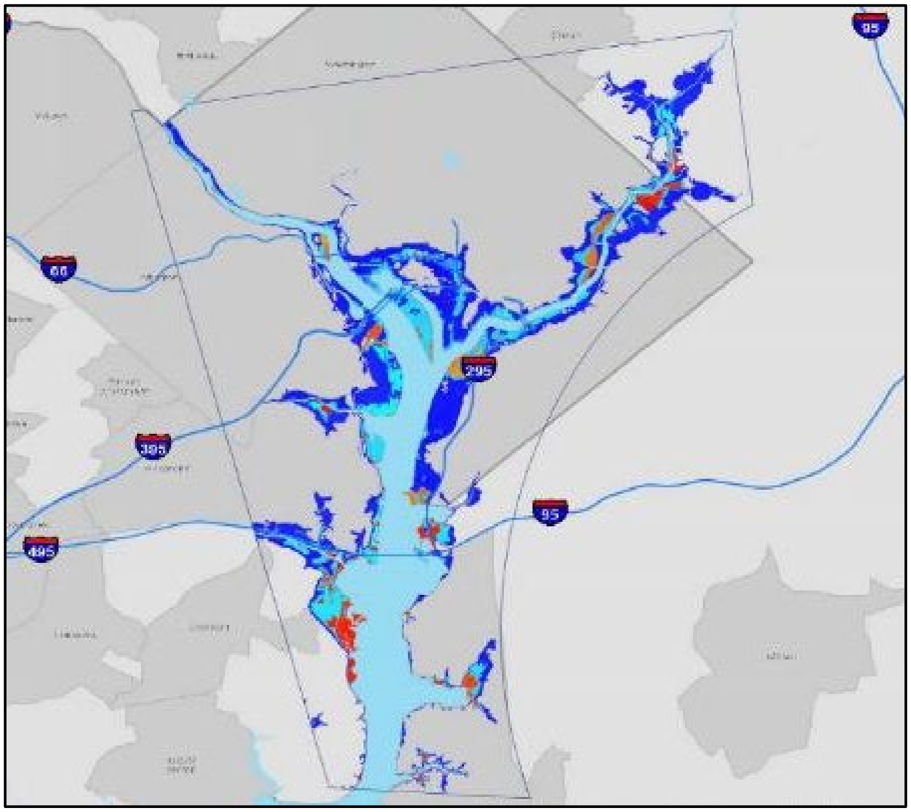
Metropolitan Washington District of Columbia Coastal Storm Risk Management Feasibility Study

Appendix E: Economic Analysis



Northern Virginia

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US Army Corps of Engineers
Baltimore District

Metropolitan Washington Council of Governments

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Contents

1. INTRODUCTION

This appendix presents an economic evaluation of flood risk reduction for the national economic development (NED), regional economic development (RED), environmental quality, and other social effects accounts undertaken for the District of Columbia Washington Metropolitan Coastal Flood Risk Management Study. The study area includes lands and water resources reasonably deemed to be within the vicinity of Arlington County, City of Alexandria, Fairfax County, Prince William County in the state of Virginia. This analysis was conducted in accordance with USACE policy dictates in 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, along with the USACE Generation II Coastal Risk Model (G2CRM) User's Manual v4.556.3. G2CRM is the coastal flood risk management certified model used to analyze the inundation damages. The damages were originally calculated with a no-exhaustive structure size using fiscal year FY2019 price levels, and a period of analysis of 50 years to the Alternative Milestone Meeting. Currently, the analysis is conducted using the fiscal year 2022 discount rate (October 2021 price level). 2031 is the base year. It is also used as the basis for plan comparison for each alternative using the FY22 discount rate of 2.25 percent.

2. FLOOD RISK REDUCTION

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

2.1 STUDY AUTHORITY

The North Atlantic coastline of the United States has been impacted by numerous coastal storms, including Hurricane Sandy in 2012, causing loss of life and extensive economic damages. In response, the U.S. Army Corps of Engineers (USACE) completed the North Atlantic Coast Comprehensive Study (NACCS), which identified flooding areas in the North of Virginia (NoVA).

The region has an existing study authorization from Congress. The resolution of the U.S. Senate Committee on Environment and Public Works dated May 23, 2001.

> "*That the Secretary of the Army is requested to review the report of the Chief of Engineers on the Potomac River and Tributaries in Maryland, Virginia, and Pennsylvania published in House Document 343, ninety-first Congress, second session, and other pertinent reports, with a view to conducting a study, in cooperation with the States of Maryland and West Virginia, the Commonwealths of Pennsylvania and Virginia, and the District of Columbia, their political subdivisions and agencies and instrumentalities thereof, other Federal agencies and entities, for improvements*

in the interest of the ecosystem restoration and protection, flood plain management, and other allied purposes for the middle Potomac River watershed."

The study authority was identified as the most recent authority that includes the study area, with the ability to investigate solutions to coastal flooding problems leading to a USACE recommendation for implementation in the form of a Chief's Report. The Baltimore District believes the Middle Potomac River and Tributaries authority may be used to advance this feasibility study as identified in the NACCS appendix identifying a focus area assessment, since the Baltimore District Office of Counsel advised that this authority could be used via a 22 April 2014 memorandum

This study is served to reduce coastal flood risk to vulnerable populations, properties, infrastructure, and environmental and cultural resources considering future climate and sea level change scenarios to support resilient communities within northern Virginia.

2.2 STUDY PURPOSE

2.2.1 Problem Description

The Northern Virginia study area is susceptible to flooding from tidal surges of hurricanes and tropical storms due to the area's low flat terrain. Coastal flooding in the densely populated study area endangers lives, damages property, and disrupts critical infrastructure. The area is also subject to riverine flooding from excess precipitation. Flood events may lead to negative environmental impacts such as damage to wastewater treatment facilities. Flooding in Northern Virginia may be further exacerbated by a combination of sea level rise and climate change over the study period.

2.2.2 Scope of the Study

The purpose of the District of Columbia Coastal Flood Risk Management Study is to investigate and recommend potential structural and nonstructural solution sets to reduce damages from coastal storms. The District of Columbia Coastal Flood Risk Management Study is also known as the Northern Virginia Coastal Flood Risk Management Study.

The primary focus of this study is storm surge inundation. While the Northern Virginia area also experiences flooding from high tides and rainfall, those issues are not within the scope of this study authorization. Without a plan to reduce damages from coastal storm surge inundation, the Northern Virginia's vulnerability to coastal storms is expected to increase over time.

USACE policy dictates that in urban and urbanizing areas, provision of a basic drainage system to collect and convey local runoff is a non-Federal responsibility [ER 1105-2-100, Section 3-3, b, (6)]. However, mitigation for any adverse impacts to storm water runoff will be included in the recommended plan if necessary.

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

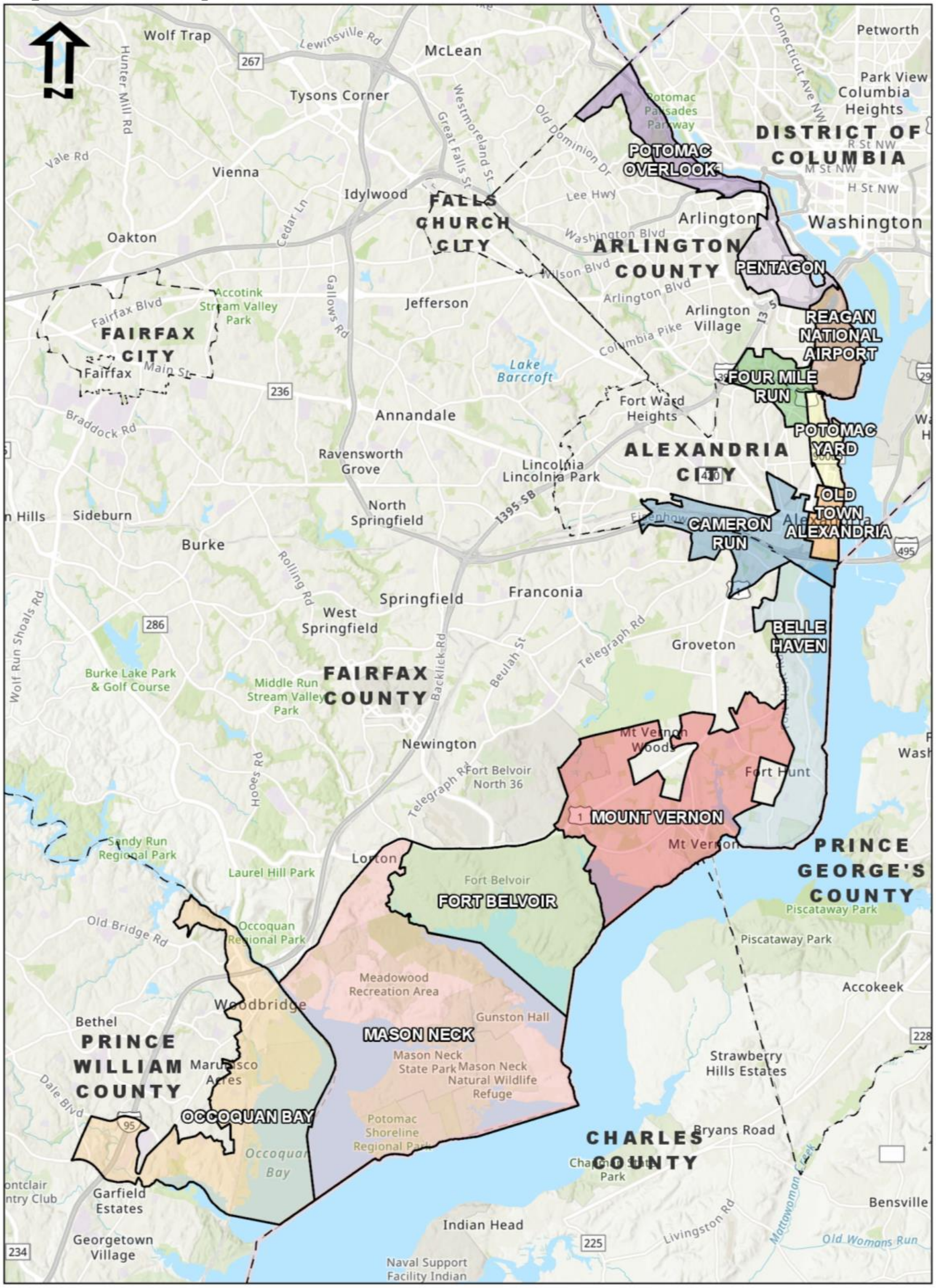
2.3 STUDY AREA DESCRIPTION

DC Coastal study area is in the Northern Virginia extending along the Potomac River from Little Falls to Neabsco Creek. The Middle Potomac Watershed boundary delimits the downstream extent of the study area. The HEC-RAS modeling for project alternatives extend from the cross-section 124.487 at Reagan Washington National Airport to the cross-section 117.487 at Belle Haven. Planning units are created for each jurisdiction by selecting census block groups in each jurisdiction that are impacted by inundation in coastal and riverine models. These block groups are aggregated based on neighborhood boundaries, the location of protected areas for existing FRM projects, and the source of inundation (tributary versus mainstem). From initial 19 planning units, some planning units were aggregated logically using major streams or road embankments as break lines in between planning units.

* Reagan National Airport and the census block upland of the Airport and south of the I-395 highway were merged into Reagan National Airport Planning Unit. Most coastal flooding impacts were concentrated at the Airport property.
* The two units in Four Mile Run were merged into Four Mile Run Planning Unit.
* The three planning units in Cameron Run were merged into Cameron Planning Unit.
* Belle Haven and Fort Hunt planning units which covers from Cameron Run to Little Hunting Creek were merged into Belle Haven Planning Unit.
* The coastal area between Little Hunting Creek and Dogue Creek were merged into Mount Vernon Planning Unit as few structures were impacted by coastal flooding along this reach.
* The two planning units between Occoquan River and the end of Middle Potomac Watershed at Neabsco Creek were merged into one planning unit as a majority of coastal flooding was in low lying areas of Potomac River and back flooding along Occoquan River.

As a result, 12 planning areas were developed as shown in Figure 1 below.

Figure 1: Planning Areas Overview



The analysis in G2CRM includes 22 Model Areas (MAs), which are the subdivisions or the aggregations of the Planning areas. Some MAs include existing protected system elements. The Northern Virginia area is restricted to regions along rivers and other waterways that are subject to tidal flooding, coastal storm flooding, and interior drainage damages within areas of coastal flooding. The study area is composed by the following four jurisdictions: the City of Alexandria, Arlington County, Fairfax County, and Prince William County.

Extensive historical damages have been the result of riverine flood events from the Potomac River, the primary flooding source within the region. Coastal storms, such as Hurricane Isabel in 2003, have also resulted in approximately 10 feet (MLLW) extreme water levels (8 feet surge) and may occur more frequently in the future. Previous hydrologic analyses have identified coastal flooding probabilities to be the controlling flooding feature within most of the study area. Additionally, with climate change, coastal flooding may be a problem in the future that is not yet fully characterized within the region. In the future, given relative sea level rise projections, the flood waters associated with a storm event of lower magnitude could potentially generate a flood comparable to what occurred during Hurricane Isabel, or possibly exceed those flood water levels.

Populations, properties, and infrastructures in the Northern Virginia communities are subject to coastal flood risk vulnerable, storms, waves, sea level rise and tides.

There is a need for this study because the Northern Virginia communities and the surrounding metropolitan areas along rivers and waterways have been subjected to intense coastal storm events resulting in major damages. Therefore, the Federal Government has an interest in reducing those damages, as doing so not only contributes to National Economic Development (NED) but may also improve the living conditions of the community and preserving historic and cultural resources. For the purposes of the economic appendix, the assets include residential and commercial structures with their content values, residential vehicles, the Arlington Water Pollution Control Plant, and the infrastructure (Buildings and Engineered Material Arresting System) and the valuation of vehicles at Reagan Washington National Airport. In addition to the benefits assessed from these assets, additional benefits are associated with storm surge and the debris clean-up cost reduction.

2.4 SOCIOECONOMIC DATA

2.4.1 Population

Table 1 displays the population for Arlington County, the City of Alexandria, Fairfax County, Prince William County in the state of Virginia for the years 1980, 1990, 2000, and 2010, as well as projections for the years 2020 to 2040. Historical data were sourced from the U.S. Census Bureau. Due to the lack of data from reputable sources pertaining to population projections, the population forecast was based on the University of Virginia Demographics Research Group, and the county government population data.

Table 1: Northern Virginia Historical and Projected Population

	1980		1990		2000		2010		2020		2030		2040	
Study Jurisdictions	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate
City of Alex.	103,217	-	111,491	0.8%	129,355	1.5%	139,966	0.8%	166,261	1.7%	182,067	0.9%	195,240	0.7%
Arlington Co	152,599	-	170936	1.1%	189,453	1.0%	207,627	0.9%	249,298	1.8%	274,339	1.0%	295,383	0.7%
Fairfax Co	596,900	-	818,600	3.2%	969,700	1.7%	1,081,726	1.1%	1,162,504	0.7%	1,244,025	0.7%	1,308,244	0.5%
Prince W. Co	144,636	-	216,540	4.1%	284,396	2.8%	402,002	3.5%	482,204	1.8%	530,300	1.0%	569,200	0.7%

2.4.2 Income and Poverty Status

The current median household income in the City of Alexandria, Prince William County, Arlington County, and Fairfax County are respectively $100,939, $107,132, $120,071, and $124,831 with the poverty rate of 10.3 percent, 6.1 percent, 7.6 percent, and 6.0 percent compared to $62,843 median household income and the poverty rate of 11.4 percent across the entire United States.

3. METHODOLOGY

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. The future without project condition is the condition that would likely exist in the future without the implementation of a federal project and incorporates projected sea level change. This condition is evaluated for a 50-year period of analysis for coastal storm management projects, and the results are expressed in terms of average annual damages. For this study, the future without project condition is for the years 2031-2080. 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 a 50-year period of analysis for the future project conditions.

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

3.1 ASSUMPTION

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

- Floodplain residents will react to a floodplain management plan in a rational manner.

- Real property will continue to be repaired to pre-flood conditions subsequent to each flood event given a rebuilding period with a maximum rebuild of 5 times, and not removed from the asset inventory (i.e., cumulative damage threshold not used).
- Residential structures are raised after receiving significant damages within the period of analysis.
- The residential depth-percent damage relationships for structure and content contained in Economic Guidance Memorandum (EGM) 01-03 and 04-01 are assumed to be representative of residential structures in the floodplain.
- Non-residential depth-percent damage relationships for structures and content are from expert elicitation found in the revised 2013 draft report (IWR Report 2013-R-05) completed by the USACE Institute of Water Resources. Non-residential flood depth-damage functions derived from expert elicitation are assumed to be representative of non-residential structures in the floodplain.
- The present valued damages, first costs, and benefits will be annualized using the FY 2022 Federal discount rate of 2.250 percent assuming a period of analysis of 50 years.
- All values are equivalent to 2021 dollars.
- All project alternatives are evaluated for a 50-year period of analysis.
- The base year when the benefits of the constructed federal project would be expected to begin is 2031.
- Elevations are in feet (ft) North American Vertical Datum of 1988 (NAVD88).
- Sea level change follows the USACE Intermediate Curve and used a sea level change rate of 0.00997 feet per year.
- Depreciation is calculated for structures (i.e., replacement values) during the life cycle analysis.

3.2 RISK AND UNCERTAINTY

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

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

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

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

3.2.1 Modeling Description

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

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

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

3.2.2 Modeling Variables

According to 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.

3.2.3 Economic Inputs

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

3.2.4 Structure Inventory

The Northern Virginia structure inventory is obtained by spatially joining building footprints with parcel records available for the four jurisdictions in the study area. The spatial join tool is used in ArcGIS to join features that include the parcel data information. During the study initiation, a topographic raster mosaic was generated using 2014 LIDAR data and various bathymetry sources in ArcGIS Pro. Online sources are also used to complete the inventory. The inventory was paired with the National Structure Inventory (NSI) and modified by Corps personnel to extract the foundation type and height, and the occupancy type.

Following the Alternative Milestone Meeting (AMM), the structure inventory was expanded. Privately owned vehicles in the study area were estimated and added to the inventory. Debris clean-up cost that the community during a flood event was evaluated and added to each residential and nonresidential structure. Assets at the Arlington Water Pollution Control Plant, and infrastructure at the Reagan Washington National Airport were added to the inventory. Three Reagan Washington National Airport Engineered Material Arresting System (EMAS) are installed at the ends of Runways 15, 33, and 22. The individual blocks that make up the EMAS are glued to the runway pavement and could float away during a flood event. The Reagan National Airport Board of Directors estimated the cost of the three EMAS in 2013 price level. The Civil Works Construction Cost Indices were used to escalate the EMAS cost to the 2021 price level. The space available at three large parking lots at the Reagan National Airport were used to evaluate the private vehicles at the airport that might potentially be exposed to flooding.

The Arlington Water Pollution Control Plant (WPCP) assets are in the inventory. The valuation of WPCP assets was provided by the sponsor. The assets will be further discussed in the Assets section of this Appendix.

A total of 18,639 structures including residential structures, nonresidential structures, and synthetic assets (private vehicles, and debris clean-up) were in the inventory. The data on public vehicles were not received and not used in the analysis. The debris clean-up assets were created for residential and nonresidential assets. To derive the structure values, the 2020 RS Means Square Foot Costs Data catalog was used to assign a depreciated replacement cost to the residential and nonresidential structures and other assets in the study area. A total of 12,186 assets represents residential, nonresidential structures and auto assets among the 18,639 structures in the inventory. They are categorized in 33 occupancy types for analysis purpose. The following Table 2 displays these occupancy types and descriptions.

Table 2: Occupancy Types for Residential, Nonresidential and Auto assets

Occupancy Type	Description	Count
AUTO-R	Auto/Residential	5,733
COM1	Average Retail	89
COM2	Average Wholesale	32
COM3	Average Personal & Repair Services	51
COM4	Average Professional/Technical Services	132
COM5	Bank	13
COM6	Hospital	1
COM7	Average Medical Office	9
COM8	Average Entertainment/Recreation	102
COM9	Average Theatre	1
COM10	Garage	28
EDU1	Average School	7
EDU2	Average college/university	1
GOV1	Average Government Services	14
HRISE	Average Urban High-Rise, More Than 4 Floors	741
IND1	Average Heavy Industrial	66
IND2	Average Light Industrial	10
IND3	Average Food/Drugs/Chemicals	3
IND5	Average High Technology	3
IND6	Average Construction	16
REL1	Church	24
RES1-1SNB	Single Family Residential, 1 Story, No Basement	1,494
RES1-1SWB	Single Family Residential, 1 Story, With Basement	1,106
RES1-2SNB	Single Family Residential, 2 Story, No Basement	848
RES1-2SWB	Single Family Residential, 2 Story, With Basement	1,009
RES2	Mobile home	67
RES3A	Multi-Family housing 2 units	319
RES3B	Multi-Family housing 3-4 units	139
RES3C	Multi-Family housing 5-10 units	83
RES3D	Multi-Family housing 10-19 units	23
RES3E	Multi-Family housing 20-50 units	16
RES3F	Multi-Family housing 50 plus units	2
RES4	Average Hotel, & Motel	4
Total		12,186

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

Most of the non-residential structures in the area reflected the masonry on wood exterior wall construction with an approximate effective age of 30 years. The masonry on wood depreciation percentage of 35 percent was applied as the most likely condition to all non-residential structures. Furthermore, to account for uncertainty, a triangular distribution was used for deriving the maximum and minimum depreciated replacement costs using a depreciation percentage of 20 percent and 50 percent, respectively, reflecting effective ages of 20 and 40 years for masonry on steel frame and wood frame exteriors, respectively. Additionally, a commercial location cost factor of 105 percent of the national square foot costs for the City of Alexandria was then applied to the depreciated cost per square foot to derive the average depreciated replacement cost per square foot with respect to each building/asset category. Finally, the square footage for each individual structure, obtained from the tax assessor when available, or from the NSI 2 data, was multiplied by the average depreciated replacement cost per square foot for each structure's building/asset category.

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

The RS Means depreciation schedule for residential structures provides depreciation percentages for structures in good, average, or poor condition and with respect to the structures' effective age. Most residential structures in the area had an approximate effective age of 30 years. The average condition depreciation percentage of 30 percent was applied as the most likely condition to all residential structures regardless of construction class. Furthermore, to account for uncertainty, a triangular distribution was used for deriving the maximum and minimum depreciated replacement costs using a depreciation percentage of 15 percent and 55 percent, respectively, reflecting effective ages of 20 and 40 years for structures in good and poor condition, respectively. Additionally, a residential location cost factor of 93 percent of the national square foot costs for the City of Alexandria was then applied to the depreciated cost per square foot to derive the average depreciated replacement cost per square foot with respect to each building/asset category and its construction class. Finally, the square footage for each individual structure, obtained from the tax assessor when available, and when not available, from the NSI 2, was multiplied by the average depreciated replacement cost per square foot for each structure's building/asset category and construction class.

For a small number of structures, when square footage values were not available from either the tax assessor or NSI 2 data, to determine a square footage per building 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, extension of the ceiling from the living space, etc. The area was multiplied by the number of floors calculate the square footage. The structure's depreciated replacement cost was derived by multiplying the structure category's mean square footage by the category's calculated depreciated replacement cost per square foot. This method was applied to both residential and nonresidential structures.

In additional to 12,186 residential, nonresidential, and auto assets in the inventory, 6,453 debris clean-up synthetic assets were created for residential and nonresidential structures. Table 3 displays the occupancy types for debris clean-up. Section 2.2.6 expends on debris clean-up data.

Table 3: Occupancy Type of Debris Clean-up data

Occupancy Type	Description	Count
D-COM1	Average Retail	89
D-COM2	Average Wholesale	32
D-COM3	Average Personal & Repair Services	51
D-COM4	Average Professional/Technical Services	132
D-COM5	Bank	13
D-COM6	Hospital	1
D-COM7	Average Medical Office	9
D-COM8	Average Entertainment/Recreation	102
D-COM9	Average Theatre	1
D-COM10	Garage	28
D-EDU1	Average School	7
D-EDU2	Average college/university	1
D-GOV1	Average Government Services	14
D-HRISE	Average Urban High-Rise, More Than 4 Floors	741
D-IND1	Average Heavy Industrial	66
D-IND2	Average Light Industrial	10
D-IND3	Average Food/Drugs/Chemicals	3
D-IND5	Average High Technology	3
D-IND6	Average Construction	16
D-REL1	Church	24
D-RES1-1SNB	Single Family Residential, 1 Story, No Basement	1494
D-RES1-1SWB	Single Family Residential, 1 Story, With Basement	1,106
D-RES1-2SNB	Single Family Residential, 2 Story, No Basement	848
D-RES1-2SWB	Single Family Residential, 2 Story, With Basement	1009
D-RES2	Mobile home	67
D-RES3A	Multi-Family housing 2 units	319
D-RES3B	Multi-Family housing 3-4 units	139
D-RES3C	Multi-Family housing 5-10 units	83
D-RES3D	Multi-Family housing 10-19 units	23
D-RES3E	Multi-Family housing 20-50 units	16
D-RES3F	Multi-Family housing 50 plus units	2
D-RES4	Average Hotel, & Motel	4
Total		6453

3.2.5 Content-to-Structure Value Ratios

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

3.2.6 Emergency Costs - Debris Clean-Up Cost

In addition to the costs from the physical impacts on the structures in a study area, the following emergency costs occur in a flooded community.

- Actions taken by police, fire, and the other organizations to warn and evacuate floodplain occupants, direct traffic, and maintain law and order just before and during an event,
- Flood fighting efforts, such as sandbagging and building closures, taken to reduce damage,
- Costs of efforts, such as debris removal, establishing emergency shelters, and the provision of money, food, and clothing, to relieve the financial situation experienced by flood victims during and after an event,
- Evacuation costs for floodplain residents, and
- The administrative costs for public agencies and private relief agencies in delivering emergency services.

Debris clean-up costs are evaluated and included in the Northern Virginia coastal storm study. The cost of debris removal can vary according to the residential or nonresidential occupancy type of the structure. The content-related debris includes white goods (refrigerators, stoves, dishwashers, etc.), electronics, and hazardous waste (paints, oil, household chemicals, poisons, etc.). Interviews were conducted with experts in the fields of debris collection, processing, and disposal following Hurricanes Katrina and Rita. The experts were asked to provide a minimum, most likely, and maximum estimate for the cleanup costs associated with the 2 feet, 5 feet, and 12 feet depths of flooding. A prototypical structure size in square feet was used for the residential occupancy categories and for the nonresidential occupancy categories. The experts were asked to estimate the percentage of the total cleanup caused by floodwater and to exclude any cleanup that was required by high winds. To account for the cost/damage surrounding debris cleanup, values for debris removal were incorporated into the structure inventory for each record according to its occupancy type. These values were then assigned a corresponding depth-damage function with uncertainty in the economic models. All values and depth-damage functions were selected according to the short-duration flooding data specified in a report titled “Development of Depth-Emergency Cost and Infrastructure Damage Relationships for Selected South Louisiana Parishes.” The debris clean-up values provided in the report were expressed in 2010 price levels for the New Orleans area. These values were converted to FY 2022 price levels for the Northern Virginia study area using the index location of the City of Alexandria, provided by Gordian's 40th edition of "Square Foot Costs with RSMeans Data." The location factor for residential structures is 0.93 and for non-residential structures is 1.05. The debris removal costs were included in the structure records for the individual residential and nonresidential structures and used to calculate the expected annual without-project and with-project debris removal and cleanup costs.

The following maximum clean-up costs are assumed in G2CRM for each occupancy type.

Table 4: Debris Clean-Up Maximum Cost for Residential and Nonresidential assets

Occupancy Type	New Orleans Study Prototype	Max Debris Clean-Up Cost ($FY2022)
D-COM1	Average Retail	43,145
D-COM2	Average wholesale	44,147
D-COM3	Average Personal & Repair Services	42,452
D-COM4	Average Prof/Tech Services	42,452
D-COM5	Bank	42,452
D-COM6	Hospital	42,452
D-COM7	Average Medical Office	42,452
D-COM8	Average Entertainment/Recreation	42,452
D-COM9	Average Theatre	43,417
D-COM10	Garage	42,452
D-EDU1	Average school	43,417
D-EDU2	Average college/university	43,417
D-GOV1	Average government services	43,417
D-HRISE	High-rise structure, 4 stories and above	43,417
D-IND1	Average heavy industrial	43,417
D-IND2	Average light industrial	53,139
D-IND3	Average Food/Drug/Chem	53,139
D-IND5	Average High Technology	53,139
D-IND6	Average Construction	53,139
D-REL1	Church	43,417
D-RES1-1SNB	Res 1, 1 Story no Basement	7,241
D-RES1-1SWB	Res 1, 1 Story w/ Basement	7,241
D-RES1-2SNB	Res 1, 2 Story no Basement	7,241
D-RES1-2SWB	Res 1, 2 Story w/ Basement	7,241
D-RES2	Mobile home	6,994
D-RES3A	Multi-Family housing 2 units	10,777

Occupancy Type	New Orleans Study Prototype	Max Debris Clean-Up Cost ($FY2022)
D-RES3B	Multi-Family housing 3-4 units	10,777
D-RES3C	Multi-Family housing 5-10 units	10,777
D-RES3D	Multi-Family housing 10-19 units	10,777
D-RES3E	Multi-Family housing 20-50 units	10,777
D-RES3F	Multi-Family housing 50 plus units	10,777
D-RES4	Average Hotel, & Motel	42,560

3.2.7 Depth-Damage Relationship

Site-specific depth-damage functions (DDF) were not available for the study area for both nonresidential and residential structures. A triangular probability distribution was used to represent the uncertainty surrounding the DDF. 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. These values can be found in NACCS report, Tables 12 through 104 for structures and content. The residential DDFs used a combination of both the aforementioned Expert Elicitation Draft Report and EGM 01-03 and 04-01. Moreover, both EGM contained a normal distribution function with an associated standard deviation of damage to account for uncertainty surrounding the damage percentage associated with each depth of flooding. This distribution was then converted into a triangular distribution for input into the model.

3.2.8 First Floor Elevation

A topographic raster mosaic was generated using 2014 LIDAR data and various bathymetry sources in ArcGIS Pro during the study initiation. The structure inventory is converted into vertices using the Feature Vertices to Points tool. The resulting points, including all adjacent points to a structure, are then assigned ground elevations by interpolating elevations using the Interpolate Shape tool. Elevations are added as fields using the Add XY tool. The statistical minimum, mean, and maximum ground elevation adjacent to the structure are generated using the Summary Statistics tool and are used as a triangle distribution in G2CRM. These are added to the attribute table using the Join tool. From Foundation Height Certificates, the foundation height of each structure was added to the ground elevation to come out with probable first floor elevations. There are two sources of uncertainty surrounding the first floor elevations: the use of the LiDAR data for the ground elevations, and the methodology used to determine the structure foundation heights above ground elevations. The error of plus and minus 0.5 from Lidar data and Foundation Height Certificates were used as uncertainties to develop a triangular distribution for the first floor elevation.

3.2.9 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 the Northern Virginia study area. The study area is comprised of individual sub-areas of different types, defined as model areas, which may interact hydraulically and may be defended by coastal defense elements, such as protective system elements, that serve to shield the areas and the assets they contain from storm damage. The model used the uncertainty surrounding the storm information to account for uncertainty surrounding the elevation of the storm surges for the study area. The Engineering Appendix contains more information regarding engineering inputs into G2CRM.

3.1.1.1 Storms

The number of storms selected was driven by schedule and budget constraints, and by knowledge gathered from other previous and ongoing USACE feasibility studies about the minimum number of storms required to adequately capture the storm surge hazard. The data applied to the DC Coastal study were developed from the NACCS. NACCS produced storm tracks that cover the probability space of potential storms. These tracks allow for selection of relevant storms for study sites. The study applied any storm with a track within a 200 km radius circle of the project site. 58 tropical storms were selected. The goal of storm selection was to find the optimal combination of storms given a predetermined number of storms to be sampled, referred to as reduced storm set. In the process of selecting the number for the study area, it was determined that a reduced storm set of this size adequately captured the storm surge hazard for the range of probabilities covered by the full storm set.

The storm selection process was performed using the design of experiments (DoE). The DoE compares still water level, hazard curves derived from the reduced storm set to “benchmark” hazard curves corresponding to the full storm set at a given number of save points within the study area. The difference between the reduced storm set hazard curves and full storm set benchmark curves is minimized in an iterative process considering multiple subsets of 58 tropical storms. In summary, the general steps in this DoE approach for selecting a subset of storms are:

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

For the Northern Virginia study in G2CRM, the bootstrap method was used to determine storm events for the period of analysis. Each G2CRM simulation run starts using the above-mentioned reduced storm set which determines the storms that are drawn randomly by bootstrapping. The bootstrap approach is based on choosing the random storms as a Poisson distribution based on average number of storms in the season (as an input) for the study area. The bootstrapping approach also considers the relative probability of each storm (i.e., higher probability storms are chosen more often), which is technically bootstrap sampling with replacement. Each of the 58 tropical storms for the study area has an associated storm probability and storm surge information (e.g., water levels) at each save points.

3.1.1.2 Save Points

The numerical modeling aspect of the study area is to provide estimates of waves and water levels for existing conditions, future without project conditions, and future with project conditions. A save point is a point of interest in the study area. From 28 save points modeled in the study area, the save point 5984 was selected in the middle of the channel between the Reagan National Airport and the Bolling Air Force Base since the other save points have approximately the same water level within a 200 km radius circle of the project site. This save point contained the water elevations and wave heights for each of the storm to be used in the model and eventually used to represent 18 model areas. The combination of the flood barrier and the bulkheads model areas will be discussed later. These water elevations will be applied to the model areas along with economic inputs to derive flood damages in the existing conditions, future without project conditions, and future with project conditions for the Northern Virginia study area.

4. EXISTING CONDITION

4.1 ASSETS

A total of 6419 residential and nonresidential structures were included in the inventory and used to develop the economic results presented on AMM. The following Table 5 presents the summary of these assets.

Table 5: Residential and Commercial Assets used in AMM

Jurisdiction	Assets Count
Arlington County	233
City of Alexandria	2,932
Fairfax County	2,624
Prince William County	630
Total	6419

Privately owned vehicles in the study area, assets at the Arlington Water Pollution Control Plant, and infrastructure at the Reagan Washington National Airport, and debris clean-up synthetic assets were added to the inventory after the AMM. The infrastructure at the Reagan National airport includes buildings and three Engineered Material Arresting Systems (EMAS). The space available at three large parking lots at the Reagan National Airport were used to evaluate the number private vehicles that may be impacted.

A total of 18,639 structures including residential, nonresidential, privately owned vehicles, and debris clean-up assets were used to develop this economic appendix.

4.1.1 Vehicle Inventory and Valuation

Vehicle valuation is based on data from the 2021 Edmunds Used Vehicle Outlook. Five years of used vehicle values are evaluated. The vehicle types selected are sedan, coupe, SUV, truck, and large vehicle. These classes are assumed to be distributed as shown in Table 6 to arrive at a weighted-average vehicle value of $27,977.

Table 6: Average Vehicle Value in the Northern Virginia study area

Vehicle Type	Percentage in Study Area	Average Cost	Weighted Cost
Sedan	40%	$23,998	$9,599
Coupe	10%	$19,988	$1,999
SUV	20%	$29,399	$5,880
Truck	20%	$32,497	$6,499
Large Vehicle	10%	$40,000	$4,000
		Weighted Average Cost:	$27,977

Note: Average vehicle cost calculated from the 2021 Edmunds Used Vehicle Outlook. data

Household vehicles included in the structure inventory are private vehicles. Using data from Table 5, "*Percentage of Respondents Moving at Least One Vehicle to Higher Ground*" from the Corps' EGM-09-04 report published in 2009, it is assumed that approximately 49.5, 19.4, and 11.9 percent of privately owned vehicles are not evacuated to higher grounds during storm events given warning time of less than 6 hours, 6 to 12 hours, and greater than 12 hours respectively. The triangular vehicle values used in the inventory are presented in Table 7.

Table 7: Private Vehicles Valuation

	Residential Vehicle Valuation		
	Minimum	**Most Likely**	**Maximum**
Weighted Average Cost	$27,977	$27,977	$27,977
Vehicle per Household (Conservative)	1	1	1
Respondents who did not move vehicles	11.90%	19.40%	49.50%
Vehicle Value per Household	$3,329	$5,428	$13,849

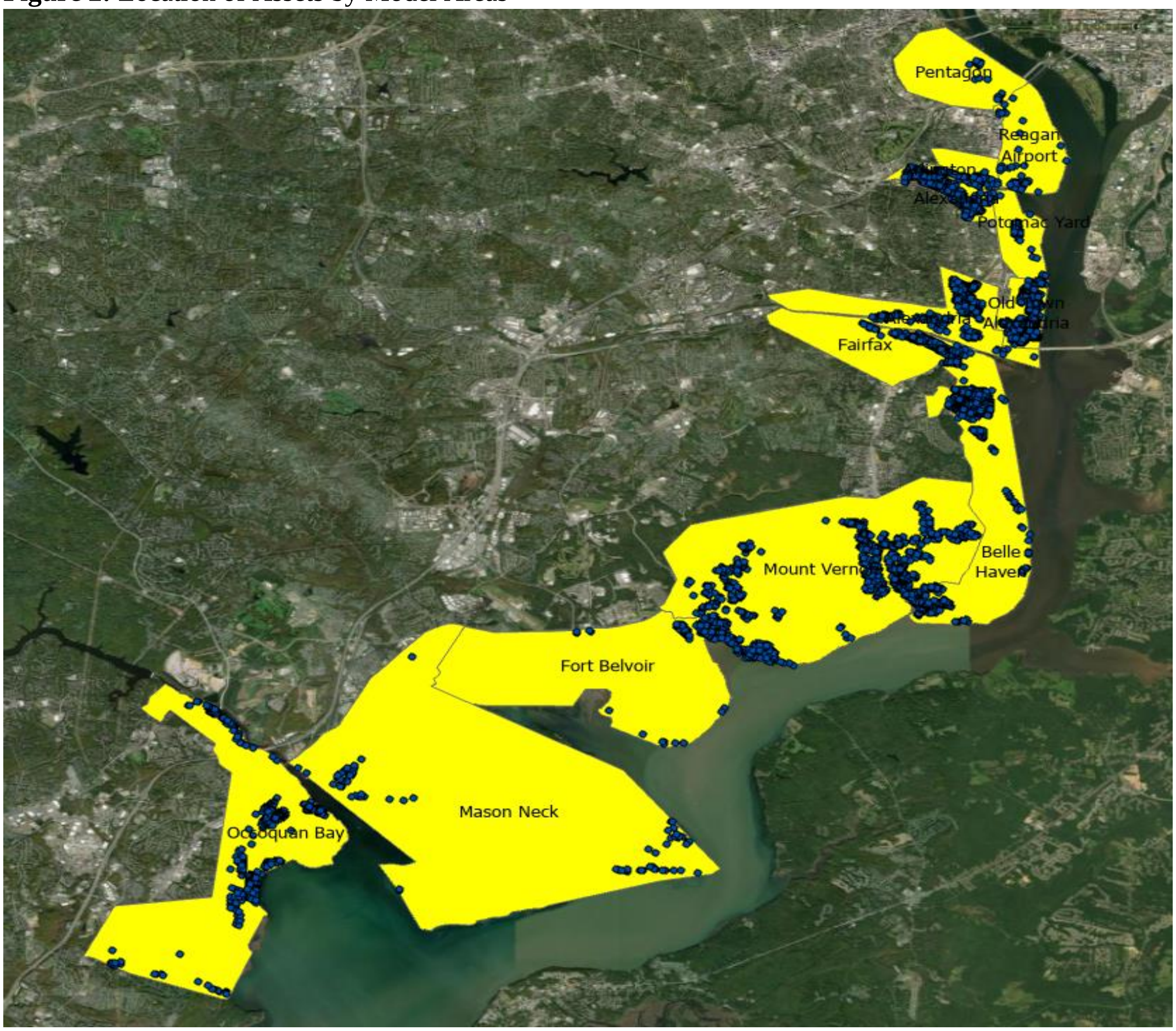
The three evacuation scenarios remaining rates resulted in the values of $3,329, $5,428, and $13,849 which were used as the triangular distribution parameters of the structure value.

In additional to the residential vehicles, three large Reagan National Airport parking lots were used to compute vehicle valuation. A conservative assumption was made that 10 percent of the vehicles are private vehicles already computed from within the study area and are removed from the airport vehicles count.

Vehicle depth-damage relationships were taken from Economic Guidance Memorandum (EGM), 09-04., Generic Depth-Damage Relationships for Vehicles.

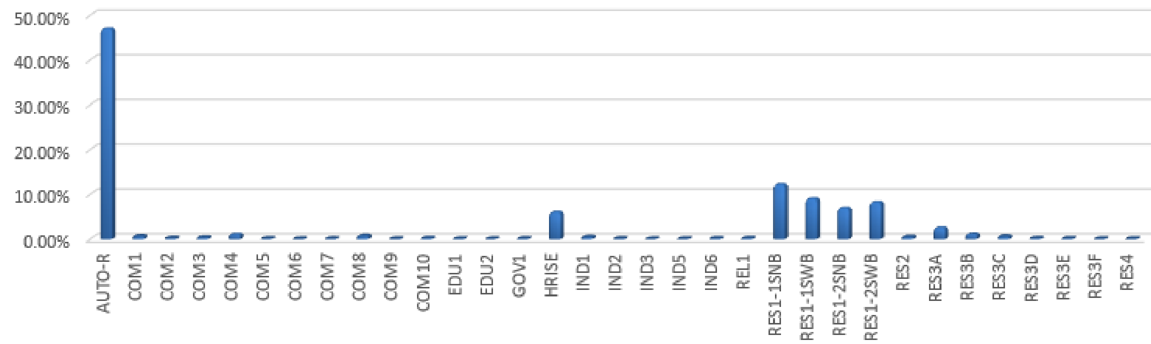
Vehicles are entered into the G2CRM model inventory in the same manner as structures. This means they are given a dollar value as discussed previously in this section and utilize vehicle depth-damage functions from data compiled by the USACE New Orleans District (USACE 2006). Vehicle ground elevations are the same as the ground elevation of the structure to which they belong. An arbitrary slab foundation type is assigned to the vehicle to determine the beginning damage elevations.

Figure 2: Location of Assets by Model Areas



The Northern Virginia study area structure inventory, as modeled, contains 18,639 structures (Figure 2). Out of residential and nonresidential structures, the occupancy types most found were single Family Residential, High Rise, and Residential Vehicles. Below Figure 3 shows the proportion of each occupancy type in the Northern Virginia area.

Figure 3: Proportion of each Occupancy Types in the Northern Virginia study area



4.1.2 Residential and Non-residential Content-to-Structure Value Ratios

Content to structure value ratios (CSVRs) used in this feasibility study were obtained from North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk, Physical Depth Damage Function Summary Report (NACCS 2015) and the Non-residential Flood Depth-Damage Functions Derived from Expert Elicitation Draft Report, revised 2013 (IWR 2013). As shown in Table 8, 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.

Table 8: Content-to-Structure Value Ratios (CSVRs)

Category	Occupancy Type	Occupancy Description	Min	Most Likely CSVR %	Max	Source
Commercial	COM1	Retail	37%	45%	53%	2013 Prototype 12
	COM2	Wholesale	31%	37%	43%	NACCS, Prototype 2
	COM3	Personal & Repair Services	56%	66%	74%	2013 Prototype 13
	COM4	Prof/Tech Services	14%	18%	24%	NACCS, Prototype 2
	COM5	Bank	14%	18%	24%	2013 Prototype 7
	COM6	Hospital	35%	44%	50%	2013 Prototype 6
	COM7	Medical Office	53%	60%	66%	2013 Prototype 5
	COM8	Entertainment/Recreation	20%	25%	31%	2013 Prototype 19
	COM9	Theatre	14%	18%	24%	NACCS, Prototype 2
	COM10	Garage	31%	37%	44%	NACCS, Prototype 3
	HRISE	Urban High-Rise	14%	18%	24%	NACCS, Prototype 4A
Public	EDU1	school	5%	7%	9%	2013 Prototype 21
	EDU2	College/University	5%	7%	9%	2013 Prototype 21
	GOV1	Government Services	14%	18%	24%	NACCS, Prototype 2
	GOV2	Emergency response	60%	70%	75%	2013 Prototype 18
	REL1	Church	5%	7%	11%	2013 Prototype 20
Industrial	IND1	Heavy industrial	32%	38%	44%	2013 Prototype 14
	IND2	Light industrial	32%	38%	44%	2013 Prototype 14
	IND3	Food/Drug/Chem	14%	18%	24%	NACCS, Prototype 2
	IND5	High Technology	14%	18%	24%	NACCS, Prototype 2
	IND6	Construction	32%	38%	44%	2013 Prototype 14
Residential	RES1-1SNB	Res 1, 1 Story no Basement	25%	50%	75%	NACCS, Prototype 5A
	RES1-1SWB	Res 1, 1 Story w/ Basement	25%	50%	75%	NACCS, Prototype 5A
	RES1-2SNB	Res 1, 2 Story no Basement	25%	50%	75%	NACCS, Prototype 5B
	RES1-2SWB	Res 1, 2 Story w/ Basement	25%	50%	75%	NACCS, Prototype 5B
	RES2	Mobile home	68%	142%	209%	M&S Res Valuation Sce
	RES3A	Multi-Family housing 2 units	8%	10%	14%	NACCS, Prototype 1A-1
	RES3B	Multi-Family housing 3-4 units	8%	10%	14%	NACCS, Prototype 1A-3
	RES3C	Multi-Family housing 5-10 units	8%	10%	14%	NACCS, Prototype 1A-3
	RES3D	Multi-Family housing 10-19 units	8%	10%	14%	NACCS, Prototype 1A-3
	RES3E	Multi-Family housing 20-50 units	8%	10%	14%	NACCS, Prototype 1A-3
	RES3F	Multi-Family housing 50 plus units	8%	10%	14%	NACCS, Prototype 1A-3
	RES4	Average Hotel, & Motel	20%	26%	33%	2013 Prototype 4

(1) 2013 – Nonresidential Flood Depth-Damage Functions Derived from Expert Elicitation, Revised 2013
(2) NACCS – NACCS Physical Depth Damage Functions Summary Report

4.1.3 Summary of the inventory

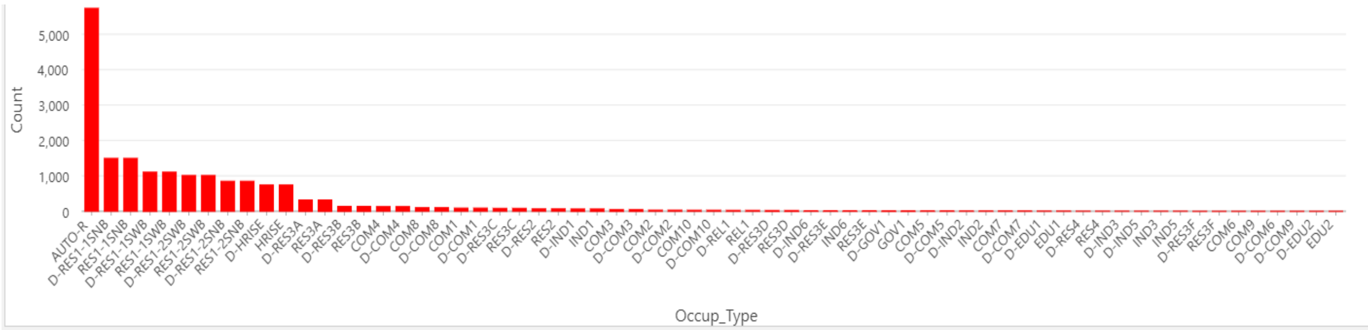
The assets were categorized as residential or nonresidential which were further categorized into occupancy types (reference Table 2 in Structure Inventory section). Table 9 below displays the count and structure value by the occupancy types.

Table 9: Structure Inventory by Occupancy Types

Occupancy Type	Description	Count	Structure Value	Content Value
AUTO-R	Auto/Residential	5,733	$110,202,000	$0
COM1	Average Retail	89	$127,319,000	$44,036,000
COM2	Average Wholesale	32	$103,947,000	$29,479,000
COM3	Average Personal & Repair Services	51	$82,889,000	$43,215,000
COM4	Average Professional/Technical Services	132	$221,310,000	$39,443,000
COM5	Bank	13	$16,393,000	$2,376,000
COM6	Hospital	1	$1,467,000	$732,000
COM7	Average Medical Office	9	$21,194,000	$12,787,000
COM8	Average Entertainment/Recreation	102	$255,665,000	$35,617,000
COM9	Average Theatre	1	$16,214,000	$4,021,000
COM10	Garage	28	$25,897,000	$6,548,000
EDU1	Average School	7	$31,239,000	$6,769,000
EDU2	Average college/university	1	$3,091,000	$311,000
GOV1	Average Government Services	14	$87,477,000	$4,229,000
HRISE	Average Urban High-Rise, More Than 4 Floors	741	$3,096,378,000	$1,807,624,000
IND1	Average Heavy Industrial	66	$1,485,563,000	$3,331,000
IND2	Average Light Industrial	10	$7,073,000	$2,162,000
IND3	Average Food/Drugs/Chemicals	3	$507,000	$49,000
IND5	Average High Technology	3	$15,060,000	$0
IND6	Average Construction	16	$31,544,000	$9,139,000
REL1	Church	24	$43,431,000	$2,841,000
RES1-1SNB	Single Family Residential, 1 Story, No Basement	1,494	$348,670,000	$146,919,000
RES1-1SWB	Single Family Residential, 1 Story, With Basement	1,106	$285,803,000	$134,078,000
RES1-2SNB	Single Family Residential, 2 Story, No Basement	848	$233,300,000	$100,644,000
RES1-2SWB	Single Family Residential, 2 Story, With Basement	1,009	$241,645,000	$115,367,000
RES2	Mobile home	67	$2,590,000	$969,000
RES3A	Multi-Family housing 2 units	319	$71,586,000	$33,341,000
RES3B	Multi-Family housing 3-4 units	139	$37,151,000	$18,369,000
RES3C	Multi-Family housing 5-10 units	83	$34,106,000	$15,752,000
RES3D	Multi-Family housing 10-19 units	23	$40,673,000	$16,178,000
RES3E	Multi-Family housing 20-50 units	16	$38,309,000	$16,506,000
RES3F	Multi-Family housing 50 plus units	2	$11,755,000	$5,877,000
RES4	Average Hotel, & Motel	4	$31,330,000	$8,146,000
Total		12,186	7,160,778,000	2,666,855,000

The sum of debris clean-up occupancies is 6453 with a dollar amount of $97,503,000 in the inventory.

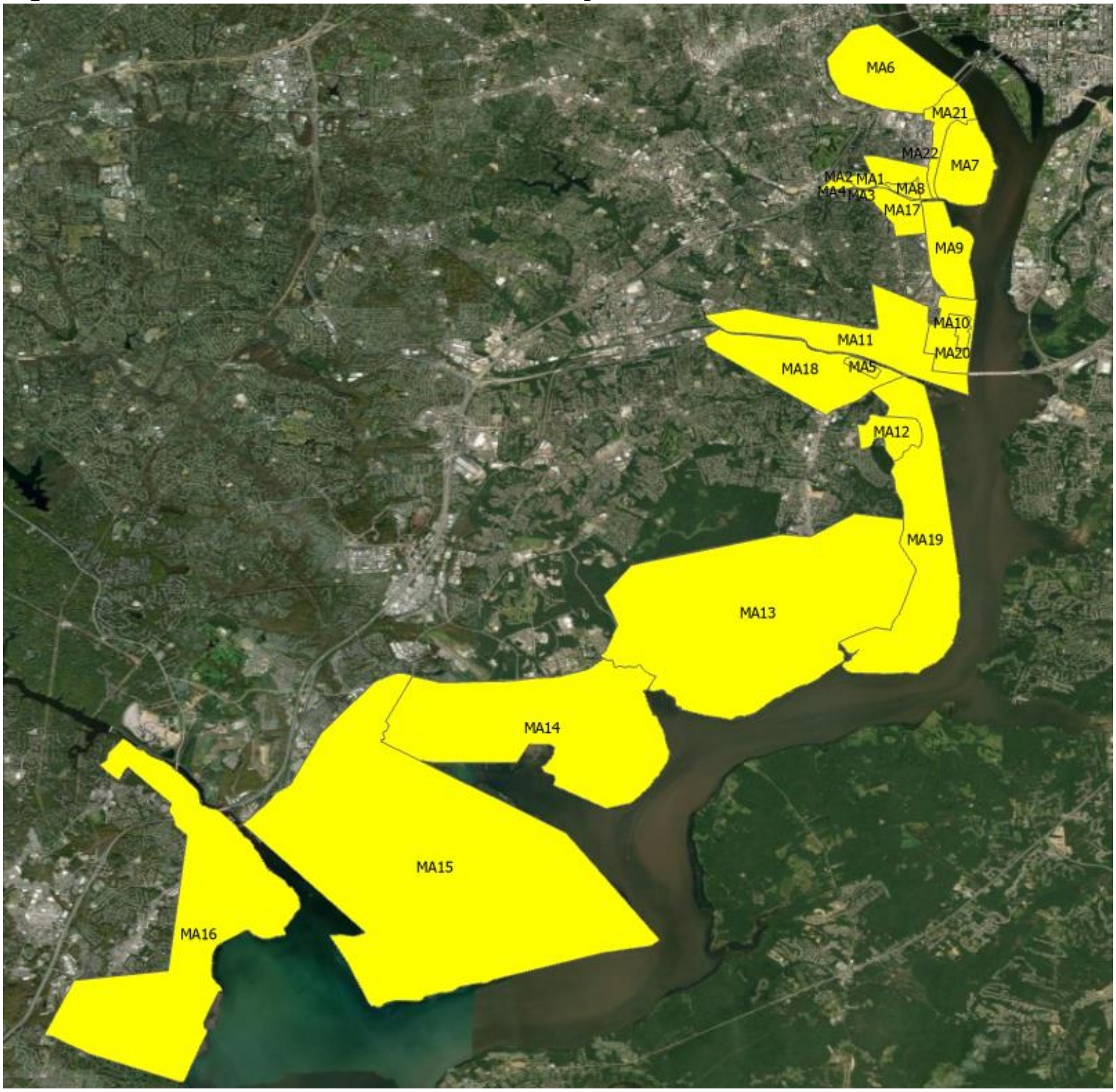
Figure 4 presents a summary count of all structures in the inventory.



4.2 MODEL AREAS

Model areas are established to represent the various geographic parts of the study area that have uniform flood elevations. 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 accounting for natural or built topological features (e.g., a ridge, highway, or railway line). Dividing the study area into model areas facilitates evaluation of flood damages by breaking the study area down into several areas having some common features. Analyzing them separately also speeds up the economic modeling process. The study area consists of 22 model areas. The 22 model areas are MA1: Four Mile Run Arlington East - Protected, MA2: Four Mile Run Arlington West - Protected, MA3: Four Mile Run Alexandria East - Protected, MA4: Four Mile Run Alexandria West - Protected, MA5: Cameron Run Protected Huntington Levee, MA6: Pentagon Unprotected, MA7: Reagan National Airport - Proposed Bulkhead, MA8: Four Mile Run Arlington - Proposed Bulkhead, MA9: Potomac Yard Unprotected, MA10: Old Town Alexandria - Proposed Bulkhead, MA11: Cameron Run Alexandria - Unprotected, MA12: Belle Haven - Proposed Bulkhead, MA13: Mount Vernon - Unprotected, MA14: Fort Belvoir - Unprotected, MA15: Mason Neck - Unprotected, MA16: Occoquan Bay - Unprotected, MA17: Four Mile Run Alexandria - Proposed Bulkhead, MA18: Cameron Run Fairfax - Unprotected, MA19: Fort Hunt - Unprotected, MA20: Old Town Alexandria - Unprotected, MA21: Reagan National Airport - Unprotected, MA22: Four Mile Run Arlington - Unprotected. These model areas are spatial areas defined by geospatial polylines as shown in Figure 5.

Figure 5: Model Area Boundaries and their Description



There are two types of model areas: unprotected MAs and upland MAs. 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 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, as mediated by a protective system element such as a bulkhead/seawall or flood barrier that must be overtopped before water appears in the MA. It also has an associated volume-stage relationship to account for filling behind the bulkhead/seawall or flood barrier during the initial stages of overtopping.

Moreover, it is important to note that some MAs have been protected by PSE that exists in the Northern Virginia study area. Therefore, having each MA be a component of an upland MA in the existing and future without project condition was a modeling strategy utilized in order to model the future with project condition. The Northern Virginia CSRM project team designed PSEs to protect MAs 7, 8, 10, 12, and 17. There are existing PSEs in the MAs 1, 2, 3, 4, and 5. A 6-feet wall is currently in construction in MA10, Old Town Alexandria. Table 10 shows the type of model area in the future with project conditions.

Table 10: Model Area Types

MA	MA Description and Type	MA Type for Modeling
MA1	Four Mile Run Arlington East - Protected	Upland
MA2	Four Mile Run Arlington West - Protected	Upland
MA3	Four Mile Run Alexandria East - Protected	Upland
MA4	Four Mile Run Alexandria West - Protected	Upland
MA5	Cameron Run Huntington Levee - Protected	Upland
MA6	Pentagon - Unprotected	Upland
MA7	Reagan National Airport – Proposed Bulkhead	Upland
MA8	Four Mile Run Arlington – Proposed Bulkhead	Upland
MA9	Potomac Yard - Unprotected	Upland
MA10	Old Town Alexandria – Proposed	Upland
MA11	Cameron Run Alexandria - Unprotected	Upland
MA12	Belle Haven – Protected – Proposed Bulkhead	Upland
MA13	Mount Vernon - Unprotected	Upland
MA14	Fort Belvoir - Unprotected	Upland
MA15	Mason Neck - Unprotected	Upland
MA16	Occoquan Bay - Unprotected	Upland
MA17	Four Mile Run Alexandria – Proposed Bulkhead	Upland
MA18	Cameron Fairfax Unprotected	Upland
MA19	Fort Hunt - Unprotected	Upland
MA20	Old Town Alexandria - Unprotected	Upland
MA21	Reagan National Airport - Unprotected	Upland
MA22	Four Mile Run Arlington - Unprotected	Upland

4.3 PROTECTIVE SYSTEM ELEMENTS

Flood hazard manifested at the storm location is mediated by the Protective System Element (PSE) such as bulkhead/seawall or flood barrier. The PSE prevents transmission of the flood hazard into the MA until the flood hazard exceeds the top elevation of the bulkhead/seawall or flood barrier.

When the flood hazard exceeds the bulkhead/seawall or flood barrier top elevation the flood hazard is instantaneously transmitted into the MA unmediated by the bulkhead/seawall or flood barrier.

PSEs are defined in G2CRM to capture the effect of built flood risk management (FRM) infrastructure (i.e., what in G2CRM is categorized as a bulkhead/seawall or a flood barrier). Figures 6 and 7 show the protected MAs with bulkhead for the future with project conditions in the study area.

Figure 6: Unprotected and Protected MAs with Bulkheads

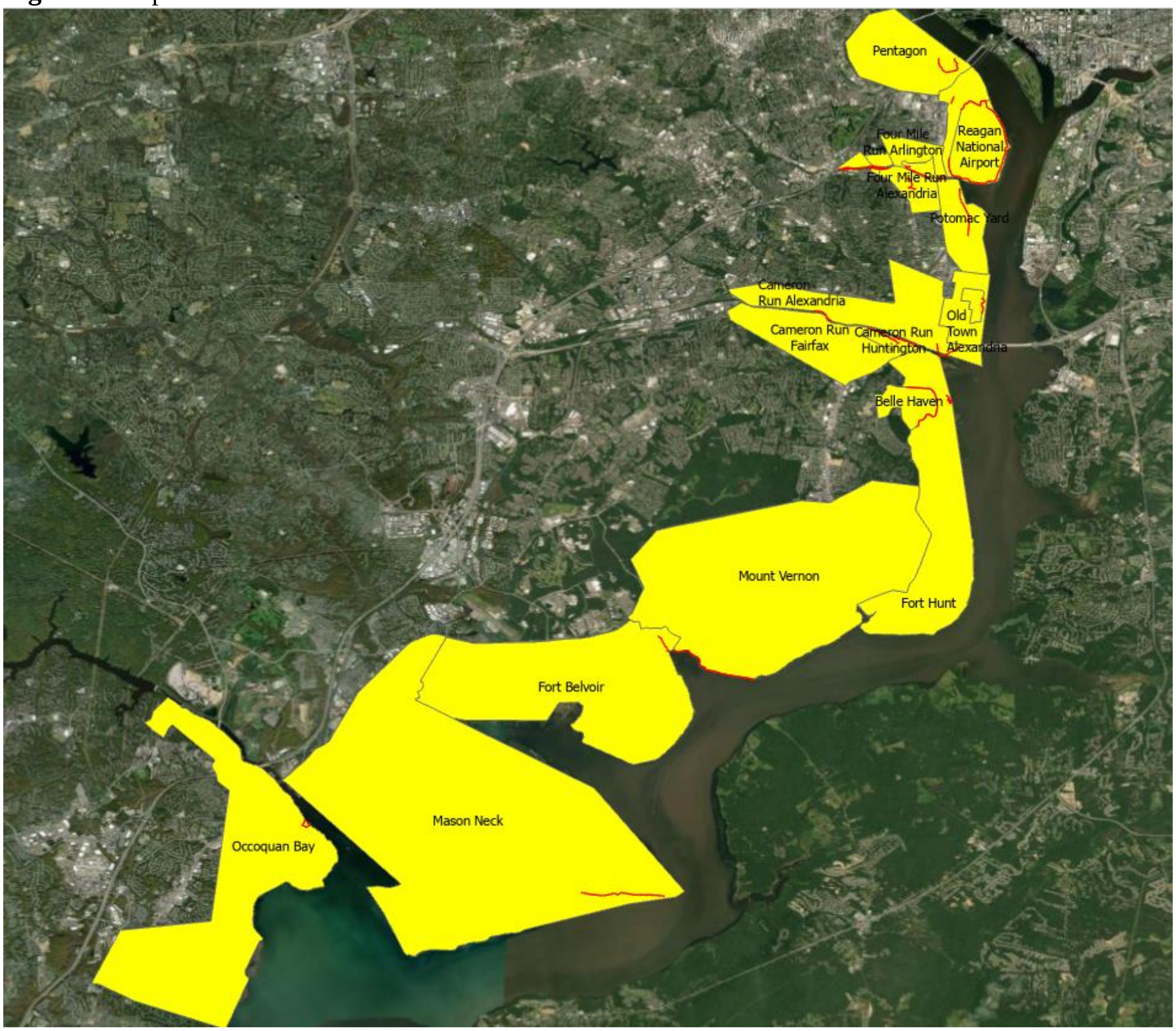
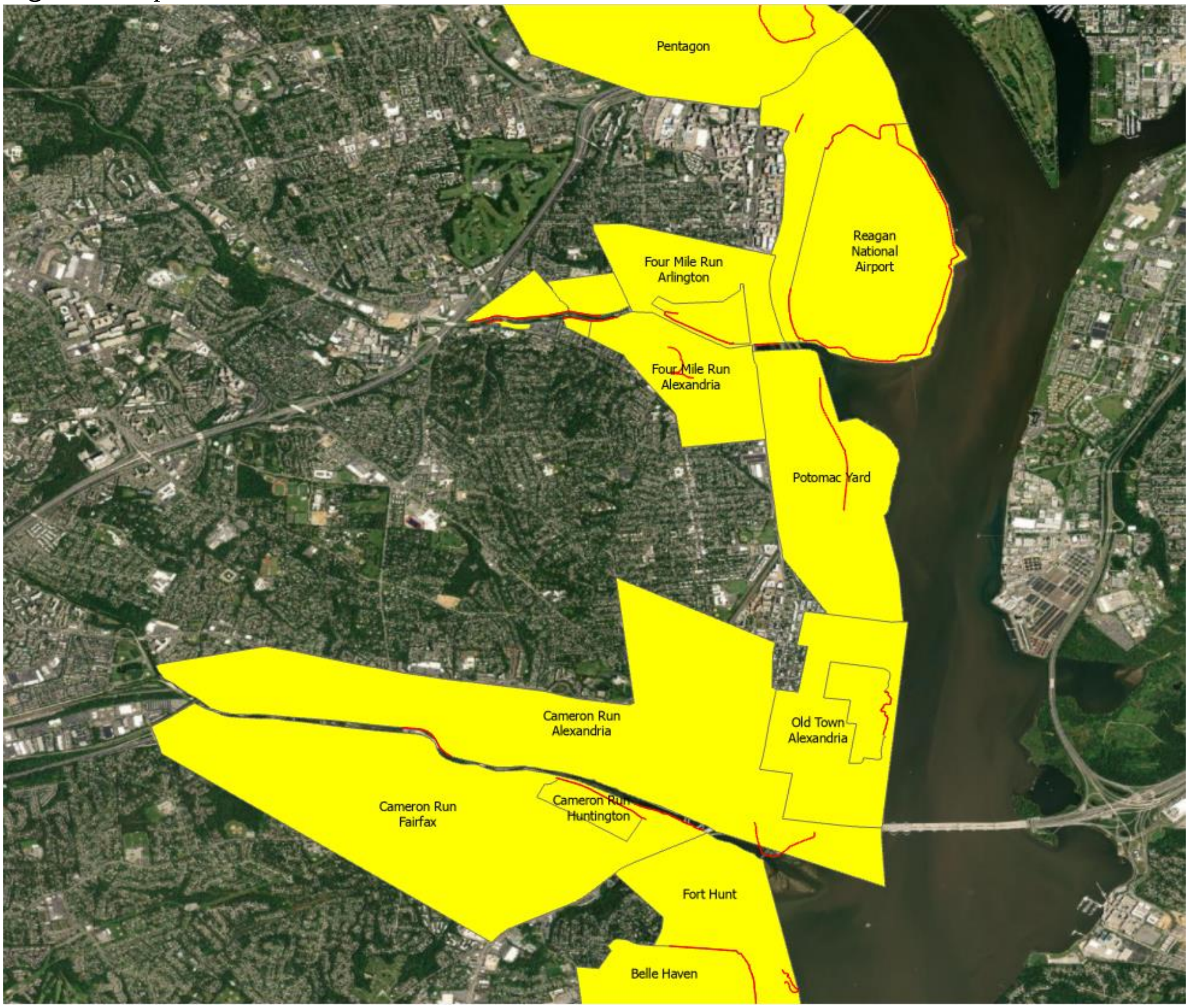


Figure 7: Unprotected and Protected MAs with Bulkheads – Partial view



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

Among 23 save points located in the study area, save points 5978, 14608, and 14731 were used to define the top of protective system elements. The maximum water level has been presented in Table 11 for selected save points:

Table 11: Maximum Water Level in Save Points 5984, 14608, and 14731

NACCS ID/ Virtual ID	1-year	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year	1000-year	2000-year	5000-year	10000-year
5984 /3	4.03	5.17	6.99	8.11	9.01	10.0	10.74	11.70	13.19	13.81	14.35	14.96	15.36
14608/ 7	3.92	4.89	6.45	7.46	8.31	9.28	10.03	11.11	12.50	13.14	13.72	14.28	14.67
14731/ 9	3.80	4.59	5.86	6.74	7.52	8.56	9.64	10.78	12.05	12.65	13.20	13.79	14.19

Based on the above WSEL for these NACCS IDs, levels of protection were displayed in Table 12 for structural measures.

Table 12: Top of Protection for Levels/Floodwalls

Project Area	NACCS ID/ Virtual ID	Top of Protection for Levees/Floodwalls ft NAVD88
Reagan National Airport	5984/3	14.3
Arlington WPCP	5984/3	14.3
Old Town Alexandria	14608/7	13.2
Four Mile Run	5984/3	13.9
Belle Haven	14731/9	13.0

Old Town Alexandria, Four Mile Run and Belle Haven have been received 1 percent of risk reduction with 3 feet of confidence levels while the critical infrastructures at Reagan National Airport and Arlington WPCP have been received 0.2 percent of risk reduction with 1 foot of confidence levels for structural measures.

With nonstructural elevation, to receive 1 percent of risk reduction the structures in Old Town Alexandria should be elevated to 11.2 feet and 11.0 feet in Belle Haven and Occoquan (100 Year flood in 2080 + 1 foot of confidence levels). Since Old Town Alexandria is historical district, structures in the district have been floodproofed. Using National Nonstructural Committee best practices, water has been stopped at 3 feet above ground with floodproofing measures.

4.4 VOLUME-STAGE FUNCTIONS

Volume-stage functions also called stage-volume functions are associated with an upland MA. For the study area, the volume-stage functions were derived from the digital terrain model (the same used to determine ground elevation of structures) provided by engineering team members and GIS sections and describe the relationship between the volume contained in the model area and the associated stage (water depths) for each MA. Stage-volume functions have been developed for each of twenty-two MAs. Water level within the MAs is computed by first estimating the volume of water passing over the PSEs and then using the stage-volume relationship to determine water level within the MAs. Once the storage area in the MAs is filled, the flood hazard is transmitted into the MAs unmediated by the bulkhead/seawall or the flood barrier.

4.5 EVACUATION PLANNING ZONES

Communities in the Northern Virginia area are vulnerable to flooding. In addition to approximately 2 million people living in the four jurisdictions, thousands of people working in the Washington DC Metropolitan area commute in the study area on a daily basis. During storm surge events, the ability of first responders to reach the location of need and the ability of individuals to reach medical facilities can be limited or cut off entirely.

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

An evacuation planning zone (EPZ) is a spatial area, defined by a polygonal boundary that is used within loss of life calculations in G2CRM to determine the population remaining in structures during a storm (i.e., population that did not evacuate). Therefore, in G2CRM, each Asset is assigned to an MA which is assigned to an EPZ and then modeled in G2RM for potential life loss given a storm event.

In G2CRM, life loss calculations are performed on a per-structure per-storm basis. In order for life loss calculations to be made, the maximum stage in the modeled area has to be greater than the foundation height plus the ground height.

Loss of life calculations are separated out by age categorization with under 65 being one category and 65 and older being the second category. They are also categorized during daytime and nighttime. There are three possible lethality functions for structure residents: safe, compromised, and chance. Safe would have the lowest expected life loss, although safe does not imply that there is no life loss, and chance would have the highest expected life loss. G2CRM model was used to compute loss of life since the Northern Virginia study area does not present substantial life threatening from flooding.

4.6 EXISTING CONDITION MODELING RESULTS

The assets assigned to each MA and EPZ were modeled in G2CRM using the 58 tropical storms with its relative probability-water level relationship. G2CRM used the economic (e.g., Assets) and engineering inputs (e.g., Storms) to generate expected present value (PV) damages for each structure throughout the life cycle (i.e., the period of analysis). The possible occurrences of each economic (i.e., triangular distribution) and engineering (i.e., relative probabilities) variables were derived through the use of Monte Carlo simulation and a total of 100 iterations were executed by the model for this analysis. That is every iteration represents expected PV damages for the period of analysis and cumulative damages of assets converged at about 100 iterations.

The sum of all damages for each life cycle were divided by the number of iterations to yield the expected PV damages for that modeled simulation. A mean and standard deviation were automatically calculated for the PV damages for each MA.

5. FUTURE WITHOUT PROJECT CONDITION

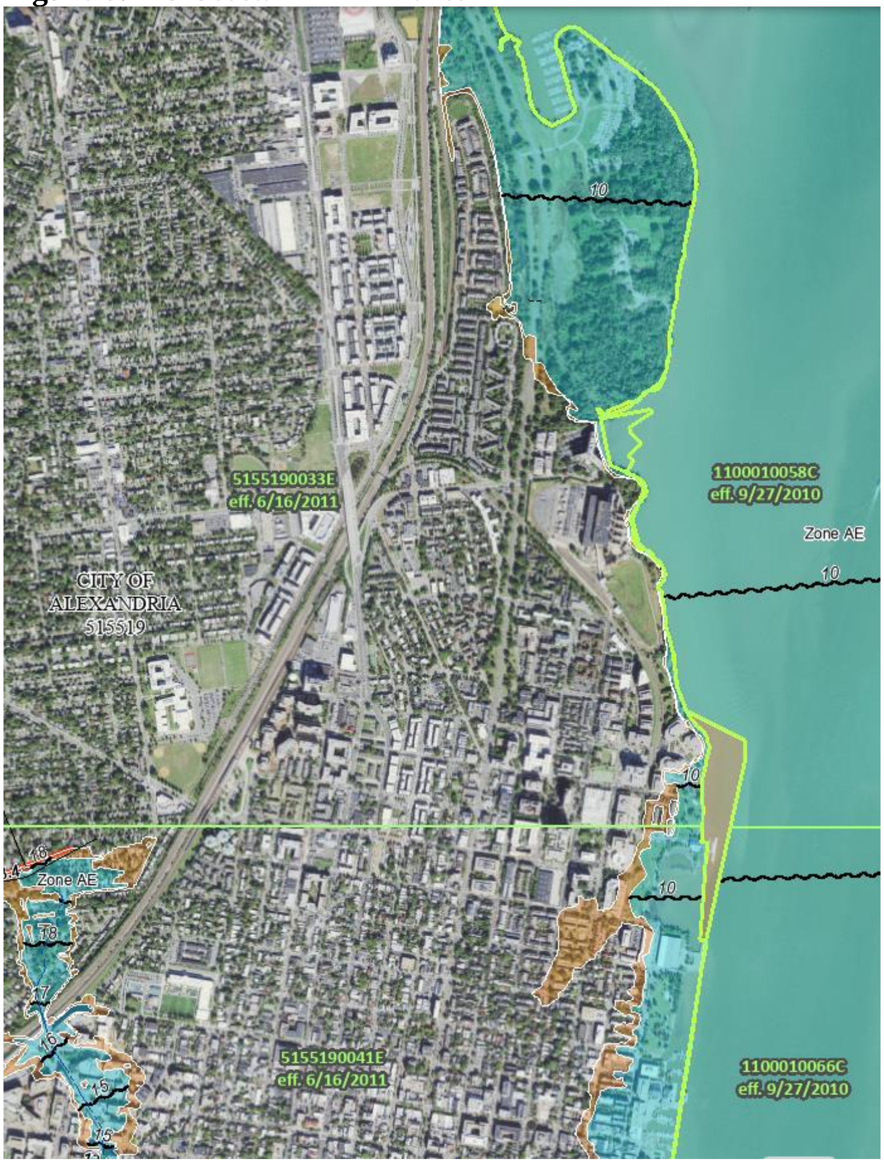
The future without project condition and forecast assumptions based on the existing condition were critical to the planning process since they provide the baseline for the subsequent evaluation and comparison phases. The following discussion includes projections about the future of the Northern Virginia study area if the federal government or local interests do not address the problems identified in this study.

5.1 BACKGROUND

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

The Northern Virginia study area without-project future conditions will be worsened by tidal influence on the Potomac River in conjunction with development in low lying areas and an overtaxed stormwater. Flooding and wave actions as continued sea level rise also contribute to future storm damages. The reconstruction of substantially damaged buildings to levels above the regulated Base Flood Elevation (BFE) in accordance with floodplain management regulations will provide them resiliencies against future storms.

Figure 8: DC Coastal FEMA Zones



According to the FEMA Flood Insurance Rate Map (FIRM), virtually (Attached figure) the Northern Virginia study area has been classified as Special Flood Hazard Area (SFHA) Zones AE which are areas of inundation by the 1-percent annual-chance flood, including areas with the 2-percent wave runup, elevation less than 3.0 feet above the ground, and areas with wave heights less than 3.0 feet. These areas are subdivided into elevation zones with BFEs assigned.

To regulate land development in the floodplain, various ordinances and regulations have been enforced to ensure public safety and reduce property damages. The ordinances and regulations call for elevating buildings above the adopted BFE for both new construction projects and substantial improvements to existing structures. The overall future condition of the study area is uncertain.

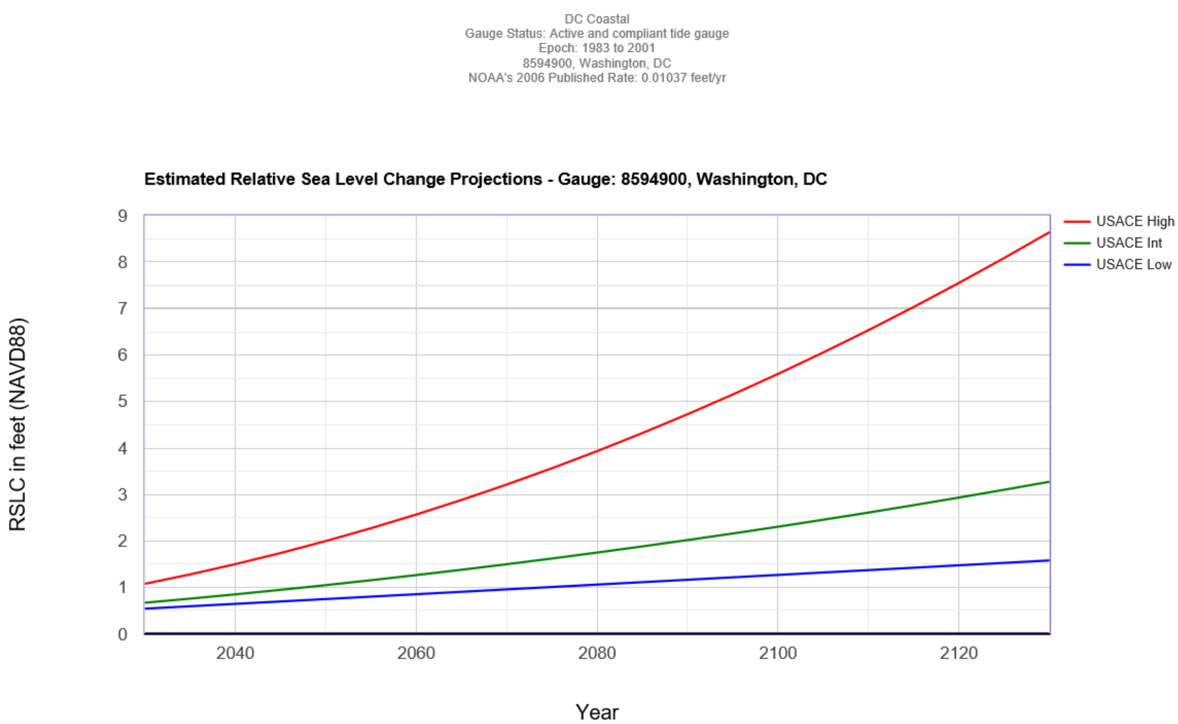
The NFIP requires that if the costs of reconstruction, rehabilitation, additions, or other improvements to a building equal or exceed 50% of the building's market value, then the building must meet the same construction requirements as a new building. Substantially damaged buildings must be brought up to the same standards. This means that a residence damaged where the cost of repairs equals or exceeds 50% of the building's value before it was damaged must be elevated above the BFE (Code Administration 703.746.4200).

The USACE low, intermediate, and high sea level change scenarios were evaluated for the without and with project condition, and with respect to determining tipping points/thresholds for impacts over the 50-year period of analysis and 100-year adaptation timeframe, and at multiple storm frequencies. NOAA's Regional Rate at Washington DC tide gauge is 0.00997 feet/year. Sea level is projected to rise as shown in Table 13 and Figure 9, based on the records at the NOAA gauge 8594900 at Washington DC, the closest to the Northern Virginia area.

Table 13: Sea Level Change Projection

Year	Low	Intermediate	High
2031	0.55	0.69	1.12
2080	1.06	1.75	3.93
2130	1.58	3.27	8.64

Figure 9: Sea Level Change Graphs



To address the flooding problems in the region, flood mitigation infrastructure has been constructed in Northern Virginia in the 21st century. A six-foot-tall wall is designed for 10-year storm protection in the City of Alexandria. Approximately, half of the floodwall is already in place. The construction of the second half is scheduled to start in 2023. The feasibility study will evaluate the performance of existing infrastructures with respect to storm risk, including structures at Four Mile Run and the Cameron Run Huntington Levee. The future without project condition analysis will consist of a comparison of WSELs to top of existing flood risk management infrastructure based on future condition surge scenarios.

Many agencies and organizations are making their own plans for adaptation to a potential disaster. But individual facilities, no matter how protected from disaster, still rely on regional utilities for energy, water, communications, and transportation that should be protected. Even regional utilities are interdependent; water pumping stations rely on electricity to function, for example.

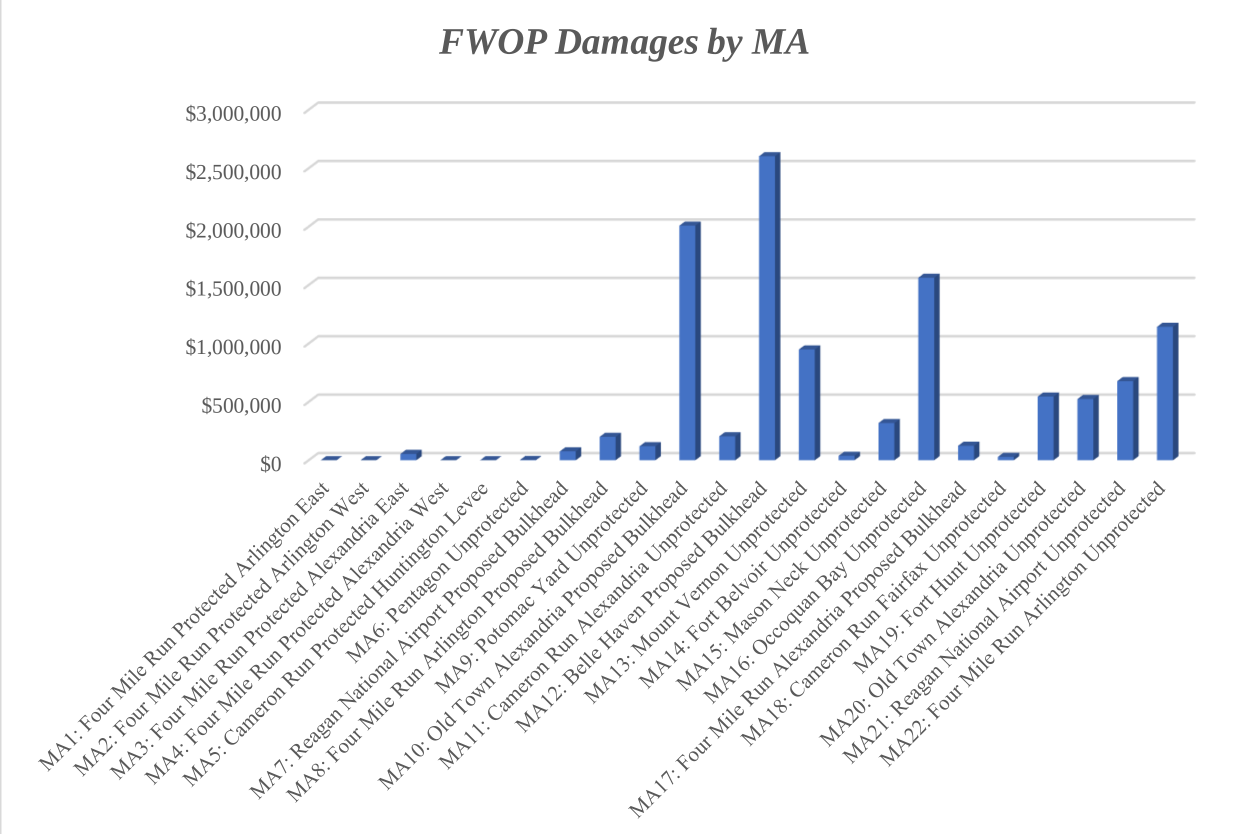
5.2 FUTURE WITHOUT PROJECT CONDITION MODELING RESULTS

The years 2031-2080 were selected to represent the future without project condition. No additional development within the study area is anticipated to be at risk since it is assumed that no new development would 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 Northern Virginia area will continue to be affected by the flooding from coastal storms and suffer increasing losses each year. The following Table 14 and Figure 10 display the expected present value (PV). In addition, Table 11 shows the equivalent annual damages (EAD) for the study area by model areas for the without project conditions by MA. Belle Haven MA in Fairfax County yields the most damages of structures in the study area followed by Old Town Alexandria and Occoquan Bay (Prince William County) MA.

Table 14: FWOP Condition Expected Annual Damages by MA.

Model Area	Present Value Damages	Equivalent Annual Damages
MA1: Four Mile Run Protected Arlington East	$0	$0
MA2: Four Mile Run Protected Arlington West	$0	$0
MA3: Four Mile Run Protected Alexandria East	$1,615,000	$54,000
MA4: Four Mile Run Protected Alexandria West	$0	$0
MA5: Cameron Run Protected Huntington Levee	$0	$0
MA6: Pentagon Unprotected	$53,000	$2,000
MA7: Reagan National Airport Proposed Bulkhead	$2,278,000	$76,000
MA8: Four Mile Run Arlington Proposed Bulkhead	$5,954,000	$200,000
MA9: Potomac Yard Unprotected	$3,583,000	$120,000
MA10: Old Town Alexandria Proposed Bulkhead	$59,900,000	$2,008,000
MA11: Cameron Run Alexandria Unprotected	$6,102,000	$205,000
MA12: Belle Haven Proposed Bulkhead	$77,625,000	$2,602,000
MA13: Mount Vernon Unprotected	$28,293,000	$948,000
MA14: Fort Belvoir Unprotected	$1,122,000	$38,000
MA15: Mason Neck Unprotected	$9,494,000	$318,000
MA16: Occoquan Bay Unprotected	$46,603,000	$1,562,000
MA17: Four Mile Run Alexandria Proposed Bulkhead	$3,686,000	$124,000
MA18: Cameron Run Fairfax Unprotected	$859,000	$29,000
MA19: Fort Hunt Unprotected	$16,271,000	$545,000
MA20: Old Town Alexandria Unprotected	$15,648,000	$524,000
MA21: Reagan National Airport Unprotected	$20,211,000	$677,000
MA22: Four Mile Run Arlington Unprotected	$34,073,000	$1,142,000
Total	$333,370,000	$11,174,000

Figure 10: FWOP Condition Expected Annual Damages by MA.



G2CRM used Monte Carlo simulation to derive the expected PV damages with 100 iterations completed. The sum of all damages for each life cycle were divided by the number of iterations to yield the expected PV damages for that modeled simulation. A mean and standard deviation were automatically calculated for the PV damages for each MA to account for uncertainty. These PV damages for each MA were summed to derive the study area expected PV damages.

The forecasted sea level rise in the future, without a project in place, resulted in higher expected average PV damages. The total future "without project" PV damages are approximately $333 million or about $11 million EAD. The forecast of the future without project condition reflects the conditions expected during the period of analysis (2031-2080) and provides the basis from which alternative plans are evaluated, compared, and selected since a portion of the flood damages would be prevented (i.e., flood damages reduced) with a federal project in place.

6. FUTURE WITH PROJECT CONDITION

The future with project condition is the most likely condition expected to exist in the future if a specific project is undertaken. There are as many futures with project conditions as there are project alternatives. A total of six alternatives were considered for the study. Of these, one was No Action, two were flood barriers alternatives, two were bulkhead alternatives, and one was a nonstructural alternative. The analysis did not formulate a project alternative for recreation because it is considered incidental to the project. The analysis includes a discussion of residual flood damages and flood damage reduction for each alternative.

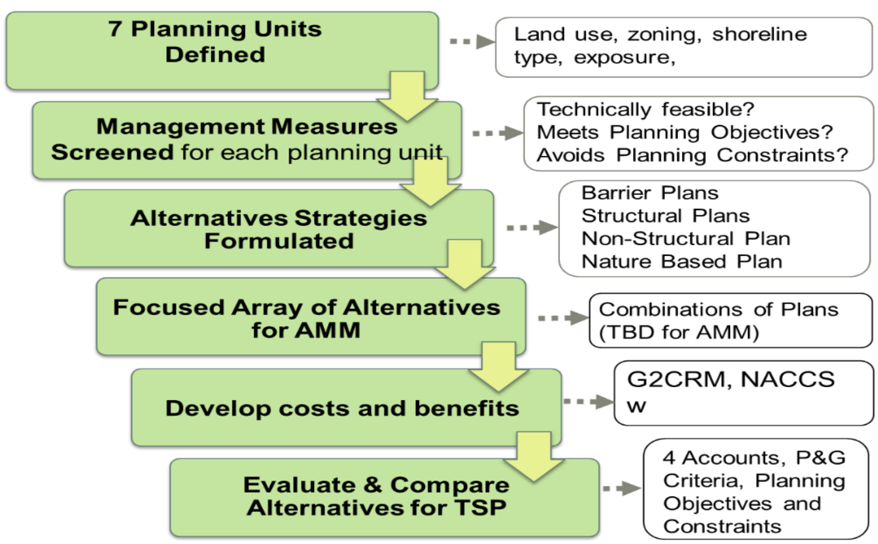
6.1 FORMULATION OF ALTERNATIVES

A formulation strategy is a systematic way of combining measures into alternative plans based on the planning objectives. No single formulation strategy will result in a diverse array of alternatives, so a variety of strategies is needed. Measures were combined into logical groupings based on a line of defense strategy. Structural measures were grouped logically landward, beginning with a surge barrier defense which would provide risk reduction for the greatest portion of the study area. The initial array of alternatives was screened based on the overall cost supported by modeled damages. Figure 11 below illustrates the plan formulation strategy.

At this stage of plan formulation, there are large uncertainties about the technical or social feasibility of implementing several measures in the areas in which they are proposed. For example, floodwalls along Reagan National Airport may have limited land area and height restrictions for implementation. They may require closure structures which would be costly and difficult to operate in the event of a coastal storm. In the Old Town City of Alexandria, tall floodwalls in this area may also be unacceptable to residents and stakeholders.

Natural and Nature-Based Features (NNBF) solutions may not be technically feasible and will not generate any CSRM economic benefits in the study area.

Figure 11: Plan Formulation Strategy



6.2 INITIAL ARRAY OF ALTERNATIVES

The initial array of alternatives was formulated despite known data gaps, 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 NNBF alternatives. Structural coastal flood risk management alternatives are man-made, constructed alternatives that counteract a flood event to reduce the hazard or to influence the course or probability of occurrence of the event.

Nonstructural coastal flood risk management alternatives are permanent or contingent alternatives applied to a structure that prevent or provide resistance to damage from flooding. Natural and nature-based coastal flood risk management alternatives work with or restore natural processes with the aim of wave attenuation and storm surge reduction.

The initial array of alternatives included:

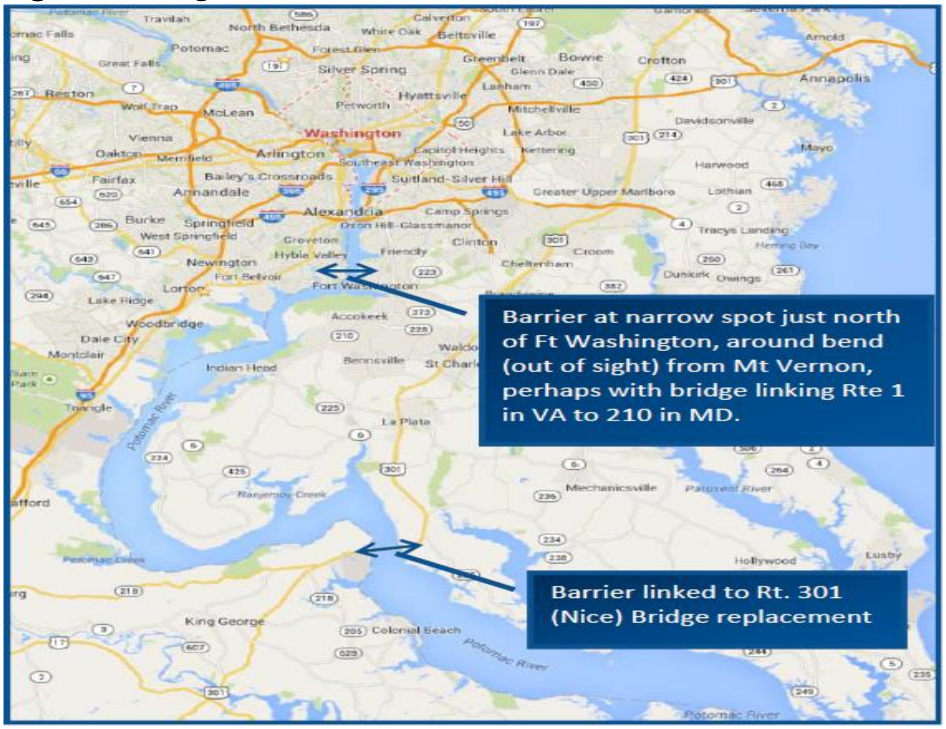
Alternative 1: No Action

The No Action alternative assumes that no actions would be taken by the Federal Government or local interests to address the problems identified by the study. Consequently, the No Action alternative would not reduce damages from coastal storm surge inundation. Although this alternative would not accomplish the purpose of this study, it will be used as a benchmark, enabling decision makers to compare the magnitude of economic, environmental, and social effects of the actionable alternatives. Additionally, the No Action alternative and future without project condition are assumed to be the same for this study.

Alternatives 2 & 3: Coastal Surge Barrier

Two different concept design surge barriers also called flood barriers were explored and broken down under Alternative 2, and Alternative 3. To evaluate their performance all 22 MAs were combined under one MA, which has the same boundary as the study area. The surge barriers will provide protection to some structures outside of the study area, in Washington D.C. and Prince George's County. Figure 12 shows locations of both surge barriers.

Figure 12: Surge Barrier Locations



Alternative 2: Comprehensive Surge Barrier

This management measure is developed with the following characteristics:

- **A total width of the surge barrier will be 8,400 feet.**
- The surge barrier will be operated with a sector gate.
- The surge barrier will have the same alignment in the channel as Route 301.

Alternative 3: Upper Surge Barrier

This management measure is developed with the following characteristics:

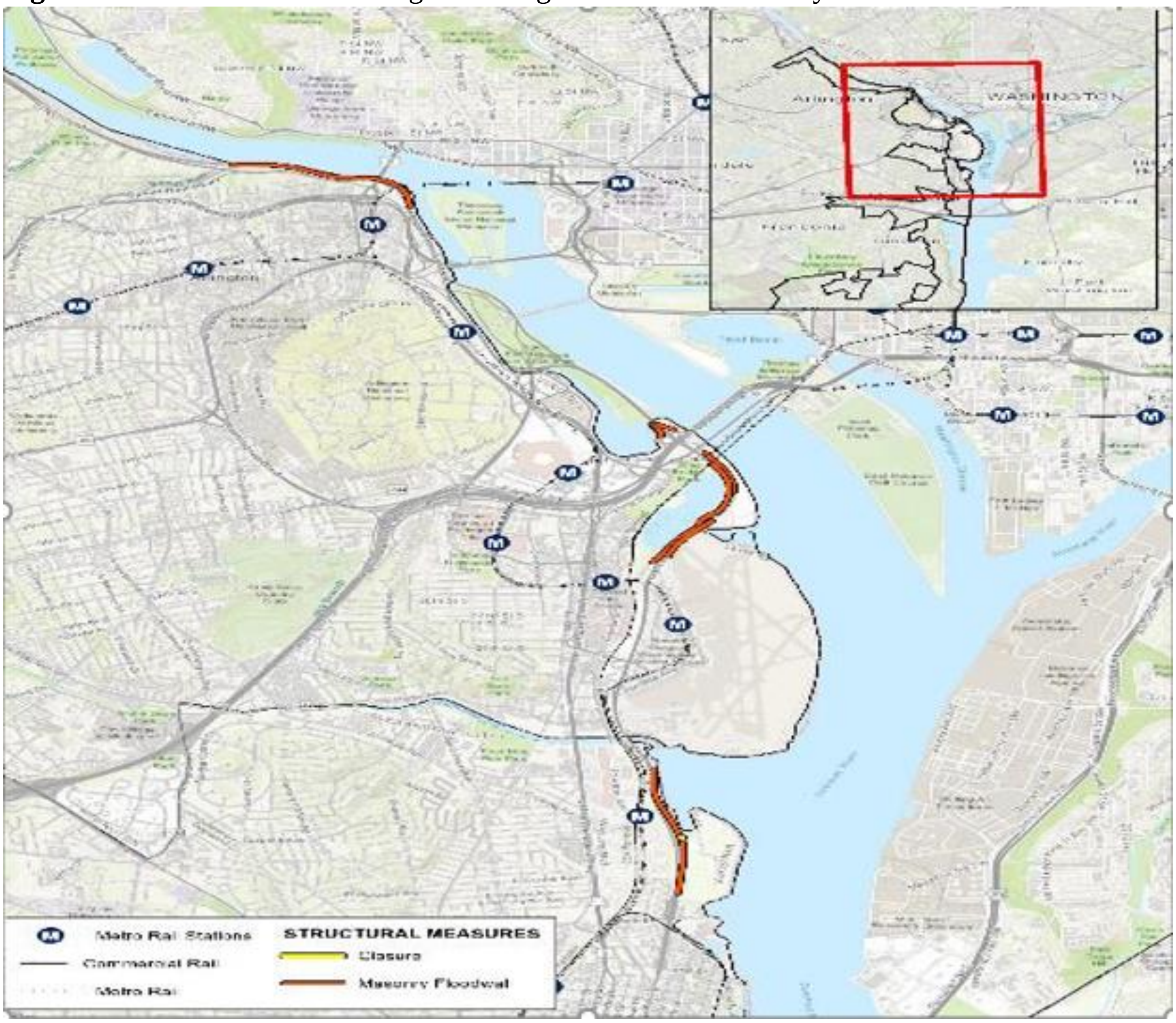
- A total width of the surge barrier will be 3,800 feet.
- The surge barrier will be operated with a sector gate of 1,000 feet.
- The surge barrier will be located just north of Fort Washington from Mt. Vernon with bridge linking Route 1 in Virginia to Route 210 in Maryland.

Alternative 4: Critical Infrastructure Plan

This alternative is broken down into three sub-alternatives: Alternative 4a is designed to protect George Washington Memorial Parkway, Alternative 4b is designed to protect Reagan National Airport, and Alternative 4c is designed to protect Arlington Water Pollution Control Plant. In addition to these critical infrastructures, fire stations, police stations, hospitals, treatment plants as well as lifeline infrastructure such as electricity, drinking water, wastewater are the most vulnerable in the study area.

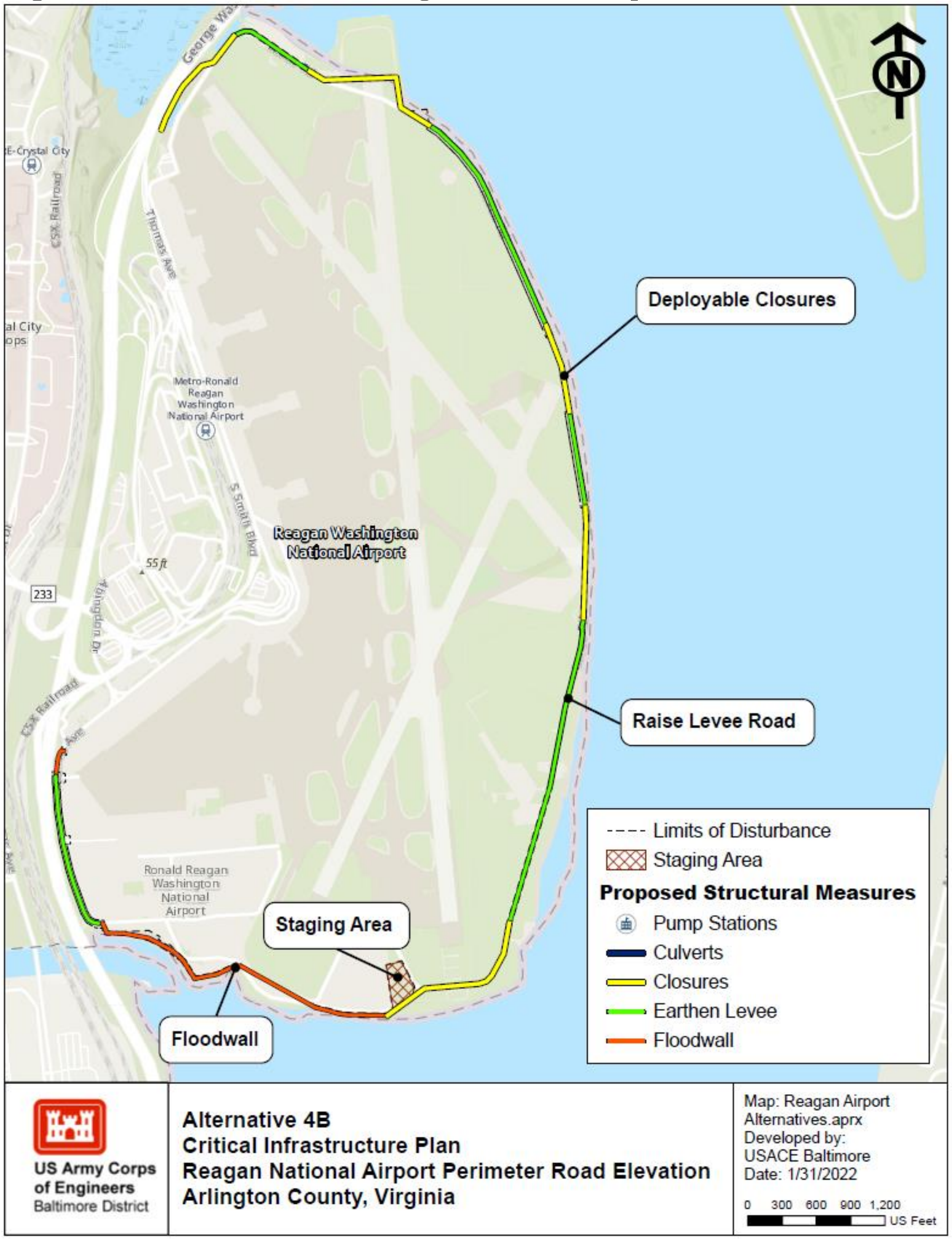
Alternative 4a proposes constructing a floodwall along George Washington Memorial Parkway. Figure 13 shows the alignment of the design.

Figure 13. Alternative 4a at George Washington Memorial Parkway



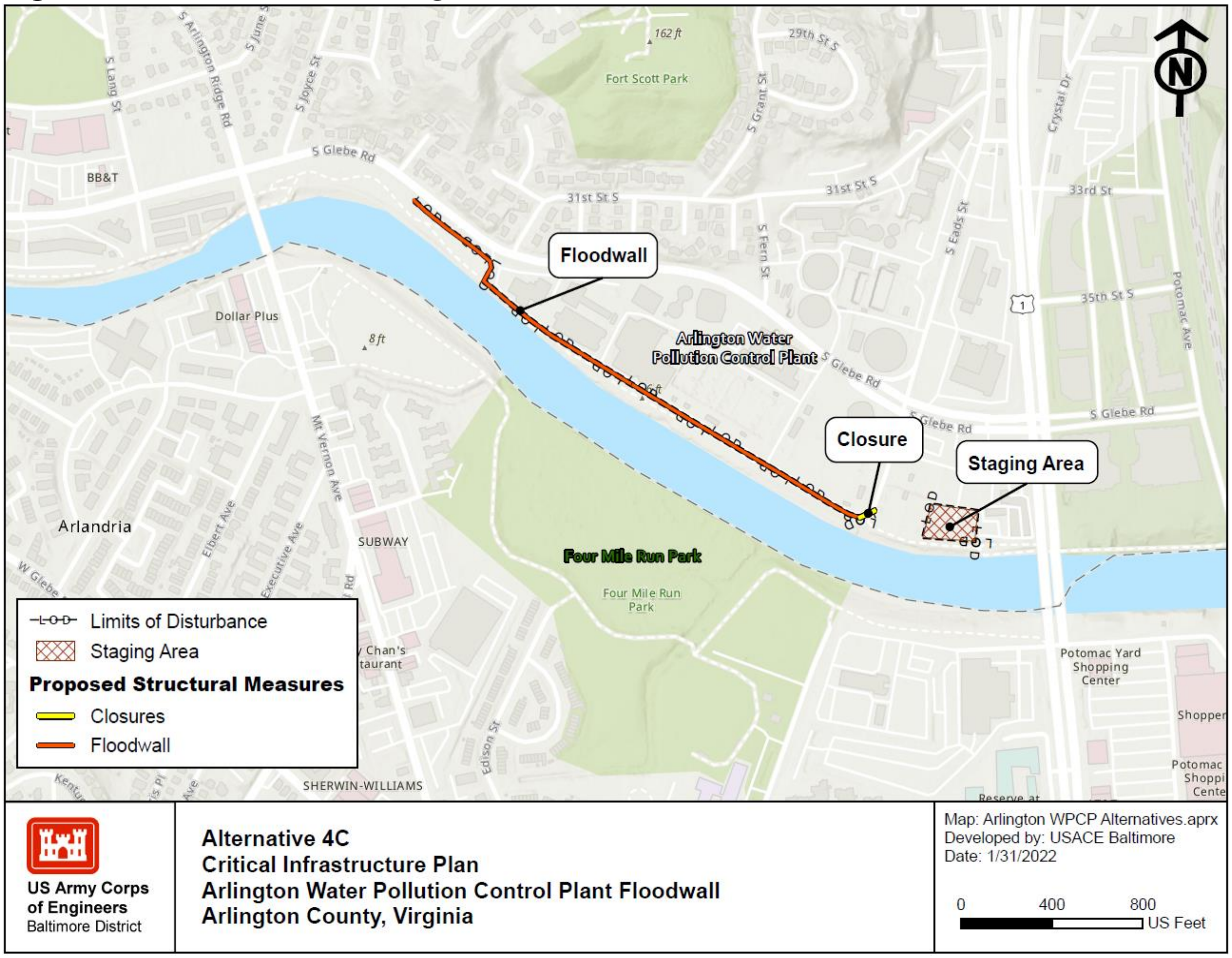
Alternative 4b proposes raising the perimeter road of Reagan National Airport. Additionally, in the two areas where there is not enough land available to raise the road, along the water's edge south of the airport and along the George Washington Memorial Parkway (GWMP), a floodwall would be constructed. Removable barriers will be used at the end of the runways to avoid impacts to airport operations. Figure 14 shows the alignment of the design.

Figure 14. Alternative 4b at Reagan National Airport



Alternative 4c proposes constructing a floodwall along the left bank of Four Mile Run between Four Mile Run and the Arlington WPCP with a closure structure on the west side of the structure. The new floodwall will tie into the bank to the east just past South Eads Street. The floodwall will wrap around the Arlington WPCP to the west where the closure structure is located along South Glebe Road as shown in Figure 15.

Figure 15. Alternative 4c at Arlington Water Pollution Control Plant

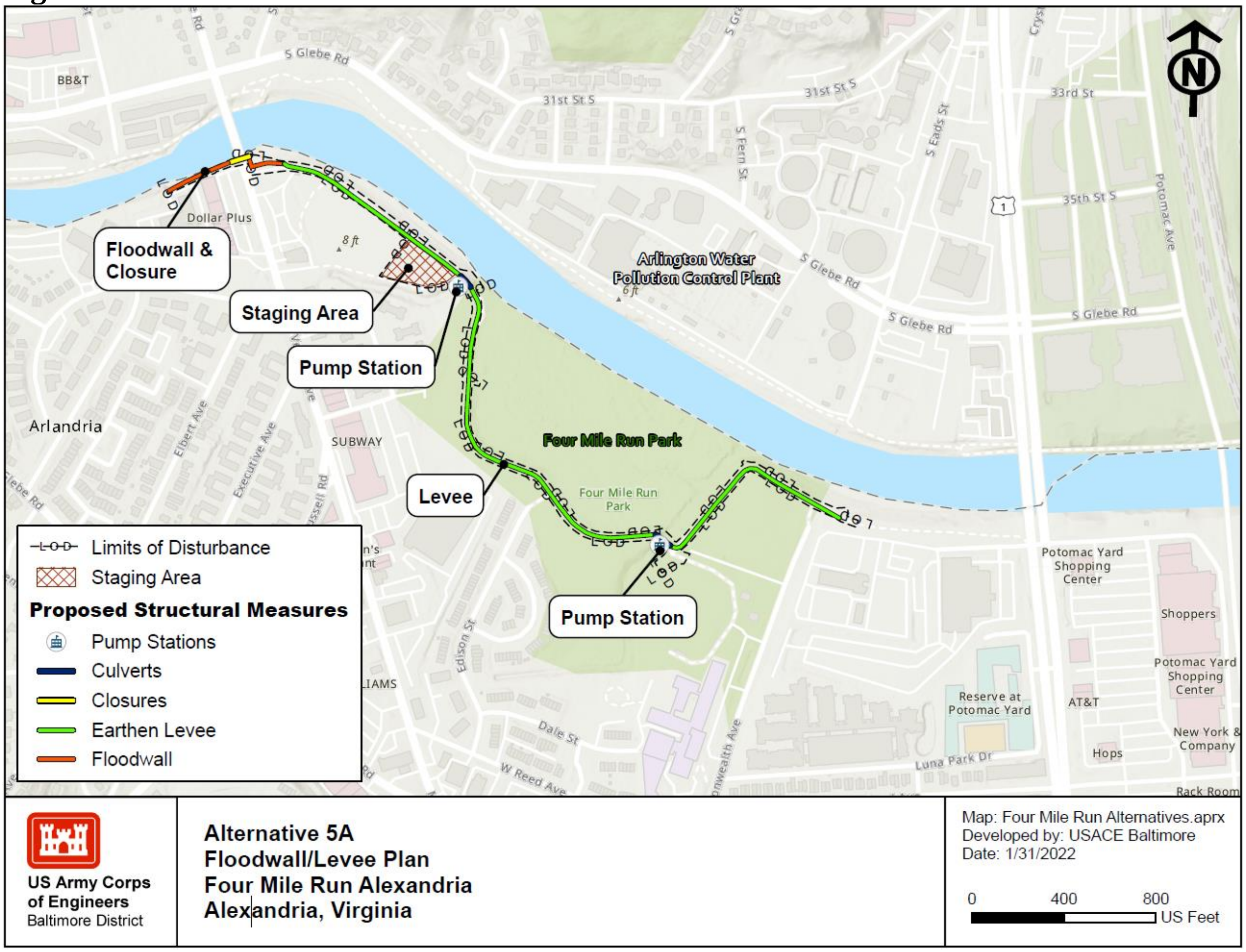


Alternative 5: Floodwall/Levee Plan

The Floodwall/Levee alternatives are focused on providing protection to damage centers (neighborhoods and retail) using structural alternatives. The subcomponents of this alternative include Alternative 5a in Arlandria at Four Mile Run, Alternative 5b in Alexandria, and Alternative 5c in Belle Haven.

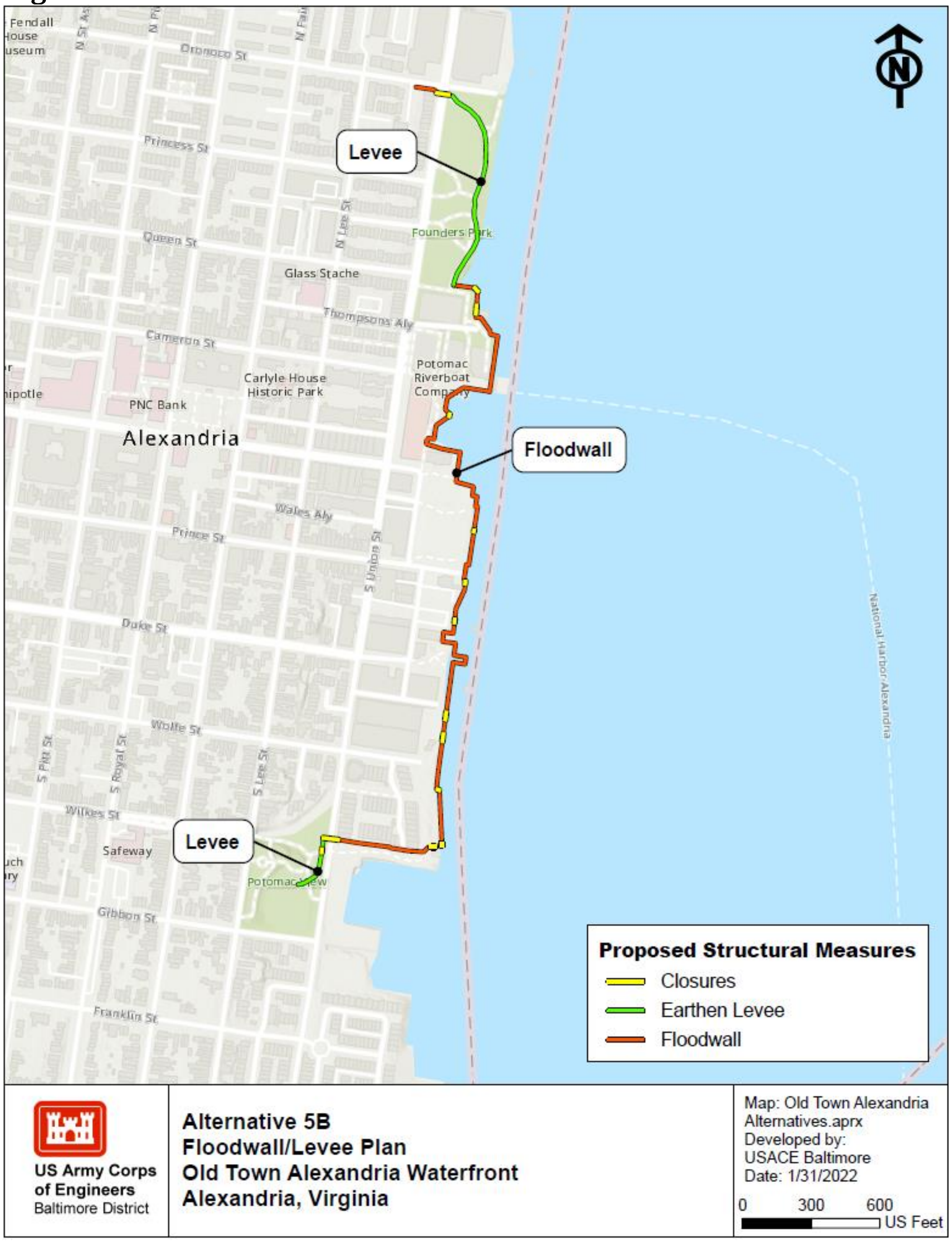
Alternative 5a proposes constructing a levee along the shoreside of Four Mile Run Park Trail from Mount Vernon Avenue to Commonwealth Avenue. Two flap gates would be located along the levee at Sunnyside Stream and the stream just west of the Four Mile Run softball field. The new levee will tie into the existing Arlandria Four Mile Run Floodwall with two portions of floodwall on either side of Mount Vernon Avenue and a closure structure along Mount Vernon Avenue as shown Figure 16.

Figure 16: Alternative 5a in Alexandria at Four Mile Run



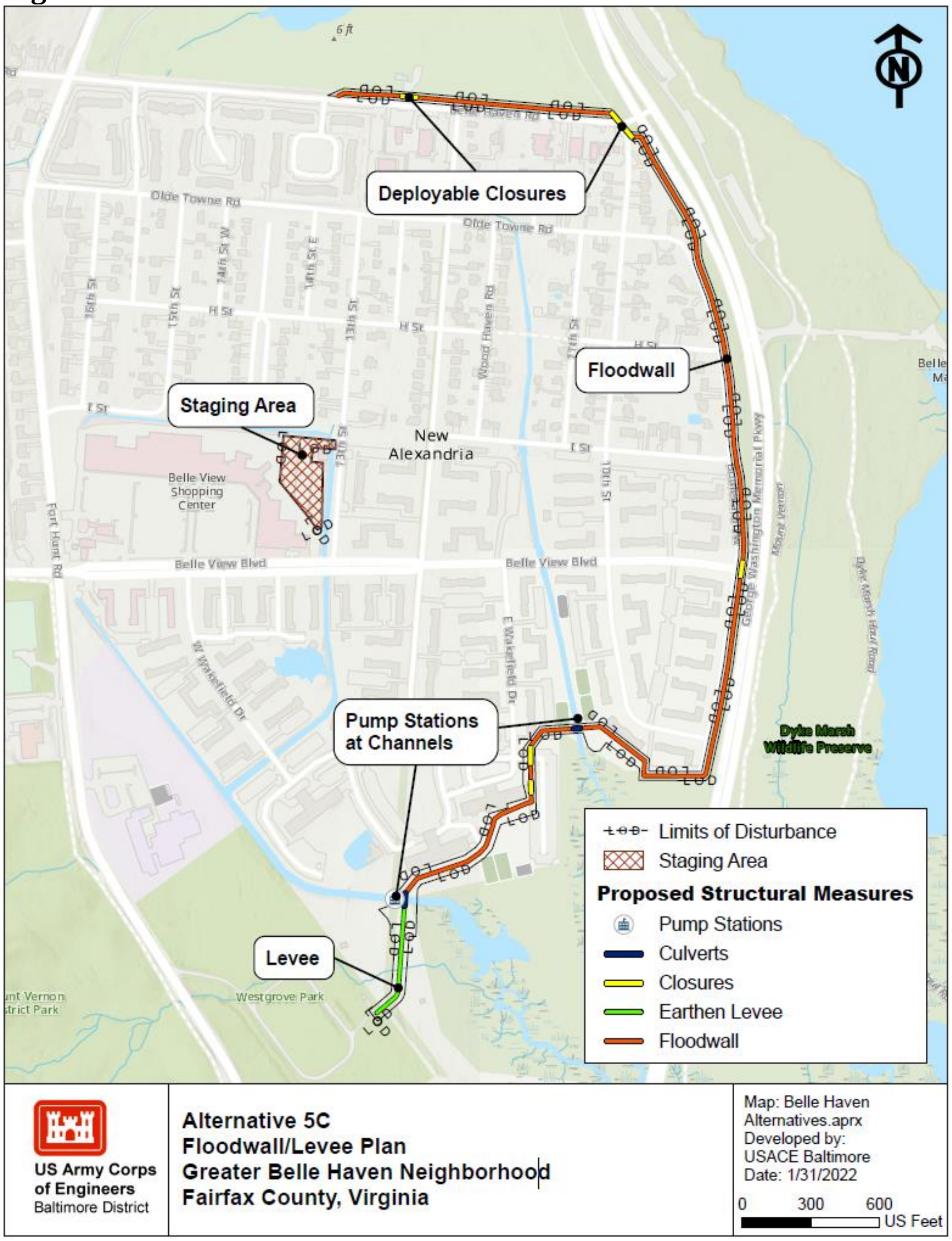
Alternative 5b proposes constructing a floodwall and levee along the Alexandria waterfront as shown in the Figure 17.

Figure 17: Alternative 5b in Alexandria waterfront



Alternative 5c proposes constructing a levee just north of Belle Haven Road from Barrister Place to 10th Street with a closure structure at 10th Street and the GWMP. Closure structures would also be constructed along Belle Haven Road and Belle View Blvd. A floodwall would tie into the closure structure at 10th Street and run south along the west side of the GWMP, curving around Boulevard View to 10th Street. A levee would tie into the floodwall and run west to East Wakefield Drive. A small portion of floodwall would tie into both sides of a closure structure on Potomac Avenue. A levee would continue west tying into the floodwall at West Wakefield Drive and ending at Westgrove Dog Park. Figure 18 shows the design in Belle Haven.

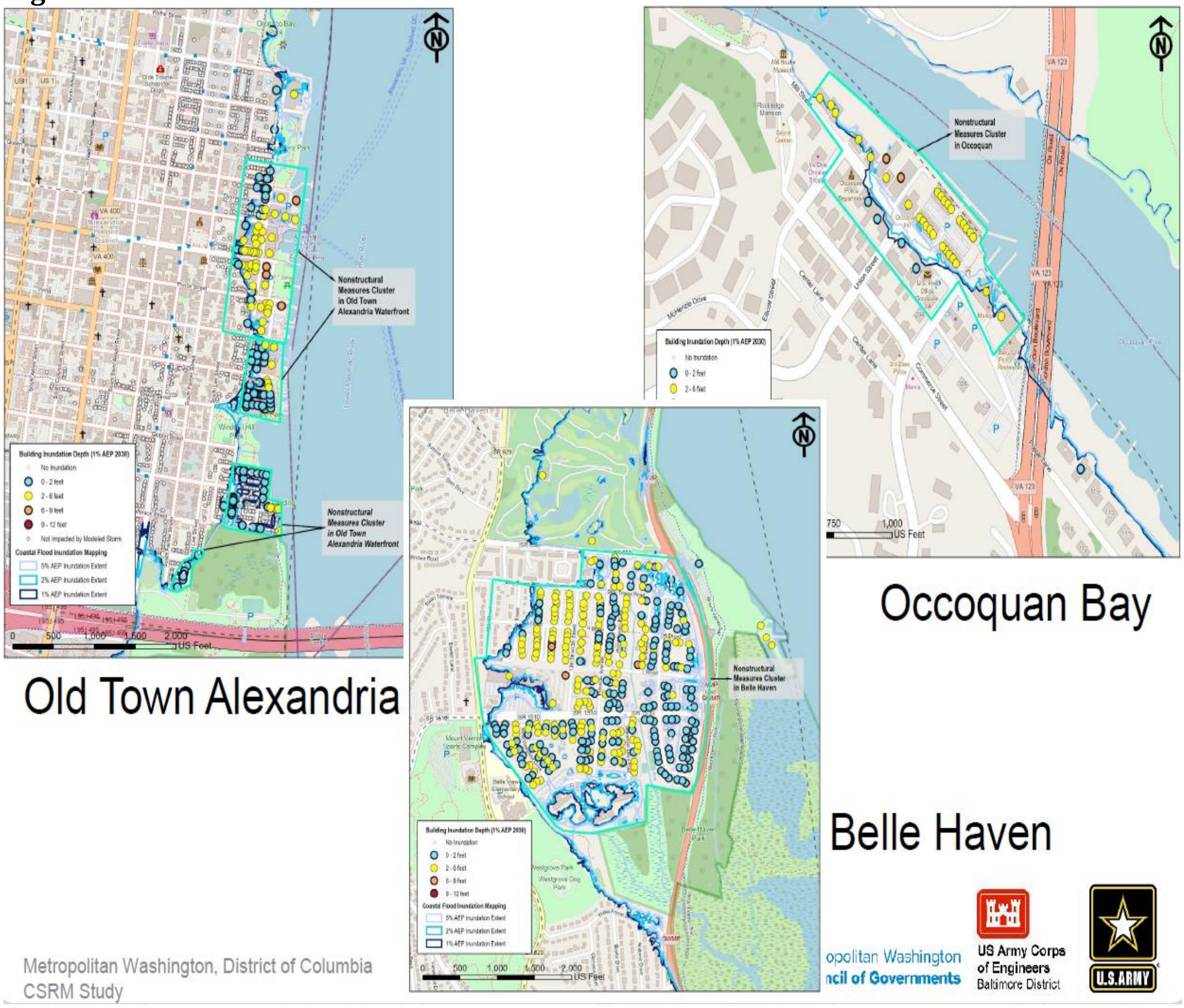
Figure 18: Alternative 5c at Bell Haven



Alternative 6: Nonstructural Plans

Figure 19 shows focus areas for nonstructural alternatives. The three areas where nonstructural measures have been evaluated are Old Town Alexandria, Bell Haven, and Occoquan Bay where there are concentrated number of structures. This alternative includes evaluation of these focus areas for floodwall, flood proofing, elevation, acquisition, and relocation. For nonstructural plans, we considered a 100-year floodplain, a 50-year floodplain, and a 20-year floodplain. The National Nonstructural Committee recommended to evaluate nonstructural measures in a 100-year, a 50-year, and 25-year floodplains but a 20-year was used instead of a 25-year since a 20-year floodplain was developed while a 25-year was not available.

Figure 19: Alternative 6 - Nonstructural Focus Areas



Alternative 7: Combination of Upper Surge Barrier and Nonstructural Measures
Alternative 7 consists of a combination of Alternatives 3 and nonstructural measures in the downstream of the study area.

Alternative 8: Combination of Alternatives 4, 5, and 6
Alternative 8 consists of a combination of alternatives 4, 5 and 6 or components of these alternatives depending on which are viable. These may include combinations of levee, floodwall, closure structures, flap gates, removable barriers, and nonstructural solutions.

6.3 ALTERNATIVES SCREENING

The 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 support the screening process, professional judgment was used to

assess how well measures met a set of criteria. Engineers, scientists, and stakeholders at the planning charrette screened the measures.
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.

6.4 FINAL ARRAY OF ALTERNATIVES

Based on the screening assessment, the flood barrier alternatives and the floodwall along George Washington Memorial Parkway were screened out for future considerations.

The flood barriers will increase the project scope significantly, by expanding the study area to include in additional to the Northern Virginia study area Prince Georges County in Maryland and District of Columbia. The following preliminary considerations indicate that the flood barriers would not be acceptable to resource agencies or local jurisdictions:

- Hydraulic constraints - riverine discharge, induced flooding impacts on either side of the barriers.
- Cultural resource constraints - impact on the George Washington Memorial Parkway and other cultural resources.
- Environmental - water quality impacts, impacts to endangered species (e.g., Atlantic Sturgeon) and other anadromous fish.

Floodwalls along the George Washington Memorial Parkway alternative will be screened out upon coordination with the National Park Service (NPS). NPS is not amenable to any impact to the parkway including to viewshed, landscape, character, or community-landscape connection. More information on alternatives that have been screened out can be found in Sec. 3 of the main report.

The No Action Alternative 1, Alternatives 4b, 4c, 5a, 5b, 5c, 6, and 8 were carried forward for evaluation. These alternatives were considered the final array of alternatives. These alternatives were regrouped under four new alternatives.

Alternative 1: No Action Alternative
There are no changes (reference Initial Array section).

Alternative 4: Reagan National Airport (Alternative 4b in MA7) and Arlington Water Pollution Control Plant (Alternative 4c in MA8)

Alternative 5: Four Mile Run Alexandria (Alternative 5a in MA17), Old Town Alexandria (Alternative 5b in MA10), and Bell Haven (Alternative 5c in MA 12)

Alternative 6: Nonstructural measures in Old Town Alexandria (MA10), Bell Haven (MA12), and Occoquan Bay (MA16).

Alternative 8: Combination of Alternatives 4, 5, and 6
Combination of alternatives 4, 5 and 6 or components of these alternatives.

6.5 EVALUATION OF ALTERNATIVES

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

6.5.1 Alternative 4 Modeling Results

Alternative 4 is designed to raise the perimeter road of Reagan National Airport. Additionally, a floodwall will be constructed along the water's edge south of the airport. To avoid impacts to airport operations removable barriers will be used at the end of the runways. This alternative is designed in MA7.

A floodwall will be constructed along the left bank of Four Mile Run between Four Mile Run and the Arlington WPCP with a closure structure on the west side of the structure. The floodwall will tie into the bank to the east just past South Eads Street. The floodwall will wrap around the Arlington WPCP to the west where the closure structure is located along South Glebe Road. This alternative is designed in MA8.

Both the existing and future without conditions simulate the top elevation for the bulkheads and that top elevation was specified at the approximate existing ground elevation within the MAs.

However, for the future with project condition, the top elevation for the protective system elements in G2CRM is specified at 14.3 feet NAVD88 in MA7 (Reagan National Airport area) and 14.3 feet NAVD88 in MA8 (Arlington WPCP area). The PSE prevent transmission of the flood hazard into the model areas until the flood hazard exceeds the top elevation of the bulkheads. When the flood hazard exceeds the PSE top elevation the flood hazard is instantaneously transmitted into the model areas unmediated by the PSE. In short, the PSE reduces flood risk (e.g., damages) in the study area up to 14.3 feet NAVD88 in MA7 and 14.3 feet NAVD88 in MA8. For Alternative 4, the following Tables display the future without project expected damages, the project conditions expected damages, and the damages reduced by MA for Alternative 4.

Table 15: Alternative 4 - Future Without Project Conditions

Model Area	Present Value Damages	Average Annual Damages
(Alt-4b) MA7: Reagan National Airport	$2,278,000	$76,000
(Alt-4c) MA8: Four Mile Run Arlington	$5,954,000	$200,000
Total	$8,232,000	$276,000

Table 16: Alternative 4 - Future With Project Conditions

Model Area	Present Value Damages	Average Annual Damages
(Alt-4b) MA7: Reagan National Airport	$367,000	$12,000
(Alt-4c) MA8: Four Mile Run Arlington	$626,000	$21,000
Total	$993,000	$33,000

Table 17: Alternative 4 - Damages Reduced

Model Area	Present Value Damages Reduced	Average Annual Damages Reduced	% Damage Reduced
(Alt-4b) MA7: Reagan National Airport	$1,911,000	$64,000	84%
(Alt-4c) MA8: Four Mile Run Arlington	$5,328,000	$179,000	89%
Total	$7,239,000	$243,000	88%

When compared the project alternative to the future without project conditions, Alternative 4 reduced the mean PV damages in Reagan National Airport MA by 84%, Four Mile Run Arlington Water Pollution Control Plan MA by 89%, and by 88% for both combined MAs.

6.5.2 Alternative 5 Modeling Results

Alternative 5 is designed to protect assets in MA10, MA12, and MA17.
Initially, a 13.2 feet floodwall, a 100-year level of protection, is designed in MA10 to protect assets in Old Town Alexandria. This plan has negative net benefits and was dropped. Since the City of Alexandria is constructing 6 feet wall designed for a 10-year level of protection, a 9.5 feet new proposed deployable floodwall was proposed for a 50-year level of protection. Hence, Alternative 5b was changed to 5b1. In MA12, a levee is designed at the north of Belle Haven Road from Barrister Place to 10th Street with a closure structure at 10th Street and the GWMP. The height of the levee is 13.0 feet NAVD88. A levee has been designed in MA17 along the shoreside of Four Mile Run Park Trail from Mount Vernon Avenue to Commonwealth Avenue. The top of protection of the levee is set to 13.9 feet NAVD88.

The following tables display the future without project conditions expected damages, the project conditions expected damages, and the damages reduced by MA for Alternative 5.

Table 18: Alternative 5 - Future Without Project Conditions

Model Area	Present Value Damages	Average Annual Damages
(Alt-5b1) MA10: Old Town Alexandria	$59,900,000	$2,008,000
(Alt-5a) MA12: Belle Haven	$77,625,000	$2,602,000
(Alt-5c) MA17: Four Mile Run Alexandria	$3,686,000	$124,000
Total	$141,211,000	$4,734,000

Table 19: Alternative 5 - Future With Project Conditions

Model Area	Present Value Damages	Average Annual Damages
(Alt-5b1) MA10: Old Town Alexandria	$12,878,000	$432,000
(Alt-5a) MA12: Belle Haven	$16,942,000	$568,000
(Alt-5c) MA17: Four Mile Run Alexandria	$605,000	$20,000
Total	$30,425,000	$1,020,000

Table 20: Alternative 5 - Damages Reduced

Model Area	Present Value Damages Reduced	Average Annual Damages Reduced	% Damage Reduced
(Alt-5b1) MA10: Old Town Alexandria	$47,022,000	$1,576,000	79%
(Alt-5a) MA12: Belle Haven	$60,683,000	$2,034,000	78%
(Alt-5c) MA17: Four Mile Run Alexandria	$3,081,000	$104,000	84%
Total	$110,786,000	$3,714,000	78%

When compared the project alternative to the future without project conditions, Alternative 5 reduced the mean PV damages in Old Town Alexandria MA by 79%, Bell Haven MA by 78%, Four Mile Run Alexandria by 84%, and by 78% for combined MAs in Alternative 5.

6.5.3 Alternative 6 - 100YR, 50YR, and 20YR Floodplains Modeling Results

The nonstructural solutions are evaluated in a 100-year, a 50-year, and 20-year frequency events in compliance with the National Nonstructural Committee Best Practice Guide 2020-06 dated *15 November 2021* on the structure aggregation methods used in the formulation and evaluation of nonstructural alternatives. A 20-year frequency event was used instead of a 25-year for hydraulic stage functions availability reason. Elevation and floodproofing technics are nonstructural measures used in this analysis. Acquisition, relocation, relocation, and various nonphysical measures such as evacuation plans, land use regulation, flood emergency preparedness plans, flood insurance, flood mapping, flood warning systems, risk communication, and zoning will be further exanimated. Old Town Alexandria, Belle Haven, and Occoquan Bay are the areas where nonstructural solutions have been implemented. Table 21 shows the breakdown of structure counts that were receiving nonstructural measures in a 100-year floodplain, a 50-year floodplain, and 20-year floodplain.

Table 21: Nonstructural treatments per location and floodplain

Planning Units	NS_100YR		NS_50YR		NS_20YR	
	Elevation	Floodproofing	Elevation	Floodproofing	Elevation	Floodproofing
MA10&20 - Old Town Alexandria	0	201	0	180	0	113
MA12 - Belle Haven	168	217	149	193	120	116
MA16 - Occoquan Bay	25	35	23	35	19	31
Total	193	453	172	408	139	260

6.6 ALTERNATIVE COMPARISON

The benefits were compared to the costs for each alternative. These comparisons provide the framework for completing the evaluation of alternative plans.

6.6.1 Benefits

The difference in expected man Present Value (PV) flood damages in the Northern Virginia study area between the future without condition and future with project condition represents the flood risk management benefits to the project. Therefore, these benefits represent damages reduced (National Economic Development - NED) from coastal storm surge inundation with the combination of sea level rise for each alternative. However, Planning Guidance (reference ER 1105-2-100) dictates that the calculation of net NED benefits of a plan is calculated in average annual equivalent terms. Therefore, the PV damages were converted to average annual damages based and the costs were annualized using the FY22 discount rate of 2.25% and a 50-year period of analysis for the purpose of the comparison.

6.6.2 Costs

Structural and nonstructural measure cost estimates were provided by the Baltimore District Cost Engineering Section Division in FY2022 (October 2021) price levels (reference Engineering Appendix for more details). To Continue the comparison process, First Cost estimates were used for each of the alternatives that were evaluated. The Interest During Construction (IDC) was computed using the First Cost and the duration of construction. For comparison to the benefits, which are average annual flood damages reduced, the first costs were stated in average annual equivalent also based on the FY2022 discount rate of 2.25% and 50 years period of analysis. The IDC was added to the First Cost to derive the investment cost. In addition, annual operation and maintenance (O&M) costs were also added to the structural alternatives. Table 22 shows the results of the costs computation

Table 22: Cost for Alternatives

Plan Alternatives	Alternative Description	First Cost	IDC	Investment Cost	O&M	Average Annual Cost
Alternative-1	No Action	.	.	.	.	.
Alt-4b	BH7: Reagan National Airport Proposed Deployable Floodwall	$86,535,000	$5,956,000	$92,491,000	$865,000	$3,129,000
Alt-4c	BH8: Four Mile Run Arlington WPCP Proposed Bulkhead	$2,626,000	$42,000	$2,668,000	$26,000	$90,000
Alternative-4	Proposed Bulkheads	$89,161,000	$5,998,000	$95,159,000	$892,000	$3,219,000
Alt-5a	BH17: Four Mile Run Alexandria Proposed Bulkhead	$33,784,000	$1,121,000	$34,905,000	$338,000	$1,181,000
Alt-5b1	BH10: Old Town Alexandria Proposed Deployable Floodwall	$152,651,000	$2,432,000	$155,083,000	$1,527,000	$1,201,000
Alt-5c	BH12: Belle Haven Proposed Bulkhead	$48,162,000	$1,268,000	$49,430,000	$482,000	$1,673,000
Alternative-5	Proposed Bulkheads	$234,597,000	$4,821,000	$239,418,000	$2,346,000	$8,103,000
	MA10 & MA20: Old Town Alexandria	$57,976,000	$3,640,000	$61,616,000	-	$2,065,000
	MA12: Belle Haven	$120,639,000	$7,573,000	$128,212,000	-	$4,297,000
	MA16: Occoquan Bay Unprotected	$18,734,000	$1,176,000	$19,910,000	-	$667,000
Alternative- 6 - NS_100YR	Elevation or Floodproofing Structures in a 1% AEP	$197,349,000	$12,389,000	$209,738,000	-	$7,030,000
	MA10 & MA20: Old Town Alexandria	$51,919,000	$3,259,000	$55,178,000	-	$1,849,000
	MA12: Belle Haven	$107,152,000	$6,727,000	$113,879,000	-	$3,817,000
	MA16: Occoquan Bay Unprotected	$18,043,000	$1,133,000	$19,176,000	-	$643,000
Alternative- 6 - NS_50YR	Elevation or Floodproofing Structures in a 2% AEP	$177,114,000	$11,119,000	$188,233,000	-	$6,309,000
	MA10 & MA20: Old Town Alexandria	$32,593,000	$2,046,000	$34,639,000	-	$1,161,000
	MA12: Belle Haven	$74,921,000	$4,703,000	$79,624,000	-	$2,669,000
	MA16: Occoquan Bay Unprotected	$15,506,000	$973,000	$16,479,000	-	$552,000
Alternative- 6 - NS_20YR	Elevation or Floodproofing Structures in a 5% AEP	$123,020,000	$7,722,000	$130,742,000	-	$4,382,000

6.6.3 Benefits-Costs Ratio

The equivalent annual benefits were compared to the average annual cost to develop net benefits and a benefit-to-cost ratio (BCR) for each alternative. The net benefits for each alternative were computed by subtracting the average annual costs from the equivalent average annual benefits. BCR was calculated by dividing average benefits by average annual costs. Net benefits were used for identification of the NED plan in accordance with the Federal objective. The following Table 23 summarizes the equivalent annual benefits, average annual costs, first cost, net benefits, and BCR for each alternative.

Table 23: Costs and Benefits Comparison of Alternatives

Plan Alternatives	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
Alternative-1	.	.	.	.		.	.	.	.
Alt-4b	$86,535,000	$5,956,000	$92,491,000	$865,000	$93,356,000	$3,129,000	$64,000	($3,065,000)	0.0
Alt-4c	$2,626,000	$42,000	$2,668,000	$26,000	$2,694,000	$90,000	$179,000	$89,000	2.0
Alternative-4	$89,161,000	$5,998,000	$95,159,000	$892,000	$96,050,000	$3,219,000	$243,000	($2,976,000)	0.1
Alt-5a	$33,784,000	$1,121,000	$34,905,000	$338,000	$35,243,000	$1,181,000	$104,000	($1,077,000)	0.1
Alt-5b1	$152,651,000	$2,432,000	$155,083,000	$1,527,000	$156,610,000	$5,249,000	$1,201,000	($4,048,000)	0.2
Alt-5c	$48,162,000	$1,268,000	$49,430,000	$482,000	$49,912,000	$1,673,000	$2,034,000	$361,000	1.2
Alternative-5	$234,597,000	$4,821,000	$239,418,000	$2,346,000	$241,765,000	$8,103,000	$3,339,000	($4,764,000)	0.4
	$57,976,000	$3,640,000	$61,616,000	-	$61,616,000	$2,065,000	$380,000	($1,685,000)	0.2
	$120,639,000	$7,573,000	$128,212,000	-	$128,212,000	$4,297,000	$782,000	($3,515,000)	0.2
	$18,734,000	$1,176,000	$19,910,000	-	$19,910,000	$667,000	$56,000	($611,000)	0.1
Alternative-6 - NS_100YR	$197,349,000	$12,389,000	$209,738,000	-	$209,738,000	$7,030,000	$1,218,000	($5,812,000)	0.2
	$51,919,000	$3,259,000	$55,178,000	-	$55,178,000	$1,849,000	$342,000	($1,507,000)	0.2
	$107,152,000	$6,727,000	$113,879,000	-	$113,879,000	$3,817,000	$684,000	($3,133,000)	0.2
	$18,043,000	$1,133,000	$19,176,000	-	$19,176,000	$643,000	$55,000	($588,000)	0.1
Alternative- 6 - NS_50YR	$177,114,000	$11,119,000	$188,233,000	-	$188,233,000	$6,309,000	$1,081,000	($5,228,000)	0.2
	$32,593,000	$2,046,000	$34,639,000	-	$34,639,000	$1,161,000	$286,000	($875,000)	0.2
	$74,921,000	$4,703,000	$79,624,000	-	$79,624,000	$2,669,000	$514,000	($2,155,000)	0.2
	$15,506,000	$973,000	$16,479,000	-	$16,479,000	$552,000	$31,000	($521,000)	0.1
Alternative- 6 - NS_20YR	$123,020,000	$7,722,000	$130,742,000	-	$130,742,000	$4,382,000	$831,000	($3,551,000)	0.2

6.7 ECONOMIC RISK ANALYSIS

The values of benefits displayed in tables above, have uncertainties associated with them. There are uncertainties in G2CRM inputs used and in the model by itself. Risk-informed planning should incorporate transparency in the estimation of benefits according to ER 1105-2-101, Planning, Risk Assessment For Flood Risk Management Studies dated on 15 July 2019. ER stated in section 8 Policy and Required Procedures (d.):

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

The following Table contains the expected mean annual damage for the without project condition and the future with project condition for each alternative. The computed values are uncertain, and their probability distributions, resulting from the risk and uncertainty inherent in the modeling variables. This information aids decision makers such as local sponsor, stakeholders, and federal officials to increase their understanding of the uncertainty inherent in each alternative and to determine ways to address residual risks and increase specific and overall resilience.

Table 24: Probabilistic Values

Plan Alternatives	Expected Annual Damages ($1,000)		Damages Reduced ($1,000)		Uncertainty ($1,000)	
	Future Without	Future With	Mean	Standard Deviation	Min	Max
Alt-4c	200	21	179	11,084	0	2,061
Alt-5c	2,602	568	2,034	12,278	0	2,785

The values shown are each the mean of the probability (uncertainty) distribution of that alternative. The damage reduced (without project minus future with project) is reported with more information about its probability (uncertainty) distribution. In addition to the mean, the standard deviation and the minimum and maximum of the distribution are included. The standard deviation describes the width of the probability distribution and the minimum and maximum describes the range.

7. SEBSITIVITY ANALYSIS

Prior to the ADM various sensitivity analyses based on low and high SLC, triangular distributions used in G2CRM model to compute benefits, and cost will be assessed to weight uncertainty in the economic analysis.

8. OTHER SOCIAL EFFECTS

The other social effects (OSE) account lays out economics and cultural aspects of different groups when evaluating the dynamics of social interaction in the Northern Virginia study area. Studies revealed that vulnerable groups and families living in poverty were less resilient when a natural disaster occurs. In order to formulate and mitigate for these issues urban and community life loss, health and safety were examinate in the Northern Virginia urban and community.

8.1 LIFE LOSS

To identify risk to life safety, each alterative was evaluated for potential life loss calculations. G2CRM is capable of modeling life loss using a simplified life loss methodology (reference to EVACUATION PLANNING ZONES section 3.2 of the Appendix). Since there is uncertainty in modeling life loss, the future without project condition was modeled to serve as a baseline. Therefore, when compared to the future with project condition, any addition or reduction of life loss from the baseline would serve as a proxy in identifying impacts to life safety the alternatives might have. Table 25 presents the mean life loss estimates for each alternative in the study area over a 50-year period of analysis.

Table 25: Alternatives Life loss

Alternative		Life Loss		
		Under 65	Over 65	Total
Alt-4b (MA7)	No Action	0.0	0.0	0.0
	Project	0.0	0.0	0.0
	Incremental Life Loss	0.0	0.0	0.0
Alt-4c (MA8)	No Action	0.0	0.0	0.0
	Project	0.0	0.0	0.0
	Incremental Life Loss	0.0	0.0	0.0
Alt-5a (MA17)	No Action	0.0	0.1	0.1
	Project	0.0	0.0	0.0
	Incremental Life Loss	0.0	-0.1	-0.1
Alt-5b1 (MA10)	No Action	0.1	2.0	2.1
	Project	0.0	1.8	1.8
	Incremental Life Loss	-0.1	-0.3	-0.3
Alt-5c (MA12)	No Action	0.4	3.5	3.9
	Project	0.0	0.4	0.5
	Incremental Life Loss	-0.3	-3.1	-3.4
Alt-6 (NS_100YR) (MA10,12,16,20)	No Action	0.6	6.5	7.1
	Project	0.6	5.5	6.1
	Incremental Life Loss	0.0	-1.0	-1.0
Alt-6 (NS_50YR) (MA10,12,16,20)	No Action	0.6	6.5	7.1
	Project	0.6	5.7	6.3
	Incremental Life Loss	0.0	-0.8	-0.8
Alt-6 (NS_20YR) (MA10,12,16,20)	No Action	0.6	6.5	7.1
	Project	0.6	5.8	6.4
	Incremental Life Loss	0.0	-0.7	-0.7

As part of the OSE analysis, it was important to learn the risk to the individuals impacted during a flood event. In addition, vulnerable populations such as the elderly were considered. Therefore, during the G2CRM modeling the vertical evacuation of vulnerable groups was considered. Life loss calculations are separated out by two ages. One category is people under 65 years and the second category is people over 65. There are three possible lethality functions for structure residents: safe, compromised, and chance. Safe would have the lowest expected life loss, although safe does not imply that there is no life loss. Chance would have the highest expected life loss.

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

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

Uncertainty is factorized in the life loss modeling. The results of the modeling should be viewed as more qualitative as opposed to a quantitative assessment of life loss even though the results are stated in numerical values. This result should be used in terms of order of magnitude compared to the baseline, No Action or the FWOP and when comparing the alternatives between each other.

As shown in Table 25, the implementation of project in each alternative would lower or show no increase in the overall life safety risk in the Northern Virginia study area when compared to the future without project condition.

8.2 HEALTH AND SAFETY

The health and safety of people living in the community within the project area were considered with the project condition in each alternative. Structural and nonstructural measures would protect the health and safety of residents from the direct impact of coastal storms by keeping flood waters away from property and eliminating future damages. Preliminary costs and benefits for providing flood risk management measures for critical infrastructure and other structures were developed for each alternative as part of this study. According to the Alexandria Demographics and Statistics Dashboard, the tract has a high population of Hispanic residents and a high percentage of renter occupied structures. The per capita income is a little less than half of the city average but is not low income. If the EJ Screen tool is run on the area affected within the census tract, the overall American Community Survey (ACS) estimates for Hispanic population proportion is lower than the entire tract and the per capita income is higher. While there would be some social benefits to the Four Mile Run alternative it may also have some negative social effects. The alternative would create an earthen berm which may be visually unappealing to some residents. It would also likely have effects on park usage during construction. The alternative also has similar impacts of fill to streams to what is proposed at Belle Haven. The PDT will continue to investigate the inclusion of critical infrastructure protection and the nonstructural measures in the communities that would most likely need additional support before, during, and after coastal flooding events. These vulnerable areas will be proposed in the recommended plan.

9. REGIONAL ECONOMIC DEVELOPMENT

When the economic activity lost in the flooded region can be transferred to another area or region in the national economy, these losses cannot be included in the NED account. However, the impacts on the employment, income, and output of the regional economy are considered part of the Regional Economic Development (RED) account. The input-output macroeconomic model

RECONS was used to address the impacts of the construction spending associated with the project alternatives

9.1 RECONS METHODOLOGY

The current certified RECONS 2.0 model was used to develop Northern Virginia Regional Economic Development (RED). The RED effects of each alternative will be examinate. The total cost for each alternative was used to input into the RECONS model.

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

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

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

9.2 RECONS RESULTS

Of the total expenditures, 99 percent will be captured within the local study area. The remainder of the expenditures will be captured within the state or national level. 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 below tables for each alternative.

Table 26: Alt-4b Regional Economic Development Summary

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$92,256,000	542	$79,817,000	$74,205,000
Secondary Impact		$81,284,000	413	$31,303,000	$52,186,000
Total Impact	$92,256,000	$173,540,000	955	$111,120,000	$126,391,000
State					
Direct Impact		$92,256,000	571	$79,817,000	$74,280,000
Secondary Impact		$95,256,000	510	$34,301,000	$58,042,000
Total Impact	$92,256,000	$187,512,000	1081	$114,118,000	$132,322,000
US					
Direct Impact		$92,432,000	672	$79,943,000	$74,391,000
Secondary Impact		$164,407,000	819	$54,712,000	$92,499,000
Total Impact	$92,432,000	$256,839,000	1491	$134,655,000	$166,890,000

Table 27: Alt-4c Regional Economic Development Summary

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$2,662,000	16	$2,303,000	$2,141,000
Secondary Impact		$2,346,000	12	$903,307	$1,506,000
Total Impact	$2,662,000	$5,008,000	28	$3,206,307	$3,647,000
State					
Direct Impact		$2,662,000	17	$2,303,000	$2,144,000
Secondary Impact		$2,743,000	15	$990,000	$1,675,000
Total Impact	$2,662,000	$5,405,000	32	$3,293,000	$3,819,000
US					
Direct Impact		$2,667,000	19	$2,307,000	$2,147,000
Secondary Impact		$4,744,000	24	$1,579,000	$2,669,000
Total Impact	$2,667,000	$7,411,000	43	$3,886,000	$4,816,000

Table 28: Alt-5a Regional Economic Development Summary

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$34,828,000	205	$30,132,000	$28,013,000
Secondary Impact		$30,686,000	156	$11,817,000	$19,701,000
Total Impact	$34,828,000	$65,514,000	361	$41,949,000	$47,714,000
State					
Direct Impact		$34,828,000	216	$30,132,000	$28,041,000
Secondary Impact		$35,878,000	192	$12,949,000	$21,912,000
Total Impact	$34,828,000	$70,706,000	408	$43,081,000	$49,953,000
US					
Direct Impact		$34,890,000	254	$30,179,000	$28,084,000
Secondary Impact		$62,066,000	308	$20,655,000	$34,919,000
Total Impact	$34,894,000	$96,956,000	562	$50,834,000	$63,003,000

Table 29: Alt-5b1 Regional Economic Development Summary

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$154,764,000	910	$133,897,000	$124,484,000
Secondary Impact		$136,359,000	693	$52,512,000	$87,545,000
Total Impact	$154,764,000	$291,123,000	1603	$186,409,000	$212,029,000
State					
Direct Impact		$154,764,000	958	$133,897,000	$124,608,000
Secondary Impact		$159,431,000	855	$57,541,000	$97,370,000
Total Impact	$154,764,000	$314,195,000	1813	$191,438,000	$221,978,000
US					
Direct Impact		$155,060,000	1127	$134,109,000	$124,795,000
Secondary Impact		$275,802,000	1369	$91,783,000	$155,172,000
Total Impact	$155,060,000	$430,862,000	2496	$225,892,000	$279,967,000

Table 30: Alt-5c Regional Economic Development Summary

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$49,324,000	290	$42,673,000	$39,673,000
Secondary Impact		$43,458,000	221	$16,736,000	$27,901,000
Total Impact	$49,324,000	$92,782,000	511	$59,409,000	$67,574,000
State					
Direct Impact		$49,324,000	305	$42,673,000	$39,713,000
Secondary Impact		$50,811,000	273	$18,339,000	$31,032,000
Total Impact	$49,324,000	$100,135,000	578	$61,012,000	$70,745,000
US					
Direct Impact		$49,418,000	359	$42,741,000	$39,773,000
Secondary Impact		$87,899,000	436	$29,252,000	$49,454,000
Total Impact	$49,418,000	$137,317,000	795	$71,993,000	$89,227,000

Table 31: Alt-6 NS_100YR Regional Economic Development Summary

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$207,266,000	1,218	$179,320,000	$166,713,000
Secondary Impact		$182,617,000	928	$70,326,000	$117,244,000
Total Impact	$207,266,000	$389,883,000	2,146	$249,646,000	$283,957,000
State					
Direct Impact		$207,266,000	1,283	$179,320,000	$166,880,000
Secondary Impact		$213,516,000	1,145	$77,061,000	$130,401,000
Total Impact	$207,266,000	$420,782,000	2,428	$256,381,000	$297,281,000
US					
Direct Impact		$207,662,000	1,509	$179,603,000	$167,131,000
Secondary Impact		$369,365,000	1,833	$122,920,000	$207,815,000
Total Impact	$207,662,000	$577,027,000	3,342	$302,523,000	$374,946,000

Table 32: Alt-6 NS_50YR Regional Economic Development Summary

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$186,015,000	1,093	$160,934,000	$149,620,000
Secondary Impact		$163,893,000	833	$63,115,000	$105,223,000
Total Impact	$186,015,000	$349,908,000	1,926	$224,049,000	$254,843,000
State					
Direct Impact		$186,015,000	1,151	$160,934,000	$149,770,000
Secondary Impact		$191,624,000	1,026	$69,160,000	$117,031,000
Total Impact	$186,015,000	$377,639,000	2,177	$230,094,000	$266,801,000
US					
Direct Impact		$186,369,000	1,354	$161,188,000	$149,994,000
Secondary Impact		$331,493,000	1,645	$110,316,000	$186,505,000
Total Impact	$186,369,000	$517,862,000	2,999	$271,504,000	$336,499,000

Table 33: Alt-6 NS_20YR Regional Economic Development Summary

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$129,201,000	760	$111,781,000	$103,922,000
Secondary Impact		$113,836,000	579	$43,838,000	$73,085,000
Total Impact	$129,201,000	$243,037,000	1,339	$155,619,000	$177,007,000
State					
Direct Impact		$129,201,000	800	$111,781,000	$104,026,000
Secondary Impact		$133,097,000	714	$48,037,000	$81,287,000
Total Impact	$129,201,000	$262,298,000	1,514	$159,818,000	$185,313,000
US					
Direct Impact		$129,448,000	941	$111,957,000	$104,182,000
Secondary Impact		$230,247,000	1,143	$76,623,000	$129,542,000
Total Impact	$129,448,000	$359,695,000	2,084	$188,580,000	$233,724,000

In summary, the construction stimulus in the Northern Virginia would generate for each alternative full-time equivalent jobs, labor income, and output in the local, State and the whole Country as shown in above tables.

10. ENVIRONMENTAL QUALITY

Wetland information and Geographic Information System Mapping (GIS) data were collected from various sources for identification of wetland areas within the study areas. USGS topographic quadrangles, U.S. Department of Agriculture (USDA) web soil surveys, Federal Emergency Management Agency floodplain mapping, and U.S. Fish and Wildlife Service's (USFWS) National Wetland Inventory (NWI) were used to access submerged aquatic vegetation, soil types, historical resources, archeological sites, environmental justice community, and aesthetics were examined in the classification of alternatives. The environmental quality (EQ) account used qualitative assessment consistent with ecosystem environmental compliance guidance to assesses the impact of floodwall, levee, and nonstructural measures in the Northern Virginia study area. The analysis does not include any quantitative EQ benefits. The scales used to evaluate the alternatives in EQ account were "Minor", "Significant", and "Severe".

11. COMPARISON OF FOUR ACCOUNTS

In Section 5 of this economic analysis, the NED was developed using G2CRM. Alt-4c and Alt-5c have positive net benefits. Detailed costs and benefits were presented but for the simplicity of the comparison the average annual net benefits will be used.

The OSE was estimated in Section 6 using G2CRM model. Each structure has an associated storm surge lethality. The vulnerable group, the elderly over 65 years old was considered separately from the population under 65 years old to assess life loss risk to the individuals impacted during a flood event.

The RED was analyzed in Section 7 of the economic appendix using RECONS model. The expenditures in each alternative were used to capture the direct and indirect impacts within the local, the state or national level. Since RECONS uses the expenditures in the study area to forecast future jobs and value added to the economy, the higher the cost of the project the higher are jobs and value added to the economy. The 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 for each alternative.

The (EQ) account assessed the impact of project on species, historical resources, proximity of project to wildlife, and air quality in the study area. In accordance with ecosystem and environmental compliance guidance the alternatives were compared using ranking scale.

Table 34 presents the comparative summary of the four accounts as required by the 5 January 2021 Policy Directive (Policy Directive) from the Assistant Secretary of the Army for Civil Works (ASA(CW)) in Comprehensive Documentation of Benefits in Decision Document.

Table 34: Summary of the four P&G Accounts

Plan Alternatives	Alternative Area Description	NED	RED		OSE	EQ	
		Nets Benefits ($)	US Jobs	Value Added ($)	Incremental Life Loss	Effects	Impact
Alt-4b	BH7: Reagan National Airport Proposed Bulkhead	($3,065,000)	1491	$166,890,000	0.0	Approximately 15,000 square feet of temporary impacts to submerged aquatic vegetation, Contaminated soils, Mount Vernon Trail Historic Resource	Moderate
Alt-4c	BH8: Four Mile Run Arlington WPCP Proposed Bulkhead	$89,000	43	$4,816,000	0.0	Potential Contaminated Soils	Minor
Alt-5a	BH17: Four Mile Run Alexandria Proposed Bulkhead	($1,077,000)	562	$63,003,000	-0.1	Approximately 2,750 square feet of permanent stream impacts, Potential contaminated soils, Archeological site, Aesthetics, Beneficial to environmental justice community	Moderate
Alt-5b1	BH10: Old Town Alexandria Proposed Bulkhead	($4,048,000)	2496	$279,967,000	-0.3	During Construction	Minor
Alt-5c	BH12: Belle Haven Proposed Bulkhead	$361,000	795	$89,227,000	-3.4	Approximately 2,500 square feet of permanent stream impacts, Potential contaminated soils, Viewshed from historic resources, Aesthetics	Moderate
Alt-6 NS_100YR	MA10 & MA20: Old Town Alexandria MA12: Belle Haven MA16: Occoquan Bay	($5,812,000)	3,342	$374,946,000	-1.0	Alexandria and Occoquan Historic Districts	Minor
Alt-6 NS_50YR	MA10 & MA20: Old Town Alexandria MA12: Belle Haven MA16: Occoquan Bay	($5,228,000)	2,999	$336,499,000	-0.8	Alexandria and Occoquan Historic Districts	Minor
Alt- 6 - NS_20YR	MA10 & MA20: Old Town Alexandria MA12: Belle Haven MA16: Occoquan Bay	($3,551,000)	2,084	$233,724,000	-0.7	Alexandria and Occoquan Historic Districts	Minor

12. TENTATIVELY SELECTED PLAN

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

Section 904 of the Water Resources Development Act of 1986 (WRDA of 1986) requires the Corps to address the following matters in the formulation and evaluation of alternative plans:

- *Protecting and restoring the quality of the total environment.*
- *The well-being of the people of the United States*
- *The prevention of loss of life.*
- *The preservation of cultural and historical values*

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

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

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

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

The project delivery team evaluated the optimization of plans. As a result of the comparison of the alternatives in the four accounts, the effects of OSE, and EQ accounts were insignificant. Since RECONS uses expenditures to forecast future jobs and value added to the economy, the higher the cost the higher are jobs and value added to the economy. Hence, RED should not be a driving factor in selection of the TSP. Alternative 8, which is the combination of Alt-4c (Proposed Floodwall at Four Mile Run Arlington WPCP) and Alt-5c (Proposed Levee and Floodwall at Belle Haven) had positive net benefits. Alternative 8 benefits were greater than the cost. It is identified as the NED Plan and has been recommended to be the TSP.

Average annualized cost and benefits are respectively $3,219,000 and $64,000 for Reagan National Airport. For Old Town Alexandria they are $5,249,000 and $1,201,000. While the transportation disruptions will have huge impacts on local and national economic at Reagan National Airport, the BCRs are near zero in both areas. In the past, some runway areas got wet, but this does not impact airplanes operations. With sea level rise we anticipate strong storm events in a future. Flooding will severely impact the airport operation and will create significant damages to local economy and to the nation in general. Reagan airport infrastructure is a part of vulnerability assessment developed by ERDC. The PDT is coordinated with airport authorities to collect data on operation disruptions, and to develop resiliency at the airport.