landing, are projected to experience more than 3 ft. of flooding under the medium environmental change scenario (Table 10). Again, neither of these facilities are elevated above the surface water elevation of the adjacent waterways (Figure 24), making them more vulnerable to these flood impacts.

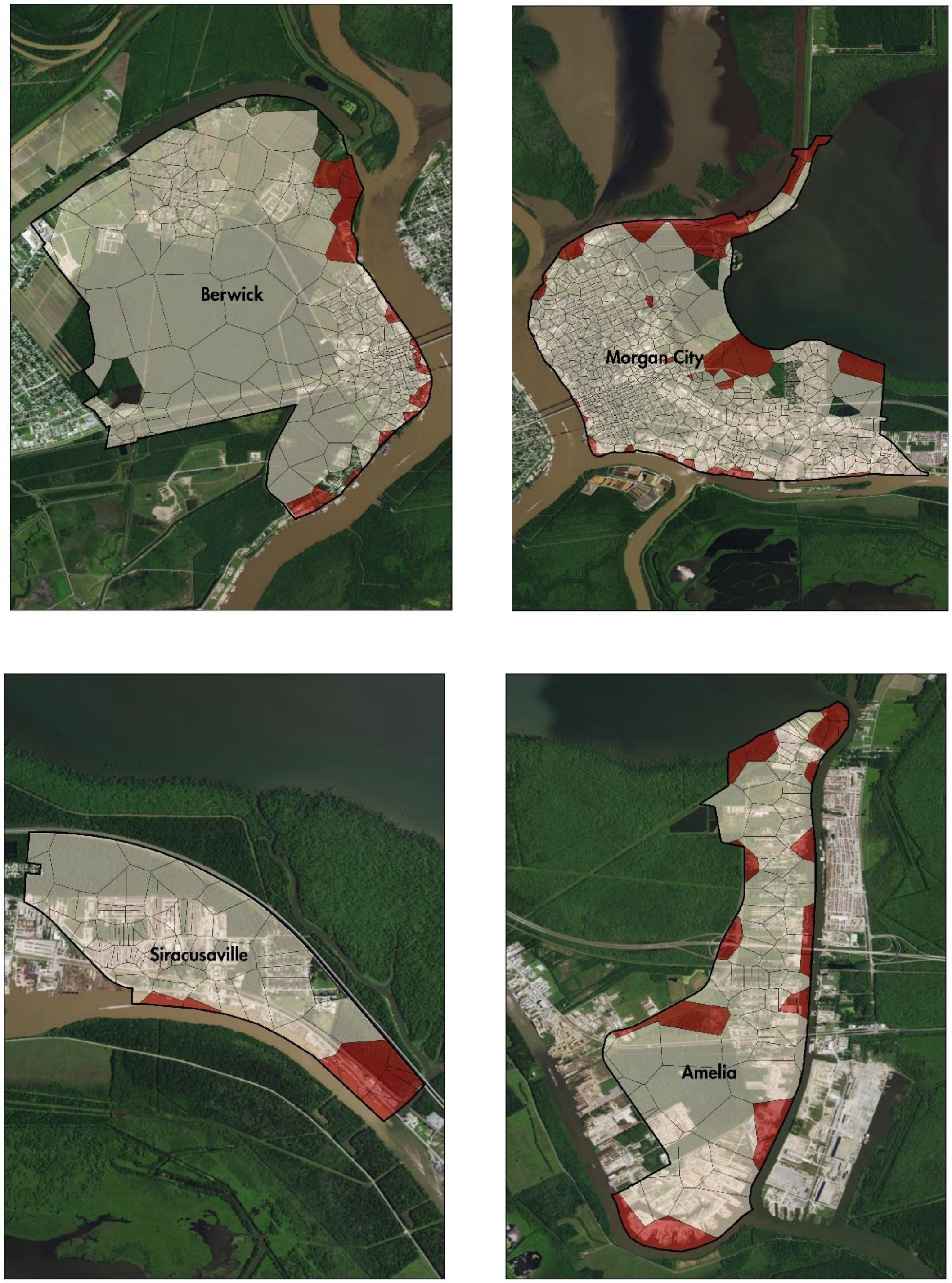

Figure 22. Projected flooding in Year 25 from a 100-Year Storm in East St. Mary Parish. Red cells indicated inundation at or above 3 ft.

Table 8. Exposure and Sensitivity of Developed Land to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 25.

Census Designated Place	Low-Intensity Developed			Medium-Intensity Developed			High-Intensity Developed			Total Developed		
	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%
Amelia	30.2	390.7	7.7	18	117.9	15.3	61.2	369	16.6	109.4	877.6	12.5
Bayou Vista	0	561.1	0	0	87.4	0	0	89.8	0	0	738.3	0
Berwick	34.9	647.8	5.4	10	109.4	9.1	19.3	97.9	19.8	64.3	855.1	7.5
Morgan City	78.1	1446.2	5.4	14.2	512.6	2.8	32.9	583.6	5.6	125.2	2542.4	4.9
Patterson	0	729.2	0	0	29.6	0	0	28	0	0	786.8	0
Siracusaville	9.8	146.1	6.7	7.1	67.2	10.6	7.3	92.1	8	24.2	305.3	7.9
TOTAL	153	3921.3	3.9	49.4	924	5.3	120.8	1260.3	9.6	323.1	6105.6	5.3

Table 9. Exposure and Sensitivity of Socially Vulnerable Population Groups to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 25 (Medium Scenario).

Demographic Category	Coastal Flood Zone (Year 25)	Study Area Total	Flood Zone Percentage	Study Area Percentage	Sensitivity Rating
Total population	355	30,891	1.1%	n/a	n/a
Hispanic or Latino	58	2,465	16.3%	8.0%	2.05
Race - White	221	20,663	62.3%	66.9%	0.93
Race - Black or African American	13	7,133	3.7%	23.1%	0.16
Race - American Indian	6	351	1.7%	1.1%	1.49
Race - Asian	71	801	20.0%	2.6%	7.71
Population less than 5 years old	29	2,239	8.2%	7.2%	1.13
Population more than 65 years old	35	3,905	9.9%	12.6%	0.78
Total households	121	11,819	1.0%	n/a	n/a
Renter-occupied households	35	4,082	28.9%	34.5%	0.84
Single-mother-occupied households	9	1,335	7.4%	11.3%	0.66

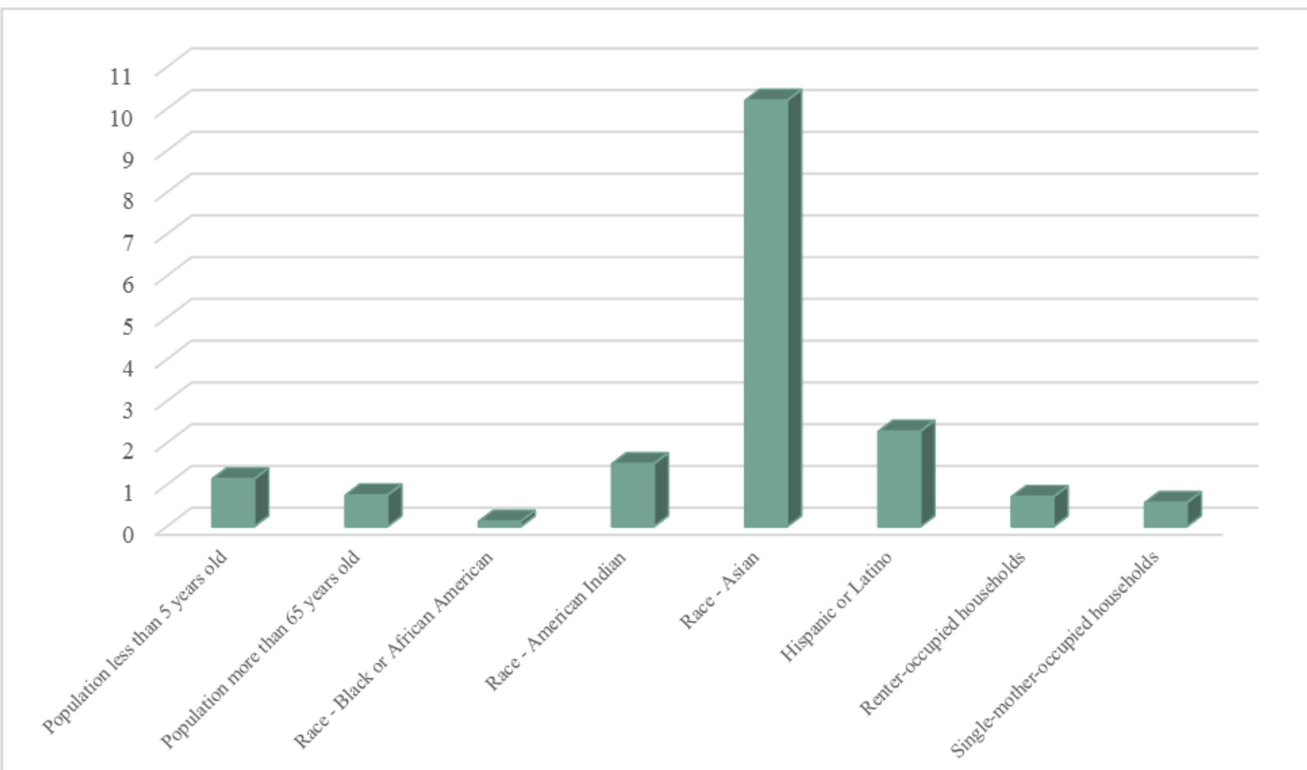

Figure 23. Odds of Exposure to Coastal Flood Events in Year 25 for Vulnerable Populations in East St. Mary Parish Study Area (Medium Scenario – 100-Year Storm Event).

Table 10. Exposure and Sensitivity of Critical and Essential Facilities to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 25 (Medium Scenario).

Critical Facilities	Coastal Flood Zone (Year 25)	Study Area Total	Flood Zone Percentage
Hospitals	0	1	0.0%
Outpatient Care Centers	0	8	0.0%
Physician Offices	0	25	0.0%
Fire Stations	0	8	0.0%
Police Stations	0	5	0.0%
Electric Companies	0	3	0.0%
Gas Companies	0	1	0.0%
Radio and TV Broadcasting	0	5	0.0%
Water and Sewerage Companies	0	3	0.0%
Essential Facilities			
Banks and Credit Unions	0	14	0.0%
Gas Stations	0	8	0.0%
Government Facilities	2	49	4.1%
Retail Grocers	0	9	0.0%
Day Care Service	0	6	0.0%
Library	0	4	0.0%
School	0	20	0.0%

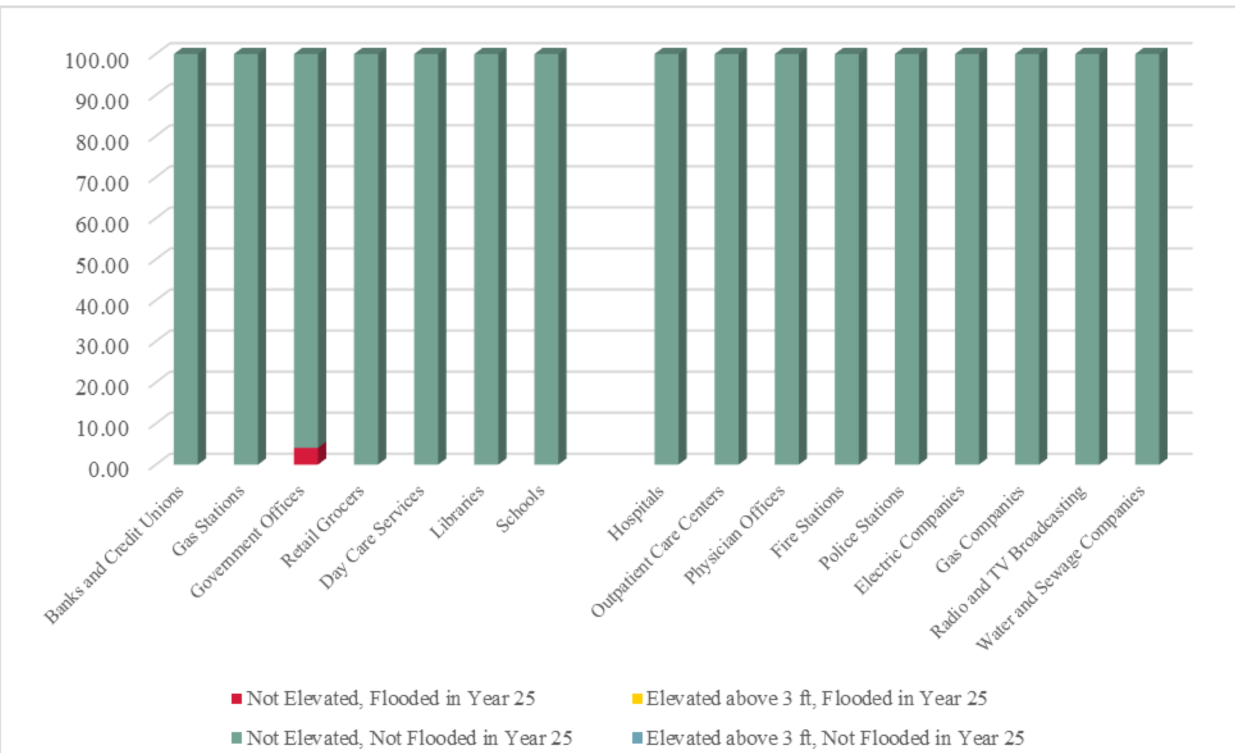

Figure 24. Elevation Dependent Sensitivity of Critical and Essential Facilities in Year 25 in East St. Mary Study Area (Medium Scenario – 100-Year Storm Event).

Year 50

Land Cover

From 25 to 50 years in the future, the areal extent of coastal flooding is projected to expand significantly, particularly in those communities adjacent to or east of the Atchafalaya River. By Year 50, Amelia is projected to have higher levels of exposure and sensitivity to coastal flooding, with nearly 90% of total developed land projected to flood during a 100-year storm event (Figure 25). Particularly notable is the high percentage (over 97%) of high-intensity developed land in Amelia projected to flood (Table 11). The low-intensity and medium-intensity developed land areas within Amelia may also anticipate high risk of exposure to flooding, with the projection of 84% of both land areas being flooded. While the exposure and levels are not as high, Morgan City and Siracusaville are also projected to have a high portion of total developed land within their boundaries flooded, approximately 40% in each community. Of the communities located to the west of the Atchafalaya River, only Berwick, which is located adjacent to the river, is projected to experience any notable impacts from coastal storm surge. Much of this flooding can be seen as an expansion Year 10 and 25 flooding along the waterways and in the wetlands and forested wetlands of the region into many of the more highly developed areas within the communities.

Residential Population

Unlike the results for earlier years in the simulation, results modeled for 50 years in the future under the medium scenario indicate that approximately one-third of the developed land in the study area is projected to flood under a 100-year storm event, an area that includes over 19% of the study area's total population (Table 12). Four socially vulnerable populations examined in this research were found to be more likely to reside within the 100-year flood zone than outside of it (Figure 26); the Asian (5.6 times more likely), Hispanic (2.8 times more likely), elderly (1.3 times more likely), and Native American (1.1 times more likely) populations. Notably, consistent with the results in Year 25, approximately 16% of the population projected to flood is Hispanic, making this the minority group most highly sensitive to coastal flooding in the region. Also, as in Year 25, almost 32% of households in the flood zone are rental units, making this socially vulnerable group the most sensitive to a 100-year storm event, despite the fact that this percentage is lower than the percentage found in the study area overall.

Critical and Essential Facilities

If no action is taken, it is projected that a significant number of critical and essential facilities would be at risk of being inundated by a 100-year storm event at Year 50 (Table 13). The greatest risk to communities at that time would be the loss of medical services for many portions of the region. While the only hospital in the region, the Teche Regional Medical Center in Morgan City, is not projected to receive significant flooding, more than half of the region's physician offices and outpatient care centers would experience flood levels greater than 3 ft. None of these structures are elevated above the modeled flood levels, increasing their vulnerability to flood impacts (Figure 27). Conversely, less than 20% of the region's 11 fire stations and 40% of the police stations are projected to flood. These results suggest that with rare exception, emergency responders in the region would be well situated to respond to a 100-year storm event, with a majority of the hospitals, police stations, and fire stations not projected to experience flooding above 3 ft. in depth.

The primary future threat to community members in terms of receiving emergency care and assistance would include the flooding of smaller neighborhood medical facilities. The critical medical facilities could also, to a large extent, be considered essential facilities, as local residents often depend on their primary physician and outpatient care centers to provide their basic medical services. Other significantly impacted facilities, essential for the day-to-day lives of community residents, include banks and credit unions (47.1% flooded) and schools (43.5% flooded). The loss of these essential services would be expected to severely reduce the level of community resilience in the region, presenting a potential impediment to the return of population in the aftermath of a coastal storm event. It is important to note that the vulnerability of all critical and essential facilities in the East St. Mary Parish study is increased due to the fact that none of the structures are currently elevated above the modeled flood depths (Figure 27). These projections and potential outcomes would obviously change if additional floodproofing measures are undertaken in the coming years.

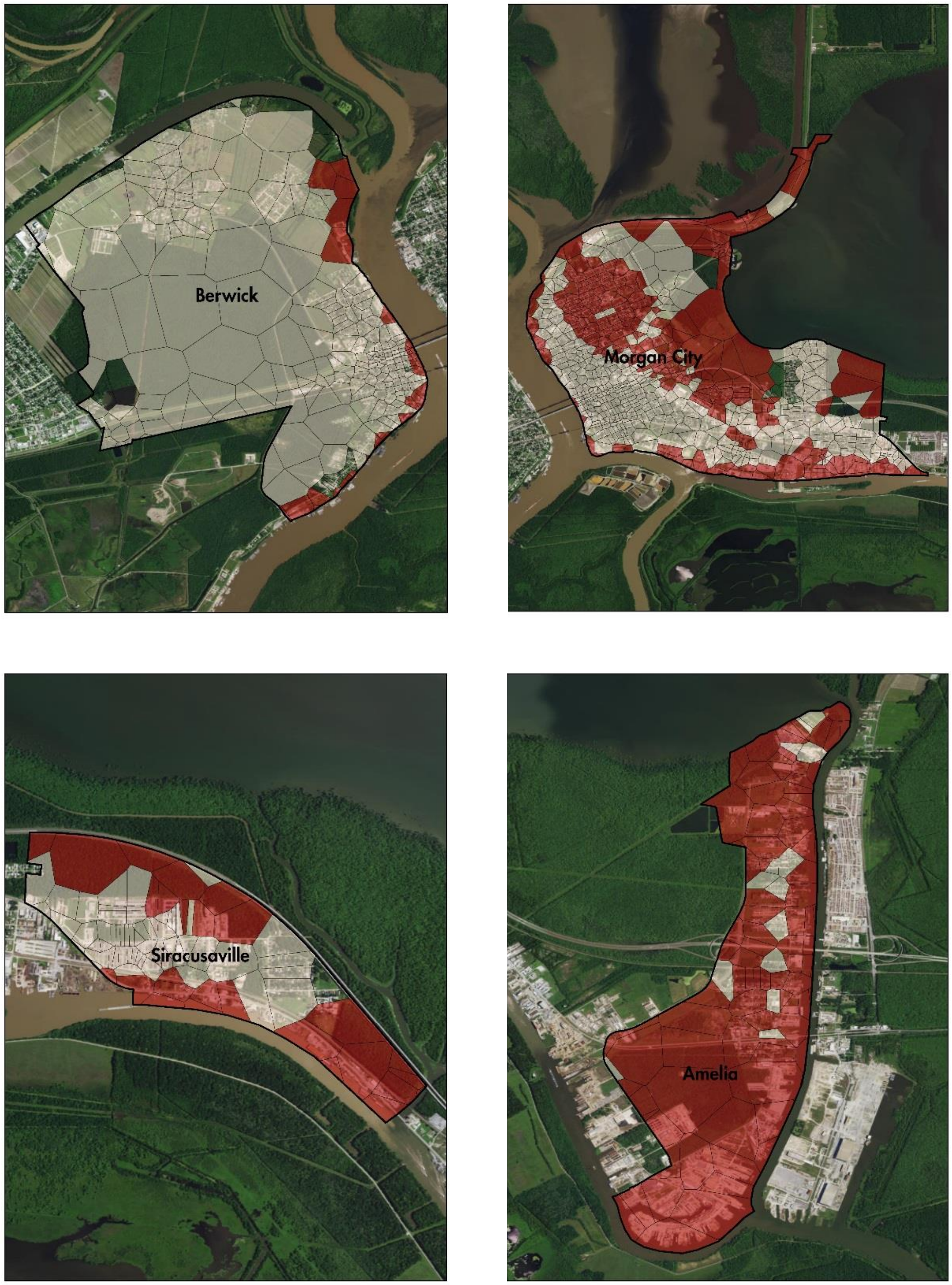

Figure 25. Projected flooding in Year 50 from a 100-Year Storm in East St. Mary Parish. Red cells indicated inundation at or above 3 ft.

Table 11. Exposure and Sensitivity of Developed Land to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 50.

Census Designated Place	Low-Intensity Developed			Medium-Intensity Developed			High-Intensity Developed			Total Developed		
	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%
Amelia	327.1	390.7	83.7	98.7	117.9	83.8	358.7	369	97.2	784.6	877.6	89.4
Bayou Vista	0	561.1	0	0	87.4	0	0	89.8	0	0	738.3	0
Berwick	35.8	647.8	5.5	10.9	109.4	10	21.1	97.9	21.6	67.8	855.1	7.9
Morgan City	602.5	1446.2	41.7	174.1	512.6	34	252.4	583.6	43.3	1029	2542.4	40.5
Patterson	0	729.2	0	0	29.6	0	0	28	0	0	786.8	0
Siracusaville	59.6	146.1	40.8	30.5	67.2	45.4	27.1	92.1	29.5	117.2	305.3	38.4
TOTAL	1025	3921.3	26.1	314.2	924	34	659.4	1260.3	52.3	1998.7	6105.6	32.7

Table 12. Exposure and Sensitivity of Socially Vulnerable Population Groups to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 50 (Medium Scenario).

Demographic Category	Coastal Flood Zone (Year 50)	Study Area Total	Flood Zone Percentage	Study Area Percentage	Sensitivity Rating
Total population	5,874	30,891	19.0%	n/a	n/a
Hispanic or Latino	916	2,465	15.6%	8.0%	1.95
Race - White	3,906	20,663	66.5%	66.9%	0.99
Race - Black or African American	797	7,133	13.6%	23.1%	0.59
Race - American Indian	71	351	1.2%	1.1%	1.06
Race - Asian	441	801	7.5%	2.6%	2.90
Population less than 5 years old	387	2,239	6.6%	7.2%	0.91
Population more than 65 years old	866	3,905	14.7%	12.6%	1.17
Total households	2,196	11,819	18.6%	n/a	n/a
Renter-occupied households	696	4,082	31.7%	34.5%	0.92
Single-mother-occupied households	207	1,335	9.4%	11.3%	0.83

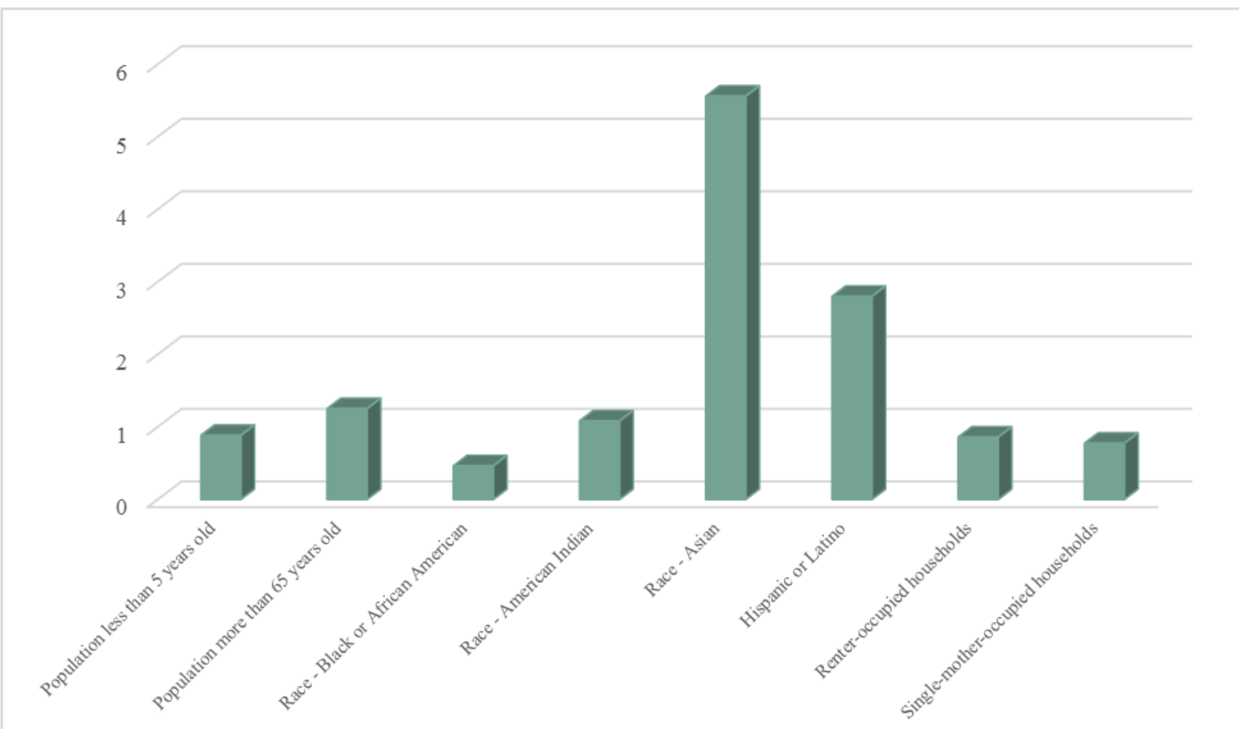

Figure 26. Odds of Exposure to Coastal Flood Events in Year 50 for Vulnerable Populations in East St. Mary Study Area (Medium Scenario – 100-Year Storm Event).

Table 13. Exposure and Sensitivity of Critical and Essential Facilities to Coastal Flooding from a 100-Year Storm in East St. Mary Parish in Year 50 (Medium Scenario).

Critical Facilities	Coastal Flood Zone (Year 50)	Study Area Total	Flood Zone Percentage
Hospitals	0	1	0.0%
Outpatient Care Centers	4	8	50.0%
Physician Offices	15	25	60.0%
Fire Stations	2	8	25.0%
Police Stations	2	5	40.0%
Electric Companies	2	3	66.7%
Gas Companies	0	1	0.0%
Radio and TV Broadcasting	2	5	40.0%
Water and Sewerage Companies	1	3	33.3%
Essential Facilities			
Banks and Credit Unions	6	14	42.9%
Gas Stations	2	8	25.0%
Government Facilities	7	49	14.3%
Retail Grocers	2	9	22.2%
Day Care Service	1	6	16.7%
Library	1	4	25.0%
School	8	20	40.0%

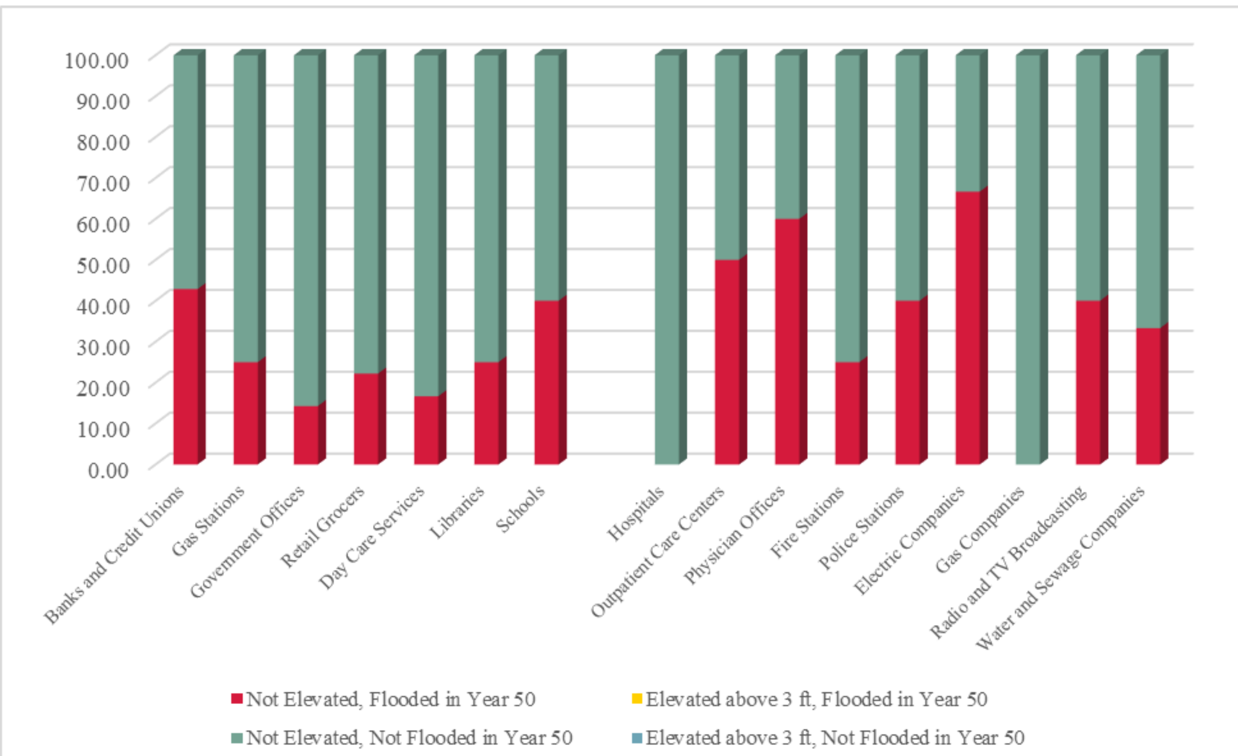

Figure 27. Elevation Dependent Sensitivity of Critical and Essential Facilities in Year 50 in East St. Mary Study Area (Medium Scenario – 100-Year Storm Event).

Case Study: Lower Lafourche Parish

BACKGROUND

Lafourche Parish is located in the southeast region of the Louisiana coast and was part of a delta lobe that formed between 2,500 and 500 years ago (Blum & Roberts, 2012). Since then, land building has migrated to other parts of the coast and the region has been in a steady elevation decline, shifting from the abandonment stage to submergence (Blum & Roberts, 2012). Coincident with this shift, wetland erosion rates in this region have been historically very high (Penland & Ramsey, 1990). Along the coastal edge of Lafourche Parish, the average shoreline erosion rate between 1887 and 2002 was approximately 67 ft. per year (Penland et al., 2005). While subsidence in southeast Louisiana is a perpetual concern, subsidence rates have recently slowed in this area compared to rates from 1960 to 1990, possibly due to a reduction in subsurface fluid extraction (Morton & Bernier, 2010).

Over 96,000 residents live in Lafourche Parish; the majority reside atop the Bayou Lafourche natural levee, the highest land in the parish (Figure 28). Because of limited high ground, most of the parish's commercial and industrial facilities are also sited on the natural levees, proximate to the parish's population centers. There are three incorporated towns located in Lafourche Parish, Thibodaux (14,500 residents), Lockport (2,500 residents), and Golden Meadow (2,000 residents). Thibodaux is Lafourche Parish's largest town as well as the parish seat. Other communities within the study area include the unincorporated towns of Raceland (10,200 residents), Larose (7,400 residents), Cut Off (6,000 residents), and Galliano (7,700 residents). Port Fourchon, a deep-draft port at the mouth of Bayou Lafourche on the Gulf of Mexico, is a major onshore staging area for Outer Continental Shelf oil and gas activities in the central and western Gulf of Mexico and the landfall for the Louisiana Offshore Oil Port. The parish is home to a sizable Native American population (2.8%) as well as African American population (13.2%) and a small Asian-American population (0.7%). In addition, 3.8% of the parish is Hispanic. In total, nearly 20% of the parish population is minority. Furthermore, for the parish as a whole, 17.6% of the population is below the U.S. Census Bureau's definition of poverty. While these overall figures are below the state average, they are significant nonetheless (Figures 29-36). Particularly noteworthy is the fact that commercial and industrial facilities and residential populations are often collocated and clustered along the region's limited high ground such as the Bayou Lafourche natural levee. This dense settlement pattern can often exacerbate vulnerability to flood risk, particularly in communities with large numbers of low-income and minority residents (Hemmerling, 2007; Hemmerling & Colten, 2004).

Historically, Lafourche Parish has been heavily impacted by hurricanes and tropical storms. One of the deadliest storms in Louisiana history, the Chenier Caminada Hurricane of 1893 decimated much of the Louisiana coastline, killing more than 2,000 coastal residents. After the storm, many of the survivors from the town of Chenier Caminada moved to Lafourche Parish, further inland, and founded the town of Leeville, while others settled in Grand Isle, Cut Off, Golden Meadow, and Lockport (Roth, 2010). Although these towns, particularly those north of Golden Meadow, are generally well protected from storm surges by over 48 miles of ring levee, the area is still vulnerable to other tropical storm impacts such as extreme rainfall, tornadoes, and gale force winds. In the latter half of the twentieth century, Lafourche Parish ranked sixth in Louisiana parishes in economic losses due to tropical storms and hurricanes with approximately $162.9 million in losses from 1960 to 2003 (Cutter et al., 2006). Between 1978 and 2003, residents of the town of Golden Meadow alone submitted over $2 million in National

Flood Insurance Program flood loss claims to the Federal Emergency Management Agency (Laska et al., 2005). Lafourche Parish also experienced more damage to its commercial fisheries industry than any other parish in Louisiana during Hurricanes Katrina and Rita, with 80 seafood dealers losing an estimated $35.5 million in damaged infrastructure and lost revenue and an additional $7 million more due to damaged fishing vessels (Erlambang, 2008).

In an attempt to ameliorate storm impacts in the region, a number of projects have been constructed in the parish. State projects planned and monitored by CPRA can be divided into coastal restoration and flood protection projects, the latter including both structural and non-structural protection projects. Two large-scale restoration projects have been completed by the state in Lafourche Parish. The first was the West Belle Pass Barrier Headland Restoration. This project was constructed in an area with very high erosion rates, up to 100 ft. per year in some areas, and it restored 183 acres of beach and 334 acres of marsh habitat. The second project is the Caminada Headland Beach and Dune Restoration where 303 acres were restored, reinforcing approximately six miles of critical habitat. In addition to the restoration projects already accomplished in this region, there are many ongoing projects in different stages of development. One proposed project is the construction of a diversion that would introduce water and sediment from the Mississippi River to Bayou Lafourche to help to restore sediment flow and rebuild land in the region. Another proposed project is the East Timbalier Island Restoration which would reconnect two island segments that are currently extremely degraded. Finally, the proposed East Leeville Marsh Creation and Nourishment project is estimated to build 358 acres of land, while nourishing and protecting 124 more acres (CPRA, 2012).

Completed storm surge protection projects in Lafourche parish include Bayou Lafourche levee improvements from Valentine to Larose and the construction of structural protection features surrounding Golden Meadow, Larose, Cut Off, and Galliano, protecting roughly 27,000 residents and ensuring continued access to Port Fourchon and other coastal industrial facilities. Non-structural risk reduction efforts are ongoing and focus on floodproofing non-residential structures, elevating residential buildings, and acquiring residential property where the 100-year flood projections are greater than 14 ft. (CPRA, 2012).

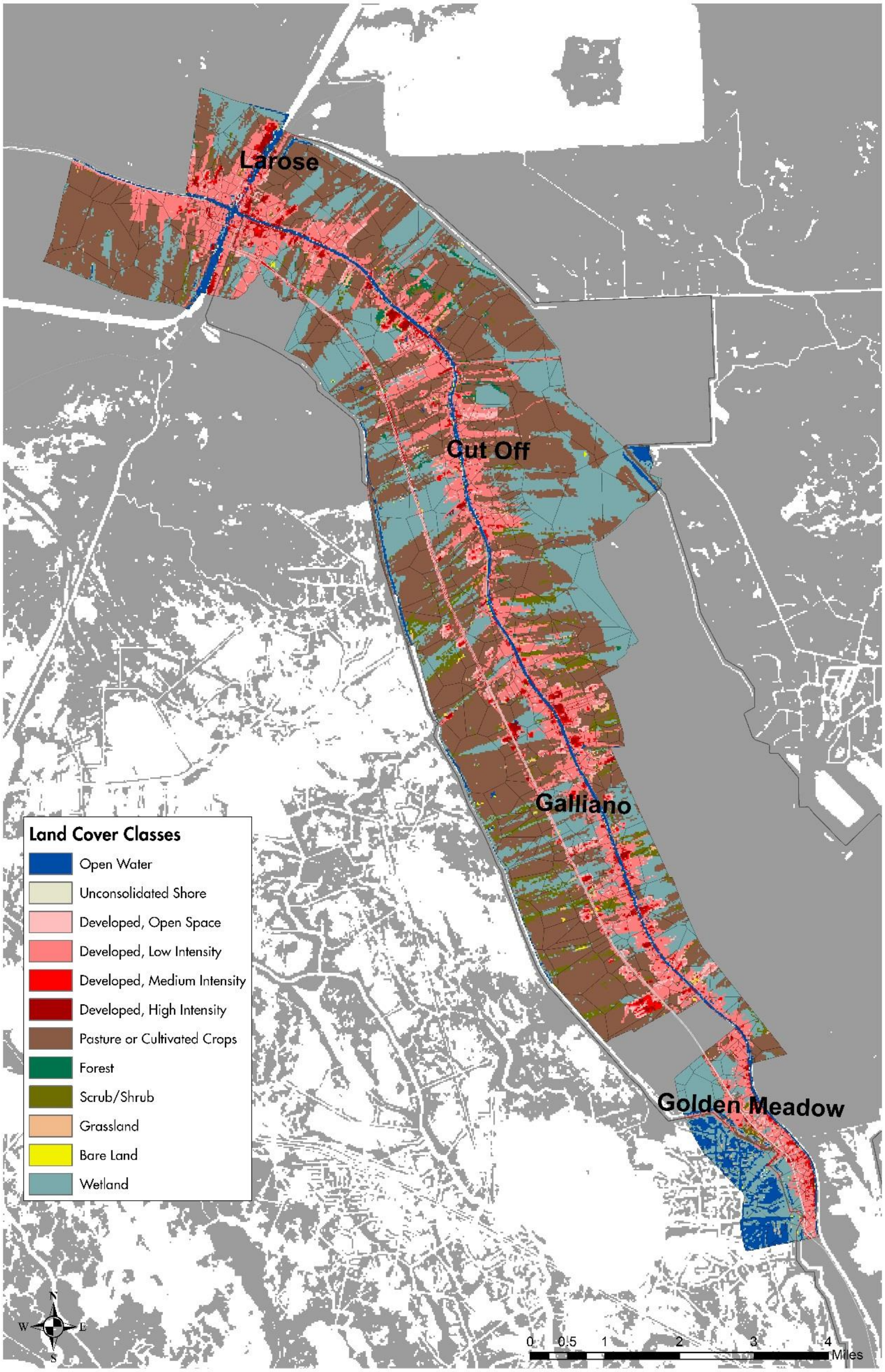

Figure 28. Land Cover Classification of Lower Lafourche Study Area.

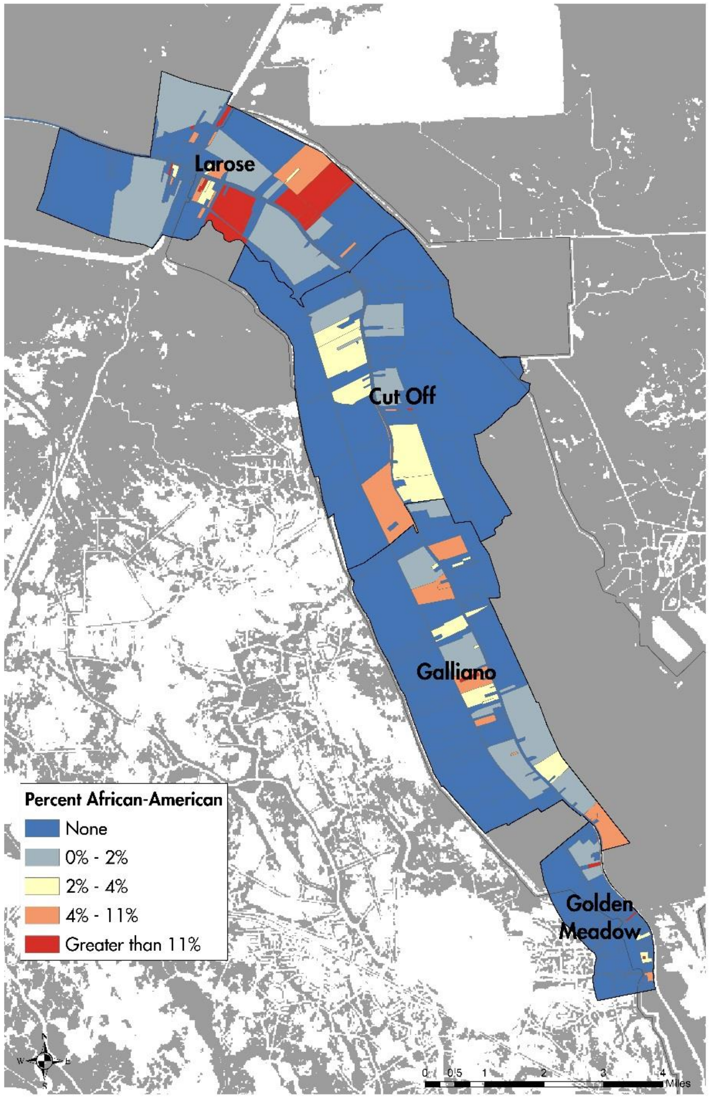

Figure 29. Percent African American Population in Lower Lafourche Parish.

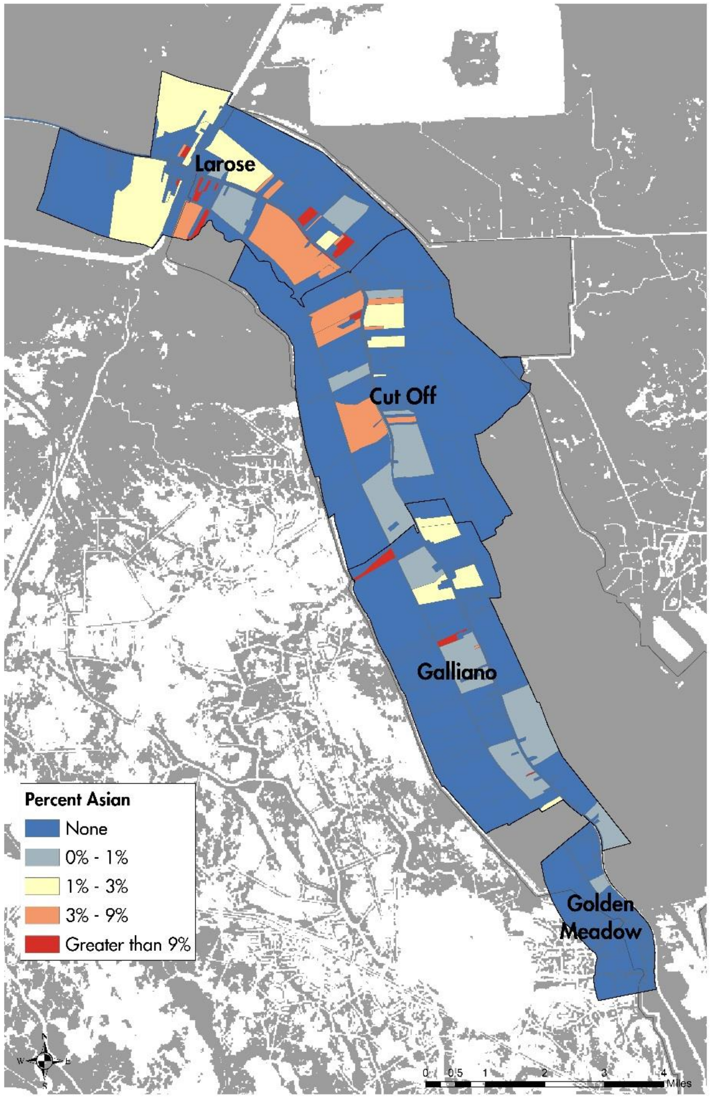

Figure 30. Percent Asian Population in Lower Lafourche Parish.

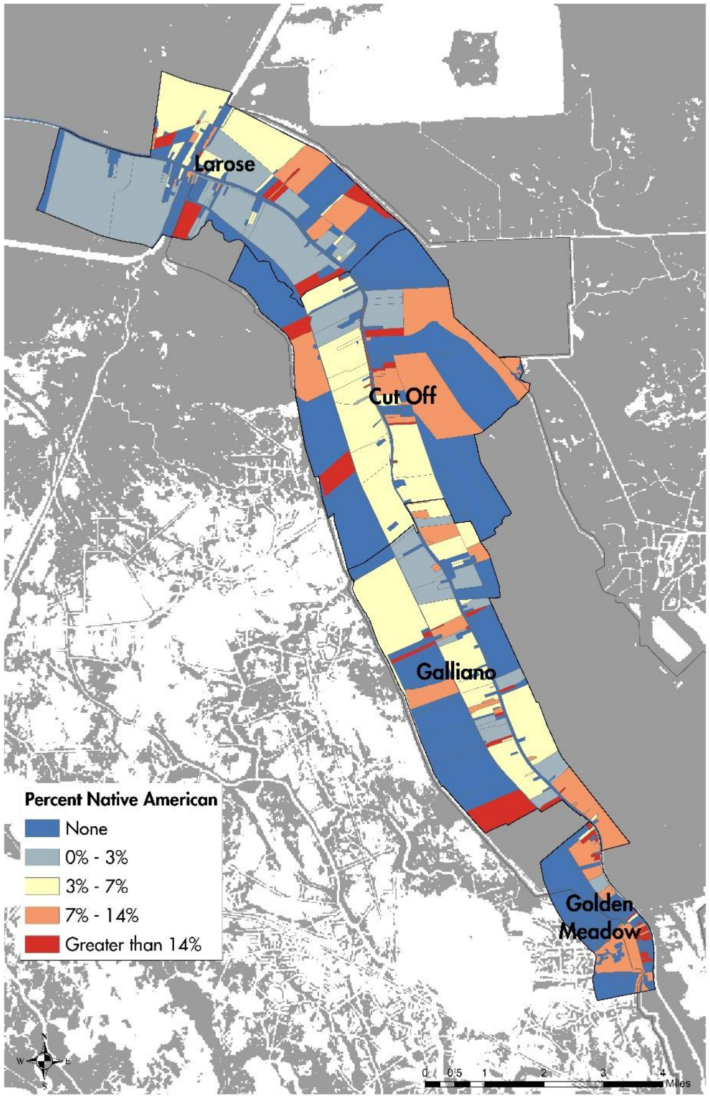

Figure 31. Percent Native American Population in Lower Lafourche Parish.

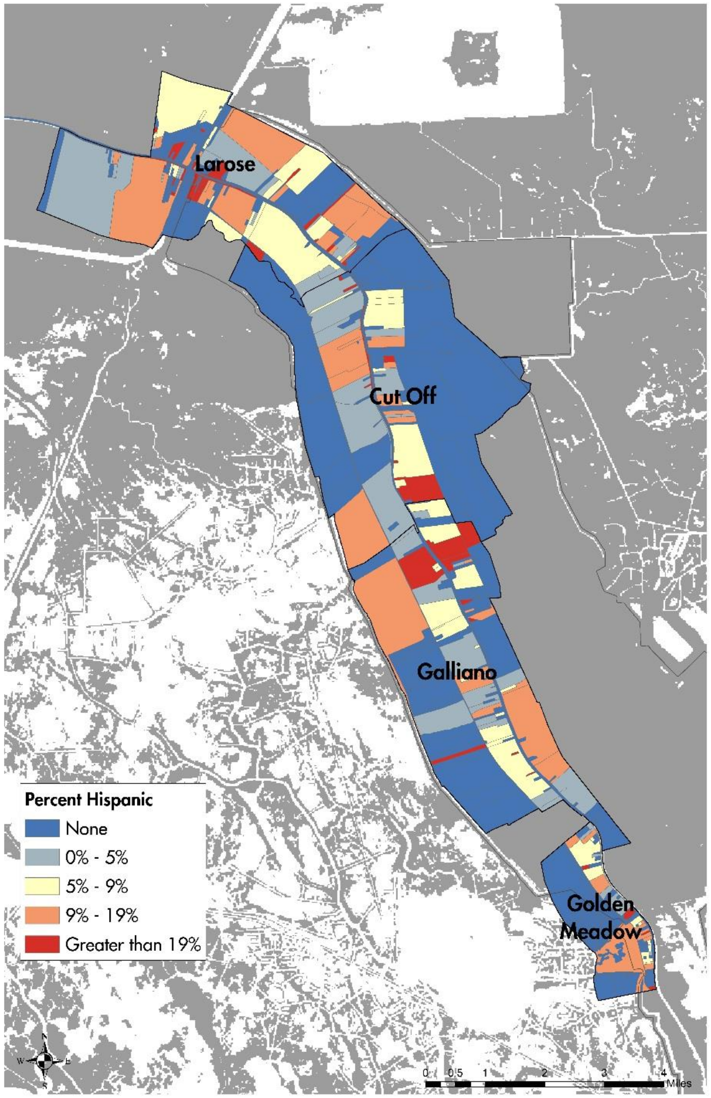

Figure 32. Percent Hispanic Population in Lower Lafourche Parish.

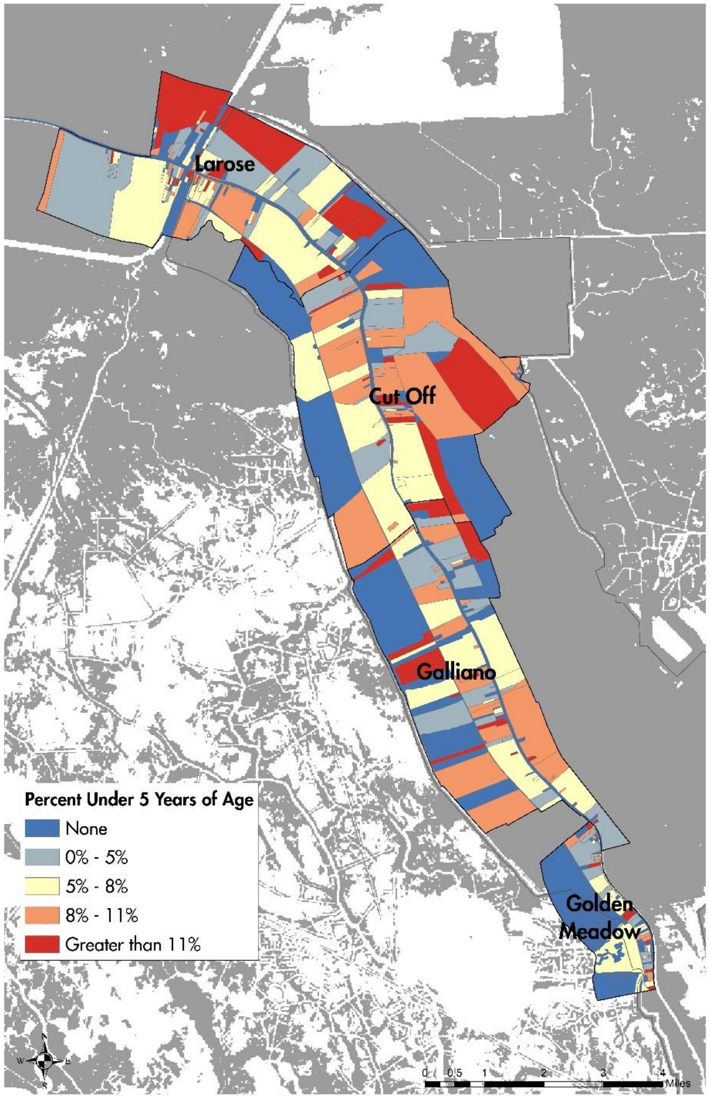

Figure 33. Percent of Population Under 5 Years of Age in Lower Lafourche Parish.

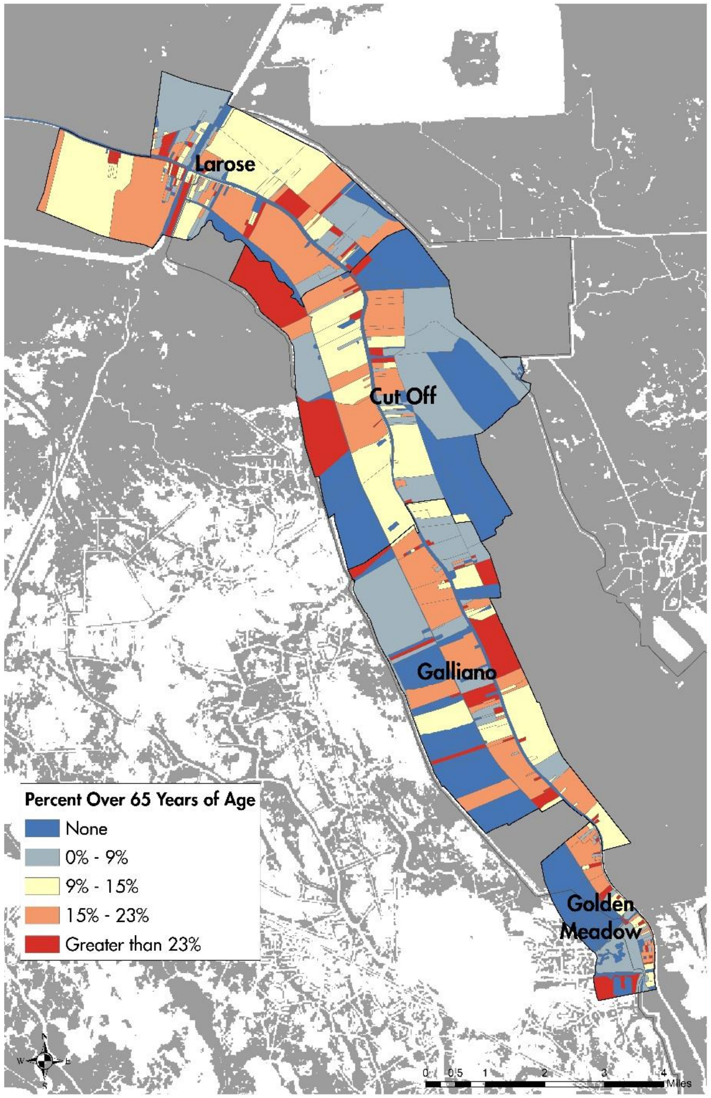

Figure 34. Percent of Population Over 65 Years of Age in Lower Lafourche Parish.

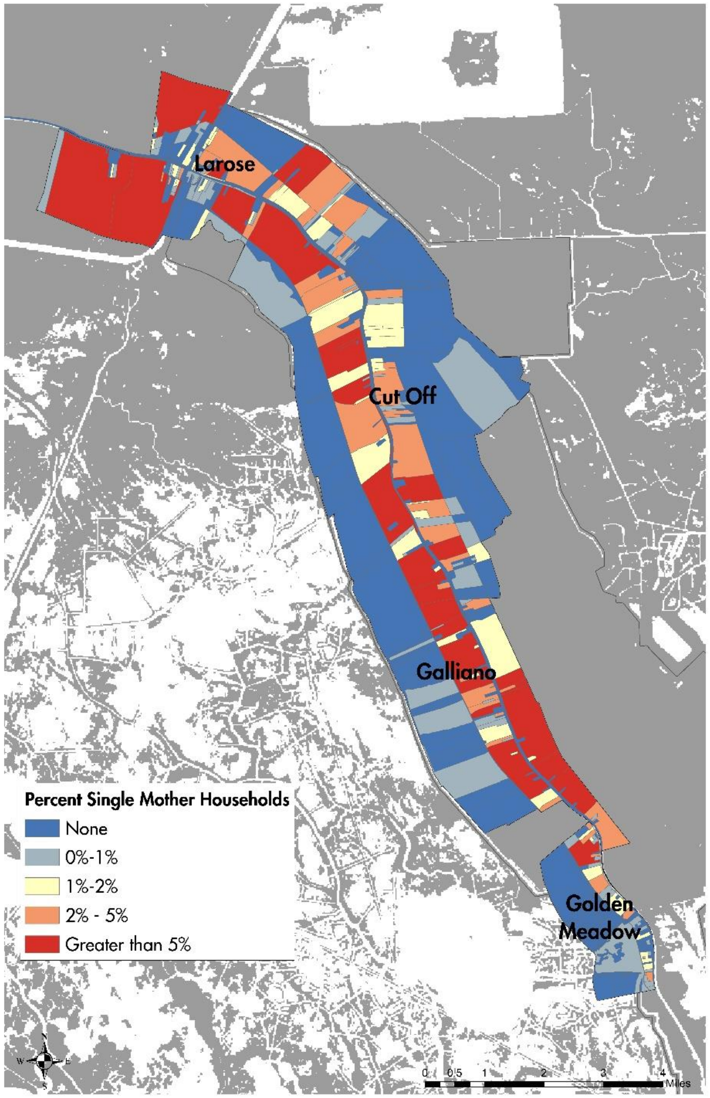

Figure 35. Percent of Single Mother Households in Lower Lafourche Parish.

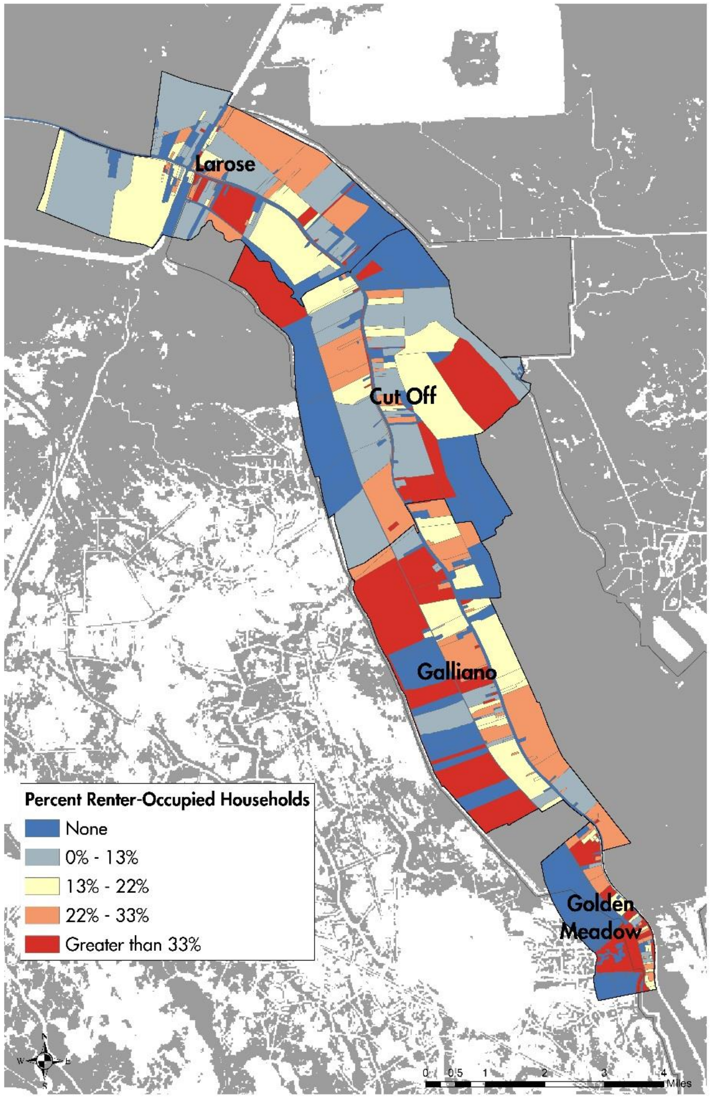

Figure 36. Percent of Renter-Occupied Households in Lower Lafourche Parish.

RESULTS

Under the medium environmental future change scenario developed for Louisiana's 2017 Coastal Master Plan, the Larose to Golden Meadow Hurricane Protection Project is predicted to protect most locations between Larose and Golden Meadow from both 100- and 500-year storms (Figure 37 and Figure 38). Outside of this levee system, including the portion of Larose north of the Gulf Intracoastal Waterway (GIWW) and communities south of Golden Meadow to Port Fourchon, residents currently face much higher levels of flood risk from storm events of all magnitudes.

Current Conditions

Land Cover

Overall, the developed land in the Lower Lafourche corridor is not projected to experience significant levels of flooding from a 100-year storm event under current environmental conditions, with approximately 6.9% of the total developed land experiencing more than 3 ft. of flooding (Table 14). Results indicate, however, that the amount and percentage of developed land in the model flood zones varies substantially across the study area. In particular, the central portion of the study area, consisting of the towns of Cut Off and Galliano are considerably more protected from storm surge than Larose and Golden Meadow, the northern and southernmost communities analyzed, respectively (Figure 39). Portions of Larose, in particular, are extremely vulnerable to coastal flooding, particularly the portion of the community located north of the GIWW, a major east-west running navigation channel that bisects the community. Under current conditions, Larose experiences considerably more exposure to coastal flooding than other communities in the region in terms of the number of acres in the projected surge zone. Likewise, the community is much more sensitive to the impacts of flooding based upon the percentage of developed land in the surge zone. Particularly notable is the percentage of high-intensity developed land in Larose projected to experience more than 3 ft. of flooding; nearly one-third of the heavily built up urban community center.

Residential Population

Results indicate that approximately 6.9% of the developed land in the entire study area is currently projected to flood under a 100-year storm event and that 6.8% of the total population in the study area would experience significant flood impacts (Table 15). This result is indicative of the fact that most of the population and development in the southern half of Lafourche Parish is located atop the limited high ground in the parish. Under current conditions, most of projected flooding within the developed portions of the study area is anticipated to occur in Larose, north of the GIWW. When socially vulnerable population groups projected to flood are analyzed, only the Asian population is significantly more likely to reside in the modeled flood zone than to reside outside the flood zone, albeit slightly (Figure 40). While overall exposure levels are relatively low, and significantly less than the overall study area average, residents of Larose occupying rental units are the vulnerable population most sensitive to flooding from a 100-year storm event under current conditions, followed by the elderly population. These results are indicative of industrial locations with an aging population.

Critical and Essential Facilities

Under current conditions, a number of critical and essential facilities are projected to experience 3 ft. or more of flooding from a 100-year storm event (Table 16). All of these facilities are located in south

Lafourche Parish outside of the protection levee system. While these facilities have mailing addresses in Golden Meadow, they are located in the small town of Leeville and proximate to Port Fourchon. Critical facilities at risk include both a police and fire station as well as the Greater Lafourche Port Commission Multi-Agency Emergency Response Operations Center. The emergency response center is the only civil defense facility in the study area while the police station is one of only two serving south Lafourche Parish. Other critical emergency response facilities, particularly the Lafourche Office of Homeland Security and Emergency Preparedness, are located outside the study area and would be in charge of coordinating the public response to hazard events. Of the critical facilities located in zones projected to receive three or more feet of flooding during a 100-year storm event, both the police station and the emergency response operations center are elevated above anticipated flood levels (Figure 41), allowing these facilities to more quickly recover and provide critical services to surrounding communities.

A number of essential facilities that serve the population of the region, particularly Leeville and Port Fourchon, are projected to be adversely impacted by a 100-year storm, including a number of gas stations and government offices, including research facilities and a state transportation facility. While these facilities represent a small portion of the total number of facilities serving the residential population in the study area, they represent vital link connecting residents and workers outside of the protection levees with the communities and facilities within the levees. As observed with critical facilities, however, the majority of the essential facilities at risk are elevated above anticipated flood levels under current conditions (Table 16), including all of the government offices and gas stations located between Golden Meadow and Port Fourchon. As a result, most of the essential services provided by these facilities that local residents would require during the recovery period following a coastal storm event would be more quickly restored, enhancing the resilience of the region.

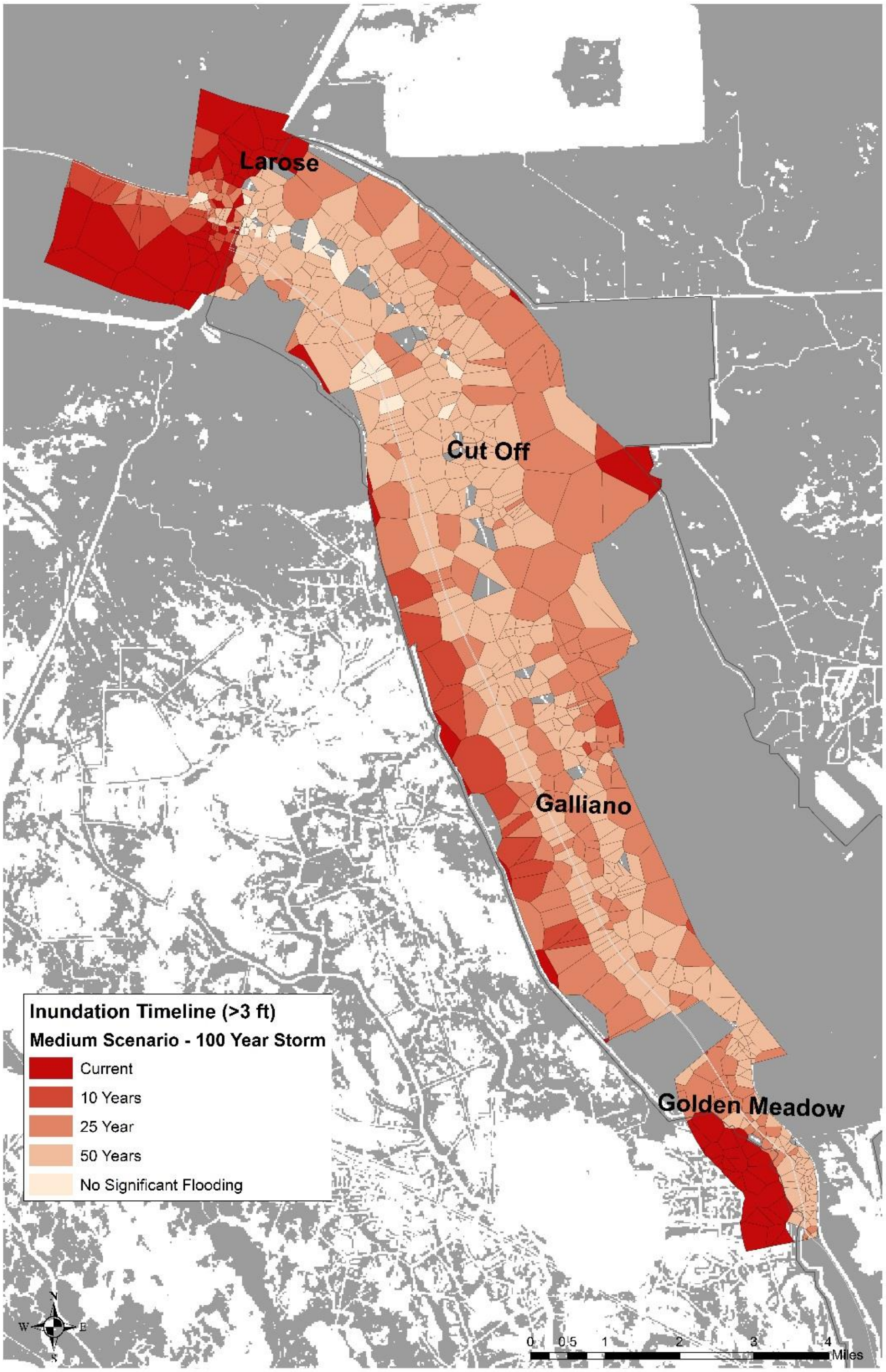

Figure 37. Inundation Timeline of a Medium Scenario 100-Year Storm in Lower Lafourche Study Area.

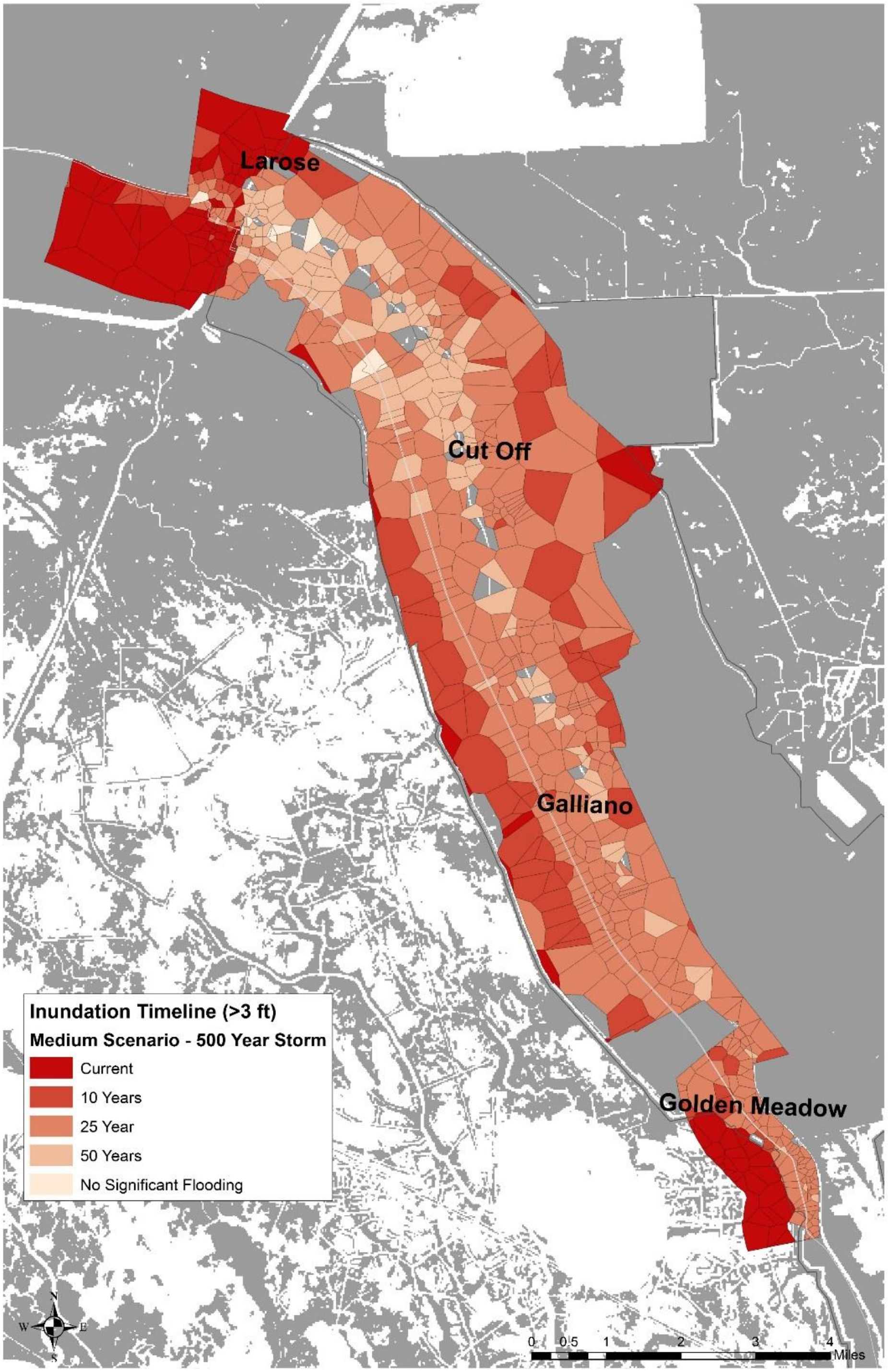

Figure 38. Inundation Timeline of Medium Scenario 500-Year Storm in Lower Lafourche Study Area.

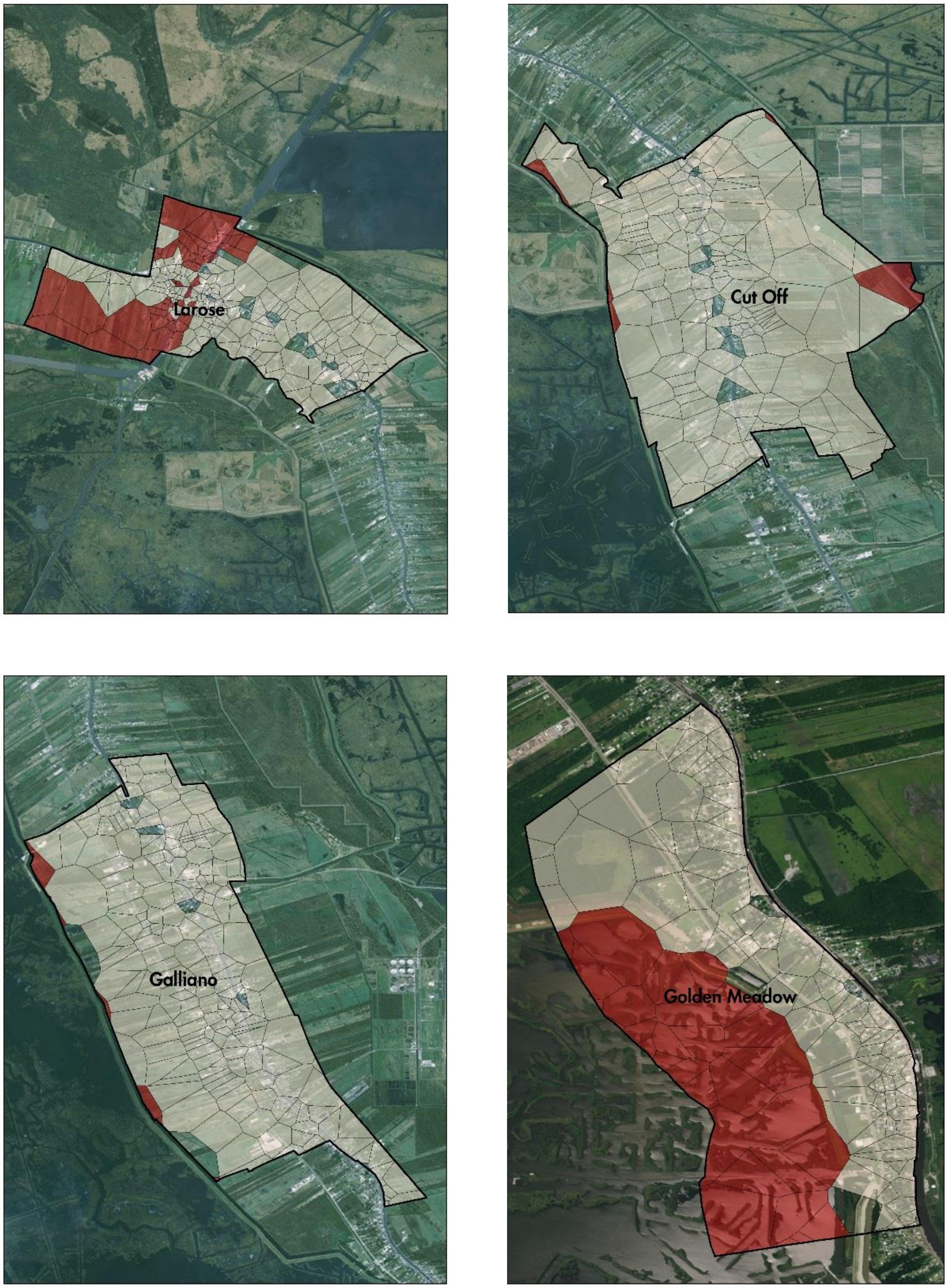

Figure 39. Projected flooding from a 100-Year Storm in Lower Lafourche Parish Under Current Conditions. Red cells indicated inundation at or above 3 ft.

Table 14. Exposure and Sensitivity of Developed Land to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish Under Current Conditions.

Census Designated Place	Low-Intensity Developed			Medium-Intensity Developed			High-Intensity Developed			Total Developed		
	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%
Cut Off	3.8	999.4	0.4	0	103.2	0	0	26.7	0	3.8	1129.3	0.3
Galliano	1.6	1377.1	0.1	0.2	190.4	0.1	0	88.7	0	1.8	1656.2	0.1
Golden Meadow	21.3	421.4	5.1	1.1	67.2	1.7	0.4	18.5	2.4	22.9	507.1	4.5
Larose	251.1	1379.5	18.2	25.1	151.2	16.6	33.1	101.2	32.7	309.4	1631.9	19
TOTAL	277.8	4177.5	6.6	26.5	512	5.2	33.6	235.1	14.3	337.8	4924.5	6.9

Table 15. Exposure and Sensitivity of Socially Vulnerable Population Groups to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish Under Current Conditions (Medium Scenario).

Demographic Category	Coastal Flood Zone (Current Conditions)	Study Area Total	Flood Zone Percentage	Study Area Percentage	Sensitivity Rating
Total population	1,574	23,153	6.8%	n/a	n/a
Hispanic or Latino	102	1,740	6.5%	7.5%	0.86
Race - White	1,391	19,445	88.4%	84.0%	1.05
Race - Black or African American	11	632	0.7%	2.7%	0.26
Race - American Indian	72	1,133	4.6%	4.9%	0.93
Race - Asian	22	277	1.4%	1.2%	1.17
Population less than 5 years old	106	1,618	6.7%	7.0%	0.96
Population more than 65 years old	193	3,151	12.3%	13.6%	0.90
Total households	565	8,447	6.7%	n/a	n/a
Renter-occupied households	73	1,729	12.9%	20.5%	0.63
Single-mother-occupied households	38	662	6.7%	7.8%	0.86

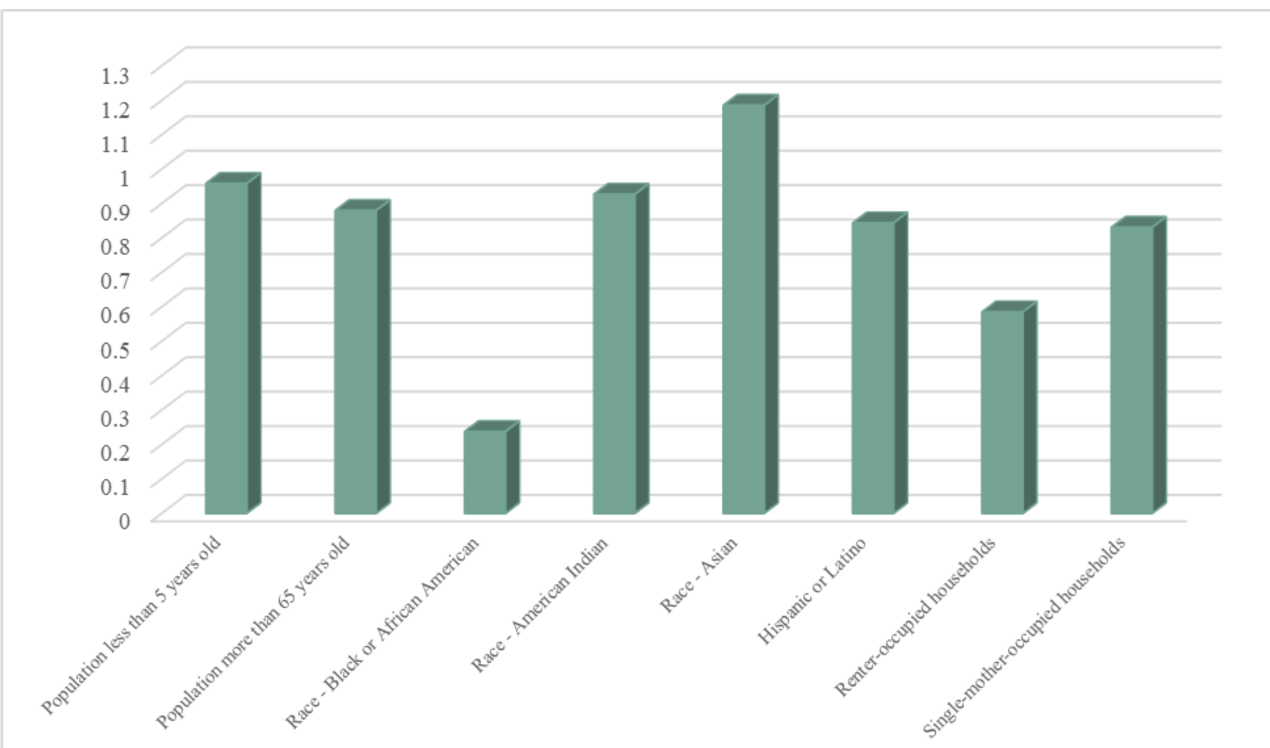

Figure 40. Odds of Exposure to Coastal Flood Events Under Current Conditions for Vulnerable Populations in Lower Lafourche Parish (Medium Scenario – 100-Year Storm Event).

Table 16. Exposure and Sensitivity of Critical and Essential Facilities to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish Under Current Conditions (Medium Scenario).

Critical Facilities	Coastal Flood Zone (Current Conditions)	Study Area Total	Flood Zone Percentage
Ambulance Services	0	1	0.0%
Hospitals	0	1	0.0%
Outpatient Care Centers	0	16	0.0%
Physician Offices	0	4	0.0%
Civil Defense	1	1	100.0%
Fire Stations	1	5	20.0%
Police Stations	1	2	50.0%
Radio and TV Broadcasting	0	4	0.0%
Essential Facilities			
Banks and Credit Unions	0	18	0.0%
Gas Stations	3	14	21.4%
Government Facilities	4	30	13.3%
Retail Grocers	0	8	0.0%
Day Care Service	0	3	0.0%
Library	0	3	0.0%
School	0	11	0.0%

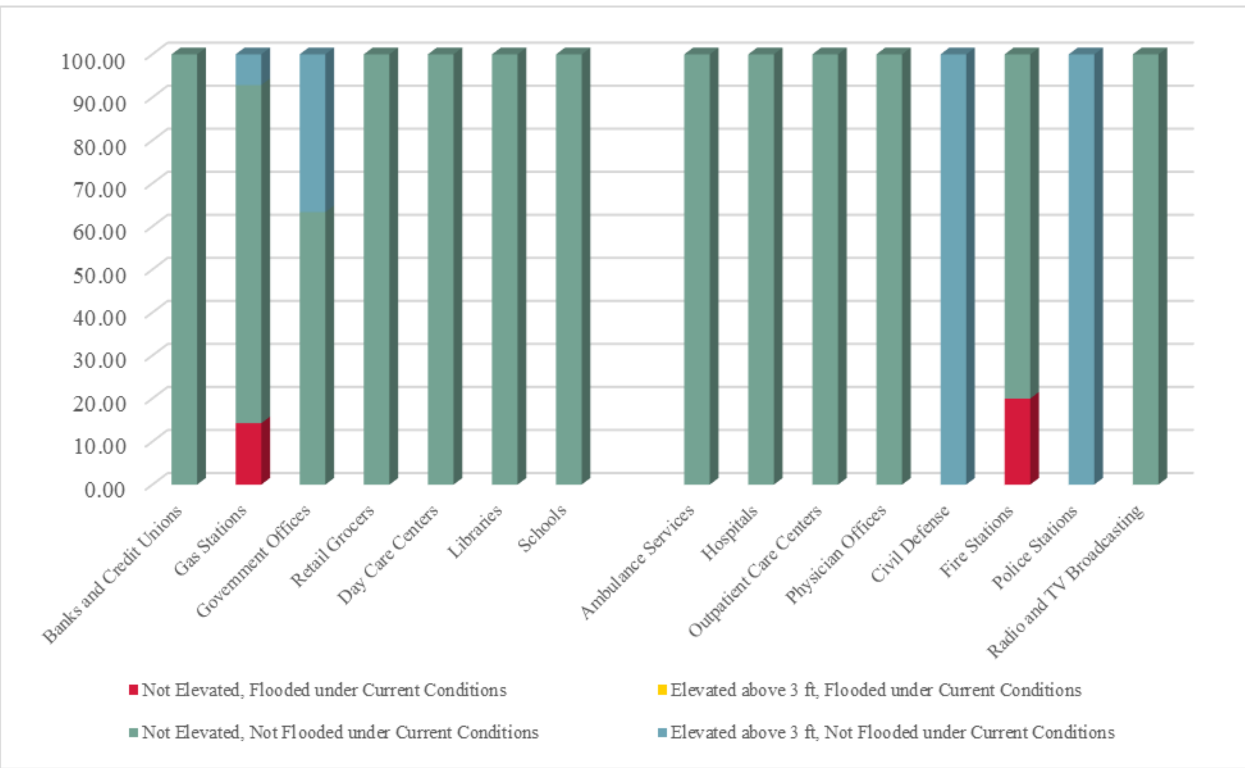

Figure 41. Elevation Dependent Sensitivity of Critical and Essential Facilities Under Current Conditions in Lower Lafourche Study Area (Medium Scenario – 100-Year Storm Event).

Year 10

Land Cover

Under the medium environmental change scenario modeled by the State of Louisiana for the 2017 Coastal Master Plan, the total area of developed land in the study area experiencing more than 3 ft. of flooding is projected to climb from 6.9 to 11% over the next 10 years (Table 17). While a very slight increase in developed land flooding is anticipated in Cutoff and Galliano, most of the additional flooding is projected to occur in Larose (Figure 42). As under the current conditions, most of the flooding in Larose is projected to occur north of the GIWW, with the flood surface shifting closer to, and in some cases abutting Bayou Lafourche. All classes of developed land in Larose are highly sensitive to coastal flooding: 31% of low-intensity developed land, 23.2% of medium-intensity developed land, and 37.8% of high intensity land would have more than 3 ft. of flooding during a 100-year storm event at Year 10 of the simulation. Together, 30.7% of all developed land in Larose is projected to flood under such a storm event.

Residential Population

While 11% of the total developed land in the study area is projected to flood under a 100-year storm event at Year 10, only 9.6% of the total population would be impacted. Under current conditions, these values are nearly identical, suggesting that a larger portion of the land projected to flood in the coming decade would be either industrial or commercial (Table 18). Most socially vulnerable population groups are no more likely to be found residing in the projected flood zone than outside of it. Of the groups examined, only the Asian population is more likely to reside in the projected flood zone than outside (Figure 43). These results mirror those found when current conditions were assessed. Similarly, residents occupying rental units are the most sensitive to flooding from a 100-year storm event under current conditions and 10 years in the future, followed by the elderly population.

Critical and Essential Facilities

Over the next 10 years, under the medium environmental change scenario, both the spatial extent and depth of flooding is projected to increase. Changes in overall facility exposure to coastal flooding during a 100-year storm event are projected to be minimal as only four additional facilities are found in the modeled flood zone (Table 19). While the spatial extent of flooding south of Golden Meadow to Port Fourchon, including the small community of Leeville, is not projected to increase, increasing flood depths (projected to exceed 15 ft. in some locations) could create additional community vulnerabilities, as several facilities are shown to experience 3 ft. or more of flooding, even those that are elevated such as the research and transportation facilities located south of Leeville (Figure 44).

In addition to the facilities located in Leeville and Port Fourchon, a radio and television broadcasting company, along with AM and FM broadcasting channels, located north of the GIWW could be at risk of flooding. The broadcasting structures themselves are not elevated above the levels of projected flooding, thus increasing their vulnerability (Figure 44). The disruption of communication in the aftermath of a hazards event represents a significant vulnerability to coastal residents. During a storm event, information transfer becomes critical. Communication about the storm itself, whether to evacuate and to where, how to learn of shelters, and where to find food, medical supplies, and other necessities (Burger et al., 2013). A study conducted after Superstorm Sandy found that television and radio were the best sources of information for impacted residents and that, during the storm event, people relied on whatever source was functioning (Burger et al., 2013). The other local radio station operating in the study area is located in Golden Meadow and owned by the United Houma Nation tribe and is not projected to flood at this time. Outside of this, residents would need to rely on broadcasts from locations outside of the study area if local stations went off the air.

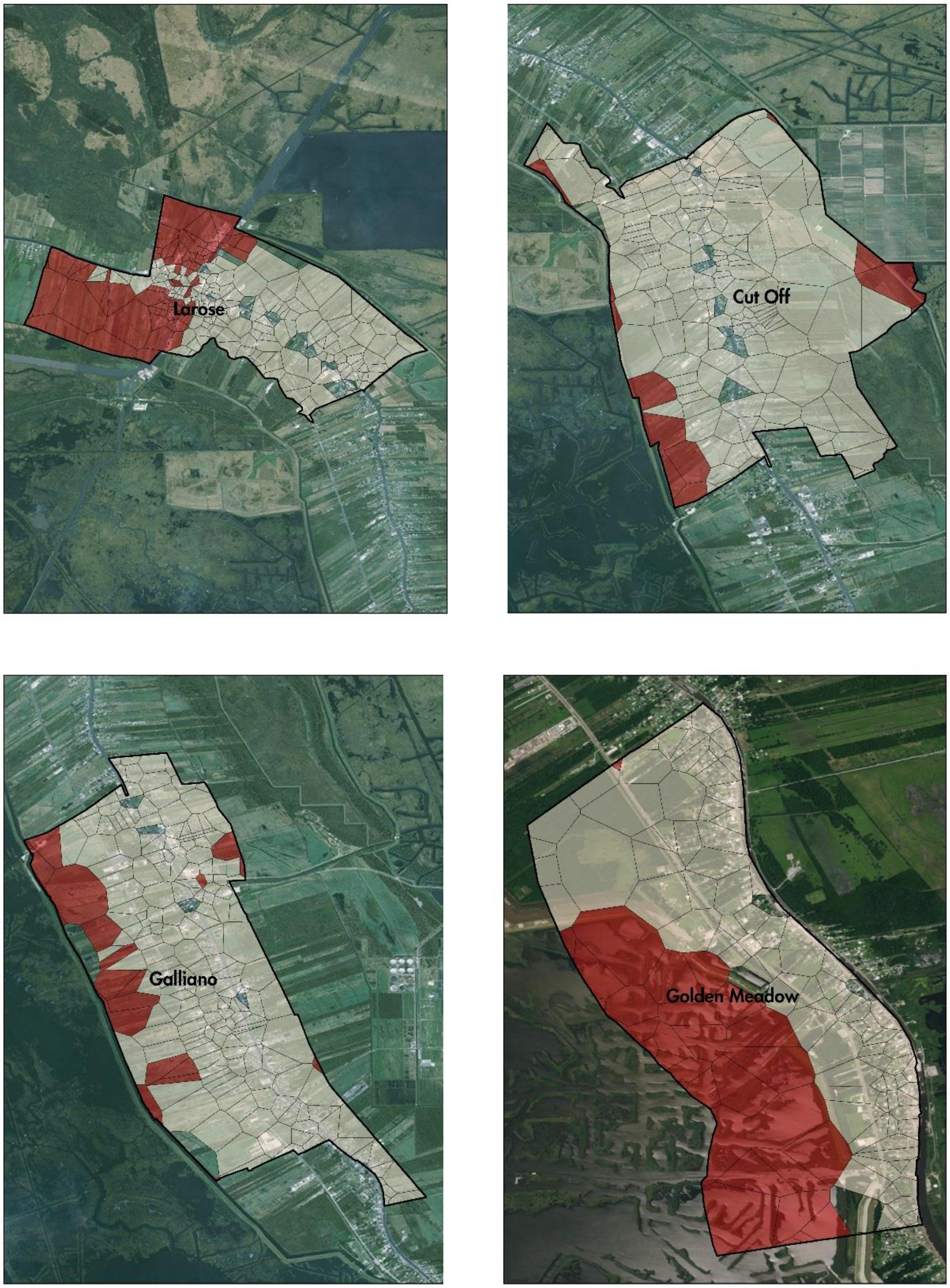

Figure 42. Projected flooding in Year 10 from a 100-Year Storm in Lower Lafourche Parish. Red cells indicated inundation at or above 3 ft.

Table 17. Exposure and Sensitivity of Developed Land to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 10.

Census Designated Place	Low-Intensity Developed			Medium-Intensity Developed			High-Intensity Developed			Total Developed		
	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%
Cut Off	5.1	999.4	0.5	0	103.2	0	0	26.7	0	5.1	1129.3	0.5
Galliano	7.8	1377.1	0.6	1.3	190.4	0.7	2.4	88.7	2.8	11.6	1656.2	0.7
Golden Meadow	21.3	421.4	5.1	1.1	67.2	1.7	0.4	18.5	2.4	22.9	507.1	4.5
Larose	427.9	1379.5	31	35.1	151.2	23.2	38.3	101.2	37.8	501.3	1631.9	30.7
TOTAL	462.1	4177.5	11.1	37.6	512	7.3	41.1	235.1	17.5	540.9	4924.5	11

Table 18. Exposure and Sensitivity of Socially Vulnerable Population Groups to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 10 (Medium Scenario).

Demographic Category	Coastal Flood Zone (Year 10)	Study Area Total	Flood Zone Percentage	Study Area Percentage	Sensitivity Rating
Total population	2,212	23,153	9.6%	n/a	n/a
Hispanic or Latino	156	1,740	7.1%	7.5%	0.94
Race - White	1,960	19,445	88.6%	84.0%	1.06
Race - Black or African American	12	632	0.5%	2.7%	0.20
Race - American Indian	89	1,133	4.0%	4.9%	0.82
Race - Asian	29	277	1.3%	1.2%	1.10
Population less than 5 years old	139	1,618	6.3%	7.0%	0.90
Population more than 65 years old	271	3,151	12.3%	13.6%	0.90
Total households	790	8,447	9.4%	n/a	n/a
Renter-occupied households	101	1,729	12.8%	20.5%	0.62
Single-mother-occupied households	51	662	6.5%	7.8%	0.82

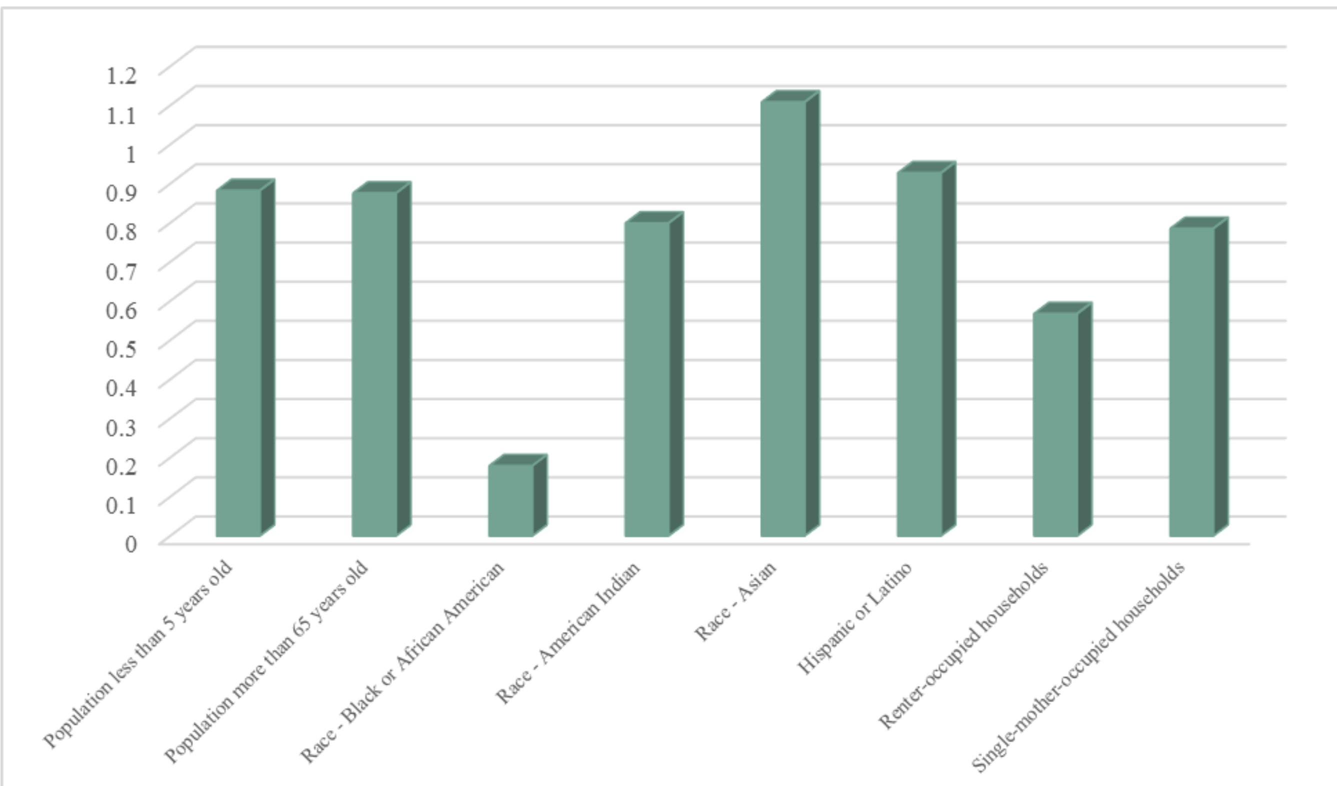

Figure 43. Odds of Exposure to Coastal Flood Events in Year 10 for Vulnerable Populations in Lower Lafourche Study Area (Medium Scenario – 100-Year Storm Event).

Table 19. Exposure and Sensitivity of Critical and Essential Facilities to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 10 (Medium Scenario).

Critical Facilities	Coastal Flood Zone (Year 10)	Study Area Total	Flood Zone Percentage
Ambulance Services	0	1	0.0%
Hospitals	0	1	0.0%
Outpatient Care Centers	0	16	0.0%
Physician Offices	0	4	0.0%
Civil Defense	1	1	100.0%
Fire Stations	1	5	20.0%
Police Stations	1	2	50.0%
Radio and TV Broadcasting	3	4	75.0%
Essential Facilities			
Banks and Credit Unions	0	18	0.0%
Gas Stations	3	14	21.4%
Government Facilities	5	30	16.7%
Retail Grocers	0	8	0.0%
Day Care Service	0	3	0.0%
Library	0	3	0.0%
School	0	11	0.0%

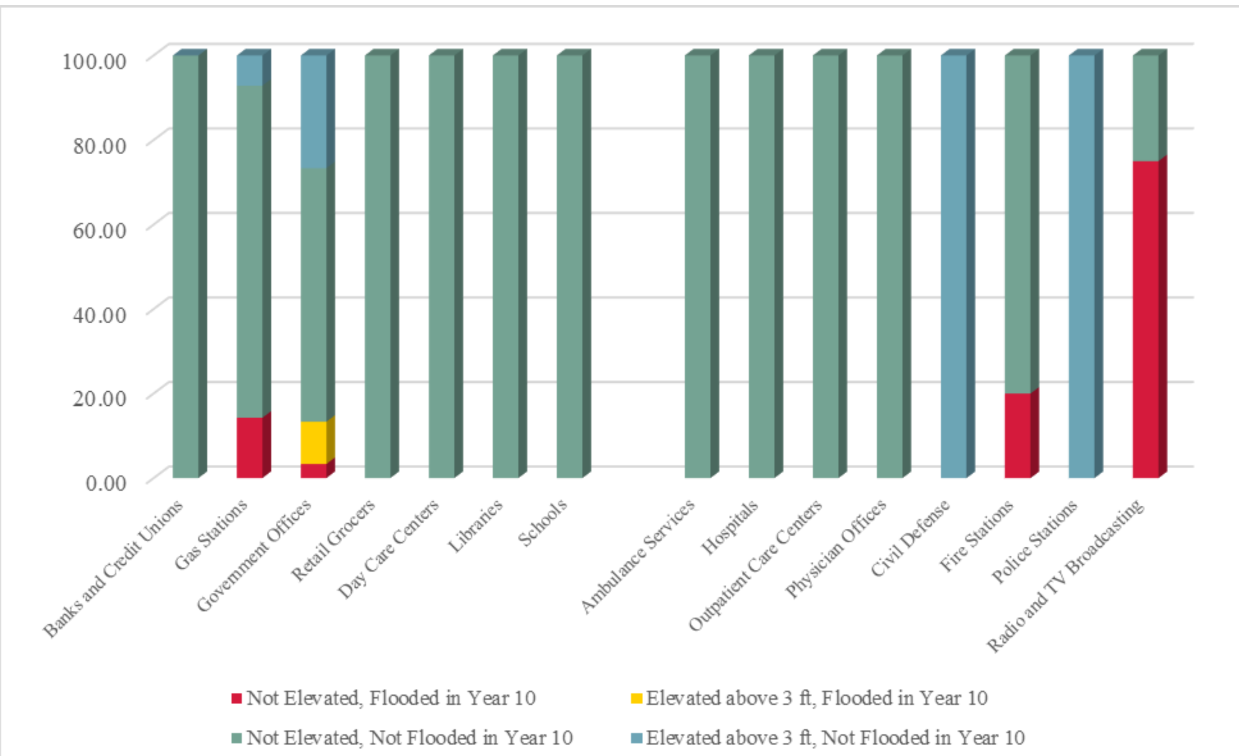

Figure 44. Elevation Dependent Sensitivity of Critical and Essential Facilities in Year 10 in Lower Lafourche Study Area (Medium Scenario – 100-Year Storm Event).

Year 25

Land Cover

Between 10 and 25 years in the future, under the medium environmental change scenario modeled by the State of Louisiana for the 2017 Coastal Master Plan, the total percentage of developed land in the Lower Lafourche Parish study area projected to experience significant flooding (greater than 3 ft.) in a 100-year event is shown to climb from 11% to nearly 30% (Table 20). It is during this time during the model simulations that flooding encroaches into the developed land in Cutoff, Galliano, and Golden Meadow, with most of the additional flooding filling in the low-lying land along the levees and migrating up the natural levees of Bayou Lafourche (Figure 45). This is seen in the portion of Larose south of the GIWW. In almost every case, the greatest increase in the percentage of land flooded is in the low-intensity developed category, which often consists of parcels of low-lying land on the backslopes of the natural levees. Most of the high-intensity developed land that does not flood in the simulation is located atop the Bayou Lafourche levee, the location with the highest elevation in the study area. It is notable, however, that the flood surface in Golden Meadow, the southern-most community in the study area, is projected to spill over the levee and Bayou Lafourche, resulting in the greatest increase in of flooding in any of the case study communities during this time period.

Residential Population

While 30% of the total developed land in the study area is projected to flood under a 100-year storm event at Year 25, almost 48% of the total population experiences 3 ft. or more of flooding, signifying that much of the new flooding would occur on highly developed, residential land (Table 21). As seen in previous model results, most socially vulnerable population groups are no more likely to be found residing in the modeled flood zone than outside of it (Figure 46). Of the groups examined, single mother households are more likely to be impacted than not, along with Hispanic populations and renter-occupied households. With over 20percent of all households projected to flood being renter-occupied, these residents may be the most sensitive to coastal flooding. This hold true for model output under current conditions, Year 10, and Year 25.

Critical and Essential Facilities

From 10 to 25 years in the future, under the medium environmental change scenario, most of the critical facilities examined in Lower Lafourche Parish remain relatively free from extensive flooding in the model simulations (Table 22). Notably, none of the hospitals, outpatient care centers, physician offices, or ambulance services would be projected experience more than 3 ft. of flooding. Similarly, while Year 25 sees the continued inundation of the Port Fourchon Fire Department, the four northernmost fire stations in the study area remain free of significant flooding. However, with the projected flooding of the Lafourche Parish Police Department in Golden Meadow, both stations included in the analysis are shown to flood in the model output. However, both facilities are also elevated at or above the projected flood levels (Figure 47), which would allow them to more quickly recover and provide critical services to the surrounding communities as the flood waters recede.

It is also during this time frame that many facilities providing essential services to local residents may become impacted. Nearly 36% of the gas stations and over 13% of all government offices are projected to flood under a 100-year storm at Year 25. Most significant is flooding of the land surrounding the Golden Meadow Town Hall, which includes the office of the Mayor and the Chief of Police, as well as the

Clerk's Office and many other government functions. Governmental functioning is vital during the response and recovery periods of hazards events as governmental agencies are vital in the coordinating response efforts, providing public access to resources, maintenance of existing operational patterns and the incorporation of new ones (Kendra & Wachtendorf, 2003). The degree to which these functions can be restored are a key indicator of community resilience. In the Lower Lafourche Parish study area, many of governmental structures are elevated above the projected flood depths, including the Golden Meadow Town Hall (Figure 47), reducing their vulnerability and potentially accelerating the recovery period after a coastal flooding event. Other key essential facilities include those related to child care. Despite the projected impacts to several other essential facilities in the region, it is notable the flood simulations suggest that schools and day care centers are relatively well protected with only two schools projected to flood (out of 13 total in the study area) and no day care centers. In fact, across the study area, from the GIWW to the southern end of Galliano, critical and essential facilities are not projected to receive significant flooding from a 100-year storm event based on the results.

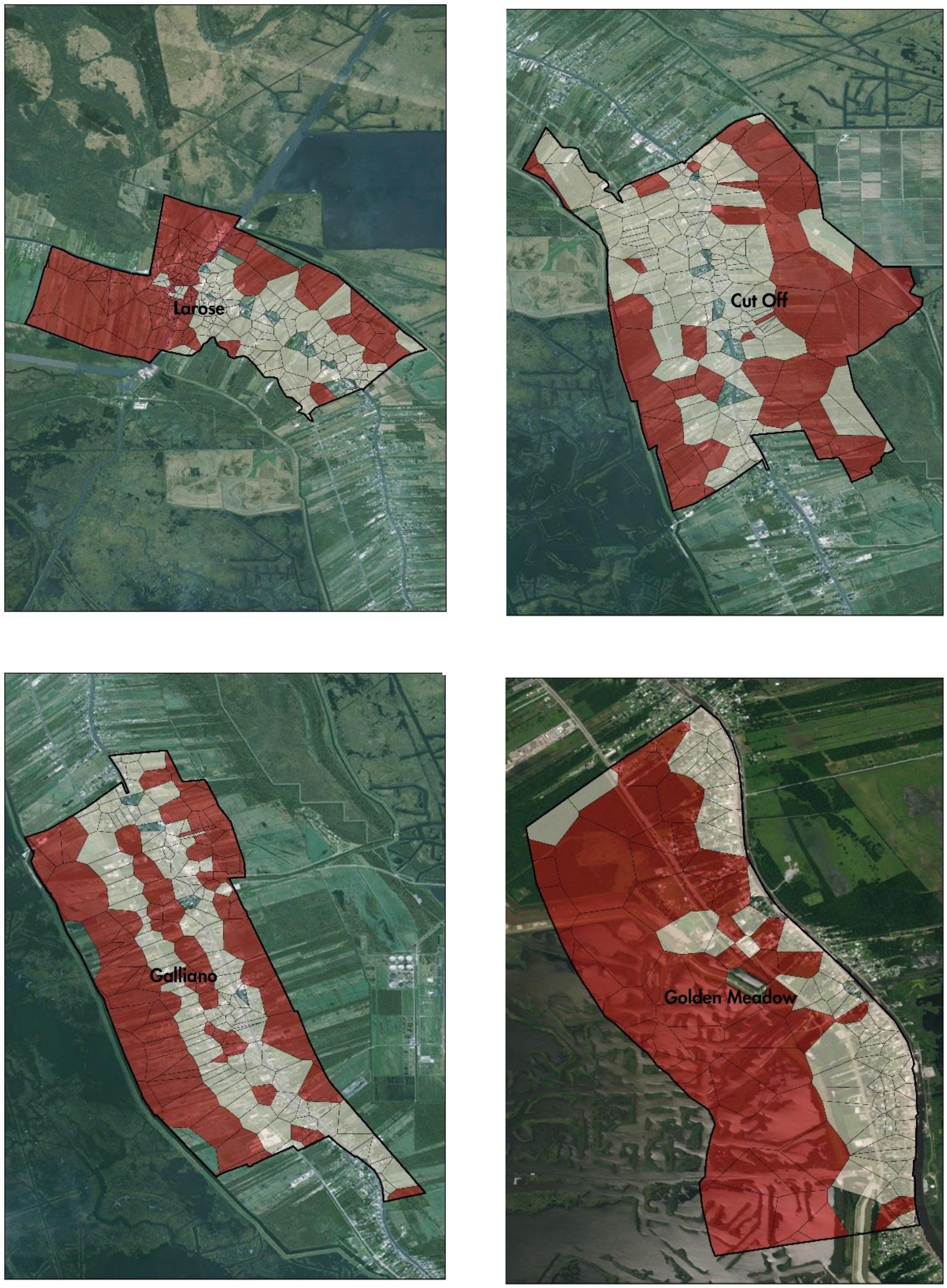

Figure 45. Projected flooding in Year 25 from a 100-Year Storm in Lower Lafourche Parish. Red cells indicated inundation at or above 3 ft.

Table 20. Exposure and Sensitivity of Developed Land to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 25.

Census Designated Place	Low-Intensity Developed			Medium-Intensity Developed			High-Intensity Developed			Total Developed		
	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%
Cut Off	120.3	999.4	12	12.9	103.2	12.5	1.6	26.7	5.8	134.8	1129.3	11.9
Galliano	327.8	1377.1	23.8	31.4	190.4	16.5	8.9	88.7	10	368.1	1656.2	22.2
Golden Meadow	163.9	421.4	38.9	17.1	67.2	25.5	4.2	18.5	22.9	185.3	507.1	36.5
Larose	674.3	1379.5	48.9	56.7	151.2	37.5	49.6	101.2	49	780.6	1631.9	47.8
TOTAL	1286.3	4177.5	30.8	118.1	512	23.1	64.3	235.1	27.3	1468.7	4924.5	29.8

Table 21. Exposure and Sensitivity of Socially Vulnerable Population Groups to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 25 (Medium Scenario).

Demographic Category	Coastal Flood Zone (Year 25)	Study Area Total	Flood Zone Percentage	Study Area Percentage	Sensitivity Rating
Total population	11,064	23,153	47.8%	n/a	n/a
Hispanic or Latino	861	1,740	7.8%	7.5%	1.04
Race - White	9,410	19,445	85.1%	84.0%	1.01
Race - Black or African American	223	632	2.0%	2.7%	0.74
Race - American Indian	513	1,133	4.6%	4.9%	0.95
Race - Asian	92	277	0.8%	1.2%	0.70
Population less than 5 years old	764	1,618	6.9%	7.0%	0.99
Population more than 65 years old	1,383	3,151	12.5%	13.6%	0.92
Total households	4,034	8,447	47.8%	n/a	n/a
Renter-occupied households	832	1,729	20.6%	20.5%	1.01
Single-mother-occupied households	332	662	8.2%	7.8%	1.05

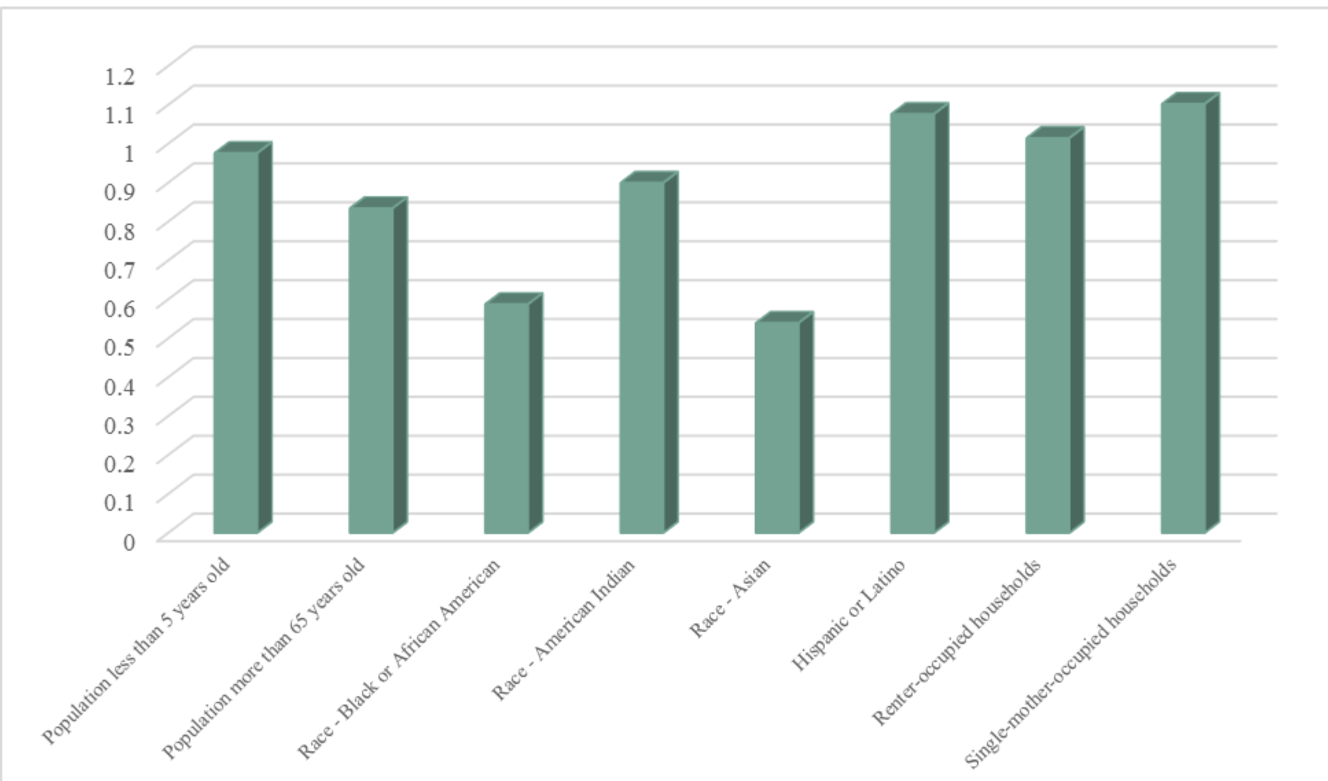

Figure 46. Odds of Exposure to Coastal Flood Events in Year 25 for Vulnerable Populations in Lower Lafourche Study Area (Medium Scenario – 100-Year Storm Event).

Table 22. Exposure and Sensitivity of Critical and Essential Facilities to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 25 (Medium Scenario).

Critical Facilities	Coastal Flood Zone (Year 25)	Study Area Total	Flood Zone Percentage
Ambulance Services	0	1	0.0%
Hospitals	0	1	0.0%
Outpatient Care Centers	0	16	0.0%
Physician Offices	0	4	0.0%
Civil Defense	1	1	100.0%
Fire Stations	1	5	20.0%
Police Stations	2	2	100.0%
Radio and TV Broadcasting	3	4	75.0%
Essential Facilities			
Banks and Credit Unions	2	18	11.1%
Gas Stations	5	14	35.7%
Government Facilities	11	30	36.7%
Retail Grocers	0	8	0.0%
Day Care Service	0	3	0.0%
Library	0	3	0.0%
School	2	11	18.2%

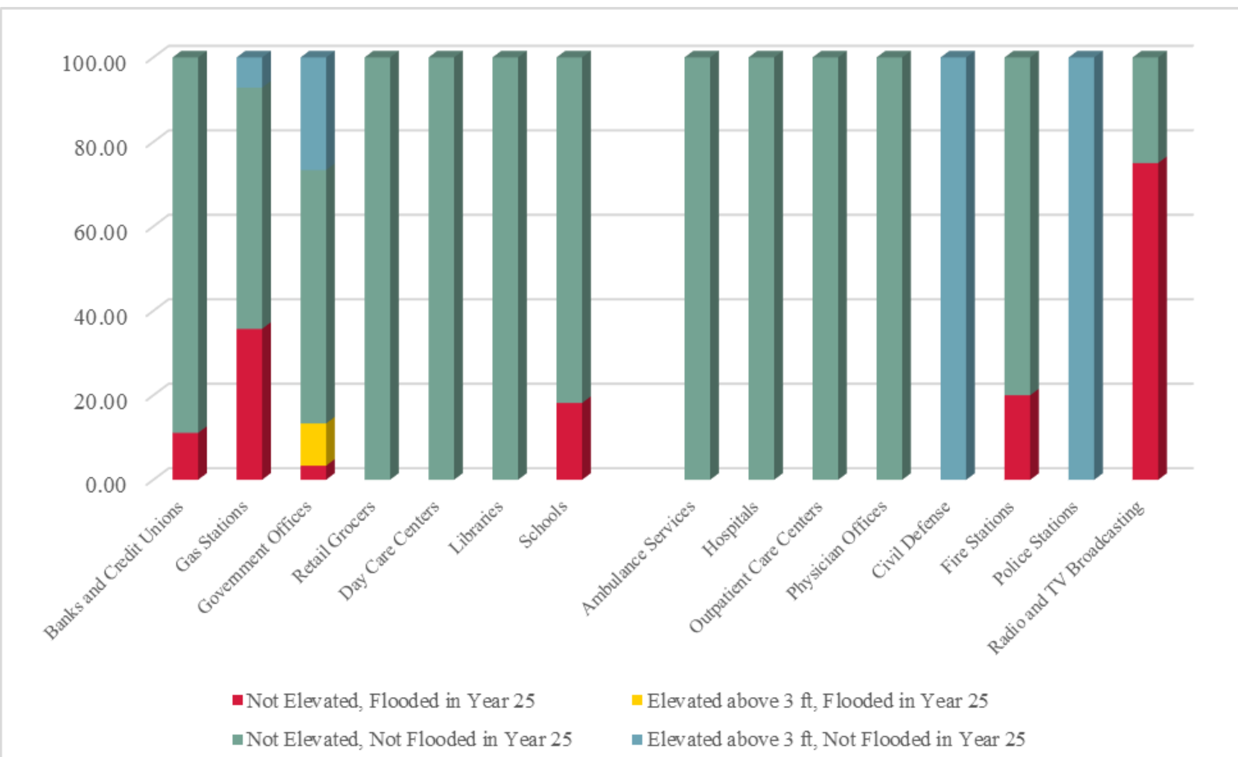

Figure 47. Elevation Dependent Sensitivity of Critical and Essential Facilities in Year 25 in Lower Lafourche Study Area (Medium Scenario – 100-Year Storm Event).

Year 50

Land Cover

From 25 to 50 years in the future, the areal extent of coastal flooding is projected to expand, particularly in the southern half of the study area. In Year 50, under the medium environmental change scenario modeled by the State of Louisiana for the 2017 Coastal Master Plan, almost the entirety of the Lafourche Parish study area is projected to experience flooding greater than 3 ft. if no action is taken (Figure 48). Model output shows 100% of Golden Meadow and Galliano, the two southernmost communities examined, developed land flooded by a 100-year storm (Table 23). Larose and Cut Off are also shown to have most of the developed land within their boundaries flooded, with both communities projected to be over 90% flooded. Even the high-intensity developed land in these communities, much of which is located on the elevated natural levee of Bayou Lafourche and within the Larose to Golden Meadow engineered levee system, are projected to be approximately 85% flooded.

Residential Population

Over 96% of the total developed land and 99% of the total population in the study area is shown to experience 3 ft. or more of flooding under a 100-year storm event at Year 50 (Table 24). This means that of the 23,153 persons residing in the study area, only 239 are not projected to flood. Similarly, of the 8,447 households in the study area, only 84 are not projected to flood. Given that almost the entire study area is shown to flood at Year 50, almost all residents, regardless of social vulnerability, are projected to flood. Notable, however is the fact that the African American (with 630 of 632 projected to flood) and Native American (with 1,126 of 1,133 projected to flood) populations are significantly more likely to reside in the flood zone than in any of the unflooded tracts of land (Figure 49). Similarly, single mother households (978 of 986 projected to flood) are more likely to be impacted than not.

Critical and Essential Facilities

From 25 to 50 years in the future, under a medium environmental change scenario, all of the critical facilities examined in Lower Lafourche Parish are shown to experience extensive flooding (Table 25). This includes all the hospitals, outpatient care centers, physician offices, and ambulance services, none of which are flooded in Year 25 model output. None of these medical facilities are elevated above anticipated flood levels (Figure 50). Significantly, however, both the emergency response operations center and the two police stations analyzed are located in the modeled flood zone, but each of these facilities are elevated above flood levels, even at 50 years in the future.

In contrast to the results seen in Year 25, 100% of the day care centers and all but two schools, which are collocated on the same property, are projected to flood in excess of 3 ft. in Year 50. In fact, of all the critical and essential facilities assessed in the study area, only these two schools and a single gas station and bank do not flood. It is important to note that the Golden Meadow City Hall complex is elevated above the modeled flood depth, potentially reducing facility damage and hastening the restoration of essential services to local residents. Nevertheless, given the extensive flooding of developed land in the study area and the almost complete flooding of residents, this region would likely have to rely heavily on outside assistance to provide critical and essential services, both during and in the aftermath of a 100-year storm event.

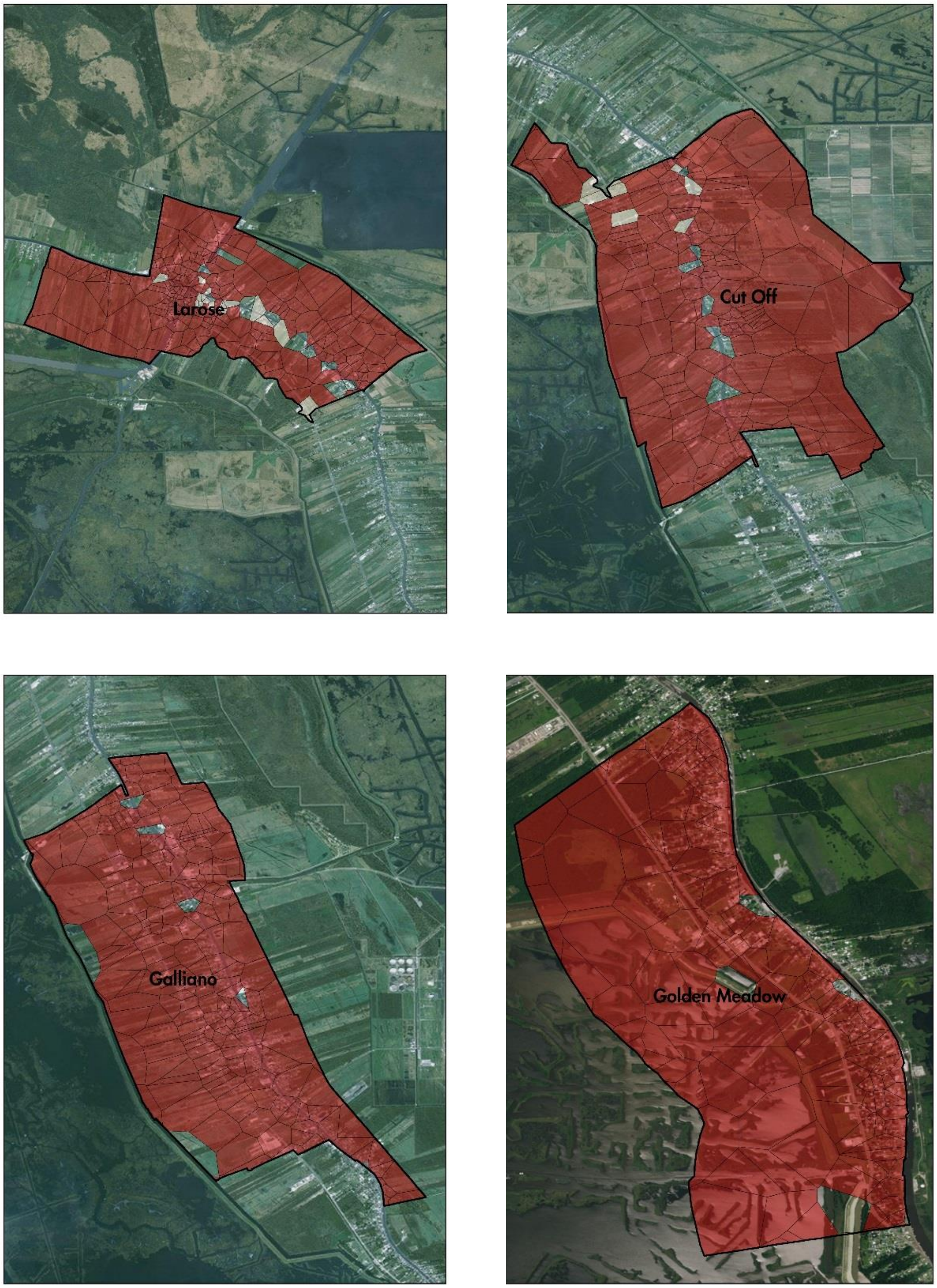

Figure 48. Projected flooding in Year 50 from a 100-Year Storm in Lower Lafourche Parish. Red cells indicated inundation at or above 3 ft.

Table 23. Exposure and Sensitivity of Developed Land to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 50.

Census Designated Place	Low-Intensity Developed			Medium-Intensity Developed			High-Intensity Developed			Total Developed		
	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%	Surge Zone, in acres	Total, in acres	%
Cut Off	972.3	999.4	97.3	94.1	103.2	91.2	22.5	26.7	84.2	1088.8	1129.3	96.4
Galliano	1377.1	1377.1	100	190.4	190.4	100	88.7	88.7	100	1656.2	1656.2	100
Golden Meadow	421.4	421.4	100	67.2	67.2	100	18.5	18.5	100	507.1	507.1	100
Larose	1280.5	1379.5	92.8	123.9	151.2	81.9	87.6	101.2	86.6	1492	1631.9	91.4
TOTAL	4051.4	4177.5	97	475.5	512	92.9	217.3	235.1	92.4	4744.1	4924.5	96.3

Table 24. Exposure and Sensitivity of Socially Vulnerable Population Groups to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 50 (Medium Scenario).

Demographic Category	Coastal Flood Zone (Year 50)	Study Area Total	Flood Zone Percentage	Study Area Percentage	Sensitivity Rating
Total population	22,914	23,153	99.0%	n/a	n/a
Hispanic or Latino	1,713	1,740	7.5%	7.5%	0.99
Race - White	19,260	19,445	84.1%	84.0%	1.00
Race - Black or African American	630	632	2.7%	2.7%	1.01
Race - American Indian	1,126	1,133	4.9%	4.9%	1.00
Race - Asian	253	277	1.1%	1.2%	0.92
Population less than 5 years old	1,597	1,618	7.0%	7.0%	1.00
Population more than 65 years old	3,114	3,151	13.6%	13.6%	1.00
Total households	8,363	8,447	99.0%	n/a	n/a
Renter-occupied households	1,708	1,729	20.4%	20.5%	1.00
Single-mother-occupied households	658	662	7.9%	7.8%	1.00

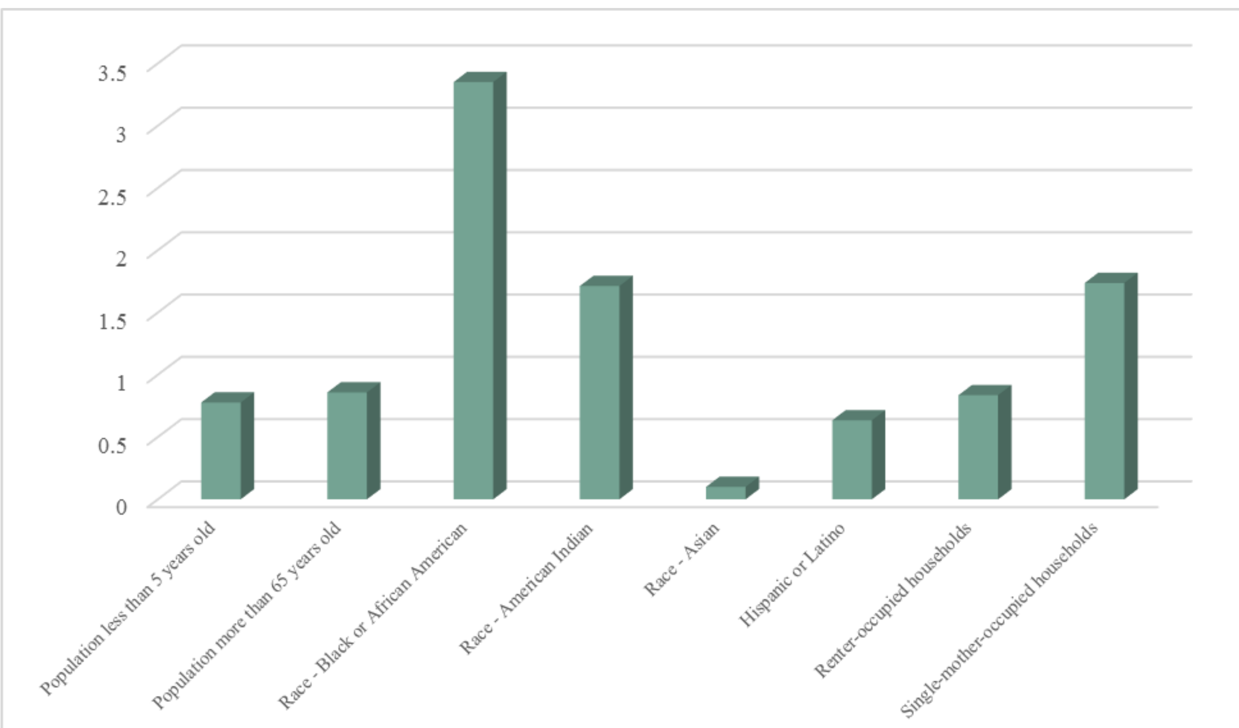

Figure 49. Odds of Exposure to Coastal Flood Events in Year 50 for Vulnerable Populations in Lower Lafourche Study Area (Medium Scenario – 100-Year Storm Event).

Table 25. Exposure and Sensitivity of Critical and Essential Facilities to Coastal Flooding from a 100-Year Storm in Lower Lafourche Parish in Year 50 (Medium Scenario).

Critical Facilities	Coastal Flood Zone (Year 50)	Study Area Total	Flood Zone Percentage
Ambulance Services	1	1	100.0%
Hospitals	1	1	100.0%
Outpatient Care Centers	16	16	100.0%
Physician Offices	4	4	100.0%
Civil Defense	1	1	100.0%
Fire Stations	5	5	100.0%
Police Stations	2	2	100.0%
Radio and TV Broadcasting	4	4	100.0%
Essential Facilities			
Banks and Credit Unions	17	18	94.4%
Gas Stations	13	14	92.9%
Government Facilities	30	30	100.0%
Retail Grocers	8	8	100.0%
Day Care Service	3	3	100.0%
Library	3	3	100.0%
School	9	11	81.8%

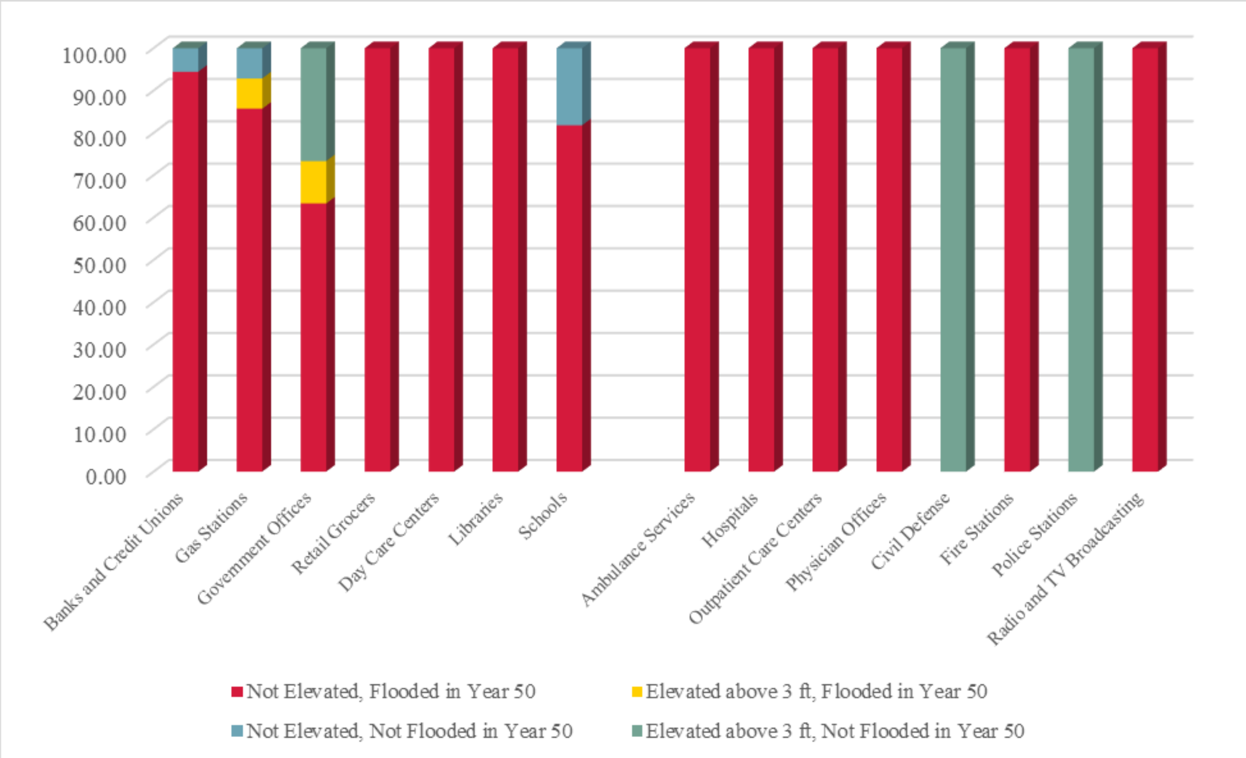

Figure 50. Elevation Dependent Sensitivity of Critical and Essential Facilities in Year 50 in Lower Lafourche Study Area (Medium Scenario – 100-Year Storm Event).

Conclusion

This research was conducted using output from the CLARA model as done for the 2017 Coastal Master Plan and elevation estimates of existing critical and essential facilities. This report compares community vulnerability to coastal flood hazards in two regions of the Louisiana coast (X and Y areas and parishes) and assesses community exposure and sensitivity, based on various socioeconomic attributes, to these hazards under future environmental change scenarios. Exposure and sensitivity comparisons provide a first-order approximation of societal vulnerability to flood hazards (Wood & Soulard, 2008).

Results show that some communities in the two study areas are primarily vulnerable to coastal flooding due to a high number of assets in flood-prone areas. In both study areas, our work suggests there is relatively low risk levels of critical and essential facilities to coastal flooding from a 100-year storm event under current conditions. However, under future conditions, levels of risk increase for developed land, vulnerable populations, and critical and essential facilities. For example, assuming that current population trends continue, in East St. Mary Parish at Year 50, the elderly population would have one of the highest levels of exposure among the vulnerable population groups assessed, while physician's offices are projected to have the highest level of exposure of all critical facilities examined. Given the special vulnerabilities of the elderly population related to potential health conditions, this combination of exposures represents an enhanced community vulnerability.

In other communities, relative vulnerability is primarily due to a community's high sensitivity to coastal flood hazards – a low asset count in flood-prone areas that represent a high percentage of the community's total assets. This is most certainly the case for a number of critical facilities in Lower Lafourche Parish. For example, there is a single emergency operations center located in the study area, and this facility is located in an area that is projected to experience more than 3 ft. of flooding from a 100-year storm event under current conditions. While the facility itself is elevated and may not experience direct flood damage, it would be essentially disconnected from the surrounding communities. Similarly, of the two police stations examined in this same study area, one, the Port Fourchon Harbor Police, is located in the modeled 100-year flood zone. As this facility is only one of two in the study area, police stations represent a high sensitivity critical facility.

Overall, based on a geospatial analysis of the distribution of developed land, socially vulnerable populations, and critical and essential facilities in these two regions, the following conclusions can be made:

1. Under current conditions, the two study areas, both of which are almost entirely within existing flood protection and river levees, are not projected to experience a large amount of significant (i.e. greater than 3 ft.) flooding from a 100-year storm event. Almost 97% of the flood zone in East St. Mary Parish (Table 26) and just over 93% of the flooded land in Lower Lafourche Parish (Table 28) is classified as undeveloped, indicating that the flood zone contains relatively few people, structures, and other development. Over the next 25 years, however, the level of flood exposure in the two study areas is increased, and differs significantly, under a moderate environmental change scenario. The percentage of developed land projected to flood in East St. Mary Parish increases at a relatively slow rate, with an overall increase of less than 2%. In Lower Lafourche Parish, the percent of land projected to flood climbs much more dramatically, with

11% of developed land projected to flood in the next decade and almost 30% at Year 25. In both study areas, the greatest flood risk occurs over the time period from 25 to 50 years in the future. Almost 33% of all developed land in East St. Mary Parish and over 96% of all developed land in Lower Lafourche Parish is projected to experience 3 ft. or more of coastal flooding from a 100-year storm event at Year 50, as modeled using a moderate environmental change scenario.

2. Both study areas have a percentage of residents above the age of 65 significantly higher than the state average of 6.3%. This is a population that may have difficulty evacuating due to potential limitations in mobility and health conditions. Under current conditions, only one tenth of one percent of the population of the East St. Mary Parish study area would be projected to flood. Results indicate that 10% of this total would be over the age of 65 (Table 26; Figure 51). Far more residents would be projected to flood under these same conditions in the Lower Lafourche Parish study area, approximately 6.8% of the total population. Of these residents, 12.3% would be over the age of 65 (Table 28; Figure 54).
3. The overall racial diversity of both study areas is lower than that of the State of Louisiana, particularly in Lower Lafourche Parish, where 84% of the residents identify themselves as white (Table 28; Figure 51) However, 4.9% of the residents identify themselves as Native American and 7.5 % of residents are of Hispanic descent (Table 26; Figure 51). The same holds true for East St. Mary Parish, which is home to a higher than average Asian (2.6%), Native American (1.1%), and Hispanic (8%) population. In both study areas, targeted risk reduction strategies that reflect potential cultural differences and language barriers may be needed (Wood & Soulard, 2008).
4. Under current conditions, no single minority group is more sensitive to coastal flooding under a 100-year storm scenario in East St. Mary Parish (Figure 51), while just the Asian population in Lower Lafourche Parish is sensitive to such a storm event (Figure 54). This same social vulnerability pattern is seen when the effects of coastal flooding is examined 10 years in the future. Under a moderate environmental change scenario, significant changes in social vulnerability are not observed until 25 years in the future. The Asian population in East St. Mary Parish becomes increasingly more sensitive by this point. By Year 50, both the Asian and Hispanic populations of East St. Mary Parish are projected to be more sensitive to the effects of coastal storms. In Lower Lafourche Parish, as the risk surface expands into low- and medium-intensity developed land, the social vulnerability surface shifts as well, with the Hispanic population becoming much more sensitive to coastal flooding in Year 25. Within 50 years, as over 96% of the developed land in Lower Lafourche Parish is projected to experience 3 ft. or more of flooding during a 100-year storm event, no single population groups has a significantly high sensitivity, although both the Native American and African American populations are more likely to reside in the flood zone than outside of it.
5. Under current conditions, the critical and essential facilities in both study areas are very well protected from coastal flood hazards. In East St. Mary Parish, only two civil works facilities located adjacent to major waterways are projected to flood under current conditions and up to 25 years in the future (Table 27; Figure 52). In Lower Lafourche Parish, different patterns of facility vulnerability are seen, with several facilities located in the modeled flood zone under current conditions (Table 29; Figure 55). These numbers gradually climb over the next 25 years of the simulation. However, contrary to East St. Mary Parish, many of these facilities, including local

government offices, police stations, and the study area's only emergency response operations center, are elevated above the modeled flood depths. While these facilities may be inaccessible during storm events due to the flooding of the land they are sited on, once flood waters subside, they will be able to come back online quickly. From 25 to 50 years in the future, under a moderate environmental change scenario, both study areas experience a significant jump in the number of critical and essential facilities projected to flood during a 100-year storm event. In East St. Mary Parish, the overall exposure levels are less than 50% across most facility categories, with the exception of physician offices and outpatient care centers. The sensitivity of these facilities, despite the fact that the one regional hospital is not projected to flood, suggests that access to primary medical care will represent a significant social vulnerability in the future. In Lower Lafourche Parish, the impacts of a 100-year storm event are much more dramatic in Year 50, with nearly 100% of all critical and essential facilities experiencing flooding. However, several key facilities are elevated above projected flood levels including the emergency response operations center, both of the police stations that serve the region, and all of the government offices located within the Golden Meadow City Hall complex (Figure 56). Again, while each of these facilities may be inaccessible during coastal flood events, once the flood waters subside, these facilities should be able to quickly recover and provide critical and essential services to community residents.

The results presented in this report represent the potential current and future impacts of a single type of coastal hazard, storm surge driven by tropical weather events, in two coastal Louisiana communities. The information presented can be used to assist coastal and emergency managers in their efforts to identify where additional preparedness, mitigation, recovery, planning, and outreach activities may be needed within the impacted coastal communities and to develop adaptation timelines based upon future environmental change scenarios (Wood & Soulard, 2008). It is important to note that the results of this research showing reduced vulnerability to storm surge and coastal flooding in certain locations does not mean that the region is safe from either riverine flooding or flooding caused by extreme rainfall events. As recently as 2011, for example, Mississippi River floodwaters were diverted into the Atchafalaya River causing businesses located on the river front in both Morgan City and Berwick to flood. While these communities may not be particularly vulnerable to coastal storm surge, they are vulnerable to direct and backwater flooding from the Atchafalaya. For this reason, these results should be interpreted with caution and viewed within the broader biogeophysical setting. With this caveat in mind, the results of this study can be utilized as an analytical tool for managers, policymakers, and private citizens to help determine where to allocate limited risk-reduction resources and attention – to the communities with high loss potentials, to communities that may be incapable of adapting to the loss of significant percentages of their assets, or to a specific demographic sector (Wood, 2007). Providing a longer view into the future will allow preparations and funding to be prioritized not just based on the most recent flood, but also for the floods to come.

Table 26. Socially Vulnerable Populations Inundated (>3 ft.) in East St. Mary Parish, Louisiana (Medium Scenario – 100-Year Storm).

Vulnerable Population	Flooded under Current Conditions	Flooded in Year 10	Flooded in Year 25	Flooded in Year 50
Total developed land	3.48	4.17	5.29	32.73
Total population	0.06	0.08	1.15	19.02
Hispanic or Latino	0.00	0.00	2.35	37.16
Race - White	0.09	0.12	1.07	18.90
Race - Black or African American	0.01	0.01	0.18	11.17
Race - American Indian	0.00	0.00	1.71	20.23
Race - Asian	0.00	0.00	8.86	55.06
Population less than 5 years old	0.00	0.00	1.30	17.28
Population more than 65 years old	0.05	0.08	0.90	22.18
Total households	0.08	0.10	1.02	18.58
Renter-occupied households	0.05	0.10	0.86	17.05
Single-mother-occupied households	0.00	0.00	0.97	13.55

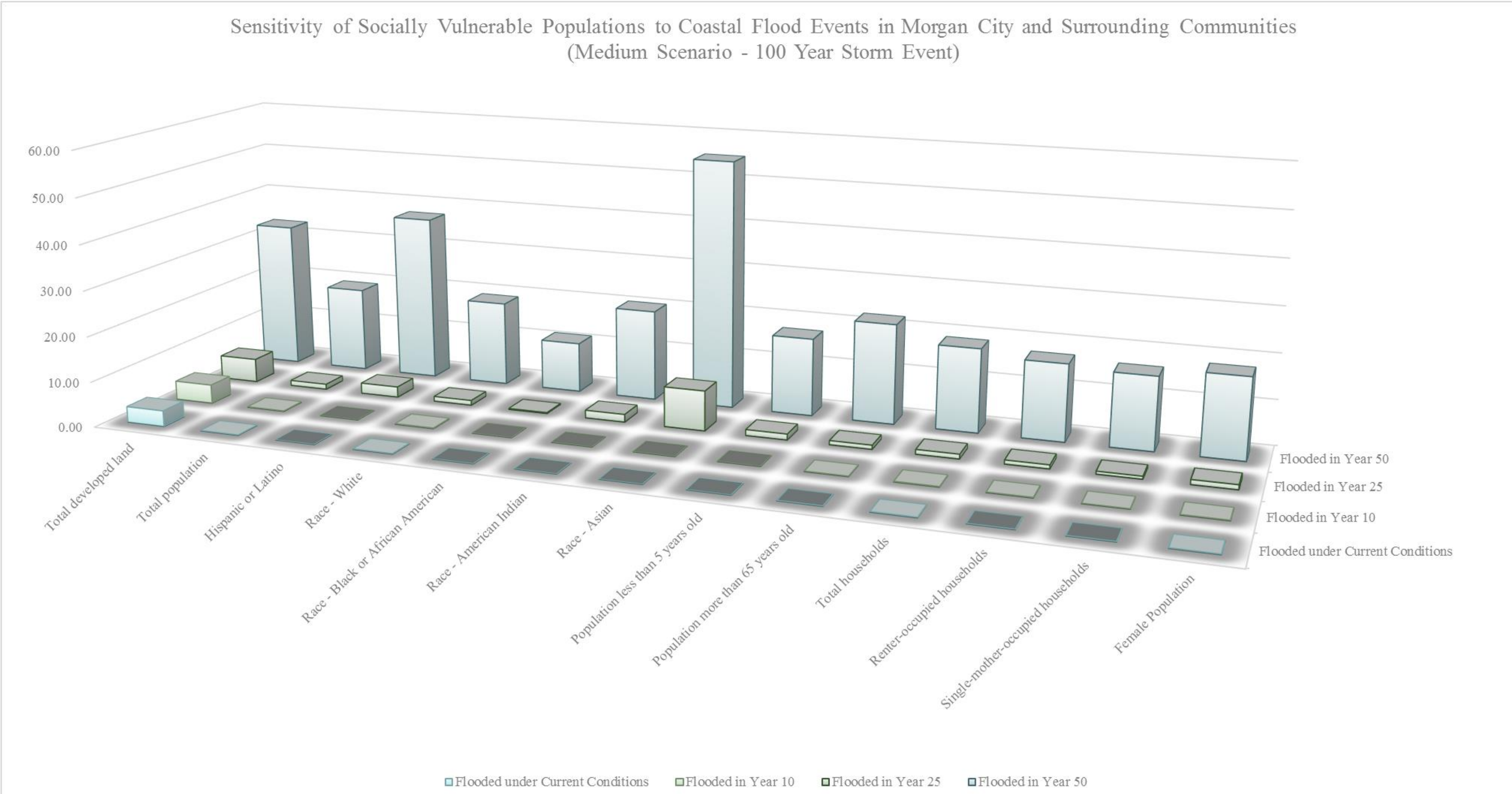

Figure 51. Sensitivity of Socially Vulnerable Populations to Storm Surge in East St. Mary Parish, Louisiana (Medium Scenario – 100-Year Storm).

Table 27. Percent of Critical and Essential Facilities Inundated (>3 ft.) in East St. Mary Parish, Louisiana (Medium Scenario – 100-Year Storm).

Facilities	Flooded under Current Conditions	Flooded in Year 10	Flooded in Year 25	Flooded in Year 50
Critical Facilities				
Hospitals	0.00	0.00	0.00	0.00
Outpatient Care Centers	0.00	0.00	0.00	50.00
Physician Offices	0.00	0.00	0.00	60.00
Fire Stations	0.00	0.00	0.00	25.00
Police Stations	0.00	0.00	0.00	40.00
Electric Companies	0.00	0.00	0.00	66.67
Gas Companies	0.00	0.00	0.00	0.00
Radio and TV Broadcasting	0.00	0.00	0.00	40.00
Water and Sewage Companies	0.00	0.00	0.00	33.33
Essential Facilities				
Banks and Credit Unions	0.00	0.00	0.00	42.86
Gas Stations	0.00	0.00	0.00	25.00
Government Offices	4.08	4.08	4.08	14.29
Retail Grocers	0.00	0.00	0.00	22.22
Day Care Services	0.00	0.00	0.00	16.67
Libraries	0.00	0.00	0.00	25.00
Schools	0.00	0.00	0.00	40.00

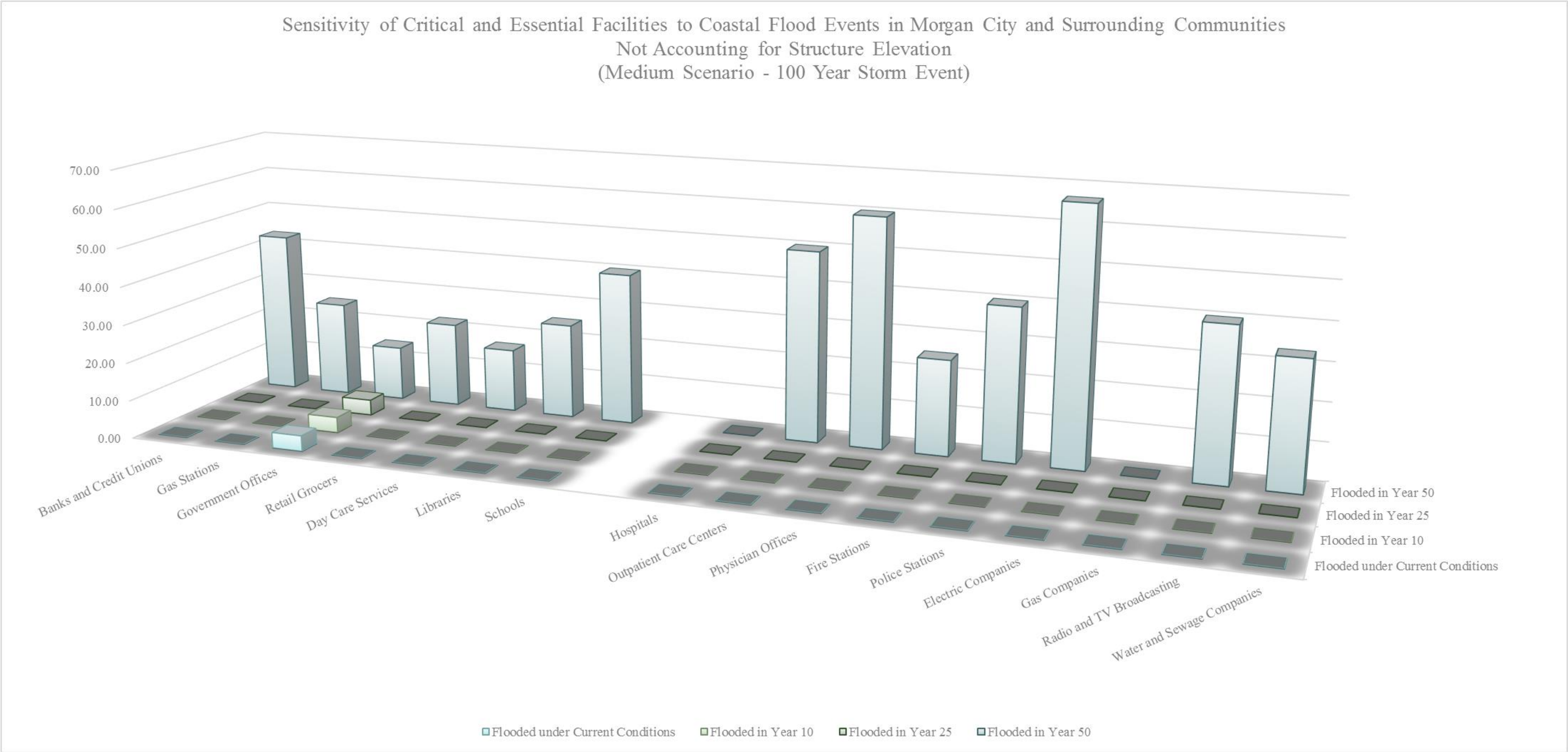

Figure 52. Sensitivity of Critical and Essential Facilities to Storm Surge in East St. Mary Parish, Louisiana (Medium Scenario–100-Year Storm).

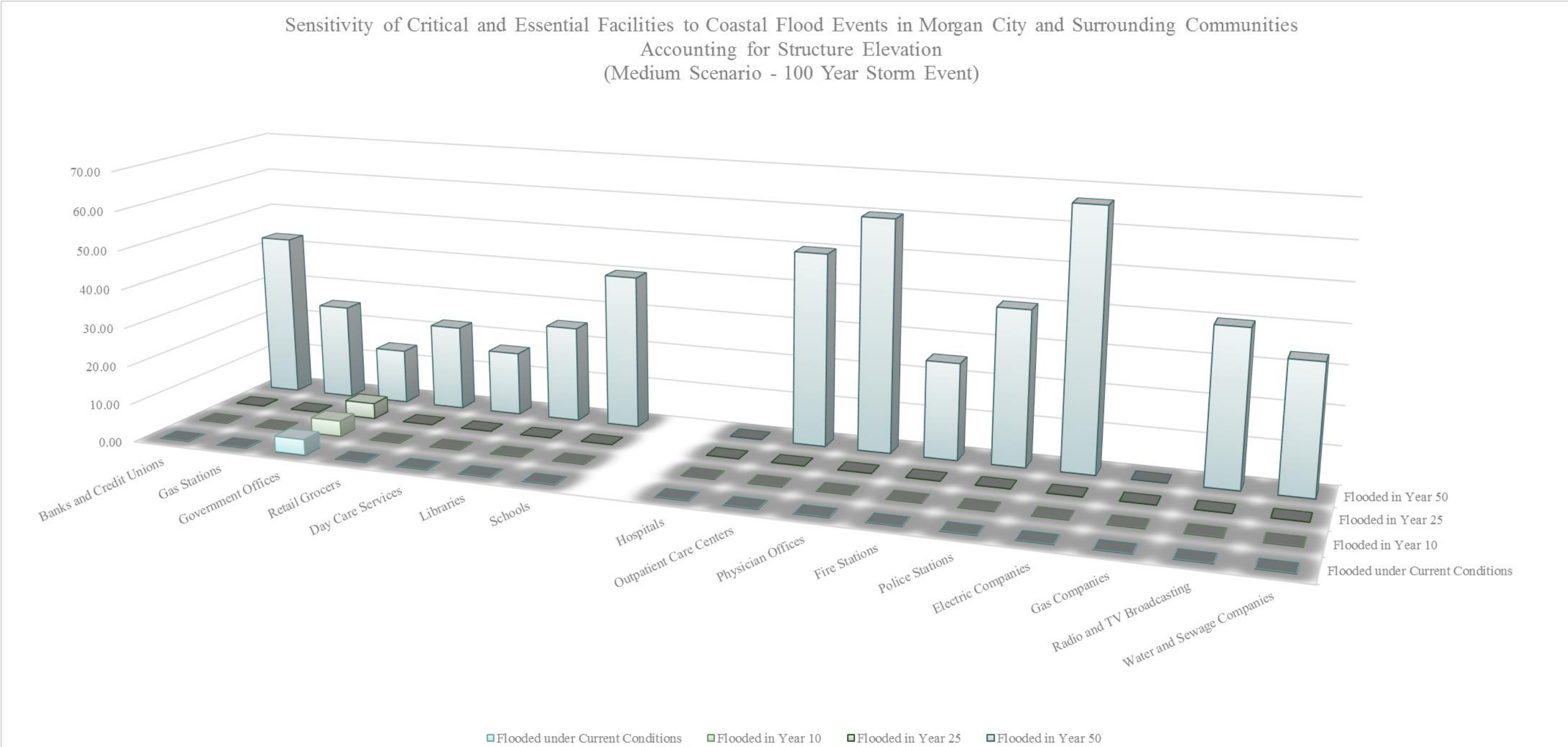

Figure 53. Sensitivity of Critical and Essential Facilities to Storm Surge in East St. Mary Parish, Louisiana, Accounting for Structure Elevation (Medium Scenario–100-Year Storm).

Table 28. Socially Vulnerable Populations Inundated (>3 ft.) in Lower Lafourche Parish, Louisiana (Medium Scenario – 100-Year Storm).

Vulnerable Population	Flooded under Current Conditions	Flooded in Year 10	Flooded in Year 25	Flooded in Year 50
Total developed land	6.86	10.98	29.82	96.34
Total population	6.80	9.55	47.79	98.97
Hispanic or Latino	5.86	8.97	49.48	98.45
Race - White	7.15	10.08	48.39	99.05
Race - Black or African American	1.74	1.90	35.28	99.68
Race - American Indian	6.35	7.86	45.28	99.38
Race - Asian	7.94	10.47	33.21	91.34
Population less than 5 years old	6.55	8.59	47.22	98.70
Population more than 65 years old	6.13	8.60	43.89	98.83
Total households	6.69	9.35	47.76	99.01
Renter-occupied households	4.22	5.84	48.12	98.79
Single-mother-occupied households	5.22	5.97	53.73	100.00

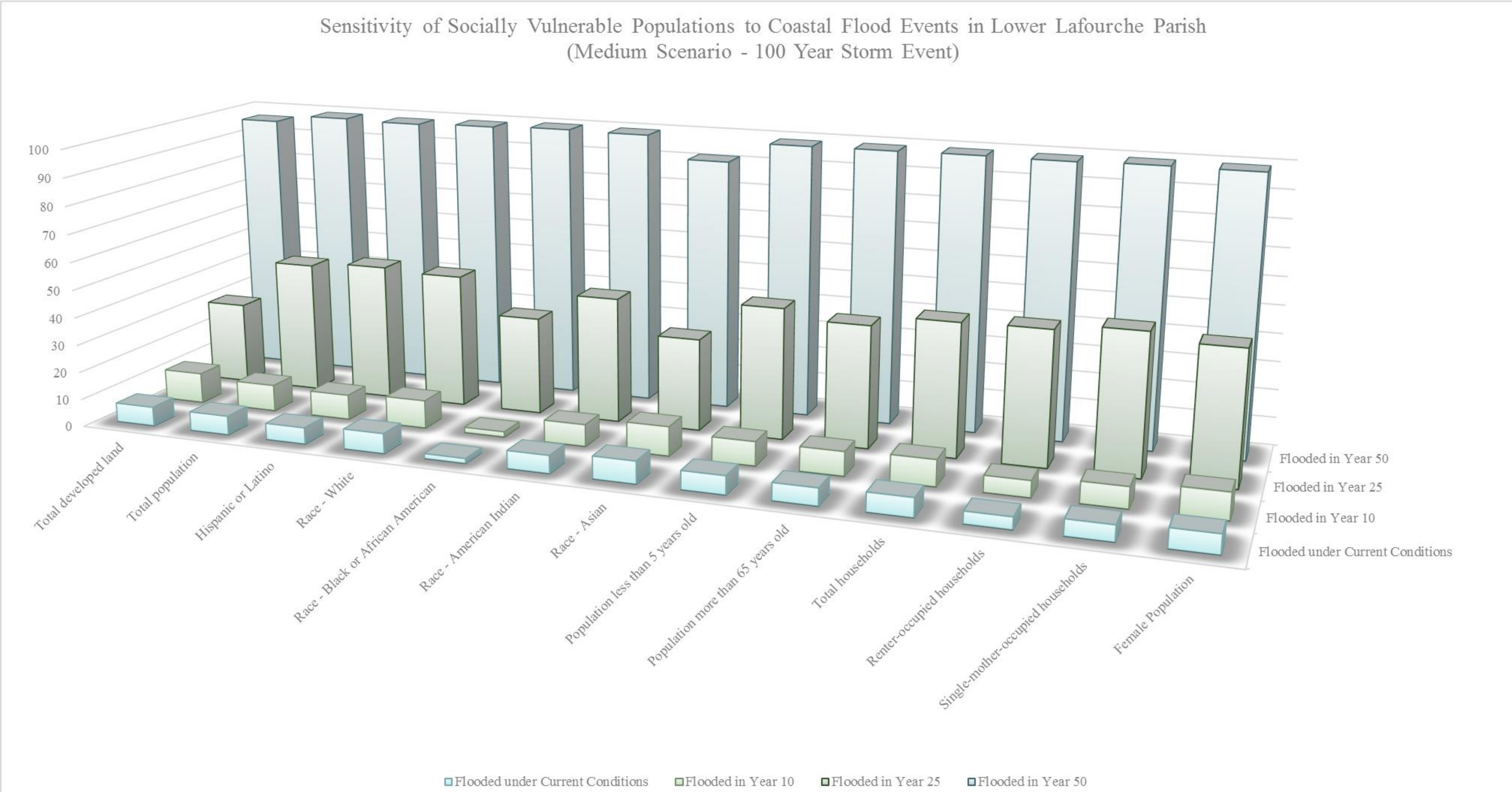

Figure 54. Sensitivity of Socially Vulnerable Populations to Storm Surge in Lower Lafourche Parish, Louisiana (Medium Scenario – 100-Year Storm).

Table 29. Percent of Critical and Essential Facilities Inundated (>3 ft.) in Lower Lafourche Parish, Louisiana (Medium Scenario – 100-Year Storm).

Facilities	Flooded under Current Conditions	Flooded in Year 10	Flooded in Year 25	Flooded in Year 50
Critical Facilities				
Ambulance Services	0.00	0.00	0.00	100.00
Hospitals	0.00	0.00	0.00	100.00
Outpatient Care Centers	0.00	0.00	0.00	100.00
Physician Offices	0.00	0.00	0.00	100.00
Civil Defense	100.00	100.00	100.00	100.00
Fire Stations	20.00	20.00	20.00	100.00
Police Stations	50.00	50.00	100.00	100.00
Radio and TV Broadcasting	0.00	75.00	75.00	100.00
Essential Facilities				
Banks and Credit Unions	0.00	0.00	11.11	94.44
Gas Stations	21.43	21.43	42.86	92.86
Government Offices	13.33	16.67	36.67	100.00
Retail Grocers	0.00	0.00	0.00	100.00
Day Care Centers	0.00	0.00	0.00	100.00
Libraries	0.00	0.00	0.00	100.00
Schools	0.00	0.00	18.18	81.82

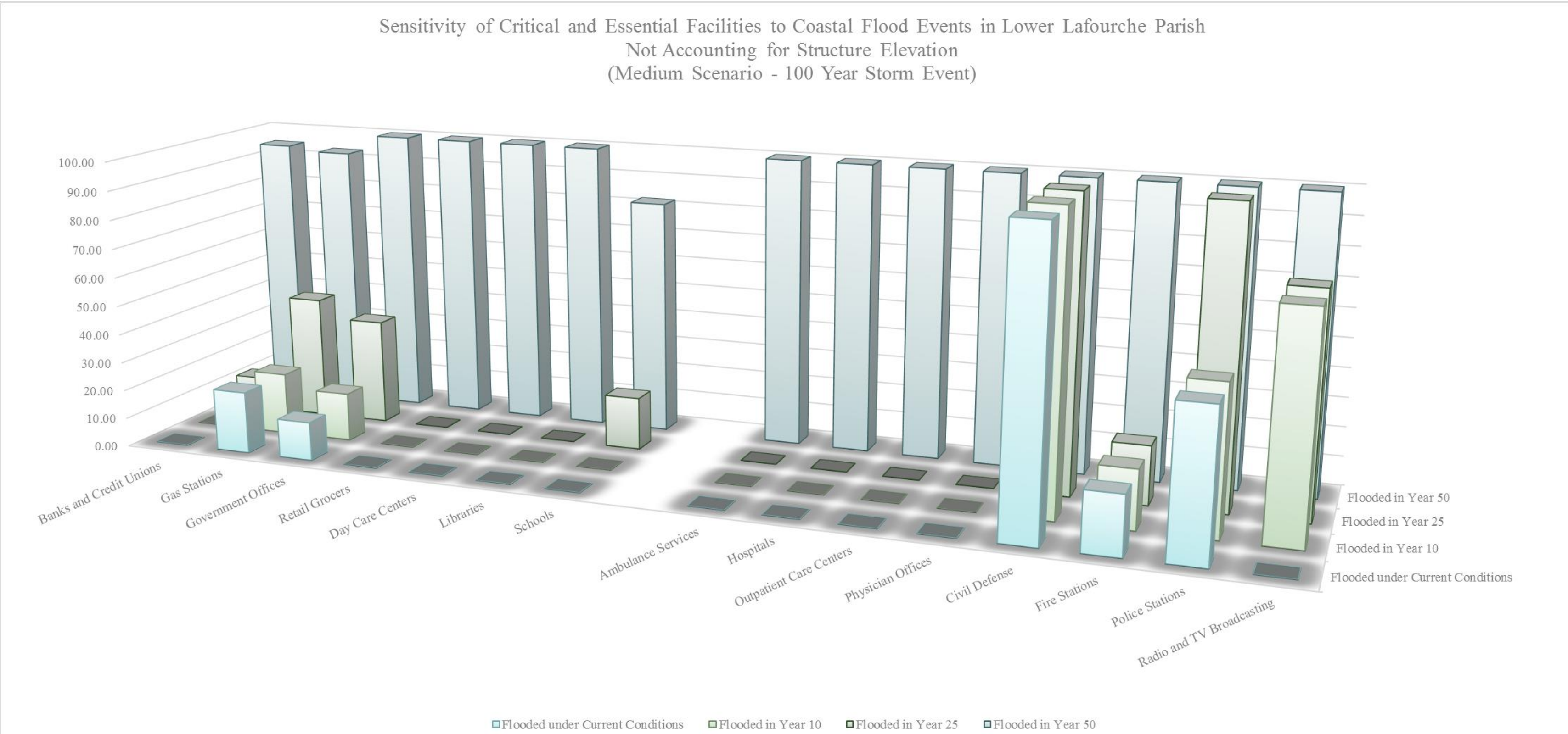

Figure 55. Sensitivity of Critical and Essential Facilities to Storm Surge in Lower Lafourche Parish, Louisiana (Medium Scenario–100-Year Storm).

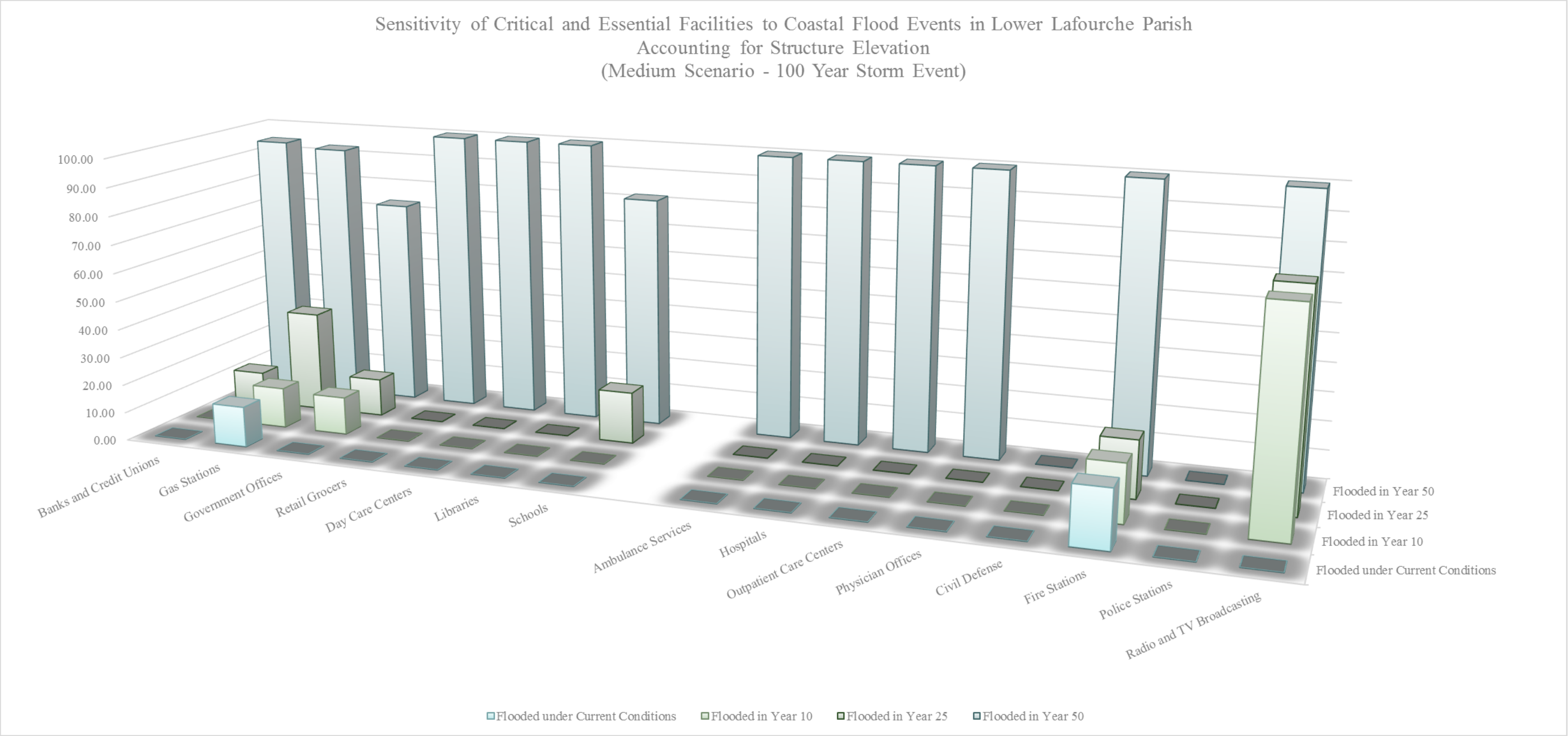

Figure 56. Sensitivity of Critical and Essential Facilities to Storm Surge in Lower Lafourche Parish, Louisiana, Accounting for Structure Elevation (Medium Scenario–100-Year Storm).

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