US Army Corps of Engineers®

CHARLESTON PENINSULA, SOUTH CAROLINA, COASTAL STORM RISK MANAGEMENT STUDY

Charleston, South Carolina

Economics: Appendix-C

February 2022

INTRODUCTION

This economic appendix documents the analysis of flood risk reduction for the national economic development (NED) and regional economic development (RED) undertaken for the Charleston Peninsula, Coastal Storm Risk Management Study. Section I documents the flood risk reduction analysis, and Section II discusses the RED impact for the project alternative.

C.1. SECTION I: FLOOD RISK REDUCTION

The Federal objective of water and related land resources project planning is to contribute to NED. Contributions to NED, expressed in monetary units, are the direct net benefits that accrue in the planning area and the rest of the Nation. Benefits from plans for reducing flood hazards accrue primarily through the reduction in actual or potential damages to affected land uses are NED. Inundation reduction benefits are the increases in net income generated by the affected land uses.

C.1.1. *STUDY AUTHORITY*

The authority to study all of coastal South Carolina, including the Charleston Peninsula, was provided in Section 110 of the Rivers and Harbors Act of 1962, P.L. 87- 874, Section 110, and Senate Committee Resolution. Section 110 reads:

> *The Secretary of the Army is hereby authorized and directed to cause surveys to be made at the following named localities and subject to all applicable provisions of section 110 of the River and Harbor Act of 1950:*
>
> *Surveys of the coastal areas of the United States and its possessions, including the shores of the Great Lakes, in the interest of beach erosion control, hurricane protection and related purposes: Provided, That surveys of particular areas shall be authorized by appropriate resolutions of either the Committee on Public Works of the United States Senate or the Committee on Public Works of the House of Representatives.*

On 22 April 1988, a Senate Committee Resolution authorized the Secretary of the Army to study the entire coast of South Carolina pursuant to Section 110:

> "*Resolved by the Committee on Environment and Public Works of the United States Senate, that the Secretary of the Army in accordance with the provisions of Section 110 of the River and Harbor Act of 1962, is hereby authorized to study, in cooperation with the State of South Carolina, its political subdivisions and agencies and instrumentalities thereof, the entire Coast of South Carolina in the interests of beach erosion control, hurricane protection and related purposes. Included in this study will be the development*

of a comprehensive body of knowledge, information, and data on coastal area changes and processes for such entire coast."

Authority to conduct this study may also be found in Public Law 84-71 (69 Stat. 132), which authorized:

an examination and survey to be made of the eastern and southern seaboard of the United States with respect to hurricanes, with particular reference to areas where severe damages have occurred [to include] possible means of preventing loss of human lives and damages to property, with due consideration of the economics of proposed breakwaters, seawalls, dikes, dams, and other structures, warning services, or other measures which might be required.

The Bipartisan Budget Act of 2018 (Public Law 115-123), Division B, Subdivision 1, Title IV (BBA 2018), appropriates funding for the study at full Federal expense. As identified under this "Supplemental Appropriation" bill, the study is subject to additional reporting requirements and is expected to be completed within three years and for $3 million dollars:

FLOOD CONTROL AND COASTAL EMERGENCIES For an additional amount for ''Flood Control and Coastal Emergencies'', as authorized by section 5 of the Act of August 18, 1941 (33 U.S.C. 701n), for necessary expenses to prepare for flood, hurricane and other natural disasters and support emergency operations, repairs, and other activities in response to such disasters, as authorized by law, $810,000,000, to remain available until expended: Provided, That funding utilized for authorized shore protection projects shall restore such projects to the full project profile at full Federal expense: Provided further, That such amount is designated by the Congress as being for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985: Provided further, That the Assistant Secretary of the Army for Civil Works shall provide a monthly report to the Committees on Appropriations of the House of Representatives and the Senate detailing the allocation and obligation of these funds, beginning not later than 60 days after the enactment of this subdivision.

C.1.2. *PURPOSE*

The intent of the Charleston Peninsula Coastal Storm Risk Management Study is to investigate and recommend potential structural and nonstructural solution sets to reduce risk to human life, critical facilities and infrastructure, and reduce risk of economic damages from coastal storm surge inundation. As a low-lying peninsula in a tidal estuary, the Charleston Peninsula, South Carolina is highly vulnerable to coastal storms, a vulnerability which will be further exacerbated by a combination of sea level rise and climate change over the period of analysis. Without a plan to address the risks posed by coastal storm surge inundation, the peninsula's vulnerability to coastal storm surge is expected to increase unabated over time.

The focus of this study is flooding due to storm surge inundation. According to the National Oceanic and Atmospheric Administration (NOAA), storm surge is produced by water being pushed toward the shore by the force of the winds moving cyclonically around a storm. The storm may be a hurricane, tropical storm, tropical depression, or nor'easter that approaches and passes the Charleston vicinity or moves on shore at or near the Charleston Peninsula. While the Charleston Peninsula also experiences flooding from tides and rainfall unrelated to coastal storm surge events, the authority for this study does not include the investigation of measures to address these aspects of flood risk management. However, the analysis of coastal storm surge inundation takes into account tidal fluctuations, sea level rise, and rainfall-induced flooding. Mitigation for adverse impacts to stormwater runoff have been investigated and addressed as appropriate per ER 1105-2-100, Section 3-3.b.(5).

This document explains what is known about the study area, existing condition flood damages, expected future condition flood damages in the absence of flood risk management measures, and development and evaluation of alternative plans to address flooding related to coastal storm events on the Charleston Peninsula. It then documents the procedures used to analyze various measures designed to reduce the risk of flood damages, incorporating National Economic Development (NED) guidelines, and culminates in identification of a Recommended Plan.

C.1.3. *STUDY AREA*

The Charleston Peninsula is approximately 8 square miles, located between the Ashley and Cooper Rivers (see Figure 1). The two rivers join off the southern end of the peninsula to form the Charleston Harbor before discharging into the Atlantic Ocean. The Charleston Harbor is a natural tidal estuary sheltered by barrier islands. The Charleston Peninsula is the historic core and urban center of the City of Charleston.

The first European settlers arrived in Charleston around 1670. Since that time, the peninsula city has undergone dramatic shoreline changes, predominantly by landfilling of the intertidal zone. Early maps show that over one-third of the present-day peninsula has been "reclaimed." Much of the landfilling occurred on the southern and western side of the peninsula. Figure 2 below depicts the Charleston shoreline in 1849 after construction of a bulkhead seawall and promenade, known as the High (East) Battery. Figure 3 depicts the Charleston shoreline today overlaid on the shoreline in 1849.

Charleston played an important role in Colonial, Revolutionary, Antebellum, and Civil War America. The southern portion of the peninsula is home to a great concentration of 18th and 19th century buildings that have been designated a National Historic Landmark District. Presently, Charleston is a popular tourist destination. The peninsula has a considerable number of hotels, restaurants, and shops in addition to residential neighborhoods. The peninsula is also home to the downtown medical district, multiple colleges, ports, and a US Coast Guard Station.

For the purposes of the economic appendix, the “Study Area” is defined as the Charleston Peninsula boundary area and inclusive of those assets (e.g. structures) located only in the Charleston Peninsula (reference Figure 1 below).

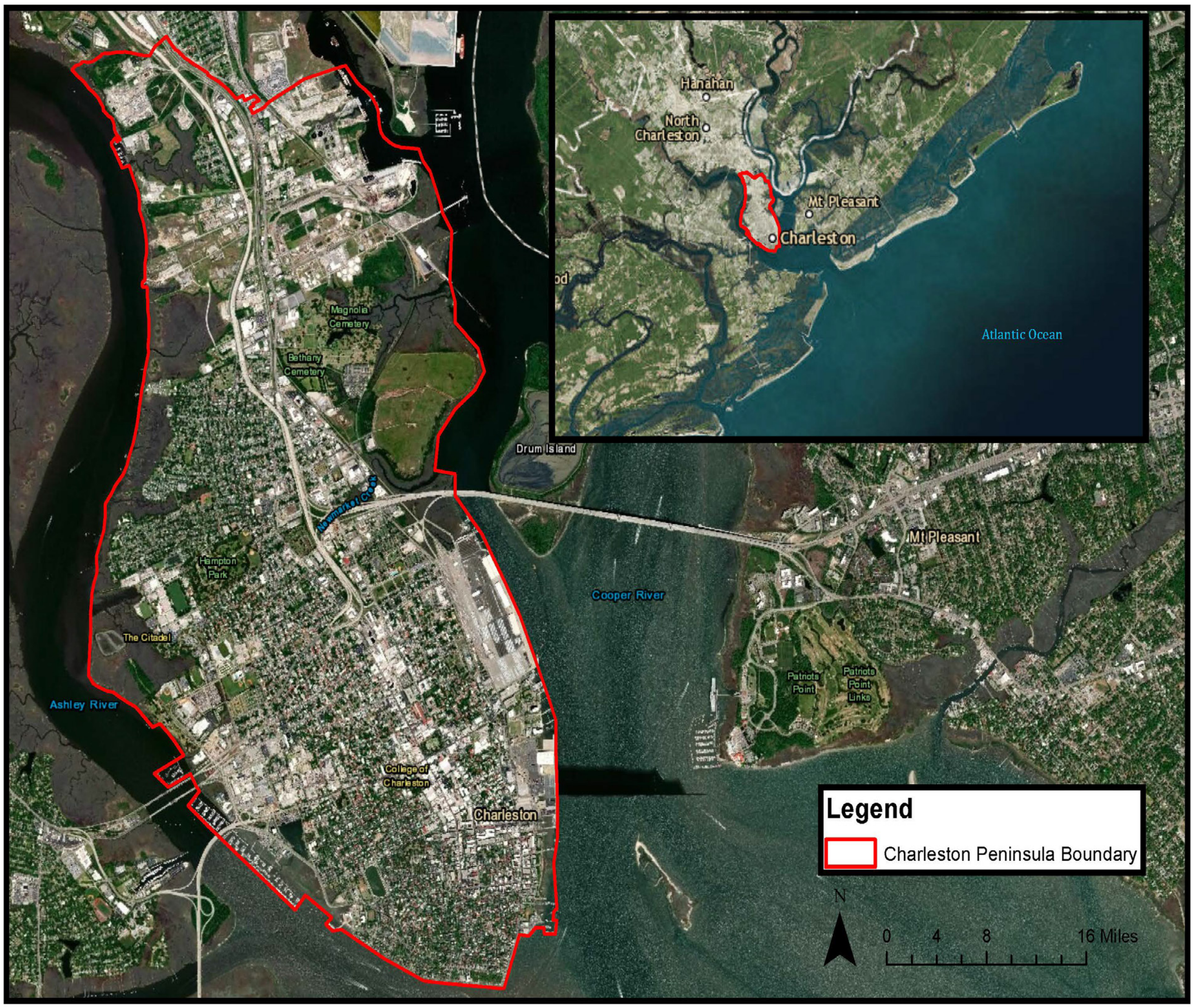

Figure 1: Study Area

Figure 2: Charleston, South Carolina shoreline in 1849 (Source: Wikimedia Commerce)

Figure 3: Charleston, South Carolina shoreline today overlaid on the 1849 shoreline

As mentioned in the purpose section, there is a need for this study because the Charleston Peninsula has been subjected to intense coastal storm events throughout its history. Since 1851, 41 tropical cyclones have made landfall in the National Weather Service's Charleston County Warning Area – 25 of these storms were hurricanes, 9 were tropical storms, and 7 were tropical depressions. There has been a general upward trend in the number of weaker tropical cyclones making landfall and a general downward trend in the number of major (Category 3 – 5) landfalling hurricanes (NOAA, 2020a).

In Charleston, the timing of a coastal storm event in relation to tidal fluctuations is key to the severity of potential damages. A major coastal storm making landfall at or near Charleston at high tide would be catastrophic for the community. But even coastal storms that pass by the Charleston Peninsula can have severe storm surge impacts on the community. Therefore, the Federal Government has an interest in reducing those damages, as doing so not only contributes to national economic development, but may also improve the living conditions of the community and preserve historic and cultural resources.

C.1.3.1. *Socioeconomic Data*

The impacts of flooding affect local industries, including tourism, commercial shipping/logistics, technology, and education, as well as residents of the peninsula. Business operations are reduced when anticipating a coastal storm, especially if evacuation orders are issued, but if the storm significantly damages property and infrastructure, operations would be impacted for a longer duration of time. Residents may have flood insurance to cover some damages, but they are still financially impacted by storm events.

Tourism is the largest sector of the Charleston County economy, comprising nearly 25% of all sales, according to the College of Charleston Office of Tourism. The city of Charleston is a top tourist destination in the U.S., with the Charleston Peninsula driving a significant portion of the attraction. According to the Charleston Regional Development Alliance (CRDA), over 7 million people visit the area each year, and these tourists contribute over $9 billion to the local economy, and support a regional workforce of more than 47,000 employees. Charleston lost an estimated $65 million in visitor spending during Hurricane Florence (September 2018), although it was downgraded to a tropical storm by the time it arrived, and the city dodged the storm's most damaging effects.

Healthcare is a major industry in the region, including the medical district located on the peninsula. According to the CRDA, the healthcare industry supports a regional workforce more than 30,000 people, including more than 2,000 physicians. The healthcare industry in Charleston has the 14th fastest growth rate among mid-sized U.S. metropolitan areas.

Commercial shipping is important to the Charleston economy. The Port of Charleston was the 9th-busiest seaport in the United States in 2020, with over 2.3 million cargo containers moving through its terminals. The Port of Charleston is owned and operated by the South Carolina State Ports Authority and has six terminals. Two of the terminals, Columbus Street and Union Pier, are located on the peninsula and are subject to future flood risk.

Charleston is also becoming a popular location for information technology jobs and corporations, and this sector has had the highest rate of growth between 2011 and 2012, due in large part to the local initiatives to attract and promote the tech economy. In 2015, Charleston's tech economy was growing 26% faster than the national average – and just as quickly as Silicon Valley.

South Carolina Population and Demographics: According to the US Census Bureau, as of April 1, 2020, the population of South Carolina is 5,118,425, reflecting a numeric change of 493,061 and a percent change of 10.7% from the 2010 Census. 51.6% of the total population identify as female and 48.4% identify as male. A strong majority of the State's population (98.0%) identify as one race alone, with 68.6% being White, 27.0% being Black or African American, 6% being Hispanic or Latino (of any race), 1.8% being Asian, 0.5% being American Indian and Alaska Native, and 0.1% being Native Hawaiian and Other Pacific Islander. Within South Carolina there are 1,921,862 households and an average household size of 2.54.

Economic Profile: In 2020, South Carolina had a personal income of $250,573.6, compared to $152,230.5 in 2010. According to BEA, the largest industry in South Carolina in 2020 was finance, insurance, real estate, rental, and leasing. This industry accounted for 19.8 percent of South Carolina GDP and had 6.7% growth rate of the GDP. The second largest industry was government and government enterprises, which accounted for 15.5 percent of South Carolina GDP and had 0.9% growth rate of the GDP.

The industry that subtracted the most from real GDP growth in South Carolina was arts, entertainment, recreation, accommodation, and food services. This industry subtracted 1.04 percentage points from the growth rate of real GDP. The second largest industry to subtract from growth was educational services, health care, and social assistance. This industry subtracted 0.45 percentage point from the growth rate of real GDP.

Charleston County Population and Demographics: According to the US Census Bureau, as of April 1, 2020, the population of Charleston County is 408,235, reflecting a numeric change of 58,026 and a percent change of 16.6% from the 2010 Census. With a population of 408,235 people, Charleston County is the 3rd most populated county in the state of South Carolina out of 46 counties; 51.7% of the population identify as female and 48.3% identify as male. A strong majority of the County's population (98.4%) identify as one race alone, with 68.9% being White, 27.3% being Black or African American, 5.1% being Hispanic or Latino (of any race), 1.7% being Asian, and 0.4% being American Indian and Alaska Native. The median age for Charleston County residents is 37.8 years

Charleston County Income and Poverty Status: The median household income (in 2019 dollars) is $64,022 with 11.9% of all people earning an income below the poverty level. Compared to the state of South Carolina the median household income is $53,199 with a poverty rate of 13.8%.

Charleston County Industry: Several of the top industries supporting Charleston's thriving economy include aerospace, energy, automotive, life sciences, and IT and defense. In the field of aerospace, Boeing remains an industry leader as one of the world's three locations for assembling wide-body aircrafts.

Charleston County Employment and Occupations: In November 2021 the Bureau of Labor Statistics reports Charleston County's unemployment rate at 2.7%, 1.2% lower than the unemployment rate for the United States. According to the U.S. Census Bureau's QuickFacts for Charleston County, South Carolina, the percent of the population age 16 years and above in the civilian labor force from 2015-2019 is estimated to be 64.4%.

Charleston County Economy: The economy of Charleston County, SC employs 211,000 people. The largest industries in Charleston County, SC are Health Care & Social Assistance (27,463 people), Accommodation & Food Services (24,337 people), and Professional, Scientific, & Technical Services (23,157 people). The highest paying industries are Finance & Insurance ($80,958), Management of Companies & Enterprises ($76,058), and Professional, Scientific, & Technical Services ($75,319).

Charleston City Population and Demographics: According to the US Census Bureau, as of April 1, 2020, the population of the City of Charleston is 150,227, reflecting a numeric change of 30,144 and a percent change of 25.1% from the 2010 Census. According to the 2020 Census, the City of Charleston is the most populated city in the state of South Carolina, surpassing Columbia SC by 136,632 people. 52.8% of the population identify as female and 47.2% identify as male. A strong majority of the County's population (98.5%) identify as one race alone, with 74.1% being White, 21.7% being Black or African American, 3.2% being Hispanic or Latino (of any race), 1.9% being Asian, and 0.1% being American Indian and Alaska Native. The median age in Charleston is 34.8 years, 34.1 years for males, and 36 years for females.

C.1.3.2. *Study Area Characteristics*

Charleston is part of a rapidly growing metropolitan area known as the Tri-County area (Berkeley County, Charleston County, and Dorchester County). According to the U.S. Census Bureau estimates for 2020, approximately 33 people move to the Tri-County area each day, making it one of the country's fastest growing regions. The Tri-County area has a population of about 820,000. Charleston is the largest city in South Carolina with a population of about 150,000. Approximately 34,000 people currently reside on the peninsula and more than 40,000 people are projected to reside on the peninsula by year 2030.

The majority of residents on the Peninsula already live in the FEMA 1% (i.e.100 year) flood zone and nearly everyone else is in the 0.2% annual chance exeedance (i.e. 500 year) flood zone. There are several housing development projects on the peninsula to accommodate the influx of new residents. Despite the city's flood risk, it is assumed people will continue to move to Charleston which increases the amount of people vulnerable to flooding.

The Charleston peninsula contains the heart of the city's historic areas, and its diverse architecture reflects the historical and cultural development of the city from its beginnings in the late-1600s to the present. Today, the peninsula contains numerous buildings dating from the late eighteenth century to – the mid nineteenth centuries that document the city's growth into a major seaport, trade center, and one of the wealthiest cities in the American colonies.

The National Register of Historic Places (NRHP) is the official list of our nation's historically significant buildings, districts, sites, structures and objects worthy of preservation, and it contains 76 resources for the Charleston Peninsula, including historic districts, individual listings, and cemeteries. These resources are recognized at the national, state and local levels for their historical significance. Charleston Old and Historic District, the largest historic district on the peninsula (approximately 1.4 square miles), is designated as a National Historic Landmark (NHL) and includes over 1400 buildings and structures. Through local historic preservation efforts, this NHL district was established in 1960 to address the historic significance of the city from 1700 to 1899. Several boundary increases have occurred since the original designation to expand the geographic limits of the district, and the last boundary increase in 1984 extended the period of significance to 1941 to include the city's twentieth century development. The district is comprised mainly of residences, but also contains commercial and governmental buildings, and places of worship.

C.1.4. *METHODOLOGY*

In order to develop plans to address water resource problems within a study area, three conditions must be fully analyzed: the "existing" condition, the "future without project" condition, and the "future with project" condition.

In this analysis, the existing condition represents current conditions that is without sea level change. The future without project condition is the condition that would likely exist in the future without the implementation of a Federal project and incorporates sea level change. This condition is evaluated for a 50-year period for coastal storm management projects, and the results are expressed in terms of average annual damages. For this study, the future without project condition is for the years 2032-2081. The future with project condition is the condition that would likely exist in the future with the implementation of a Federal project, using the same 50-year period as in the future without project condition.

The difference in expected annual flood damages to the Charleston Peninsula assets between the future without and the future with project conditions represents the flood risk management benefits to the project. Economic and other significant outputs may accrue to the project as well, including recreation benefits, ecosystem restoration benefits, regional economic benefits, and other social effects. Other social effects, which often defy quantification in monetary terms, range from improvement in the quality of life within the study area to community impacts. This analysis attempts to recognize and, where possible, quantify the reduction of damages from coastal storm surge inundation due to the Federal project in the study area (i.e. NED benefits).

C.1.4.1. *Assumptions*

This section of the analysis presents the assumptions used in computing average annual equivalent flood damages for the study area:

- Floodplain residents will react to a floodplain management plan in a rational manner.
- Real property will continue to be repaired to pre-flood conditions subsequent to each flood event given a rebuilding period with a maximum rebuild of 5 times.
- Assets are not removed from the asset inventory due to using cumulative damage threshold (i.e. cumulative damage threshold not used).
- Residential structures are raised after receiving significant damages (i.e. 50% or more of the structure value) within the period of analysis.
- The residential depth-percent damage relationships for structure and content contained in Economic Guidance Memorandum (EGM) 01-03 and 04-01 are assumed to be representative of residential structures in the floodplain.
- Non-residential depth-percent damage relationships for structure and content are from expert elicitation found in the revised 2013 draft report completed by the USACE Institute of Water Resources. Non-residential flood depth-damage functions derived from expert elicitation are assumed to be representative of non-residential structures in the floodplain.
- The present valued damages, first costs, and benefits will be annualized using the FY 2022 Federal discount rate of 2.25% assuming a period of analysis of 50-years.
- All values are equivalent to 2021 dollars unless specifically stated.
- All project alternatives are evaluated for a 50-year period of analysis.
- The base year is 2032. Present values and the first year of the period of analysis are at this base year.
- Unless otherwise stated, elevations are in feet (ft) North American Vertical Datum of 1988 (NAVD88).
- The sea level change rate used is 0.01033 feet per year which is associated with the NOAA 2006 published relative sea level change (RSLC) rate associated with

the observed trend based on the NOAA tide gauge 8665530, Charleston, SC and represents the LOW USACE scenario for Charleston.
- The RSLC evaluation approach for the economic analysis used a single scenario (i.e. intermediate) and identified the preferred alternative under that scenario. That alternative's performance would then be evaluated under the other scenarios (i.e. low and high) to determine its overall performance. This approach corresponds to item 6.d.2 of ER 1110-2-8162 (reference Section C.1.7.4.3).
- Depreciation is calculated for structures (i.e. replacement values) during the life cycle analysis.

There is uncertainty regarding how rational property owners will act when presented with repetitive damages due to flooding. The risk associated with this assumption most likely impacts the estimation of future flood damages. In other words, this assumption could mean overstating damages or underestimating residual damages. As stated above the assumption is that real property will continue to be repaired to pre-flood conditions after each flood event and that a cumulative damage threshold is not used.

The rationale for not using the cumulative damage threshold feature within the model is because using a cumulative damage threshold entails removing structures from the asset inventory when a cumulative damage threshold is exceeded. This rationale is not particularly accurate for the study area. The study area is a peninsula, there is not much land to relocate to (e.g. buildings removed cannot be placed somewhere else). The study area is also a historical area with many historical buildings that just cannot be abandoned or removed. These reasons contribute to the assumption that structures most likely will not be removed because of repetitive damages due to flooding. Property owners are rational and understand that by removing structures from the peninsula, they are relocating from the peninsula itself. On the contrary, it is more likely that property owners would continuously repair the structure due to minor flood damages and perform major rebuild after a major flood event because this often has occurred on the peninsula in the past (i.e. home elevations).

Furthermore, using the cumulative damage threshold, entails first setting the damage threshold. However, this threshold cannot be established with any proper certainty. Moreover, if this cumulative damage threshold was established, structures will be removed accordingly from the analysis which could underrepresent residual risk if this threshold was not properly estimated. In contrast, the "rebuild and reraise" threshold for a structure was estimated based on FEMA's Substantial Improvement / Substantial Damage rules which require buildings to meet current building regulations if the construction cost is over 50% of the fair market value of the building. This includes repairs from damage or improvements. Also, it is important to note that these assumptions are applicable to both future without project and future with project conditions. Each future with project condition will be compared to the same future without project condition

There also exists uncertainty regarding future adaptation actions, related to future flooding risk in response to future effect of RSLC and hydrology climate change scenarios. Therefore, the assumption is that regardless of the RSLC and hydrology climate change scenarios, in the future with project condition, the specific elevation used to derive inundation reduction benefits is the upper limit (reference C.1.7.1.3 for more information). Further information regarding adaptation or resiliency at the specific elevation can be found in the Engineering Appendix.

C.1.4.2. *Risk and Uncertainty*

Risk and uncertainty are inherent in water resources planning and design. These factors arise due to errors in measurement and from the innate variability of complex physical, social, and economic situations. The measured or estimated values of key planning and design variables are rarely known with certainty and can take on a range of possible values. Risk analysis in flood risk management projects is a technical task of balancing risk of design exceedance with reducing the risk from flooding; trading off uncertainty of flood levels with design accommodations; and providing for reasonably predictable project performance. Risk-based analysis is therefore a methodology that enables issues of risk and uncertainty to be included in project formulation.

The U.S. Army Corps of Engineers (USACE or Corps) has a mission to manage flood risks:

> *"The USACE Flood Risk Management Program (FRMP) works across the agency to focus the policies, programs and expertise of USACE toward reducing overall flood risk. This includes the appropriate use and resiliency of structures such as levees and floodwalls, as well as promoting alternatives when other approaches (e.g., land acquisition, flood proofing, etc.) reduce the risk of loss of life, reduce long-term economic damages to the public and private sector, and improve the natural environment."*

As a part of that mission, the Institute for Water Resources (IWR) in cooperation with other Corps groups has developed the Generation II Coastal Risk Model (G2CRM) to support planning-level studies of hurricane protection systems (HPS).

C.1.4.2.1. *Modeling Description*

G2CRM is distinguished from other models currently used for that purpose by virtue of its focus on probabilistic life cycle approaches. This allows for examination of important long-term issues including the impact of climate change and avoidance of repetitive damages. G2CRM is a desktop computer model that implements an object-oriented probabilistic life cycle analysis (PLCA) model using event-driven Monte Carlo simulation (MCS). This allows for incorporation of time-dependent and stochastic event-dependent behaviors such as sea level change, tide, and structure raising and removal. The model is based upon driving forces (storms) that affect a coastal region (study area). The study area is comprised of individual sub-areas (model areas) of different types that may interact hydraulically and may be defended by coastal defense elements that serve to shield the areas and the assets they contain from storm damage. Within the specific terminology of G2CRM, the important modeled components are:

- *Driving forces* - storm hydrographs (surge and waves) at locations, as generated externally from high fidelity storm surge and nearshore wave models.
- *Modeled areas* - areas of various types (e.g. coastal upland, unprotected area) that comprise the overall study area. The water level in the modeled area is used to determine consequences to the assets contained within the area.
- *Protective system elements* - the infrastructure that defines the coastal boundary whether it is a coastal defense system that protects the modeled areas from flooding (e.g. levees, pumps, closure structures), or a locally developed coastal boundary comprised of bulkheads and/or seawalls.
- *Assets* – spatially located entities that can be affected by storms. Damage to structure and contents is determined using damage functions. For structures, population data at individual structures allows for characterization of loss of life for storm events.

The model deals with the engineering and economic interactions of these elements as storms occur during the life cycle, areas are inundated, protective systems fail, and assets are damaged and lives are lost. A simplified representation of hydraulics and water flow is used. For this study, modeled areas currently include unprotected areas and coastal uplands defended by a seawall or bulkhead. Protective system elements are limited to bulkheads/seawalls.

C.1.4.2.2. *Modeling Variables*

According the USACE Engineering Regulation (ER) 1105-2-101, 7. Variables in Risk Assessment. (b.):

> *A variety of variables and their associated uncertainties may be incorporated into the risk assessment of a flood risk management study. For example, economic variables in an urban situation may include, but are not necessarily limited to depth-damage curves, structure values, content values, structure first-floor elevations, structure types, flood warning times, and flood evacuation effectiveness. Uncertainties in economic variables include building valuations, inexact knowledge of structure type or of actual contents, method of determining first-floor elevations, or timing of initiation of flood warnings. Other key variables and associated uncertainties include the hydrologic and hydraulic conditions of the system. Uncertainties related to changing climate should be addressed using the current USACE policy and technical guidance.*

As previously stated, G2CRM is a desktop computer model that implements an object-oriented probabilistic life cycle analysis (PLCA) model using event-driven Monte Carlo simulation (MCS). Monte Carlo Simulation (MCS) is a method for representing uncertainty by making repeated runs (iterations) of a deterministic simulation, varying the values of the uncertain input variables according to probability distributions. A triangular distribution is a three-parameter statistical distribution (minimum value, most likely value, maximum value) used throughout G2CRM to characterize uncertainty for inputs in the model. The following sections attempt to characterize the uncertainties for both the economic and engineering inputs that went into the G2CRM, version 0.4.564, for the study area.

C.1.4.2.2.1. Economic Inputs

Uncertainty was quantified for errors in the underlying components of structure values for residential and nonresidential structures, content to structure value ratios for residential and nonresidential structures, depth-percent damage relationship for both residential and nonresidential structures, and first floor elevations for all structures. G2CRM used the uncertainty surrounding these variables to estimate the uncertainty surrounding the storm-damage relationships developed for each in the study area.

C.1.4.2.2.1.1. Structure Inventory

A structure inventory of nonresidential and residential structures was obtained from Charleston County and integrated with data from the National Structure Inventory version 2 (NSI v.2) and modified by Corps personnel to produce the Spatial Asset Data input for G2CRM. The number of assets (i.e. structure inventory) was based on county tax assessor databases reflecting development in the year 2018 and include 11,885 assets. There was also 210 newly permitted construction assets as of 2019. Thus, the complete asset inventory includes 12,095 assets. These assets will be further discussed in the Assets section of this Appendix.

To derive the structure values, the 2019 RS Means Square Foot Costs Data catalog was used to assign a depreciated replacement cost to the residential and nonresidential structures/assets in the study area. These residential and nonresidential structures/assets were defined by 4 main damage categories: Public (i.e. GOV, REL, EDU), Commercial (i.e. AGR, COM), Industrial (i.e. Ind), and Residential (i.e. RES). These assets were further categorized in 39 occupancy types for the purpose of analysis. The following Figure displays these occupancy types and descriptions. RES1 was further categorized by number of stories (i.e. 1,2,3), if split level (i.e. SL), and with or without basements (i.e. WB or NB): RES1-1SNB, RES1-2NB, RES1-3NB, RES1-1SWB, RES1-2WB, RES1-3WB, RES1-SLNB, RES1-SLWB.

RES1	Single Family Dwelling	COM7	Medical Office/Clinic
RES2	Mobile Home	COM8	Entertainment & Recreation
RES3A	Multi Family Dwelling - Duplex	COM9	Theaters
RES3B	Multi Family Dwelling – 3-4 Units	COM10	Parking
RES3C	Multi Family Dwelling – 5-9 Units	IND1	Heavy
RES3D	Multi Family Dwelling – 10-19 Units	IND2	Light
RES3E	Multi Family Dwelling – 20-49 Units	IND3	Food/Drugs/Chemicals
RES3F	Multi Family Dwelling – 50+ Units	IND4	Metals/Minerals Processing
RES4	Temporary Lodging	IND5	High Technology
RES5	Institutional Dormitory	IND6	Construction
RES6	Nursing Home	AGR1	Agriculture
COM1	Retail Trade	REL1	Church/Membership Organizations
COM2	Wholesale Trade	GOV1	General Services
COM3	Personal and Repair Services	GOV2	Emergency Response
COM4	Business/Professional/Technical Services	EDU1	Schools/Libraries
COM5	Depository Institutions	EDU2	Colleges/Universities
COM6	Hospital		

Figure 4: Occupancy Types

Nonresidential replacement costs per square foot were provided in the RS Means catalog for six exterior wall types with respect to each RS Means building/asset category (2-4 Story Office, Bank, Convenience Store, etc.). An average replacement cost per square foot was calculated using the six exterior wall types specific to the corresponding RS Means building/asset category with respect to the mean square footage calculated for all assets within its category. The RS Means depreciation schedule for non-residential structures provides depreciation percentages for three structure frames: wood frame exterior, masonry on wood frame, and masonry on steel frame.

Based on a windshield survey to observe the effective age of structures/assets, the majority of the non-residential structures in the area reflected the masonry on wood exterior wall construction with an approximate effective age of 15 years. The masonry on wood depreciation percentage of 20% was applied as the most likely condition to all of the non-residential structures. Furthermore, to account for uncertainty, a triangular distribution was used for deriving the maximum and minimum depreciated replacement costs using a depreciation percentage of 3% and 35%, respectively, reflecting effective ages of 5 and 25 years for wood frame and masonry on steel frame exteriors, respectively. Additionally, a commercial location cost factor of 85% of the national square foot costs for the City of Charleston was then applied to the depreciated cost per square foot to derive the average depreciated replacement cost per square foot with respect to each building/asset category. Finally, the square footage for each individual structure, obtained from the tax assessor when available, and when not available, from the NSI, was multiplied by the average depreciated replacement cost per square foot for each structure's building/asset category.

Residential replacement costs per square foot were provided for four exterior walls types (wood frame, brick veneer, stucco, or masonry) with respect to each building/asset category (RES1-1SNB, RES1-2NB, RES1-3NB, etc.) and its construction class (average, custom or luxury). An average replacement cost per square foot was calculated using the four exterior wall types specific to the corresponding RS Means building/asset category with respect to the mean square footage calculated for all assets with its category. That is, the mean square footage was calculated for each residential asset category regardless of construction class. Then, an average replacement cost per square foot was calculated using the four exterior wall types with respect to each asset category and construction class.

Again, a windshield survey was conducted to delineate differences in the structures' construction class, effective age, and to verify the first-floor elevations of the assets. The RS Means depreciation schedule for residential structures provides depreciation percentages for structures in good, average, or poor condition and with respect to the structures' effective age. Based on a windshield survey to observe the effective age of the structures/assets, the majority of the residential structures in the area had an approximate effective age of 15 years. The average condition depreciation percentage of 15% was applied as the most likely condition to all of the residential structures regardless of construction class. Furthermore, to account of uncertainty, a triangular distribution was used for deriving the maximum and minimum depreciated replacement costs using a depreciation percentage of 7% and 30%, respectively, reflecting effective ages of 10 and 15 years for structures in good and poor condition, respectively. Additionally, a residential location cost factor of 95% of the national square foot costs for the City of Charleston was then applied to the depreciated cost per square foot to derive the average depreciated replacement cost per square foot with respect to each building/asset category and its construction class. Finally, the square footage for each individual structure, obtained from the tax assessor when available, and when not available, from the NSI, was multiplied by the average depreciated replacement cost per square foot for each structure's building/asset category and construction class.

In a small number of instances, some structures' square footage values were not available from the tax assessor nor NSI data. Using best professional judgment, these structures depreciated replacement cost was derived by multiplying the structure category's mean square footage by the category's calculated depreciated replacement cost per square foot. This method was applied to both residential and nonresidential structures.

C.1.4.2.2.1.2. Content-to-Structure Value Ratios

Site-specific Content-to-Structure Value Ratios (CSVR) information was not available for the study area. The nonresidential CSVR were taken from Appendix E Table E-1 of the Nonresidential Flood Depth-Damage Functions Derived from Expert Elicitation Draft Report, revised 2013. Moreover, these functions contained a triangular distribution (i.e. minimum, maximum, most likely) to account for the uncertainty surrounding the ratio for each nonresidential occupancy type. The residential CSVR used a combination of both the aforementioned Expert Elicitation Draft Report and EGM 01-03 and 04-01. Moreover, both EGMs contained guidance to account for uncertainty associated with content/structure value ratio, which implies that the uncertainty in the content-to-structure value ratio should be inherent in the content depth-damage relationship as contained in both respective EGMs.

C.1.4.2.2.1.3. Depth-Damage Relationship

Site-specific depth-damage functions (DDF) were not available for the study area for either nonresidential and residential structures. The nonresidential DDFs were taken from the Draft Report, Nonresidential Flood Depth-Damage Functions Derived from Expert Elicitation. These values can be found in Appendix D, Tables D-22 through D-42 for structures and Tables D-42 through D-63 for content, of the report. Moreover, these functions contained a triangular distribution (i.e. minimum, maximum, most likely) to account for the uncertainty surrounding the damage percentage associated with each depth of flooding. The residential DDFs used a combination of both the aforementioned Expert Elicitation Draft Report and EGM 01-03 and 04-01. Moreover, both EGM contained a normal distribution function with an associated standard deviation of damage to account for uncertainty surrounding the damage percentage associated with each depth of flooding. This distribution was then converted into a triangular distribution for input into the model.

C.1.4.2.2.1.4. First Floor Elevation

The Digital Elevation Model (DEM) for South Carolina that used topographical data obtained from the Light Detection and Ranging (LiDAR) survey conducted in 2017 for the study area was used to determine ground elevations at the centroid of each parcel where the structure is most likely located using ArcGIS (i.e. ArcMap developed by Esri). The heights above ground were estimated from windshield survey of the structures in the study conducted in 2019. This windshield survey involved using map grids with all the structures located in the study area overlaid on each map grid (88 produced by geographic information system) and noting the observed finished first floor height of each structure or group of structures (e.g. by street blocks). The sum of the ground elevation and the finished floor height above ground elevation is the first-floor elevation and used as the most likely value for each structure (see Figure 5).

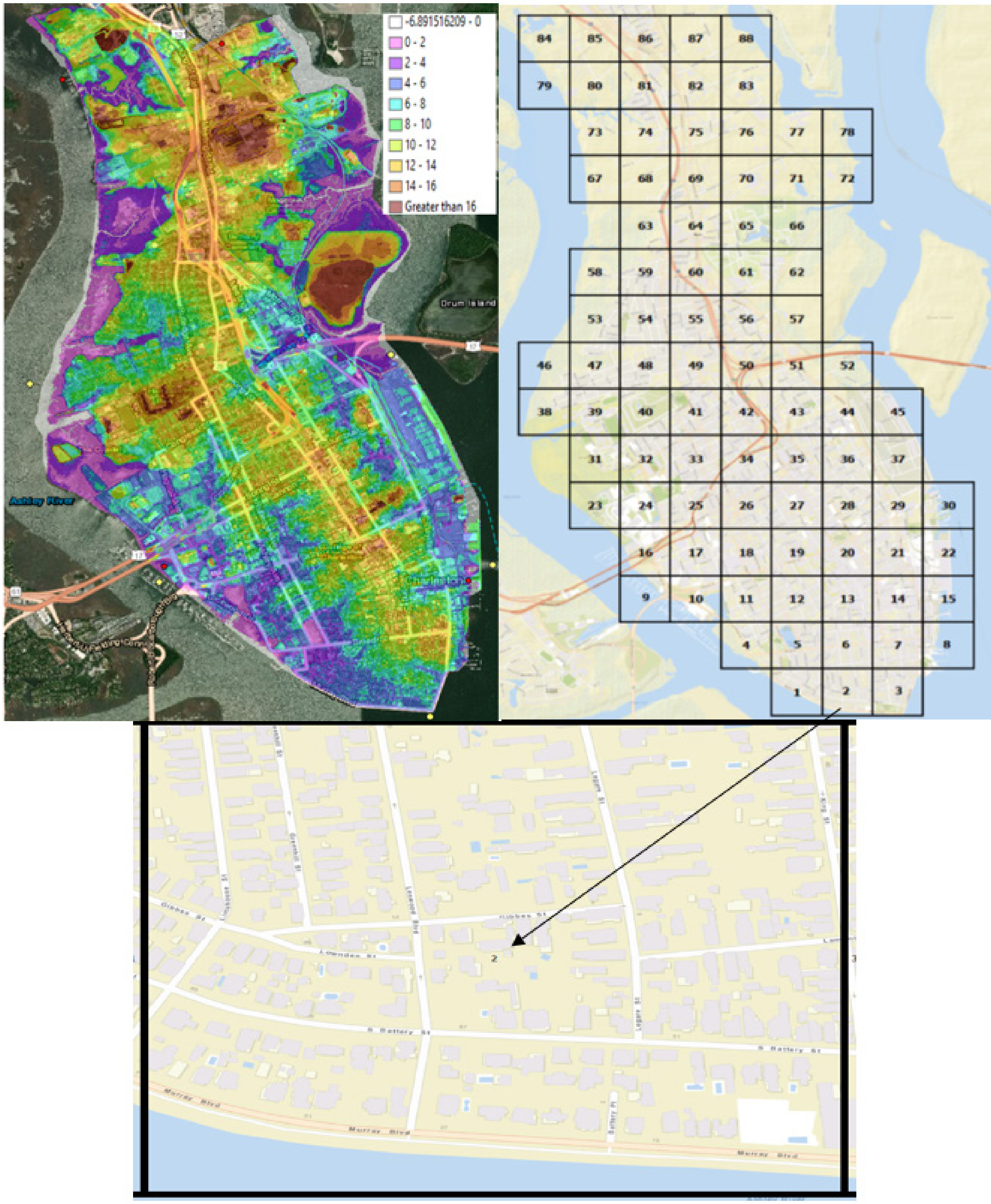

Figure 5: LiDAR and Map Grids of Charleston Peninsula

A first-floor standard error of 0.6 feet with a deviation of 0.3 feet assuming normal distribution was used to quantify uncertainty based on guidance found in Engineering Manual (EM) 1110-2-1619, Table 6-5, aerial survey, 2-ft contour interval. The datum used to determine first floor elevations is the same datum Engineering used to determine water level elevations for the simulated coastal storms. There are two sources of uncertainty surrounding the first-floor elevations: the use of the LiDAR data for the ground elevations, and the methodology used to determine the structure foundation heights above ground elevations. The uncertainty used to determine first floor elevations was a triangular distribution using 1.5 feet from the most likely value as the minimum value and maximum value.

C.1.4.2.2.2. Engineering Inputs

The uncertainty surrounding the key engineering parameters was quantified and entered into G2CRM. The model is based upon driving forces (i.e. storms) that affect a study area. The study area is comprised of individual sub-areas of different types, defined as model areas, which may interact hydraulically and may be defended by coastal defense elements, such as protective system elements, that serve to shield the areas and the assets they contain from storm damage. The model used the uncertainty surrounding the storm information to account for uncertainty surrounding the elevation of the storm surges for the study area. The Engineering Appendix and Coastal Sub Appendix contains more information regarding engineering inputs into G2CRM.

C.1.4.2.2.2.1. Storms

The goal of storm selection was to find the optimal combination of storms given a predetermined number of storms to be sampled, referred to as a reduced storm set. The number of storms selected was driven by schedule and budget constraints and by knowledge gathered from other previous and ongoing USACE feasibility studies about the minimum number of storms required to adequately capture the storm surge hazard. For the study area, a reduced storm set of 25 synthetic tropical cyclones (i.e. storms) was selected from the original South Carolina Storm Surge Project of 122-storm suite (i.e. full storm set). In the process of selecting the number for the study area, it was determined that a reduced storm set of this size adequately captured the storm surge hazard for the range of probabilities covered by the full storm set. The tracks of these 25 storms are shown in the Figure 6.

The storm selection process was performed using the design of experiments (DoE). The DoE compares still water level, hazard curves derived from the reduced storm set to "benchmark" hazard curves corresponding to the full storm set at a given number of save points within the study area. The difference between the reduced storm set hazard curves and full storm set benchmark curves is minimized in an iterative process considering multiple subsets of 25 tropical cyclones. In summary, the general steps in this DoE approach for selecting a subset of storms are:

1. Identify a set of save points critical to a project or study area, where optimization will be performed.
2. Develop hazard curves for the full storm set.
3. Select number of storms to be sampled.
4. Develop hazard curves for the reduced storm set.
5. Choose the range of probabilities for which hazard curves will be compared. The reduced storm set versus full storm set differences can be computed along the entire hazard curve, or by prioritizing a specific segment of the curves, for example, 50 to 500 years.
6. Compute differences between reduced storm set and full storm set hazard curves.
7. An iterative sensitivity analysis is performed to determine the optimal combination of storms constituting the reduced storm set.
8. Once the optimal combination of storms is determined, an optional analysis can be performed to evaluate the benefits of increasing storm subset size; finalize storm selection.

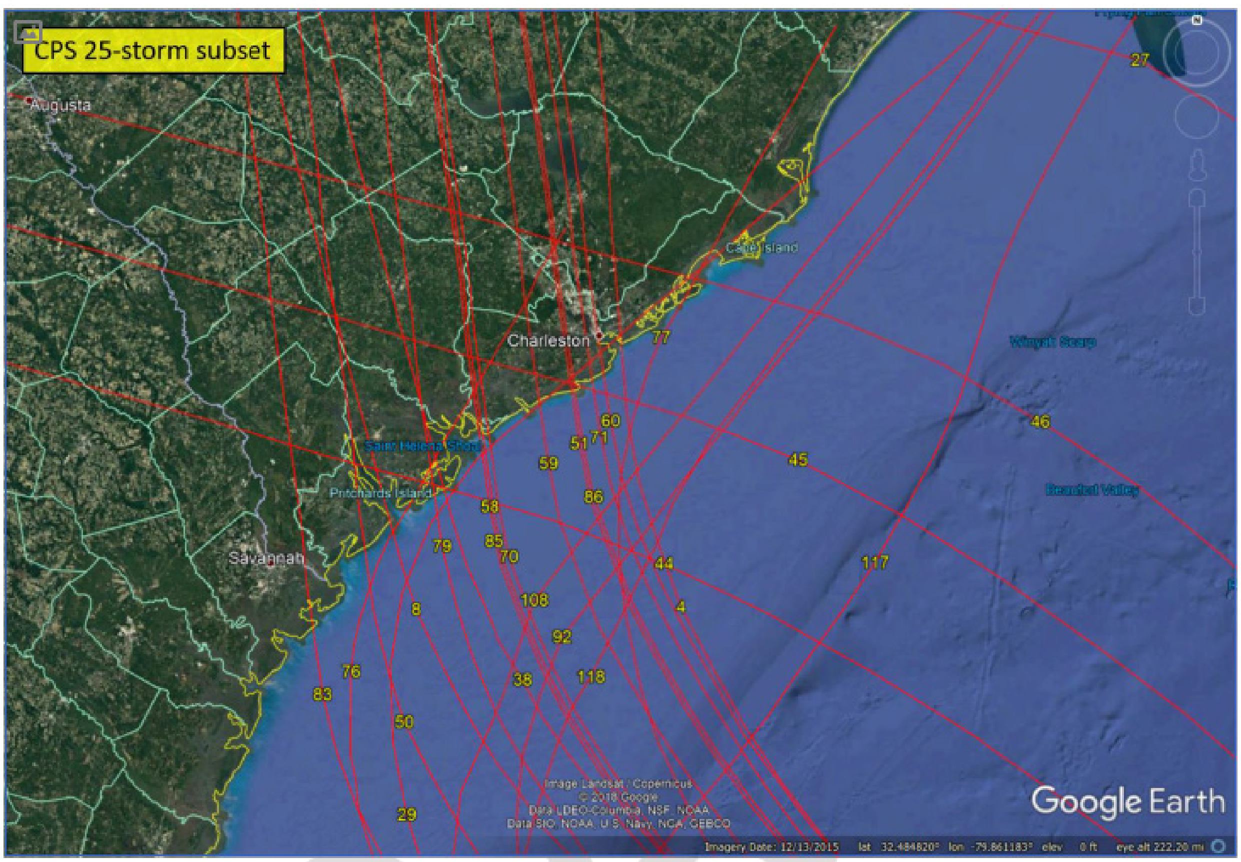

Figure 6: Track of the Reduced Storm Set

For the Charleston Peninsula G2CRM, each G2CRM simulation run used the abovementioned reduced storm set, and storms were drawn randomly by the bootstrapping method. The bootstrap calculates a Poissan distribution based on average number of storms in the season (as an input) for the study area. The bootstrapping approach also takes into the account the relative probability of each storm (i.e. higher probability storms are chosen more often), which is technically bootstrap sampling with replacement. Each of the 25 storms for the study area has an associated storm probability and storm surge information (e.g. water levels) at the save points.

After further evaluation by the Engineering and Economics product delivery team members, it was determined that of the reduced storm set of 25, two storms happened too frequently, and the water levels produced by these storms realistically would not cause any damages. Therefore, storms 27 and 117 (reference storm Figure above) were deleted from the storm suite used in the modeling to prevent potential overestimation of flood damages.

C.1.4.2.2.2.2. Save Points

The numerical modeling aspect of the study area is to provide estimates of waves and water levels for existing condition, future without project condition, and future with project condition. A save point is a point of interest in the study area. From a dataset of over 1000 points, 5 save points were selected. These save points contained the water elevations and wave heights for each of the storm in the final reduced storm set (i.e. 23) to be used in the model and eventually used to represent 5 modeled areas. These water elevations will be applied to the modeled areas along with economic inputs to derive flood damages in the existing condition, future without project condition, and future with project condition for the Charleston Peninsula. The following Figure displays the location of the 5 save points (i.e. yellow circles) amongst the 1000 points (i.e. red squares). Furthermore, storm statistics such as average numbers of storms in a season and relative probabilities were also derived at each save point.

Figure 7: Save Points

C.1.5. *EXISTING CONDITION*

There are approximately 6,670 structures (out of 12,095) in the FEMA 1% annual chance exceedance (ACE) floodplain on the Charleston Peninsula. These property owners are technically required to purchase flood insurance, although flood insurance has eligibility requirements and numerous exclusions. The FEMA National Flood Insurance Program does not cover additional living expenses, such as temporary housing, while the building is being repaired or is unable to be occupied; loss of use or access to the insured property; financial losses caused by business interruption; property and belongings outside of an insured building, such as trees, plants, wells, septic systems, walks, decks, patios, fences, seawalls, hot tubs and swimming pools; most self-propelled vehicles, such as cars, including their parts; and personal property kept in basements. Federal flood insurance coverage is also capped at $250,000 per building and $100,000 for contents.

In June 2019, personnel from the U.S. Army Corps of Engineers surveyed the structure inventory within the Charleston Peninsula study area. Parcel data was obtained from the Charleston County tax assessor's office and used to build a Geographic Information System (GIS) database identifying which parcels and structures fell within the FEMA 0.2% annual chance exceedance event floodplain. The structure inventory survey identified 12,095 structures. The inventoried structures were categorized as residential or nonresidential which were further categorized into occupancy types (reference Structure Inventory section). The Table below displays the count and structure value (estimated replacement cost less depreciation updated to 2021 values based on 2021 RS Means publication) of the structure inventory by the main occupancy types.

Table 1: Structure Inventory by Occupancy Types

Occupancy Type	Description	Count	Structure Value
AGR1	Agriculture	3	$337,000
COM1	Retail Trade	163	$216,000,000
COM2	Wholesale Trade	152	$378,000,000
COM3	Personal and Repair Services	135	$151,200,000
COM4	Business/Professional/ Technical Services	422	$1,188,000,000
COM5	Depository Institutions	26	$56,160,000
COM6	Hospital	4	$7,560,000
COM7	Medical Office/Clinic	48	$43,200,000
COM8	Entertainment & Recreation	207	$982,800,000
COM9	Theaters	2	$562,000
COM10	Parking	10	$23,760,000
EDU1	Schools/Libraries	13	$18,360,000
EDU2	Colleges/Universities	8	$24,840,000

GOV1	General Services/Emergency Response	64	$216,000,000
IND1	Heavy Industrial	36	$124,200,000
IND2	Light Industrial	63	$63,720,000
IND3	Food/Drug/Chemicals	9	$10,800,000
IND4	Metals/Minerals Processing	9	$18,360,000
IND5	High Technology	7	$5,400,000
IND6	Construction	153	$388,800,000
REL1	Church/Membership Organizations	162	$324,000,000
RES1	Single Family Dwelling	7195	$2,523,960,000
RES2	Mobile home	8	$540,000
RES3	Multi Family Dwelling	3102	$2,079,000,000
RES4	Temporary Lodging	44	$132,840,000
RES5	Institutional Dormitory	41	$176,040,000
RES6	Nursing Home	9	$14,040,000
Total		**12095**	**$9,168,479,000**

Critical facilities on the Charleston Peninsula include 6 fire stations and 2 police stations, 6 colleges and 12 public schools (including 3 charter, 6 elementary, 2 middle, and 1 high). The Charleston Peninsula is also home to the Charleston Medical District which includes the Medical University of South Carolina (MUSC), Roper St. Francis Hospital, and Ralph H. Johnson Veterans Affairs Medical Center. The MUSC's 700-bed center has 4 hospitals: the MUSC Children's Hospital, the Institute of Psychiatry, Ashley River Tower and University Hospital. The MUSC center also has a Level I Trauma Center and South Carolina's only transplant center. The Ralph H. Johnson VA Center serves 75,000 Veterans along the South Carolina and Georgia Coast. The Medical District along Lockwood Drive is particularly vulnerable to storm surge inundation because of its location on filled intertidal zone on the western side of the peninsula. For reference regarding elevations on the peninsula, the Figure below displays the approximated contours line at elevations 6, 9, and 12 feet NAVD88.

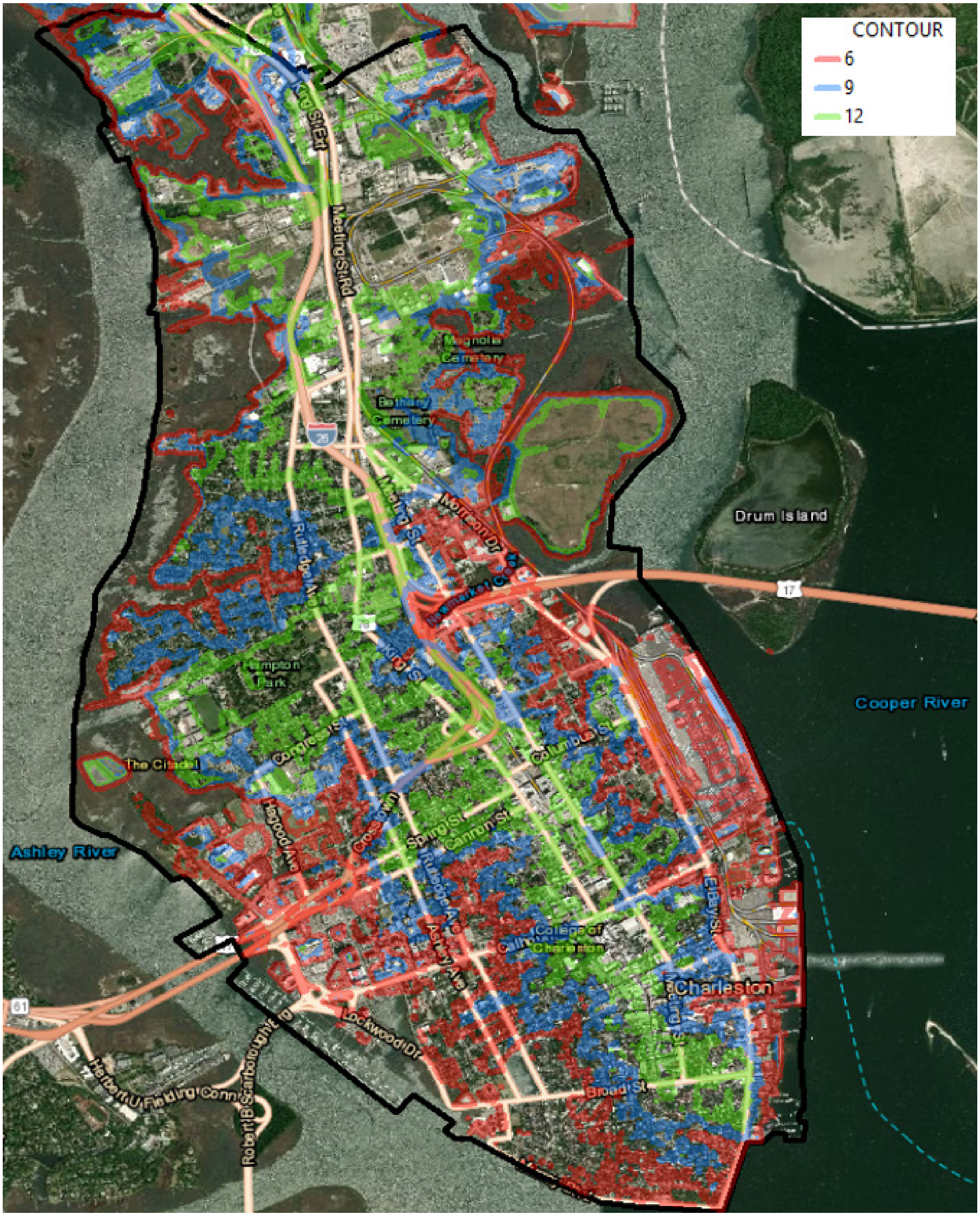

Figure 8: Approximated Contour Lines

C.1.5.1.1. *Model Areas*

The term “model areas” describe various geographic units that may exist within the study area. Flood elevations are uniform within a model area (MA). A storm event is processed to determine the peak stage in each defined MA, and it is this peak stage that is used to estimate consequences to assets within the MA. Therefore, MA boundaries tend to correspond to the drainage divides separating local-scale watersheds. Considerable professional judgment was used in defining MA boundaries including taking into account natural or built topological features (e.g. a ridge, highway, or railway line) to define MA boundaries. Dividing the study area into model areas facilitates evaluation of flood damages by breaking the study are down into several areas having some common features; analyzing them separately also speed up the economic modeling process. The study area consists of 5 distinct model areas: Battery, Port (formerly known as Cruise Terminal), Newmarket, Wagener Terrace, and Marina. These model areas are spatial areas defined by geospatial polylines (reference Figure below and Engineering Appendix and Coastal Sub Appendix for more details).

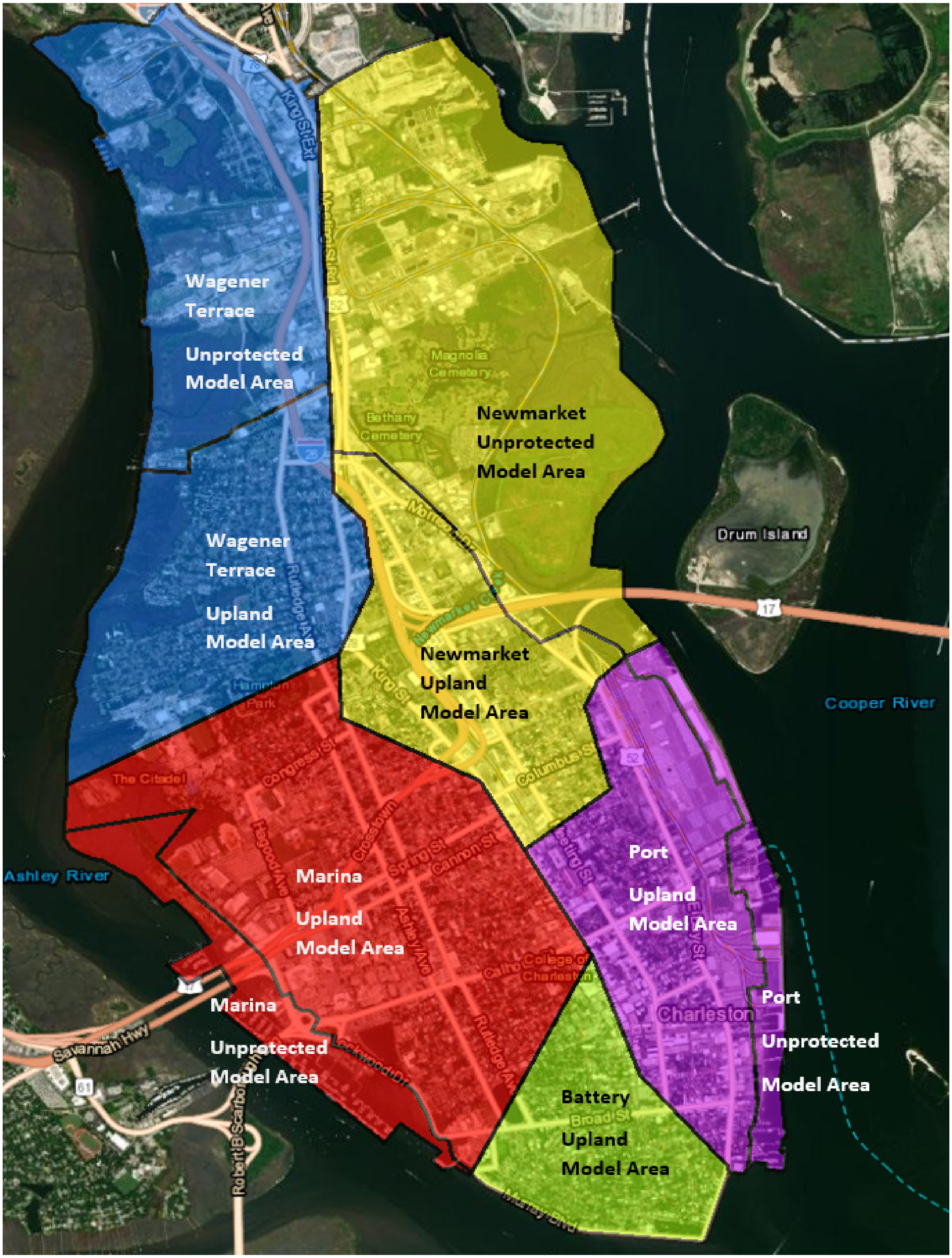

Figure 9: Model Areas

C.1.5.1.1.1. Model Area Types

The study area is divided into 5 model areas and within each MA, the model areas are further defined by types: unprotected and upland. An unprotected modeled area is a polygonal boundary within G2CRM that contains assets and derives associated stage from the total water level (i.e. storm surge plus wave contribution plus sea level change contribution plus tide contribution) calculated for a given storm, without any mediation by a protective system element (PSE). An upland modeled area is a polygonal boundary within G2CRM that contains assets and derives associated stage from the total water level (i.e. storm surge plus wave contribution plus sea level change contribution plus tide contribution) calculated for a given storm, as mediated by a protective system element such as a bulkhead/seawall that must be overtopped before water appears on the modeled area. It also has an associated volume-stage relationship to account for filling behind the bulkhead/seawall during the initial stages of overtopping.

Moreover, it is important to note that currently the only PSE that exists is located in the Battery MA, which has a Low and High Battery wall. By the base year 2032, both walls will be at an elevation around 9 feet; however, the Battery wall does not tie into high ground. The Battery wall ends where the Port MA begins to the east and Marina MA begins to the west (i.e. at lower elevations); therefore, the Battery MA is subject flooding that goes around the Battery Wall. Since the Battery wall is subject to this kind of flooding from coastal storm surge, the Battery Wall for the existing and future without project condition was given an elevation height of 4 feet instead of 9 feet, in the model, to reflect the level of flood risk reduction it more likely provides.

The reason each of the 5 model areas were modeled as an Upland MA is because in the future with project condition each of these model areas would have a PSE (reference the following subsection) and would be an Upland MA (further discussed and explained in the future with project condition section of this Appendix). Therefore, having each MA be a component of an Upland MA in the existing and future without project condition was a modeling strategy utilized in order to model the future with project condition.

C.1.5.1.1.2. Protective System Elements

Flood hazard as manifested at the storm location is mediated by the associated bulkhead/seawall PSE. The PSE prevents transmission of the flood hazard into the MA until the flood hazard exceeds the top elevation of the bulkhead/seawall. When the flood hazard exceeds the bulkhead/seawall top elevation the flood hazard is instantaneously transmitted into the MA unmediated by the bulkhead/seawall.

PSEs are defined in G2CRM to capture the effect of built flood risk management (FRM) infrastructure (i.e. what in G2CRM is categorized as a bulkhead/seawall). For the study area the FRM infrastructure is neither present in the existing condition nor future without project condition, but rather a part of an alternative FRM plan. Since this was the case, this influenced the decision on the MA type to use. That is a MA is not protected by a bulkhead/seawall in the existing condition but one of the FRM alternatives to be considered involves protecting the MA with an engineered bulkhead/seawall.

Therefore, for both the existing and future without condition simulation, in G2CRM, the top elevation is specified at the approximate existing ground elevation within the MA. In this way, the bulkhead/seawall does not influence the existing condition consequences of the flood hazard. For the future with project condition the bulkhead/seawall top-elevation is raised and its influence on consequences is captured.

C.1.5.1.1.3. Volume-Stage Functions

Volume-stage functions (alternatively called stage-volume functions) are associated with an upland MA. For the study area, the volume-stage functions were derived from the digital terrain model (the same used to determine ground elevation of structures) provided by Engineering and GIS sections and describe the relationship between the volume contained in the model area and the associated stage (water depths) for each MA. Water levels within the MA are computed by first estimating the volume of water passing over the PSE and then using the stage-volume relationship to determine water level within the MA. Once the storage area in the MA is filled, the flood hazard is transmitted into the MA unmediated by the bulkhead/seawall.

C.1.5.2. *Assets*

Assets are spatially located entities that can be affected by storms. For this analysis, assets consist mainly of those structures and its contents located within the Charleston Peninsula as shown in the Figure below. Charleston is a highly urbanized, relatively flat community with nearly all areas below elevation 20 feet. The low elevations and tidal connections to the Ashley and Cooper Rivers and Charleston Harbor place a significant percentage of the city at risk of flooding from nor'easters, tropical storms, hurricanes, and other storms.

Charleston is part of a rapidly growing metropolitan area known as the Tri-County area (Berkeley County, Charleston County, and Dorchester County). Moreover, according to the U.S. Census Bureau estimates, the City of Charleston has a total population of 150,227 as of April 1, 2020. Approximately 34,000 people currently reside on the peninsula and more than 40,000 people are projected to reside on the peninsula by year 2030. Currently, the Charleston Peninsula structure inventory, as modeled because the base year is 2032, contains about 12,095 structures. The reasons for the base year and structure inventory will be further discussed in the future without project condition section. Residential structures accounted for 10,399 structures, with the remaining 1,696 being nonresidential. Out of those residential and nonresidential structures, the occupancy type most commonly found was RES1 (Single Family Dwelling), RES3 (Multi Family Dwelling) and COM4 (Bus. /Prof. /Tech. Services). The following Table and Figures summarize the number of structures in each MA along with its estimated depreciated replacement costs and content values, and a breakdown of the structure occupancy types for the study area.

Table 2: Assets by Model Areas (2021 Price Level)

Model Area	Counts	Structure Value	Content Value	Total Value
Battery	1,757	$1.3 Billion	$1.1 Billion	**$2.4 Billion**
Port	1,334	$2.4 Billion	$1.1 Billion	**$3.5 Billion**
Newmarket	2,030	$1.8 Billion	$1.1 Billion	**$2.9 Billion**
Marina	4,041	$2.4 Billion	$1.7 Billion	**$4.1 Billion**
Wagener Terrace	2,933	$1.3 Billion	$1.0 Billion	**$2.3 Billion**
Total	**12,095**	**$9.2 Billion**	**$6.0 Billion**	**$15.2 Billion**

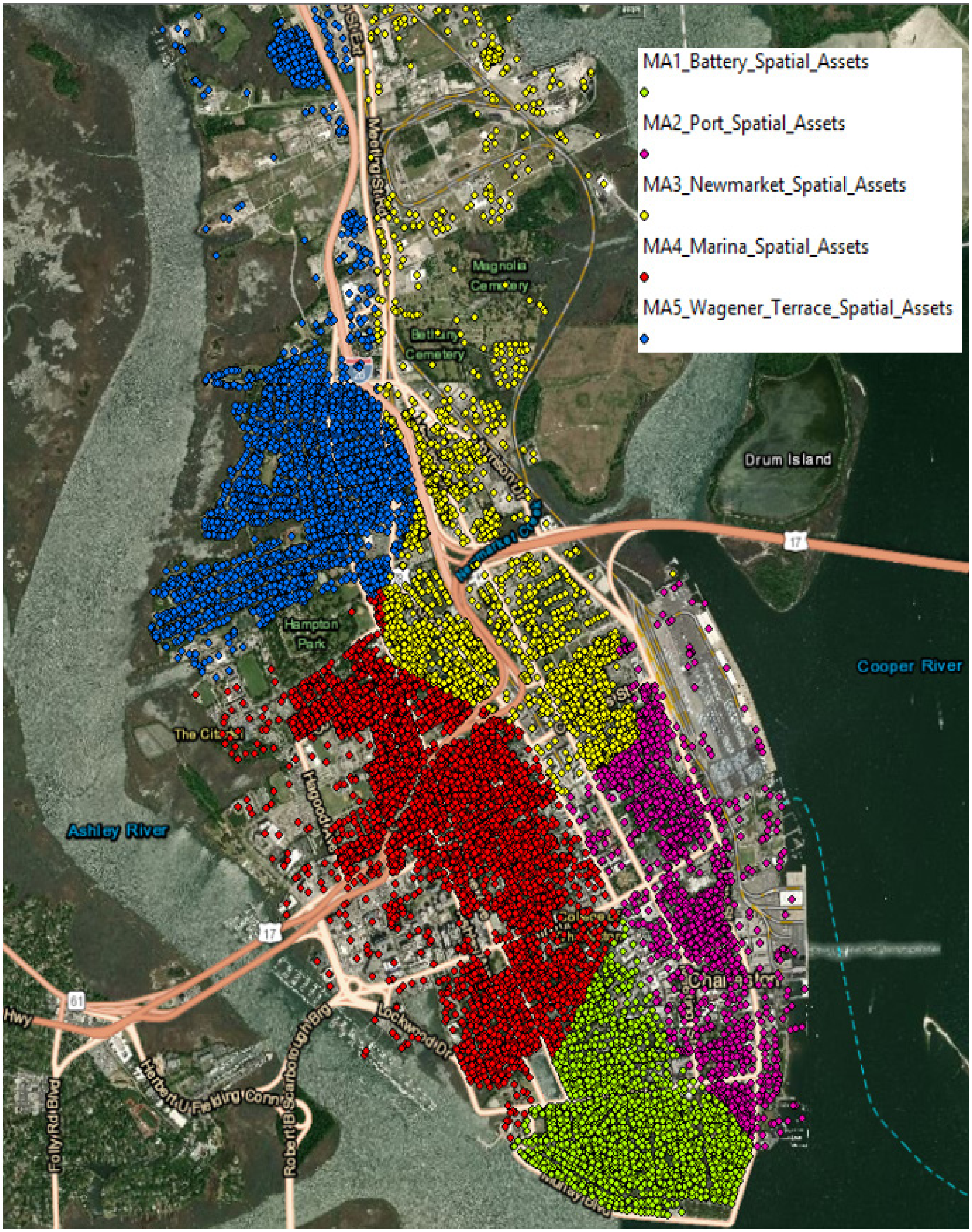

Figure 10: Location of Assets by Model Areas

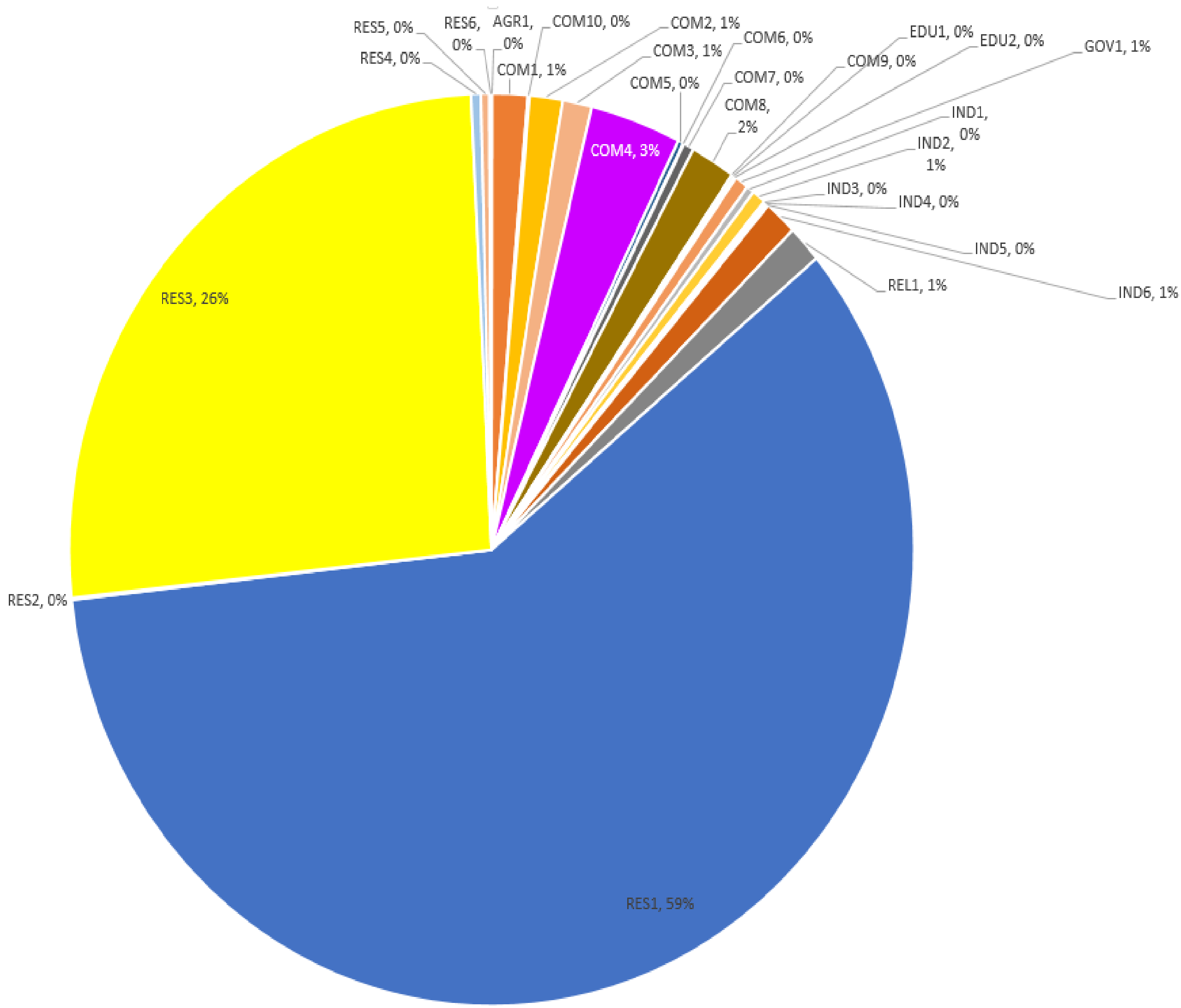

Figure 11: Occupancy Types located within the Study Area

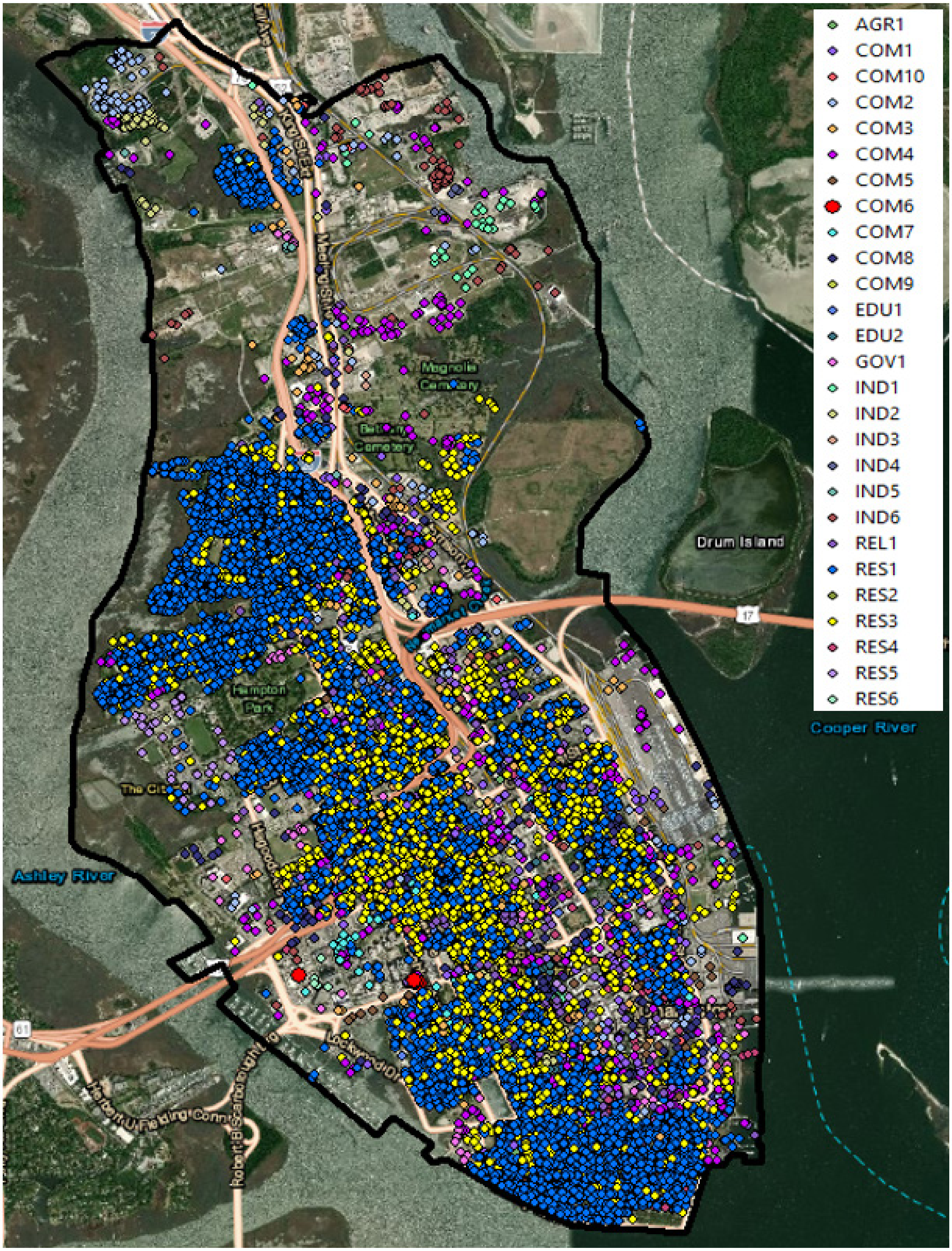

Figure 12: Location of Assets by Main Occupancy Types
(reference Table 1 for description of Occ Types**)**

C.1.5.3. *Evacuation Planning Zones*

According to the Fourth National Climate Assessment, communities in the Southeast are particularly vulnerable to flooding. Extreme weather and climate-related events can have lasting mental health consequences in affected communities, particularly if they result in degradation of livelihoods or community relocation. Populations including older adults, children, low-income communities, and some communities of color are often disproportionately affected by, and less resilient to, the health impacts of climate change. Lessons from numerous coastal storm events have made it clear that even if the elderly, functionally impaired persons, and/or low-income residents wish to evacuate from areas at risk from a pending coastal storm, they are unable to evacuate due to their physical or socioeconomic condition. Flooding in urban areas can cause serious health and safety problems for the affected population. The most obvious threat to health and safety is the danger of drowning in flood waters. Swiftly flowing waters can easily overcome even good swimmers. When people attempt to drive through flood waters, their vehicles can be swept away in as little as two feet of water.

Surface streets as well as U.S. Route 17 already close during flood events, limiting movement on the peninsula. US Route 17 currently floods more than 10 times per year. During storm events, public access to the hospitals is limited. Hospitals in the peninsula's medical district are already using johnboats and tactical vehicles to transport staff between facilities. The Medical University of South Carolina (MUSC) recently purchased a storm ready truck that can plow through four feet of water to transport doctors, nurses, and other essential employees through floodwaters on the MUSC campus.

In addition to the population on the peninsula, thousands of commuters and tourists/day users may be on the peninsula. During storm surge events, the ability of first responders to reach the location of need and the ability of individuals to reach medical facilities can be limited or cut off entirely. When a hurricane threatens South Carolina's coast, residents may plan to leave voluntarily or may be ordered to evacuate. Residents on the Charleston Peninsula will use the normal west-bound lanes of Interstate 26. To prepare for Hurricane Dorian in 2019, the South Carolina Highway Patrol and Department of Transportation reversed eastbound lanes on Interstate 26 in response to an evacuation order. The following Figure displays the location of the hospitals as well as main roads for evacuation.

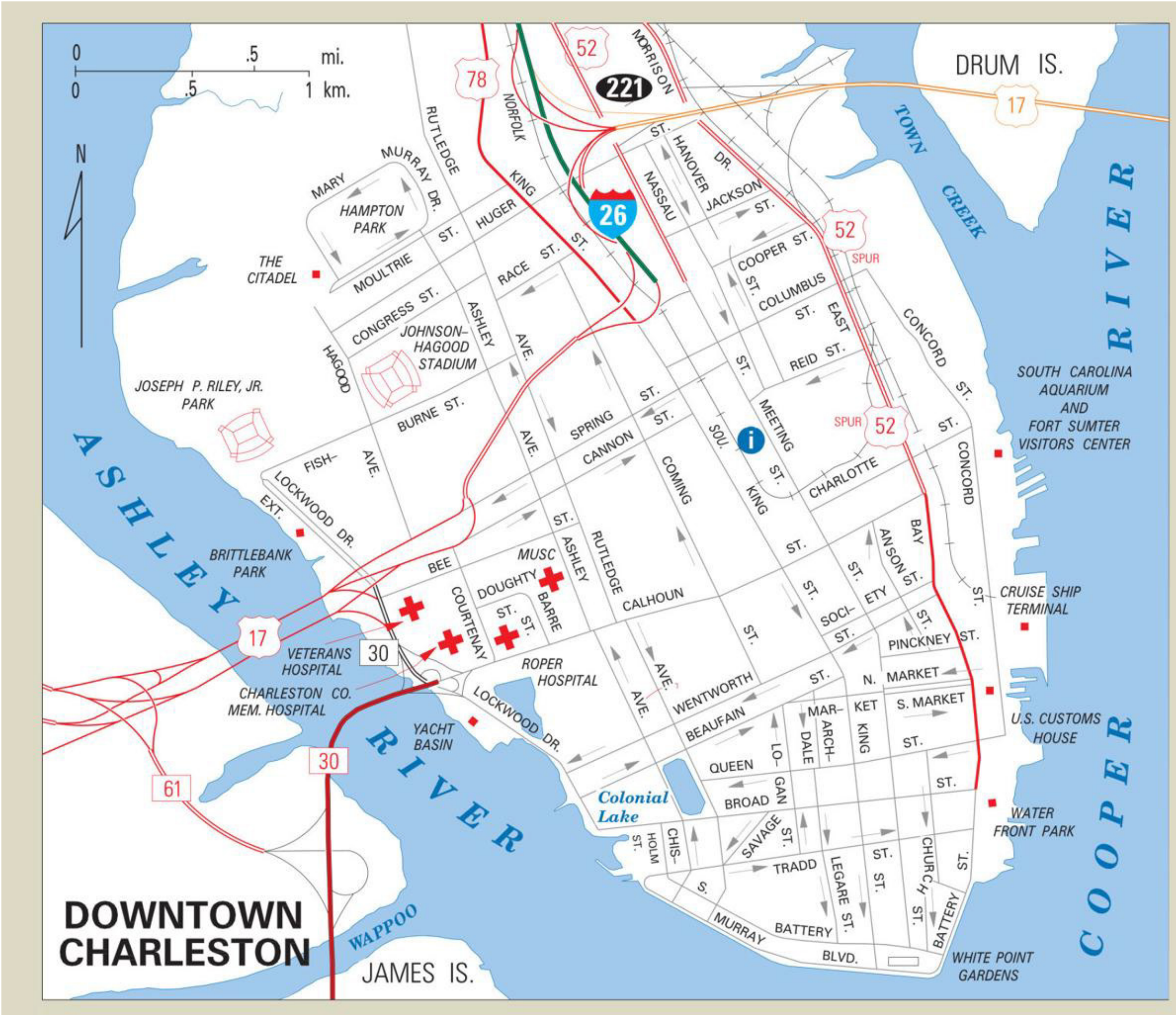

Figure 13: Medical Facilities and Evacuation Routes

An evacuation planning zone (EPZ) is a spatial area, defined by a polygonal boundary that is used within loss of life calculations in G2CRM to determine the population remaining in structures during a storm (i.e. population that did not evacuate). Since the study area was divided into 5 model areas, each MA is an EPZ as shown in the following Figure. Therefore, in G2CRM, each Asset is assigned to an MA which is subsequently assigned to an EPZ and modeled in G2RM for potential life loss given a storm event.

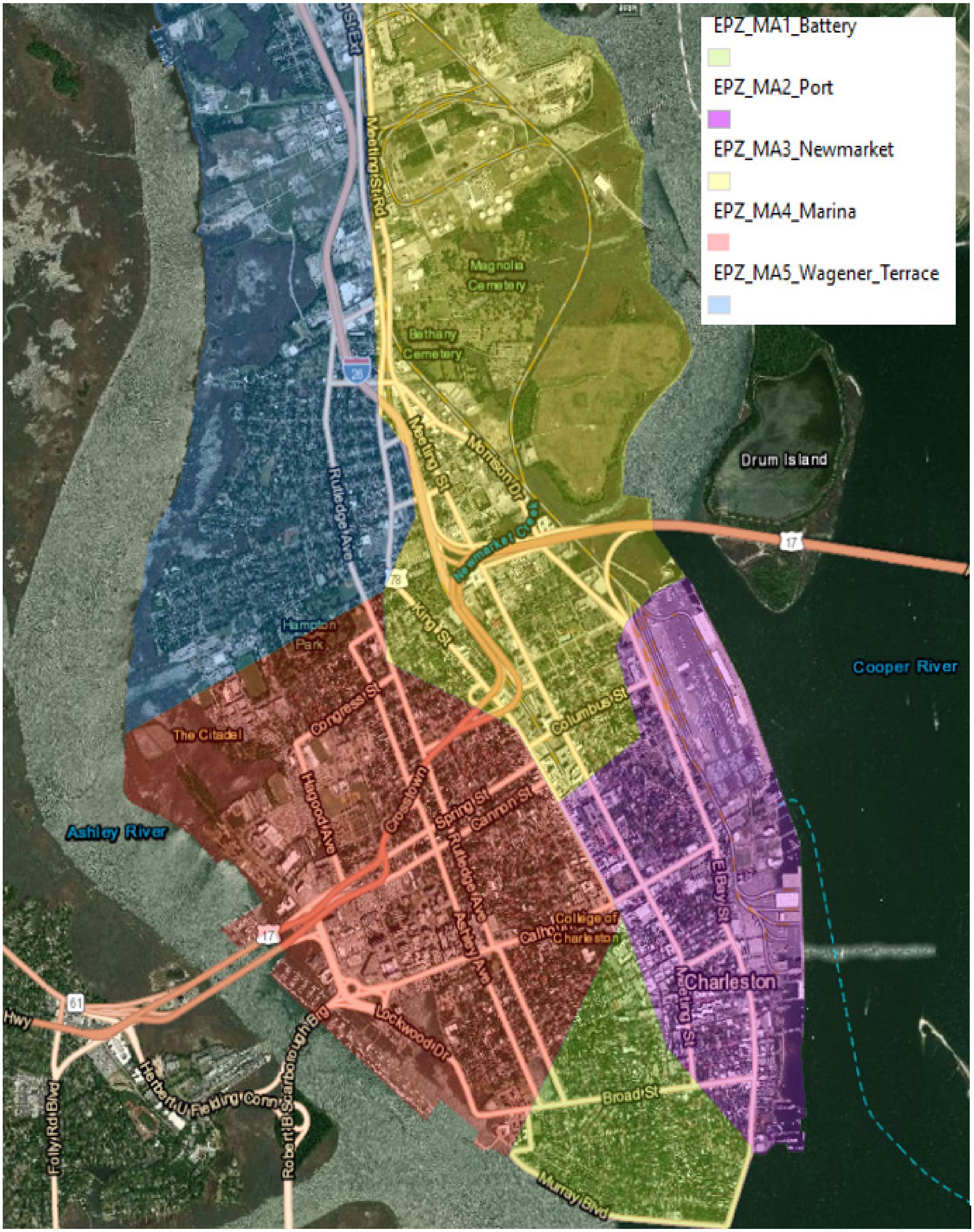

Figure 14: Evacuation Planning Zones

In G2CRM, life loss calculations are performed on a per-structure per-storm basis. In order for life loss calculations to be made, the maximum stage in the modeled area has to be at least two feet over ground elevation for foundation heights greater than or equal to two feet, or the maximum stage must be greater than the foundation height plus the ground location for foundation heights under two feet.

Loss of life calculations are separated out by age categorization with under 65 being one category and 65 and older being the second category. There are three possible lethality functions for structure residents: safe, compromised, and chance. Safe would have the lowest expected life loss, although safe does not imply that there is no life loss, and chance would have the highest expected life loss.

C.1.5.4. *Existing Condition Modeling Results*

The assets assigned to each MA and EPZ were modeled in G2CRM using the 23 storms with its relative probability-water level relationship. G2CRM used the economic (e.g. Assets) and engineering inputs (e.g. Storms) to generate expected present value (PV) damages for each structure throughout the life cycle (i.e. the period of analysis). The possible occurrences of each economic (i.e. triangular distribution) and engineering (i.e. relative probabilities) variables were derived through the use of Monte Carlo simulation and a total of 100 iterations were executed by the model for this analysis. That is every iteration represents expected PV damages for the period of analysis and cumulative damages of assets converged at about 100 iterations.

The sum of all damages for each life cycle were divided by the number of iterations to yield the expected PV damages for that modeled simulation. A mean and standard deviation were automatically calculated for the PV damages for each MA. For this analysis, G2CRM used 23 out of the 25 synthetic storms produced by high fidelity coastal modeling (reference Engineer Appendix) for each MA. Each storm had a relative probability associated with it. Any chance of that storm happening in the model simulation was based on that relative probability. Moreover, each storm given its relative probability had an equivalent specific peak water level. These water levels were applied to each structure in each MA and EPZ to determine damages and life loss. It is important to note that due to time and modeling constraints, each MA was modeled as a separate G2CRM (i.e. 5 G2CRMs for the study area). Therefore, to derive the PV damages for the study area, the PV damages of the 5 G2CRMs were summed. The following Table displays the mean expected PV damages and average annual damages for the study area by model areas for the existing condition.

Table 3: Existing Conditions Expected Damages

Model Area	Present Value Damages	Average Annual Damages
Battery	$ 4,508,000,000	$158,900,000
Port	$ 3,690,000,000	$130,100,000

Newmarket	$ 2,117,000,000	$ 74,700,000
Marina	$ 5,890,000,000	$207,700,000
Wagener Terrace	$ 1,955,000,000	$ 68,900,000
Total	**$18,160,000,000**	**$640,300,000**

According to the Table above, there are about $18.2 billion in expected PV or about $640 million in average annual flood damages due to coastal storm for the period of analysis under the existing condition. The existing flood damages are the potential damages to structures, contents affected by flooding at the time of the study. No projection is involved, and the existing condition encompasses relevant factors that best characterize the planning perceptions of the affected area in the situation without a plan. This existing condition provides the data from which to evaluate the condition that would likely exist in the future without the implementation of a Federal project. Under the future without project condition, which represents expected damages in the absence of a flood risk management project, damages are expected to increase. Exacerbating the flooding is the phenomenon of relative sea level rise, which is the combination of water level rise and land subsidence. The existing condition modeling did not take into account sea level change but the future without project condition, described in the following section, did.

C.1.6. *FUTURE WITHOUT PROJECT CONDITION*

Forecast assumptions based on the existing condition are critical to the planning process since they provide the baseline for the subsequent evaluation and comparison phases. The following discussion includes projections about the future of the Charleston Peninsula if the federal government or local interests do not address the problems identified in this study.

C.1.6.1. *Background*

The City of Charleston has experienced a marked increase in the number of days of “minor coastal flooding” over time, which will increase along with rising sea levels. Similarly, the water table below Charleston will continue to rise, limiting the effectiveness of gravity drain potential post-storm. Subsidence will increase as soil deposited naturally, or by humans, compacts over time.

According to an evaluation in the 1984 Master Drainage Plan, the existing stormwater drainage facilities within the peninsula consist mainly of vitrified clay pipe or brick arches, some of which date back to the 1850’s, and the majority of which are inadequate for design limits. However, since the1990s, the City of Charleston has made major strides in addressing interior drainage issues on the peninsula. The city has been working on alleviating drainage problems since the establishment of the Stormwater Utility in 1996, using this money to fund only stormwater projects. In addition to this fund, the city has sought other funding sources to tackle large capital improvement projects and improve the quality of life on the peninsula. The city has invested over $260 million in drainage projects, with several more unfunded projects in the works.

The study assumes that the check valve program on the drainage system outfalls will be completed in the future without project condition, preventing tidal backflow into the system. The local drainage system will slowly be improved during the period of analysis subject to funding availability. The future without-project condition assumes that each local drainage project is complete. This assumption has been coordinated with the City of Charleston throughout the study and in good faith confirmed still to be accurate. These projects have been permitted, and some are currently under construction and estimated to be completed between 1 to 4 years depending on the specific drainage project. These projects will address some site-specific flooding problems but still will leave the city vulnerable to storm surge inundation.

In the future without project condition, the Low Battery Seawall project is complete. However, the people and properties behind the seawall remain at risk because the Battery does not tie into high ground. This same assumption was applied in the existing condition (reference the PSE section of this Appendix). Moreover, it is important to note that development and population in the study area is projected to increase in both future conditions. There are several housing development projects on the Charleston Peninsula to accommodate the influx of new residents.

Nevertheless, since the base year is projected to be 2032 for modeling purpose, those structures that already received building permits and have broken ground but not completed or yet built were included in the asset inventory inclusive of estimates for structure and content values and population numbers. After the base year 2032 to the year 2081, for modeling purposes, there were no other future projection for development assumed (i.e. to avoid deriving future damages and consequences for unknown development). This assumption is reasonable because the City of Charleston strictly enforce floodplain management ordinances. In addition, the City of Charleston is already increasing freeboard recommendations for new facilities and infrastructure to 2 to 3 feet above base flood elevation, incentivizing private property owners to implement green infrastructure, conducting a vulnerability analysis to inform the Comprehensive Plan Update and revaluation of the City's zoning ordinance, and creating design guidelines for retrofitting historic buildings and assisting property owners in developing resilient design solutions.

The study area is also highly urbanized so there are not extensive natural resources present. There are some small tidal creeks, mudflats, and saltmarshes around the perimeter of the peninsula. While marsh habitat has adapted to fluctuating water levels and periodic inundation, there is concern regarding storm-induced erosion to existing marsh. As development pressures continue to reduce open space and degrade the natural habitat in the Charleston Peninsula, the quantity and quality of natural habitat and open space will continue to decline.

Historic and cultural resources will continue to be at risk from flooding events. A major draw for tourism is the Charleston Old and Historic District comprising a large portion of the southern peninsula (reference Figure below). The historic district contains primarily residential buildings in addition to commercial, ecclesiastical, and government-related buildings. The great concentration of 18th and 19th century buildings give the district a flavor of an earlier America. Moreover, surface streets as well as U.S. Route 17 already close during flood events, limiting movement on the peninsula (reference the Figure below). U.S. Route 17 currently floods more than 10 times per year and is expected to experience up to 180 floods annually by 2045 (NCA4).

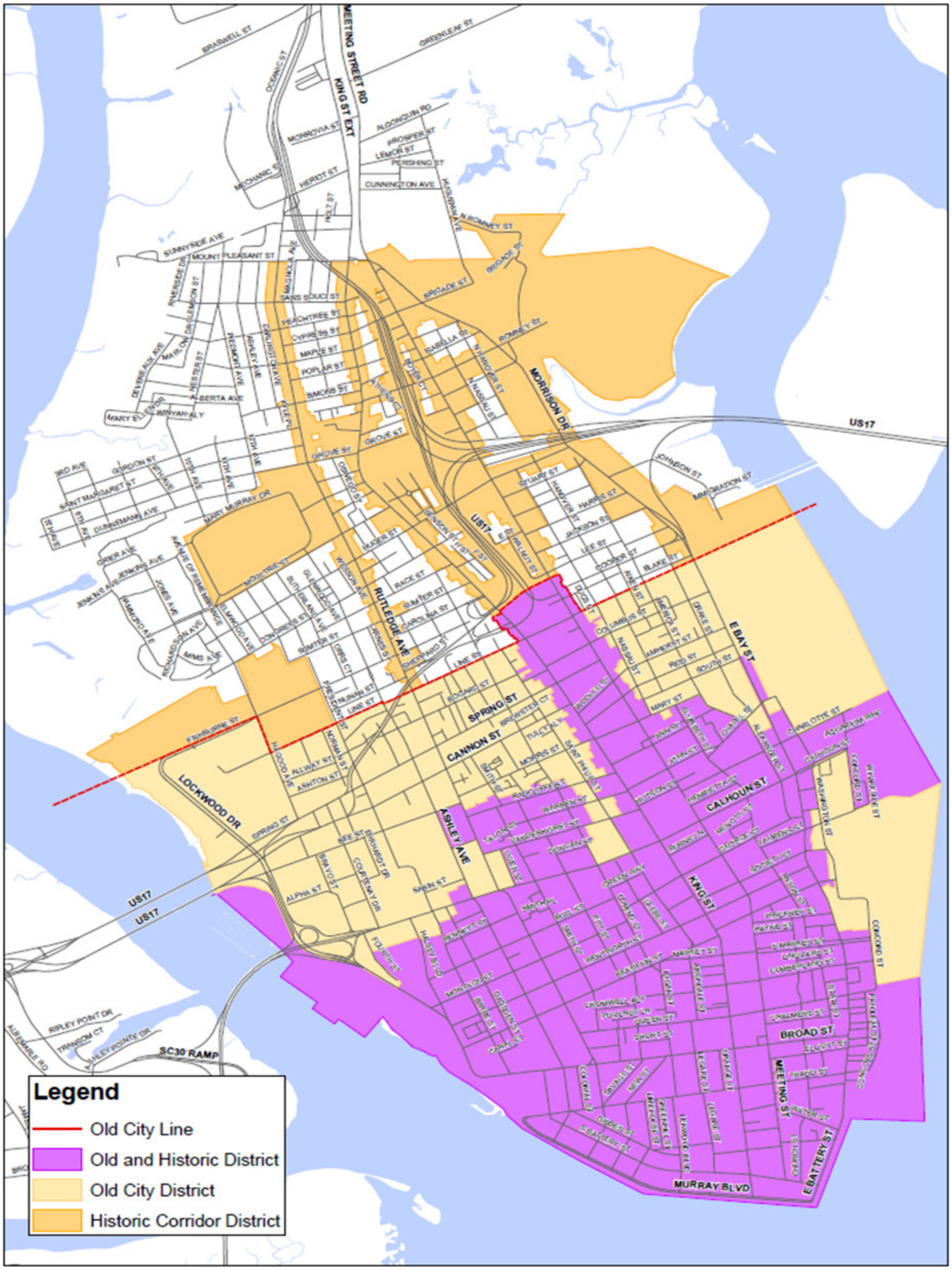

Figure 15: Charleston Peninsula Districts
(Source: City of Charleston Dept. of Planning, Preservation & Sustainability)

The Charleston Harbor tide gauge has been measuring sea level continuously since 1921. In that nearly 100-year time span, local sea level has risen 1.07 feet. The City of Charleston has experienced a marked increase in the number of days of minor coastal flooding, commonly called nuisance, sunny day, or high tide flooding. Currently, low-lying areas of the peninsula begin to flood when water levels reach 7 feet above mean lower low water (MLLW). Charleston has experienced 8 of the top 15 tides ever recorded in the last four years, although not all were associated with storms. This analysis considers the impacts that relative sea level rise will have on the elevation of high tides under both future with and without project alternatives consistent with ER 1100-2-8162, "Incorporating Sea Level Change in Civil Works Programs." Sea level rise will result in a corresponding increase in tidal elevations. Research by climate science experts predict continued or accelerated climate change for the 21st Century and possibly beyond, which would cause a continued or accelerated rise in the sea level in the Charleston area.

C.1.6.2. *Future Without Project Condition Modeling Results*

The years 2032-2081 were selected to represent the future without project condition. For modeling purposes, it was assumed that development built after the base year would not be subject to future flood risk during the period of analysis. However, a combination of both wealth and complementary effects are likely to contribute to growth in the value of the assets at risk in the study area. The same 12,095 structures on the Charleston Peninsula will continue to be affected by the risk of flooding from coastal storms and suffer increasing losses each year. The following Table displays the mean expected PV damages and average annual damages for the study area by model areas for the without project condition. Moreover, the following Figure (stack chart) display the % of asset counts, values, and the future without project condition PV damages for each MA. According to the following Figure, the Marina MA makes up the most count, value, and damages of structures in the study area.

Table 4: Future Without Project Condition Damages

Model Area	Present Value Damages	Average Annual Damages
Battery	$ 5,547,000,000	$186,000,000
Port	$ 6,287,000,000	$211,000,000
Newmarket	$ 3,259,000,000	$109,000,000
Marina	$ 7,389,000,000	$248,000,000
Wagener Terrace	$ 2,652,000,000	$ 89,000,000
Total	**$25,134,000,000**	**$842,000,000**

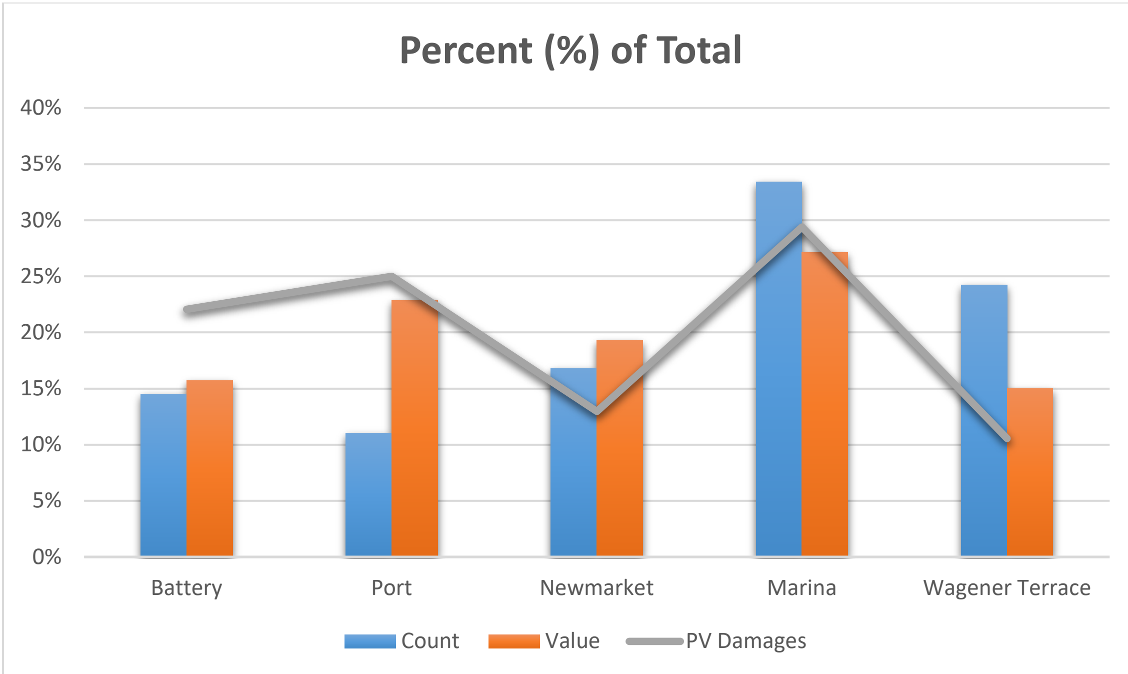

Figure 16: Asset Count, Value, and PV Damages by Model Areas

The result shown above is the sum of all damages for each life cycle were divided by the number of iterations to yield the expected PV damages for that modeled simulation. A mean and standard deviation were automatically calculated for the PV damages for each MA to account for uncertainty. These PV damages for each MA were summed to derive the study area expected PV damages.

The forecasted sea level rise in the future, without a project in place, resulted in higher expected average PV damages. According to the Table above, the total future "without project" PV damages are approximately $25 billion or about $842 million average annually. The forecast of the future without project condition reflects the conditions expected during the period of analysis and provides the basis from which alternative plans are evaluated, compared, and selected since a portion of the flood damages would be prevented (i.e. flood damages reduced) with a Federal project in place.

Furthermore, according to the modeling results, for a typical life cycle (reference Figure below), the majority of damages were shown to have incurred more toward the beginning of the life cycle, levels off some in the middle of the life cycle, and then decrease some towards the end of the life cycle. This seems reasonable given the modeling assumptions (reference Assumptions Section) that people will react in a rational manner. When assets get damaged, there will be a rebuilding period (assets offline in the model and not receiving damages) and these same assets would be rebuilt to a higher elevation (i.e. to reduce risk of future flooding). Therefore, as the life cycle gets toward the end, these damages would be more reflective of water levels associated with the less frequent storm events; thus, these damages (towards the end) would be less than those damages reflective in the beginning of the life cycle.

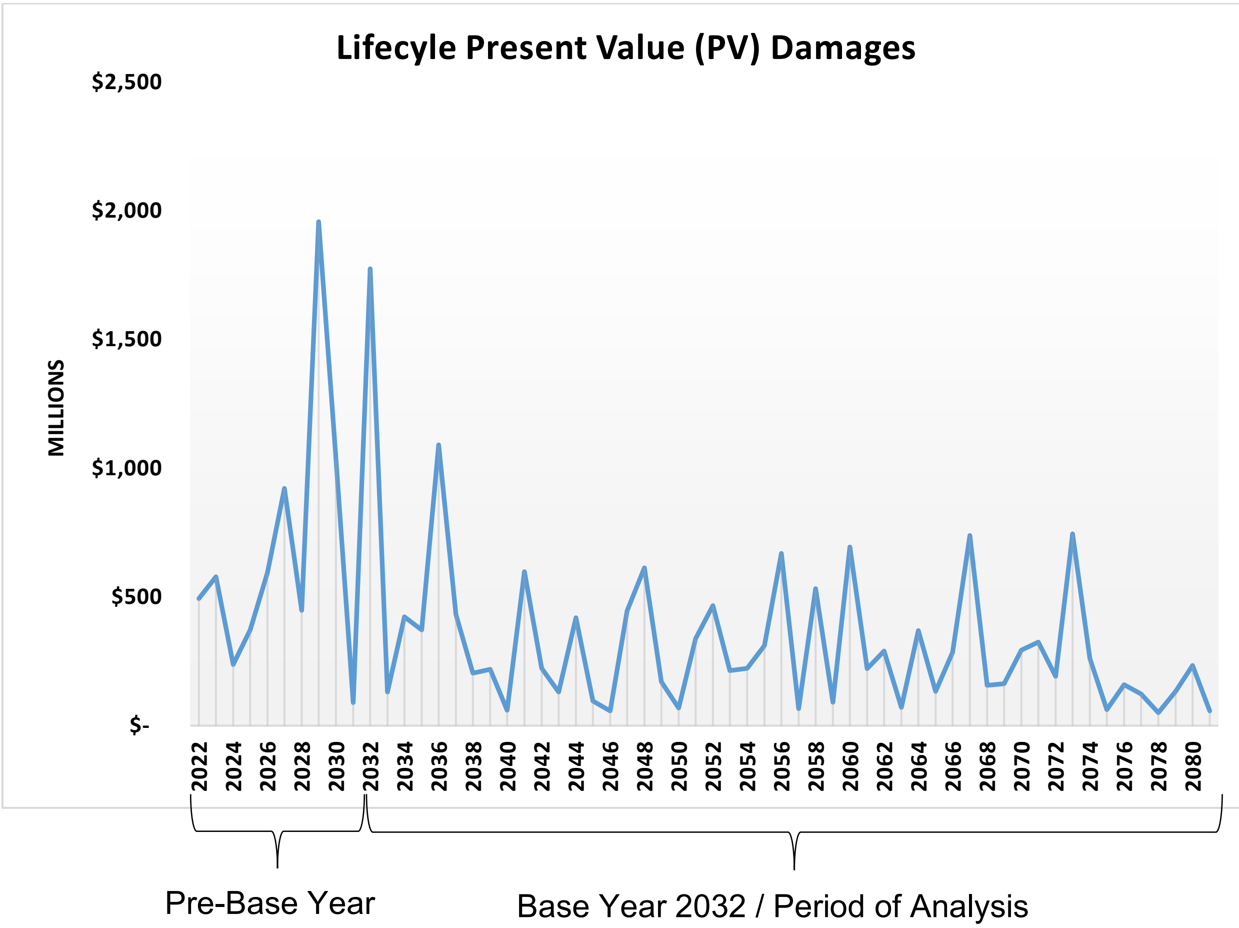

Figure 17: PV Damages for a Typical Modeled Life Cycle Analysis

Additionally, the damages based on a typical life cycle from the model, was shown to be more concentrated in the low-lying areas of the peninsula which are along the peninsula's coast (reference Figure 8). More specifically, these higher damages were shown to be predominately in the Marina MA along Lockwood Drive and the Port MA around East Bay Street. While most of Charleston Peninsula is made up of residential structures and shown to receive damages, mainly in the Old and Historic District (reference Figure 15), the Marina MA contains the Medical District and like the Port MA contains many commercial structures (reference Figure 9, Figure 10, and Figure 12).

C.1.7. *FUTURE WITH PROJECT CONDITION*

The future with project condition is the most likely condition expected to exist in the future if a specific project is undertaken. There are as many future with project conditions as there are project alternatives. A total of four alternatives were considered for the study. The analysis did not formulate a project alternative for recreation because it is considered incidental to the project. The analysis includes a discussion of residual flood damages and flood damage reduction for each alternative.

C.1.7.1. *Formulation of Alternatives*

A formulation strategy is a systematic way of combining measures into alternative plans based on the planning objectives. No single formulation strategy will result in a diverse array of alternatives, so a variety of strategies is needed. During the first planning iteration, the project delivery team (PDT) considered that there are basically three things to do with floodwater: store it, blocking it from inundating a specific area, or convey it to another area. Using these three strategies, alternative plans were formulated. During the second planning iteration, spatial aspects were added to the strategies to address conditions specific to the Charleston Peninsula. However, when the PDT determined that measures related to storage, conveyance, and historical creek restoration would not reasonably reduce storm surge inundation, these measures were screened from further consideration and alternatives that were developed using those strategies were likewise removed from consideration.

For this study, the following strategies were used in formulating the initial array of alternatives:

Diversion – This strategy focused on measures that would divert floodwaters from damageable property. Since the primary concern is floodwater from coastal storm surge and not riverine sources, the measures were variations of in-water and shoreline based barriers.

Nonstructural – This strategy focused on measures and actions that would allow the Charleston Peninsula to live with the flood waters. Nonstructural measures are permanent or contingent measures applied to a structure and/or its contents that prevent or provide resistance to damage from flooding. Nonstructural measures differ from Structural measures in that they focus on reducing the consequences of flooding instead of focusing on reducing the probability of flooding. This strategy resulted in a stand-alone nonstructural alternative.

Spatial – This strategy focused on applying different management measures to specific areas of the peninsula. For example, nonstructural measures would be applied to areas where construction of a structural barrier is constrained by other considerations.

C.1.7.1.1. *Initial Array of Conceptual Alternatives*

No Action Alternative

The No Action Alternative assumes that no actions would be taken by the Federal Government or local interests to address the problems identified by the study.

Consequently, the No Action Alternative would not reduce damages from coastal storm surge inundation. Although this alternative would not accomplish the purpose of this study, it must always be included in the analysis and can serve several purposes. The No Action Alternative will be used as a benchmark, enabling decision makers to compare the magnitude of economic, environmental, and social effects of the actionable alternatives. Additionally, the No Action Alternative and future without project condition are assumed to be the same for this study.

1. Perimeter Protection Alternative

This alternative was a result of the diversion formulation strategy. This alternative consists of the following measure:

- A wall or levee along the perimeter of the Peninsula, strategically placed onshore or in marsh to reduce damages from storm surge inundation while maintaining access to property.

This wall or levee would be newly constructed and aligned to avoid or minimize impacts to existing marsh, wetland habitat, and cultural resources. The structure would be strategically located to allow for continued operation of all ports, marinas, and the Coast Guard Station. The structure would tie into the existing Battery seawall and potentially raise the seawall to provide a consistent level of performance.

A variety of different structures were considered during the early formulation process. Further analysis determined that the footprint of an earthen levee embankment was too large for the heavily developed peninsula and would require condemnation of too many properties and/or excessive salt marsh impacts. The most effective and most efficient type of structure would be a T-wall on land and a combination wall in the marsh. Existing topography, relatively high ground elevations, and other constraints makes extension of a wall or levee into the Neck Area of the peninsula impracticable . A refined description of this alternative can be found in the Final Array of Alternatives section.

2. Perimeter Protection + Nonstructural Alternative

This alternative was formulated using a combination of formulation strategies: diversion and spatial. The management measures included in this alternative are:

- A wall or levee along the perimeter of the Peninsula
- Buyout structures
- Elevate structures
- Floodproof structures

The wall along the perimeter of the Peninsula would adhere to the same constraints and assumptions as the Perimeter Protection Alternative. For structures outside of the wall alignment, a suite of nonstructural measures including buyouts, structure elevation, or floodproofing measures could apply. Oyster reef-based living shoreline sills would be constructed in appropriate locations as part of this alternative; however, upon further USACE review the living shoreline component was determined to be ineffective in the reduction of coastal storm surge when combined with a wall, but effective in mitigating the impact of a wall on adjacent habitat.

3. Perimeter Protection + Wave Attenuating Structure + Nonstructural Alternative

This alternative was formulated using a combination of formulation strategies: diversion and spatial. The management measures included in this alternative are:

- A wall or levee along a portion of the Peninsula's perimeter
- Wave attenuating structure
- Buyout of structures
- Elevate structures
- Floodproof structures

The storm surge wall along the perimeter of the Peninsula and nonstructural measures in this alternative would adhere to the same constraints and assumptions as described in Alternative 2. A wave attenuation structure would be constructed in the Charleston Harbor to dampen waves, reduce loading on seawalls, and prevent waves from overtopping during storm events. For the purposes of this study, the wave attenuating structure is assumed to be a breakwater made of granite stone or rubble mound. If this measure was incorporated into the recommended plan, other types of wave attenuating structures would be considered during the preconstruction, engineering, and design phase, such as a nearshore berm made of dredged material or a manufactured breakwater. Additional analysis would determine the actual numbers of structures proposed for buyout, elevation, or floodproofing.

4. Nonstructural Alternative

This alternative was formulated to include both actions that can be implemented by the Corps and actions that can only be implemented by the non-Federal sponsor (shown in italics). This alternative would consist of the following measures:

- Relocation or buyout of structures
- Elevate structures
- Floodproof structures
- *Flood warning system*
- *Revise emergency response plan*
- *Low-impact development / green infrastructure measures*

Storm surge inundation would not be limited on the Charleston Peninsula with this alternative, but damages would be reduced due to the application of nonstructural measures to vulnerable structures. Additional analysis would determine the actual numbers of structures proposed for buyout, elevation, or floodproofing.

C.1.7.1.2. *Alternatives Screening*

The PDT performed additional planning iterations with a focus on screening alternatives that would not meet planning objectives. Without substantial data to base the screening on, professional judgment was used to assess how well alternatives met a set of criteria.

The screening criteria used in this study for the initial array of conceptual alternatives include effectiveness, efficiency, acceptability, and completeness as defined in the Economic and Environmental Principles and Guidelines for Water and Land Related Resources Implementation Studies (Principles and Guidelines), by the Water Resources Council pursuant to the Water Resources Planning Act of 1965, as amended. Effectiveness is the ability of the measure to meet or partially meet a study objective. Efficiency is the extent to which an alternative plan is the most cost-effective means of alleviating the specified problems and realizing the specified opportunities, consistent with protecting the Nation's environment. Acceptability is the extent to which the alternative plans are acceptable in terms of laws, regulations, and public policies. Completeness is the extent to which a given alternative plan provides and accounts for all necessary investments or other actions to ensure the realization of the planned effects.

Study constraints were also used as a screening criterion. Study Constraints is the likelihood that the measure does not violate a constraint identified. The following Tables contains an assessment of how well each alternative meets the study objectives and avoids the constraint. Additionally, how well each alternative met the four evaluation criteria as prescribed in the Principles and Guidelines. More information regarding alternatives screening is found in the Main Report.

Table 5: Screening Assessment

Alternative	Assessment	Objective: Reduce Economic Damages and Increase Resilience?	Objective: Reduce Risk to Human Health, Safety, and Emergency Access?
No Action	No action would be taken by the Federal Government to address the problems identified by the study, therefore the No Action Alternative would not reduce damages from coastal storm surge inundation or meet study objectives.	No	No
1. Perimeter Protection	The strategically placed wall or levee would reduce damages to structures by limiting storm surge inundation on the peninsula. A wall or levee would reduce risk to human life and safety by limiting road closures, thereby improving access to critical facilities, emergency services, and evacuation routes. Impacts to public health would also be reduced by limiting illness and injury associated with storm surge inundation. Perimeter protection would benefit a representative cross-section of socio-economic communities on the peninsula. However, areas where perimeter protection is impracticable would lack protection	Yes	Yes
2. Perimeter Protection + Nonstructural	Like Alternative 1, this alternative would reduce damages to structures and reduce risk to human health and safety for a representative cross-section of socio-economic communities on the peninsula, including environmental justice communities. This alternative would provide comprehensive risk reduction because nonstructural measures would be applied to residential structures in areas where a storm surge wall or levee would not be practicable.	Yes	Yes
3. Perimeter Wall + Nonstructural +Wave Attenuator	Like Alternatives 1 and 2, this alternative would reduce damages to structures and reduce risk to human health and safety. A wave attenuation structure in the Charleston Harbor might reduce the effect of waves from overtopping floodwalls during coastal storm events, further limiting inundation on the peninsula. The wave attenuation structure might also reduce wave loading on the Battery Wall.	Yes	Yes
4. Nonstructural Only	This alternative would reduce damages to structures by elevating, floodproofing, or otherwise acquiring vulnerable structures on the peninsula. This alternative would not address storm surge inundation	Yes	No

	that limits access to critical facilities, emergency services, and evacuation routes. It would increase some, but not all, aspects of resilience. Further, a buyout of structures vulnerable to storm surge inundation would violate the constraint of minimizing adverse effects to historic districts and buildings.		

Table 6: Screening of Alternatives Based on Evaluation Criteria from the Principles and Guidelines

Alternative	Completeness	Effectiveness	Efficiency	Acceptability	Score	Result
1. Perimeter Protection	High (3)	Medium (2)	Medium (2)	Medium (2)	9	Screen
2. Perimeter Protection + Nonstructural	High (3)	High (3)	High (3)	Medium (2)	11	Retain
3. Perimeter Protection + Nonstructural + Wave Attenuator	High (3)	High (3)	Low (1)	Medium (2)	9	Screen
4. Nonstructural Only	High (3)	Medium (2)	Low (1)	Low (1)	7	Screen

Each alternative in the initial array fulfills both study objectives with the exception of the Alternative 4, the Nonstructural Only Alternative, which fails to address impaired access to critical facilities, emergency services, and evacuation routes during coastal storm events, and would achieve some but not all aspects of resilience. Additionally, a buyout of vulnerable structures would violate the constraint of minimizing adverse effects to historic districts and buildings. Even widespread floodproofing and elevation of structures could have cumulative adverse impacts to historic districts on the peninsula. Although Alternative 1 addresses both study objectives, Perimeter Protection alone, reduces economic damages to a lesser degree, by leaving neighborhoods vulnerable to storm surge inundation where a wall or levee is impracticable to construct. In conclusion, Alternatives 2 and 3 were assessed to be the most effective at addressing both study objectives.

Alternative 4 received an overall score of 7, which is the lowest score on the Principles and Guidelines evaluation criteria assessment. The alternative scored low in effectiveness because it would not adequately address risks to human health and safety as discussed in Table 5, and would only partially realize the opportunity to increase the resilience of the Charleston Peninsula to storm surge flooding. Alternative 4 received a low efficiency score due to the high density of high-cost structures vulnerable to storm surge inundation that would need to be treated with nonstructural measures, some of which are not susceptible to such measures (for example, medical facilities and infrastructure). Alternative 4 also received a low score in acceptability due to negative anticipated reactions from the public.

Alternative 3 received an overall score of 9 on the P&G evaluation criteria. The alternative received a high effectiveness score because the storm surge wall is effective at reducing storm surge inundation; however, after further review it was determined that the wave attenuating structure is not. Instead, the wave attenuating structure is effective at reducing impacts from wave attack and erosion, which translates to minimal inundation reduction benefits when combined with a wall. Alternative 3 received a low efficiency score because the wave attenuation measure is a high-cost measure that does not produce inundation reduction benefits in addition to the storm surge wall. The April 2020 draft FR/EA identified Alternative 3 as the plan that most reasonably maximized net benefits; however, refined engineering and economic analyses showed that the wave attenuator did not generate benefits to justify its cost, resulting in a reduced efficiency score as reflected in Table 3-2 of this report. Accordingly, since Alternative 3 without the wave attenuation structure was the same as Alternative 2, it was screened from further consideration.

Alternative 1 also received an overall score of 9 on the P&G evaluation criteria. However, the alternative received a medium effectiveness score because while the storm surge wall is effective at reducing storm surge inundation, the neighborhoods in areas where a wall or levee is impracticable would be left vulnerable to storm surge as discussed above. Alternative 1 received a medium efficiency score because it does not capture damage reduction benefits of the nonstructural measures.

In summary, Alternative 4 was screened because it did not address both study objectives and it also scored the lowest on the P&G evaluation criteria assessment. Alternative 3 was screened due to the significant inefficiency of the wave attenuator measure. Alternative 1 was screened because it did not provide a comprehensive solution for the entire study area, leaving Alternative 2 and the No Action Alternative to be carried forward to the Final Array of Conceptual Alternatives.

C.1.7.1.3. *Final Array of Alternatives*

Based on the screening criteria and process outlined above, the final array of alternatives includes the No Action Alternative and Alternative 2 as described below. At this point in the study, additional information has been developed and incorporated into the description of each alternative.

No Action Alternative

The No Action Alternative assumes that no actions would be taken by the Federal Government to address the problems identified by the study. Consequently, the No Action Alternative would not reduce the risk of damages from coastal storm surge inundation. As noted above, although this alternative would not accomplish the purpose of this study, the National Environmental Policy Act requires that it must always be included in the analysis and can serve several purposes. The No Action Alternative is used as a benchmark, enabling decision makers to compare the magnitude of economic, environmental, and social effects of the actionable alternatives. Additionally, the No Action Alternative leads to the future without-project condition.

Alternative 2

The management measures included in this alternative are:

- Storm surge wall along the perimeter of the Peninsula (approximately 8.7 miles)
- Nonstructural measures (approximately 100 structures)

The storm surge wall would be constructed along the perimeter of the peninsula to reduce damages from storm surge inundation. Where feasible, it would be strategically aligned to minimize impacts to existing wetland habitat, cultural resources, and private property. The wall would be strategically located to allow for continued operation of all ports, marinas, and the Coast Guard Station. The wall would tie into high ground as appropriate, including the shoreline near the Citadel and the existing Battery wall. Due to its age and uncertainty about the integrity of the structure, the High Battery wall would be reconstructed to meet USACE construction standards and raised to provide a consistent level of performance. This alternative would include permanent and temporary pump stations to the extent justified per USACE policy, as well as pedestrian, vehicle, railroad, boat, and storm (tidal flow) gates.

As previously noted, a storm surge wall was determined to be more appropriate than a levee due to the large amount of real estate that would need to be acquired to accommodate a significant levee footprint. Also, since much of the existing shoreline is fill material, a levee large enough to reduce storm surge damages would likely be subject to subsidence, which would result in maintenance and performance issues. On land, the storm surge wall would be a T-wall with traditional concrete stem walls and pile supported bases. In the marsh, the storm surge wall would be a combination wall (combo-wall), which consists of continuous vertical steel piles on the storm surge side and battered steel pipe piles on the other side, connected by a concrete cap. To withstand earthquakes, pilings for both wall types would be 50 to 70 feet deep to tie into the bedrock. From the center of the wall on each side, a perpetual 25-foot-wide easement is required for maintenance, plus a 10-foot-wide temporary construction easement.

A wall with an elevation 13 feet NAVD88 or higher was not analyzed due to topographic, infrastructure, and viewshed constraints, as well as increases in cost and impacts to the construction duration. A storm surge wall at elevation 13 feet NAVD88 or higher would require that the Low Battery Seawall, currently being repaired and elevated by the City of Charleston, would need to be demolished and replaced due to insufficient strength and stability to support higher elevations.

Along Lockwood Drive, the storm surge wall would be located beneath elevated segments of Spring Street and Cannon Street. A wall at 13 feet NAVD88 or higher would interfere with the bridge superstructures, requiring reconstruction to integrate the wall and bridges. Such construction may require closing Spring Street and Cannon Street which are also US Highway 17, a major thoroughfare with high average daily traffic and important access on and off the peninsula. Traffic disruptions would likely occur for a period of 12 months or more.

A wall with an elevation 13 feet NAVD88 or higher would eliminate opportunities to tie-in to higher ground near the Citadel Campus. This would eliminate construction phasing opportunities on the Ashley River side of the peninsula and increase the timeframe for benefits to be realized for the critical infrastructure of the medical district. The length of the wall would also increase to be able to tie into high ground or form a complete closure system. Additional vehicular gates, including a gate crossing US Highway 52, a major thoroughfare, would be required, further complicating project operations. Although not estimated, increases in cost and completion schedule would be significant. Adding a foot of elevation to the proposed 12 feet NAVD88 wall would materially increase the construction cost along the entire length of the wall.

Finally, a wall with an elevation 13 feet NAVD88 or higher would also require additional mitigation measures to compensate for increased loss of viewshed and increased length of combo-wall in the marsh. Although mitigation costs are not estimated, they are expected to be significant. A wall with a top elevation of 13 feet NAVD88 or higher would incur the cost and completion schedule increases described above. A wall with a top elevation of 13 feet NAVD88 or higher is not likely to be incrementally justified and is considered to be impracticable due to additional costs and construction schedule impacts. The final optimized alignment of a 12 feet NAVD88 wall would be determined in PED should the alternative be selected.

In addition to the storm surge wall, this alternative includes nonstructural measures that would be applied to residential structures in locations where it would be impracticable to construct the perimeter wall. The neighborhoods of Rosemont and Bridgeview in the Neck Area of the Peninsula have been identified as nonstructural areas because of topographical and other constraints (reference Main Report regarding nonstructural measures). Smaller wall systems in these neighborhoods would require acquisition of a significant proportion of the community and/or significant impacts to remaining marsh habitat. Utilities in the Lowndes Point neighborhood have been identified for nonstructural measures because residential homes are already elevated to or above 12 feet NAVD88.

Figure 18: Alternative 2 Illustration

C.1.7.2. *Evaluation of Alternatives*

Relevant data for each of the alternatives described above were entered into G2CRM as alternative plans and potential for flood damages reduced were calculated. The modeling results for each alternative are summarized in the following sections.

C.1.7.2.1. *No Action Alternative*

The No Action Alternative and future without-project condition are assumed to be the same for this study. Therefore, the modeling results of the No Action Alternative is the same as the modeling results for the future without-project condition as discussed in Section C.1.6.2.

C.1.7.2.2. *Alternative 2 Modeling Results*

Alternative 2 includes a perimeter wall that would be constructed along the perimeter of the peninsula. It would be strategically placed onshore or in marsh to reduce damages from storm surge inundation while maintaining access to property. For the purposes of alternative evaluation, a footprint for a wall with a top elevation of 12 feet NAVD88 was assumed. Moreover, as mentioned in the Protective Systems Elements section of this Appendix, both the existing and future without condition simulation the top elevation for the bulkhead/seawall PSE was specified at the approximate existing ground elevation within the MA.

However, for the future with project condition, the top elevation for this same bulkhead/seawall PSE in G2CRM is specified at 12 feet NAVD88 for Alternative 2 to represent the perimeter wall measure in the future with project condition. The PSE prevents transmission of the flood hazard into the model areas until the flood hazard exceeds the top elevation of the bulkhead/seawall. When the flood hazard exceeds the bulkhead/seawall top elevation the flood hazard is instantaneously transmitted into the model areas unmediated by the bulkhead/seawall and the model then calculates water surface elevations within the model area based on the stage-volume function. In short, the PSE reduces flood risk (e.g. damages) in the study area up to 12 feet NAVD88.

Moreover, nonstructural measures were modeled in conjunction with the perimeter wall in G2CRM. The nonstructural measures included structural elevation of houses in the Wagener Terrace area and floodproofing buildings in the Newmarket area. The structural elevation in the Wagener Terrace was limited to single family residential structures (i.e. RES1 occupancy type) in the Rosemont Community that were identified to have a first floor elevation of less than 12 feet NAVD88. The floodproofing in Newmarket was limited to multi-family residential structures (i.e. RES3 occupancy type) for the Bridgeview Community and consisted of dry floodproofing the buildings. These buildings have a first-floor elevation of around 9 to 10 feet NAVD88 and with dry floodproofing would receive a reduction in flood risk up to 3 feet above the first-floor elevation. Both of these communities (shown in Figure 19) were considered for nonstructural measures because constructing a perimeter wall at these locations mostly likely would not be practicable (e.g. no natural high ground to tie into). Due to this fact, these nonstructural measures are inclusive of Alternative 2 and would be evaluated as one alternative. More information regarding the Rosemont and Bridgeview communities can be found in the Environmental Justice Section of the Environmental Appendix.

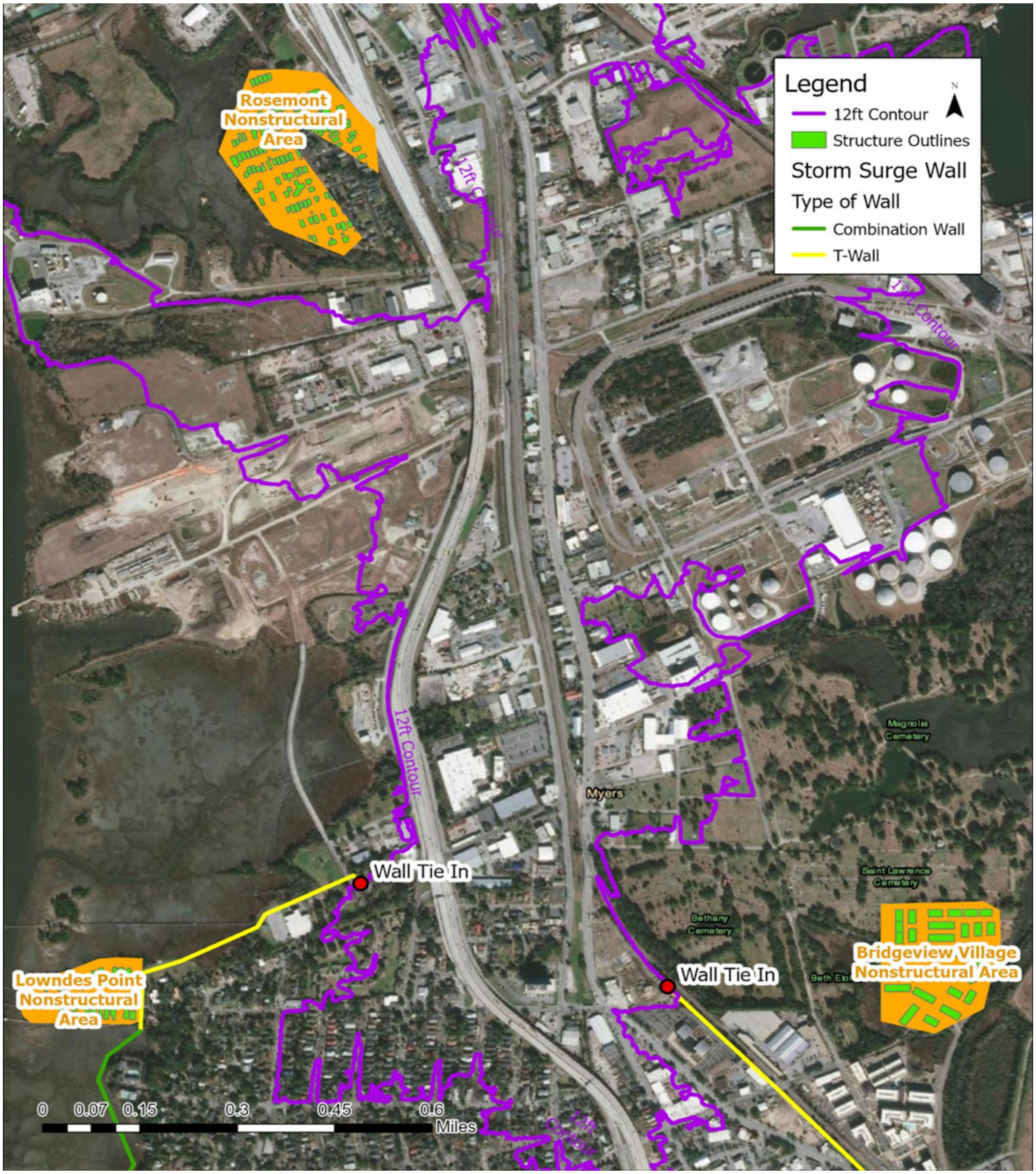

Figure 19: Alternative 2 Nonstructural Areas

For Alternative 2, the following Table displays the mean expected PV damages and average annual damages for the study area by model areas.

Table 7: Alternative 2 Expected Damages

Model Area	Present Value Damages	Average Annual Damages
Battery	$ 1,813,000,000	$ 61,000,000
Port	$ 3,465,000,000	$116,000,000
Newmarket	$ 1,637,000,000	$ 55,000,000
Marina	$ 2,324,000,000	$ 78,000,000
Wagener Terrace	$ 1,172,000,000	$ 39,000,000
Total	**$10,411,000,000**	**$349,000,000**

As shown in the Table above, Alternative 2 was shown by modeling to reduce expected flood damages in the study area. The reduction of flood damages was seen across all model areas. Damage reduction is the difference between the mean PV damages for the future without project condition and the mean PV damages for Alternative 2. The model areas with the most flood damage reductions were Marina and Battery as shown in the following Table. For example, when compared to the future without project condition, Alternative 2 reduced the mean PV damages as well as average annual damages for the Marina and Battery MA by about 68% and 67% respectively. The damages reduced seems reasonable since most the Marina as well as the Battery are both at lower lying elevation (reference Figure 8) and would benefit from a level of flood risk reduction equivalent to 12 feet NAVD88 in elevation. Moreover, both areas had the most damages in the future without projection condition (reference Figure 16).

Table 8: Damage Reduced by MA for Alternative 2

Model Area	Present Value Damages Reduced	Average Annual Damages Reduced
Battery	$ 3,734,000,000	$125,000,000
Port	$ 2,822,000,000	$ 94,000,000
Newmarket	$ 1,622,000,000	$ 54,000,000
Marina	$ 5,065,000,000	$170,000,000
Wagener Terrace	$ 1,480,000,000	$ 50,000,000
Total	**$14,723,000,000**	**$493,000,000**

C.1.7.2.2.1. Nonstructural Incremental Justification

Referencing ER 1105-2-100, Appendix E, page E-9, Section I, E-3. c. (2):

> *"Separable Element. "A separable element is any part of a project which has separately assigned benefits and costs, and which can be implemented as a*

separate action (at a later date or as a separate project)… Separable elements usually must be incrementally justified."

Even though the nonstructural measure is inclusive of Alternative 2 and not a standalone alternative, the nonstructural measure can be implemented as a separate action (separate project) from the perimeter wall. Therefore, the nonstructural measure can be considered an increment of the plan and must be incrementally justified. The following Table displays the nonstructural measure incremental justification (i.e. BCR ≥ 1.0).

Table 9: Nonstructural Incremental Analysis

Present Value Damages Reduced	Average Annual Benefits (Damages Reduced)	Nonstructural Measure First Cost	Nonstructural Measure Annual Cost	Net Benefits	BCR
$38,300,000	$1,290,000	$34,300,000	$1,150,000	$140,000	1.1

C.1.7.2.2.2. Raising Cost NED Benefits

Referencing ER 1105-2-100, page E-100 and E-102 and IWR 2011-R-09 "The NED Manual for Coastal Storm Risk Management" in Section 8.3 page 103-109, states the types of damages that should be permissible for counting as part of an NED benefits evaluation. For example, on page 109 includes the following:

"Public and Private Protective Measures. These include costs in the future for avoiding public and private expenditures on measures to protect coastal property. This could be erosion protection or storm-proofing costs that could be incurred in construction of a new or existing development."

As part of the modeling result, G2CRM is able to model and display the cost of raising structures for the period of analysis. As mentioned in the assumptions, floodplain residents will react to a floodplain management plan in a rational manner which means residential structures (i.e. RES1 occupancy type) are raised after receiving significant damages within the period of analysis (reference C.1.4.1). Therefore, it can be assumed that private property owners would be spared significant rebuilding costs because the perimeter wall (i.e. the structural measure) would obviate the need for the owners to raise structures that would otherwise be necessary or prudent. Although these avoided costs would be borne by private property owners, this cost avoidance nevertheless represents a NED benefit associated with project implementation. This cost avoidance was calculated as the observed raising cost difference for the future without project condition compared to the future with project as costs reduced shown in the following Table.

Table 10: Raising Cost Reduced by MA

Model Area	Present Value Costs Reduced	Average Annual Costs Reduced
Battery	$ 59,405,000	$32,913,000
Port	$ 13,264,000	$ 5,307,000
Newmarket	$ 22,513,000	$ 8,493,000
Marina	$ 49,945,000	$19,762,000
Wagener Terrace	$ 44,805,000	$14,273,000
Total	**$189,932,000**	**$80,748,000**

C.1.7.2.2.3. Raising Cost Benefits

As discussed and displayed in the previous section, there could be a case made to claim the raising cost avoidance as NED benefits for the perimeter wall. However, also indicated in ER 1105-2-100 and IWR 2011-R-09, from a risk-inform perspective, it is implied that uncertainty exists and claiming these benefits would entail more information regarding the assumptions. In the case of both the future without and with project condition, the assumption was that property owner will always choose to incur the raising cost in the modeling and no uncertainty was applied to this assumption. Moreover, the raising cost for elevation of a residential structure, although considered conservative, was based on derived costs provided from one company that did home raises in the study area. Since there were no other empirical evidence or surveys used to derive raising cost, and since the raising cost benefits calculated represented less than 1% of the inundation reduction benefits (reference Table 8), the raising cost avoidance benefits would not be used to calculate net benefits or the benefits-to-cost ratio for Alternative 2. However, adhering to the Memorandum for *Comprehensive Documentation of Benefits in Feasibility Studies dated 3 April 2020 from the ASA (CW)*, it is acknowledged that there would be raising cost benefits for the perimeter wall as shown in Section C.1.7.2.2.1; however, these benefits were not used in the NED net benefits analysis.

C.1.7.3. *Comparison of Alternatives*

Comparison of benefits with regards to costs was performed for each alternative. These comparisons provide the framework for completing the evaluation of alternative plans.

C.1.7.3.1. *Benefits*

The difference in expected mean PV flood damages to the Charleston Peninsula assets between the future without and with project conditions represents the flood risk management benefits to the project. Therefore, these benefits represent reduction of damages from coastal storm surge inundation (i.e. NED benefits) for each alternative. Since the No Action Alternative is the same as the future without project condition, the No Action Alternative would yield no damage reduction; therefore, there are no benefits for the future without project condition. Planning Guidance (reference ER 1105-2-100) dictates that the calculation of net NED benefits of the plan (i.e. alternative) are calculated in average annual equivalent terms; therefore, the PV damages were converted to average annual damages based on the FY22 discount rate and period of analysis shown in the following Table as the average annual benefits.

Table 11: NED Benefits

Category	No Action	Alternative 2	Alternative 2
	PV Damages	**PV Damages**	**PV Damages Reduced**
Structure	$15,189,000,000	$ 6,403,000,000	$ 8,786,000,000
Contents	$ 9,945,000,000	$ 4,008,000,000	$ 5,937,000,000
Total	$25,134,000,000	$10,411,000,000	$14,723,000,000
			Benefits
Average Annual	**$842,000,000**	**$349,000,000**	**$493,000,000**

C.1.7.3.2. *Costs*

Continuing the comparison process, first cost estimates were developed for Alternative 2. MCACES costs were provided by Cost Engineering Section Division in 2021 price levels (reference Engineering Appendix for more details). The No Action Alternative has an assumed first cost of zero. For comparison to the benefits, which are average annual flood damages reduced, the first cost for Alternative 2 was stated in average annual equivalent also based on the FY22 discount rate and period of analysis. Interest during construction (IDC) was added to the first cost assuming 10 years for the alternative. In addition, annual operation, maintenance, relocations, rehabilitation, and repair (OMRR&R) costs were also added to the alternatives. The following Table displays the results of the costs calculation.

Table 12: Project Costs

Alternative	First Cost[1]	IDC	Investment Cost	OMRR&R	Average Annual Cost
2	$1,133,000,000	$136,000,000	$1,269,000,000	$3,000,000	$45,500,000

C.1.7.3.3. *Benefits to Costs*

The equivalent annual benefits were then compared to the average annual cost to develop net benefits and a benefit-to-cost ratio (BCR) for each alternative. The net benefits for each alternative were calculated by subtracting the average annual costs from the equivalent average annual benefits, and a BCR was derived by dividing average benefits by average annual costs. Net benefits were used for identification of

[1] Project first cost was rounded up to the nearest million.

the NED plan in accordance with the Federal objective. For comparative purposes, the following Table summarizes the equivalent annual damages (benefits), average annual costs, first cost, net benefits, and BCR for Alternative 2. The net benefits and BCR calculation for the No Action Alternative is not applicable.

Table 13: Comparison of Benefits and Costs

Cost/Benefit Item	Alternative 2
Investment Costs	
Project First Cost	$1,133,000,000
Interest During Construction	$ 130,000,000
Total Investment Cost	$1,269,000,000
Average Annual Cost	
Average Annual First Cost	$42,500,000
Annual OMRR&R Cost	$ 3,000,000
Average Annualized Costs	$45,500,000
Benefits	
Average Annualized Benefits	$493,000,000
Net Benefits	$447,500,000
BCR	10.8

As a result of the comparison of the alternatives, Alternative 2 was identified as the NED plan. Alternative 2 yielded positive net benefits and BCR. Alternative 2 also maximized net benefits, which is the criterion used for identification of the NED Plan in accordance with the Federal objective. Therefore, the NED Plan, Alternative 2, has been identified as the Recommended Plan (RP).

C.1.7.3.4. *Economic Risk Analysis*

Risk-informed planning should incorporate transparency in the estimation of benefits. The single value displayed for benefits, shown in the Table above, has uncertainties associated with it (reference the Model Variables section). According to ER- 1105-2-101, Planning, Risk Assessment For Flood Risk Management Studies, 8. Policy and Required Procedures (d.):

> *The estimate of net NED benefits and benefit/cost ratio will be reported both as an expected (mean) value and on a probabilistic basis for each alternative. The probability that net benefits are positive and that the benefit/cost ratio is at or above one (1.0) will be presented for each alternative.*

The following Table contains the average (mean) annual damage for the without project condition and the future with project condition for Alternative 2. The computed values are uncertain, and their probability distributions, resulting from the risk and uncertainty inherent in the modeling variables.

Table 14: Probabilistic Values

	Expected Annual Damages (1,000)		Damages Reduced (1,000)		Uncertainty (1,000)	
Alt.	Future Without	Future With	Mean	Standard Deviation	Min	Max
2	$842,000	$349,000	$493,000	$36,500	$341,600	$568,600

The values shown are each the mean of the probability (uncertainty) distribution of that alternative. Most of the modeling variables used in G2CRM had an associated triangular distribution to incorporate uncertainty. The damage reduced (future without project minus future with project) is reported with more information about its probability (uncertainty) distribution. In addition to the mean, the standard deviation and the minimum and maximum of the distribution are included. The standard deviation describes the width of the probability distribution and the minimum and maximum describes the range.

Furthermore, the following Table contains a summary of the average annual values of benefits (damage reduced) and costs, and more probabilistic information about the net benefits (benefits minus costs). The probability distribution of net benefits is described by the average annual benefits, the standard deviation, and the range benefits, as described in Table below. In addition, the probability that net benefits are greater than zero is included.

Table 15: Risk Analysis
Probability that Average Annual Benefits Exceed Annual Costs

Cost/Benefit Item	Alternative 2
Average Annual Benefits	$493,000,000
Standard Deviation	$ 36,500,000
Minimum Average Annual Benefits	$341,600,000
Maximum Average Annual Benefits	$568,600,000
Average Annual Costs	$ 45,500,000
Average Annual Net Benefits	$447,500,000
Average Annual BCR	10.8
Probability Benefits Exceed Costs And BCR is greater than 1.0	100%

The probability of each value above being exceeded is readily apparent. From the modeling results, Alternative 2 has a 100% chance that its benefits will exceed its costs. This is seen by the minimum average annual benefits for Alternative 2 being greater than the annual costs.

C.1.7.4. *Recommended Plan*

According the USACE Planning and Guidance Notebook (i.e. ER 1105-2-100), Chapter 2-3, (4):

> *Section 904 of the Water Resources Development Act of 1986 (WRDA of 1986) requires the Corps to address the following matters in the formulation and evaluation of alternative plans:*
>
> - *Protecting and restoring the quality of the total environment.*
> - *The well-being of the people of the United States*
> - *The prevention of loss of life.*
> - *The preservation of cultural and historical values*

The ER goes on to state in Chapter 3-3 (11), Flood Damage Reduction:

> *… An essential element of the analysis of the recommended plan is the identification of residual risk for the sponsor and the flood plain occupants, including residual damages and potential for loss of life, due to exceedance of design capacity. …*

Moreover, ER 1105-2-101, Planning, Risk Assessment For Flood Risk Management Studies, 5.Context:

> *…All flood risk managers must balance the insights of USACE's professional staff with stakeholder concerns for such matters as residual risks, life safety, reliability, resiliency and cost while acknowledging no single solution will meet all objectives, and trade-offs must always be made….*

Therefore, the adherence to this guidance, evaluation of the RP is summarized in the following sections.

C.1.7.4.1. *Life Loss*

In an effort to identify risk to life safety this alternative might have, the RP was modeled for potential life loss. G2CRM is capable of modeling life loss using a simplified life loss methodology (reference EPZ section of Appendix). Since there exists much uncertainty in modeling life loss, the future without project condition was modeled to serve as a baseline. Therefore, when compared to the future with project condition, any addition or reduction of life loss from the baseline would serve as a proxy in identifying impacts to life safety the alternative might have. The following Tables present the mean life loss estimates for each alternative in the study area over the 50-year period of analysis.

Table 16: Future Without Project Condition Potential Life Loss

Model Area	Battery	Port	Newmarket	Marina	Wagener Terrace	Total
Under 65	11.1	4.0	3.8	6.5	3.1	28.5
Over 65	15.6	8.4	36.5	54.1	34.8	149.4
Total	26.7	12.4	40.3	60.6	37.9	177.9

Table 17: RP Potential Life Loss

Model Area	Battery	Port	Newmarket	Marina	Wagener Terrace	Total
Under 65	1.7	1.3	1.9	0.9	0.9	6.7
Over 65	3.3	2.1	35.1	10.7	12.3	62.4
Total	5.0	3.4	37.0	11.5	13.1	70.1

Life loss calculations are separated out by age categorization with under 65 being one category and 65 and older being the second category. There are three possible lethality functions for structure residents: safe (0.0002), compromised (0.12), and chance (0.91). Safe would have the lowest expected life loss, although safe does not imply that there is no life loss, and chance would have the highest expected life loss. The majority of residential structures in the study area are 2-story; however, there are some 1-story structures.

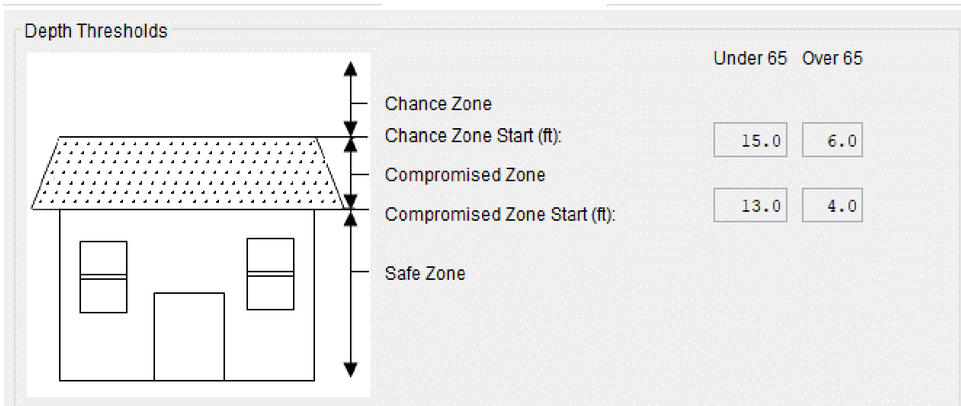

Figure 20: Depth Thresholds for 1-Story Structures

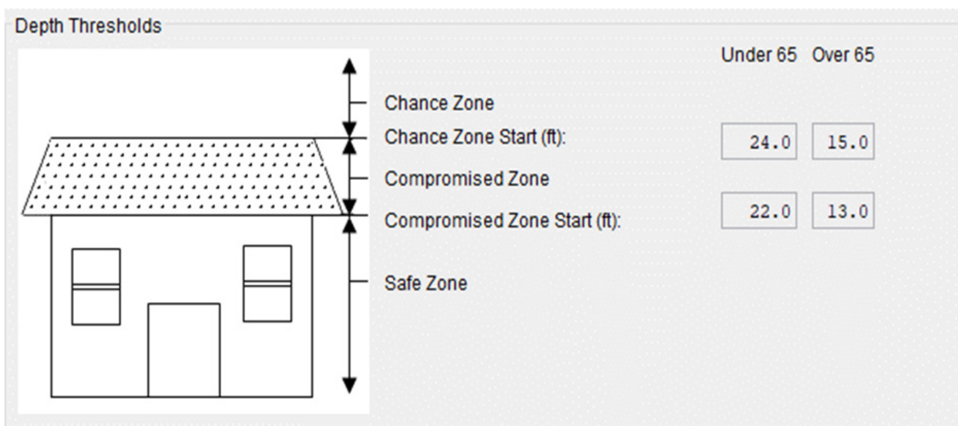

Figure 21: Depth Thresholds for 2-Story Structures

Each structure has an occupancy type, which has an associated storm surge lethality. The surge over the foundation height is the minimum for a lethality zone (safe, compromised, chance). These surge over foundation heights are age-specific. There is one surge height for under 65 and another for 65 and older.

During each storm, the model cycles through every active structure. For each structure, the model defaults the lethality function to safe and checks for the maximum lethality function such that the modeled area stage is greater than the sum of the first flood elevation of the structure and the lethality function's surge above the foundation. This will be checked separately for under and over 65, as these two age groups can have different lethality functions depending on the age-specific surge above foundation for that occupancy type.

The fraction of population remaining for each EPZ is calculated based on the EPZ on a per storm basis. If the maximum surge at the storm location exceeds the threshold defined by the EPZ, then the remaining population values will be used as the minimum, mode, and maximum to form a triangular distribution to choose the fraction remaining. If the surge threshold is not met, then 100% of the population will remain.

Using the proper lethality function, a random number is generated and interpolated using the Lethality Function Values to get the expected fraction of life loss. The way the default lethality functions are formed is that the smaller the random number, the higher the life loss. This interpolation from the lethality function is multiplied by the nighttime population for the corresponding age range and the remaining population fraction in order to calculate the life loss under 65 and life loss for 65 and older. This is recorded in fractions of lives, so depending on the level of output, there exists small rounding differences.

As previously mentioned, there exists much uncertainty regarding the modeling of life loss; therefore, the results of the modeling should be viewed as more qualitative as oppose to a quantitative assessment of life loss even though the results are stated in numerical values. Also, the results should be viewed in terms of order of magnitude compared to the baseline. Viewing the results in this manner is a better use of the model to understand whether or not any recommended alternatives could have an impact to life safety as oppose to no action (e.g. introducing more risk of flooding). As shown in the Tables above, the plan showed no increase in the overall life safety risk for the Charleston Peninsula when compared to the future without project condition.

C.1.7.4.2. *Residual Risk*

Residual Risk is the flood risk that remains in the study area after a proposed flood risk management project is implemented. Residual risk includes the consequence of capacity exceedance as well as consideration of the project flood risk reduction. The project alternative considered formulation to reduce and manage residual life safety risks. The following Tables and Figure address residual risk for the period of analysis (i.e. 50 years with a base year of 2032).

Table 18: Residual Damages for Study Area

Alt.	Expected Annual Damages (1,000)		Residual Damages
	Future Without	Future With	Percentage
2	$594,500	$101,000	17%

Table 19: Residual Damages by Model Area

Model Area	Residual Damages
Battery	0.1%
Port	35%
Newmarket	32%
Marina	5%
Wagener Terrace	22%
Total	**17%**

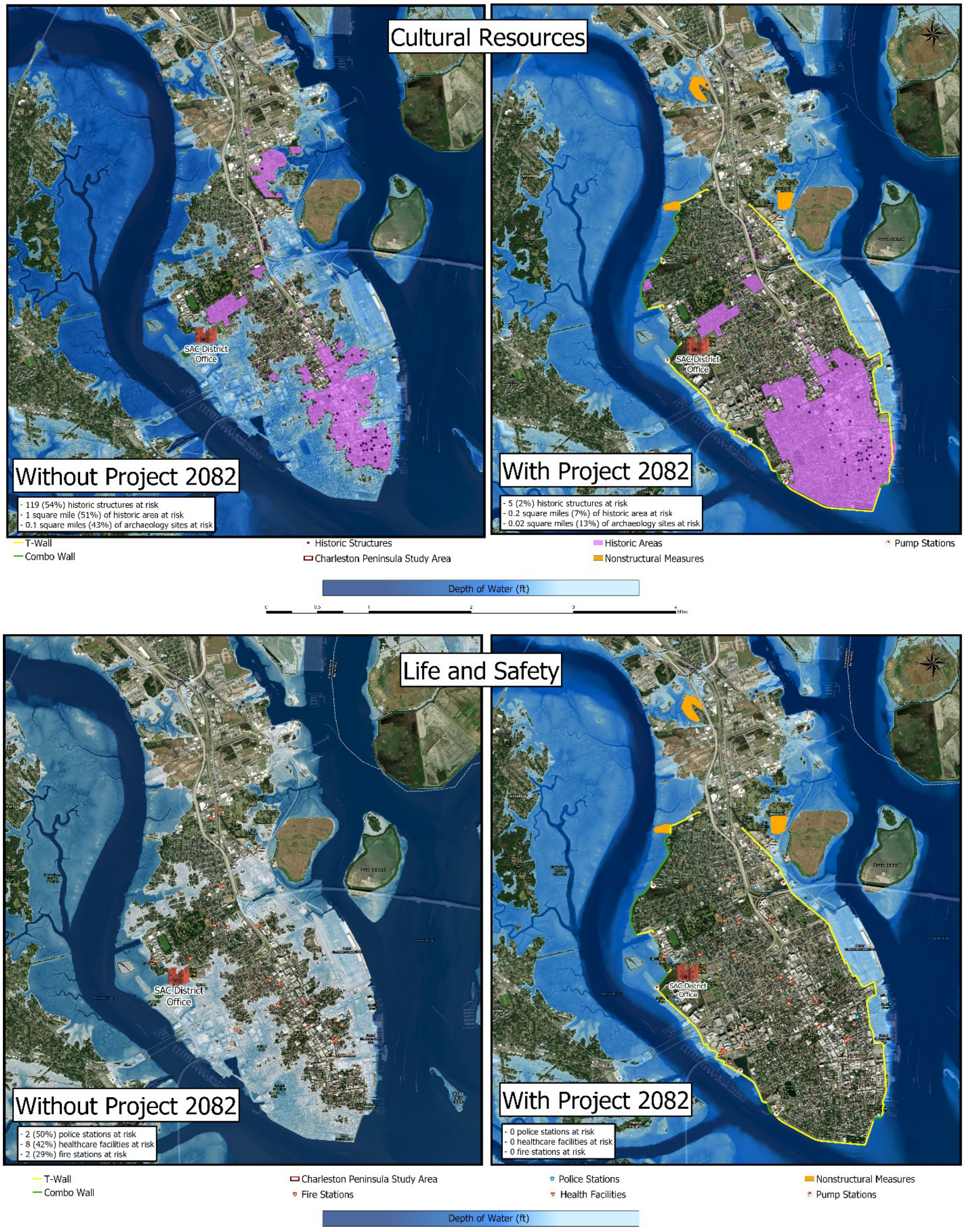

Figure 22: Illustration of Residual Risk

As shown in the Tables above, the total average annual damages remaining in the study area if the RP was implemented would be around $101 million or about 17%. In other words, the RP would be effective enough to reduce about 83% of the flood damages modeled in the Charleston Peninsula with only about 17% of potential flood damages remaining (i.e. residual) as illustrated in the Figure above for the period of analysis.

This Figure compares the future with and without-project conditions, using stillwater elevations. Without a project to address storm surge inundation, assuming a high rate of sea level rise, in the year 2082, 50% of police stations, 42% of health care facilities, and 29% of fire stations would be flooded to elevation 9 feet NAVD88 during a 20% annual exceedance probability (AEP) storm event. Similarly, 54% of historic structures and 43% of archaeological sites would be flooded to elevation 9 feet NAVD88 as displayed in the Figure. Under the with-project condition, critical facilities and most of the historic resources stay dry during the 20% AEP storm event.

The RP includes a perimeter wall which is at 12 feet NAVD88. ER 1105-2-101 states that the mean AEP values be used for economic analyses, but when communicating project performance, the AEP values at the 90% confidence level should be used. Based on the probability of annual exceedance for the wall at elevation 12 ft NAVD88 (considering dynamic water surface elevations which includes storm surge, astronomical tides, wave setup and sea level rise at an intermediate rate) would provide approximately between 2.8% - 3.6% AEP event with a 90% confidence level of flood risk reduction due to coastal storms for the period of the analysis. More information regarding confidence of the wall, at this elevation, is found in the Engineering Appendix and Coastal Sub Appendix.

C.1.7.4.3. *Sensitivity Test: Sea Level Change*

Current USACE guidance requires that potential relative sea level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence. The base level of potential relative sea-level change is considered the historically recorded changes for the study site, which is estimated to be an increase of 0.01033 feet/year. All economic analyses for which results are tabulated in previous sections of this report were based on this intermediate rate of sea level change. However, in accordance with Engineering Regulation ER 1100-28162 (incorporating Sea Level changes in Civil Works Program, 31 Dec 2013), proposed projects that are subject to coastal storm surges must be also evaluated for a range of possible sea level rise rates. In addition to using intermediate sea level change curve over the period of analysis, the RP was also evaluated using “low” and “high” rates derived from USACE curve calculator for sea level rise respectively over the 50-year period of analysis. At the end of the period of analysis, the low rate of sea level change is 0.93 feet Local Mean Sea Level (LMSL); the intermediate rate is 1.65 feet LMSL; and the high rate of sea level rise is 3.93 feet LMSL. The results of all analyses under all three sea level rise conditions are presented in the following Tables.

Table 20: Damages by Sea Level Change Rate Scenarios

Impacts of Sea Level Rise on Damages				
Average Annual	**Condition/ RP**	**Low**	**Intermediate**	**High**
Damages	Without	$766,100,000	$842,000,000	$1,142,200,000
	RP	$327,700,000	$349,000,000	$ 429,400,000
Damages Reduced	RP	$438,400,000	$493,000,000	$ 712,800,000

Table 21: Benefits by Sea Level Change Rate Scenarios

Impacts of Sea Level Rise on Benefits			
Benefits	**Low**	**Intermediate**	**High**
Annual Benefits	$438,400,000	$493,000,000	$712,800,000
Annual Costs	$ 45,500,000	$ 45,500,000	$ 45,500,000
Net Benefits	$392,900,000	$475,500,000	$667,300,000
BCR	9.6	10.8	15.7

For the different SLC, it is important to note that the performance of the wall was not assumed to be sensitive to the rate of SLC. Moreover, it was assumed that regardless of the relative sea level change scenarios, the RP would provide benefits up to the 12 feet NAVD 88. It was assumed that water levels at an elevation of 12 feet would create the maximum possible stress on the wall so the high SLC scenario would not increase the likelihood of failure or risk to the structure integrity but would affect the frequency of flooding events as shown by higher damages in the Tables above. The performance of the RP has similar sensitivity to RSLC. More information regarding performance (specifics) of the plan can be found in the Engineering Appendix.

Additionally, to address the assessment of benefits from sea level rise, an analysis of the 3 SLC scenarios for the future with project and future without project was done in accordance with Section 113(b) of the Water Resources Development Act of 2020. Referencing the Implementation Guidance for Section 113(b) of WRDA 2020, Paragraph 7, Page 4, of the Memorandum dated 17 September 2021 signed by the ASA (CW), states the following:

> *"Analysis of the three scenarios of the Future With Project and Future Without Project conditions, using the same storm frequency assumptions as in the analyses*

incorporating sea level change according to the scenarios in reference 3.a, but assuming a static sea level over the period of economic analysis equal to the sea level used for the initiation of the sea level change scenarios, will be conducted. The project conditions under this run will be subtracted from the benefits computed under the three sea level scenarios to yield the increment of benefits relating to the sea level rise. For each seal level scenario considered in computation of benefits, this method will yield the portion of those benefits relating to SLR only. This analysis does not yield additional benefits but parse our the SLR benefits from the storm events calculated benefits."

The following Tables display this cited (underlined) analysis referenced above.

Table 22: Damages without Sea Level Rise

Without Impacts of Sea Level Rise on Damages		
Average Annual		
Damages	Future Without Project	$635,100,000
	Future With Project	$281,300,000
Damages Reduced	Future With Project	$353,800,000

Table 23: Benefits relating to SLR only

Impacts of Sea Level Rise on Damages			
Benefits	**Low**	**Intermediate**	**High**
Annual Benefits	$438,400,000	$493,000,000	$ 712,800,000
Attributable to SLR only	$84,600,000 ($438.4[2] - $353.8)	$139,200,000 ($493 - $353.8)	$359,000,000 ($712.8 – $353.8)
Attributable to SLR only as %	19%	28%	50%

[2] Values are in millions

C.2. SECTION II: REGIONAL ECONOMIC DEVELOPMENT

When the economic activity lost in the flooded region can be transferred to another area or region in the national economy, these losses cannot be included in the NED account. However, the impacts on the employment, income, and output of the regional economy are considered part of the Regional Economic Development (RED) account. The input-output macroeconomic model Regional Economics Systems (RECONS) was used to address the impacts of the construction spending only associated with the Recommended Plan, since this alternative was selected based on NED.

C.2.1. *BACKGROUND*

The management measures included in this alternative are:

- Storm surge wall along the perimeter of the Peninsula (approximately 8.7 miles)
- Nonstructural measures (approximately 100 structures)

The storm surge wall would be constructed along the perimeter of the peninsula to reduce damages from storm surge inundation. Where feasible, it would be strategically aligned to minimize impacts to existing wetland habitat, cultural resources, and private property. The wall would be strategically located to allow for continued operation of all ports, marinas, and the Coast Guard Station. The wall would tie into high ground as appropriate, including the shoreline near the Citadel and the existing Battery wall. Due to its age and uncertainty about the integrity of the structure, the High Battery wall would be reconstructed to meet USACE construction standards and raised to provide a consistent level of performance. This alternative would include permanent and temporary pump stations to the extent justified per USACE policy, as well as pedestrian, vehicle, railroad, boat, and storm (tidal flow) gates.

In addition to the storm surge wall, this alternative includes nonstructural measures that would be applied to residential structures in locations where it would be impracticable to construct the perimeter wall. The neighborhoods of Rosemont and Bridgeview in the Neck Area of the Peninsula have been identified as nonstructural areas because of topographical and other constraints.

C.2.2. *RECONS METHODOLOGY*

When the economic activity lost in the study area can be transferred to another area or region in the national economy, these losses cannot be included in the NED account. However, the impacts of the employment, income, and output of the regional economy are considered part of the RED account. The input-output macroeconomic model RECONS was used to address the impacts of the construction spending associated with the Recommended Plan (RP).

For this Regional analysis, the regional economic development (RED) effects of implementing the RP will be estimated. The RECONS Standard Geographic Area for the Charleston County was selected using an expenditure year of 2032.

This RED analysis, using RECONS, employs input-output economic analysis, which measures the interdependence among industries and workers in an economy. This analysis uses a matrix representation of a region's economy to predict the effect of changes, the implementation of a project of a specific USACE Business Line, to the various industries that would be impacted. The greater the interdependence among industry sectors, the larger the multiplier effect on the economy. Changes to government spending drive the input-output model to project new levels of sales (output), value added (Gross Regional Product or GRP), employment, and income for each industry.

The specific input-output model used in this analysis is RECONS (Regional Economic System). This model was developed by the Institute for Water Resources (IWR), Michigan State University, and the Louis Burger Group. RECONS uses industry multipliers derived from the commercial input-output model IMPLAN to estimate the effects that spending on USACE projects have on a regional economy. The model is linear and static, showing relationships and impacts at a certain fixed point in time. Spending impacts are composed of three different effects: direct, indirect, and induced.

Direct effects represent the impacts the new federal expenditures have on industries which directly support the new project. Labor and construction materials can be considered direct components to the project. Indirect effects represent changes to secondary industries that support the direct industries. Induced effects are changes in consumer spending patterns caused by the change in employment and income within the industries affected by the direct and induced effects. The additional income workers receive via a project and spent on clothing, groceries, dining out, and other items in the regional area are secondary or induced effects.

The inputs for the RECONS model are expenditures that are entered by work activity or industry sector, each with its own unique production function. The Flood Risk Management production function of "Flood Risk Management Construction" was selected to gauge the impacts of the construction of the RP. The baseline data used by RECONS to represent the regional economy of Charleston County, SC are annual averages from the Bureau of the Census, the Bureau of Labor Statistics, and the Bureau of Economic Analysis for the year 2021. The model results are expressed in 2022 dollars.

C.2.3. *ASSUMPTIONS*

Input-output analysis rests on the following assumptions. The production functions of industries have constant returns to scale, so if inputs are to increase, output will increase in the same proportion. Industries face no supply constraints; they have access to all the materials they can use. Industries have a fixed commodity input structure; they will not substitute any commodities or services used in the production of output in response to price changes. Industries produce their commodities in fixed proportions, so an industry will not increase production of a commodity without increasing production in every other commodity it produces. Furthermore, it is assumed that industries use the same technology to produce all of its commodities. Finally, since the model is static, it is assumed that the economic conditions of 2021, the year of the socio-economic data in the RECONS model database, will prevail during the years of the construction process.

C.2.4. *DESCRIPTION OF METRICS*

“Output” is the total sum of transactions that take place as a result of the construction project, including both value added and intermediate goods purchased in the economy. “Labor Income” includes all forms of employment income, including employee compensation (wages and benefits) and proprietor income. “Gross Regional Product (GRP)” is the value-added output of the study region. This metric captures all final goods and services produced in the study areas because of the project’s existence. It is different from output in the sense that one dollar of a final good or service may have multiple transactions associated with it. “Jobs” is the estimated worker-years of labor required in full time equivalent units to build the project.

C.2.5. *RECONS RESULTS*

For Charleston County, SC, the construction stimulus of $1.132 billion would generate 10,696 full-time equivalent jobs, $817 million in labor income, and $1.505 billion in output. For the state of South Carolina, as a whole, the construction stimulus would generate 12,932 full-time equivalent jobs, $896,641 million in labor income, and $1.798 billion in output. For the Country, as a whole, the construction stimulus would generate 18,499 full-time equivalent jobs, $1.358 billion in labor income, and $3.076 billion in output (see table below). The secondary impacts are referred to as the combined indirect and induced multiplier effects.

RECONS - Overall Summary					
Area	**Local Capture ($000)**	**Output ($000)**	**Jobs***	**Labor Income ($000)**	**Value Added ($000)**
Local					
Direct Impact		$868,937	7,057.6	$591,701	$587,835
Secondary Impact		$636,631	3,639.1	$225,363	$368,704
Total Impact	$868,937	$1,505,568	10,696.7	$817,064	$956,539
State					
Direct Impact		$962,847	8,124.4	$625,697	$645,760
Secondary Impact		$835,145	4,807.9	$270,944	$459,714
Total Impact	$962,847	$1,797,992	12,932.3	$896,641	$1,105,474
US					
Direct Impact		$1,080,294	9,589.7	$722,287	$730,855
Secondary Impact		$1,955,438	8,909.7	$635,633	$1,087,996
Total Impact	$1,080,294	$3,075,732	18,499.4	$1,357,920	$1,818,850

* Jobs are presented in full-time equivalence (FTE)