ECONOMICS APPENDIX

FLORIDA KEYS COASTAL STORM RISK MANAGEMENT FEASIBILITY STUDY
MONROE COUNTY, FLORIDA

FINAL INTEGRATED FEASIBILITY STUDY AND ENVIRONMENTAL IMPACT STATEMENT

APPENDIX C

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1 INTRODUCTION

This appendix presents an economic evaluation of the Recommended National Economic Development Plan for the Florida Keys Coastal Storm Risk Management Feasibility Study for Monroe County, Florida. The study area includes the Florida Keys, located in Monroe County, Florida. The Keys consist of more than 1,700 islands that stretch 123 miles from Key Largo in the north to Key West at the southern tip of the archipelago. The non-Federal sponsor for this study is Monroe County, Florida.

The Recommended Plan is expected to provide an average annual benefit of $131,603,000 at an average annual cost of $85,557,000. With a benefit-cost ratio of 1.5, the project will produce an average annual net benefit of $46,046,000.

This analysis was conducted in accordance with Engineer Regulation (ER) 1105-2-100, Planning Guidance Notebook, and ER 1105-2-101, Planning Guidance, Risk Analysis for Flood Damage Reduction Studies. The National Economic Development Procedures Manual for Flood Risk Management and Coastal Storm Risk Management, prepared by the Water Resources Support Center, Institute for Water Resources, was also used as a reference. The primary National Economic Development (NED) benefit of the Recommended Plan is measured by the reduction in damage caused by storm inundation. Generation II Coastal Risk Model (G2CRM) was used to model damage to residential and commercial structures; the model is designed to evaluate inundation of areas not immediately adjacent to beaches but still in a coastal environment, where the effect of wave action contributes to the damage. The G2CRM analysis is covered in greater detail in Chapter 4. The estimated cost of the Recommended Plan was developed by cost engineering and is detailed in a certified Total Project Cost Summary (TPCS). The TPCS is thorough utilized in this appendix for the benefit-cost analysis. The remaining chapters of this appendix details information on study area characteristics, study methodology, modeling information, and the final economic evaluation of the Recommended Plan.

1.1 NED Benefit Categories Considered

The NED benefits attributable to the Florida Keys project are largely the reduction of inundation damage to structures and their contents based on nonstructural alternatives. These alternatives include a combination of elevating the first floor of residential structures above the floodplain, floodproofing commercial structures, and/or acquiring properties to be returned to their natural state as they were before development.

In addition to inundation benefits, the study also evaluated measures to reduce risk to segments of US Route 1, which runs approximately 110 miles between Key Largo and Key West.

Physical Flood Damage Reduction Benefits. Physical flood damage reduction benefits include the decrease in potential damage to residential, commercial, industrial, or public structures and their contents. Damage to associated vehicles and reduction in emergency services were not evaluated due to the nonstructural solution which would not protect vehicles. Future population growth was not projected for the study. A future structure inventory based on development was not included in the damage calculations due to the limited remaining available land and the proposed zoning and development restrictions that are expected to be implemented by Monroe County through a Non-Residential Rate of Growth Ordinance enacted in 2001 (Monroe County, 2011).

Other NED/NER Benefits. Other benefits of coastal storm management projects beyond those tied to flood damage reduction include recreation benefits which result from the additional recreation opportunity provided by the project. This was not evaluated for this study since there are no alternatives under consideration that would significantly affect the recreation opportunities currently found in the study area.

1.2 Regional Economic Development.

When economic activity lost in a 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 RECONS will be used to address the impacts of the construction spending only associated with the Recommended Plan, since only this alternative provides detailed cost information necessary to prepare a complete and accurate analysis. The RED account is addressed in Section 10.

2 STUDY AREA CHARACTERISTICS

The next few sections will outline relevant characteristics of the study area, Monroe Country. The following topics are discussed: geographic location, land use, socioeconomics, recent storm history and compliance.

2.1 Geographic Location

The study area includes all land and water resources within the vicinity of the Florida Keys, a 123 mile long chain of islands extending into the Gulf of Mexico from the southern tip of mainland Florida, provided they are located entirely within the jurisdictional boundary of Monroe County, Florida. The average elevation of the islands ranges from 0 to 20 feet (NAVD88). Based on the low lying topography and location relative to hurricane tracks, the Florida Keys are recognized as an area of elevated risk to impacts from sea level rise and coastal storms.

Due to the number of water bodies, the 81 miles of coastal shoreline, and varied land use, the study area of Monroe County is divided into 34 model areas (MAs) to facilitate initial economic analysis of the project alternatives using the Planning-certified model Generation 2 Coastal Risk Model (G2CRM). The 34 model areas and save points (discussed further in Section 4.2.3.2) are represented below in Figures 1, 2, and 3.

Figure 2-1: Model Areas 1 – 10

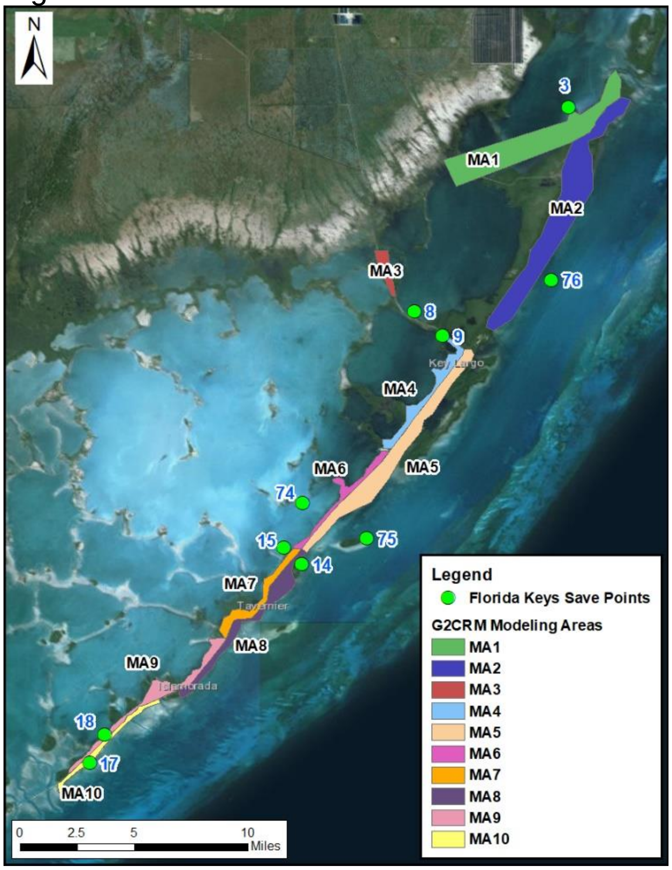


Figure 2-2: Model Areas 11 – 21

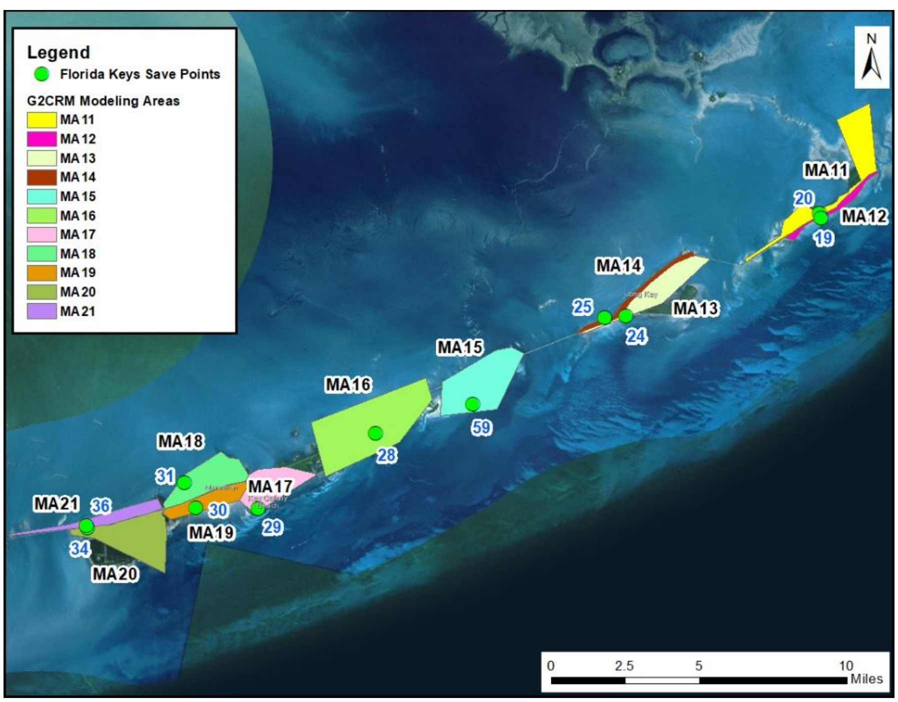
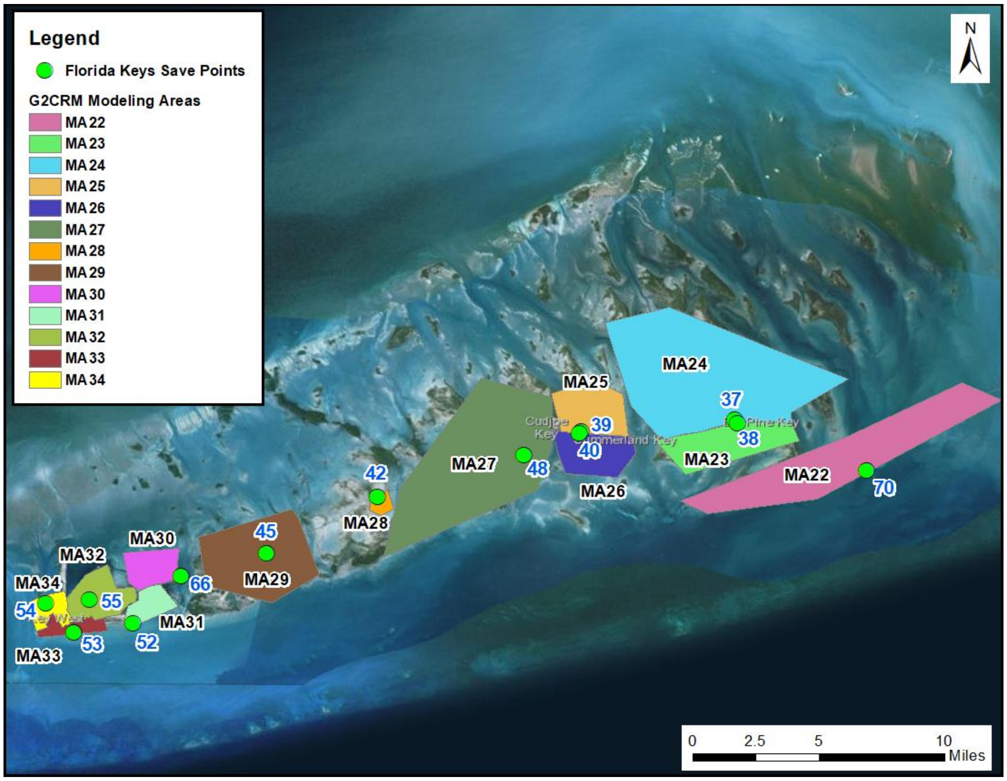


Figure 2-3: Model Areas 22 - 34



2.2 Land Use

The amount of developed and undeveloped land within Monroe County is estimated at 3,738 square miles, of which 983 square miles is land and 2,754 square miles is water. It is the largest county in the State of Florida (Florida) by total area. While 87% of the county's land area is on the mainland, that region is either part of the Everglades National Park or Big Cypress National Preserve and is virtually uninhabited. Over 99% of the county's population lives on the Florida Keys.

Land Use in the Keys is similar throughout the Upper and Middle Keys. It is predominantly low and middle intensity development dispersed along population centers on US Route 1. Key Largo, Tavernier, Islamorada, and Marathon are large population centers. The developed landscape intensifies with more middle intensity development near Marathon. In the Lower Keys, Boca Chica Key and Key West in particular, are large population centers, with an urban landscape of low, medium- and high-density development.

At 74.3 people per square mile (28.6/km2), Monroe County's population density is moderately lower than the US as a whole, and substantially lower than the rest of

Florida. However, the Florida Keys islands portion of Monroe County has a population density of 591 per square mile (227.3/km2)[1].

2.3 Socioeconomics

The following sections provide information on the socioeconomic profile of Monroe County on the following topics: population and housing, income, and employment.

2.3.1 Population and Housing

Based on the US Census Bureau's American Community Survey, Monroe County had a total population of 76,212 in 2019 and contained 30,982 households in 2018. Monroe County experienced population decline of 8.17% between 2000 and 2010, but has grown slowly by 4.27% since. Monroe County is projected to experience low levels (less than 1%) of population growth through 2040. Actual, estimated, and projected population levels for the Monroe County and Florida are shown below in Table 2-1.

Table 2-1: Population, 1990 - 2040

	Monroe Country		State of Florida	
Year	**Population**	**Change From Previous Period**	**Population**	**Change From Previous Period**
1990	78,024		12,937,926	
2000	79,589	2.01%	15,982,378	23.53%
2010	73,090	-8.17%	18,801,310	17.64%
2019	76,212	4.27%	21,208,589	12.80%
2030	76,800	0.77%	24,426,200	15.17%
2040	77,400	0.78%	26,428,700	8.20%
Source: American Community Survey, US Census Bureau, current estimate (2019) and projections from UFL Bureau of Economic and Business Research, January 2020				

Available information on housing units is provided in Tables 2-2 and 2-3. The number of households has declined by 5.05% between 2010 and 2018 (latest available data). There is no available data specifying how non-owner occupied housing units are categorized into vacant units, rental units, or units for occasional use (seasonal).

[1] Information from this section is sourced from the 2020 State of the County and Information Guild and the previous US Decennial Census

Table 2-2: Households, 1990 - 2018

	Monroe Country		**State of Florida**	
Year	**Population**	**Change From Previous Period**	**Population**	**Change From Previous Period**
1990	33,583		5,134,869	
2000	35,086	4.48%	6,337,929	23.43%
2010	32,629	-7.00%	7,420,802	17.09%
2018	30,982	-5.05%	7,621,760	2.71%
Source: US Census Bureau, 2018 uses the 2014-2018 American Community Survey 5-year estimate				

Table 2-3: Housing Units, 2018

	Monroe Country	**State of Florida**
Housing Units	53,455	9,547,305
Owner Occupied Housing Unit Rate	59.6%	65.0%
Source: US Census Bureau, Owner Occupied Housing Unit Rate is a 2014-2018 American Community Survey 5-year estimate		

Additional demographic data is shown below in Table 2-4. The population in Monroe County is primarily white, with other races generally making up slightly more than 10% of the population. Compared to the state as a whole, Monroe County has slightly higher percentage of older citizens. When compared to the State of Florida, Monroe County has a slightly higher median age of 46.7 compared to 42; only 15.1% of people under 18 years old compared to 19.9%, and a slightly higher percentage of people in the 65 years or older demographic, at 23% compared to 20.5% for the entire state. It also has a higher percentage of white population at 89.3% compared to 77.3% for Florida. Hispanic or Latino populations are classified by the US Census Bureau as a person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin regardless of race. Therefore, this population is already included in applicable race categories.

Table 2-4: Demographics, 2018

	Monroe Country		State of Florida	
Demographic	**Number**	**Percentage**	**Number**	**Percentage**
Age				
Median Age (Years)	46.7	N/A	42	N/A
Under 18 years	11,329	15.10%	4,238,566	19.90%
19 to 64 Years	46,442	61.90%	12,694,398	59.60%
65 years and over	17,256	23.00%	4,366,362	20.50%
Race				
White	67,672	88.70%	15,529,098	75.40%
Black or African American	5,399	7.10%	3,316,376	16.10%
American Indian and Alaska Native	114	0.10%	58,118	0.30%
Asian	977	1.30%	559,168	2.70%
Native Hawaiian or Pacific Islander	107	0.10%	12,887	0.10%
Two or More Races	1,135	1.50%	542,340	2.60%
Hispanic or Latino (of Any Race)	18,206	23.90%	5,184,720	25.20%
Total	75,027	100%	21,299,325	100%
Source: Estimates retrieved from 2014-2018 American Community Survey 5-year estimates, US Census				

2.3.2 Income

Table 2-5 exhibits median household income levels for Monroe County and Florida between 2000 and 2018. Income has risen steadily for Monroe County, with higher average growth than Florida as a whole. Household income growth slowed for both Monroe County and Florida between 2005 and 2010, largely due to the Great Recession; it has since risen above pre-recession levels.

Table 2-5: Median Household Income, 2000 - 2018

	Monroe Country		State of Florida	
Year	**Income**	**Change Monroe from Previous Period**	**Income**	**Change Monroe from Previous Period**
2000	42,447		38,856	
2005	47,268	11.36%	42,990	10.64%
2010	50,388	6.60%	44,066	2.50%
2015	58,332	15.77%	48,825	10.80%
2018	67,094	15.02%	54,644	11.92%
Source: Federal Reserve Bank of St. Louis, not inflation adjusted, not seasonally adjusted				

2.3.3 Employment

Major employment sectors in Monroe County include Hospitality, Retail Trade, Healthcare, and Construction. Monroe County experienced County high unemployment rates around the time of the Great Recession (2007-2009). Currently, however, the county has a relatively low unemployment rate of 2.6%, even lower than Florida's 3.6%. Summary data regarding unemployment rate, labor force size, and employment by industry for the study area are shown below in Table 2-6.

The tourism industry is a pillar of Monroe County's economy, supporting a total of 26,506 employees. Direct, indirect, and induced tourism-related employment constitute nearly 70% of total employment in 2018 for Monroe County. Residents and tourists are attracted to the beaches, resorts, and recreational activities in the Florida Keys such as sailing, snorkeling, fishing, state parks, and cruises. The 5.1 million visitors in 2018 generated $2.4 billion in tourism spending and 1.8 billion in total economic impact in Monroe County. (2018 Tourism in the Florida Keys & Key West, 2018)

Table 2-6: Labor Force and Employment, 2018

	Monroe Country		**State of Florida**	
Category	**Number of People**	**Percentage**	**Number of People**	**Percentage**
Labor Force				
Unemployment	1,058	2.60%	365,097	3.60%
Total Labor Force	40,693	100%	10,234,770	100%
Employment, by Industry				
Hospitality	8,602	21.70%	908,997	9.21%
Retail	4,958	12.51%	1,312,667	13.30%
Healthcare	3,424	8.64%	1,312,667	13.30%
Construction	2,865	7.23%	675,086	6.84%
government	2,547	6.43%	443,148	4.49%
Education	2,124	5.36%	775,756	7.86%
Professional (Scientific, Technical)	2,063	5.20%	660,281	6.69%
Real Estate	1,745	4.40%	280,299	2.84%
Other Services	1,743	4.40%	526,054	5.33%
Administrative	1,670	4.21%	595,141	6.03%
Entertainment	1,624	4.10%	302,999	3.07%
Transportation	1,596	4.03%	429,331	4.35%
Finance and Insurance	1,069	2.70%	480,653	4.87%
Manufacturing	959	2.42%	509,275	5.16%

	Monroe Country		State of Florida	
Agriculture, Forestry, Fishing, hunting	710	1.79%	96,723	0.98%
Wholesalers	689	1.74%	276,351	2.80%
Utilities	602	1.52%	74,023	0.75%
Information	564	1.42%	192,459	1.95%
Oil, Gas, and Mining	60	0.15%	8,883	0.09%
Management	21	0.05%	7,896	0.08%
Total Employment	39,635	100%	9,869,673	100%
Sources: Bureau of Labor statistics, not seasonally adjusted, full-time employment				

2.4 Recent Storm History

During the past 100 years, Monroe County has been impacted by 14 major tropical events. Table 2-7 below lists storm events and their associated Federal Emergency Management Agency (FEMA) disaster and emergency numbers.

Table 2-7: Historical Storm Events and FEMA Disaster Declarations

	Storm Event	Date	FEMA Disaster Number
1	The Key West Hurricane	September 9-10, 1919	N/A
2	“Bahamas”	September 28-29, 1929	N/A
3	Florida Keys Labor Hurricane	September 3,1915	N/A
4	Unnamed Hurricane	September 20-22, 1948	N/A
5	Unnamed Hurricane	October 5, 1948	N/A
6	Hurricane Donna	September 8-10, 1960	DR-106
7	Hurricane Cleo	August 26-27, 1964	DR-175
8	Hurricane Betsy	September 8, 1965	DR-209
9	Hurricane Andrew	August 23-24, 1992	DR-955
10	Tropical Storm Gordon	November 14-16, 1994	DR-1043
11	Hurricane Georges	September 24,1998	EM-3131 & DR-1249
12	Hurricane Irene	October 14-15,1999	EM-3150 & DR-1306

	Storm Event	Date	FEMA Disaster Number
13	Hurricane Wilma	October 23-24, 2005	DR-1609
14	Hurricane Irma	September 9-11, 2017	EM-3385 & DR-4337

Hurricane Donna - 1960

Hurricane Donna had a variable trajectory as it made its way across the Atlantic before hitting the Upper Keys on September 10, 1960 as a Category 4 hurricane. Areas in the Middle and Upper Keys experienced almost complete destruction. In Key West, over 500 homes were destroyed and over 1000 were damaged. The storm surge reached 8 to 12 feet above mean sea level in the Middle and Upper Keys.

Hurricane Irene - 1999

Hurricane Irene made landfall in the lower keys as a Category 1 Hurricane with gusts reported on Big Pine Key at 100 miles per hour (mph). The storm was called a “major rainmaker” by the National Hurricane Center.

Hurricane Wilma - 2005

Hurricane Wilma is the second strongest storm recorded in the Atlantic Ocean basin. Wilma was a Category 3 hurricane (111-130 mph) when it passed by Key West. This event created the largest water surface elevation ever recorded by the Vaca Key gauge.

Hurricane Irma - 2017

Hurricane Irma made landfall as a Category 4 hurricane at Cudjoe Key with maximum sustained winds at 130 mph. Wind gusts were reported at Big Pine Key at 160 mph. The event produced the second largest water level on record for Vaca Key gauge.

Table 2-8 provides a summary of Federal Emergency Management Agency (FEMA) flood claims paid to Monroe County individual policyholders as a result of these tropical events; including the number of paid losses, the total amount paid, and the average amount paid on each loss. The table excludes losses that were not covered by flood insurance such as wind damage.

Table 2-9 provides the amount of Public Assistance grant funding to Monroe County, for approved projects dealing with debris removal, public buildings, utilities, roads and bridges. The grants also covered protective measures provided during storm events such as emergency operations centers and security measures to provide for public safety, respond to emergency needs, block flooded roads and carry out nighttime patrols in areas without power (OpenFEMA Dataset).

Table 2-8: FEMA Flood Claims in Monroe County

Storm Event	Year	Number of Paid Claims	Total Amount Paid - 2020 CPI Adjusted ($)	Average Amount Paid - 2020 CPI Adjusted ($)
Hurricane Andrew	1992	184	190,700	1,036
Tropical Storm Gordon	1994	188	2,122,000	11,287
Hurricane Georges	1998	7,266	69,665,200	9,588
Hurricane Irene	1999	859	7,603,300	8,851
Hurricane Wilma	2005	9,193	452,674,000	49,241
Hurricane Irma	2017	8,172	308,767,100	37,784
Source: Federal Insurance & Mitigation Administration National Flood Insurance Program (FIMA NFIP)				

Table 2-9: Public Assistance Projects

FEMA Disaster Number	Year of Declaration	Incident Type	Totals Paid 2020 CPI-Adjusted ($)
1306	1999	Hurricane	5,384,000
1539	2004	Hurricane	335,000
1545	2004	Hurricane	45,000
1551	2004	Hurricane	465,000
1595	2005	Hurricane	8,454,000
1602	2005	Hurricane	8,090,000
1609	2005	Hurricane	85,464,000
1785	2008	Severe Storm(s)	4,430,000
3259	2005	Hurricane	3,404,000
3293	2008	Hurricane	787,000
4084	2012	Hurricane	950,000
4337	2017	Hurricane	115,030,000
Source: FEMA Public Assistance Funded Projects			

2.5 Compliance

Given growth restrictions anticipated in the study area, it is not expected that development or redevelopment will be greatly impacted by a coastal storm risk management system. PGL 25 and Executive Order 11988 states that the primary objective of a flood risk reduction project is to protect existing development, rather than to make undeveloped land available for more valuable uses. The PDT has confidence that the current Recommended Plan is compliant with this policy guidance.

3 SCOPE OF STUDY

The next few sections review two important components related to the scope of this study: the problem description and an overview of the potential structural and nonstructural measures which could be used to mitigate damage caused from coastal storm flooding.

3.1 Problem Description

The overarching problem to be addressed by this study is that coastal storm events cause damage to the natural and built environment in the Florida Keys as a result of flooding, wave action, and erosion. There are several more specific drivers and issues within this problem:

- Critical infrastructure features, including fire stations, airports, hospitals, etc., are vulnerable to the effects of coastal storms.
- Critical transportation routes and US Route 1 specifically is vulnerable to the effects of coastal storms and there have been instances of storm surge and erosion affecting evacuation before/during storms and the timely return of residents after the evacuation is lifted post-storm.
- Structures (commercial and residential), are vulnerable to the effects of coastal storms.
- There are rich environmental resources that are unique to the study area that are vulnerable to the effects of coastal storms. Some of these resources, mangroves for example, provide a reduction in the impacts of coastal storms on the study area and their loss increases the risk of storm impacts on the study area.

3.2 Project Measures and Alternatives

Plan alternatives were derived in order to alleviate the problems described above of the study area. The scope of this study includes investigating the effectiveness, benefits, and costs of structural and nonstructural measures which comprise alternative plans. Project alternatives, including the Recommended Plan, are detailed in this appendix and also in chapters 7 – 9 in the feasibility report. The following sections describe the various measures considered. The remainder of this appendix outlines the study methodology for (1) modeling these measures, (2) evaluating the plan alternatives, and (3) selecting the Recommended Plan.

3.2.1 Structural Measures

Most alternatives that included structural solutions, especially large-scale measures such as sea walls and surge barriers, were eliminated early in plan formulation due to site conditions. The Florida Keys are a unique study area: the islands' characteristics increase the area's vulnerability to coastal storms and ultimately limit the application of many risk reduction measures that are used in other coastal communities. Most coastal communities in the US, even those in southern Florida, have a defined coastline where coastal storms make landfall and then coastal risk gradually decreases moving inland away from the coast. As an archipelago situated between the Atlantic Ocean and Gulf of Mexico, coastal storms can make landfall from any direction and the Islands are so small that there is effectively no area to retreat. Most structural measures are designed to reduce storm surge and wave energy from one direction, so that there is an area behind that measure with significantly reduced risk. However, in the Keys, there is effectively no way to reduce risk to an area behind a wall or surge barrier without encircling an entire island. Considering this and also the porous limestone geology in the Keys, all large-scale structural measures were screened from consideration except for shoreline stabilization with a revetment. The rational for including the revetment as an alternative is discussed later in this appendix.

3.2.2 Nonstructural Measures

There are three nonstructural measures considered in the alternative plans: elevation, floodproofing, and acquisition. An overview of these measures provided below.

3.2.2.1 Elevation

This nonstructural technique involves lifting a structure to a higher elevation. For structures within Coastal AE or VE Zones, the lowest horizontal member must be located above the design water surface elevation. This can add an additional foot of elevation, considering the depth of the floor joists, when measuring to the top of the first floor. In addition, the FEMA Base Flood Elevations in these zones include additional elevation above the still water to account for wave action, specifically 1.5' – 3' in Coastal A Zone and 3'+ in VE Zone. For structures in these zones, the recommended course of action is to add 1.5' to the Design Water Surface Elevation for buildings in the Coastal A Zone and 3' to the Design Water Surface Elevation for buildings in the VE Zone to account for wave action.

3.2.2.2 Floodproofing

This mitigation measure was employed on non-residential structures where the first floor is located below the FEMA 1% annual chance flood elevation + 2075 immediate sea level rise. For the economic analysis, the floodproofing height limit was set at 3 feet above the ground stage. According to the Flood Insurance Administration Technical Bulletin 3-93, floodproofing to flood heights greater than 3 feet may be cost prohibitive. Floodproofing is not an appropriate measure in a coastal A or VE Zones where wave action is expected. Additionally, it should be noted that FEMA certification requires an additional foot of floodproofing above BFE. Therefore, the assumption of 3 feet, used in the modeling/economic analysis, may not result in a measure that would be certified by FEMA. USACE does not, specifically, formulate to NFIP requirements even though compliance with the NFIP is a requirement for local sponsors to partner with USACE.

3.2.2.3 Floodproofing (dry)

This nonstructural technique involves sealing building walls with an impermeable layer or other materials to prevent entry of floodwaters. Additional methods include the use of barriers for window and door openings. For this economic analysis, the floodproofing height was set at 3 feet above the ground stage. Dry floodproofing is appropriate for areas without wave action or scour potential and shallow and low velocity flooding.

3.2.2.4 Buyout/Acquisition

This mitigation measure removes the structure, subject to damage, from the structure inventory. The land becomes open space, making room for the water. When strategically planned, multiple acquisitions can be grouped together to provide recreation and/or nature-based opportunities. Recreation opportunities can have positive benefits reflected in increased property values and health benefits through recreation opportunities. While it is the only measure that completely removes flood risk, the significant financial and social implications of acquiring properties and potentially disrupting communities and removing structures from the tax base can make it a less favored option.

4 STUDY 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, 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 damage. For this study, the future without project condition is for the years 2035-2084. 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 damage to the Monroe County study area assets between the future without- and with- project conditions represent the flood risk management benefit 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 recognizes and, where possible, quantifies the reduction of damage from coastal storm surge inundation due to the Federal project in the study area (i.e. NED benefits). The main benefit used for analysis is the reduction in expected damage.

The following sections discuss several key aspects about the study methodology, aspects which include risk and uncertainty, G2CRM information, and details about modeling.

4.1 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 expedience 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 US 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 G2CRM to support planning-level studies of hurricane protection systems (HPS). Even with modeling, risk and uncertainty are present. Study-specific risk and uncertainty associated with the Recommended Plan is discussed later in this appendix.

4.2 Model Information

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 damage. The model version used for this analysis is G2CRM 4.558.3. 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 model components are discussed below.

- **Driving forces** - storm hydrographs (surge and waves) at locations, as generated externally from high fidelity storm surge and nearshore wave models such as ADCIRC and STWAVE.
- **Modeled areas** (MAs) - areas of various types (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.
- **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.

- **Assumptions** – In any model-based analysis, assumptions are an important and necessary component to outline in detail. General G2CRM- and study-related assumption are listed later in this appendix.

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. The economic and engineering variables that compose these components are discussed in the following sections.

4.2.1 Model 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 for the study area. By definition, it is impossible to fully capture and quantify uncertainty. However, the PDT is confident in reasonably capturing much of the uncertainty described in the following sections by modeling with 100 iterations. This high number of iterations allows model estimates to account for variations in the economic and engineering inputs.

4.2.2 Economic Inputs

Uncertainty was quantified for errors in the underlying components of structure values for residential and non-residential structures, content-to-structure value ratios for residential and non-residential structures, depth-percent damage relationship for both residential and non-residential 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.

The uncertainty surrounding each of the economic and engineering variables is also considered in the model. Either a normal probability distribution, with a mean value and a standard deviation, or a triangular probability distribution, with a most likely, maximum and minimum value, was entered into the models to quantify the uncertainty associated with the key economic variables. A normal probability distribution was entered into the model to quantify the uncertainty surrounding the ground elevations. The number of years that stages were recorded at a given gage was entered for each study area reach to quantify the hydrologic uncertainty or error surrounding the stage-probability relationships.

4.2.2.1 Structure Inventory

Parcel boundaries and tax assessor data from the year 2018 were provided by Monroe County to assist with characterizing residential and non-residential structures for the economic analysis. Data included addresses, property class description, property use, dwelling year built, dwelling condition/grade, crawl code, number units, number of floors, etc. With the building footprints provided by the County, property class descriptions and Google Maps were used to classify buildings into damage categories and occupancy types. First floor elevation assumptions were based on foundation type and verified with available elevation certificates or Google street views. Florida statewide building footprints were used to validate building footprints and to fill in data gaps in the structure inventory dataset. Critical infrastructure status is also noted in the inventory in order to assist in analyzing and comparing the plan alternatives, detailed later in this appendix.

4.2.2.2 Structure Values

Depreciated replacement value per square foot was calculated for residential and non-residential structures using data from Gordian’s 40th edition of “Square Foot Costs with RS Means Data.”

According to the RS Means depreciation schedule, structures were depreciated based on age, and then, depreciated an additional percentage to equal a regional adjustment of 80% for residential, as determined by RS Means for the Ft. Myers area (the most comparable locality available). This process was used to calculate a most-likely cost per square foot for each construction class within each residential occupancy category. When appropriate and necessary, categories were grouped with respect to the RS Means tables available. These estimates are based on nearly 90% of the structure inventory dataset. The most-likely depreciated cost per square foot was then multiplied by the square footage of individual structures in each occupancy to obtain a total depreciated cost or value for each structure in an occupancy.

Since square footage was not available for all structures, to determine a square footage per building, the following methodology was used. The polygon area of the building footprint was calculated in ArcGIS and multiplied by 0.9 to allow for unusable space such as doors, walls, etc. This area was multiplied by the number of floors, not to exceed the number of floors within the depth-damage function for the occupancy type of the structure. An average square footage was calculated for three construction classes (economy, average, and luxury) within each residential occupancy category reflecting the quality of the materials used in the construction of the buildings. An average replacement cost per square foot was calculated for four exterior wall types (wood frame, brick veneer, stucco, or masonry) within each construction class.

An average square footage was calculated for each non-residential category or occupancy, and an average replacement cost per square foot was calculated for six exterior wall types (decorative concrete with steel frame and bearing walls frame, face brick with concrete block back-up with steel frame and bearing walls frame, metal sandwich panel with steel frame, a precast concrete panel with bearing walls frame) within each occupancy. Based on Monroe County 2018 Assessor's data, it was determined that the average non-residential structure in the study area was approximately 30 years old. The RS Means depreciation schedule for non-residential structures provides three depreciation percentages for structures based on their exterior wall type: wood frame exterior walls; masonry on wood frame; and masonry on steel frame. The masonry on wood exterior wall depreciation percentage was used as the most-likely value and applied to all the non-residential structures in the structure inventory. An additional regional adjustment of 84 percent, or a 6% decrease in value, was incorporated to adjust from the Ft. Myers area to the Monroe area; this adjustment was applied to the depreciated cost per square foot. This process was used to calculate a most-likely cost per square foot for each structure within a non-residential category or occupancy. The most-likely depreciated cost per square foot was then multiplied by the actual square footage of the individual structures in each occupancy to obtain a total depreciated cost. The Replacement Values have been indexed using the RS Means 2021 Historical Cost Indexes to calculate FY21 price levels. It should be noted that structures values at $50,000 or below were screened out due to the likelihood of the structure not being a separable asset (for example, the 'structure' may actually be a shed). As there are over 40,000 in the initial structure inventory, it was difficult to do a full structure-by-structure analysis to ensure the quality and accuracy of each inventory item. Therefore, the PDT determined this to be a necessary screening.

4.2.2.3 Future Development Inventory

Due to the density of structures in the County, state-imposed growth restrictions, and limited vacant land, a future development structure inventory was *not* included in the damage calculations. It is anticipated that the majority of future development will be the infill of structures on the limited vacant land, or, most likely, redevelopment. The percentage of infill or new development is anticipated to have a negligible impact on the growth of the structure inventory and future damage as existing floodplain ordinance require new or substantially improved structures in FEMA's Special Flood Hazard Area, or the 1% annual chance floodplain, to be constructed at BFE plus three feet of additional elevation. In addition, structures within FEMA's Zone X, or the 0.2% annual chance floodplain to be elevated 18 inches above the highest adjacent grade.

4.2.2.4 Content-to-Structure Value Ratios

Site-specific Content-to-Structure Value Ratio (CSVR) information would be the most precise data for this estimation. However, this information was not available for the study area. Therefore, residential and non-residential CSVRs used in this feasibility study were obtained from the 2016 Norfolk Coastal Storm Risk Management Study and the revised 2013 Expert Elicitation draft report completed by the USACE Institute of IWR. To estimate the value of structure contents, these ratios are multiplied by approximated area-specific depreciated structures replacement values. This should result in a reasonably accurate approximation since the ratios are relative to structure values.

As shown in Table 4-1, a CSVR was computed for each residential and non-residential structure in the study as a percentage of the total depreciated replacement value. A triangular distribution was used to estimate the error. The appropriate categories were utilized for the study.

Table 4-1. Content-to-Structure Value Ratios and Triangular Distribution

	Structure Category	Percent		
		CSVR Most Likely	Min	Max
Residential	One-Story, No Basement (1SNB)	50.00	25.00	75.00
	One Story With Basement (1SWB)	50.00	25.00	75.00
	Two Story No Basement (2SNB)	50.00	25.00	75.00
	Two Story With Basement (2SWB)	50.00	25.00	75.00
	Mobile Home*	142.00	0.64 SD	
	Apartment, One story, No Basement (A-1SNB)	9.90	7.50	13.50
	Apartment, Three Story, No Basement (A-3SNB)	9.90	7.50	13.50
non-residential	Engineered, Non Perishable (ENG-NP)	18.10	14.00	24.00
	Grocery (GROC-LG)	70.00	61.50	78.50
	Grocery, Convenience (GROC-SM)	34.00	25.00	40.00
	Hospital (HOSPITAL)	43.90	35.00	50.00
	Hotel (HOTEL)	25.60	20.00	32.50
	Urban High Rise (HRISE-U)	18.10	14.00	24.00
	Beach High Rise (HRISE-B)	9.90	7.50	13.50
	Medical Office (MEDICAL)	60.49	53.20	66.20
	Office (OFFICE)	18.10	14.00	24.00
	Pre-Engineered Non-Perishable (PREENG-NP)	38.20	31.50	44.00
	Restaurant (REST)	22.90	16.50	28.50
	Restaurant, Fast Food (REST-F)	27.20	21.00	32.50
non-residential	Retail Clothing (RETAIL-C)	45.00	36.50	52.50
	Retail Electronics (RETAIL-E)	65.00	60.00	75.00
	Retail Furniture (RETAIL-F)	36.50	31.00	42.60
	Service Station (SERVICE)	66.00	55.50	73.80
	Industrial Light (LT)	38.20	31.50	44.00
	Warehouse, Non-refrigerated (WARE-N)	37.40	31.00	43.50

Structure Category		Percent		
		CSVR Most Likely	Min	Max
	Warehouse, Refrigerated (WARE-R)	35.60	30.00	41.50
	Education (EDU)	6.50	5.00	9.00
	Protective Services (RESCUE)	69.50	60.00	75.00
	Recreation (RECR)	24.60	20.00	31.00
	Religious Facility (RELIGIOUS)	6.90	5.00	10.50

4.2.2.5 First Floor Elevations

Ground elevations were obtained from Light Detection and Ranging (LiDAR) digital elevation model (DEM), developed in support of new FEMA coastal Flood Insurance Rate Map update, using NAVD88. Parcel data from the 2018 real estate assessment tables provided by the County included type of foundation for some structures but was supplemented with foundation type data from the National Structure Inventory (NSI2). The Norfolk team determined the average height above ground for each foundation type and validated with FEMA Elevation Certificates provided by the County. The foundation height (sum of the number of stairs) was added to the ground elevation to determine the first floor elevation of each structure in NAVD88.

4.2.2.6 Depth-Damage Relationships

Various depth-damage functions (DDFs) were considered for use in the study. However, given that no geographically specific curves were available for the Florida coastal region, a broader geographic collection of curves was considered. Residential and Non-residential depth-percent damage relationships are sourced from (1) the 2015 North Atlantic Coast Comprehensive Study (NACCS) Physical Depth-Damage Function Summary Report and (2) the revised 2013 Expert Elicitation draft report completed by the USACE Institute of Water Resources (IWR). Various flood depth-damage functions were used with respect to structure characteristics. These depth-damage functions are assumed to be representative of the structures in the floodplain. The DDFs established within the NACCS Physical Depth Damage Function Summary Report were determined to be appropriate for use in the study. The NACCS curves were used to model damage for all residential structures and the majority of non-residential structures, unless curves for more specific non-residential structure types were developed as part of the non-residential Flood Depth-Damage Functions Derived from Expert Elicitation Report in 2013. These curves were used in lieu of the NACCS curves for non-residential inundation to more closely match specific non-residential occupancy types within the structure inventory.

The PDT determined it appropriate to primarily source from the 2015 NACCS as it provides more updated functions and more conservative residential DDFs compared to other sources, such as the generic residential DDFs offered in the EGM 01-03. The risk is more likely that the team underestimated damage estimates by primarily sourcing from the 2015 NACCS verses potentially overestimating damage by sourcing from the EGM 01-03. As Table 4-2 will show, single story residential home represents nearly 40% of the structure inventory. The table below compares DDFs from the two sources mentioned previously to highlight this difference between the two.

Table 4-2: Comparison of DDFs

Single-Story Home, No Basement		
Depth	*Expected Damage (%)*	
	2015 NACCS	*(EGM) 01-03*
-1	*0*	*2.5*
0	*1*	*13.4*
1	*18*	*23.3*
2	*28*	*32.1*
3	*33*	*40.1*
5	*42*	*53.2*
7	*55*	*63.2*
10	*65*	*73.2*

4.2.2.7 Uncertainty Surrounding the Economic Inputs

The uncertainty surrounding the four key economic variables (structure values, contents-to-structure value ratios, first floor elevations, and depth-damage relationships) was quantified and entered into the economic models. The G2CRM model used the uncertainty surrounding these variables to estimate the uncertainty surrounding the stage-damage relationships developed for each study area reach.

4.2.2.7.1 Structure Values

A triangular distribution based on the depreciated replacement costs derived for the three construction classes (economy, average, and luxury) was used to represent the uncertainty surrounding the residential structure values in each occupancy category. The most-likely depreciated replacement value was based on the average construction class, the minimum value was based on the economy construction class, and the maximum value was based on the luxury construction class. These values were then converted to a percentage of the most-likely value with the most-likely value equal to 100% of the average value for each occupancy category; the minimum value equal to 80% of the most likely, and the maximum value equal to 120% of the most likely. The triangular probability distributions were entered into the G2CRM model to represent the uncertainty surrounding the structure values in each residential occupancy category.

A triangular probability distribution based on the depreciation percentage associated with the three exterior wall types (wood frame, masonry on wood frame, and masonry on masonry or steel) was used to represent the uncertainty surrounding the non-residential structure values in each occupancy category. The most-likely depreciated value was based on the depreciation percentage assigned to a masonry exterior wall construction, the minimum value was based on the depreciation percentage assigned to a wood frame exterior wall construction, and the maximum value was based on the depreciation percentage assigned to a masonry on masonry/steel exterior wall construction. These values were then converted to a percentage of the most-likely value with the most-likely value being equal to 100% and the minimum and maximum values equal to percentages of the most-likely value. The triangular probability distributions were entered into the economic models to represent the uncertainty surrounding the structure values for each non-residential occupancy category.

4.2.2.7.2 Content-to-Structure Value Ratios

A triangular probability distribution was used to represent the uncertainty surrounding the contents-to-structure value ratios (CSVRs) for residential structures. The minimum CSVR value, 25 percent, was obtained from the Willoughby GRR, an evaluation completed in Norfolk, Virginia, while the maximum CSVR value, 70 percent, was based on a survey of homes in coastal Louisiana. The most-likely value, 50 percent, was obtained from an economic analysis completed in support of a Continuing Authorities Program, Section 205 study on Newmarket Creek, Hampton, VA. A triangular probability distribution was also used to represent the uncertainty surrounding the CSVRs for the non-residential occupancies. The minimum, maximum, and most-likely values were based on data obtained from either the Physical Depth Damage Function Summary Report published as a part of NACCS study or the 2013 Draft Non-residential Flood Depth-Damage Functions Derived from Expert Elicitation, depending on the type of non-residential occupancy.

4.2.2.7.3 Depth-Damage Relationships

A triangular probability density function was used to determine the uncertainty surrounding the damage percentages associated with each depth of flooding for the various residential and non-residential occupancy categories. A minimum, maximum, and most-likely damage estimate for each depth of flooding was obtained from the Physical Depth Damage Function Summary Report published as a part of NACCS study and the 2013 Draft non-residential Flood Depth-Damage Functions Derived from Expert Elicitation. A national panel of building, construction, insurance, and restoration experts was used to develop the data contained in these reports. Moreover, both 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.

4.2.3 Engineering Inputs to the Model

The proceeding sections provide details on the following engineering model inputs: storms, save points, and stage-probability relationships. The uncertainty around these variables is also discussed.

4.2.3.1 Storms – H5 Data

G2CRM requires a probabilistic storm suite (storm hydrographs (surge and waves) at locations, as generated externally from high fidelity storm surge and nearshore wave models such as ADCIRC and STWAVE) as the driving forces. For Monroe County, 388 storms from the FEMA SFL Study data were included in the Tropical Storm probabilistic storm suite. The water level and wave hydrographs provided from these storms were developed into an h5 input file to be used by the model. Additional detail on the storms modeled can be found in the engineering appendix.

4.2.3.2 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. These save points contained the water elevations and wave heights for each of the storms in the reduced storm set to be used in the model and eventually used to represent the final model areas. These water elevations were applied to the model areas along with economic inputs to derive flood damage in the existing condition, future without project condition, and future with project condition for the Monroe County Study Area.

The initial economic analysis leading up to the TSP and Recommended Plan was based on a course granularity of storm data, using only 5 save points for the 9 modeled areas delineated across the Keys. As the study was refined, additional save points were incorporated to finalize the number of structures to be evaluated for the Agency Decision Milestone. Additional model areas were also added to improve the analysis. Therefore, the model areas are more so based on the save points rather than localities and/or municipalities. The study currently has 34 save points and 34 model areas. Specific details for the revised save points can be found in engineering appendix.

4.2.3.1 Uncertainty Surrounding the 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. 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 contains more information regarding G2CRM engineering inputs.

4.3 Model Assumptions and Settings

The G2CRM model version 0.4.558.3 was used to evaluate flood damage using risk-based analysis. Damage were reported at the index location for each of the 34 model areas for which a structure inventory had been conducted. The model also used the number of years that stages were recorded at a given gage to determine the hydrologic uncertainty surrounding the stage-probability relationships.

The possible occurrences of each variable were derived through the use of Monte Carlo simulation, which used randomly selected numbers to simulate the values of the selected variables from within the established ranges and distributions. For each variable, a sampling technique was used to select from within the range of possible values. With each sample, or iteration, a different value was selected. The number of iterations performed affects the simulation execution time and the quality and accuracy of the results. This process was conducted simultaneously for each economic and hydrologic variable. The resulting mean value and probability distributions formed a comprehensive picture of all possible outcomes. Model assumptions and additional configuration settings are listed below.

For this analysis, assumptions made in the model include the following:

- The number of iterations selected for the analysis was 100. The sum of all sampled values was divided by the number of samples to yield the expected value for a specific simulation. At 100 iterations the estimates were found to be efficient with the least variance.
- The G2CRM model used the economic and engineering inputs to generate a stage-damage relationship for each structure category in each study area reach under existing (2035) and future (2084) conditions.
- Using Monte Carlo simulation, the G2CRM model estimates a mean structure present value damage and standard deviation given the simulated storm and tidal conditions
- 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, and not removed from the asset inventory (i.e. cumulative damage threshold not used).
- Residential structures are raised after receiving significant damage within the period of analysis with respect to the appropriate elevation height as detailed in the previous section.
- Residential and Non-residential depth-percent damage relationships for structure and content are sourced from (1) the North Atlantic Coast Comprehensive Study (NACCS) Physical Depth-Damage Function Summary Report and (2) the revised 2013 Expert Elicitation draft report completed by the USACE Institute of Water Resources (IWR). Various flood depth-damage functions were used with respect to structure characteristics. These depth-damage functions are assumed to be representative of the structures in the floodplain.
- The present valued damage, first costs, and benefits will be annualized using the fiscal year 2021 Federal discount rate of 2.5% assuming a period of analysis of 50 years.
- All values are equivalent to fiscal year 2021 dollars.
- All project alternatives are evaluated for a 50-year period of analysis.
- The project construction is scheduled to begin in 2026.
- The final year of the 50-year period of analysis ends December 31, 2079.
- Unless otherwise stated, elevations are in feet (ft) North American Vertical Datum of 1988 (NAVD88).
- Depreciation is calculated for structures (i.e. replacement values) during the life cycle analysis (before inputted into the model).
- Expected sea level rise was modeled using the High Sea Level Curve (SLC) setting in G2CRM and the mean sea level trend of 0.0126 ft/yr (Vaca Key, FL) was used as the sea level change rate.

Additional model configuration settings:

- Project base year, the year in which benefits begin to accrue: 2035
- Sea Level Change basis year: 1992
- USACE High Curve
- Calculate Depreciation: No
- Raise Structures: Yes
- Calculate Assets: Yes
- Use Benefit Bases: No
- Cumulative Damage Removal: No
- Calculate Life Loss: No
- Auto-Generated Waves: On

4.4 Modeling the Structural and Nonstructural Measures

The next few sections provide an overview of the G2CRM modeling process for the structural and nonstructural measures.

4.4.1 The US 1 Revetment

The primary objective of the structural measure is to stabilize the shoreline along six sections of US 1, rather than reduce inundation. G2CRM was initially utilized to estimate potential benefit provided by the revetment. Since G2CRM is an inundation model, however, the PDT has since determined that G2CRM should not be used to evaluate this measure. Therefore, there is no G2CRM modeling information that needs to be provided for this measure.

4.4.2 Elevation

Elevation is a nonstructural measure carried forward as a component in multiple alternatives (discussed later in this appendix). The PDT and vertical team determined that elevation should be based on protecting against damage caused by storm surge and waves associated with a 100-year storm event. Design elevation heights for each MA were determined by 100-year storm event still water estimates (with respect to the 50% confidence level and for the year 2084). Additional height was added to design elevations to account for waves. If a structure is in a VE or V zone, the full estimated wave height was added to the design elevation height (if wave data was available, a standard 3 feet was added). If a structure is in an AE, AH, or AO zone, 25% of the estimated wave height was added (If no wave data was available, a standard .75 feet was added.

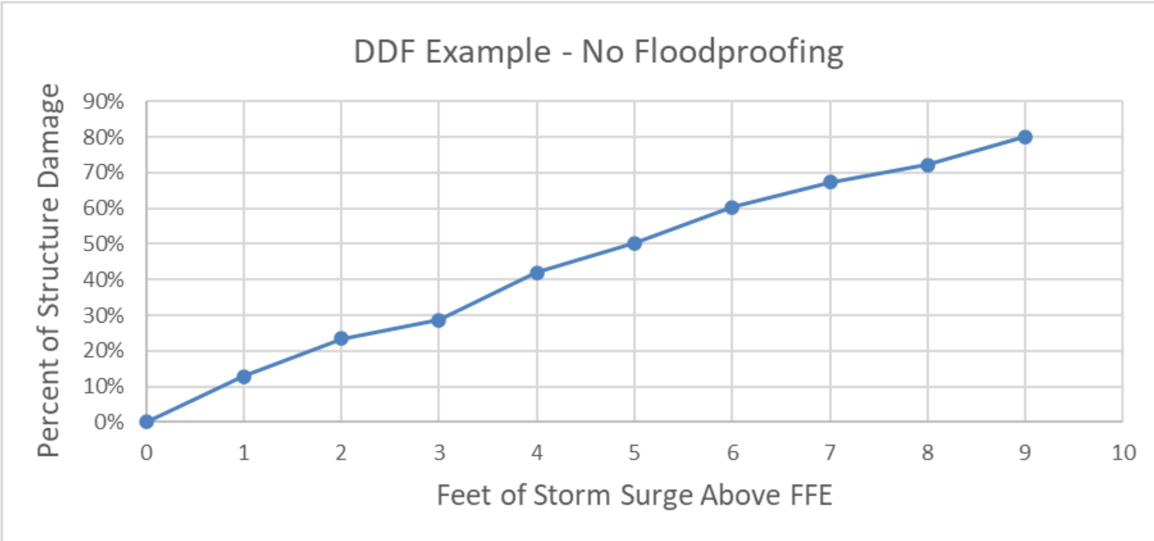
Given the varying geography of the study area, the required foundation height to elevate structures ranges from 1-12 feet. 12 feet is used as a maximum foundation height allowed to elevate a structure from the ground; This is due to structural integrity and wind load issues. Other USACE projects use a similar maximum height. Surveys would need to be conducted regardless to determine if structures can withstand all the horizontal and vertical forces expected to act on structures. This also depends on the current number of stories on the structure, and the elevation of the current roof top. Some localities have limits as to how high the roof can be and this would limit how high structures can be elevated as well. Consequentially, not all structures are permitted to be elevated at a height that would maximize the reduction in expected damage. These situations will be identified and better understood during PED.

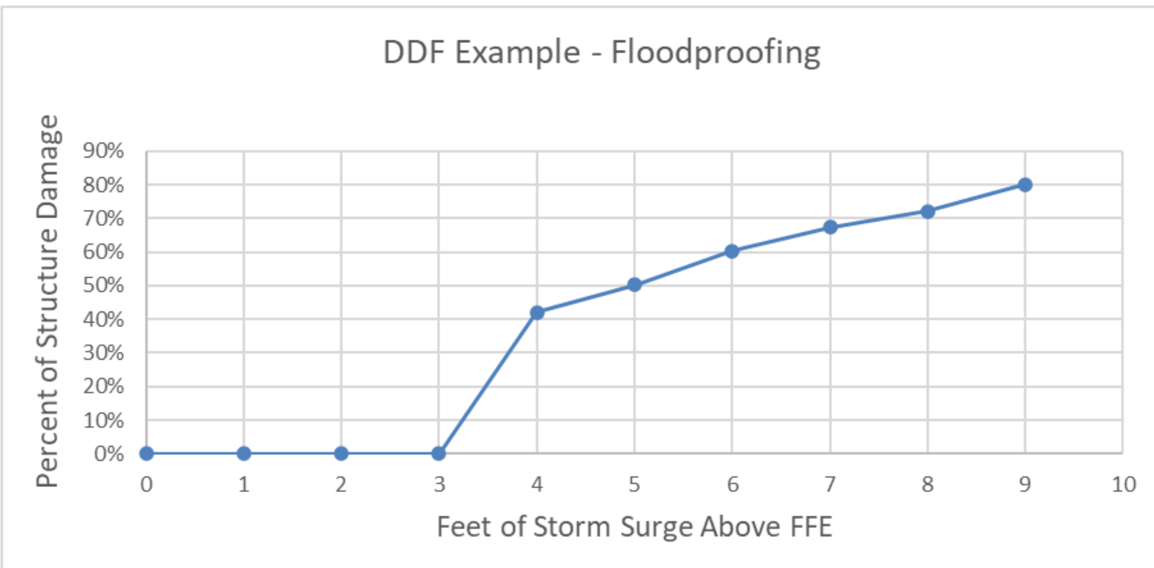
Only single-family residential homes were considered for elevation. The elevation of these structures was modeled by utilizing the same DDF, respective of the structure's occupancy type, and adjusting the first-floor elevation to the determined design elevation height.

4.4.3 Floodproofing (Dry)

Dry floodproofing is another nonstructural measure considered in a few plan alternatives. Commercial buildings, government buildings and non-single-family residential structures (apartments/condominiums) were considered for floodproofing. These structures were modeled to be floodproofed to the maximum suggested height of three feet[2] above ground level. The DDFs for structures, modeled to be floodproofed, were adjusted as shown in the two figures below. This adjustment is to model the added storm surge protection of up to three feet about the structures first floor elevation (FFE).

[2] Sourced from Flood Proofing Tests: Tests of Materials and Systems for Flood Proofing Structures (USACE 1988)





4.4.4 Acquisition

Acquisition is the third nonstructural measure initially included as a component in multiple plan alternatives. While acquiring a residential structure fully mitigates flood risk, the measure can be extremely involved and expensive to the Federal Government and non-Federal Sponsor (NFS). The costs and benefits for acquisition and elevation were compared for residential structures in order to determine the most economical measure. The PDT determined that acquisition should be screened out of the alternatives, based on preliminary modeling and analysis. There is no G2CRM modeling information that needs to be provided for this measure.

4.4.5 Nonstructural Cost Estimation for Analysis

Preliminary cost estimates were utilized to support initial analysis and identify which structures would likely benefit from nonstructural measures. The estimations for floodproofing, elevating, and acquiring were largely derived from the USACE New Orleans District (USACE, 2012) and adapted for the Monroe Country area. This was required as preliminary estimates were not provided by cost engineer as requested. The next few sections provide some detail on these estimations. While they were accounted for in the analysis, the formulas and tables below exclude contingencies for risk, construction management, environmental mitigation, etc.

The ultimate cost estimates used to evaluate study alternatives are from the Total Project Cost Summary (TPCS), estimated by cost engineering. More details on estimations and cost contingencies of the certified TPCS should be found in the cost engineering appendix.

4.4.5.1 Preliminary Floodproof Cost

The preliminary floodproofing cost estimation utilized costs shown in the table below; the estimation can be described in the following formula:

Floodproofing First Cost = (Cost) + (Floodproofing Fee)

Table 4-3: Preliminary Floodproofing Costs

Category	Square Footage Range	Cost ($)	Additional Floodproofing Fee ($)	First Cost ($)
1	0-30,000	181,000	1,000	182,000
2	30,000-100,000	428,000	1,000	429,000
3	100,000+	1,058,000	1,000	1,059,000

(1) Estimates are in FY 2021 dollars and rounded
(2) The cost utilized is with respect to the square footage of the structure

4.4.5.2 Preliminary Elevation Cost

Much of the cost for elevating a structure is attributed to overhead and initial material costs. The marginal cost to elevate a structure an additional foot is relatively small compared to the initial cost, as shown in the table below. Utilizing the costs noted below, the preliminary cost estimation for elevating can be described in the following formula:

Elevation First Cost = (Parameter Square Foot) x (Square Foot Cost) + (Elevation Fees)

Table 4-4: Preliminary Elevation Costs per Square Foot

	Foundation Type			
Feet Raised	Slab-1 Story ($)	Slab-2+ Story ($)	Other-1 Story ($)	Other-2+ Story ($)
1	97	106	84	92
2	97	106	84	92
3	97	106	84	92
4	97	106	84	92
5	97	106	84	92
6	104	115	97	106
7	104	115	97	106
8	104	115	97	106
9	104	115	97	106
10	104	115	97	106
11	104	115	97	106
12	104	115	97	106

(1) Estimates are in FY 2021 dollars and rounded
(2) Other foundation types included crawl space and pile
(3) The elevation fees were estimated at around $9,300; the cost includes both relocation benefits and administration fees.

4.4.5.3 Preliminary Acquisition Cost

The cost to acquire as structure can be partitioned into two main components: the structure fair market value and a summation of acquisition fees (broken down in the table below). Fair market value estimates were based on the most current tax assessor data. However, real estate team members compared this data with current housing prices and determined that tax assessor data was lower on average. Tax assessor estimates were increased by 30% to account for this; this increase should also account for expected increases in housing demand across Monroe County given expected rate of growth restriction ordinances. This percent increase was determined and agreed upon by the real estate team and larger PDT. The preliminary acquisition cost estimation can be described as the following:

Acquisition First Cost = (Fair Market Value) x (130%) + (Acquisition Fees)

Table 4-5: Preliminary Acquisition Costs

Acquisition Fee Item	Cost ($)
Demolition	15,000
Replacement Housing Payment	31,000
Moving Fee	10,000
Last Resort Housing	25,000
Survey Cost	5,000
Review Appraisal Cost	3,000
Full-Service Support	73,000
Condemnation Cost	38,000
Acquisition Fees Total	200,000
(1) Estimates are in FY 2021 dollars and rounded (2) Condemnation cost was derived by multiplying the expected cost by the rate of condemnation	

As mentioned in the previous section, Acquisition was screened out as a nonstructural measure. While the measure completely reduced structure damage, it is extremely costly (and likely more costly than our current estimates). The example below provides a direct comparison of preliminary costs for elevation and acquisition. This example is meant to provide a top-level understanding and is therefore based on inventory averages for a two-story residential home with a crawl space. It is assumed that new design elevation foundation height is six feet.

Cost Comparison:

Elevation First Cost = (Parameter Square Foot) x (Square Foot Cost) + (Elevation Fees)
Elevation First Cost = (2,000) x ($106) + ($9,300)
Elevation First Cost = $221,300

Acquisition First Cost = (Fair Market Value) x (130%) + (Acquisition Fees)
Acquisition First Cost = ($977,000) x (130%) + ($200,000)
Acquisition First Cost = $1,470,100

Elevation First Cost vs. Acquisition First Cost
$221,300 vs. $1,470,100

The next comparison presents the expected benefits associated with each structure compared with the expected costs in order to estimate and compare expected net benefits.

Net Benefits Comparison:

Elevation Average Benefit = (Average Structure FWP Damage Reduction Estimate)[3]
Elevation Average Benefit = ($520,300)
Elevation Average Net Benefit = ($520,300) – ($221,300)
Elevation Average Net Benefit = $299,000

Acquisition Average Benefit = (Average Structure FWOP Damage Estimate)[4]
Acquisition Average Benefit = ($939,300)
Acquisition Average Net Benefit = ($939,300) – ($1,470,100)
Acquisition Average Net Benefit = - $530,800

Elevation Net Benefit vs. Acquisition Net Benefit
$299,000 vs. - $530,800

These examples show what was largely found in the aggregate for residential structures: the cost to acquire a structure is extremely higher than the cost to elevate a structure. While acquisition fully reduces damage to a structure, this comparison shows that reduction in damage does not justify the cost of acquisition, leading to negative net benefits. In contrast, elevation reduces damages to a lesser extent; but it was found to be a more economical measure for residential structures and produces positive net benefits. Planning guidance requires a plan to be efficient, acceptable, and complete. The measure of acquisition was not determined to support an efficient and acceptable plan. The PDT was transparent in this screening with the USACE North Atlantic Division review team and NFS.

5 EXISTING CONDITIONS

There are thousands of structures in the FEMA 1% annual chance exceedance (ACE), or 100-year, floodplain in the Monroe County Study Area. 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

[3] This estimate is based on the average present value mean FWP damage reduction estimate for structures included in the current Recommended Plan. Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035.
[4] This estimate is based on the average present value mean FWOP damage estimate for structures included in the current Recommended Plan. Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035.

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[5], 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.

Parcel data from the 2019 real estate assessment tables provided by the County included type of foundation for some structures, but was supplemented with foundation type data from the National Structure Inventory (NSI2). The inventoried structures were categorized as residential or non-residential and were further categorized into occupancy type.

5.1 Model Areas

The term “model area” describes 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 damage by breaking the study are down into several areas having some common features and analyzing them separately also speed up the economic modeling process. The study area consists of 34 MAs. Within each MA, the model areas are further defined by types: unprotected and upland. An unprotected MA 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

[5] The PDT has reserved the option to include vehicles as damageable inventory in optimization after TSP, but before ADM.

overtopping. It was determined by PDT members and model reviewers that the use of unprotected MAs is most appropriate for the study area.

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 Monroe County study area as shown in the table below. The low elevations and tidal connections place a significant percentage of the county at risk of flooding from nor'easters, tropical storms, hurricanes, and other storms.

The residential and non-residential assets included in the economic analysis were classified into distinct damage categories (residential, commercial/industrial, and public) and structure occupancies. The table below provides an overview of the structure inventory and respective estimated depreciated replacement values. For modeling, depreciated replacement values were calculated on a structure-structure basis using RSMeans data. Value of land was not included in the valuation analysis.

Table 5-2: Existing Structure Inventory, by Structure Category

Category	Count	Average Depreciated Replacement Value ($)	Average Depreciated Replacement Value, Including contents ($)
Residential			
One Story House	15,273	169,000	254,000
Two Story House	8,955	314,000	472,000
Three Story House	1,995	383,000	574,000
Condominium	2,869	659,000	987,000
Mobile Home	5,089	42,000	58,000
Residential Total	34,181	242,000	362,000
Commercial and Industrial			
Urban/Beach High Rise	169	5,427,000	5,968,000
Hospital	723	636,000	946,000
Nursing Home	13	781,000	1,172,000
Bank	43	884,000	1,280,000
Industrial	209	504,000	595,000
Retail	1,323	460,000	667,000
Garage	3	1,032,000	1,713,000
Other Commercial	155	706,000	835,000
Commercial and Industrial Total	2,638	853,000	1,101,000
Public			

Category	Count	Average Depreciated Replacement Value ($)	Average Depreciated Replacement Value, Including contents ($)
Government	1,348	579,000	684,000
Religious	155	1,016,000	1,087,000
Recreation Center	301	318,000	395,000
Education	47	802,000	856,000
Public Total	1,851	579,000	624,000
Total Structure Inventory	**38,670**	**300,000**	**433,000**
(1) Replacement value estimates with respect to fiscal year 2021 (2) Estimates rounded			

6 FUTURE WITHOUT-PROJECT CONDITION

The future without-project condition uses the study area's existing conditions and storm event data to model those conditions during the period of analysis. The modeled expected damage provides the basis for which alternative plans are evaluated, compared, and selected since a portion of the flood damage would be prevented (i.e. flood damage reduced) with a Federal project in place.

The years 2020-2084 were selected to represent the future without-project (FWOP) condition, where no action is taken. This time period represents the 50-year period used for analysis in addition to expected project implementation and construction periods. Any damage estimates provided within this appendix are with respect to this time period and are generated utilizing the USACE high sea level change rate, unless specifically noted otherwise. However, the years 2035-2084 represent the 50-year period used for benefit-cost analyses of the array of plan alternatives. The year 2035 is the expected base year for all project measures to be fully constructed and when benefits are realized.

No additional development within the study area is anticipated since it is assumed that new development will 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 structures in the Monroe County study area will continue to be affected by the risk of flooding from coastal storms and suffer increasing losses each year. Under the future without-project condition, which represents expected damage in the absence of a flood risk management project, damage is expected to increase. Exacerbating the flooding is the phenomenon of relative sea level rise, a combination of water level rise and land subsidence. The following tables detail the FWOP modeling results for the study area produced by G2CRM, both by structure type and by incorporated municipality.

Table 6-1: Future Without-Project Condition Damage, by Structure Category

Category	Count	Average Total Present Value Damage ($)	Average Annual Damage ($)
Residential			
One Story	15,273	371,000	13,000
Three Story	1,995	438,000	15,000
Two Story	8,955	394,000	14,000
Condominium	2,869	1,281,000	45,000
Mobile Home	5,089	692,000	24,000
Residential Total	34,181	505,000	18,000
Commercial and Industrial			
Bank	43	2,631,000	93,000
Garage	3	6,437,000	227,000
Hospital	723	1,065,000	38,000
Industrial	209	1,578,000	56,000
Nursing Home	13	1,057,000	37,000
Other Commercial	155	2,249,000	79,000
Recreation Center	301	1,360,000	48,000
Retail	1,323	1,741,000	61,000
Urban/Beach High Rise	169	1,745,000	62,000
Commercial and Industrial Total	2,939	1,566,000	55,000
Public			
Education	47	1,849,000	65,000
Government	1,348	2,390,000	84,000
Religious	155	1,450,000	51,000
Public Total	1,550	2,279,000	80,000
Total Structure Inventory	**38,670**	**657,000**	**23,000**

(1) Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035
(2) Damage estimates are with respect to the time period 2020-2084 and are generated utilizing the USACE high sea level change curve
(3) Average annual damage estimates are with respect to a capital recovery factor of 3.5%
(4) Estimates rounded

Table 6-2: Future Without-Project Condition Damage, by Incorporated Municipality

Locality	Count	Total Present Value Damage ($1,000s)	Average Annual Damage ($1,000s)
City of Key Colony Beach	593	425,000	15,000
City of Key West	7,463	7,165,000	253,000
City of Layton	156	115,000	4,000
City of Marathon	4,251	3,421,000	121,000
Monroe County	21,893	13,039,000	460,000
Village of Islamorada	4,314	1,234,000	43,000
Total Structure Inventory	38,670	25,398,000	895,000

(1) Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035
(2) Damage estimates are with respect to the time period 2020-2084 and are generated utilizing the USACE high sea level change curve
(3) Average annual damage estimates are with respect to a capital recovery factor of 3.5%
(4) Estimates rounded

The modeling results suggest that the study area will be subject to significant damage in the future without a Federal project. Relative to other residential building categories, on average, condominium buildings are expected to receive significantly higher damage with an expected average annual damage estimate of $45,000. These is likely due to the fact that the size and square footage of a multiunit condominium building is typically larger than, for example the size and square footage of a typical single-family home. This reasoning can likely also explain the relatively high damage of garages compared to other commercial and industrial buildings. Finally, government buildings are expected to receive expected average annual damage of $84,000. Average annual damage estimates capture the anticipated magnitude of annual damage on an individual structure basis. Categorical structure counts can provide an understanding of the scope of magnitude for damage. Over half of the structure inventory consists of single-family residential homes[6]. Damage to single-family residential homes, therefore, constitute approximately 40% of overall damage in the Study Area.

Relative to the entire study area, the majority of structures and expected damage is spread throughout unincorporated areas of Monroe County. Approximately a quarter of structures and expected damage is concentrated within the City of Key West. The expected present value damage estimate for the entire 50-year period of analysis, in addition to the years leading up to this period, is over $25 billion for the entire study area. The expected annual damage estimate is approximately $865 million.

[6] This includes one-, two-, and three-story residential buildings listed in Table 6-1.

The next few sections will provide further detail for the expected FWOP condition modeled by G2CRM for model areas 30-34 (which contain the City of Key West, in addition to pockets of unincorporated jurisdictions of Monroe County). About half of the Recommended Plan is concentrated in the City of Key West so this is likely the most relevant and representative subset of the Study Area. Furthermore, this subset included over a quarter of the entire structure inventory, as seen in Table 6-3 below. It is reasonable to expect the FWOP results presented below to be fairly generalizable throughout the remaining Study Area.

Table 6-3: Structure Counts for Selected MAs

MA	Count of Structures	Percent of Total
MA 30	769	1.99%
MA 31	1,301	3.36%
MA 32	3,754	9.71%
MA 33	1,870	4.84%
MA 34	2,065	5.34%
Total for MA Sample	**9,759**	**25.24%**
Total Study Area	**38,670**	**100.00%**

6.1 Further FWOP Condition Detail

In both the FWOP and FWP conditions, the same 388 storms are modeled. The table below provides the expected mean, median, maximum, and minimum for the maximum storm stage across all storms. The table compares these estimates with the average ground elevation in each MA. This table assists in understanding the damage results below since storm surge damage is largely a function of storm surge levels. The difference between the average ground elevation and storm surge level represents storm surge which could cause damage to structures. However, it is important to note that the ground elevation throughout each MA, and the study area as a whole, can vary considerably. Still, the table below provides an overview understanding of storm surge using the central tendency of ground elevation in each MA.

Table 6-4: Analysis of Maximum Storm Stage Levels Across all Storms, By MA

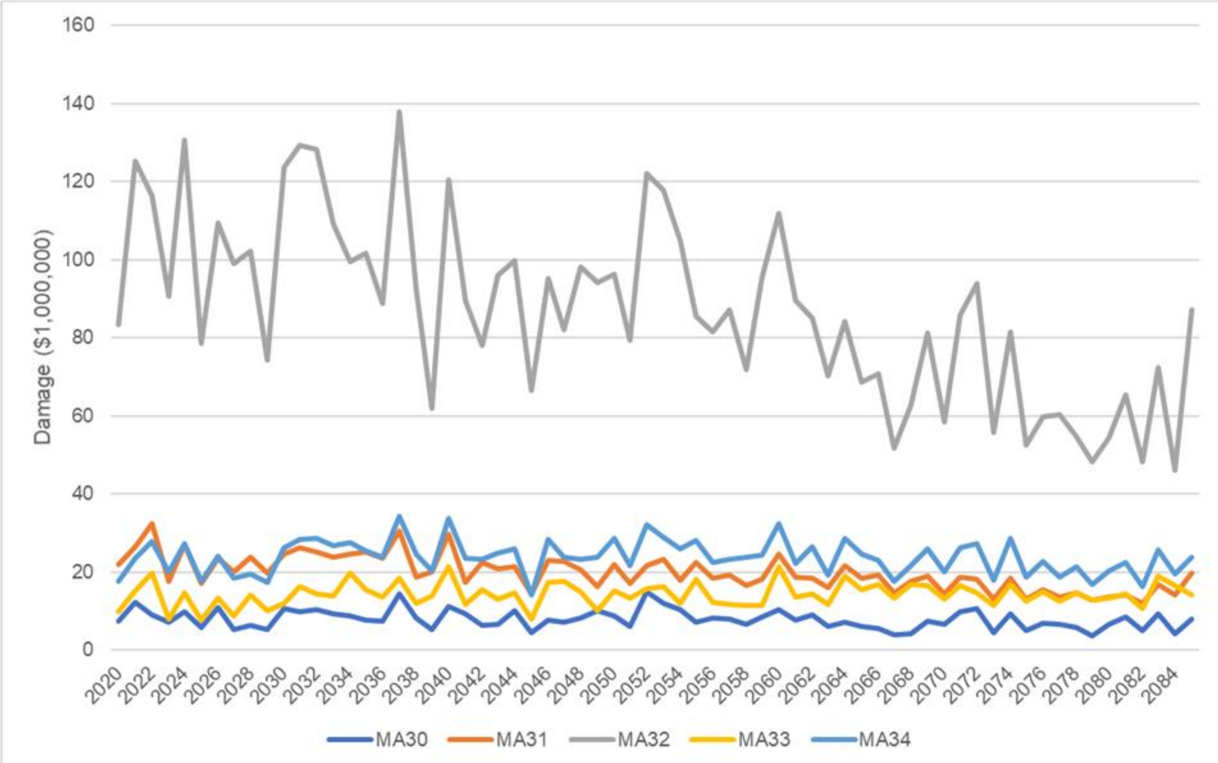
	MA30	MA31	MA32	MA33	MA34
Average Ground Elevation (Feet)	3.23	2.09	2.74	4.57	5.35
Mean (Feet)	5.99	4.97	6.04	4.73	5.70
Median (Feet)	4.98	4.06	5.15	3.60	4.94
Maximum (Feet)	18.98	14.06	17.89	13.65	15.99
Minimum (Feet)	1.56	1.09	1.46	1.11	1.19

(1) Estimates are with respect to NAVD88
(2) Estimates for each storm's maximum storm stage were derived from modeling 100 iteration of G2CRM
(3) Total number of storms modeled: 388

The figure below presents annual total present value damage for the selected MAs. The damage estimates, which include both structure and content damage, are with respect to the project base year of 2035. The City of Key West is expected to receive significant damage in the FWOP condition. The damage for MA 32 is considerably higher relative to the other MAs; this is largely because nearly 10% of structures in the entire study area are located within the MA. Furthermore, Table 6-4 highlights that mean and median storm surge levels are expected to be higher in MA 32 relative to the surrounding MAs. Therefore, both the scale (referring to the proportion of structures within this MA) and magnitude of damage is focused in this MA. Within MA 32, damage is partly concentrated in the small and densely populated island of Dredgers Key located just off the coast of Key West.

Damage estimates slightly decline in MA 32 through the 50-year period of analysis, as presented in Figure 6-1. This slight decline is likely due to the structure rebuilds and removals expected to take place in MA32, as shown in the next two tables.

Figure 6-1: Total FWOP Present Value Damage, by Year and Per MA



A structure can receive significant damage from a storm to the point where the structure owner would likely need to rebuild. These incidences were accounted for in the model and the results for the FWOP condition are presented in the table below for the selected MAs. The rebuilds were aggregated into two different time periods: (1) the period of implementation and construction (2020-2034) and (2) the 50-year period of analysis (2035-2084). Significant damage was defined in G2CRM by a damage value equal to or greater than 50% of the structure's total value. It was assumed that a structure would be rebuilt with a first-floor elevation consistent with the structure's base flood elevation plus 1 additional foot (BFE+1). To clarify, these rebuilds/elevations are assumed to be paid by an entity other than USACE, such as the homeowner, Country, or NFIP.

Table 6-5: G2CRM Modeled FWOP Condition Rebuilds

MA	2020-2034	2035-2084
MA 30	12	85
MA 31	22	179
MA 32	211	521
MA 33	11	83
MA 34	7	61
Sample Total	**263**	**929**

G2CRM also has a function which highlights structures expected to receive significant and repetitive damage throughout the life-cycle analysis. It is a reasonable assumption that a homeowner or building owner would likely not rebuild a structure if it has been rebuilt multiple times. This assumption is incorporated into the model through this function. G2CRM is set to remove a structure from the asset inventory if a it receives significant damage five times; the structure will no longer be rebuilt after reaching that threshold. The expected number of removed structures in the FWOP condition for each of the selected MAs is provided below.

Table 6-6: Removed Structures in the FWOP Condition

MA	2020-2034	2035-2084
MA 30	0	0
MA 31	0	98
MA 32	0	373
MA 33	0	2
MA 34	0	11
Sample Total	**0**	**484**

The high levels of damage and expectations for structure rebuilds and removals in the study area suggest the potential need for a Federal project in the Study Area. The next section explores project plan alternatives considered for achieving planning objectives and mitigating storm surge damage. A federal project that successfully mitigates storm surge damage in the Study Area should also reduce expected structure rebuilds and removals.

7 Analysis of Project Plan Alternatives

The initial array of alternatives was formulated and then refined throughout the planning process as information was collected and developed. The initial array of alternatives consists of a variety of structural, nonstructural, and natural or nature-based measures. Structural coastal flood risk management measures are man-made, constructed measures that counteract a flood event in order to reduce the hazard or to influence the course or probability of occurrence of the event. Nonstructural coastal flood risk management measures are permanent or contingent measures applied to a structure and/or its contents that prevent or provide resistance to damage from flooding. Natural or nature-based coastal flood risk management measures work with or restore natural processes with the aim of wave attenuation and storm surge reduction.

The initial array of alternatives consisted of eight alternatives and the following table provides descriptions for each alternative. Again, any damage estimates provided within this appendix are with respect to the time period 2020-2084 and are generated utilizing the USACE high sea level change rate, unless specifically noted otherwise.

Table 7-1. Initial Array of Alternatives

Alternative	Description	Measures
1	US Route 1	Shoreline stabilization (revetment)
2	Critical Infrastructure	Floodproofing
3	Population/Development	Floodproofing, elevation, and acquisition
4	Combo Alts 1 + 2	Shoreline stabilization (revetment) and floodproofing
5	Combo Alts 1 + 3	Shoreline stabilization (revetment), floodproofing, elevation, and acquisition
6	Combo Alts 2 + 3	Floodproofing, elevation, and acquisition
7	Combo Alts 1 + 2 + 3	Shoreline stabilization (revetment), floodproofing, elevation, and acquisition
8	No Action	N/A

7.1 Alternatives Screening

The planning delivery team (PDT) performed additional planning iterations with a focus on screening measures and alternatives that would not meet the planning objectives in an effective and efficient manner. Without substantial data to base the screening on, professional judgment was used to assess how well measures met a set of criteria.

The screening criteria used in this study include effectiveness, efficiency, and acceptability. 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 workability and viability of the alternative plan with respect to acceptance by state and local entities and the public and compatibility with existing laws, regulations, and public policies.

Completeness, constructability, and study constraints were also used as screening criteria, but did not result in elimination of any measures. 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. Constructability at this stage of planning is the subjective assessment of whether a feature could be constructed or implemented using standard industry techniques and is compliant with Corps policy for implementation. Study Constraints is the likelihood that the measure does not violate a constraint. Each conceptual alternative was found to be complete, constructible, and compliant with study constraints.

7.2 Final Array of Alternatives

Based on the screening assessment, none of the alternatives were able to be excluded from further analysis.

7.3 Evaluation of Alternatives

The future with-project (FWP) condition utilizes a modified version of the study area's existing conditions; this condition is modeled with the structural and/or nonstructural measures of the plan alternatives in order to estimate residual damage. The reduction in damage between the FWOP and FWP defines the economic benefit for the various alternative plans. The following sections detail each plan alternative and their respective benefit-cost analysis. More detailed information on construction costs and cost contingencies can be found in the engineering and cost engineering appendices. The damage estimates are provided in present value levels and annualized in order to allow for a direct comparison with annualized costs. The benefit for each alternative is represented by the average annual reduction in damage provided by the alternative in the 50-year period of analysis. Maximum, minimum, and median damage estimate are provided in the Economic Risk Analysis section. Subtracting the average annual costs from average annual benefits results in the net remaining benefits.

7.3.1 Alternative 1: US Route 1

This alternative was designed to address the first planning objective: Reduce the risk of damage to U.S. Route 1 caused by wave action and erosion associated with coastal storms in the Florida Keys over the 50-year period of analysis. US Route 1 is the only roadway that connects all the Florida Keys to each other and then to the Florida mainland. Plan formulation for US Route 1 focused on measures that would maintain the road structure as much as possible even if inundated by surge so that once a storm has passed, the roadway would likely remain intact. The only structural measure carried forward was shoreline stabilization. Rock revetment structures were designed for six at risk areas along US Route 1 to reduce damage to the roadway by stabilizing the shoreline and reducing the risk of washout due to wave action and erosion. Initially the benefit of this alternative was to be measured in terms of reduction in damage. However, it was difficult to find a model that could be configured appropriately to generate accurate benefits for the alternative. At the same time, the highway is critical to residents of the Florida Keys for evacuation and safety purposes.

Due to the necessity of US Route 1, the PDT and vertical team determined it would be acceptable to justify the measure based on life safety. While G2CRM has a life loss function, the planning team determined that the USACE HEC-LifeSim model would be a more appropriate model to use for life loss analysis. Given this, average annual benefit (measured by damage reduction) is not available for this alternative.

The total average annual cost for the six-part revetment is estimated to be $964,000. The annualized cost estimate incorporates interest during construction and operation and maintenance (O&M) costs. The benefit-cost analysis for Alternative 1 is shown below in Table 7-2. This alternative does not provide any reduction in damage in the Study Area caused by storm surge; However, it is successful in addressing the first planning objective by helping to preserve U.S. Route 1 from wave action and erosion associated with coastal storms in the Florida Keys over the 50-year period of analysis.

Table 7-2: Alternative 1 Benefit-Cost Analysis

Item	Alternative 1
Total First Cost	$19,746,000
Interest During Construction	$102,000
Annualized IDC	$4,000
Annualized O&M Cost	$161,000
Total Average Annualized Cost	$964,000
PV Damages FWOP	$25,398,605,000
PV Damages FWP	$25,398,605,000
Present Value Benefit	N/A
Total Average Annual Benefits	N/A
Benefit-Cost Ratio	**N/A**
Net Remaining Benefits	- **-$964,000**

(1) Interest rate: 2.5%
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Damage estimates are generated using the USACE high sea level change curve
(4) Estimates rounded
(5) Assumed O&M annual costs are $5,000. Reconstruction costs are estimated to be 10% of the initial first cost and will occur every five years in the period of analysis.

7.3.2 Alternative 2: Critical Infrastructure

This alternative was designed to address the second planning objective: Reduce the risk of damage to critical infrastructure caused by storm surge inundation associated with coastal storms in the Florida Keys over the 50-year period of analysis. The only measures carried forward that would reduce damage to any structure vulnerable to storm surge flooding, critical or not, are nonstructural. The size of critical infrastructure buildings prevents the use of elevation and the necessity of the structures eliminate the use of acquisition. Therefore, the only nonstructural measure appropriate for critical infrastructure is floodproofing. There are engineering and safety restrictions that limit floodproofing to a maximum of three feet above ground level, which may leave some structures vulnerable to damage from storm surge that exceeds three feet. However, floodproofing is still expected to reduce a significant amount of vulnerability and damage to critical infrastructure in the study area. This reduction in damage is the main quantified benefit for this alternative. The methodology for selecting structures to evaluate for floodproofing is consistent with the methodology described for nonstructural measures in the next section. There are 53 structures considered critical infrastructure that are included in this alternative for floodproofing.

The total average annual benefit and cost for alternative 2 are estimated at about $5,818,000 and $839,000, respectively. There is no O&M cost as this is a nonstructural measure. Alternative 2 is economically justified with a BCR of 6.9 and net remaining benefits at $4,979,000. The benefit-cost analysis for Alternative 2 is shown below in Table 7-3. This measure alleviates flood risk for the 53 structures included in the alternative and achieves the second planning objective. Floodproofing provides added protection (up to three feet) to these 53 structures, which are largely spread evenly throughout the FL Keys. This protection helps prevent storm surge damage caused from more frequent storm events, which are typically less severe with lower water levels. However, significant residual damage in the Study Area remain. Alternative 2 is only expected to reduce less than 1% of overall expected total PV damage in the area over the 50-year period of analysis. The alternative may produce a high BCR; but it is not effective at reducing overall storm surge damage in the Study Area.

Table 7-3: Alternative 2 Benefit-Cost Analysis

Item	Alternative 2
Total First Cost	$20,672,000
Interest During Construction	$64,000
Annualized Interest During Construction Cost	$2,000
Annualized O&M Cost	$0
Total Average Annual Cost	$839,000
FWOP PV Damage	$25,398,605,000
FWP PV Damage	$25,233,593,000
FWP Present Value Benefit	$165,012,000
Total Average Annual Benefit	$5,818,000
Benefit-Cost Ratio	**6.9**
Net Remaining Benefits	**$4,979,000**

(1) Interest rate: 2.5%
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Damage estimates are generated using the USACE high sea level change curve
(4) Estimates rounded

7.3.3 Alternative 3: Development

This alternative was designed to address the third planning objective: Reduce the risk of damage to development (residential and non-residential structures) caused by storm surge inundation associated with coastal storms in the Florida Keys over the 50-year period of analysis. The only measures carried forward that would reduce storm damage to structures in the study area that are vulnerable to storm surge flooding are nonstructural. All nonstructural measures were considered, however the PDT focused on elevation and floodproofing to alleviate damage to structures over the 50-year period of analysis. An aggregation method was used to identify structures to evaluate for nonstructural measures. Structure were grouped by first-floor elevation (FFE) and included for evaluation if the FFE was lower than the respective 100-year storm event still water levels (with respect to the 50% confidence level and for the year 2084). This threshold was reviewed and agreed upon by the PDT.

The economic analysis identified 4,698 structures for elevation and 1,052 structures for floodproofing. The total average annual benefit and cost of alternative 3 is $125,785,000 and $83,754,000, respectively. There is no O&M cost as these are nonstructural measures. Alternative 3 is economically justified with a BCR of 1.5 and net remaining benefits at $42,031,000. Table 7-4 below details the costs and benefits associated with alternative 3. This alternative, focused on addressing the third planning objective, succeeds at reducing some risk of damage to residential and non-residential structures caused by storm surge inundation. Nearly half of all structures identified for nonstructural measures were located within or near the City of Key West. These results are consistent with what was observed in the FWOP condition, where high levels of storm surge damage were observed in around this area (MAs 30-34). The remaining structures identified for nonstructural measures were largely spread somewhat evenly throughout incorporated and unincorporated areas of Monroe County. The floodproofing of 1,052 is expected to protect structures as described in the section for the previous alternative, but at a larger scale. The elevation of 4,698 residential homes is expected to add significant protection for those selected structures. Given the design elevation heights determination noted above, it is expected that elevated structures should largely be protected from storm surge damage caused low- to medium-severe storm events expected to occur in the future. Alternative 3 is more successful at alleviating storm surge damage compared to the previous alternatives.

Table 7-4: Alternative 3 Benefit-Cost Analysis

Item	Alternative 3
Total First Cost	$2,063,044,000
Interest During Construction	$6,378,000
Annualized Interest During Construction Cost	$225,000
Annualized O&M Cost	$0
Total Average Annual Cost	$83,754,000
FWOP PV Damage	$25,398,605,000
FWP PV Damage	$21,831,052,000
FWP Present Value Benefit	$3,567,553,000
Total Average Annual Benefits	$125,785,000
Benefit-Cost Ratio	**1.5**
Net Remaining Benefits	**$42,031,000**

(1) Interest rate: 2.5%
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Damage estimates are generated using the USACE high sea level change curve
(4) Estimates rounded

7.3.4 Alternative 4: US Route 1 and Critical Infrastructure

This alternative is a combination of the US Route 1 shoreline stabilization plan (alternative 1) and the critical infrastructure identified for floodproofing (alternative 2). This alternative meets the first, second, and fourth planning objectives. The forth planning objective is to reduce the risk to human life, health, and safety to the population in the Florida Keys that is caused by the inundation of development and critical infrastructure and the reduced evacuation efficiency that is associated with coastal storm events over the 50-year period of analysis.

The total average annual benefit and cost of alternative 4 is $5,818,000 and $1,803,000, respectively. Alternative 4 is economically justified with a BCR of 3.2 and net remaining benefits estimated at $4,015,000. Table 7-5 below details the costs and benefits associated with alternative 4. Since Alternative 1 does not provide reduction in storm surge damage, the reduction in damage for Alternative 4 is consistent with Alternative 2. Consequently, Alternative 4 is only expected to reduce less than 1% of overall expected total PV damage in the area over the 50-year period of analysis. The alternative may produce a high BCR; but it is not effective at reducing overall storm surge damage in the Study Area.

Table 7-5: Alternative 4 Benefit-Cost Analysis

Item	Alternative 4
Total First Cost	$40,418,000
Interest During Construction	$166,000
Annualized Interest During Construction Cost	$6,000
Annualized O&M Cost	$161,000
Total Average Annual Cost	$1,803,000
FWOP PV Damage	$25,398,605,000
FWP PV Damage	$25,233,593,000
FWP Present Value Benefit	$165,012,000
Total Average Annual Benefits	$5,818,000
Benefit-Cost Ratio	**3.2**
Net Remaining Benefits	**$4,015,000**

(1) Interest rate: 2.5%
(2) (2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis damage estimates are generated using the USACE high sea level change curve
(3) Estimates rounded

7.3.5 Alternative 5: US Route 1 and Development

This alternative is a combination of the US Route 1 shoreline stabilization plan (alternative 1) and the structures identified for either floodproofing or elevation (alternative 3). This alternative meets the first, third, and fourth planning objectives.

The total average annual benefit and cost of alternative 5 is $125,785,000 and $84,718,000, respectively. Alternative 5 is economically justified with a BCR of 1.5 and net remaining benefits estimated at $41,067,000. Table 7-6 below details the costs and benefits associated with alternative 5. The reduction in damage expected with this alternative is consistent with the reduction in damage expected with Alternative 3. However, the net benefit expected with Alternative 5 is slightly lower since it includes the US Route 1 six-part revetment.

Table 7-6: Alternative 5 Benefit-Cost Analysis

Item	Alternative 5
Total First Cost	$2,082,790,000
Interest During Construction	$6,479,000
Annualized Interest During Construction Cost	$228,000
Annualized O&M Cost	$161,000
Total Average Annual Cost	$84,718,000
FWOP PV Damage	$25,398,605,000
FWP PV Damage	$21,831,052,000
FWP Present Value Benefit	$3,567,553,000
Total Average Annual Benefits	$125,785,000
Benefit-Cost Ratio	**1.5**
Net Remaining Benefits	**$41,067,000**

(1) Interest rate: 2.5%
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Damage estimates are generated using the USACE high sea level change curve
(4) Estimates rounded

7.3.6 Alternative 6: Critical Infrastructure and Development

This alternative is a combination of the critical infrastructure identified for floodproofing (alternative 2) and the structures identified for either floodproofing or elevation (alternative 3). This alternative meets the second, third, and fourth planning objectives.

The total average annual benefit and cost of alternative 6 is $131,603,000 and $84,593,000, respectively. Alternative 6 is economically justified with a BCR of 1.6 and net remaining benefits estimated at $47,010,000. Table 7-7 below details the costs and benefits associated with Alternative 6. This alternative has the highest expected reduction in damage (benefit) compared to all previous alternatives.

Table 7-7: Alternative 6 Benefit-Cost Analysis

Item	Alternative 6
Total First Cost	$2,083,716,000
Interest During Construction	$6,441,000
Annualized Interest During Construction Cost	$227,000
Annualized O&M Cost	$0
Total Average Annual Cost	$84,593,000
FWOP PV Damage	$25,398,605,000
FWP PV Damage	$21,666,040,000
FWP Present Value Benefit	$3,732,565,000
Total Average Annual Benefits	$131,603,000
Benefit-Cost Ratio	**1.6**
Net Remaining Benefits	**$47,010,000**

(1) Interest rate: 2.5%
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Damage estimates are generated using the USACE high sea level change curve
(4) Estimates rounded

7.3.7 Alternative 7: US Route 1, Critical Infrastructure, and Development

This alternative is a combination of all measures included in alternatives 1, 2, and 3. It would reduce coastal storm risk to US Route 1, critical infrastructure, and residential and commercial structures. This alternative meets all of the planning objectives.

The total average annual benefit and cost of alternative 7 is $131,603,000 and $85,557,000, respectively. Alternative 7 is economically justified with a BCR of 1.5 and net remaining benefits estimated at $46,046,000. Table 7-8 below details the costs and benefits associated with alternative 7. This alternative has an expected reduction in damage (benefit) equal to expected reduction in damage from Alternative 6. However, the net benefit expected with Alternative 7 is slightly lower than alternative 6 since Alternative 7 includes the US Route 1 six-part revetment.

Table 7-8: Alternative 1 Benefit-Cost Analysis

Item	Alternative 7
Total First Cost	$2,103,462,000
Interest During Construction	$6,543,000
Annualized Interest During Construction Cost	$231,000
Annualized O&M Cost	$161,000
Total Average Annual Cost	$85,557,000
FWOP PV Damage	$25,398,605,000
FWP PV Damage	$21,666,040,000
FWP Present Value Benefit	$3,732,565,000
Total Average Annual Benefits	$131,603,000
Benefit-Cost Ratio	**1.5**
Net Remaining Benefits	**$46,046,000**

(1) Interest rate: 2.5%
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Damage estimates are generated using the USACE high sea level change curve

(4) Estimates rounded

7.3.8 Alternative 8: No Action

The no action plan assumes that no action would be taken by USACE as a result of this study and is effectively the future without project condition. This is the alternative/condition by which all other alternatives are compared.

Table 7-9: Alternative 8 Benefit-Cost Analysis

Item	Alternative 8
Total First Cost	0
Interest During Construction	0
Annualized Interest During Construction Cost	0
Annualized O&M Cost	0
Total Average Annual Cost	0
FWOP PV Damage	25,398,592,000
FWP PV Damage	25,398,592,000
FWP Present Value Benefit	0
Total Average Annual Benefits	0
Benefit-Cost Ratio	**N/A**
Net Remaining Benefits	**0**

(1) Interest rate: 2.5%
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Damage estimates are generated using the USACE high sea level change curve

(4) Estimates rounded

8 FUTURE WITH-PROJECT CONDITION

8.1 A total of eight alternatives were considered for the study. This section first reviews the selection, analysis, and construction details of the Recommended Plan. This section then reviews the most likely future with-project condition expected to exist if the Recommended Plan is undertaken. Again, any damage estimates provided within this appendix are with respect to the time period 2021-2084 and are generated utilizing the USACE high sea level change rate, unless specifically noted otherwise. Selection and Optimization of the Recommended Plan

Based on the economic analysis and project review, the PDT proceeded with plan alternative 7, which includes the roadway revetment system, nonstructural measures, and critical infrastructure floodproofing. Other large-scale structural alternatives, aside from the revetment, do not warrant Federal interest in the Florida Keys. While the chosen structural measure is technically economically unjustified, protecting US Route 1 is critical for a comprehensive storm risk management plan. The net benefits were used to help determine the economic justification of the project alternative. A plan that reasonably maximizes net national economic development (NED) benefits, consistent with the Federal objective, is identified as the NED plan (ER 1105-2-100). Therefore, as shown in Table 8-a, the NED plan is technically Alternative 6 since it provides annual net NED benefits of $47,010,000. The addition of the revetment leads the Recommended Plan to have a slightly lower BCR and net NED benefits ($46,046,000) compared to plan alternative six. However, protecting the critical highway is essential for a comprehensive storm risk management plan. A waiver has been requested of the Office of the Assistant Secretary of the Army for Civil Works to allow the team to formally select Alternative 7 as the recommended Plan rather than Alternative 6, the NED Plan.

In total, the Recommended Plan is economically justified with a BCR of 1.7 and net remaining benefits totaling $53,471,000. The following sections present additional information on the benefit-cost analysis, initial construction schedule, and implementation plan of the Recommended Plan.

Table 8-1: Alternatives Comparison

	Total Average Annualized Cost ($1,000)	Total Average Annual Benefits ($1,000)	Benefit-Cost Ratio	Net Remaining Benefits ($1,000)
Alternative 1	964	N/A	N/A	-964
Alternative 2	839	5,818	6.9	4,979
Alternative 3	83,754	125,785	1.5	42,031
Alternative 4	1,803	5,818	3.2	4,015
Alternative 5	84,718	125,785	1.5	41,067
Alternative 6	84,593	131,603	1.6	47,010
Alternative 7	**85,557**	**131,603**	**1.5**	**46,046**
Alternative 8	0	0	N/A	0

The nonstructural measures component is a main pillar of the Recommended Plan, both in cost and benefit. The nonstructural part of the plan was optimized and refined with two screenings: (1) Structures with an individual BCR of .8 or higher were included in the plan. (2) Structures with an existing FFE within 1 foot of the design elevation height were excluded from the plan; the cost of rebuilding and elevating the foundations of these structures is likely not worth the marginal benefit. Table 8-2 below provides detail by locality or municipality of the final counts for nonstructural measures.

Table 8-2: Nonstructural Measure Counts by Municipality

Locality	Elevation	Floodproofing	Critical Infrastructure Floodproofing	Total Nonstructural
City of Key Colony Beach	30	7	2	39
City of Key West	2,028	382	12	2,422
City of Layton	31	9	1	41
City of Marathon	562	225	14	801
Village of Islamorada	1,839	348	15	2,202
Monroe County	208	81	9	298
Grand Total	**4,698**	**1,052**	**53**	**5,803**

8.2 Recommended Plan Benefit-Cost Analysis

The tables below depict the benefits and costs for the structural and nonstructural components of the Recommended Plan, including average annual construction costs, the annual operation and maintenance costs, and the total average annual costs, total average annual benefits, BCR, and total annual net benefits. The interest during construction cost is also included in the calculation of total average annual costs. Interest during construction (IDC) was calculated for each measure. The expected annual benefits attributable to the project alternative were converted to an equivalent time frame by using the fiscal year 2021 Federal discount rate of 2.5% for the Recommended Plan. The base year for this conversion is the year 2035. The equivalent annual benefits were then compared to the average annual costs to develop a benefit-to-cost ratio for the alternative. The net benefits for the alternative were calculated by subtracting the average annual costs from the equivalent annual benefits.

The sections and tables below summarize the benefit and cost calculations for the Recommended Plan and by measure. More detailed information on construction cost line items (lands and damage; planning, engineering, and design, construction management, etc.) and cost contingencies can be found in the engineering and cost engineering appendices.

Table 8-3: Recommended Plan Benefit-Cost Analysis

Recommended Plan Economic Summary	Total
Revetment Sections	6
Critical Infrastructure to Floodproof	52
Structures to Elevate	4,698
Structures to Floodproof	1,052
Total First Cost	$2,103,462,000
Interest During Construction	$6,543,000
Annualized Interest During Construction Cost	$231,000
Annualized O&M Cost	$161,000
Total Average Annual Cost	$85,557,000
FWOP PV Damage	$25,398,605,000
FWP PV Damage	$21,666,040,000
FWP Present Value Benefit	$3,732,565,000
Total Average Annual Benefits	**$131,603,000**
Benefit-Cost Ratio	**1.5**
Net Benefits	**$46,046,000**

(1) Interest rate: 2.5%
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Damage estimates are generated using the USACE high sea level change curve
(4) Estimates rounded

8.3 Recommended Plan Construction Schedule

The Recommended Plan has a 10-year construction schedule with the total construction cost divided into annual increments. The structural component of the selected plan, the six-part revetment, is estimated to take five months for each section. Unlike the various project increments that comprise the structural component of the plan, each individual structure comprising the nonstructural component is essentially a self-contained, fully functioning, stand-alone project increment. The construction period for each structure contained in the nonstructural component (elevation or floodproofing) of the plan would be no more than three months.

8.3.1 Interest During Construction

The calculation of interest during construction follows the USACE National Nonstructural Committee Best Practice Guide 2020-01: Calculating Interest During Construction for Nonstructural Alternatives. The technique was also adapted for the structural measure by appropriately changing the mid-point of construction estimate. The following example displays the estimated IDC for Alternative 2, where the total elevation first cost (*P*) is $20,163,000, the discount rate (*i*) is .025, and the midpoint construction period (*n*) is .125. Best Practice Guide 2020-01 suggests using a mid-period quarterly basis to calculate IDC "because it is not known exactly when the work orders will be paid during the 3-month construction period." So, while the construction period is 3 months, the formula uses a midpoint estimate of 1.5 months.

$$IDC = \Sigma P * [(1+i)n-1]$$
$$IDC = \$20,163,000 * [(1+.025).125-1]$$
$$IDC=\$62,330$$

8.3.2 Benefits During Construction

Some benefits of the selected plan are expected to begin accruing before the end of the 10-year construction period. A structure elevated within the first year of the 10-year construction period, for example, will capture benefits long before the project base year, when full project benefits typically begin accruing. A similar argument can be made for the floodproofing and the structural measure. Additional benefits are likely to be realized during construction; however, they were not quantified and included in the analysis mainly due to study timeframe constraints. Incorporating these benefits would require additional detailed information and certainty of the implementation and construction plans and assumptions to determine the sequence of structures receiving measures.

8.4 Expected Future With-Project Condition

This section details the expected FWP condition given the Recommended Plan.

Table 8-4: FWP Condition Damage, by Structure Category

Category	Count	Average Total Present Value Damage ($)	Average Annual Damage ($)
Residential			
One Story	15,273	288,000	10,000
Three Story	1,995	322,000	11,000
Two Story	8,955	286,000	10,000
Condominium	2,869	1,262,000	45,000
Mobile Home	5,089	692,000	24,000
Residential Total	34,181	432,000	15,000
Commercial and Industrial			
Bank	43	1,918,000	68,000
Garage	3	5,018,000	177,000
Hospital	723	1,027,000	36,000
Industrial	209	1,227,000	43,000
Nursing Home	13	1,057,000	37,000
Other Commercial	155	1,786,000	63,000
Recreation Center	301	1,141,000	40,000
Retail	1,323	1,407,000	50,000
Urban/Beach High Rise	169	1,745,000	62,000
Commercial and Industrial Total	2,939	1,322,000	47,000
Public			
Education	47	1,305,000	46,000
Government	1,348	2,082,000	73,000
Religious	155	964,000	34,000
Public Total	1,550	1,947,000	69,000
Total Structure Inventory	**38,670**	**560,000**	**20,000**

(1) Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035
(2) Damage estimates are with respect to the time period 2020-2084 and are generated utilizing the USACE high sea level change curve
(3) Average annual damage estimates are with respect to a capital recovery factor of 3.5%
(4) Estimates rounded

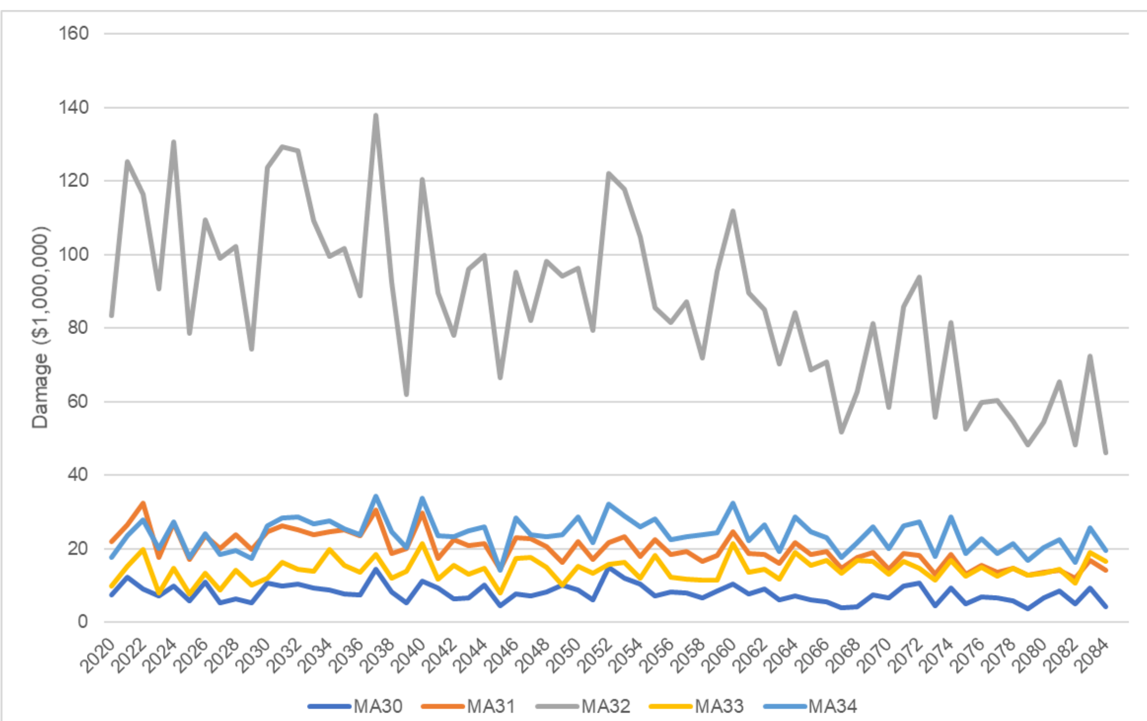
Table 8-5: FWP Condition Damage, by Incorporated Municipality

Locality	Count	Total Present Value Damage ($1,000s)	Average Annual Damage ($1,000s)
City of Key Colony Beach	593	363,000	13,000
City of Key West	7,463	5,615,000	198,000
City of Layton	156	89,000	3,000
City of Marathon	4,251	2,807,000	99,000
Monroe County	21,893	11,716,000	413,000
Village of Islamorada	4,314	1,072,000	38,000
Total Structure Inventory	**38,670**	**21,662,000**	**764,000**

(1) Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035
(2) Damage estimates are with respect to the time period 2020-2084 and are generated utilizing the USACE high sea level change curve
(3) Average annual damage estimates are with respect to a capital recovery factor of 3.5%
(4) Estimates rounded

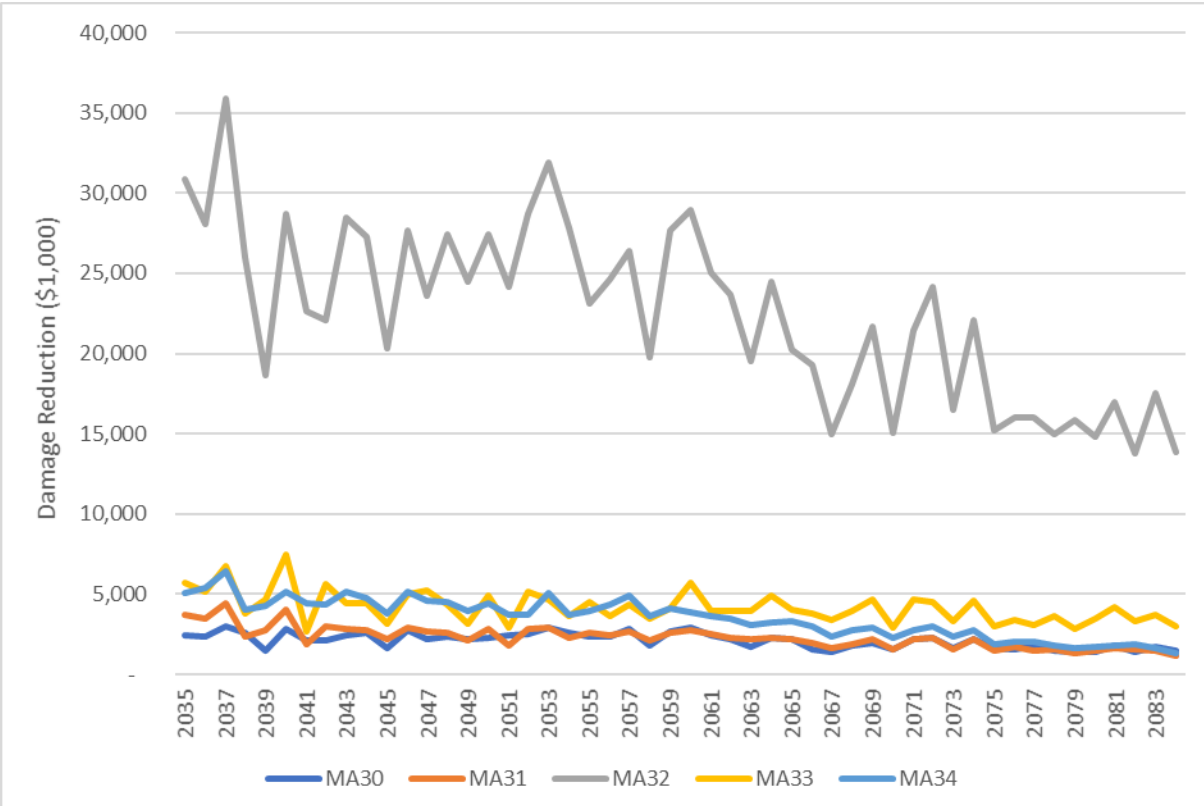
The figure below presents annual total present value damage for the selected MAs. The damage estimates, which include both structure and contents damage, are with respect to the project base year of 2035. The City of Keys West is expected to receive less damage in the FWP condition, compared to the expected damage in the FWOP condition.

Figure 8-1: Total FWP Present Value Damage, by Year and Per MA



The figure below presents the expected damage reduction between the FWOP and FWP conditions for selected MAs to show the effect of the Recommended Plan more clearly. The present value estimates are with respect to the project base year of 2035.

Figure 8-2: Total FWP Present Value Damage Reduction, by Year and Per MA



A structure can receive significant damage from a storm to the point where the structure likely should be rebuilt. These incidences were accounted for in the model and the results for the FWP condition are presented in the table below for select MAs. The rebuilds were aggregated into two different time periods: (1) the implementation and construction period (2020-2034) and (2) the 50-year period of analysis (2035-2084). Significant damage was defined in G2CRM by a damage value equal to or greater than 50% of the structure's total value. It was assumed that a structure would be rebuilt with a first-floor elevation consistent with the structure's base flood elevation (plus 1 additional foot). To clarify, these rebuilds outside of the Recommended Plan and are assumed to be paid for by an entity other than USACE, such as the homeowner, Country, or NFIP. Furthermore, these rebuild can be considered reactive; that is, they are expected to occur after a storm event causes significant damage. In contrast, the elevations associated with the Recommended Plan are proactive; that is, they should occur before a storm event causes significant damage. The Recommended Plan significantly reduces the G2CRM modeled rebuilds expected during the 50-year period of analysis by about 80%. This reduction suggests that that Recommended Plan appropriately targets vulnerable structures receiving significant damage in the FWOP condition.

Table 8-6: G2CRM Modeled FWP Condition Rebuilds

MA	2020-2034	2035-2084
MA 30	12	20
MA 31	22	117
MA 32	211	31
MA 33	11	0
MA 34	7	10
Sample Total	**263**	**178**

This cost reduction in rebuilds/elevations, estimated at $220 million[7], could be considered an incidental benefit of the project. However, it is unknown what entity (the County, NFIP, etc.) would receive this benefit, therefore this was not incorporated as an NED benefit for the project.

The expected number of removed structures in the FWP condition for each of the selected MAs is provided below. The number of removed structures was aggregated into two different time periods: (1) the implementation and construction period (2020-2034) and (2) the 50-year period of analysis (2035-2084). The expected number of structures removed from the asset inventory, due to repetitive damage, was slightly reduced by 31 structures for the selected sample of MAs.

Table 8-7: G2CRM Modeled FWP Condition Removed Structures

MA	2020-2034	2035-2084
MA 30	0	0
MA 31	0	97
MA 32	0	343
MA 33	0	2
MA 34	0	11
Sample Total	**0**	**453**

[7] This estimate is based on preliminary cost estimates, not a total project cost estimate. Across all residential homes in Monroe County, the most typical (reoccurring) home has the following characteristics: 2,000 SQFT, 2 stories, and a crawl or pile foundation (which both have the same elevation cost estimates). This typical home was used to approximate this estimate. The cost of rebuilding and elevating a structure to its respective BFE+1 can vary based of the structure's characteristics and elevation height requirement. The average BFE+1 among structures expected to be rebuild was used for this estimate.

9 RISK AND UNCERTAINTY

The USACE defines risk in ER 1105-2-101 as the following: “Risk is broadly defined as a situation or event where something of value is at stake and its gain or loss is uncertain.” The following sections provide information on risk and uncertainty with respect to the Recommended Plan.

9.1 Residual Damage in the Study Area

The Recommended Plan is economically justified and adds protection to the study area. However, significant residual risk is still expected to be realized between now and the end of the 50-year period of analysis. The table below provides the expected residual risk by incorporated municipality, assuming the Recommended Plan is implemented in the Study Area.

Table 9-1: Residual Damage, by Incorporated Municipality

	Structure Count	**Total Present Value Residual Damage ($1,000s)**	**Average Annual Residual Damage ($1,000s)**	**Residual Damage Remaining**
City of Key Colony Beach	593	363,000	13,000	87%
City of Key West	7,463	5,615,000	198,000	78%
City of Layton	156	89,000	3,000	75%
City of Marathon	4,251	2,807,000	99,000	82%
Monroe County	21,893	11,716,000	413,000	90%
Village of Islamorada	4,314	1,072,000	38,000	88%
Total Structure Inventory	**38,670**	**21,662,000**	**764,000**	85%

(1) Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035
(2) Damage estimates are with respect to the time period 2020-2084 and are generated utilizing the USACE high sea level change curve
(3) Average annual damage estimates are with respect to a capital recovery factor of 3.5%
(4) Estimates rounded

9.2 Economic Risk Analysis

Table 9-2 contains the average annual damage (AAD) for the without-project condition and the with-project condition for each alternative. The table also provides information on to damage reduction uncertainty captured by the model. G2CRM utilizes its inputs to estimate damage with respect to a triangular distribution, resulting in mean, minimum, median, and maximum damage estimates.

Table 9-2: Economic Risk Analysis

Alt.	Average Annual Damage ($1,000)		AAD Reduced ($1,000)	Uncertainty in AAD Reduced ($1,000)		
	Without Alternative	With Alternative	Mean	Minimum	Median	Maximum
1	895,505	895,505	0	0	0	0
2	895,505	889,687	5,818	3,515	5,795	7,109
3	895,505	769,720	125,785	75,730	132,051	136,088
4	895,505	889,687	5,818	3,515	5,795	7,109
5	895,505	769,720	125,785	75,730	132,051	136,088
6	895,505	763,902	131,603	79,245	137,846	143,197
7	**895,505**	**763,902**	**131,603**	**79,245**	**137,846**	**143,197**

The mean, median, and maximum expected average annual damage reduction (benefit) estimates exceed the average annual cost of the project, $85,557,000. The minimum expected average annual damage reduction (benefit) estimate, $79,254,000, is slightly lower than then the average annual cost of the project; however, it is unlikely that realized benefits will reach this extreme. Realized project benefits are most likely to follow mean and median estimates. These results suggest, with a high level of confidence, the project is likely economically justified with a BCR greater than 1.0 regardless of uncertainties captured in the model.

9.3 Sea Level Rise Scenarios

Plan formulation and primary modeling was conducted using the USACE high sea level change curve, as advised by the USACE Climate Community of Practice. However, this section presents the economic analysis at the USACE Intermediate and low sea level curve rates. The table below provides the economic cost and benefits of the Recommended Plan with respect to the three USACE sea level change rates. The results for the USACE high sea level change curve suggest that the Recommended Plan is economically justified. Admittedly, the BCR for the USACE low sea level curve rate is just below 1.0. However, these results suggest that economic justification for the Recommended Plan are largely robust to the USACE intermediate and low sea level curve rates.

Table 9-3: Sea Level Rise Uncertainty

Sea Level Rise Rate	Total Average Annualized Benefit ($1,000)	Total Average Annual Cost ($1,000)	Benefit-Cost Ratio	Net Remaining Benefits ($1,000)
High	131,603	85,557	1.54	46,046
Intermediate	94,834	85,557	1.11	9,277
Low	82,480	85,557	0.96	-3,078

9.4 Participation Rate Uncertainty

The recommended plan includes elevation of residential homes and floodproofing of non-residential structures throughout Monroe County. The primary economic analysis assumes 100% participation of the structures included in the Recommended Plan. The total project cost that is ultimately authorized into law will be the estimated cost to implement 100% of the structures recommended for nonstructural measures. However, while project economics have confirmed that 100% of these structures comprise a plan that provides NED benefits, these measures will be implemented on a voluntary basis and structure owners may choose to participate in the project. For this reason, study teams should consider participation rates that are appropriate for the study and utilize sensitivity analyses of different participation rates to clearly communicate to decision makers the uncertainty in benefits and costs for voluntary nonstructural measures.

The study team considered other USACE nonstructural projects and coordinated with Monroe County to complete an evaluation of the expected participation rate for nonstructural measures in the Recommended Plan. The study team used the five factors in the USACE Nonstructural Committee's Best Practice Guide 02 (BPG 2020-02) to evaluate the likely participation in voluntary nonstructural measures in the Florida Keys. These factors are discussed below based on information specific to Monroe County and assigned a qualitative score of slight, moderate, or significant depending on how much of an effect that factor is expected to have on the participation in nonstructural measures.

1. Temporal Proximity of Severe Flood Damage
   The BPG states that owners who experienced significant flood damage more than 10 years ago are less likely to participate than owners damaged more recently. Furthermore, the likelihood that properties have changed ownership is increased, and new owners that have not personally experienced flood damages are less likely to participate. On the other hand, should recent flood damages be catastrophic, the more difficult it is for ownership of the properties to be proved, hindering participation. In Monroe County, the destruction brought by Hurricane Irma is still recent enough to have a positive impact on the participation rate in nonstructural measures. There has also been enough time since Irma that there should not be ownership issues that would interfere with the implementation of the project. Most study area residents experienced Hurricane Irma and are aware that the Keys are extremely vulnerable to coastal storms, so this factor is expected to significantly increase the participation rate for nonstructural measures.

2. Decent, Safe, and Sanitary
   In order to participate in a USACE project, property owners must correct existing violations of state and local heath, sanitary and safety codes, which have been identified by a local code enforcement official and which are the minimum necessary to assure decent, safe and sanitary (DSS) living conditions. The BPG states that in older metropolitan communities with stringent code adoption, the extra costs imposed on the owner to correct violations can be significant enough to hinder participation. In Monroe County, 88.4 percent of the owner-occupied housing units are valued at $200,000 or more, which is well above the state and national percentages of 53.9 and 53.7. This indicates that the average quality of homes in the Florida Keys is higher than it is in other parts of Florida and the rest of the country. Considering this, there is not a concern that the structures recommended for nonstructural measures would not already be consistent with current health, sanitary, and safety codes where it would affect the overall participation rate. However, because the homes in the Keys are generally higher value, it is possible that some homeowners would have concerns that the elevation would negatively affect the aesthetic of their home, which could slightly reduce the participation rate. The higher quality of homes in the Keys is expected to have a more positive effect on this factor than the possible concern of homeowners and overall, the study team expects this factor to slightly increase the participation rate for nonstructural measures.

3. Hazardous, Toxic, Radioactive Waste
   Owners must provide proof that their property contains no Hazardous, Toxic, or Radioactive Waste (HTRW) to participate in a USACE project. The BPG states that if a property does contain HTRW, the owner may still participate if they are willing to pay for remediation. The HTRW information recorded in the Authorizing Document is a good reference source. A community construction department may be consulted for an average age of the housing stock. This may be supplemented with the structure inventory conducted for the assessment of the nonstructural alternatives. A higher rate of structures constructed prior to approximately 1980 is correlated with higher rates of remediation and with lower rates of participation (this is a result of 42 U.S.C. Ch. 63A: Residential Lead-Based Paint Hazard Reduction, which requires disclosure of known information on lead-based paint and lead-based hazards before the sale or lease of most housing built before 1978). In Monroe County, 49.3 percent of all housing units were built before 1980. This is higher than the 37.7 percent of housing units in the State of Florida, but slightly lower than the national percentage of 53.6. Because the percentage of homes built before 1980 is not significantly lower in Monroe County than the national average, this factor is not expected to have a measurable impact on the participation rate for nonstructural measures.

4. Temporary Relocation

   Owners must be willing and able to afford temporary relocation if structures are to be elevated. The BPG states that for owners dependent upon community services/transportation, this may be cost-prohibitive. Even if owners are willing, adequate temporary housing with some proximity could be in short demand if many structures will be elevated around the same timeframe, which could necessitate non-participation. Even if temporary housing exists in the timeframe needed, owners may not be able to afford it, especially if they carry a mortgage on their own structure, as they would be required to pay both mortgage and temporary housing costs concurrently. Any of these factors can significantly hinder participation. Employment statistics recorded in the Authorizing Document can be considered to indicate owner ability to afford temporarily relocation. Higher unemployment rates, higher rates of families below the poverty line, and lower median income rates are considered to correlate with lower ability to afford temporary relocation costs and hence with lower participation rates. This factor affecting participation rates only relates to structures being elevated. In the Florida Keys, the median household income is significantly higher than the state and national averages. The portion of the population in poverty is slightly lower than the state and national averages and the employment is slightly higher than the state average, but consistent with the national average. This indicates that on the basis of cost, more homeowners in the Keys should be able to temporarily relocate as compared to other locations in the country. In addition, more of the housing units in Monroe County are rented as compared to Florida and the nation. Tenants of rental properties receive financial assistance for temporary relocation as part of the project cost. In Monroe County, 59.5 percent of housing units are owner occupied, which is less than the state and national averages of 65.4 and 64.0 percent. Additionally, there is a portion of homeowners in Monroe County that do not occupy their home all year round and only live there seasonally. Seasonal residents may temporarily relocate to their alternate residence while their home in the Florida Keys is being elevated. However, while the higher than average household income, number of rentals, and seasonal residents all would increase the participation rate, the County has expressed concern that it may be difficult to find lodging for residents while their homes are being elevated. The Keys are a high demand vacation destination and hotels and other short-term rentals that would be used for temporary location while homes are elevated are consistently booked throughout most of the year. During the summer (which is also hurricane season) tourism is less than the rest of the year, but generally lodging in the Keys is expensive and in short supply. If a large number of structures were to be elevated at once, there is concern that there would not be enough lodging available to house all of the residents during the elevation. Timing the implementation of home elevations to occur when there are fewer visitors in the Keys would make this less of a concern. The average household income, seasonal residents, and higher than average number rental properties in the Keys would be expected to increase participation but may not completely outweigh the possible negative impact that lodging availability may have on temporary relocation and this factor is expected to slightly decrease the participation rate for nonstructural measures.

5. Physical Requirements
   Owners must have the physical ability to perform any required maintenance or operational actions required to complete the protection (e.g., place door shields in anticipation of flooding in the case of dry floodproofing). For communities with a significant elderly population (or those with a significant number of very young children), participation could be hindered. The BPG states that higher rates of residents age 65 and above and higher rates of children under the age of five are correlated with lower ability to perform human intervention tasks and therefore lower participation rates. This factor only relates to those structures not being elevated. In Monroe County, 23.7 percent of the population is 65 or older. This is a higher portion of the overall population when compared to 20.0 percent for the state of Florida and 16.5 percent for the entire U.S. Interestingly, 23.7 percent of the 65 and older population in Monroe County is disabled, as compared to 32.8 and 34.5 percent for Florida and the nation. The portion of the total population with a disability is also much lower in Monroe than the state and nation. However, because the overall portion of the population in Monroe County is 65 or older and the Keys are a well-known location for retirees, this factor is expected to slightly decrease the participation rate for nonstructural measures.

6. Other Local Factors
   In addition to the five factors from the BPG, the study team identified some additional factors that are expected to affect the participation rate for nonstructural measures. These additional considerations are expected to moderately increase the participation rate for nonstructural measures. These local factors include:
   - Concern over sea level rise and “sunny day flooding” which is already experienced in some parts of the Keys on a more frequent basis and currently negatively impacting daily life for some residents. Residents of the Florida Keys have an awareness of the risk coastal storms and sea level change pose. The fact that some residents are currently being impacted by sea level change and coastal storms increases the likelihood that residents would participate in measures such as elevation and floodproofing if given the opportunity.

- In Monroe County, 91.4 percent of the population has a high school diploma and 34.4 percent has a bachelor's degree. This is higher than the state and national averages and would suggest that residents of the Keys should be somewhat more likely to understand climate change and coastal storm risk than other coastal communities. Higher education also may make outreach and educations efforts conducted during implementation of nonstructural measures more effective in helping the public understand the project.
- Home elevation was formulated for the 100-year water surface elevation plus additional height to allow for the high rate of sea level rise over the 50-year period of analysis, which is approximately three feet. This water surface elevation was identified as the target height for the first-floor elevation of homes included in the recommended plan for elevation as it is the height that maximized net National Economic Development benefits. However, this target height is also likely to be at or possibly above the 100 year plus one foot required for participation in the National Flood Insurance Program. Reductions in flood insurance premiums is expected to increase the participation in nonstructural measures given the savings homeowners could gain over time.

Table 9-4: Relevant Census Bureau Statistics

	Monroe County	Florida	United States
Population (Total)	74,228	21,477,737	328,239,523
Population, 65 and Over (%)	23.7	20.9	16.5
Education, High School	91.4	88.2	88.0
Education, Bachelor's	34.4	29.9	32.1
Health, Disability, 65 and Over (%)	23.7	32.8	34.5
Health, Disability, All (%)	10.3	13.4	12.6
Civilian Labor Force	62.7	58.5	63.0
Median Household Income	$70,033	55,660	62,843
Persons in Poverty (%)	9.9	12.7	10.5
Housing Units (Total)	53,892	9,673,682	139,684,244
Housing, Owned	59.5	65.4	64.0
Housing, Rented	40.5	34.6	36.0
Housing, Same as 1yr Ago (%)	81.6	84.5	85.8
Housing, Built before 1980[2] (%)	49.3	37.7	53.6
Housing, Value $200K or Greater (%)[3]	88.4	53.9	53.7

(1) Population Estimates, July 1, 2019 (V2019) from U.S. Census Bureau, Population Estimates Program (PEP), updated annually.
(2) Percent of total housing units, from U.S. Census American Community Survey
(3) Percent of owner-occupied units

Scores of slight, moderate, or significant increases or decreases in the participation rate were applied to an estimated minimum “worst case scenario” participation rate of 50 percent of the recommended structures to determine the most likely participation rate. The minimum of 50 percent was established in a recent USACE coastal storm risk management study that recommended a similar nonstructural plan comprised of elevation and floodproofing. Using 50 percent as a base score, 5 percentage points were added for a slight effect, 10 percentage points were added or subtracted for a moderate effect, and 15 percentage points were added or subtracted for a significant effect to determine the most likely participation rate. Results of this scoring are shown in Table 9-4.

Table 9-5: Results of Factors Affecting Participation Rate Evaluation

Factor	Evaluation	Score
Temporal Proximity of Severe Flood Damage	Significant Increase	+15
Decent, Safe, and Sanitary	Slight Increase	+5
HTRW	No Impact	0
Temporary Relocation	Slight Decrease	-5
Physical Requirements	Slight Decrease	-5
Other Local Factors	Moderate Increase	+10
Total	Overall Increase	+20

Given the results of this evaluation and the minimum expected rate of 50 percent, the estimated most likely participation rate for nonstructural measures in the recommended plan is 70 percent. An optimistic upper bound or “best case scenario” participation rate was also established in addition to the worst case and most likely rates. In assuming that in the best case scenario temporary relocation and physical requirements factors did not have a slightly negative effect on the overall scoring, 80 percent was determined to be the upper bound for participation in nonstructural measures. The table below represents the economic analysis adjusted with respect to these participation rates. The estimates below were calculated by applying each participation rate percentage both the benefits (total present value damage reduction) and cost (total first cost). Average annual estimates where then recalculated. This general approach is meant to avoid making direct assumptions about which structures to include in the Recommended Plan. Various levels of participation in the project would likely impact the costs and benefits proportionally resulting in a consistent BCR. However, overall annual net benefits decrease as participation decreases.

Table 9-6: Participation Rate Analysis

Recommended Plan	Participation Rate			
	100%	80%	70%	50%
AAC ($1,000)	85,557	43,222	37,819	27,014
AAB ($1,000)	131,603	68,952	60,333	43,095
BCR	1.5	1.6	1.6	1.6
Net Benefits ($1,000)	46,046	25,730	22,513	16,081

(1) Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035
(2) The present value benefit estimate is with respect to the base year 2035 and the 50-year period of analysis
(3) Average annual damage estimates are with respect to a capital recovery factor of 3.5%
(4) Estimates rounded

9.5 Tidal Data Uncertainty

Through review, there was concern raised for utilizing storm data which includes tidal information as an input into G2CRM. The PDT's team member from the U.S. Army Engineer Research and Development Center performed an analysis in order to determine the impact this could have on damage estimates. It was concluded that pre-adding tidal components may affect the damage estimates when compared to the traditional method of using G2CRM. The analysis showed that damage could be up to 5% higher by using storm data which includes tidal information. However, it is argued that the inclusion of the tidal component allows for more accurate calculations of nonlinear residuals resulting in an increased water elevation when compared to simple linear superposition of tides. Even still, Recommended Plan details below reflect that the project is still economically justified if damage is reduced by 5%.

Table 9-3: Tidal Data Uncertainty

Recommended Plan Economic Analysis	
Average Annual Cost ($1,000)	85,557
Average Annual Benefit ($1,000)	131,603
Average Annual Benefit, Reduced by 5% ($1,000)	125,023
BCR	1.5
Net Benefits ($1,000)	39,466
(1) Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035 (2) Damage estimates are with respect to the time period 2020-2084 and are generated utilizing the USACE high sea level change curve (3) Average annual damage estimates are with respect to a capital recovery factor of 3.5% (4) Estimates rounded	

9.6 Floodproofing Risk

Dry floodproofing a structure located within the FEMA V Zone is typically not permitted due to safety and structural reasons. Structures within the V Zone, as determined by FEMA's most recent effective flood insurance rate map, were excluded from the Recommended Plan. However, there are still structures in the Recommended Plan that are anticipated to be reassigned to the V Zone based on preliminary results of FEMA's next flood insurance rate map. These structures remain in the plan since this map is not yet final but have been identified so that they can be reexamined during PED. The table below lists these structures by Asset ID.

Table 9-7: Preliminary Future Flood Zone – Structures Likely Within the VE Zone

Asset Reference	Model Area	Locality	Current Flood Zone	Preliminary Future Flood Zone
8923	MA30	City of Key West	AE/AO	VE
5530	MA32	City of Key West	AE/AO	VE
9656	MA32	City of Key West	AE/AO	VE
27849	MA32	City of Key West	AE/AO	VE
28266	MA32	City of Key West	AE/AO	VE
29815	MA32	City of Key West	AE/AO	VE
31242	MA32	City of Key West	AE/AO	VE
35636	MA32	City of Key West	AE/AO	VE
38664	MA32	City of Key West	AE/AO	VE
23165	MA4	Monroe County	AE/AO	VE
11119	MA5	Monroe County	AE/AO	VE
12273	MA5	Monroe County	AE/AO	VE
18247	MA5	Monroe County	AE/AO	VE
31494	MA5	Monroe County	AE/AO	VE
36752	MA5	Monroe County	AE/AO	VE
6994	MA8	Monroe County	AE/AO	VE
28659	MA8	Monroe County	AE/AO	VE
33350	MA8	Monroe County	AE/AO	VE
34865	MA8	Monroe County	AE/AO	VE
4697	MA10	Village of Islamorada	AE/AO	VE
18198	MA10	Village of Islamorada	AE/AO	VE
19736	MA10	Village of Islamorada	AE/AO	VE
6279	MA13	Monroe County	AE/AO	VE
13416	MA14	City of Layton	AE/AO	VE
152	MA16	City of Marathon	AE/AO	VE
156	MA16	City of Marathon	AE/AO	VE
15506	MA16	City of Marathon	AE/AO	VE
28513	MA16	City of Marathon	AE/AO	VE
29630	MA17	City of Marathon	AE/AO	VE
32132	MA20	City of Marathon	AE/AO	VE
2003	MA23	Monroe County	AE/AO	VE
9847	MA23	Monroe County	AE/AO	VE
18877	MA23	Monroe County	AE/AO	VE
24332	MA23	Monroe County	AE/AO	VE
37350	MA23	Monroe County	AE/AO	VE
9106	MA24	Monroe County	AE/AO	VE
11325	MA24	Monroe County	AE/AO	VE
16966	MA24	Monroe County	AE/AO	VE
4512	MA27	Monroe County	AE/AO	VE
19143	MA28	Monroe County	AE/AO	VE

There also may be risk of hydrostatic pressure for floodproofing a structure which is expected receive storm surge beyond the added three feet of protection. Some suggest that these floodproofed structures may be damaged to an even greater extent and should therefore remain as is. However, the PDT is unaware of available DDFs that can account for this hydrostatic pressure. This could be a cause for concern given the expected levels of protection for floodproofed structures, noted in the table below, compared to the expected levels of max storm surge noted in Table 6-4.

Table 9-8: Recommended Plan Floodproofing - Residual Risk

Locality	Average First Floor Elevation (Feet)	Average Level of Protection with Floodproofing (Feet)
City of Key Colony Beach	4.51	7.51
City of Key West	4.40	7.40
City of Layton	2.58	5.58
City of Marathon	4.36	7.36
Monroe County	4.77	7.77
Village of Islamorada	5.44	8.44
Study Area Average	4.58	7.58
(1) Averages based of structures included in the Recommended Plan for floodproofing (2) Levels with respect to NAVD88		

Depending on these structure's construction type, among other characteristics, additional reinforcement can be constructed to combat this. Additionally, while the suggested limit of floodproofing is typically three feet, there may be situations where a structure can be floodproofed higher. Determining the appropriateness of floodproofing these structures can be better understood in detail during PED. Given this, engineering teammates determined it appropriate to leave these structures in the Recommended Plan.

9.7 First-Floor Elevation Estimation and Risk

9.7.1 First-Floor Elevation Estimation

Structure first-floor elevation estimates are a key variable input into G2CRM. This section describes the derivation of first-floor elevation estimates. Initial first-floor elevation estimates (FFE_1) were derived from ground elevation estimates[8] (GE_1) and initial foundation height estimates[9] (FH_1). Elevation certificate data were available for a small sample of structures in the structure inventory. First-floor elevation estimates were replaced for the structures that had elevation certificate data. Additional corrections were made to FFE estimates for one-story residential structures with a slab foundation. The majority of structures in the elevation certificate dataset fell into this structure category and the sample suggested that FFE estimates are potentially higher on

[8] Ground elevation estimates were sourced from USGS digital elevation model data.

[9] Initial foundation height estimates were determined by assumptions based on structure foundation type: (1) 0.5-1' for slab, (2) 2-4' for crawl, and (3) 7' for pile. These assumptions were based on some Google Earth/Maps viewing, comparing to elevation certificates, using FEMA and NSI V2 assumptions for typical structures, and speaking to local floodplain building managers.

average than what was previously assumed for initial foundation heights. Therefore, the assumptions for this structure category were modified[10] to better reflect the elevation certificate dataset. The updated first-floor elevation estimates (FFE_2) were then used to re-estimate foundation height estimates (FH_2). This correction assumes that the error is with initial foundation height assumptions (FH_1) rather than ground elevation estimates (GE_1). These steps/transitions can also be understood with the following notation:

$$GE_1 + FH_1 = FFE_1$$
$$FFE_1 \rightarrow FFE_2$$
$$FFE_2 - GE_1 = FH_2$$

The tables below provide FWOP and FWP descriptive statistics for each of the three final estimates. Given the size of the Study Area and variation of elevations throughout the islands, tables may be more informative given the size of the Study Area and variation of elevations throughout the islands. Given the negative minimum foundation height estimate, there is likely error either in the ground elevation estimates or in the foundation height assumptions. However, the majority of the estimates seem reasonable given the mean, standard deviation and quartile estimates. That is, the error is likely concentrated on a small number of structures.

Table 9-9: FWOP Descriptive Statistics for Ground Elevation, Foundation Height, and First-Floor Elevation

	GE	FH	FFE
Count	38,670	38,670	38,670
Mean	3.46	4.98	8.43
SD	2.24	2.54	2.88
Minimum	0.00	-9.89	1.00
Quartile1	1.97	3.00	6.13
Median	2.84	4.00	8.47
Quartile3	4.22	7.00	10.24
Maximum	19.53	21.62	25.34
Estimates are in feet, with respect to NAVD88			

There are 4,698 structures currently identified for elevation, however, this is only about 12% of the structure inventory. Therefore, in aggregate, only slight differences can be seen between the FWOP and FWP tables for the FH and FFE estimates.

[10] The subset of one-story residential structures with a slab foundation initially presented skewed (to the right) FH and FFE data.

Table 9-10: FWP Descriptive Statistics for Ground Elevation, Foundation Height, and First-Floor Elevation

	GE	FH	FFE
Count	38,670	38,670	38,670
Mean	3.46	5.63	9.08
SD	2.24	2.87	2.90
Minimum	0.00	-9.89	1.00
Quartile1	1.97	3.00	7.56
Median	2.84	7.00	9.34
Quartile3	4.22	8.00	10.93
Maximum	19.53	21.62	25.34
Estimates are in feet, with respect to NAVD88			

Ground elevation estimates were based on fairly reliable data. However, the reliability for foundation height assumptions may not hold across the entire Study Area. Additionally, some modified foundation height estimates (FH_2) were simply a byproduct of re-estimate foundation height estimates (FFE_2) and ground elevation estimates (GE_1). Therefore, any potential error in ground elevation estimates is likely captured in the modified foundation height estimates (FH_2). The next section explores if the risk around first-floor elevation estimates may impact the economic analysis.

9.7.2 First-Floor Elevation Risk

There is potential risk from error in first-floor elevation (FFE) estimates, which would directly impact expected damage estimates. If FFE estimates are overestimated, then the reduction in damage (benefit) from the Recommended Plan would likely be equal to or greater than the current estimated reduction in damage. The risk is if actual FFE estimates are underestimated. MA32 was selected to test how adding uncertainty to the FFE estimates input may affect modeling results[11]. This uncertainty was incorporated by creating an additional upper and lower bound (+/- 1.5 ft.) for the FFE estimates parameter[12]. The table below shows that the benefits of the Recommended Plan only decrease, on average, by approximately 5%. That is, potential uncertainty around FFE estimates should not impact plan selection or justification. If this reduction in benefit was extended across all MAs, the Recommended Plan would still be selected and economically justified. Furthermore, if a structure's first-floor elevation was found to be significantly higher during planning engineering and design, the structure would likely be reconsidered for elevation/floodproofing.

[11] MA32 was selected for this analysis since it contains the largest number of total structures in an individual MA; MA32 also contains the largest number of structures included in the Recommended Plan.
[12] The use of 1.5 ft. is consistent with EM 1110-2-1619 (Table 6-5).

Table 9-11: Foundation Height Sensitivity Analysis

MA32	First-Floor Elevation Estimates	
	Estimates Utilized	Estimates with Uncertainty
FWOP Damage ($1,000)	5,656,363	5,639,052
FWP Damage ($1,000)	4,532,761	4,573,492
Benefit ($1,000)	1,123,602	1,065,560

(1) Present value estimates utilize the current FY discount rate and are with respect to the project base year 2035
(2) Damage estimates are with respect to the time period 2020-2084 and are generated utilizing the USACE high sea level change curve
(3) Average annual damage estimates are with respect to a capital recovery factor of 3.5%
(4) Estimates rounded

10 REGIONAL ECONOMIC DEVELOPMENT

The Regional Economic Development (RED) benefit of the Recommended Plan is provided in the following sections.

10.1 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.

For this Regional analysis, the regional economic development (RED) effects of implementing the Recommended Plan or Alternative seven will be estimated. The RECONS Standard Geographic Area for the Monroe County was selected using an expenditure year of 2027.

This RED analysis 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 in one industry on others. 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 (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 Berger Group. RECONS uses industry multipliers derived from the commercial input-output model IMPLAN to estimate the effects that spending on USACE projects has 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. RECONS is designed to evaluate a discrete spending stimulus, which means that all expenditures occurring over multiple years that are required to complete a project are considered to occur in a single year. Therefore, RECONS is not time-sensitive with respect to the calculation of effects and reporting of outputs. 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 may be spent on clothing, groceries, dining out, and other items in the regional area.

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 production function "FRM Construction" was selected to gauge the impacts of the construction of the Recommended Plan. The model results are expressed in 2027 dollars.

10.2 Assumptions

Input-output analysis rests on the following assumptions. The production functions of industries have constant returns to scale, so if output is to increase, inputs 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 2020, the year of the socio-economic data in the RECONS model database, will prevail during the years of the construction process.

10.3 Description of Metrics

“Output” is the sum total 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 regions. 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 to build the project.

10.4 Results

The expenditures associated with all work activities of the Recommended Plan are estimated to be approximately $2.0 billion. Of this total expenditure, $1.3 billion will be captured within the local impact area of Monroe County. The remainder of the expenditures will be captured within the state and the nation. These direct expenditures generate additional economic activity, often called secondary or multiplier effects. The direct and secondary impacts are measured in output, jobs, labor income, and gross regional product (value added) as summarized in the following tables. The regional economic effects are shown for the local, state, and national impact areas. In summary, the project expenditures support an estimated total of 18,607 full-time equivalent jobs, $1.1 billion in labor income, $1.2 Billion in value added output, and $2 billion in economic output in the local impact area. More broadly, these expenditures support 36,044 full-time equivalent jobs, $2.4 billion in labor income, $3.2 billion in the gross regional product, and $5.4 billion in economic output in the nation.

Table 10-1: Regional Economic Development

Area	Local Capture ($1,000s)	Output ($1,000s)	Jobs	Labor Income ($1,000s)	Value Added ($1,000s)
Local					
Direct Impact		1,305,873	14,036	864,872	834,875
Secondary Impact		730,443	4,571	229,793	414,493
Total Impact	1,305,873	2,036,316	18,607	1,094,665	1,249,368
State					
Direct Impact		1,404,648	11,107	785,293	817,386
Secondary Impact		1,607,803	9,348	512,371	885,595
Total Impact	1,659,168	3,012,452	20,455	1,297,664	1,702,981
US					
Direct Impact		1,904,892	18,843	1,292,057	1,243,069
Secondary Impact		3,522,066	17,200	1,120,831	1,918,473
Total Impact	1,904,892	5,426,958	36,044	2,412,887	3,161,542
(1) Jobs are presented in full-time equivalence (FTE) (2) Estimates are with respect to 2021					

The table above provides total impact estimates. However, the impact will be spread out over the 10-year period. The table below provides estimates for average annual impact to output, with respect to the 10-year period of construction.

Table 10-2: Impact to Output, by Area

Area	Total Impact to Output ($1,000)	Average Annual Impact to Output ($1,000)
Local	2,036,316	208,722
State	3,012,452	308,776
National	5,426,958	556,263
(1) Total impact with respect to 2021 (2) Annual estimates are with respect to a 10-year construction period and a 2.5% discount rate		

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