US Army Corps of Engineers®

Baltimore Metropolitan
Coastal Storm Risk Management Feasibility Study

APPENDIX E

Economic Analysis

FINAL REPORT

May 2024

Table of Contents

1. INTRODUCTION

This appendix presents an economic evaluation of coastal storm risk management (CSRM) for the national economic development (NED), regional economic development (RED), environmental quality (EQ), and other social effects (OSE) accounts undertaken for the Baltimore Coastal Storm Risk Management Feasibility Study (Baltimore Coastal Study). This economic evaluation was conducted in accordance with the U.S. Army Corps of Engineers (USACE) Planning Guidance Notebook in Engineer Regulation (ER) 1105-2-100, and the Risk Analysis for Flood Damage Reduction Studies in ER 1105-2-101. 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 (IWR) (USACE, 2011), was also used as a reference, along with the USACE Generation II Coastal Risk Model (G2CRM) User's Manual v4.556.3 (USACE, 2021). G2CRM is the CSRM certified model used to analyze flood damages. The economic evaluation was conducted using the fiscal year (FY) 2024 discount rate (October 2023 price level) and G2CRM version 4.564. The year 2031 was used as the base year and the basis for alternative comparison using the FY24 discount rate of 2.75 percent in the final recommended plan.

2. STUDY BACKGROUND

The federal objective of water and related land resources project planning is to contribute to NED consistent with protecting the nation's environment, reducing life loss, and increasing RED benefits, while complying with applicable executive orders and other federal planning requirements. Contributions to NED, expressed in monetary units, are the direct net benefits that accrue in the planning area and the rest of the nation. NED benefits accrue primarily through the reduction in actual or potential damages to affected land uses. Inundation reduction benefits are the increases in net income generated by the affected land uses.

2.1 STUDY AUTHORITY

The Baltimore metropolitan area has an existing study authorization from Congress: the resolution of the U.S. House of Representatives Committee on Public Works and Transportation dated 30 April 1992.

> *"Resolved by the Committee on Public Works and Transportation of the United States House of Representatives, That the Board of Engineers for Rivers and Harbors, is requested to review the report of the Chief of Engineers on the Baltimore Metropolitan Area, Maryland, published as House Document 589, Eight-seventh Congress, Second Session, and the reports of the Chief of Engineers on Baltimore Harbor and Channels, Maryland, and Virginia, published as House Document 181, Ninety-fourth Congress, First Session, and House Document 86, Eighty-fifth Congress, First Session, and other pertinent reports, to determine whether modifications of the recommendations contained therein are advisable at the present time, in the interest of flood control, hurricane risk reduction,*

navigation, erosion, sedimentation, fish and wildlife, water quality, environmental restoration, recreation, and other related purposes."

Following Hurricane Sandy in 2012, USACE completed the North Atlantic Coast Comprehensive Study (NACCS), which identified nine high-risk areas on the Atlantic Coast that warranted further investigation of CSRM solutions. The Baltimore metropolitan area was identified as one of the nine high-risk areas recommended by NACCS for a follow-on feasibility study to investigate solutions to coastal flooding problems.

The study authority was identified by USACE, Baltimore District, 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. Although the study authority also identifies other purposes, this study focuses solely on CSRM. This study is an interim response to the study authority.

2.2 STUDY AREA

The study area encompasses the portion of the City of Baltimore and surrounding metropolitan areas in eastern Baltimore County and northern Anne Arundel County to approximately the Francis Scott Key Bridge (I-695) and along the tidally influenced areas that were subject to flooding, storm surge, and damages because of Hurricane Sandy and other recent storms (Figure 1). The study area includes the coastline from Coffin Point to the Cox Creek Dredged Material Containment Facility (DMCF). The Baltimore metropolitan coastline in the study area is approximately 33.3 square miles.

The study area was defined to also include many assets of importance to the non-federal sponsor (NFS), the Maryland Department of Transportation (MDOT) including the Martin State Airport[1] in Baltimore County as shown in Figures 2, 3, and 4. Within the Patapsco River study area, Baltimore City contains approximately 69 miles, Anne Arundel contains 1.5 miles, and Baltimore County contains 4 miles of shoreline. The Baltimore County study area contains approximately 4 miles of shoreline along Martin State Airport.

The population within the extent of the category 4 inundation zone is approximately 85,000. There are several locations of national significance in the study area including the Fort McHenry National Monument and Historic Shrine (a unit of the National Park Service), historic structures and districts, and an important United States Coast Guard (USCG) boatyard and dry-dock facility. Critical infrastructure in the study area includes the Port of Baltimore, Interstate I-95 and I-895 tunnels and bridges including the Fort McHenry Tunnel (I-95) and the Baltimore Harbor Tunnel (I-895), Harbor Hospital, Martin State Airport, electrical generation and transmission systems, water and communications utilities, and cargo and commuter rail systems.

[1] Martin State Airport is a joint civil-military airport in Baltimore County, MD. The Maryland Aviation Administration operates the airport on behalf of the Maryland Department of Transportation.

Figure 1: Baltimore Metropolitan Study Area

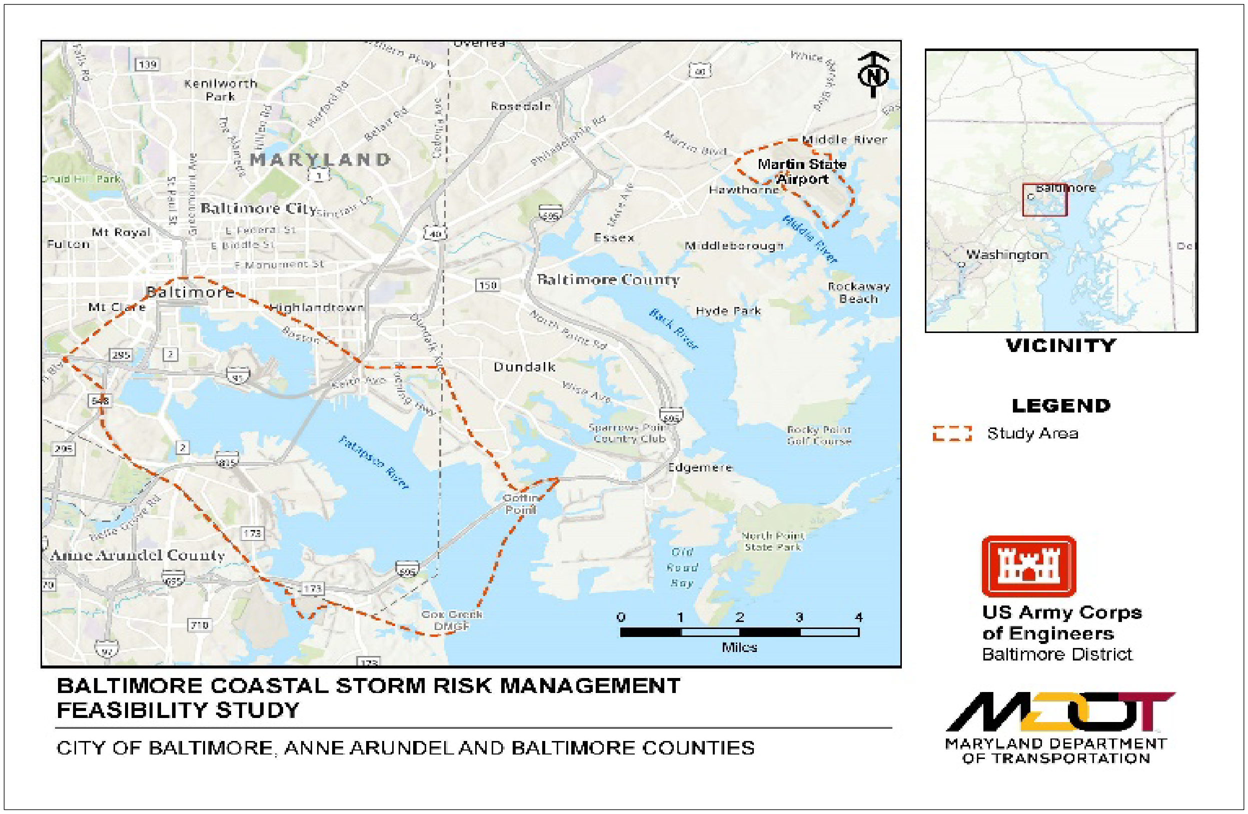


Figure 2: Baltimore Harbor Tunnel (I-895)

Figure 3: Fort McHenry Tunnel (I-95)

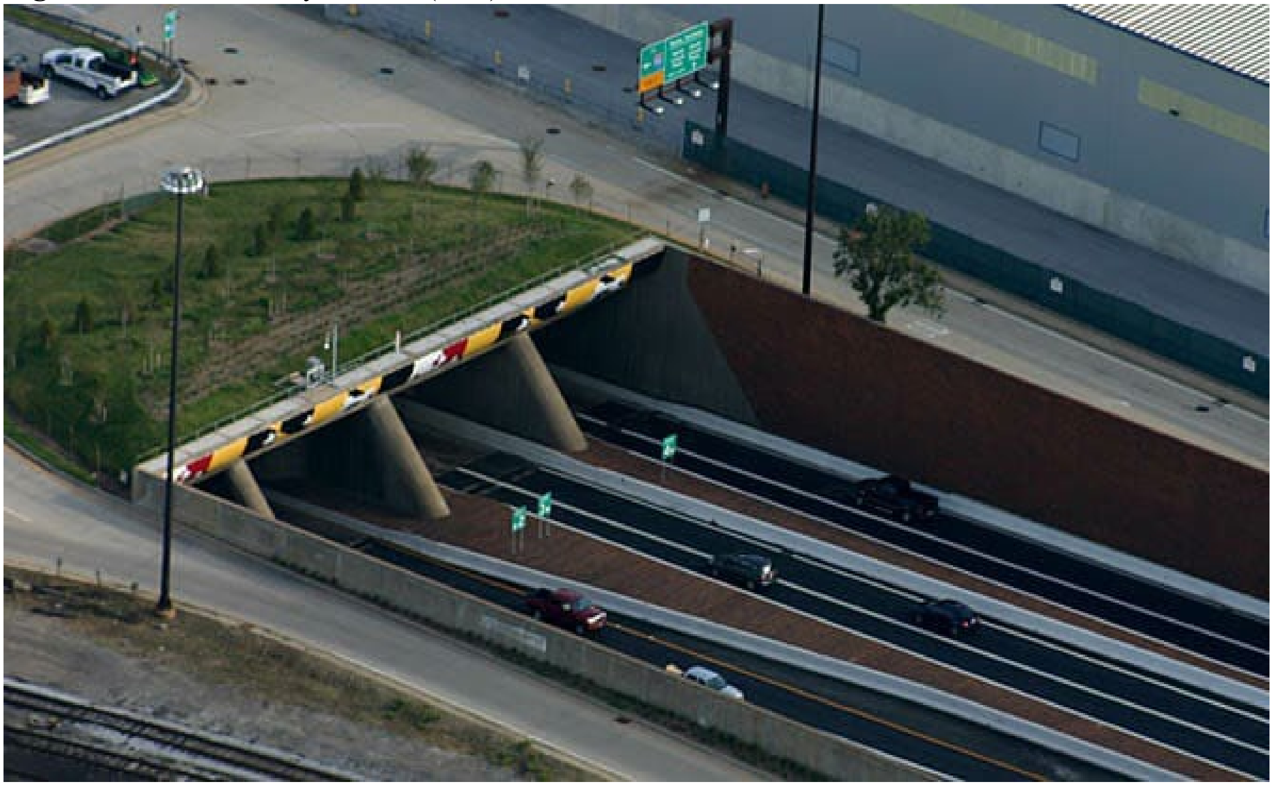


Figure 4: Martin State Airport

2.3 PURPOSE

The purpose of the Baltimore Coastal Study is to evaluate the feasibility of federal participation in implementing solutions to problems associated with coastal storm damage and to support resilient communities in the study area. The study is needed to consider alternatives to reduce coastal flood risk to vulnerable populations, properties, infrastructure, and environmental and cultural resources in the study area, considering future climate and sea level change (SLC) scenarios.

The study area has been impacted by numerous major tropical and extratropical events, most notably by Hurricane Able (September 1952), Hurricane Hazel (November 1954), Hurricane Connie (August 1955), Tropical Storm Agnes (June 1972), Tropical Storm David (September 1979), Hurricane Isabel (September 2003), Tropical Storm Ernesto (September 2006), Tropical Storm Hanna (September 2008), and Hurricane Irene (August 2011). Hurricane Isabel in 2003 resulted in extreme water levels and caused millions of dollars of damage to residences, businesses, and critical infrastructure. High storm surges occurred along the Chesapeake Bay and its tributaries. Over 570 homes and 15 businesses were declared uninhabitable from flooding. The problem in the study area is economic damages caused by storm surge and waves from coastal storms, that produce flooding in low lying areas.

2.4 PROBLEM DESCRIPTION

The Baltimore metropolitan area is characterized by flat terrain. This is causing the area to be highly susceptible to flooding from the tidal surges of hurricanes and tropical storms, as well as riverine flooding from excess precipitation. Exacerbating the flooding is the phenomenon of relative sea level change (RSLC), which is the combination of the water level rising and the land subsiding.

The highest storm surge that has occurred within the operating life of the Baltimore Harbor Tunnel (I-895) or Ft. McHenry Tunnel (I-95) was Tropical Storm Isabel in September of 2003, which caused tidal surge about 8 feet higher than normal. The tunnels did not suffer any damage from this storm, and no other coastal storm has yet reached that water level in this area. However, higher storm water levels are expected within the tunnels' operating life in the future. A storm of similar or greater magnitude has the potential to damage the tunnel infrastructure and support systems.

Recent events resulted in partial or total shutdown of the tunnels:

a) On 12 August 2014, traffic to the I-895 Tunnel was temporarily detoured due to flash flooding caused by heavy rainfall.

b) On 18 October 2005, the I-895 Tunnel was closed, while traffic on Interstate 95 through the Fort McHenry Tunnel was limited to one lane in each direction for about two hours due to a "terrorist threat". This situation created transportation disruption and loss of income and economic opportunities for the region.

c) Tunnels are periodically closed for maintenance, traffic incidents, and other special events, resulting in economic loss for the Baltimore metropolitan area.

The impacts of Hurricane Sandy in the study area were relatively minimal compared to the large-scale damage experienced from Hurricane Isabel in 2003 and other past storm events of record. The problem in the study area is economic damages caused by coastal storms, which produce direct damages through wave action and induce flooding in low lying areas.

Coastal storms have produced extensive property damage and loss of life resulting from storm surge and flooding in recent years, particularly from Hurricane Isabel in 2003. Hurricane Isabel resulted in approximately $4.8 million in damages (based on 2003 price levels) in the City of Baltimore, up to $252 million in southern Baltimore County, and one fatality due to flooding. Damages from the hurricane rendered 570 homes and 15 businesses uninhabitable, and 70,000 people were without power.

There is a need for this study because Baltimore City 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 NED, but may also improve the living conditions of the community and preserve historic and cultural resources. For the purposes of this economic appendix, assets include residential and nonresidential structures with their content values, residential vehicles, infrastructure, and cargo at the Port of Baltimore, the I-95 Tunnel, the I-895 Tunnel, Baltimore Shot Tower Metro Station, and the munition depot at Martin State Airport. In addition to the benefits assessed from these assets, additional benefits are associated with storm surge and the debris clean-up cost reduction.

2.5 SCOPE OF THE STUDY

The primary focus of the Baltimore Coastal Study is storm surge inundation. While the Baltimore metropolitan area also experiences flooding from high tides and rainfall, those issues are not within the scope of this study authorization. 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 1105-2-103. 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 CSRM measures, and development and evaluation of alternative plans to address flooding related to coastal storm events in the Baltimore metropolitan area. It also documents the procedures used to analyze various measures designed to reduce the risk of flood damages, incorporating comprehensive assessment and documentation of benefits in the conduct of USACE water resources development project planning. Hence, the analysis evaluates NED, RED, EQ, and OSE benefits, and identifies the Tentatively Selected Plan.

2.6 SOCIOECONOMIC DATA

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

The Baltimore metropolitan area is a major tourist destination in the U.S., with the City of Baltimore driving a significant portion of the attraction. In 2018, 26.7 million people visited Baltimore, with an estimated $10.7 billion in total business sales connected to tourism. Tourism sustained over 86,000 jobs in the Baltimore region, both directly and indirectly.

The Port of Baltimore constitutes a major platform for the national and international economy not only for the State of Maryland, but for the entire U.S. The Port was responsible for $2.9 billion in personal income. According to the U.S. Bureau of the Labor Statistics, the Port of Baltimore's average salary for the direct job holder is 16.4 percent higher than the average annual wage for the State of Maryland.

The Port of Baltimore supports approximately 33,920 jobs including cargo and vessel jobs and indirect local jobs in the State of Maryland. A total of 93,700 jobs in the State of Maryland are directly related to activities at the Port. Related jobs are those jobs with Maryland companies that chose to import and export their cargo through the Port of Baltimore, but they have the option of shipping their products or supplies through several other ports. These companies benefit from having a healthy port nearby in Baltimore to assist their logistics. If the Port of Baltimore were not available to them, these firms could suffer an economic penalty over the longer term but would likely survive because they are less dependent upon the Port than the direct, induced, and indirect jobs. When combining direct and indirect jobs with related jobs, there are over 127,600 jobs linked to the Port of Baltimore.

2.7 POPULATION

Table 1 shows the historic and projected population numbers for Baltimore County and Anne Arundel County, Maryland. The study team was unable to locate valid population projections for Baltimore City from 1980 through 2030. Within the study area, the City of Baltimore is the most affected by flooding among the three Baltimore metropolitan jurisdictions. The population of Baltimore City declined from 620,770 in 2010 to 585,708 in 2020 according to Census Bureau data.

Table 1: Historic and Projected Population in Baltimore County and Anne Arundel County, Maryland

	1980		1990		2000		2010		2020		2030	
	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate	Population	Avg. Growth Rate
Baltimore County	655,615	-	692134	0.5%	754,292	0.9%	805,029	0.7%	854,535	0.6%	849,000	-0.1%
Anne Arundel County	370,775	-	427,239	1.4%	489,656	1.4%	537,656	0.9%	588,261	0.9%	572,800	0.3%

Sources: U.S. Census Bureau https://worldpopulationreview.com/us-counties/md/

The population and housing statistics in the Baltimore Coastal Study planning units from the 2017 American Community Survey is presented in Table 2.

Table 2: Population and Housing Statistics in Planning Units

Planning Unit Name	American Community Survey 2017, 5-Year Population Estimate	American Community Survey 2017, 5-Year Housing Unit Estimate
Martin State Airport	0	0
Inner Harbor	24,001	11,483
Patapsco North	3,273	1,522
Patapsco South	0	0
Middle Branch	16,168	6,969
Patapsco East	1,106	412
Locust Point	3,539	1,659
TOTALS	48,087	22,045

6.2 INCOME AND POVERTY STATUS

The current median household income in the City of Baltimore, Baltimore County, and Anne Arundel County are respectively $50,379, $76,866, and $100,798 with the poverty rate at 21.2%, 8.9%, and 5.8% in 2019 according to Census Bureau data.

3. METHOD OF ANALYSIS

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 SLC. This condition is evaluated for a 50-year period of analysis for CSRM 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 50-year period of analysis.

The difference in expected annual flood damages to the Baltimore metropolitan area assets between the future without condition and the future with project condition represents the CSRM 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 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 ASSUMPTIONS

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

- Floodplain residents will react to a floodplain management plan in a rational manner.
- The rebuild option was turned off in G2CRM. Hence, there are zero rebuilds allowed. This action prevents not only non-conforming structures to be raised but also conforming structures during model simulations. In addition, all new buildings, and additions to the buildings to post-Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) buildings after July 1, 1991, must be elevated at least as high as FEMA Base Flood Elevation (BFE) and are not included in the benefit base. The Baltimore Coastal study area has many historic buildings that cannot be abandoned, removed, or altered without prior approval from applicable local and state government agencies. Moreover, it is more likely that property owners would continuously repair damage to their properties due to flooding since flooding often occurs in the study area. This is essentially due to high demand for housing in the Baltimore metropolitan area, people behavior, and their cultural norms to stay in their own community.
- Floodproofing is used on the selected structures at 0.05, 0.02, and 0.01 annual exceedance probability (AEP).
- The residential depth-percent damage relationships for one-story and two-story structures with no basement are contained in Economic Guidance Memorandum (EGM) 01-03 and (EGM) 04-01 (content-to structure value ratio (CSVR)) 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 IWR. Non-residential flood depth-damage functions (DDFs) 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 2024 federal discount rate of 2.750% assuming a 50-year period of analysis in the final recommended plan.
- All values in the final recommended plan are equivalent to October 1, 2023, dollars, FY 2024.
- All project alternatives are evaluated for a 50-year period of analysis.
- Model simulation begins in 2023. This year determines the start year for G2CRM.
- 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).
- SLC follows the USACE intermediate curve and the published sea level rate of 0.01010 ft 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 USACE 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 IWR in cooperation with other USACE groups developed G2CRM to support CSRM planning-level studies.

3.2.1 MODEL DESCRIPTION

G2CRM is distinguished from other models currently used to analyze inundation damages 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 SLC, 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) 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 (PSE)* – 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, 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, bulkhead, or levee. PSEs are limited to bulkheads/seawalls and levee.

3.2.2 MODEL VARIABLES

According to the USACE 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 PLCA model using event-driven MCS. The 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.

3.2.2.1 ECONOMIC INPUTS

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

3.2.2.1.1 STRUCTURE INVENTORY

The parcel data and building data used to develop a structure inventory of residential and nonresidential structures were obtained from Baltimore City, Baltimore County, and Anne Arundel County. Cargo including vehicles at the Port of Baltimore, wastewater treatment facilities, and tunnels data were received from MDOT Maryland Port Authority) which is the study's NFS. Privately owned vehicles in the study area were estimated and added to the inventory. Debris clean-up cost that the community incurs during a flood event was evaluated and added to each residential and nonresidential structure. The assets will be further discussed in the assets section (Section 4.1) and the emergency costs section (Section 3.2.2.1.3). This inventory was integrated with data from the National Structure Inventory (NSI 2) and modified by USACE to produce the Spatial Asset Data input for G2CRM. The number of assets (i.e., structure inventory) were based on city and county tax assessor databases reflecting development up to the year 2018. A total of 14,223 structures including residential structures, nonresidential structures, and synthetic assets (private vehicles and debris clean-up) were included in the inventory. Newly permitted construction assets from 2019 through 2021 were not provided by the NFS. Moreover, to derive the structure values, the 2020 RS Means[2] Square Foot Costs Data catalog was used to assign a depreciated replacement cost to the residential and nonresidential structures assets in the study area. Among the 14,223 structures in the inventory, 8,917 assets represented residential and nonresidential structures. The residential and nonresidential structures and other assets were further categorized into 29 occupancy types for evaluation. Table 3 displays the occupancy types and descriptions.

Table 3: Occupancy Types for Residential, Nonresidential and Auto assets in the Baltimore Coastal Study Area.

Occupancy Type	Description	Count
AUTO-N	Auto/Commercial	64,339
AUTO-R	Auto/Residential	3,404
COM1	Average Retail	548
COM2	Average Wholesale	161
COM3	Average Personal & Repair Services	123
COM4	Average Professional/Technical Services	143
COM5	Bank	10
COM7	Average Medical Office	15
COM8	Average Entertainment/Recreation	44
COM9	Average Theatre	3
COM10	Garage	13
EDU1	Average School	12

[2] The depreciated replacement values (DRV's) will not account for the inflation of the cost of construction materials since the beginning of the pandemic as DRV's move on a 5-year average.

Occupancy Type	Description	Count
GOV1	Average Government Services	81
GOV2	Average Emergency Response	2
HRISE	Average Urban High-Rise, More Than 4 Floors	635
IND1	Average Heavy Industrial	79
IND2	Average Light Industrial	347
IND3	Average Food/Drugs/Chemicals	37
IND4	Average Metals/Minerals Processing	25
IND5	Average High Technology	20
IND6	Average Construction	34
REL1	Church	16
RES1-1SNB	Single Family Residential, 1 Story, No Basement	36
RES1-1SWB	Single Family Residential, 1 Story, With Basement	18
RES1-2SNB	Single Family Residential, 2 Story, No Basement	1,024
RES1-2SWB	Single Family Residential, 2 Story, With Basement	1,755
RES3A	Condominium, Living Area, 1-2 Floors	4
RES3B	Condominium, Living Area, 3-4 Floors	117
RES4	Average Hotel, & Motel	4
Total		8,917

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 to 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% 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% and 50%, 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 94% of the national square foot costs for the City of Baltimore 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 within the structure 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% 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% and 55%, respectively, reflecting effective ages of 20 and 40 years for structures in good and poor condition, respectively. Additionally, a residential location cost factor of 92% of the national square foot costs for the City of Baltimore 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 to 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.

3.2.2.1.2 CONTENT-TO-STRUCTURE VALUE RATIOS

Site-specific Content-to-Structure Value Ratios (CSVR) information was not available for the study area. The nonresidential CSVR information was 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 EGMs.

3.2.2.1.3 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,
- The administrative costs for public agencies and private relief agencies in delivering emergency services.

Debris clean-up costs are evaluated and included in the Baltimore Coastal Study. The cost of debris removal can vary according to the residential or nonresidential occupancy type of each 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 field 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 ft, 5 ft, and 12 ft depths of flooding. A prototypical structure size in square feet was used for each residential and nonresidential occupancy category. 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 DDF with uncertainty in the economic models. All values and DDFs were selected according to the short-duration flooding data specified in a report entitled: *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 Baltimore metropolitan area, using the indexes provided by Gordian's 40th edition of "Square Foot Costs with RS Means Data." The debris removal costs associated with individual residential and nonresidential structures were included in the inventory as separable records. They are used to calculate the expected annual without-project and with-project debris removal and cleanup costs. The debris removal DDFs are different from the physical building DDFs.

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

Table 4: Debris Clean-Up Maximum Cost for Each Structure

Occupancy Type	New Orleans Study Prototype	Maximum 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-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-GOV1	Average government services	43,417
D-GOV2	Average Emergency Response	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-RES3A	Multi-Family housing 2 units	10,777
D-RES3B	Multi-Family housing 3-4 units	10,777
D-RES4	Average Hotel, & Motel	42,560

3.2.2.1.4 DEPTH-DAMAGE RELATIONSHIP

Site-specific DDFs were not available for the study area for both nonresidential and residential structures. The nonresidential DDFs were taken from the *Draft Report, Nonresidential Flood Depth-Damage Functions Derived from Expert Elicitation*. These values can be found in Appendix D, Tables D-22 through D-42 for structures and Tables D-43 through D-63 for content, of the report. The residential DDFs used a combination of the IWR *Expert Elicitation Draft Report*, EGM 01-03, EGM 04-01, and NACCS depths damage curves for high-rise structures. Moreover, both EGMs 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.

3.2.2.1.5 FIRST FLOOR ELEVATION

The 2017 Light Detection and Ranging (LiDAR) raster in ft NAVD 88 was used to determine ground elevations at the centroid of each parcel where the structure is most likely located (using ArcGIS). For the TSP, the NFS provided the foundation heights using foundation height certificates. The foundation height of each structure was added to the ground elevation to determine probable first floor elevations.

There are two sources of uncertainty surrounding first floor elevations: the use of the LiDAR data for the ground elevations, and the survey technique used to determine the structure foundation heights above ground elevation. Desktop analysis was conducted and found a survey technique error of +/- 0.5 ft for each occupancy type.

Error in the LiDAR data was further calculated to have a fundamental vertical accuracy of 18.13 centimeters (cm) at a 95% confidence level using RMSE(z) x 1.9600 (RMSE – Root Mean Square error) as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines. The following table shows uncertainty calculations around ground elevations.

Table 5: Uncertainties around Ground Elevations

Ground – LiDAR (Conversion cm to inches then to feet)		
+/- 18.13 cm @ 95% confidence		18.13cm
	x	0.3937
z = (x – u)/ std. dev.		7.1378in
	÷	12
1.96 = (0.5948 – 0)/ std. dev.		0.5948ft
0.3035 = std. dev.		

The combined triangular uncertainty distribution surrounding the foundation height and the ground elevation is:

$$\sqrt{(0.5^2 + 0.3035^2)} = 0.58 \text{ feet}$$

For instance, if the finished floor elevation (FFE) likelihood value is found to be 10 feet, the minimum and maximum values will be 9.42 ft and 10.58 ft, respectively.

3.2.2.2 ENGINEERING INPUTS

The uncertainty surrounding the key engineering parameters was quantified and entered into G2CRM. The model is based upon driving forces (i.e., storms) that affect a study area. The study area is comprised of individual sub-areas of different types, defined as model areas, which may interact hydraulically and may be defended by coastal defense elements, such as PSEs, 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 storm surge elevations for the study area. The modeled water surface elevations (WSELs) were adjusted for anticipated changes due to SLC for another 5 years through the end of the period analysis, year 2080. The level of performance is based on the 100-year WSEL with an approximately 95% confidence level and intermediate SLC curve through year 2080. The Baltimore Coastal Study Civil Engineering Appendix (Appendix A) contains more information regarding engineering inputs into G2CRM.

3.2.2.2.1 STORMS

NACCS produced storm tracks that cover the probability space of potential storms. These tracks allow for selection of relevant storms for study sites. A reasonable number of storms are needed to adequately capture the storm surge hazard. The goal of storm selection is to find the optimal combination of storms given a predetermined number of storms to be sampled, referred to as a reduced storm set. For the Baltimore Coastal Study, storm tracks within a 200-kilometer radius of the study area were selected. A total of 291 tropical storms and 100 extra tropical storms were selected. 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 291 tropical storms and 100 extra 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 to compare the hazard curves. The differences between the reduced storm set and the full storm set can be computed along the entire hazard curve, or by prioritizing a specific segment of curves, for example, 50 to 500 years.
6. Compute differences between the 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 the increasing storm subset size.

9. Finalize storm selection.

The bootstrap method was used to determine storm events for the period of analysis in G2CRM. Each G2CRM simulation run starts with using the above-mentioned reduced storm set. Storms are drawn randomly by bootstrapping. The bootstrap approach is based on choosing the random storms as a Poisson distribution based on an 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. A rate of 0.015 storms per month was applied from June to November for the tropical season and 0.1689 storms per month was applied for the extratropical season. Datum conversions for tide and surge were calculated based on the NACCS Coastal Hazards System (CHS). Conversion data available for save points was applied within the metadata files to convert water levels to NAVD88 used for the asset inventory. Each of the 291 tropical storms and 100 extra tropical storms for the study area has an associated storm probability and storm surge information (e.g., water levels) at each save point. However, 7 storms, (storms identifiers NACCS_96, NACCS_97, NACCS_98, NACCS_99, NACCS_997, NACCS_998, and NACCS_999) had a water level of zero.

3.2.2.2.2 TIDE GAUGE

Baltimore Harbor tides were evaluated using NOAA tide gauge 8574680 at Fort McHenry installed in September of 1989. The mean tide range in the Harbor is 1.14 feet and the diurnal range is 1.66 feet. Occasionally, abnormally high, or low water levels occur as a result of changes in atmospheric pressure, storm surge, the magnitude and direction of wind and/or waves, and other meteorological anomalies. The highest water level observed was 8.15 feet mean lower low water (MLLW) (7.31 ft NAVD88) during Hurricane Isabel on 19 September 2003.

3.2.2.2.3 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. The Advanced Circulation Model (ADCIRC) is a high-fidelity model that predicts water levels and currents based on input parameters including subsurface bathymetry, wind velocity, atmospheric pressure, and storm tracks. The results of ADCIRC are in the form of water level hydrographs and are reported in save points. From many points, three comprehensive save points (5944, 10930, and 13228) were selected for the study area. Save point 5944 is in Fort McHenry, save point 10930 is in Martin State Airport, and save point 13228 is near the Port of Baltimore. These save points contained the water elevations for each storm to be used in the model and eventually used to represent 25 model areas. The STWAVE domain with wave actions was not available for the save points used in the economic model. The points were extracted from the ADCIRC domain. Table 6 presents the list of the save points in each model area.

Table 6: Save Point Locations by Model Area (MA)

MA	MA Description	MA Type	Save Point	MA Subject to Waves and/or Surge	Ground Elevation
MA1	Martin State Airport	Upland	10930	Surge Only	4.6
MA2	Martin State Airport West Bulkhead	Upland	10930	Surge Only	4.6
MA3	Martin State Airport East Bulkhead	Upland	10930	Surge Only	8
MA4	Patapsco East	Upland	13228	Surge Only	5.3
MA5	Patapsco North	Upland	13228	Surge Only	4.7
MA6	Patapsco North Dundalk Bulkhead	Upland	13228	Surge Only	4.7
MA7	Patapsco North Seagirt Bulkhead	Upland	13228	Surge Only	6.2
MA8	Patapsco North I-895 Tunnel Bulkhead	Upland	13228	Surge Only	7.6
MA9	Inner Harbor	Upland	5944	Surge Only	2.2
MA10	Inner Harbor Canton Bulkhead	Upland	5944	Surge Only	2.2
MA11	Inner Harbor Bulkhead	Upland	5944	Surge Only	2.8
MA12	Inner Harbor Ritz Carlton Bulkhead	Upland	5944	Surge Only	7.9
MA13	Inner Harbor Harborview Bulkhead	Upland	5944	Surge Only	7.9
MA14	Locust Point	Upland	13228	Surge Only	2.9
MA15	Locust Point Museum of Industry Bulkhead	Upland	13228	Surge Only	2.9
MA16	Locust Point American Sugar Bulkhead	Upland	13228	Surge Only	5
MA17	Locust Point Fort McHenry Bulkhead	Upland	13228	Surge Only	2.9
MA18	Locust Point I-95 Tunnel Facility Bulkhead	Upland	13228	Surge Only	9.4
MA19	Locust Point I-95 Tunnel Bulkhead	Upland	13228	Surge Only	4
MA20	Middle Branch Patapsco River	Upland	13228	Surge Only	2.6
MA21	Middle Branch Patapsco River Bulkhead	Upland	5944	Surge Only	2.6
MA22	Patapsco South	Upland	13228	Surge Only	2.9
MA23	Patapsco South Fairfield Bulkhead	Upland	13228	Surge Only	2.9
MA24	Patapsco South I-895 Tunnel Bulkhead	Upland	13228	Surge Only	6.8
MA25	Middle Branch Wheelabrator Incinerator Plant	Upland	5944	Surge Only	2.6

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 for the existing conditions, future without project conditions, and future with project conditions for the Baltimore Coastal study area.

4. EXISTING CONDITION

4.1 ASSETS

Parcel data was obtained from the Baltimore City, Baltimore County, and Anne Arundel County tax assessor's office and used to build a Geographic Information System (GIS) database identifying which parcels and structures fell within the FEMA 0.2% annual chance exceedance event floodplain. The structure inventory identified 8,917 structures and vehicles. The National Highway Consultation Cost Index (NHCCI) was used to develop the depreciated replacement value (DRV). The structures are broken down as:

- Residential and commercial structures with their content values.
- Infrastructure and cargo at the Port of Baltimore.
- I-95 Tunnel with a DRV of $4.1 billion (DRV obtained by MPA consultant).
- I-895 Tunnel with a DRV of $2.2 billion (DRV obtained by MPA consultant).
- Baltimore Shot Tower Metro Station with a DRV of $60.5 million.
- Munition depot with a DRV of $50 million at Martin State Airport (DRV obtained by the Office of Engineers at Martin State Airport).

Table 7 shows the number of assets by jurisdictions.

Table 7: Asset Count by Jurisdiction

Jurisdiction	Number of Structures	Number of Vehicles	Total Number of Assets
Baltimore City	5,115	3,515	8,630
Baltimore County	150	96	246
Anne Arundel County	41	0	41
Total	**5,304**	**3,611**	**8,917**

4.1.1 VEHICLE INVENTORY AND VALUATION

Vehicle valuation is based on data from the 2021 Edmunds Used Vehicle Outlook. Five-year used vehicle values were evaluated. The vehicle types selected were sedan, coupe, SUV, truck, and large vehicle. These classes are assumed to be distributed as shown in Table 8 to arrive at a weighted-average vehicle value of $27,977.

Table 8: Average Vehicle Value in the Baltimore Coastal 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 data in the 2021 Edmunds Used Vehicle Outlook.

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 EGM-09-04, it is assumed approximately 49.5, 19.4, and 11.9% of privately owned vehicles are not evacuated to higher grounds during storm events given a 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 9.

Table 9: Private Vehicles Valuation

	Residential Vehicle Valuation		
	Minimum	**Most Likely**	**Maximum**
Weighted Average Cost	$27,977	$27,977	$27,977
Vehicle per Household	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 remaining evacuation rates resulted in values of $3,329, $5,428, and $13,849, which were used as the triangular distribution parameters of the structure value.

In addition to residential vehicles, there are a significant number of cargo vehicles and heavy equipment at the Port of Baltimore that were counted using aerial imagery. A total of 207 vehicle lots were counted. A conservative assumption was made that 50% of the vehicles would be removed if a flood hazard were anticipated. Hence, 50% is applied to the value of the cargo. Table 10 shows the triangular distribution values of cargo vehicles and heavy equipment at the Port of Baltimore. Vehicles parked at Maryland Port Administration (MPA) facilities are not assumed to be moved to higher ground during a flood event. Hence their triangular distribution values are shown in the Table 10 below.

Table 10: Maryland Port Administration Vehicle Inventory

	Port Cargos (Vehicles) Values			
	Count	Minimum	Most Likely	Maximum
Cars	44,664	$7,500	$12,500	$17,500
Heavy Equipment	15,435	$1,150	$12,500	$13,500
Luxury Cars	615	$20,000	$25,000	$30,000
Tractors	804	$10,834	$12,500	$14,167
Trucks	2,821	$12,500	$17,500	$22,500

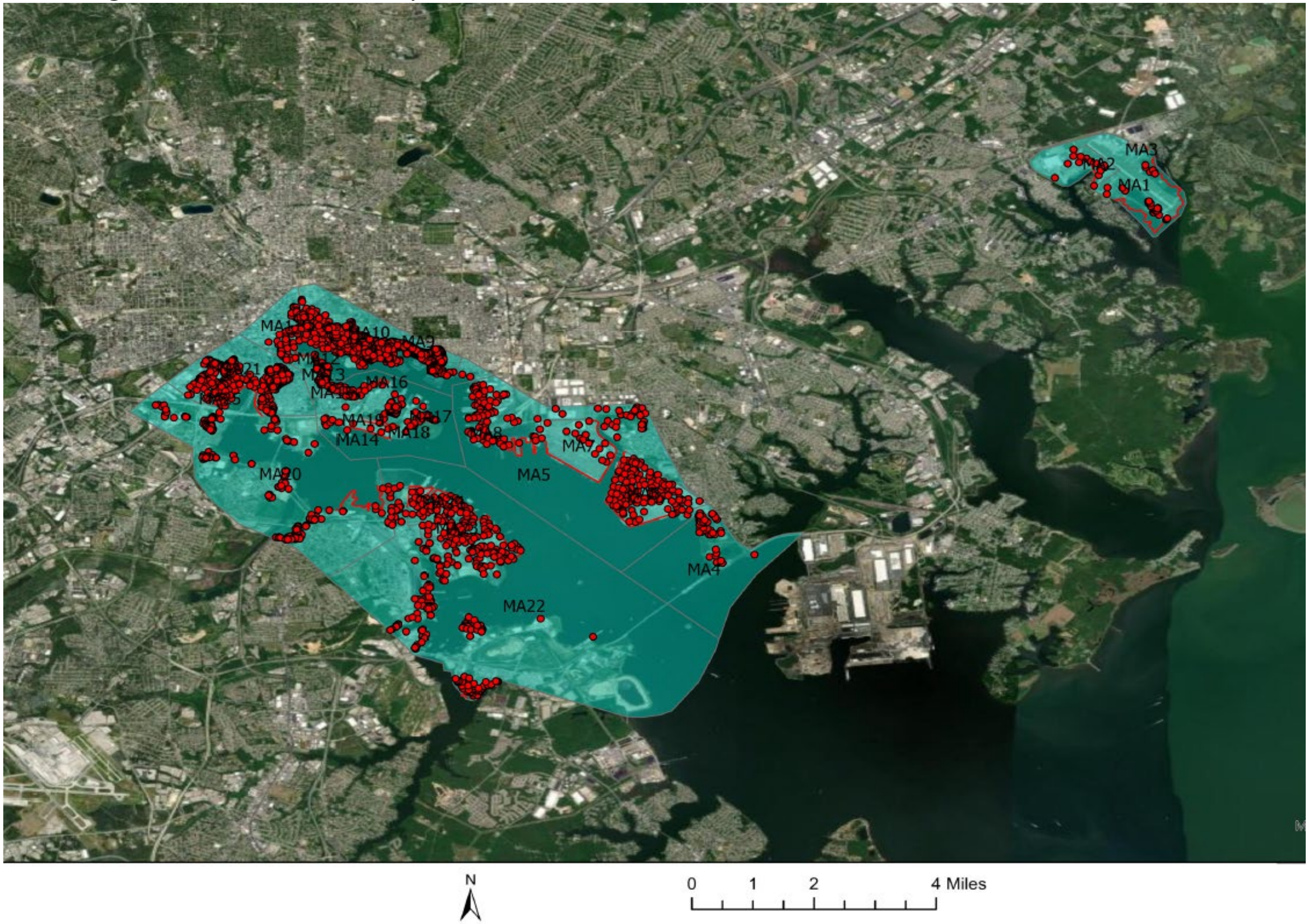
Residential and commercial vehicle depth-damage relationships were taken from EGM 09-04., *Generic Depth-Damage Relationships for Vehicles*.

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 DDFs 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.

Assets are spatially located entities that can be affected by storms, waves, sea level change and tides. For this analysis, assets consist of the residential and commercial structures with their content values; residential vehicles; infrastructure and cargo at the Port of Baltimore; I-95 Tunnel;

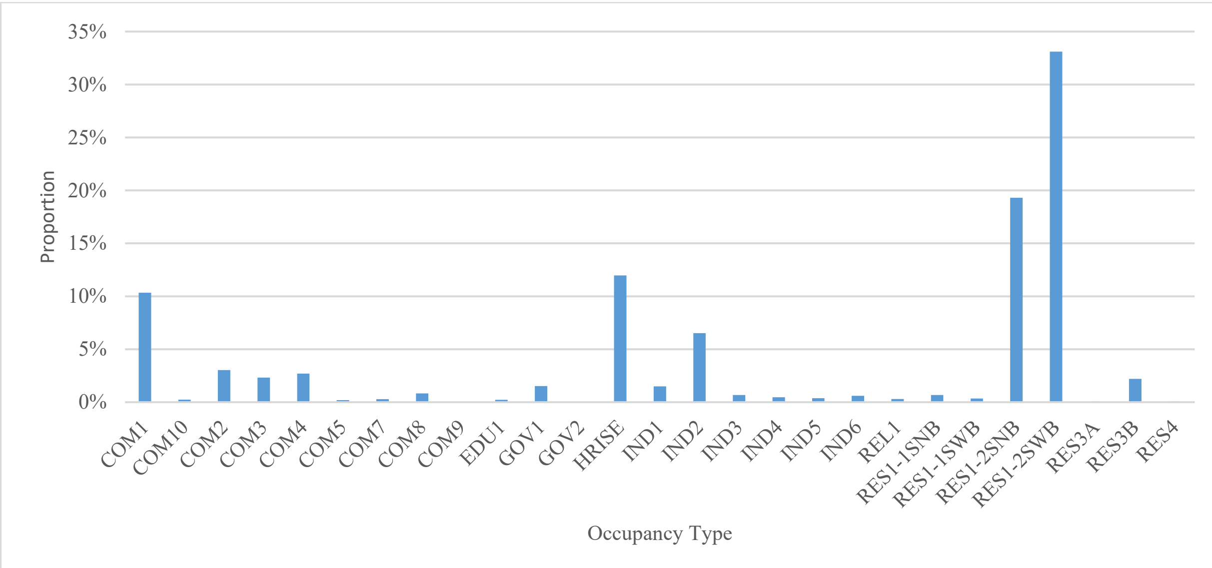
I-895 Tunnel; Baltimore Shot Tower Metro Station; and the munition depot at Martin State Airport as shown in the Figure 5 below. The study area is a highly urbanized, relatively flat community with nearly all areas below elevation 20 ft. The low elevations and tidal connections to Baltimore Harbor place a significant percentage of the city at risk of flooding from tropical storms, extra tropical storms, hurricanes, and other storms.

Figure 5: Location of Assets by Model Areas



The Baltimore Metropolitan study area structure inventory, as modeled, contains 8,917 structures. Out of the residential and nonresidential structures, the occupancy types most found were single-family residential, residential vehicles, condominium living area and retail stores, wholesale, and professional and technical services. Figure 6 shows the proportion of each occupancy type in the Baltimore metropolitan area. Note that the proportion is rounded to a whole number.

Figure 6: Proportion of each Occupancy Type in the Baltimore Coastal Study Area



4.1.2 RESIDENTIAL AND NON-RESIDENTIAL CONTENT-TO-STRUCTURE VALUE RATIOS

Residential and nonresidential site-specific DDF were not available for the Baltimore Coastal study area. The nonresidential DDFs were taken from the draft report: *Nonresidential Flood Depth-Damage Functions Derived from Expert Elicitation*. From structure triangular distribution values, triangular distributions (i.e., minimum, maximum, most likely) were developed for the content values to account for the uncertainty surrounding the damage percentage associated with each depth of flooding. The residential DDFs used a combination of both the *Expert Elicitation Draft Report* and EGM's 01-03 and 04-01. Moreover, both EGMs contained a normal distribution function with an associated standard deviation of damage to account for uncertainty surrounding the damage percentage associated with each depth of flooding. This distribution was then converted into a triangular distribution for input into the model.

4.1.3 SUMMARY OF THE INVENTORY

The assets were categorized as residential or nonresidential which were further categorized into occupancy types (reference Table 3). Table 11 below displays the count and structure value by occupancy type.

Table 11: Structure Inventory by Occupancy Type

Occupancy Type	Description	Count	Structure Value ($FY22)	Content Value ($FY22)
AUTO-N	Auto/Commercial	64,339	$825,080,000	$0
AUTO-R	Auto/Residential	3,404	$17,947,000	$0
COM1	Average Retail	548	$404,075,000	$181,834,000
COM10	Garage	13	$41,761,000	$15,452,000
COM2	Average Wholesale	161	$499,216,000	$184,710,000
COM3	Average Personal & Repair Services	123	$131,887,000	$87,046,000
COM4	Average Professional/Technical Services	143	$447,510,000	$80,552,000
COM5	Bank	10	$7,119,000	$1,281,000
COM7	Average Medical Office	15	$36,205,000	$21,723,000
COM8	Average Entertainment/Recreation	44	$225,359,000	$56,340,000
COM9	Average Theatre	3	$51,487,000	$9,268,000
EDU1	Average School	12	$61,738,000	$4,322,000
GOV1	Average Government Services	81	$295,814,000	$53,246,000
GOV2	Average Emergency Response	2	$1,104,000	$773,000
HRISE	Average Urban High-Rise, More Than 4 Floors	635	$7,480,368,000	$1,241,765,000
IND1	Average Heave Industrial	79	$263,301,000	$100,054,000
IND2	Average Light Industrial	347	$1,003,586,000	$441,840,000
IND3	Average Food/Drugs/Chemicals	37	$28,570,000	$55,195,000
IND4	Average Metals/Minerals Processing	25	$21,479,000	$3,866,000
IND5	Average High Technology	20	$175,917,000	$31,665,000
IND6	Average Construction	34	$73,199,000	$6,363,723,000
REL1	Church	16	$27,404,000	$1,918,000
RES1-1SNB	Single Family Residential, 1 Story, No Basement	36	$11,783,000	$5,892,000
RES1-1SWB	Single Family Residential, 1 Story, With Basement	18	$3,432,000	$1,716,000
RES1-2SNB	Single Family Residential, 2 Story, No Basement	1,024	$239,046,000	$119,523,000
RES1-2SWB	Single Family Residential, 2 Story, With Basement	1,755	$353,197,000	$176,599,000
RES3A	Condominium, Living Area, 1-2 Floors	4	$1,361,000	$136,000
RES3B	Condominium, Living Area, 3-4 Floors	117	$64,897,000	$5,768,000
RES4	Average Hotel, & Motel	4	$31,330,000	$8,146,000
Total		**8,917**	**$12,825,175,000**	**$9,254,351,000**

Critical infrastructure in the study area includes Baltimore City fire stations, Baltimore City Police Department Headquarters, Maryland Transportation Authority Police - Dundalk Marine Terminal, U.S Customs and Border Protection Field Office, and Maryland Port Administration's World Trade Center Building. Baltimore City is also home to medical facilities in the study area which include MedStar Harbor Hospital and Mercy Medical Center. Schools such as The Crossroads School, Sharp Leadenhall Elementary School, Mother Seton Academy, and New Century School are in the 1% Annual Exceedance Probability (AEP) area except Sharp Leadenhall which is in 0.2% AEP. Power plants such as Domino Sugar Baltimore, Inner Harbor East Heating Plant, Middle Branch Wheelabrator Incinerator Plant and the Patapsco Wastewater Treatment Plant are subject to flooding. Other critical infrastructure in the study area includes Martin State Airport in Baltimore County and the Curtis Bay U.S. Coast Guard yard in Anne Arundel County. The water-dependent Baltimore City Fire Boat Station, two power-plants supplying power and hot water to private businesses, and the field office for U.S. Customs and Border Protection are also at risk at the 1 percent AEP. The historic relative sea level trend is 0.01 feet/year based on NOAA's Baltimore MD tide gauge.

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 taking into account natural or built topological features (e.g., a ridge, highway, or railway line) to define MA boundaries. Dividing the study area into model areas facilitates evaluation of flood damages by breaking the study area down into several areas having some common features. Analyzing them separately also speeds up the economic modeling process. The study area consists of 25 model areas. The 25 model areas are: MA1: Martin State Airport unprotected, MA2: Martin State Airport West, MA3: Martin State Airport East, MA4: Patapsco East, MA5: Patapsco North, MA6: Patapsco North Dundalk, MA7: Patapsco North Seagirt, MA8: Patapsco North I-895 Tunnel, MA9: Inner Harbor, MA10: Inner Harbor Canton, MA11: Inner Harbor Harborplace, MA12: Inner Harbor Ritz Carlton, MA13: Inner Harbor Harborview, MA14: Locust Point, MA15: Locust Point Museum of Industry, MA16: Locust Point American Sugar, MA17: Locust Point Fort McHenry, MA18: Locust Point I-95 Tunnel Facility, MA19: Locust Point I-95 Tunnel, MA20: Middle Branch Patapsco, MA21: Middle Branch Patapsco River, MA22: Patapsco South, MA23: Patapsco South Fairfield, MA24: Patapsco South I-895 Tunnel, MA25: Middle Branch Wheelabrator Incinerator Plant. These model areas are spatial areas defined by geospatial polylines as shown in Figures 7, 8 and 9.

Figure 7: Model Area Boundaries in the Baltimore Coastal Study Area

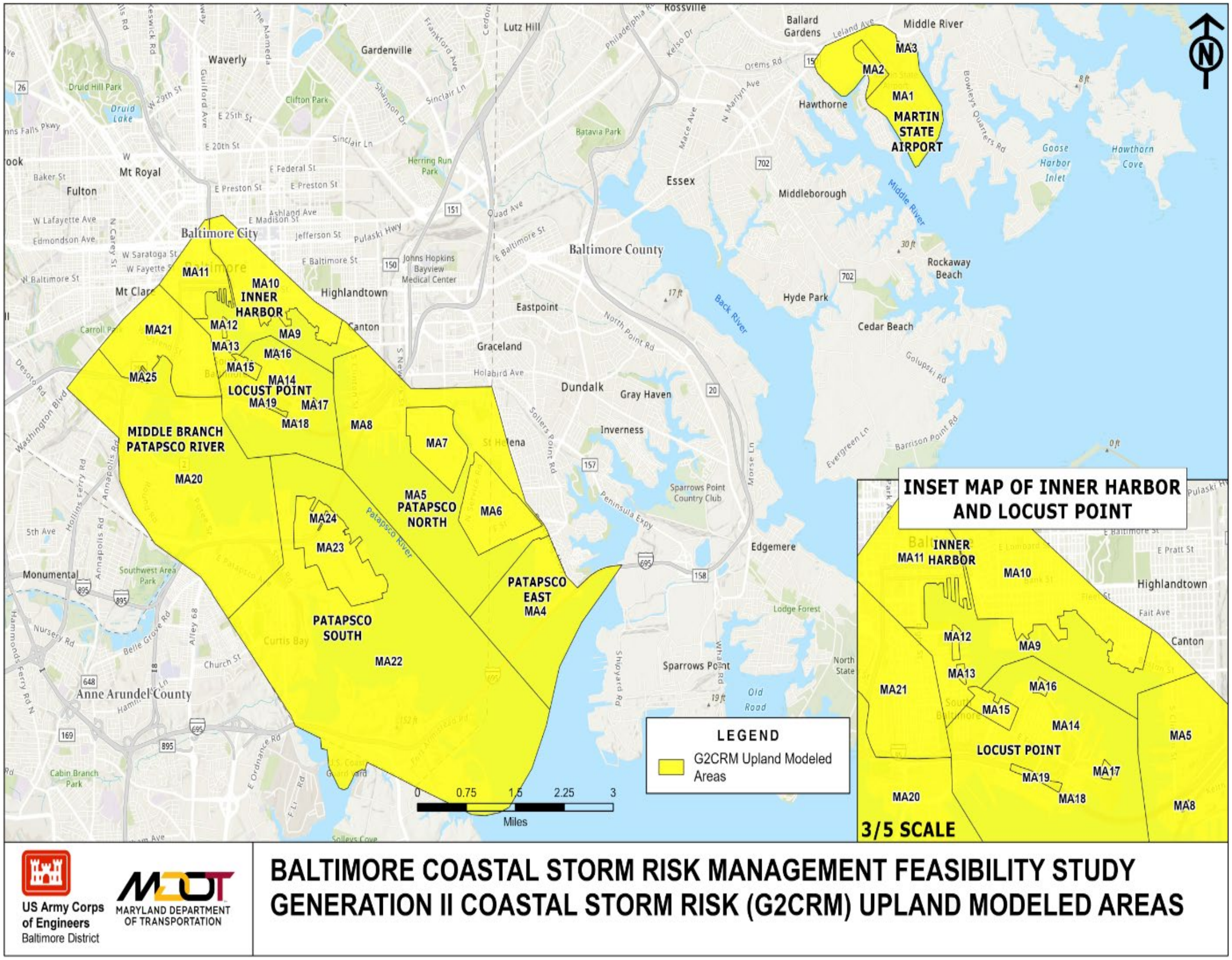


Figure 8: Model Area Boundaries in Harbor Area

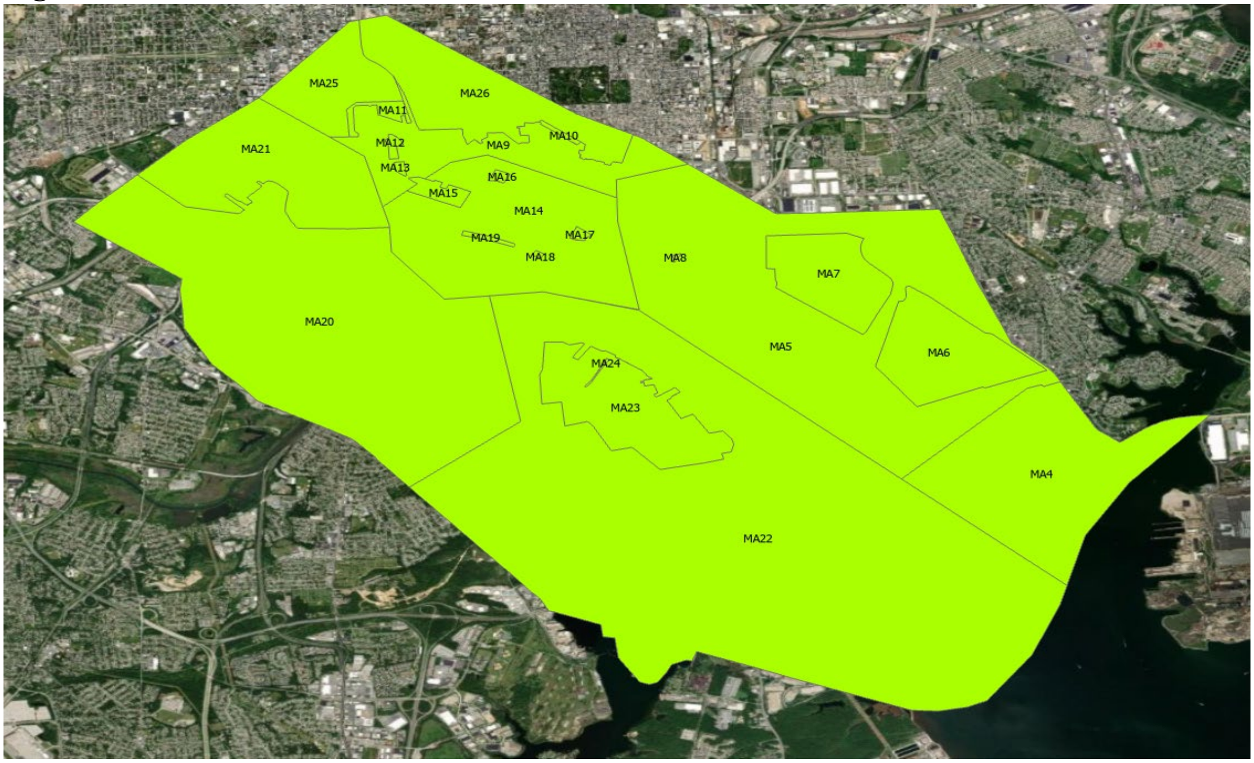


Figure 9: Model Area Boundaries at Martin State Airport

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

Moreover, it is important to note that there is no PSE that exists in the Baltimore Coastal study area before this study began. Hence, the PSEs were developed in the upland shapefile in the Existing and the FWOP conditions by setting their height lower than the lowest structure first-floor elevation. Therefore, having each MA be a component of an upland MA in the existing and the FWOP conditions was a model strategy utilized in order to model the FWP condition since only one of both shapefiles: upland MA or unprotected MA can be used in the Existing, the FWOP, and the FWP conditions. Table 12 shows each MA and if it is protected or unprotected by bulkheads in the future with project conditions.

Table 12: Model Area Types

MA	MA Descript	MA Type
MA1	Martin State Airport Unprotected	Upland
MA2	Martin State Airport West Bulkhead	Upland
MA3	Martin State Airport East Bulkhead	Upland
MA4	Patapsco East Unprotected	Upland
MA5	Patapsco North Unprotected	Upland
MA6	Patapsco North Dundalk with existing Bulkhead	Upland
MA7	Patapsco North Seagirt Bulkhead	Upland
MA8	Patapsco North I-895 Bulkhead	Upland
MA9	Inner Harbor Unprotected	Upland
MA10	Inner Harbor Canton Bulkhead	Upland
MA11	Inner Harbor Harborplace Bulkhead	Upland
MA12	Inner Harbor Ritz Carlton Bulkhead	Upland
MA13	Inner Harbor Harborview Bulkhead	Upland
MA14	Locust Point Unprotected	Upland
MA15	Locust Point Museum of Industry Bulkhead	Upland
MA16	Locust Point American Sugar Bulkhead	Upland
MA17	Locust Point Fort McHenry Bulkhead	Upland
MA18	Locust Point I-95 Tunnel Facility Bulkhead	Upland
MA19	Locust Point I-95 Tunnel Bulkhead	Upland
MA20	Middle Branch Patapsco River	Upland
MA21	Middle Branch Patapsco River Bulkhead	Upland
MA22	Patapsco South Unprotected	Upland

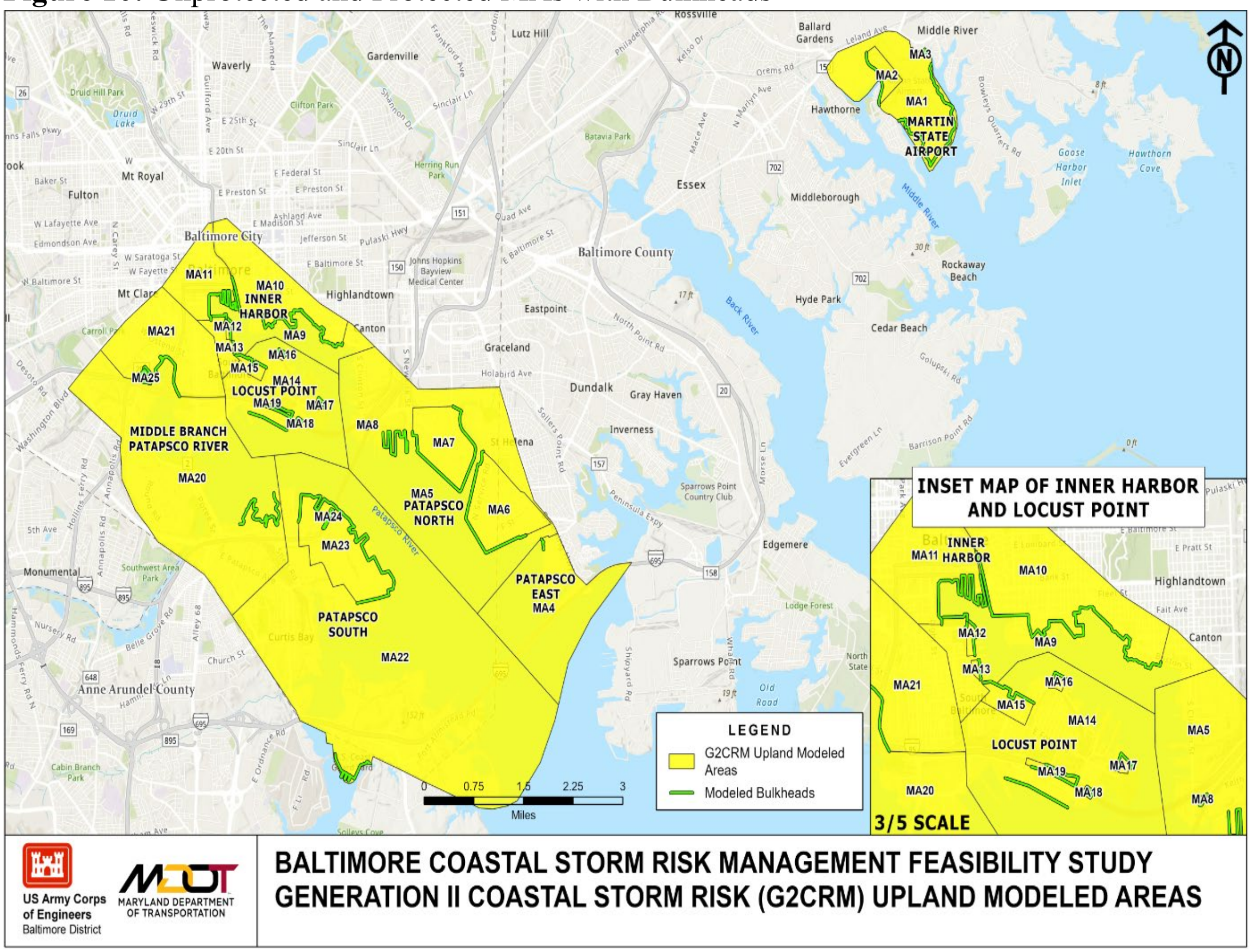
MA23	Patapsco South Fairfield Bulkhead	Upland
MA24	Patapsco South I-895 Tunnel Bulkhead	Upland
MA25	Middle Branch Wheelabrator Incinerator Plant	Upland

4.3 PROTECTIVE SYSTEM ELEMENTS (PSE)

Flood hazards are mediated by the 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 (in G2CRM is categorized as a bulkhead/seawall or a flood barrier). Figure 10 shows the protected MAs with bulkheads for the future with project conditions in the study area.

Figure 10: Unprotected and Protected MAs with Bulkheads



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. Therefore, 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 top elevation of the bulkhead/seawall or the flood barrier is increased and its influence is captured.

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) to describe the relationship between the volume contained in the model area and the associated stage (water depths) for each MA. 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 levels 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 study area are vulnerable to flooding. In addition to more than 48,087 people, thousands of commuters and tourists are 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 in 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.

4.6 EXISTING CONDITION MODELING RESULTS

The assets assigned to each MA and EPZ were modeled in G2CRM using the 291 tropical storms and 100 extra 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 using the Monte Carlo simulation. 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 model simulation. A mean and standard deviation were automatically calculated for the PV damages for each MA. Seven of the 291 tropical storms had a water level of zero. Each storm had a relative probability associated with it. Any chance of that storm happening in the model simulation was based on the relative probability. Moreover, each storm given its relative probability had an equivalent specific peak water level. These water levels were applied to each structure in each MA and EPZ to determine damages and consequences.

5. FUTURE WITHOUT PROJECT CONDITION

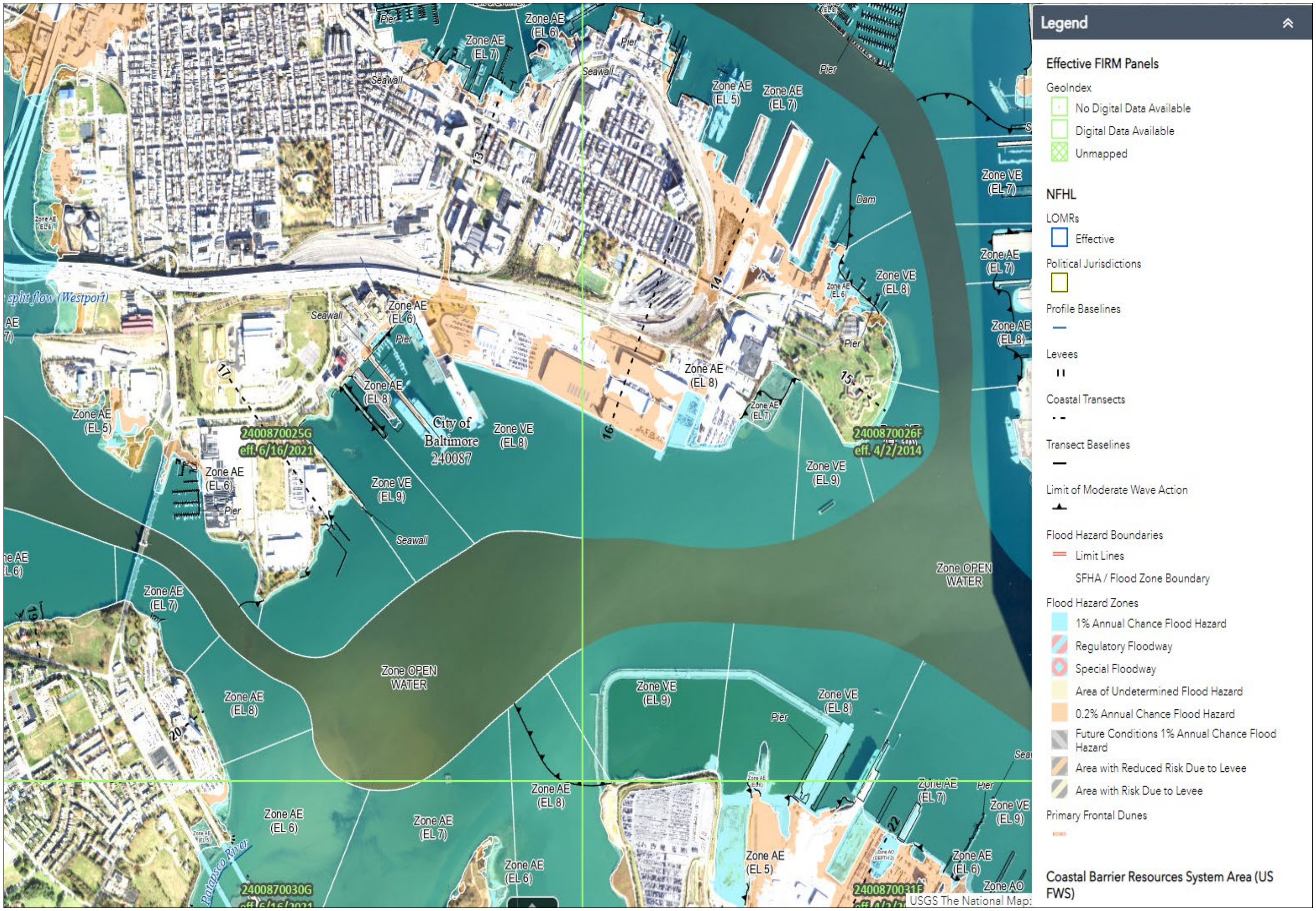
The future without project condition and forecast assumptions based on the existing condition were critical to the planning process since they provide the baseline for the subsequent evaluation and comparison phases. The following discussion includes projections about the future of the Baltimore Coastal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

5.1 BACKGROUND

The Baltimore Coastal 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 Baltimore will continue to rise, limiting the effectiveness of gravity drain potential post-storm.

The study area in the without-project future conditions will be worsened by tidal influence in the Inner Harbor in conjunction with development in low lying areas and an overtaxed stormwater system. Flooding, wave action, and continued sea level change contribute to future storm damages. The reconstruction of substantially damaged buildings to levels above the regulated BFE in accordance with floodplain management regulations will provide them resiliencies against future storms.

Figure 11: Base Flood Elevation Snapshot in the Inner Harbor



According to the FEMA Flood Insurance Rate Map (FIRM), virtually all the Baltimore Coastal study area has been classified as Special Flood Hazard Area (SFHA): Zone AE, which are areas of inundation under the 1% annual chance flood, including areas within the 2% wave runup, elevations less than 3 ft above the ground, and areas with wave heights less than 3 ft. These areas are subdivided into elevation zones with BFEs assigned.

To regulate land development in the floodplain, various ordinance/s 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 National Flood Insurance Program (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.

Infrastructure and cargo would be damaged at MPA facilities. Vehicles that are waiting for import/export in the parking lots at Dundalk, South Locust Point, and Fairfield terminals are subject to flooding. At any given time, these terminals have thousands of vehicles which are vulnerable to damage from coastal flooding. The Port of Baltimore is the economic backbone of the region.

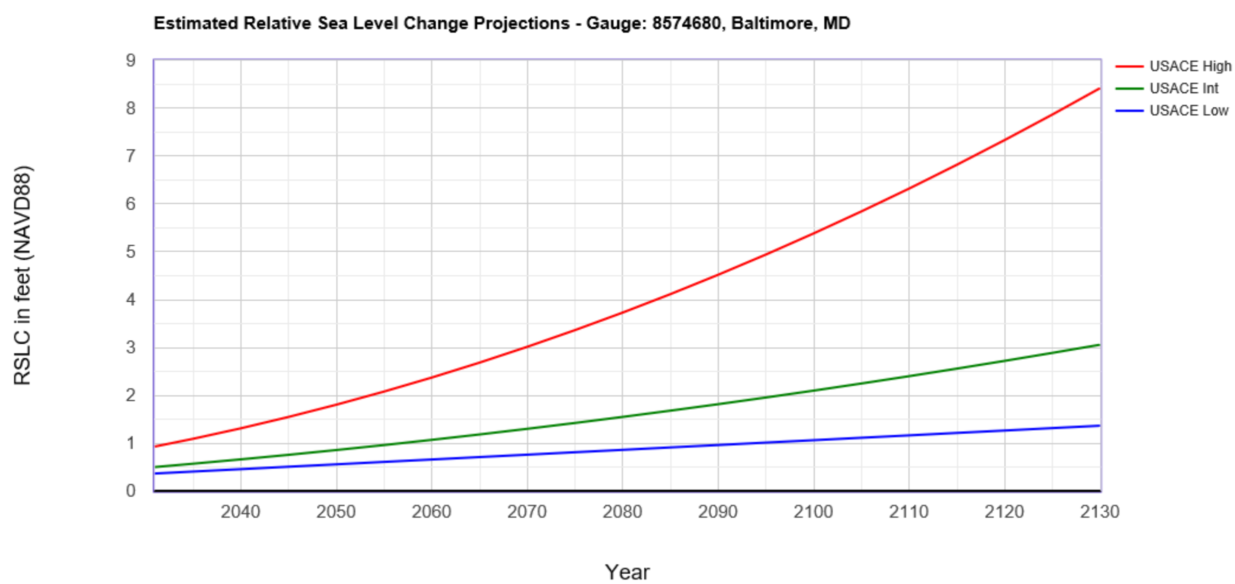
Maryland State Highway Administration assets are vulnerable to damage from coastal flooding. Ones of the most vulnerable areas to flooding are the I-95 Tunnel, the I-895 Tunnel, and their supporting infrastructure. Floodwaters may enter the tunnels and cause damage to systems in the tunnels, and structures on land housing ventilation and other equipment would be damaged during a coastal flood event. The I-95 Tunnel is also exposed to waves coming from the south side of the tunnel along McComas Street while the ground elevation of the I-895 Tunnel is at the edge of the water. Floodwaters usually get into these tunnels and impair the circulation of vehicles and the economy of the region.

The southern portion of the Martin State Airport runway would be inundated in a coastal storm and is susceptible to damage. Also, on Strawberry Point at the southern end of the airport, hangars housing the Maryland State Police aviation unit would be damaged and operations would need to be relocated. The airport fuel tank farm and Wilson Point Road would be inundated. As a result, the access to the residential community of Wilson Point would be cut off. Maryland Air National Guard facilities, a tenant of the airport, would be damaged, including munitions storage, and the primary access road to the base would be inundated. Finally, coastal flooding would damage mitigation systems in place for the remediation of groundwater contamination at Martin State Airport.

The project base year is identified as 2031. Using the intermediate sea level change curve, many structures in the Baltimore Coastal study area will be subjected to coastal storm inundation during a 1% AEP storm if no federal action is taken. According to EC 1165-2-211, distinction should be made between global mean sea level (GMSL) and local (or "relative") mean sea level (MSL). NOAA's GMSL is 0.00994 and the MSL at the Ft. McHenry tide gauge 8574680 is 0.01010 feet per year. MSL was used in G2CRM to develop the economics. Sea level is projected to rise as shown in Table 13, based on the sea level gauge at Fort McHenry.

Table 13: Seal Level Change Projection at Ft. McHenry Gauge in Feet

Year	Low	Intermediate	High
2031	0.36	0.50	0.93
2080	0.86	1.55	3.73
2130	1.36	3.06	8.43



Source: https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

There are numerous development projects, both proposed and under construction, within the study area. They are all expected to be built to Baltimore City code with a first-floor elevation of 2 feet above base flood elevation. Section 308 of the 1990 Water Resource Development Act (WRDA) limits structures built or substantially improved after 01 July 1991, in designated floodplains not elevated to the 0.01 AEP flood elevation from being included in the benefits of the economic analysis. No damages are forecast from these developments.

Baltimore Gas and Electric (BGE) is replacing underwater high voltage transmission cables at the Key Bridge with an overhead crossing of the Patapsco River. When the transmission line is replaced, the existing Sollers Point terminal station will be deactivated. This terminal station is at risk of flooding from coastal storms.

The Port of Baltimore is expected to continue to attract a diverse array of vessels transporting containers, coal, vehicles, and general cargo. The MPA and its partners are pursuing upgrades of Berth 3 at the Seagirt Marine Terminal which would allow for two berths to service large container ships of around 14,000 TEU (twenty-foot equivalent unit) capacity. MPA is also pursuing upgrades to all berths at the Dundalk Marine Terminal, installing a sea coastal curb during the upgrade process which will provide some risk reduction to coastal flooding. Therefore, this project will not provide any mitigation at the Dundalk Marine Terminal, and any damage reduction derived from the Dundalk Marine Terminal bulkhead will not be considered in the analysis.

5.2 FUTURE WITHOUT PROJECT CONDITION MODELING RESULTS

The years 2031 to 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 was 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 Baltimore Coastal study area will continue to be affected by flooding from coastal storms and suffer increasing losses each year. Table 14 and figures 12 and 13 display the expected present value (PV). In addition, Table 14 shows the equivalent annual damages (EAD) for the study area by model areas for the without project conditions by MA. Inner Harbor MAs make up the most damages of structures in the study area followed by the tunnels MAs. Values in Table 14 are on 01 October 2021, price levels (FY2022; 2.25% discount rate).

Table 14: Future Without Project Condition Expected Annual Damages by Model Area (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Present Value Damages ($FY22)	Equivalent Annual Damages ($FY22)
MA1: Martin State Airport	$2,424,000	$81,000
MA2: Martin State Airport West Bulkhead	$1,190,000	$40,000
MA3: Martin State Airport East Bulkhead	$0	$0
MA4: Patapsco East	$456,000	$15,000
MA5: Patapsco North	$7,719,000	$259,000
MA6: Patapsco North Dundalk	$22,649,000	$759,000
MA7: Patapsco North Seagirt Bulkhead	$7,725,000	$259,000
MA8: Patapsco North I-895 Tunnel Facility Bulkhead	$20,000	$1,000
MA9: Inner Harbor	$24,529,000	$822,000
MA10: Inner Harbor Canton Bulkhead	$157,240,000	$5,270,000
MA11: Inner Harbor Bulkhead	$98,064,000	$3,287,000
MA12: Inner Harbor Ritz Carlton Bulkhead	$1,307,000	$44,000
MA13: Inner Harbor Harborview Bulkhead	$264,000	$9,000

Model Area	Present Value Damages ($FY22)	Equivalent Annual Damages ($FY22)
MA14: Locust Point	$44,591,000	$1,495,000
MA15: Locust Point Museum of Industry Bulkhead	$5,290,000	$177,000
MA16: Locust Point American Sugar Bulkhead	$6,539,000	$219,000
MA17: Locust Point Fort McHenry Bulkhead	$3,515,000	$118,000
MA18: Locust Point I-95 Tunnel Facility Bulkhead	$2,000	$0
MA19: Locust Point I-95 Tunnel Bulkhead	$197,413,000	$6,617,000
MA20: Middle Branch Patapsco River	$28,831,000	$966,000
MA21: Middle Branch Patapsco River Bulkhead	$47,852,000	$1,604,000
MA22: Patapsco South	$16,995,000	$570,000
MA23: Patapsco South Fairfield Bulkhead	$28,985,000	$972,000
MA24: Patapsco South I-895 Tunnel Bulkhead	$113,252,000	$3,796,000
MA25: Middle Branch Wheelabrator Incinerator Plant	$302,000	$10,000
Total	**$817,154,000**	**$27,390,000**

Figure 12: Dot Plot of Cumulative Present Value Damages for the Future Without Project Condition

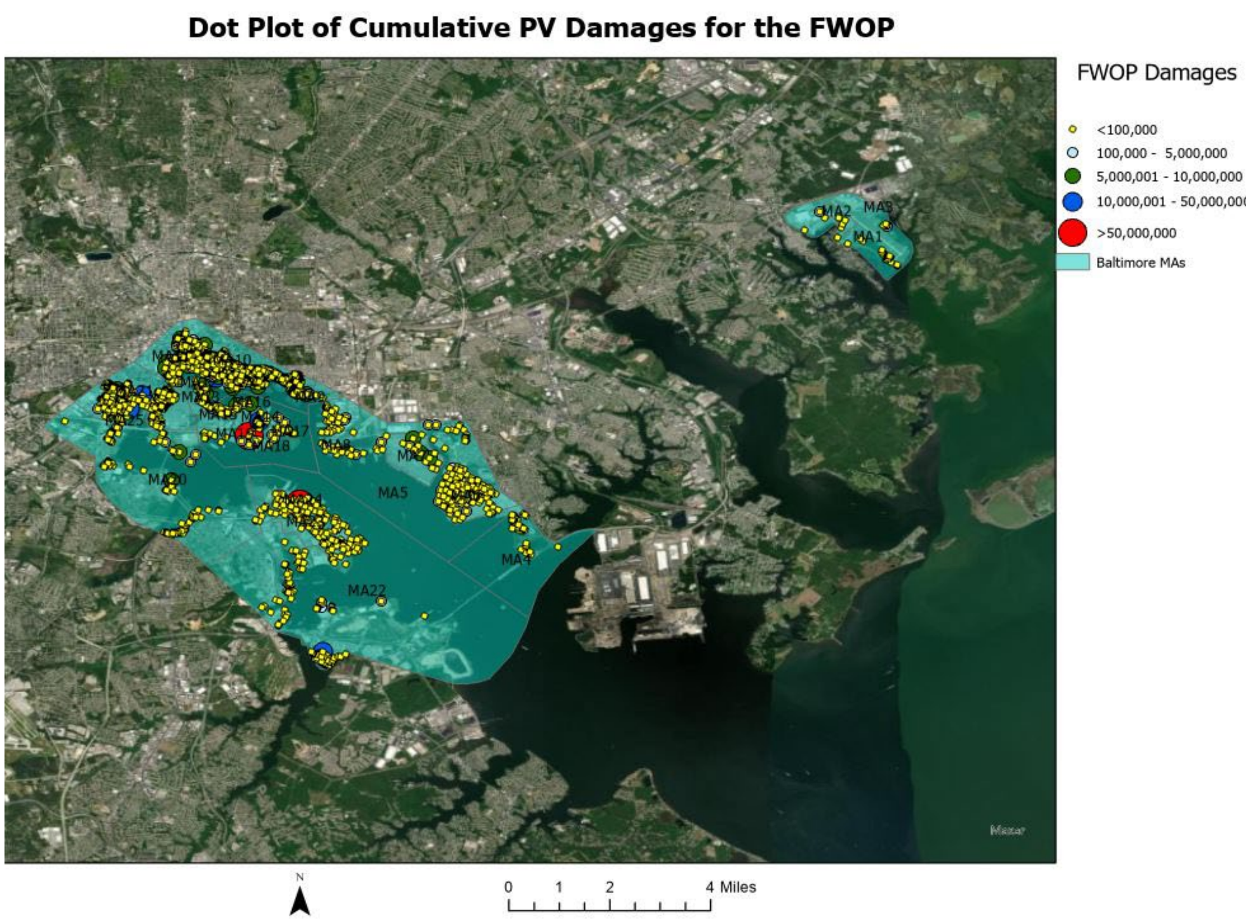
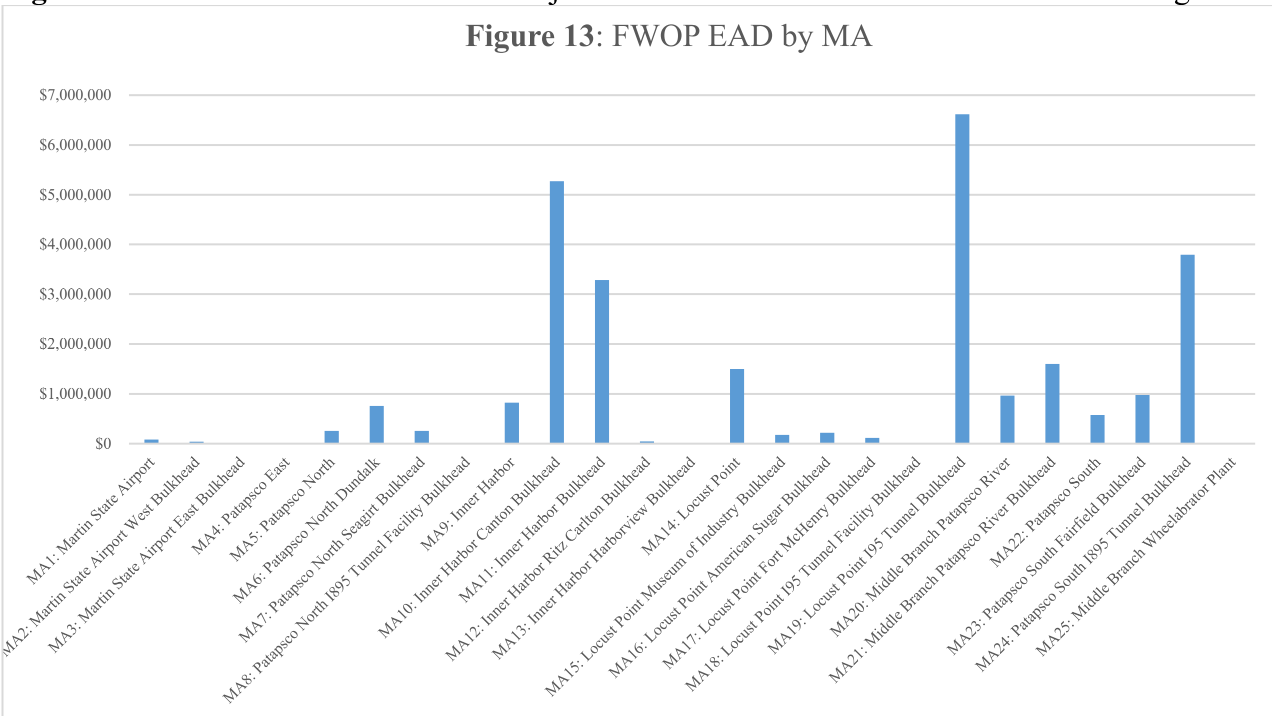


Figure 13: Dot Plot of Future Without Project Conditions Present Value Cumulative Damages



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.

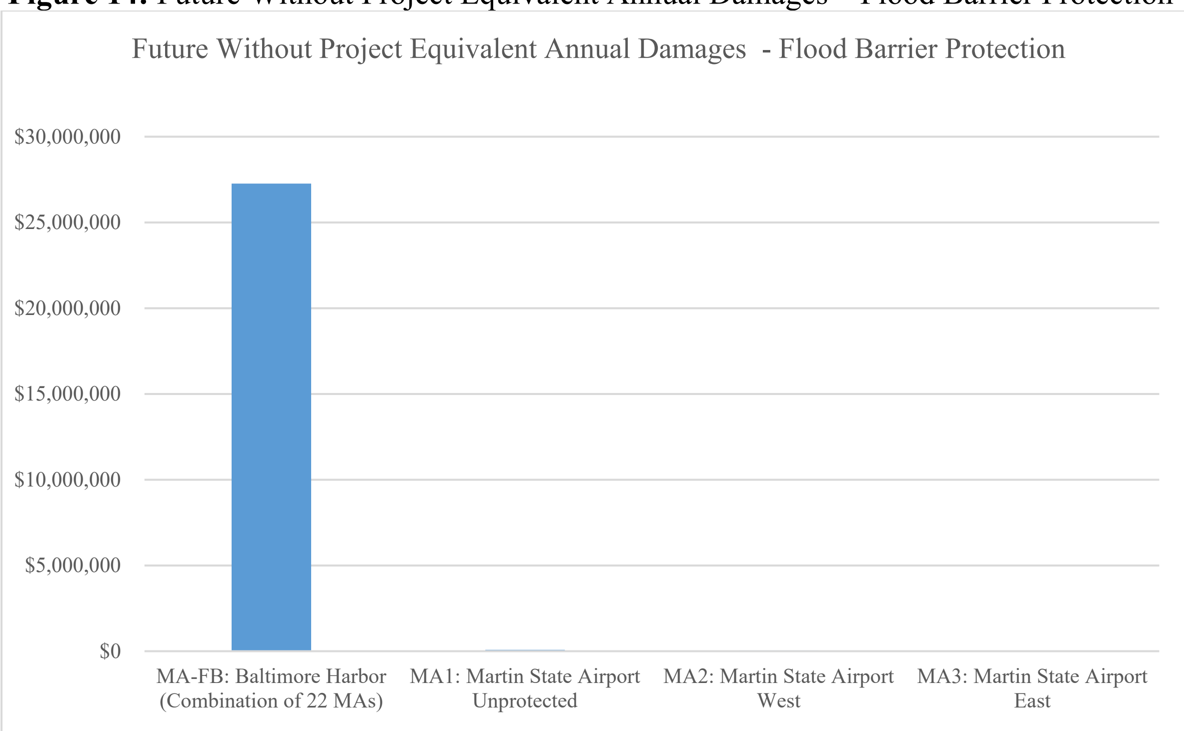
The forecasted sea level change in the future, without a project in place, resulted in higher expected average PV damages. The total future "without project" PV damages are approximately $817.2 million or about $27.4 million EAD. The forecast of the future without project condition reflects the conditions expected during the period of analysis (2031 to 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.

Note in this section that for one of the project alternatives, surge barrier and bulkheads were combined. The surge barrier would be in Baltimore Harbor and would protect 22 MAs. The remaining three MAs are in Martin State Airport. Table 15 and Figure 14 show the damages for the combined surge barrier MA and the Martin State Airport MAs.

Table 15: Future Without Project Damages for the Combined Flood Barrier and Bulkheads (October 2021 price level, FY22 discount rate of 2.25%)

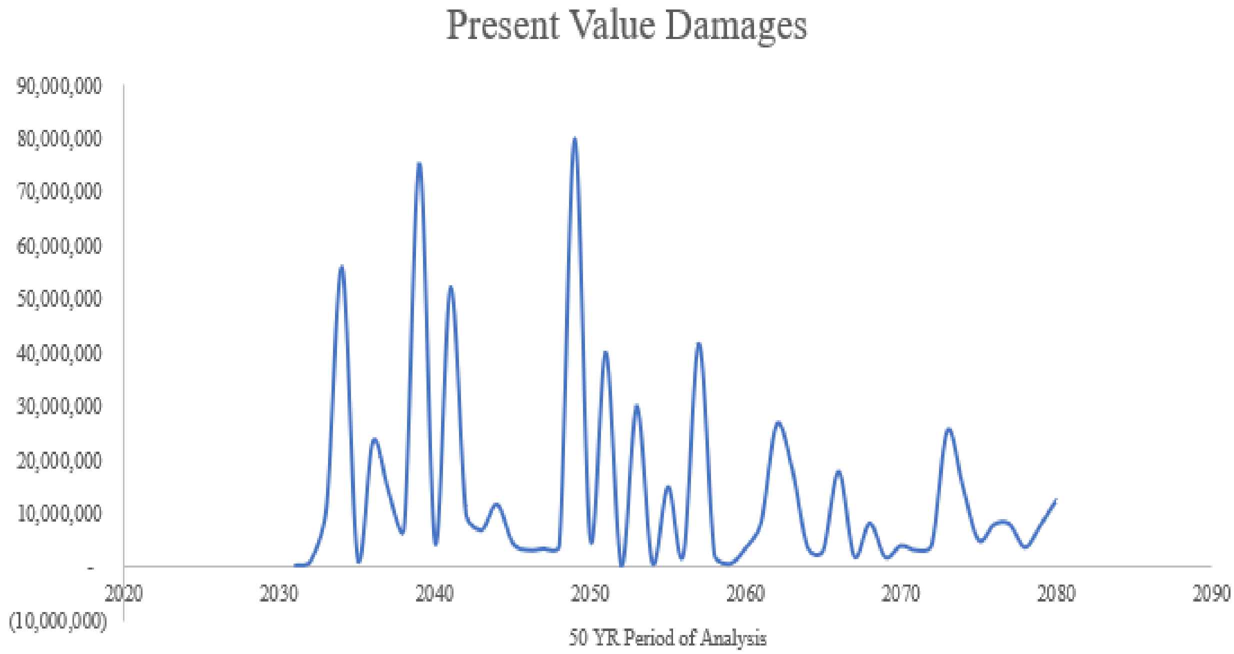
Model Area	Present Value Damages	Equivalent Annual
MA-FB: Baltimore Harbor (Combination of 22 MAs)	$813,540,000	$27,269,000
MA1: Martin State Airport Unprotected	$2,424,000	$81,000
MA2: Martin State Airport West	$1,190,000	$40,000
MA3: Martin State Airport East	$0	$0
Total	$817,154,000	$27,390,000

Figure 14: Future Without Project Equivalent Annual Damages – Flood Barrier Protection



Based on modeling results presented on Figure 15, most damages were shown to have incurred around the years 2040 and 2050, and level off around 2045 and toward the end of the life cycle. This seems reasonable since people will react in a rational manner. When assets get damaged, there will be a rebuilding period (assets offline not receiving damages) and these same assets would be rebuilt to a higher elevation. Therefore, as the life cycle gets toward the end, these damages would be more reflective of less frequent storm events; thus, these damages (towards the end) would be less than those damages reflective in the beginning of the life cycle.

Figure 15: Present Value Damages Over Time



Additionally, the damages based on a typical life cycle from the model was shown to be more concentrated in low lying areas of both tunnels. More specifically, the higher damages were shown to be predominately on the I-95 Tunnel from McComas Street to Winder Street. Most of the study area is made up of residential structures and shown to receive damages, mainly in the Inner Harbor, especially in MA 10.

Table 16: Statistics for the Future Without Project Present Value Damages.

Statistics for FWOP PV Damages	
Mean	817,155,362
Standard Error	142,059,403
Median	269,001,909
Standard Deviation	1,420,594,029
Kurtosis	8
Skewness	3
Range	7,457,756,161
Minimum	1,636,518
Maximum	7,459,392,679
Sum	81,715,536,184
Count	100

5.3 SENSITIVITY ANALYSIS – SEA LEVEL CHANGE

The Baltimore Coastal study area is subject to an intermediate sea level change. USACE Guidance document ER 1100-2-8162 requires evaluating alternative plans based on the future local mean SLC. A hydrology & hydraulics analysis evaluated the WSL over 100 years while factorizing into the analysis climate change using risk-inform decision making.

Table 17: Elevation of protective system elements.

Year		1992	2031	2031	2031	2080	2080	2080	2130	2130	2130
USACE Sea Level Change Scenarios		None	Low	Medium	High	Low	Medium	High	Low	Medium	High
Sea Level Change, ft		0	0.36	0.5	0.93	0.86	1.55	3.73	1.36	3.06	8.43
Recurrence Interval	Percent Chance Exceedance	Water Surface Elevations plus Sea Level Change, ft (Level of Performance 12.2 ft)									
5000	0.02	17.5	17.9	18.0	18.5	18.4	19.1	21.3	18.9	20.6	26.0
2000	0.05	16.5	16.9	17.0	17.5	17.4	18.1	20.3	17.9	19.6	25.0
1000	0.1	15.6	15.9	16.1	16.5	16.4	17.1	19.3	16.9	18.6	24.0
500	0.2	14.4	14.7	14.9	15.3	15.2	15.9	18.1	15.7	17.4	22.8
200	0.5	12.4	12.8	12.9	13.3	13.3	14.0	16.1	13.8	15.5	20.8
100	1	11.0	11.4	11.5	11.9	11.9	12.5	14.7	12.4	14.1	19.4
50	2	9.6	10.0	10.1	10.6	10.5	11.2	13.4	11.0	12.7	18.1
20	5	8.1	8.5	8.6	9.1	9.0	9.7	11.9	9.5	11.2	16.6
10	10	7.4	7.7	7.9	8.3	8.2	8.9	11.1	8.7	10.4	15.8
5	20	6.9	7.2	7.4	7.8	7.7	8.4	10.6	8.2	9.9	15.3
2	50	6.3	6.7	6.8	7.3	7.2	7.9	10.1	7.7	9.4	14.8
1	100	5.2	5.5	5.7	6.1	6.0	6.7	8.9	6.5	8.2	13.6

(pink) Flooding will occur during these conditions (WSEL greater than or equal to 12.2 feet NAVD88)

(green) No flooding will occur during these conditions (WSEL less than 12.2 feet NAVD88)

SLC sensitivity was developed using triangular distribution in G2CRM. Current USACE guidance requires that potential RSLC must be considered in every USACE coastal flooding study. The base level of potential RSLC is considered the historically recorded changes for the study site, which is estimated to be an increase of 0.01010 feet/year. All economic analyses for which results are tabulated in previous sections of this report were based on this historic intermediate rate of SLC. However, in accordance with ER 1100-2-8162 (incorporating Sea Level Changes in Civil Works Program, 31 Dec 2013), proposed projects that are subject to coastal storm surges must be also evaluated for a range of possible SLC rates: low, intermediate, and high. Based on NOAA projection at gage 8574680 (Ft. McHenry), the low, intermediate, and high sea level rates in base year 2031 are respectively 0.36, 0.50, and 0.93 and 0.86, 1.55, 3.73 over a 50-year of period of analysis. They will be increased respectively by 0.5, 1.05, and 2.8 over the period of analysis. The results of the future without project under all three sea level change conditions for each bulkhead are presented in Table 18. It was determined at the early phase of the study that based on 12.2-ft high bulkheads, tunnels and their building facilities will be protected over a 50-year period of analysis under the intermediate SLC curve. After the ADM, the updated hydrology and hydraulics data were used to reassess the height of the bulkhead to 12.5 ft. The subsequent results in the appendix up to Section 14 were based on 12.2 ft. The results in the Section 15 (Optimization of the TSP) were developed with the updated height of 12.5 ft.

Table 18: Impact on Sea Level Change on Future Without Project Condition Damages (October 2021 price level, FY22 discount rate of 2.25%)

FWOP Present Value Damages by Sea Level Change Curve				**% Change from Intermediate SLC Curve**	
Model Area	**Low**	**Intermediate**	**High**	**Low**	**High**
MA1: Martin State Airport	2,017,000	2,424,000	4,415,000	-16.79%	82%
MA2: Martin State Airport West Bulkhead	1,011,000	1,190,000	2,147,000	-15.04%	80%
MA3: Martin State Airport East Bulkhead	-	-	-	-	-
MA4: Patapsco East	357,000	456,000	959,000	-21.71%	110%
MA5: Patapsco North	6,400,000	7,719,000	15,219,000	-17.09%	97%
MA6: Patapsco North Dundalk	18,740,000	22,649,000	42,044,000	-17.26%	86%
MA7: Patapsco North Seagirt Bulkhead	6,419,000	7,725,000	14,105,000	-16.91%	83%
MA8: Patapsco North I-895 Tunnel Facility Bulkhead	14,000	20,000	51,000	-30.00%	155%
MA9: Inner Harbor	20,750,000	24,529,000	42,520,000	-15.41%	73%
MA10: Inner Harbor Canton Bulkhead	133,151,000	157,240,000	271,791,000	-15.32%	73%
MA11: Inner Harbor Bulkhead	83,342,000	98,064,000	182,510,000	-15.01%	86%
MA12: Inner Harbor Ritz Carlton Bulkhead	1,136,000	1,307,000	2,209,000	-13.08%	69%
MA13: Inner Harbor Harborview Bulkhead	221,000	264,000	464,000	-16.29%	76%
MA14: Locust Point	36,829,000	44,591,000	87,495,000	-17.41%	96%
MA15: Locust Point Museum of Industry Bulkhead	4,400,000	5,290,000	10,354,000	-16.82%	96%
MA16: Locust Point American Sugar Bulkhead	5,578,000	6,539,000	12,542,000	-14.70%	92%
MA17: Locust Point Fort McHenry Bulkhead	2,833,000	3,515,000	6,779,000	-19.40%	93%
MA18: Locust Point I-95 Tunnel Facility Bulkhead	-	2,000	28,000	-100.00%	1300%
MA19: Locust Point I-95 Tunnel Bulkhead	162,900,000	197,413,000	358,914,000	-17.48%	82%
MA20: Middle Branch Patapsco River	23,873,000	28,831,000	59,423,000	-17.20%	106%
MA21: Middle Branch Patapsco River Bulkhead	40,353,000	47,852,000	85,686,000	-15.67%	79%
MA22: Patapsco South	14,188,000	16,995,000	34,113,000	-16.52%	101%
MA23: Patapsco South Fairfield Bulkhead	24,435,000	28,985,000	55,651,000	-15.70%	92%
MA24: Patapsco South I-895 Tunnel Bulkhead	94,149,000	113,252,000	192,987,000	-16.87%	70%
MA25 Middle Branch Wheelabrator Incinerator Plant	265,000	302,000	526,000	-12.25%	74%
All MAs	**683,361,000**	**817,154,000**	**1,482,932,000**	**-20.41%**	**139.63%**

Evaluating SLC is a vital component in the planning process to ensure alternatives are selected based on risk-informed decision making. Risks to human life are a fundamental component of all CSRM studies and must receive explicit consideration in the planning process. The Baltimore Coastal study area is subject to an intermediate SLC. Hence, the floodwall height of 12.2 ft NAVD88 is designed to manage flood risk to both tunnels and their ventilation buildings from an intermediate SLC event over a 50-year period of analysis according to USACE Guidance document ER 1100-2-8162 that requires evaluating alternative plans based on future local mean SLC. There is a low likelihood of life safety risk and economic consequences during a high SLC event toward the end of the period of analysis based on the tunnel closure plan provided by the Maryland Transportation Authority (MDTA).

Based on the MDTA's *Flood Preparedness for the Fort McHenry and Baltimore Harbor Tunnels*, tunnel closures in preparation for coastal flood events are based on water levels and begin at a water level of 6 feet NAVD88. Tunnel tubes are progressively closed as water levels increase with full closure of the Baltimore Harbor Tunnel at a water level of 8 feet NAVD88. The Fort McHenry Tunnel begins closures at a water level of 8 feet NAVD88 with tunnel use limited to emergency and responder traffic at a water level of 11 feet NAVD88. The I-95 Tunnel will be closed for all traffic at a water level of 12 feet NAVD88.

To incorporate risk into the analysis, the future without project and future with project conditions must be run assuming three distinct future rates of SLC. EC 1165-2-211 provides both a methodology and a procedure for determining a range of SLC estimates based on the local historic rate, the construction year of the project, and the design life of the project. While the Baltimore Coastal Study is formulated to the USACE intermediate curve, the high and low curves as well as the no SLC curve were evaluated further in the analysis after the Agency Decision Milestone (ADM) for the future without project and future with project conditions. Hence, the TSP will be reevaluated to see if it is economically justified under each sea level rise scenario. More information on risk and uncertainty and resilience and adaptability can be found in Sections 6.7.1 and 6.6 in the Baltimore Coastal Study Integrated Feasibility Report/Environmental Assessment (IFR/EA).

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 future with project conditions as there are project alternatives. Structural and nonstructural alternatives were considered for the study. The analysis did not formulate a project alternative for recreation because it is considered incidental to the project. The analysis includes a discussion of residual flood damages and flood damage reduction for each alternative.

6.1 FORMULATION OF ALTERNATIVES

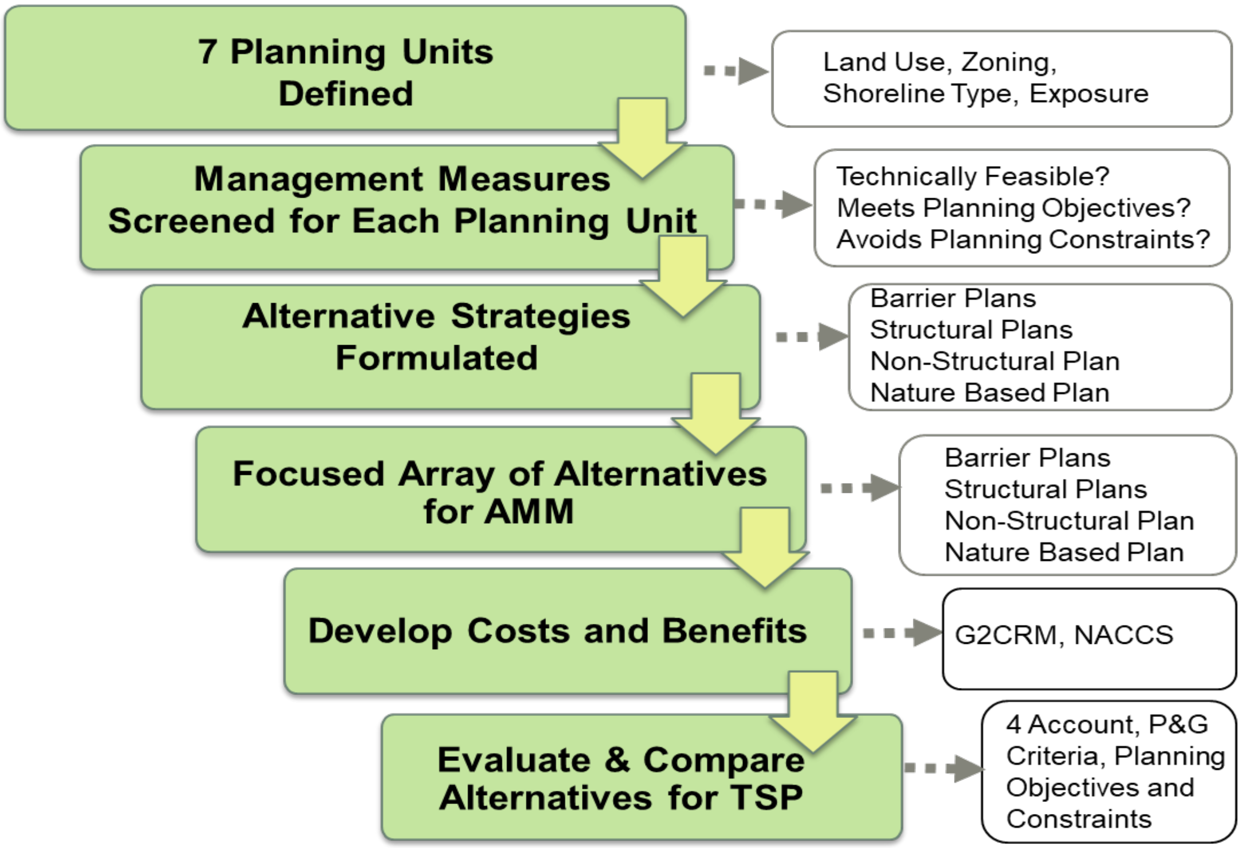
A formulation strategy is a systematic way of combining measures into alternative plans based on the planning objectives. No single formulation strategy will result in a diverse array of alternatives, so a variety of strategies is needed. Measures were combined into logical groupings based on a line 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 16 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 the Inner Harbor planning unit may have limited land area for implementation. They may require many closure structures which would be costly and difficult to operate in the event of a coastal storm. Floodwalls in this area may also be unacceptable to residents and stakeholders.

Natural and Nature-Based Features (NNBF) solutions in the Middle Branch that rely on placement of dredged material on existing substrate may not be technically feasible. The Tidal Middle Branch Continuing Authorities Program, Section 206 project, undertaken in the mid-2000s found that geotechnical stability in the Middle Branch is problematic and the cost to restore wetlands was found to be very high.

Issues raised during the 1960 investigation of coastal storm barriers remain today. These include concerns about water circulation and impact to navigation. Environmental impacts are of great concern as a “fishable, swimmable” harbor is a goal of many stakeholders. These issues were explored in depth when selecting the TSP.

Figure 16: 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 measures. Structural coastal flood risk management measures are man-made, constructed measures that counteract a flood event to reduce the hazard or to influence the course or probability of occurrence of the event. Nonstructural CSRM measures are permanent or contingent measures applied to a structure that prevent or provide resistance to damage from flooding. NNBF CSRM measures work with or restore natural processes with the aim of wave attenuation and storm surge reduction.

The initial array of alternatives consisted of eleven alternatives and the following are the descriptions for each alternative.

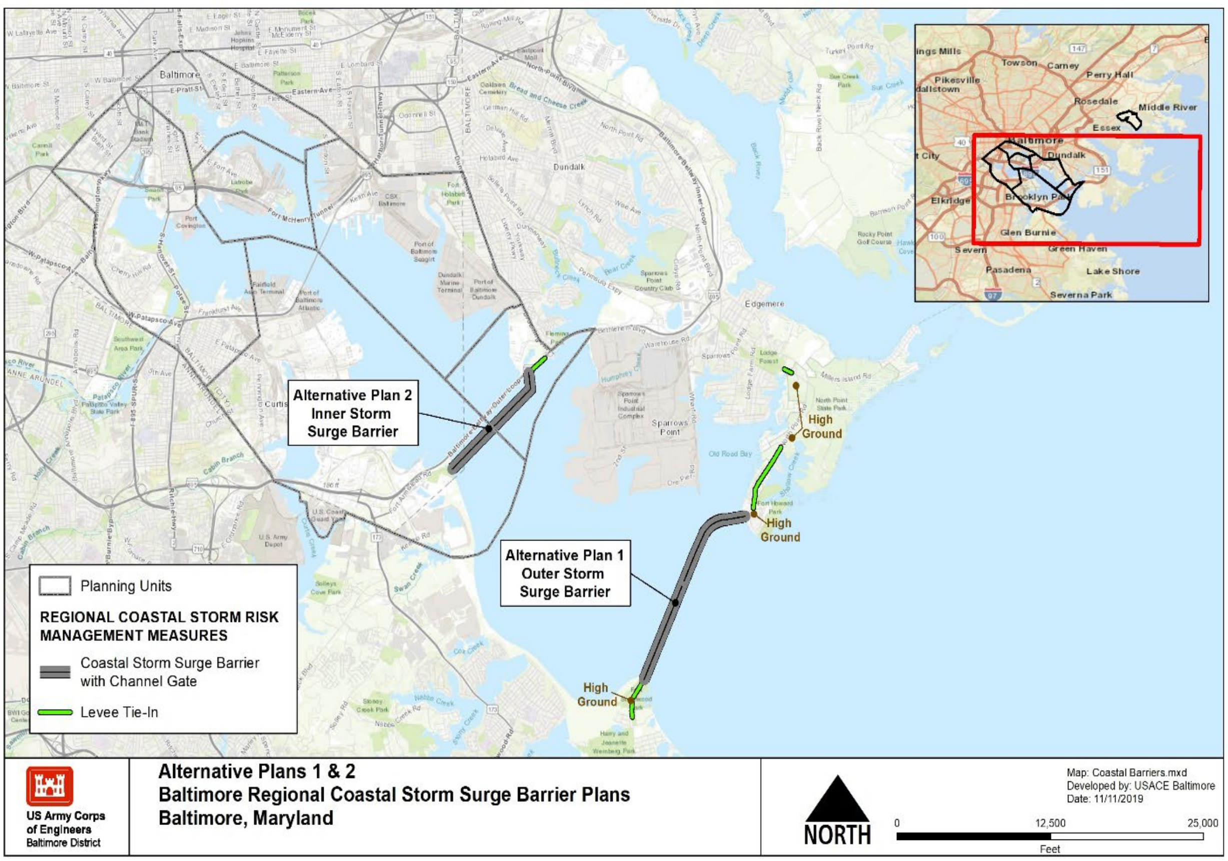
No Action Alternative:

The No Action Alternative assumes that no actions would be taken by the federal government or local interests to address the problems identified by the study. Consequently, the No Action Alternative would not reduce damages from coastal storm surge inundation. Although this alternative would not accomplish the purpose of this study, it 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.

Alternative 1 – Outer Surge Barrier and Alternative 2 – Inner Surge Barrier

Two varieties of surge barriers were examined. The Baltimore Outer Harbor 16,000-ft-long barrier with 1,000 ft of sector gate, and the Baltimore Inner Harbor 10,000-ft-long barrier with 1,000 ft of sector gate were alternatives considered during the early formulation process and each protects approximately the same assets. Further analysis determined that the most effective and most efficient type of barrier was the Baltimore Inner Harbor 10,000-ft-long barrier with 1,000 feet of sector gate. Therefore, the inner surge barrier was retained for consideration at the initial array of alternatives. Figure 17 shows the location of both surge barriers proposed under Alternative 2.

Figure 17: Inner and Outer Surge Barriers



The Baltimore Inner Harbor Storm Surge and Bulkheads management measures were developed in the following areas:

- 10,000-ft-long inner surge barrier with 1,000 ft sector gate in Patapsco River that connects at east Hawkins Point Shoal and at west Sollers Point
- Bulkhead protecting the west side of Martin State Airport

- Bulkhead protecting the east side of Martin State Airport

The inner flood barrier provides protection to all infrastructure located in Baltimore City including the I-895 Tunnel, the I-95 Tunnel , Baltimore Fire Department Marine unit, USACE Baltimore District facility at Ft. McHenry, Ft. McHenry National Monument, Baltimore Gas and Electric (BGE) Spring Garden natural gas facility, a casino, a portion of the Carroll Camden industrial neighborhood, Middle Branch Waterfront Park, Cherry Hill Park, Westport, and the Harbor Hospital.

The two bulkheads on the east and west sides of Martin State Airport would provide protection to the facilities of the Maryland State Police Aviation Unit headquarters, Baltimore City Police aviation unit, Baltimore County Police aviation unit, and the Maryland Air National Guard.

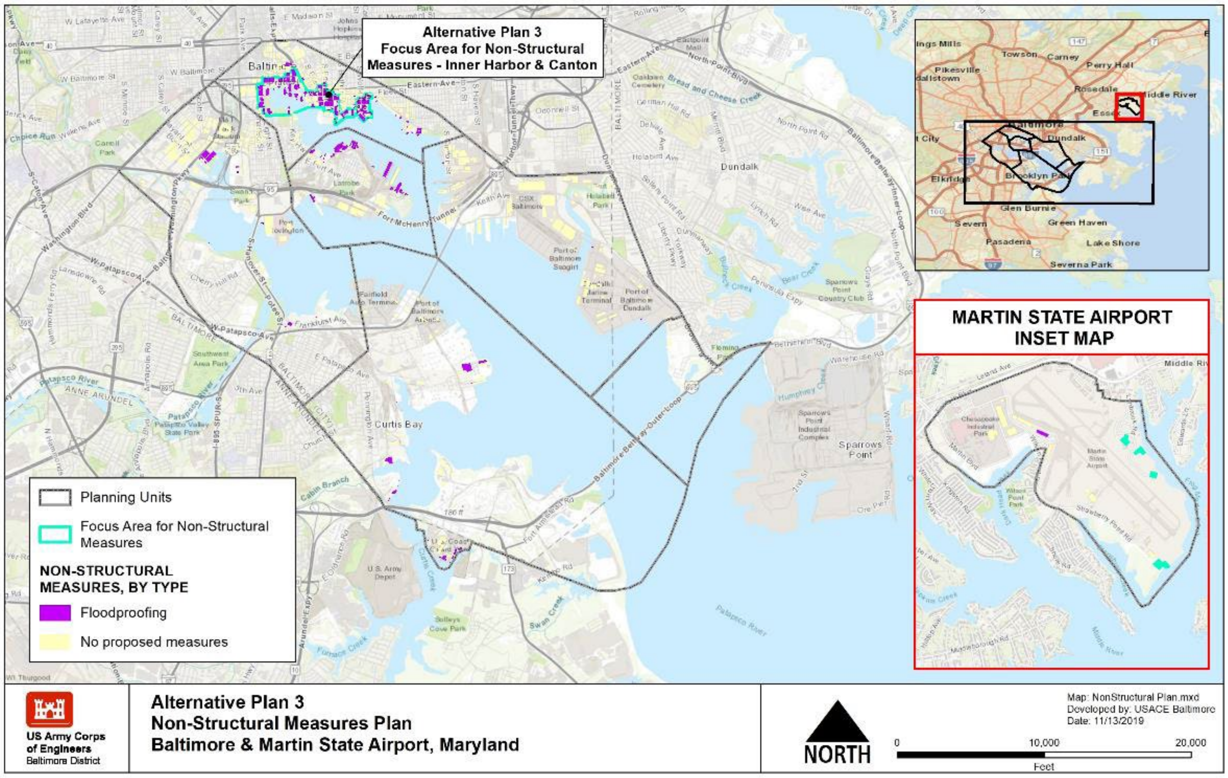
Alternative 3 - Nonstructural Only

This alternative was formulated to include the following actions that can be implemented by USACE:

- Relocation or buyout of structures
- Floodproofing of structures

Nonstructural treatments have been applied on 1096 structures in the 1% AEP, 493 structures in the 2% AEP and 286 structures in the 5% AEP. Since these structures were in the Baltimore Metropolitan historical district, elevation measures cannot be proposed without prior approval from local and state government agencies. Figure 18 shows the location of nonstructural solutions proposed under Alternative 3.

Figure 18: Nonstructural Solutions



The second category of measures would be implemented by the NFS:

- Flood warning system
- Revise emergency response plan
- Low-impact development / green infrastructure measures

The structures proposed for relocation, buyout, elevation, or flood proofing located in the Inner Harbor and Canton planning units are shown in Figure 18. Per USACE policy, in urban and urbanizing areas, low-impact development / green infrastructure measures are a non-federal responsibility. Flood warning systems and emergency response plans are also non-federal responsibilities.

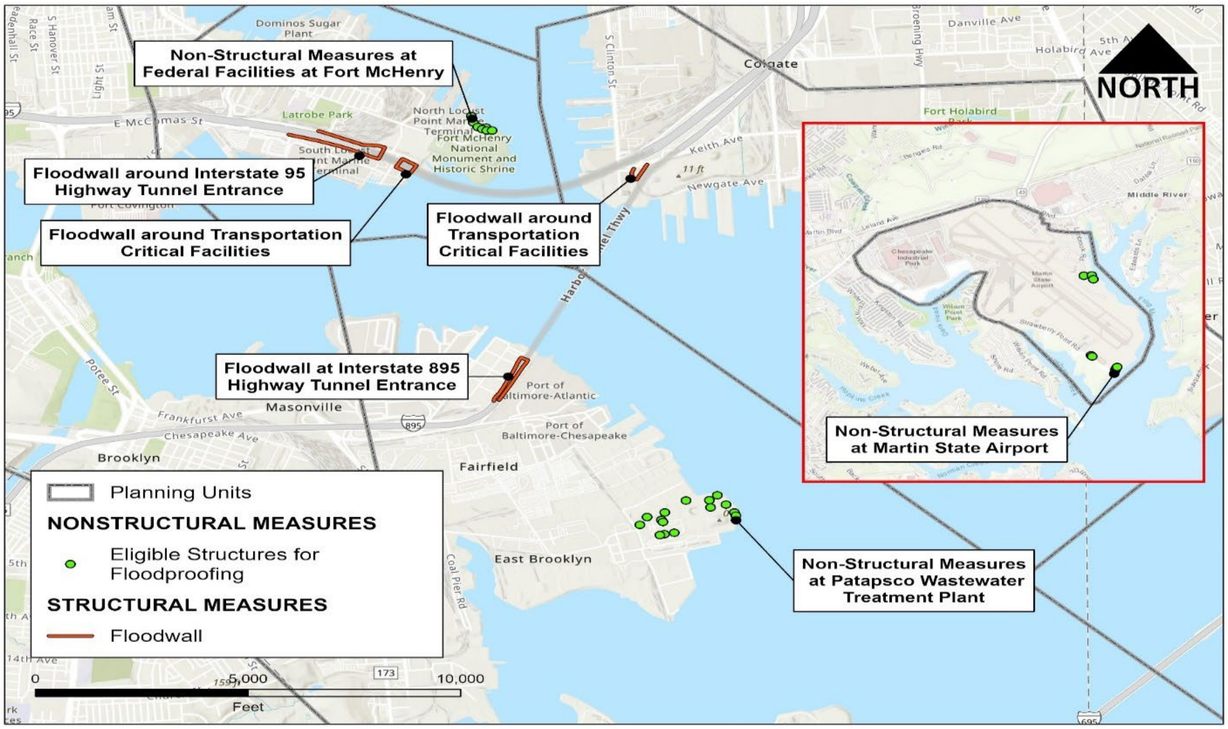
Alternative 4 - Critical Infrastructure Only: Locust Point and Patapsco (Bulkheads 8, 18, 19, and 24)

This alternative was developed for the following areas:

- Masonville dredged material containment facility (DMCF) to the Cox Creek DMCF in Patapsco South.
- Dundalk Marine Terminal to Danville Avenue and Clinton Street in Patapsco North.
- Baltimore Waterfront Promenade at the Baltimore Fire Department maintenance facility on Key Highway to the former BGE Gould Street Powerplant at Gould Street in Locust Point.

This alternative includes a bulkhead with a top elevation of 12.2 ft to protect water from getting into the I-895 Tunnel and the I-95 Tunnel, and to protect the tunnels' ventilation buildings. Nonstructural measures were also proposed for federal facilities in this alternative. This alternative would help to minimize transportation disruptions in the region and would manage flood risk to vulnerable infrastructure in the Baltimore metropolitan area. Figure 19 shows the locations of critical infrastructure proposed under Alternative 4.

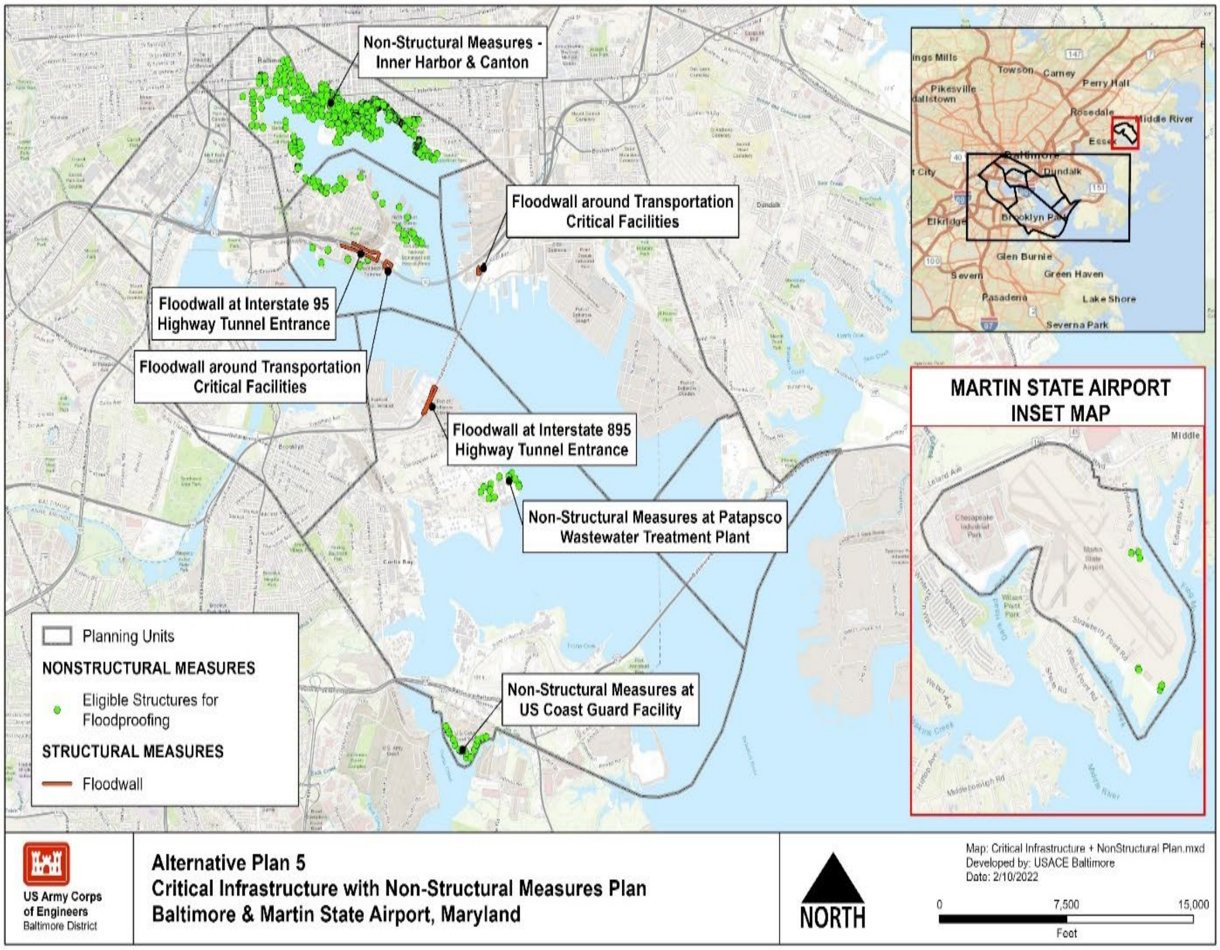
Figure 19: Critical Infrastructure in Locust Point and Patapsco



Alternative 5 - Critical Infrastructure with Nonstructural Measures

This alternative includes the bulkheads described in Alternative 4 in addition to nonstructural measures on 1096 structures in the 1% AEP, 493 structures in the 2% AEP, and 286 structures in the 5% AEP. These structures are categorized as residential and nonresidential located in Martin State Airport, the Inner Harbor, and in the Locust Point and Patapsco South neighborhoods. Figure 20 shows the locations of critical infrastructure and nonstructural measures covered under Alternative 5.

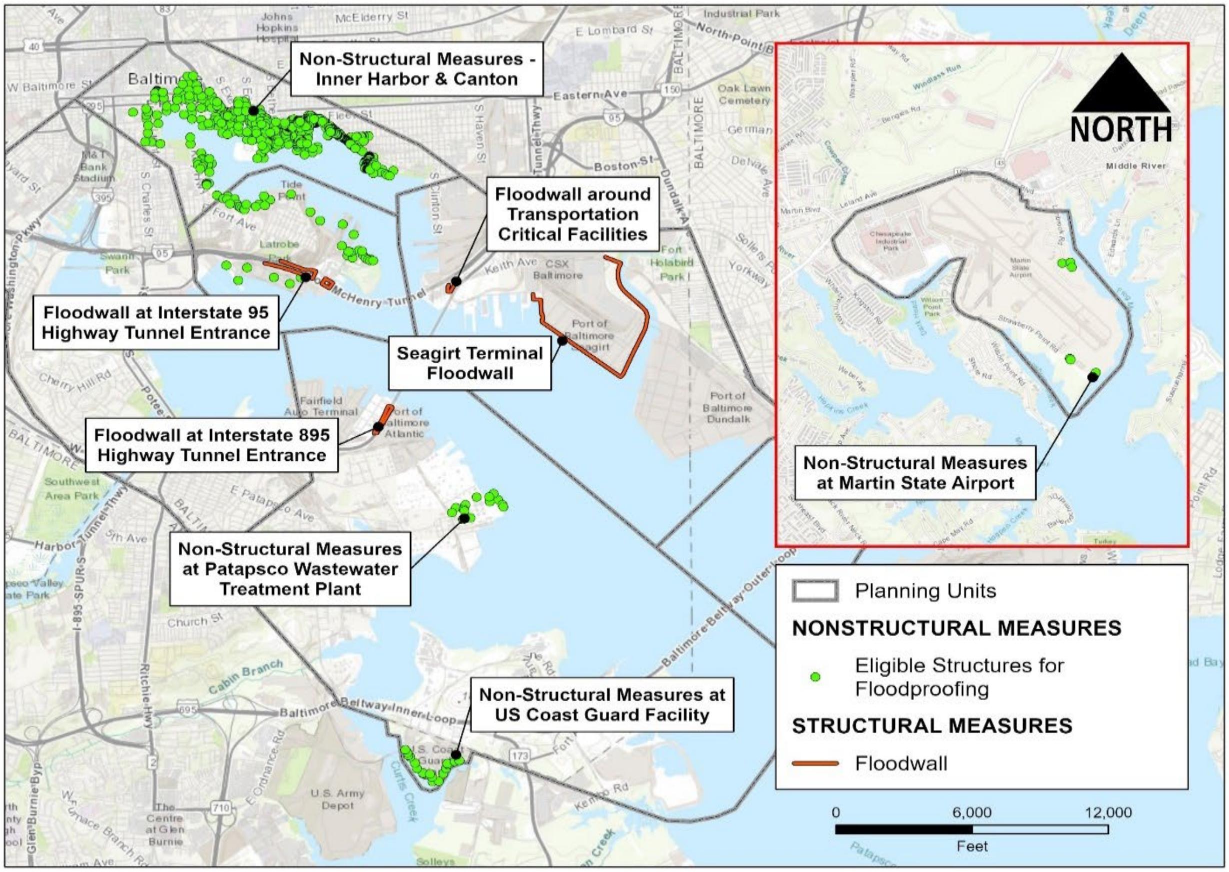
Figure 20: Critical Infrastructure with Nonstructural Measures



Alternative 6 – Critical Infrastructure Balanced (Bulkheads 7, 8, 18, 19, and 24)

This alternative includes elements of Alternative 5 in addition to the coastal floodwall at Seagirt Marine Terminal in Patapsco North, and at Dundalk Marine Terminal. This alternative was screened out early on because MPA has initiated design and construction of the floodwall. Figure 21 shows the locations of the critical infrastructure and nonstructural measures covered under Alternative 6.

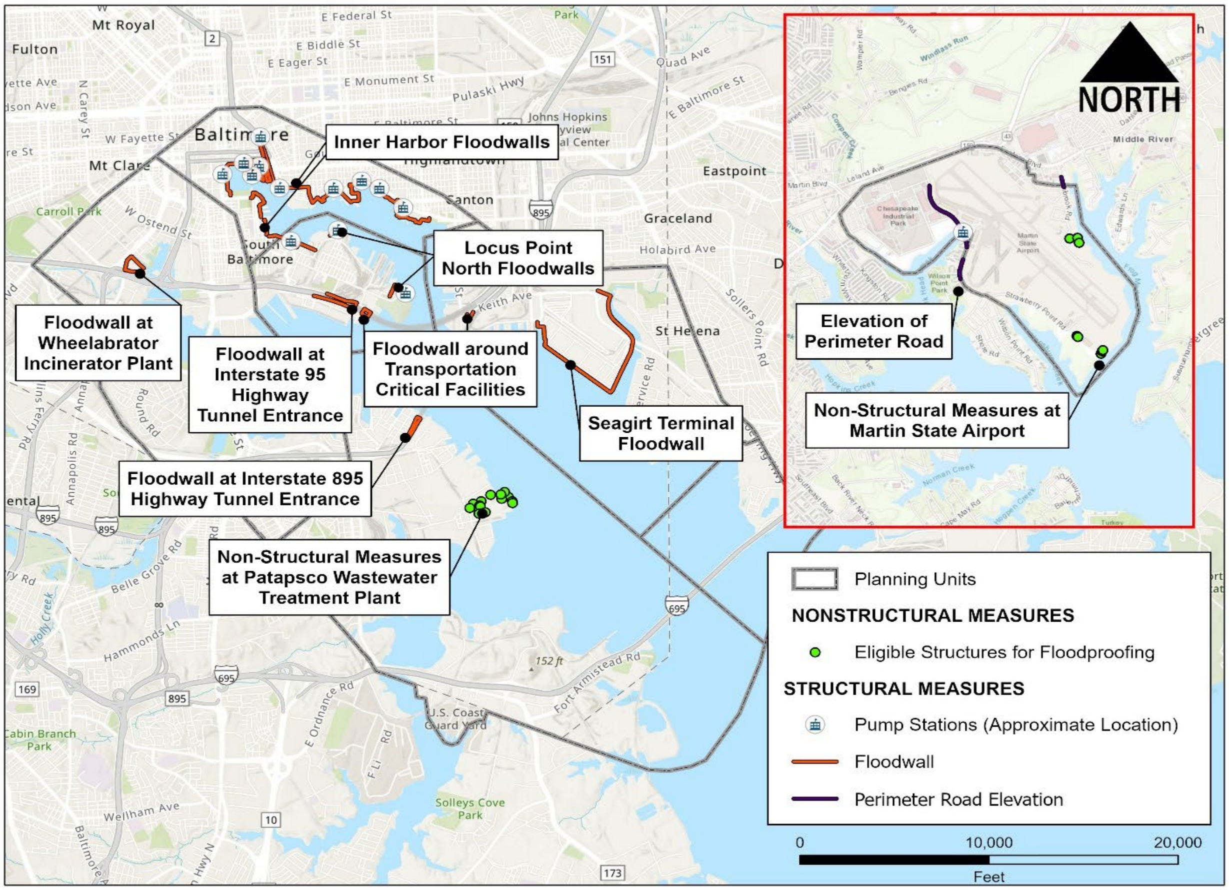
Figure 21: Critical Infrastructure Balanced



Alternative 7 – Mid-tier Balanced (Bulkheads 2, 3, 7, 8, 10, 11, 12, 13, 15, 16, 17, 18, 19, 24, and 25)

This alternative includes 13 floodwalls/levees that act as a linear coastal barrier in Inner Harbor and Locust Point. Two additional floodwalls are included on the east and west sides of Martin State Airport. The top elevation of all floodwalls/levees under this alternative is 12.2 ft. This alternative also includes nonstructural measures for federal facilities. Figure 22 shows the locations of critical infrastructure and nonstructural measures covered under Alternative 7.

Figure 22: Mid-tier Balanced.



Flood risk would be managed in the following locations under this alternative:

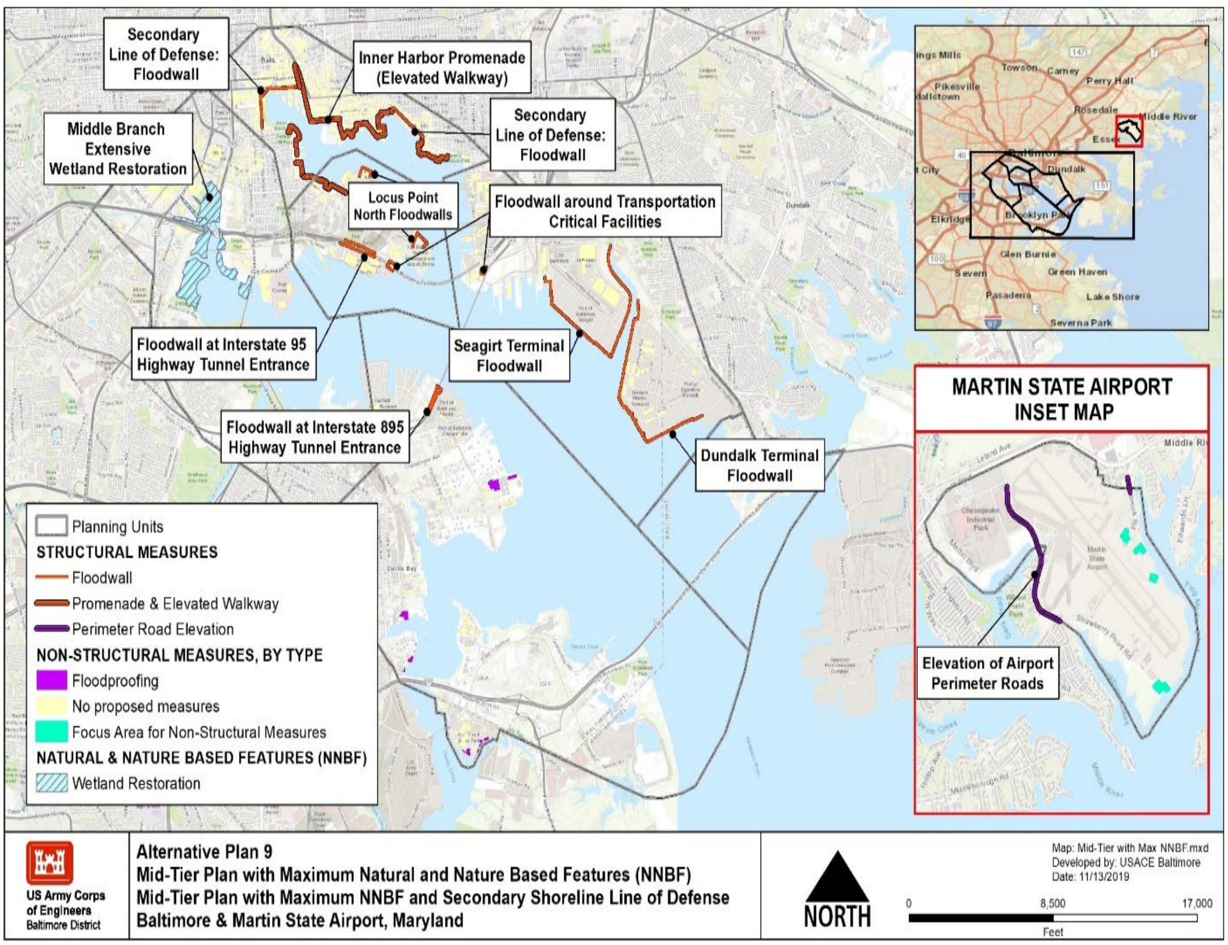
- Masonville DMCF to the Cox Creek DMCF in Patapsco South.
- Dundalk Marine Terminal to Danville Avenue and Clinton Street in Patapsco North.
- Baltimore Waterfront Promenade at the Baltimore Fire Department maintenance facility on Key Highway to the former BGE Gould Street Powerplant at Gould Street in Locust Point.
- Danville Avenue and Clinton Street to the end of the Baltimore Waterfront Promenade at the Baltimore Fire Department maintenance facility on Key Highway.
- Gould Street Powerplant (currently closed) at Gould Street to the Masonville DMCF.
- Middle River, Baltimore County, encompassing Martin State Airport and the Warfield Air National Guard Base.

Structures include the BGE Spring Garden natural gas facility, a casino, a portion of the Carroll Camden industrial neighborhood, Middle Branch Waterfront Park, Cherry Hill Park, Westport, Harbor Hospital, Martin State Airport, and facilities for the Maryland State Police Aviation Unit headquarters, Baltimore City Police aviation unit, Baltimore County Police aviation unit, and the Maryland Air National Guard.

Alternative 8 - Mid-tier with Enhanced NNBF

This alternative includes elements of Alternative 7 in addition to NNBF. NNBFs were initially considered across the different planning units within the study area. However, the urban character and shoreline type along a large portion of the study area limited the use of NNBF within the South Baltimore-East Channel, Port of Baltimore, Masonville to Wagners Point, and the Hawkins Point planning units. Federal Aviation Administration guidelines restrict land-use practices such as the construction of wetlands that could attract wildlife in the areas surrounding public airports, due to the hazard wildlife poses to aviation. These restrictions limited the use of NNBF within the Martin State Airport planning unit. Figure 23 shows the locations of critical infrastructure and NNBF measures covered under Alternative 8.

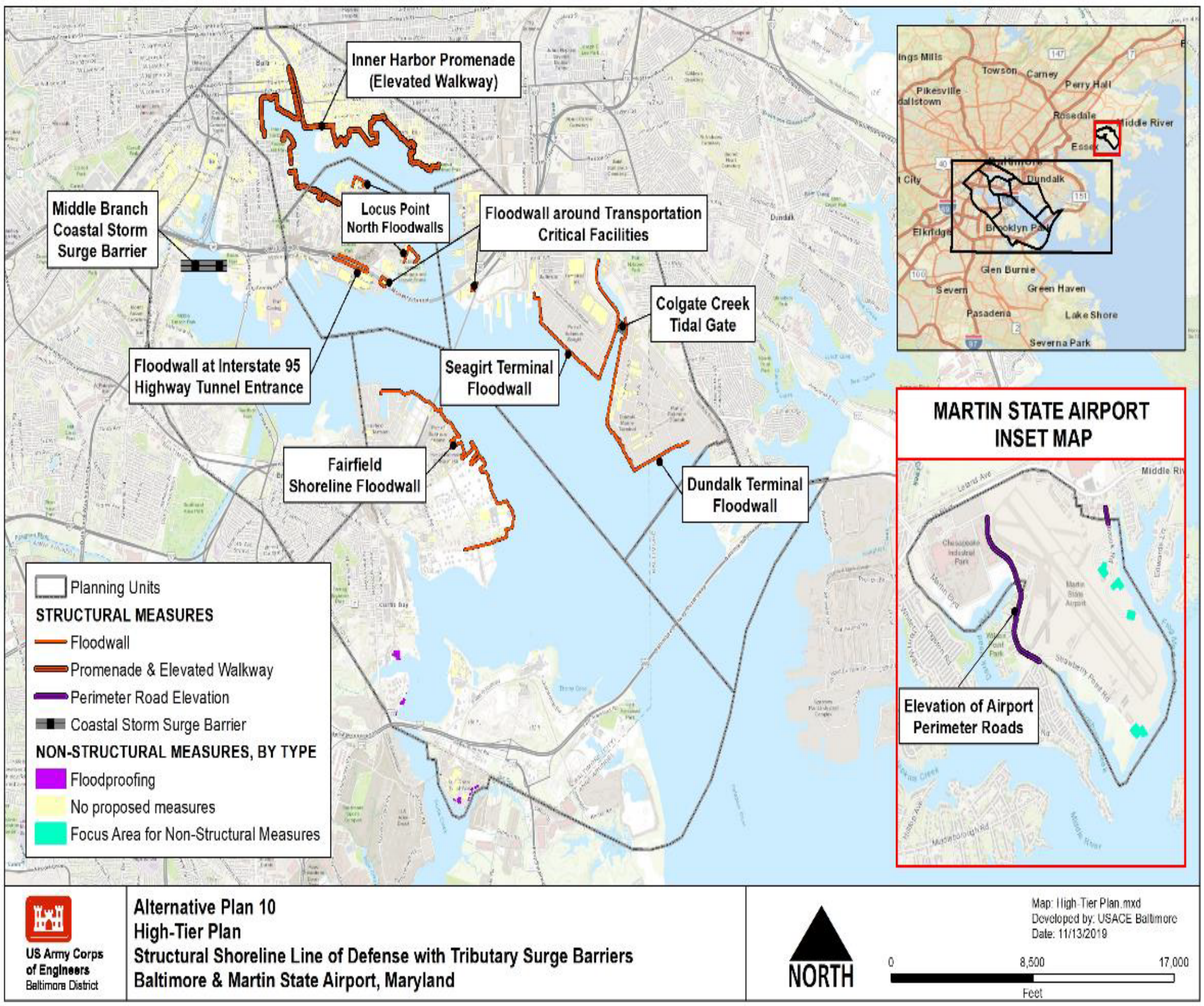
Figure 23: Mid-tier with NNBF



Alternative 9 - Mid-tier with Maximum NNBF

This alternative includes elements of Alternative 8 with additional NNBF in the upper Middle Branch planning unit. This planning unit was identified as a suitable area for the use of NNBF to manage flood risk. The Middle Branch has soft, green shorelines along the water's edge as well as existing parklands and open spaces. There are existing wetlands within the Middle Branch located primarily along the northern portion and near Smith Cove on the southwestern edge. Historically, existing tidal wetlands and natural beaches in the Middle Branch have been steadily lost as a result of shoreline hardening, development, and re-development. The City of Baltimore's Middle Branch Master Plan outlines opportunities to maintain the existing green shoreline and expand environmental restoration through redevelopment initiatives. Area characteristics and ongoing initiatives make the Middle Branch a potentially suitable location for wetland restoration and the implementation of NNBF. Figure 24 shows the locations of critical infrastructure and NNBF measures covered under Alternative 9.

Figure 24: Mid-tier with Maximum NNBF



Alternative 10 - High-tier

This alternative includes elements of Alternative 7 and as well as the replacement of floodwall/levee structures in Middle Branch with a local surge barrier structure.

Alternative 11 - High-tier with Maximum NNBF (Shoreline Limit Site Disturbance)

This alternative includes elements of Alternative 9 with extended shoreline floodwall structures around Fairfield Marie Terminal and nearby properties.

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 included 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 USACE policy for implementation. Each conceptual alternative was found to be complete, constructible, and compliant with study constraints.

The following table contains an assessment of how well key measures in each alternative met the study objectives and how well each alternative met the four evaluation criteria as prescribed in the *Economic and Environmental Principles and Guidelines for Water and Land Related Resources Implementation Studies*. More information regarding alternatives screening can be found in the Baltimore Coastal Study IFR/EA.

Table 19: Screening of Alternatives Based on Evaluation Criteria from the Principles and Guidelines

Alternative	Completeness	Effectiveness	Efficiency	Acceptability	Overall Risk	Result
1. Outer Surge Barrier	High	High	Low	Low	High	Screen Out
2. Inner Surge Barrier	High	High	Medium	Low	High	Screen Out

Alternative	Completeness	Effectiveness	Efficiency	Acceptability	Overall Risk	Result
3. Nonstructural Only	High	Low	Medium	High	Medium	Screen Out
4. Critical Only	High	Medium	High	High	Low	Retain
5. Critical & Nonstructural	High	High	High	High	Low	Retain
6. Critical Balanced	High	High	High	High	Medium	Retain
7. Mid-tier Balanced	High	High	Medium	High	Medium	Retain
8. Mid-tier w/NNBF	High	Medium	Medium	Medium	High	Screen Out
9. Mid-tier, Max NNBF	High	Medium	Low	Medium	High	Screen Out
10. High-tier	High	High	Low	High	Medium	Screen Out
11. High-tier w/Max NNBF	High	Medium	Low	Medium	High	Screen Out

6.4 FINAL ARRAY OF ALTERNATIVES

6.4.1 ALTERNATIVE MODELING

Alternatives 1 and 2 (surge barriers) were screened out because these measures would increase the project scope significantly. The following preliminary considerations indicate that the surge barriers would most likely 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 historical communities and other cultural resources.
- Environmental - water quality impacts, impacts to endangered species (e.g., Atlantic Sturgeon) and other anadromous fish.
- Initial economic evaluation shows negative net benefits.

Alternative 3 (nonstructural only) was screened out since it cannot address by itself coastal flooding problems in the Baltimore metropolitan area.

Alternatives 7 through 11 (tiered alternatives) were screened out because of their high costs.

Additional explanation on the screening process for these alternatives can be found in Section 3.5 of the IFR/EA.

The alternatives carried forward for evaluation included the No Action Alternative and Alternatives 4, 5, 6, and 7. These alternatives were considered the final array of alternatives. Since these were the final array of alternatives, additional information has been developed and incorporated into the description of each alternative in Section 3.4.7 of the IFR/EA. For the economic analysis, these alternatives were regrouped under 12 new alternatives plus a No Action Alternative based on the three AEPs (1%, 2%, and 5%).

Alternative 1: No Action Alternative

There are no changes to this alternative.

Alternative 4: Critical Infrastructure Plan – Nonstructural (NS)_100YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Developing nonstructural treatments on 30 federal facilities in MAs 1, 17, and 23 with 1% risk reduction.

Alternative 4: Critical Infrastructure Plan – NS_50YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Developing nonstructural treatments on 14 federal facilities in MAs 1, 17, and 23 with 2% risk reduction.

Alternative: 4: Critical Infrastructure Plan – NS_20YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Developing nonstructural treatments on 9 federal facilities in MAs 1, 17, and 23 with 5% risk reduction.

Alternative 5: Critical Infrastructure and Nonstructural Plan – NS_100YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Developing nonstructural treatments on 1096 structures in MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 with 1% risk reduction.

Alternative 5: Critical Infrastructure and Nonstructural Plan – NS_50YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Developing nonstructural treatments on 493 structures in MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 with 2% risk reduction.

Alternative 5: Critical Infrastructure and Nonstructural Plan – NS_20YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Developing nonstructural treatments on 286 structures in MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 with 5% risk reduction.

Alternative 6 Critical Infrastructure Balanced Plan – NS_100YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Protecting Seagirt Marine Terminal from coastal flooding in MA 7.
- Developing nonstructural treatments on 1096 structures in MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 with 1% risk reduction.

Alternative 6: Critical Infrastructure Balanced Plan – NS_50YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Protecting Seagirt Marine Terminal from coastal flooding in MA 7.
- Developing nonstructural treatments on 1096 structures in MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 with 2% risk reduction

Alternative 6 Critical Infrastructure Balanced Plan – NS_20YR

- Protecting I-95 and I-895 tunnels from coastal flooding in MAs 8, 18, 19, and 24.
- Protecting Seagirt Marine Terminal from coastal flooding in MA 7.
- Developing nonstructural treatments on 1096 structures in MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 with 5% risk reduction

Alternative 7: Mid-Tier Plan – NS_100YR

- Protecting Inner Harbor with linear floodwalls/levees in MAs 7, 8, 10, 11, 12, 13, 15, 16, 17, 18, 19, 24, and 25, and Martin State Airport with floodwalls in MAs 2 and 3.
- Developing nonstructural treatments on 23 federal facilities in MAs 1 and 23 with 1% risk reduction.

Alternative 7: Mid-Tier Plan – NS_50YR

- Protecting Inner Harbor with linear floodwalls/levees in MAs 7, 8, 10, 11, 12, 13, 15, 16, 17, 18, 19, 24, and 25, and Martin State Airport with floodwalls in MAs 2 and 3.
- Developing nonstructural treatments on 7 federal facilities in MAs 1 and 23 with 2% risk reduction.

Alternative 7: Mid-Tier Plan – NS_20YR

- Protecting Inner Harbor with linear floodwalls/levees in MAs 7, 8, 10, 11, 12, 13, 15, 16, 17, 18, 19, 24, and 25, and Martin State Airport with floodwalls in MAs 2 and 3.

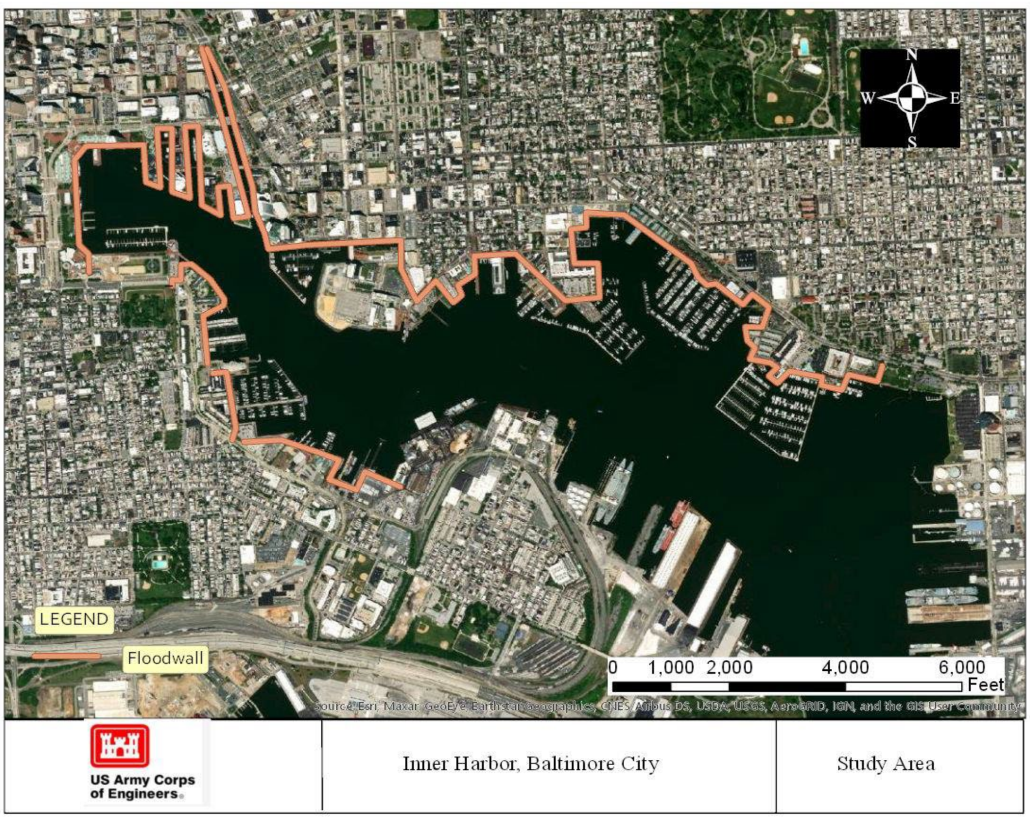
- Developing nonstructural treatments on 2 federal facilities in MAs 1 and 23 with 5% risk reduction.

6.4.2 TOP OF PROTECTION AND ALIGNMENT FOR STRUCTURE ALTERNATIVES

All the PSEs in the study area were designed with a top elevation of 12.2 ft NAVD88 to the USACE intermediate SLC curve for a 100-year storm. The LiDAR survey conducted by USACE Baltimore District was used to estimate the length of the alignment.

The Inner Harbor alignment consists of the waterfront from the Baltimore Museum of Industry to Canton Waterfront Park. This alignment is approximately 6.3 miles of floodwall as shown in Figure 25.

Figure 25: Inner Harbor Protective System Element



The Locust Point alignment consists of the I-95 tunnel and the tunnel ventilation building, US Naval Reserve Building and Domino Sugar Waterfront to the Baltimore Museum of Industry. This alignment is approximately 2.3 miles of floodwall as shown in Figure 26 below.

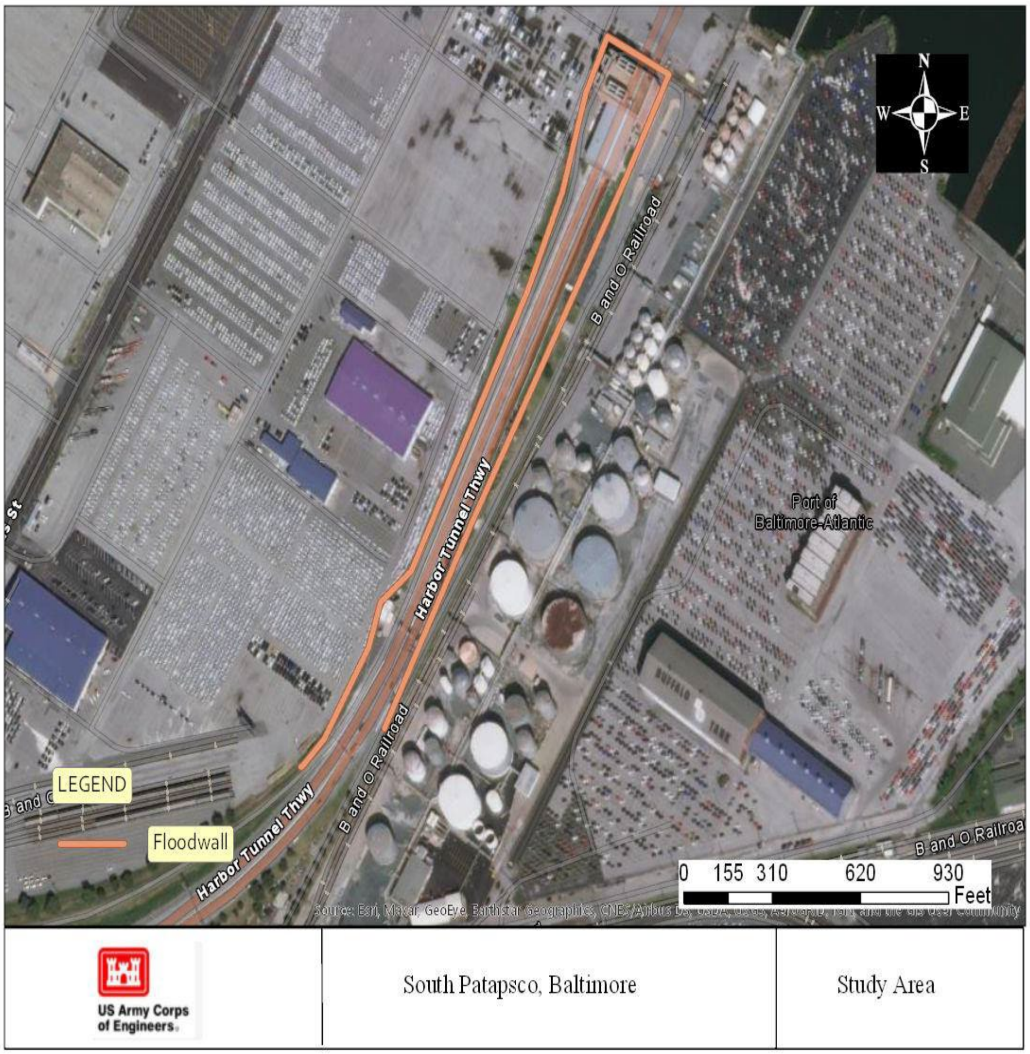
Figure 26: I-95 Tunnel and West Ventilation Building Protective System Element

The North Patapsco alignment consists of a 2.7-mile-long floodwall at the waterward edge of the Seagirt Marine Terminal at the Port of Baltimore as shown in Figure 27 below.

Figure 27: Port of Baltimore Seagirt Marine Terminal Protective System Element

The South Patapsco alignment consists of a 0.6-mile-long floodwall surrounding the I-895 Tunnel and west ventilation building as shown in Figure 28 below.

Figure 28: I-895 Tunnel and Ventilation Building Protective System Elements



The Middle Branch alignment consists of a 0.5-mile-long floodwall surrounding the Middle Branch Wheelabrator Incinerator Plant as shown in Figure 29 below.

Figure 29: Middle Branch Protective System Element

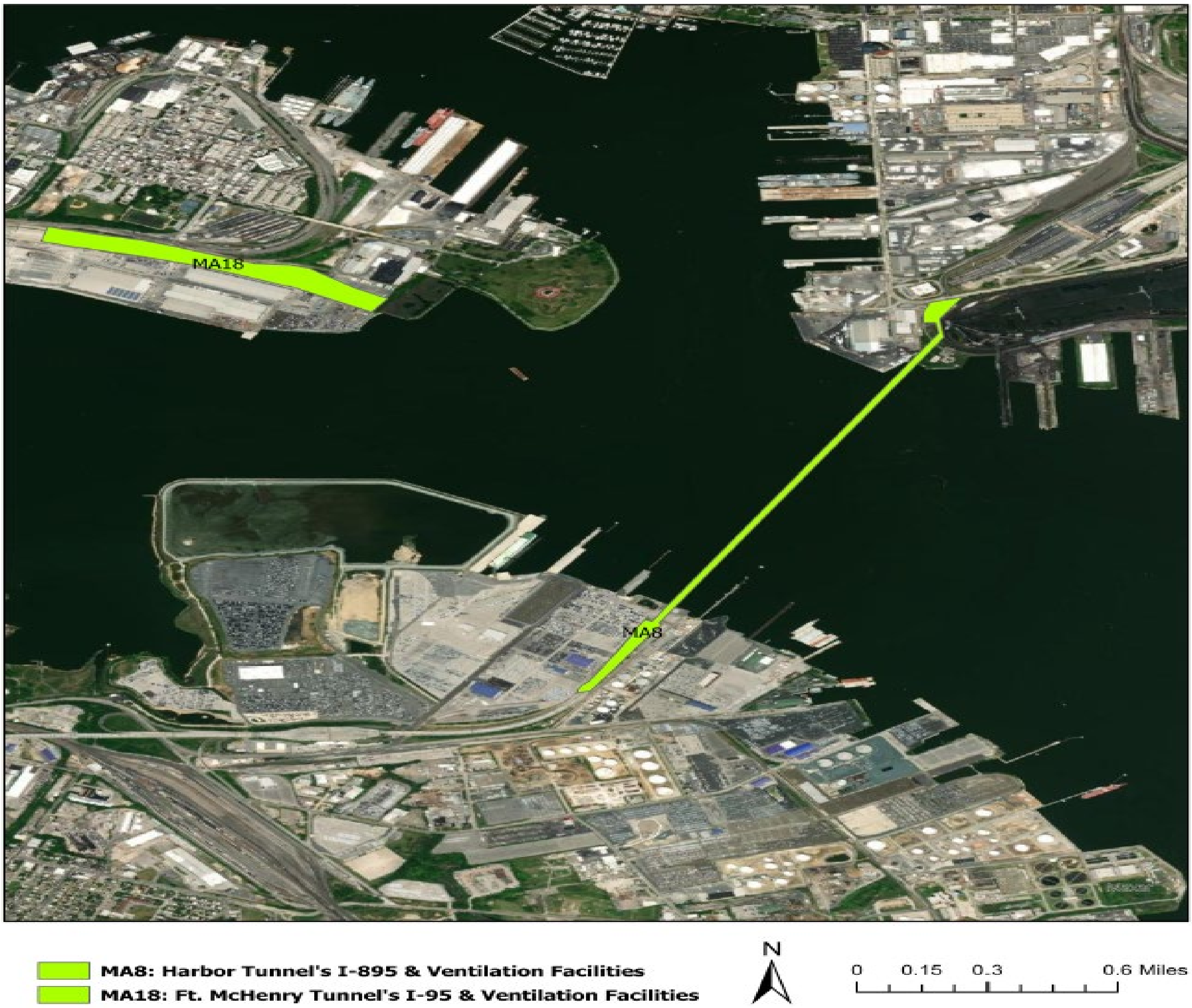
Martin State Airport consists of 0.75-mile-long floodwall from Wilson Point Road to Lynbrook Road as shown in Figure 30 below.

Figure 30: Martin State Airport Protective System Element

7. REVALUATION OF TUNNELS AND THEIR VENTILATION BUILDINGS

Engineering data were reevaluated especially in MA8, MA18, MA19, and MA24 where tunnels and their facilities are located. The results showed that each tunnel and its facilities have the same hydrologic connection. Hence, the I-895 tunnel in MA24 and its facilities in MA8 are now regrouped under the same model area MA8. The I-95 tunnel previously in MA19 and its facilities in MA18 are now regrouped under the same model area MA18 as shown in Figure 31 below.

Figure 31: Tunnels' Model Areas and their Ventilation Buildings



7.1 TUNNEL DAMAGE MODELING IMPROVEMENTS

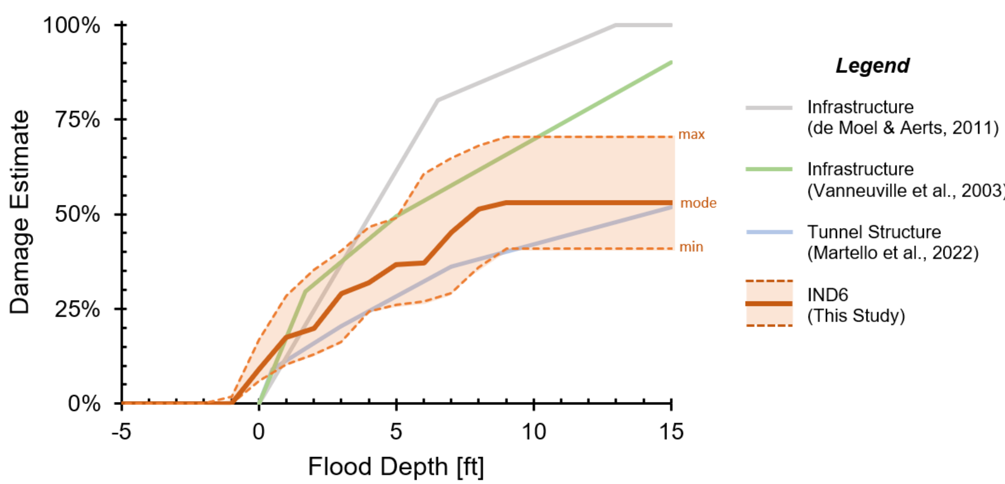
The I-95 and I-895 tunnels are among the most valuable and critical assets in the study area. As such, it is important that the sensitivity and fragility of these tunnels is well-characterized. Exposure of these tunnels to saltwater during a coastal flood event is likely to damage support infrastructure in the tunnel (ventilation system components, power conduit, lighting, etc.; Martello et al., 2023). Additionally, roadway surfaces, and tunnel structure are also likely to experience damage, as saltwater exposure would likely result in accelerated rates of material degradation (e.g., corrosion and spalling) particularly at construction joints and the location of preexisting cracks (FHWA, 2005; Nazarchuk, 2008; Chen & Lalas, 2012). Informed by recent research and methodological advancements in flood damage modelling for tunnels and underground infrastructure (Martello et al., 2023; Martello & Whittle, 2023) this section presents a reassessment of the relationship between flood depth (at the ground surface) and damage to each of the tunnels.

The remainder of this subsection first establishes the validity of the previously employed depth damage curve. The next subsection presents a methodology for developing a set of new depth damage curves, which are specific to each tunnel (I-95, I-895) informed by tunnel geometry and estimated inflows for a set of sample coastal flood events. Lastly, the final subsection presents the results of this analysis, inclusive of the modified depth-damage curves, and discuss their implications on the economic assessment.

7.1.1 VALIDATION OF PRIOR DEPTH-DAMAGE CURVE

Absent relevant empirical data, a qualitative comparison of the previously employed depth damage curve (IND6) to similar curves available elsewhere (i.e., validation via benchmarking) is the best available method for assessing the validity of depth-damage curves (Gerl et al., 2016). Compared to residential and commercial properties, the relationship between flood-depth and damage for transportation infrastructure assets is less well understood (Habermann & Hedel 2018). While there are generic depth-damage curves for infrastructure assets (Vanneuville et al., 2003; de Moel & Aerts, 2011; Habermann & Hedel 2018) and a specific curve for tunnels available in the academic literature (Martello et al., 2023) no road tunnel specific curves were found in the literature. Relying on the few relevant curves available in the literature, validation of the depth-damage curve previously employed for both tunnels (IND6) is conducted via a qualitative benchmarking approach. As shown in Figure 32, the IND6 curve aligns well with the general infrastructure curves found in the literature (de Moel & Aerts, 2011; Vanneuville et al., 2003) with the tunnel structure curve (Martello et al., 2023) approximately aligned with the lower bound of the IND6 curve. Here, it is noted that the damage estimates shown are expressed as a percentage of asset replacement cost (e.g., tunnel replacement cost). Exercising a degree of engineering judgement, qualitatively, this comparison suggests that it would be reasonable to apply the IND6 curve for the road tunnels in the study area. As such, the IND6 curve serves as the basis of the modified depth-damage assessment for both tunnels, detailed further in the following subsection.

Figure 31: Comparison of the IND6 depth-damage curve to relevant curves available in literature.

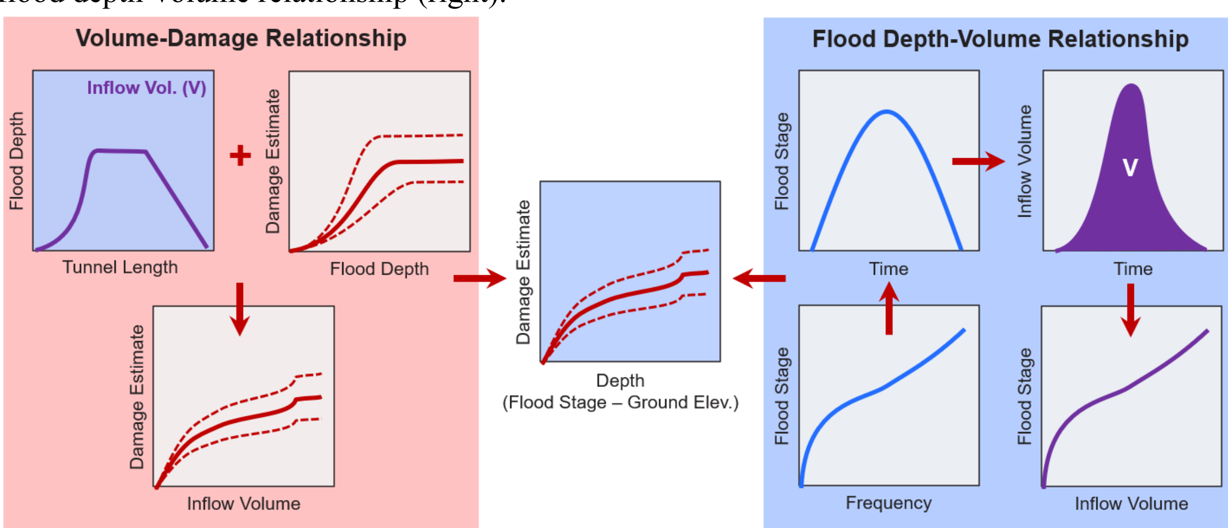


7.1.2 METHODOLOGY

Unlike most other assets, due to its long length and varied elevations along its profile, a partially flooded tunnel will experience a range of flood depths, with the highest flood depths occurring at the deepest portions of the tunnel. As such, as flood depths vary along the length of a flooded tunnel, associated flood damages will also vary along the length of the tunnel. Proper evaluation of flood damages in a tunnel should consider this variation (Martello & Whittle, 2023). Further, assuming the geometry of a tunnel (i.e., its cross section, length, and invert elevations) is known, a relationship between inflow volume and flood depths along the tunnel can be developed (i.e., given an inflow volume, flood depths along the tunnel can be computed). As shown in Figure 33, when these flood depths are evaluated using a depth-damage curve, a volume damage relationship can be developed for a tunnel. That is, for a given volume of inflow into a tunnel, the corresponding flood depths along the tunnel can be computed, for which a damage estimate can be developed.

However, for a volume-damage relationship to be useful, a relationship between tunnel inflow volumes and flood event characteristics must exist. Rephrased, a relationship between flood depth at a tunnel opening and the subsequent volume of inflow into the tunnel is required (as shown in the right side of Figure 33). Relying on water surface elevation time series data and hydraulic characteristics of an assumed flow path into the tunnel, inflows over time can be estimated for specific flood events. Evaluating the total inflow into a tunnel for a sample set of flood events, a relation is developed between flood depth (at a tunnel opening) and inflow volume. Finally, given this relationship between flood depth vs. inflow volume and the relation between inflow volume and damage, a tunnel-specific relation between flood depth (at a tunnel opening) and damage is developed. This new depth-damage curve can readily characterize damage to an entire tunnel given its critical ground elevation, thereby enabling the consideration of the tunnel as a single asset within the G2CRM model, consistent with the prior modelling approach.

Figure 23: Summary of the methodology used to develop the tunnel-specific depth damage curve (center) directly informed by a tunnel-specific: volume-damage relationship (left), and flood depth-volume relationship (right).



7.1.2.1 VOLUME-DAMAGE RELATIONSHIP

A key aspect of developing the volume-damage relationship is calculating the volume of the tunnel. Here, it is assumed that for a given flood event, the tunnel will be filled to a maximum hydraulic grade line (max. HGL), effectively a still-water elevation. This assumption is consistent with prior simulations and analysis presented in Martello & Whittle (2023). Here, the tunnel is discretized into several segments, wherein segments are delineated by a change in tunnel slope. For any given flood event, each of these segments will be at least partially: dry, fully flooded (condition a), or partially flooded (condition b). For a fully filled tunnel segment (i) consisting of n tubes, the flood volume ($V_{i\,filled}$) can be calculated as:

$$V_{i\,filled} = n\pi R_i^2 L_{i\,filled}$$

Where $L_{i\,filled}$ is the filled length of the tunnel segment. The flood volume of a partially filled segment ($V_{i\,part}$) can be calculated as:

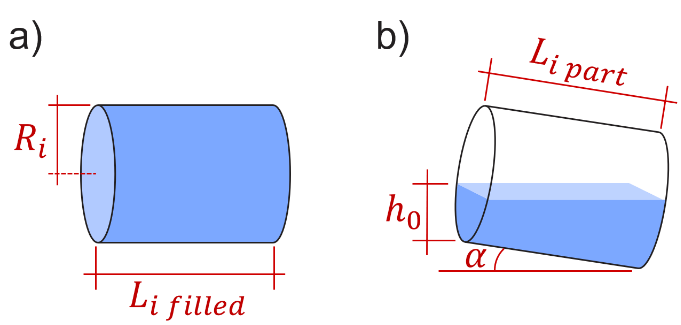
$$V_{i\,part} = n\frac{R_i^3}{\tan(\alpha)}\left(K\,arccos(K) - \frac{1}{3}\sqrt{1-K^2}(K^2+2) - C\arccos(C) + \frac{1}{3}\sqrt{1-C^2}(C^2+2)\right)$$

where:

$$K = 1 - \frac{h_0}{R_i} \qquad C = K - \frac{L_{i\,part}\tan(\alpha)}{R}$$

And $L_{i\,part}$ denotes the partially filled length of the tunnel segment. Figure 34 visualizes these two conditions, along with the key measurements employed in the volume calculations. Informed by the available contract drawings, the I-895 tunnel was modelled as two 14.5 ft inner diameter boreholes (i.e., $n = 2; R = 14.5\,ft$), whereas the I-95 tunnel was modelled as four 17.25 ft inner diameter boreholes (i.e., $n = 4; R = 17.25\,ft$).

Figure 33: Key parameters for a) fully flooded tunnel segment; b) partially flooded tunnel segment



As such, for a given max HGL, and known tunnel geometry (i.e., segment lengths, elevations, radii, number of tubes), an estimated flooded tunnel volume can be developed. Further, given a max HGL, for any given segment of tunnel, the flood depth can be characterized as a linear relationship:

$$h(x) = mx + h_1$$

where m is the slope of the tunnel and h_1 is the flood depth at the reference edge of the tunnel segment. Given this equation, the flood depth can be continuously evaluated along any given tunnel segment. Crucially, assuming there exists a closed form solution for the depth-damage relationship, it is possible to continuously evaluate the (min, mode, or max) depth-damage function for any given segment of tunnel. Here, a logistic function is fit to the data underlying the IND6 depth-damage curve:

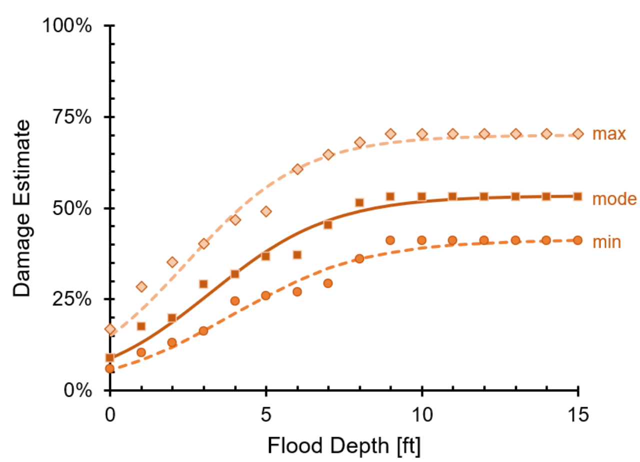
$$DDF(x) = \frac{L}{1 + e^{-k(mx+h_1-d_0)}}$$

Wherein the key function parameters for the min, mode, and max curves are shown in 20. The fitted curves and the underlying data for IND6 are shown in Figure 35.

Table 20: IND6 logistic function variables for the min, mode, and max curves

Variable	min	mode	max
L	0.41	0.53	0.70
k	0.47	0.51	0.53
d_0	3.91	3.20	2.44

Figure 34: Logistic function curves fitted to the min, mode, and max of the IND6 depth-damage relationship.



Given these fitted curves, it is possible to continuously evaluate the depth-damage function along any given tunnel segment. Further, this allows for the evaluation of the average damage across the segment by evaluating the integral of the depth-damage function and dividing by the segment length (distance between x_2 and x_1):

$$DDF_{avg} = \frac{1}{(x_2 - x_1)} \int_{x_1}^{x_2} DDF(x)dx$$

Wherein the integration of the depth-damage function is computed as:

$$\int_{x_1}^{x_2} DDF(x)dx = \frac{L}{km(x_2 - x_1)} \cdot \left(ln\left(e^{-kmx_2 - h_1 k}(e^{kmx_2 + h_1 k} + e^{d_0 k})\right) + kmx_2 - ln(e^{-kmx_1 - h_1 k}(e^{kmx_1 + h_1 k} + e^{d_0 k}) - kmx_1) \right)$$

In this manner, it is possible to compute a damage estimate for each tunnel segment. Aggregating these segment damage estimates based on a length-weighted average, an overall damage estimate for the entire tunnel can be computed. This approach is employed to estimate inflow volume and overall tunnel damage for a range of max HGL values, thereby enabling the development of a volume damage relationship.

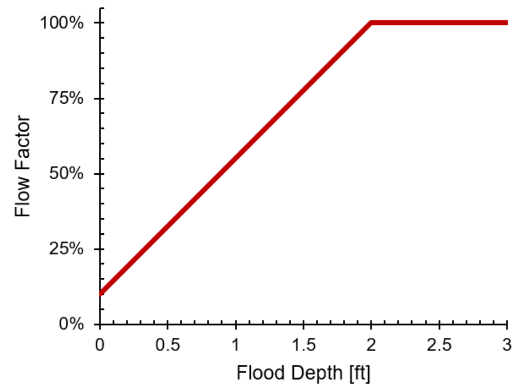
7.1.2.2 FLOOD DEPTH-VOLUME RELATIONSHIP

Developing a relationship between flood depth at the surface (i.e., at the ground level of the critical inflow path) and inflow volume requires an understanding of where and how water will flow into each of the tunnels. For both the I-95 and I-895 tunnels, it was assumed that this critical inflow path would arise after failure of existing concrete walls. It is assumed the walls will fail along a critical section of predetermined length (50 ft for the I-895 parapet wall, and 100 ft for the I-95 concrete barrier wall). Based on an assessment of the existing walls, these critical section lengths are a likely lower bound; as such, the resultant inflow estimates are rather conservative.

Informed by the contract drawings, survey data, and field inspections, it was concluded that the concrete barrier along a low point (+6.5 ft NAVD88) of the eastern I-95 tunnel approach is in poor condition, and likely to leak upon hydrostatic loading, as there is an apparent lack of groundwater cutoff below the wall. Based on this condition assessment, it was concluded that this wall was very likely to fail, even under a small degree of hydrostatic loading (specifically less than 2 feet of flooding). Similarly, upon review of the contract drawings, it was concluded the parapet wall around the southern approach to the portal of the I-895 tunnel is likely to fail under flood loads along a low point (+6 ft NAVD88). Considering these assessments, it is assumed that these walls will progressively fail along a critical section.

Operationalizing the condition assessments of these critical wall sections, a flow factor is developed to characterize a progressive failure of the critical wall sections. As shown in Figure 36, this flow factor is dependent upon the flood depth at the critical wall section. Here, an initial flow factor of 10% is assumed, reflecting a leakage rate through the critical wall section as soon as it is exposed to water. As flood depth increases, so too does the leakage rate (i.e., the flow factor increases linearly to approximate a progressive failure), until a flood depth of 2 ft is reached, after which it is assumed, the critical section will completely fail, thereby allowing water to fully flow through the critical section.

Figure 35: Flow factor vs. flood depth for the critical wall sections.



Weir flow is assumed through the critical section (L_{crit}) for each of the tunnels, wherein the flow at any given time step, $Q(t)$, is directly dependent upon the depth of water, $h(t)$, and the flow factor shown above, $F_f(h(t))$. The resultant inflow [ft^3/s] into the tunnel is computed as:

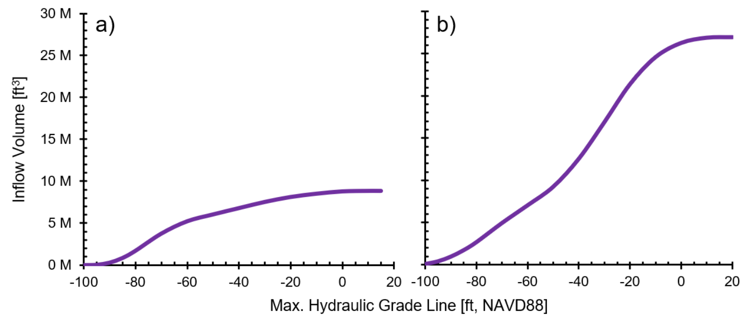
$$Q(t) = F_f(h(t))3.33\big(L_{crit} - 0.2h(t)\big)h(t)^{\frac{3}{2}}$$

Given these assumptions, it is possible to develop a time-dependent estimate inflow rates into the tunnels for a sample set of coastal flood events. Relying on the coastal flood risk data available from the North Atlantic Comprehensive Coastal Survey (NACCS; Nadal-Caraballo & Melby, 2014; Cialone et al., 2015, USACE CHL, 2023) at the relevant STWAVE save point (1946) inflows into both the I-895 and I-95 tunnels are estimated for a sample set of simulated tropical storm events, estimating inflows at each time step. Inflows are estimated for a set of n=6 simulated tropical storms under baseline sea level conditions with random tides (TS_SimB-post0) and n=6 simulated tropical storms under 1 m of sea level rise with random tides (TS_SimB_RTgslc1). In addition to estimating tunnel inflow rates over time, estimate of total inflow into the tunnels are also developed via numerical integration. Lastly, given these total inflows and the maximum flood depths (as measured at the ground surface of the critical sections) for each tunnel, a relationship between flood depth and inflow volume is developed. This relationship enables the mapping of flood depths (at the ground surface) to the volume-damage function, thereby directly enabling the development of a new depth-damage function for each tunnel in its entirety.

7.1.3 RESULTS

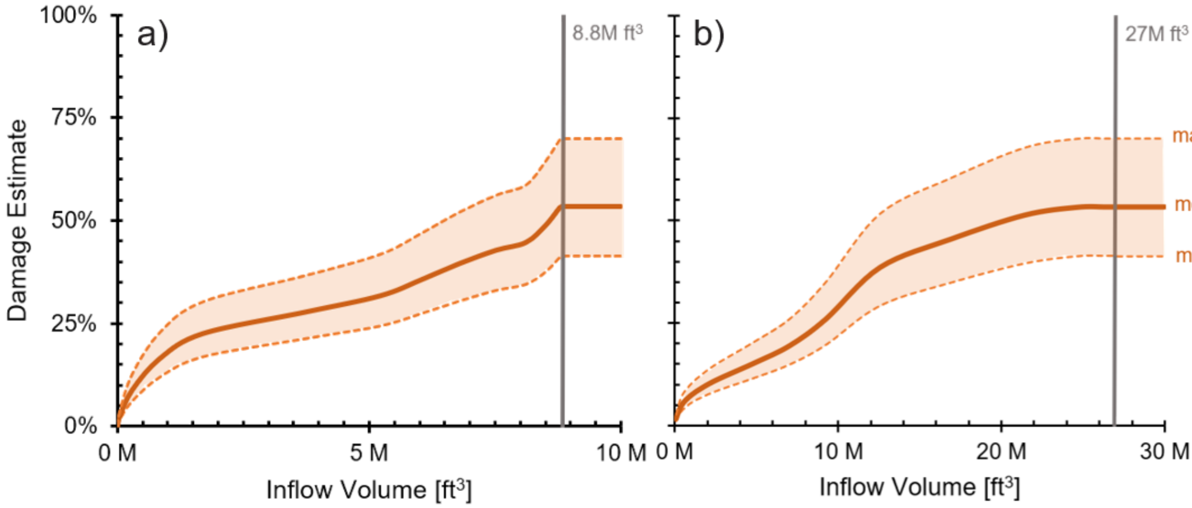
For the development of the volume-damage relationship for the I-895 and I-95 tunnels, inflow volume is evaluated and related damage for a total of n=16 distinct flood conditions (i.e., max HGL elevations). Figure 37 provides the relationship between inflow volume and max. HGL for the I-895 and I-95 tunnels. Note that the slope of the curves shown is directly informed by the longitudinal alignment of the tunnels. Informed by these results, it is estimated that the total volume of the I-895 tunnel is 8.8M cubic feet, and the I-95 tunnel has a volume of 27M cubic feet.

Figure 36: Tunnel inflow volume vs. maximum hydraulic grade line (max. HGL) for the a) I-895 tunnel, b) I-95 tunnel.



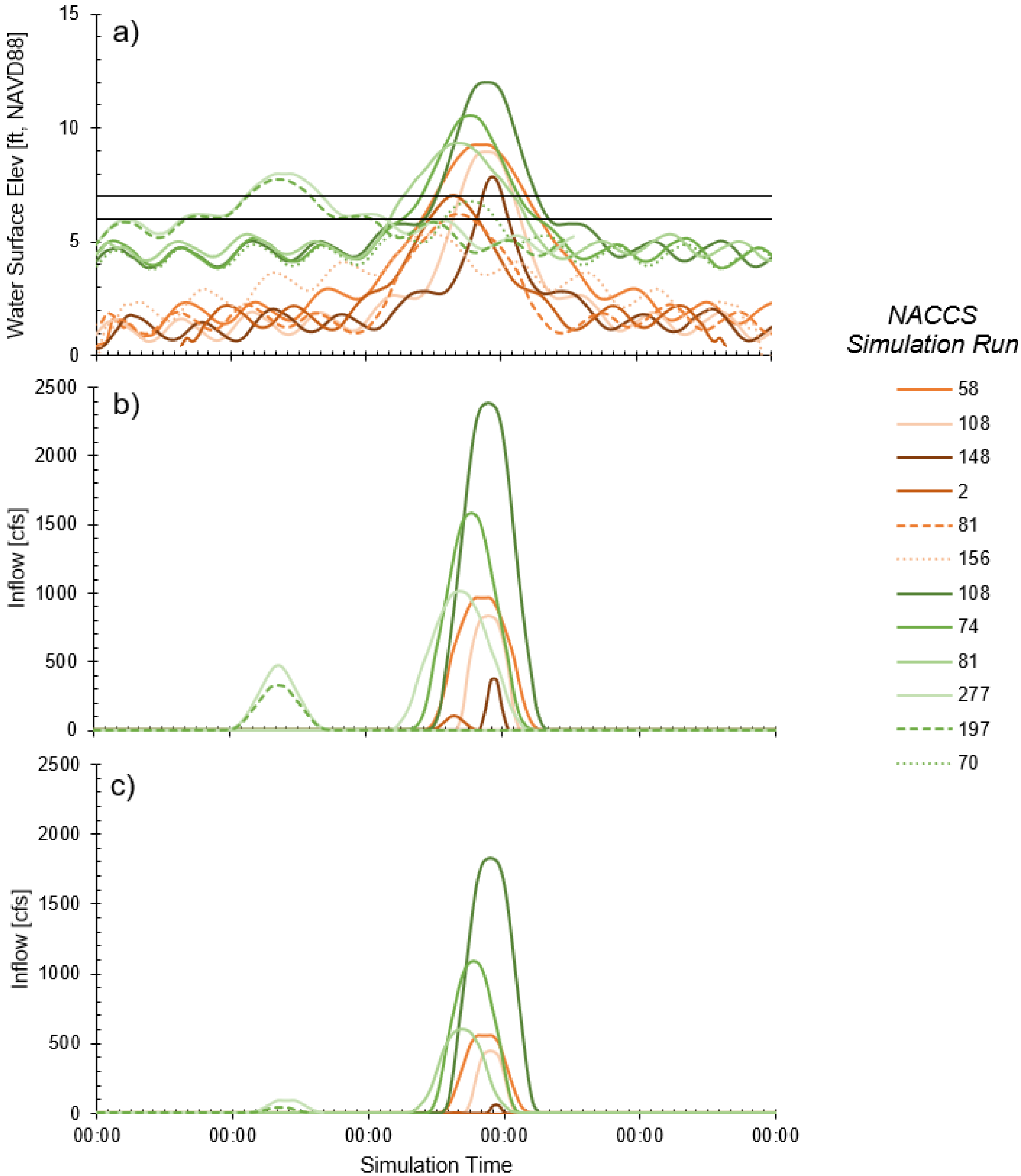
Relating these inflow volumes to damage, Figure 38 provides the estimated minimum, mode, and maximum volume-damage curves for the I-895 and I-95 tunnels. Again, it is noted that the longitudinal alignment of the tunnels directly informs the slope of these curves. Notably, due to its comparatively more gradual slope on its western end, the I-95 tunnel reaches maximum damage more gradually than the I-895 tunnel, which only reaches maximum damage after the final segment of the northern end of the tunnel begins to flood.

Figure 37: Damage estimate vs. inflow volume (volume-damage curves) for the a) I-895 tunnel, b) I-95 tunnel.



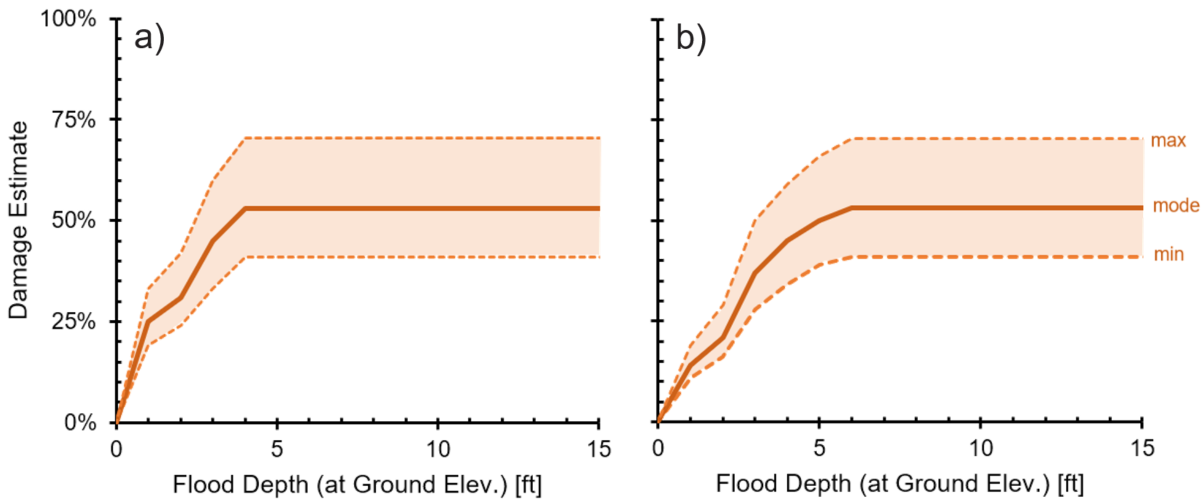
Shifting to the relationship between ground surface flood depths and inflow volumes, Figure 39 provides the water surface elevation time series for the sample storm events (a), along with the resulting inflows into the I-895 (b) and I-95 tunnels (c) given the critical sections and failure modes described in the previous subsection. Here, it is noted that for the same storm event, the I-895 tunnel is expected to experience inflows sooner than the I-95 tunnel, due to its comparatively lower ground elevation. Relatedly, for a given storm event, a larger estimated inflow rate for the I-895 tunnel is observed compared to the I-95 tunnel for the same time step.

Figure 38: Time series of a) water surface elevations (WSE), b) inflows into the I-895 tunnel, and c) inflows into the I-95 tunnel for a sample set of NACCS simulation runs.



Informed by these results, a depth-damage relationship for both tunnels is developed, wherein flood depth is measured at the relative to the ground elevation at the critical inflow section, as shown in Figure 40. Due to its lower ground elevation, greater inflow volumes, and comparatively smaller total volume, the I-895 tunnel is expected to fill faster than the I-95 tunnel. Consequently, the (min, mode, and max) depth-damage curves for the I-895 tunnel reach their maximum values (41%, 53%, and 70% damage, relative to tunnel replacement cost) at a flood depth of 4 feet. By contrast, the depth-damage curves for the I-95 tunnel reach these same maximum values at a flood depth of 6 feet, implying that the I-95 tunnel is marginally less sensitive to flood damages, all else being equal.

Figure 40: Depth-damage curves (damage estimate vs. flood depth at ground elevation) for the: a) I-895 tunnel, b) I-95 tunnel.



7.1.4 DISCUSSION AND IMPLICATIONS

The results of this analysis demonstrate that even under rather conservative inflow assumptions (based on rather narrow critical section lengths), both the I-895 and I-95 tunnels are very sensitive to coastal flood exposure. These results largely align with prior work (Martello & Whittle, 2023), wherein tunnel portals were previously identified as the primary source of significant inflows into transportation tunnels.

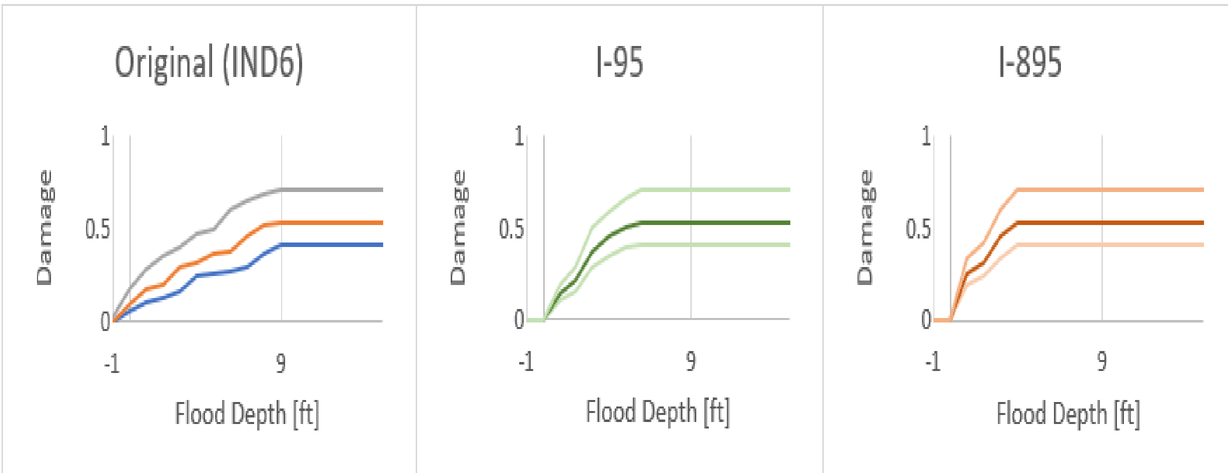
The resultant tunnel-specific depth-damage functions directly imply that both tunnels reach maximum damage at much lower flood depths than previously estimated using the IND6 curve. Under the previous approach using the IND6 curve, both tunnels would not reach maximum damage until a flood depth of 10 feet. By contrast, with the volume-informed depth-damage curves, the I-895 tunnel reaches maximum damage at a depth of just 4 feet, while the I-95 tunnel reaches maximum damage at just 6 feet of flood depth at the ground surface as show in Table 21.

Table 21: IND6, I-95, and I-895 percentage damages relative to flood depth

Flood Depth	Original (IND6)			I-95			I-895		
	min IND6-S-Min Structure	mode IND6-S-MostLikely Structure	max IND6-S-Max Structure	min I95T-S-Min	mode I95T-S-MostLikely	max I95T-S-Max	min I895T-S-Min	mode I895T-S-MostLikely	max I895T-S-Max
-200	0	0	0	0	0	0	0	0	0
-15	0	0	0	0	0	0	0	0	0
-9	0	0	0	0	0	0	0	0	0
-8	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0
-6	0	0	0	0	0	0	0	0	0
-5	0	0	0	0	0	0	0	0	0
-4	0	0	0	0	0	0	0	0	0
-3	0	0	0	0	0	0	0	0	0
-2	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0
0	0	0	0.019	0	0	0	0	0	0
1	0.06	0.089	0.168	0.11	0.14	0.19	0.19	0.25	0.33
2	0.104	0.174	0.284	0.16	0.21	0.29	0.24	0.31	0.42
3	0.13	0.198	0.352	0.28	0.37	0.5	0.33	0.45	0.6
4	0.162	0.29	0.402	0.34	0.45	0.59	0.41	0.531	0.704
5	0.244	0.318	0.467	0.39	0.5	0.66	0.41	0.531	0.704
6	0.26	0.367	0.491	0.41	0.531	0.704	0.41	0.531	0.704
7	0.27	0.371	0.606	0.41	0.531	0.704	0.41	0.531	0.704
8	0.292	0.453	0.647	0.41	0.531	0.704	0.41	0.531	0.704
9	0.36	0.514	0.681	0.41	0.531	0.704	0.41	0.531	0.704
10	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
11	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
12	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
13	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
14	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
15	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
16	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
17	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
18	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
19	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
20	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
21	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
22	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
23	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704
24	0.41	0.531	0.704	0.41	0.531	0.704	0.41	0.531	0.704

The flood depth has significant implications for the economic analysis, as all else being equal, the resulting damage estimates will be notably higher under these volume-informed depth-damage curves. Consequently, the estimated benefits of avoided flood damages are also higher when considering damage to these tunnels using these volume-informed curves. Figure 41 shows the comparative damages between the original curve (IND6) used for the tunnels, and the I-95 and I-895 curves.

Figure 41: IND6, I-95 tunnel, and I895 tunnel Depth-damage curves (damage estimate vs. flood depth at ground elevation) comparison.



While the methodology used to derive these volume-informed depth-damage curves is aligned with current best practices for tunnel flood damage assessment (Martello & Whittle, 2023), it is not without its limitations. Notably, the relationship between flood depth at the ground surface and inflow volume is likely to vary with sea level change (Martello & Whittle, 2023). Additionally, the shape of the depth-damage curve at low flood depths (i.e., < 2 feet) is highly sensitive to the failure assumptions for the critical wall sections. Further, given that the critical lengths assume are likely a lower bound, the relationship between flood depth and inflow volume is likely conservative. As such, it is plausible that the tunnel could flood fully at a shallower flood depth (as measured at the ground surface) depending on the realized length of the critical section. Should it be warranted, further extension of the analysis framework could further consider uncertainty in this critical length, as well as additional uncertainty in the wall failure mechanism and resultant leakage rate. Further refinements in the estimated cross-sectional volume of each tunnel would also refine the volume-damage estimate. Nonetheless, the volume-informed depth-damage functions presented here and applied in this study serve as a reasonable and conservative estimate of the sensitivity of both the I-895 and I-95 tunnels to coastal flooding. As such, the volume-informed depth-damage curves presented above were applied for both the I-895 and I-95 tunnels in the G2CRM model.

The analysis and potential extensions presented above are focused exclusively on estimating the direct damages to the tunnels resulting from flood exposure. However, significant indirect damages are highly likely to accrue if either tunnel is damaged by a flood event, as the tunnels would be closed to traffic during a flood event and until the tunnels are (at least partially) repaired deemed safe for traffic. This disruption would impact road users (e.g., commuters, commercial truck traffic) with detours or partial road closures increasing their travel time and delaying freight delivery, which would likely result in lost wages and freight revenue (CDOT, 2020). The extent and severity of the indirect damages arising from such disruption directly depends upon the duration of full or partial roadway closure arising from these flood events and subsequent repairs. If traffic volumes for affected roadways are known, methods are readily available to estimate these disruption costs (CDOT, 2020) assuming that full and partial disruption durations are known or satisfactorily characterized. If a relationship between direct damages (expressed as a percentage of replacement cost) and closure duration can be developed or assumed for the I-895 and I-95 tunnels, it would enable the development of depth-damage curves for these indirect costs. Given the high traffic volume through both tunnels, these costs are likely to be significant and may warrant further consideration and future study.

8. 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.

8.1 ALTERNATIVE 4-NS_100YR

The I-895 tunnel in Patapsco South MA 24 has its support facilities in Patapsco North MA 8. The I-95 tunnel in Locust Point MA 19 has its support facilities in Locust Point MA 18. The PSE (floodwall) would manage flood risk (e.g., damages) in the study area up to 12.2 feet NAVD88.

Floodproofing measures would provide a 1% risk reduction to a total of 30 federal facilities in MAs 1, 17, and 23.

Table 22 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alternative 4-NS_100YR.

Table 22: Alternative 4 – NS_100YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 17, 23 NS_100YR	$3,401	$114	0.42%
Alternative 4 – NS_100YR	$192,492	$6,452	23.56%

Note: Numbers are in $000s

Note that damage figures have been rounded to the nearest thousand. Hence, 100% damages reduced is less than 100% since there are residual damages, and 0% damages reduced is more than 0%.

Comparing the project alternative with the future without project condition, Alternative 4 – NS_100YR reduced the mean PV damages by 23.56% in the entire study area.

8.2 ALTERNATIVE 4-NS_50YR

Alternative 4-NS_50YR contains the same structural PSEs as Alt 4-NS_100YR. The difference is that 14 federal facilities in MAs 1, 17, and 23 would receive a 2% risk reduction with floodproofing measures.

Table 23 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alt 4-NS_50YR.

Table 23: Alternative 4 – NS_50YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 17, 23 NS_50YR	$2,178	$73	0.27%
Alternative 4 – NS_50YR	$191,268	$6,411	23.41%

Note: Numbers are in $000s

Comparing the project alternative with the future without project condition, Alternative 4 – NS_50YR reduced the mean PV damages by 23.41% in the entire study area.

8.3 ALTERNATIVE 4-NS_20YR

Alternative 4-NS_20YR includes the same structural PSEs as Alternative 4-NS_100YR and Alternative 4-NS_50YR. The only difference is that 9 federal facilities in MAs 1, 17, and 23 would receive a 5% risk reduction with floodproofing measures.

Table 24 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alt 4-NS_20YR.

Table 24: Alternative 4 – NS_20YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 17, 23 NS_20YR	$1,640	$55	0.20%
Alternative 4 – NS_20YR	$190,731	$6,393	23.34%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 4 – NS_20YR reduced the mean PV damages by 23.34% in the entire study area.

8.4 ALTERNATIVE 5-NS_100YR

This alternative contains the same structural components as Alt 4-NS_100. The nonstructural measures were expanded in Martin State Airport, Inner Harbor, Locust Point and Patapsco South neighborhoods. A total of 1096 structures in the 1% AEP would receive floodproofing treatments.

Table 25 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alternative 5-NS_100YR.

Table 25: Alternative 5 – NS_100YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_100YR	$123,872	$4,152	15.16%
Alternative 5 – NS_100YR	$312,306	$10,468	38.22%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 5 – NS_100YR reduced the mean PV damages by 38.22% in the entire study area.

8.5 ALTERNATIVE 5-NS_50YR

Alternative 5-NS_50YR includes the same structural PSEs as Alt 5-NS_50YR. The difference is that 493 structures in the 2% AEP would receive a 2% risk reduction with floodproofing measures.

Table 26 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alternative 5-NS_50YR.

Table 26: Alternative 5 – NS_50YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_50YR	$98,453	$3,300	12.05%
Alternative 5 – NS_50YR	$287,544	$9,638	35.19%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 5 – NS_50YR reduced the mean PV damages by 35.19% in the entire study area.

8.6 ALTERNATIVE 5-NS_20YR

Alternative 5-NS_20YR includes the same structural PSEs as Alternative 4-NS_20YR. The only difference is that 286 structures in the 5% AEP would receive a 5% risk reduction with floodproofing measures.

Table 27 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alternative 5-NS_20YR.

Table 27: Alternative 5 – NS_20YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_20YR	$68,351	$2,291	8.36%
Alternative 5 – NS_20YR	$257,441	$8,629	31.50%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 5 – NS_20YR reduced the mean PV damages by 31.50% in the entire study area.

8.7 ALTERNATIVE 6-NS_100YR

In addition to the structural and nonstructural components in Alternative 5-NS_100, Alternative 6-NS_100YR has a coastal PSE at Seagirt Marine Terminal.

Table 28 displays the future without project expected damages, the project conditions expected damages, and the damages reduced in Alternative 6-NS_100YR.

Table 28: Alternative 6 – NS_100YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
BH7: Patapsco North Seagirt Bulkhead	$4,624	$155	0.57%
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_100YR	$123,872	$4,152	15.16%
Alternative 6 – NS_100YR	$317,587	$10,645	38.87%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 6 – NS_100YR reduced the mean PV damages by 38.87% in the entire study area.

8.8 ALTERNATIVE 6-NS_50YR

Alternative 6-NS_50YR includes the same structural PSEs as Alternative 5-NS_50YR. The difference is that 493 structures in the 2% AEP would receive a 2% risk reduction with floodproofing measures.

Table 29 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alternative 6-NS_50YR.

Table 29: Alternative 6 – NS_50YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
BH7: Patapsco North Seagirt Bulkhead	$4,624	$155	0.57%
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_50YR	$98,453	$3,300	12.05%
Alternative 6 – NS_50YR	$292,168	$9,793	35.75%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 6 – NS_50YR reduced the mean PV damages by 35.75% in the entire study area.

8.9 ALTERNATIVE 6-NS_20YR

Alternative 6-NS_20YR includes the same structural PSEs as Alternative 5-NS_20YR. The difference is that 286 structures in the 5% AEP would receive a 5% risk reduction with floodproofing measures.

Table 30 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alternative 6-NS_20YR.

Table 30: Alternative 6 – NS_20YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
BH7: Patapsco North Seagirt Bulkhead	$4,624	$155	0.57%
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_20YR	$68,351	$2,291	8.36%
Alternative 6 – NS_20YR	$262,065	$8,784	32.07%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 6 – NS_20YR reduced the mean PV damages by 32.07% in the entire study area.

8.10 ALTERNATIVE 7-NS_100YR

Alternative 7-NS_100YR includes 13 floodwalls/levees that would act as a linear coastal barrier in the Inner Harbor and Locust Point. Two additional floodwalls would manage flood risk on the east and west sides of Martin State Airport.

Fourteen federal facilities in MAs 1 and 23 would receive a 1% risk reduction with floodproofing measures.

Table 31 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alternative 7-NS_100YR.

Table 31: Alternative 7 – NS_100YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
BH2: Martin State Airport West Bulkhead	$537	$18	0.07%
BH3: Martin State Airport East Bulkhead	$0	$0	0.00%
BH7: Patapsco North Seagirt Bulkhead	$4,624	$155	0.57%
BH10: Inner Harbor Anchorage Marina Bulkhead	$85,505	$2,866	10.46%
BH11: Inner Harbor Harborplace Bulkhead	$52,330	$1,754	6.40%
BH12: Inner Harbor Ritz Carlton Bulkhead	$656	$22	0.08%
BH13: Inner Harbor Harborview Bulkhead	$60	$2	0.01%
BH15: Locust Point Museum of Industry Bulkhead	$2,715	$91	0.33%
BH16: Locust Point American Sugar Bulkhead	$4,207	$141	0.51%
BH17: Locust Point Fort McHenry Bulkhead	$2,417	$81	0.30%
BH25: Middle Branch Wheelabrator Incinerator Plant	$0	$0	0.00%
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 23 NS_100YR	$1,760	$59	0.22%
Alternative 7 – NS_100YR	$343,901	$11,527	42.09%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 7 – NS_100YR reduced the mean PV damages by 42.09% in the entire study area.

8.11 ALTERNATIVE 7-NS_50YR

Alternative 7-NS_50YR includes the same structural PSEs as Alternative 7-NS_100YR. The difference is that 7 federal facilities in MAs 1 and 23 would receive a 2% risk reduction with floodproofing measures.

Table 32 displays the future without project expected damages, the project with project expected damages, and the damages reduced in Alternative 7-NS_50YR.

Table 32: Alternative 7 – NS_50YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
BH2: Martin State Airport West Bulkhead	$537	$18	0.07%
BH3: Martin State Airport East Bulkhead	$0	$0	0.00%
BH7: Patapsco North Seagirt Bulkhead	$4,624	$155	0.57%
BH10: Inner Harbor Anchorage Marina Bulkhead	$85,505	$2,866	10.46%
BH11: Inner Harbor Harborplace Bulkhead	$52,330	$1,754	6.40%
BH12: Inner Harbor Ritz Carlton Bulkhead	$656	$22	0.08%
BH13: Inner Harbor Harborview Bulkhead	$60	$2	0.01%
BH15: Locust Point Museum of Industry Bulkhead	$2,715	$91	0.33%
BH16: Locust Point American Sugar Bulkhead	$4,207	$141	0.51%
BH17: Locust Point Fort McHenry Bulkhead	$2,417	$81	0.30%
BH25: Middle Branch Wheelabrator Incinerator Plant	$0	$0	0.00%
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%
MAs 1, 23 NS_50YR	$537	$18	0.07%
Alternative 7 – NS_50YR	$342,678	$11,486	41.94%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 7 – NS_50YR reduced the mean PV damages by 41.94% in the entire study area.

8.12 ALTERNATIVE 7-NS_20YR

Alternative 7-NS_20YR includes the same structural PSEs as Alternative 7-NS_100YR and Alternative 7-NS_50YR. The difference is that 2 federal facilities in MAs 1 and 23 would receive a 5% risk reduction with floodproofing measures.

Table 33 displays the future without project expected damages, the future with project expected damages, and the damages reduced in Alternative 7-NS_20YR.

Table 33: Alternative 7 – NS_20YR Future Without Project Damages, Future with Project Damages, and Damages Reduced (October 2021 price level, FY22 discount rate of 2.25%)

Model Area	Damages Reduced	Average Annual Damages Reduced	% Damages Reduced
BH2: Martin State Airport West Bulkhead	$537	$18	0.07%
BH3: Martin State Airport East Bulkhead	$0	$0	0.00%
BH7: Patapsco North Seagirt Bulkhead	$4,624	$155	0.57%
BH10: Inner Harbor Anchorage Marina Bulkhead	$85,505	$2,866	10.46%
BH11: Inner Harbor Harborplace Bulkhead	$52,330	$1,754	6.40%
BH12: Inner Harbor Ritz Carlton Bulkhead	$656	$22	0.08%
BH13: Inner Harbor Harborview Bulkhead	$60	$2	0.01%
BH15: Locust Point Museum of Industry Bulkhead	$2,715	$91	0.33%
BH16: Locust Point American Sugar Bulkhead	$4,207	$141	0.51%
BH17: Locust Point Fort McHenry Bulkhead	$2,417	$81	0.30%
BH25: Middle Branch Wheelabrator Incinerator Plant	$0	$0	0.00%
I-95 Tunnel & Facility Bulkheads	$112,685	$3,777	13.79%
I-895 Tunnel & Facility Bulkheads	$76,406	$2,561	9.35%

MAs 1, 23 NS_20YR	$0	$0	0.00%
Alternative 7 – NS_20YR	$342,141	$11,468	41.87%

Note: Numbers are in $000s

Comparing the project alternative to the future without project condition, Alternative 7 – NS_20YR reduced the mean PV damages by 41.87% in the entire study area.

Table 34 is a compilation of the risk reduction by each alternative from Table 22 to Table 33.

Table 34: Risk Reduction by Each Alternative

Alternative	FWOP	FWP	Damages Reduced	% Damages Reduced
Alternative 4-NS_100YR	$817,154	$624,662	$192,492	23.56%
Alternative 4-NS_50YR		$625,886	$191,268	23.41%
Alternative 4-NS_20YR		$626,423	$190,731	23.34%
Alternative 5-NS_100YR		$504,848	$312,306	38.22%
Alternative 5-NS_50YR		$529,610	$287,544	35.19%
Alternative 5-NS_20YR		$559,713	$257,441	31.50%
Alternative 6-NS_100YR		$499,567	$317,587	38.87%
Alternative 6-NS_50YR		$524,986	$292,168	35.75%
Alternative 6-NS_20YR		$555,089	$262,065	32.07%
Alternative 7-NS_100YR		$473,253	$343,901	42.09%
Alternative 7-NS_50YR		$474,476	$342,678	41.94%
Alternative 7-NS_20YR		$475,013	$342,141	41.87%

9. ALTERNATIVE COMPARISON

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

9.1 BENEFITS

The difference in expected mean present value (PV) flood damages in the Baltimore Coastal study area between the future without project condition and the future with project condition represents the flood risk management benefits to the project. These benefits represent damages reduced (National Economic Development - NED) from coastal storm surge inundation with the combination of SLC for each alternative. However, planning guidance (reference ER 1105-2-103) 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 and the costs were annualized using the FY22 discount rate of 2.25% for a 50-year period of analysis for the comparison.

9.2 COSTS

Structural and nonstructural measure cost estimates were provided by the USACE Baltimore District Cost Engineering Section in FY2022 (October 2021) price levels (reference the Civil

Engineering Appendix (Appendix A) for more details). For the comparison process, cost estimates were used for each alternative that was evaluated.

The interest during construction (IDC) was computed using the first cost and the duration of construction. IDC was calculated based on the estimated length of construction for structural and nonstructural alternatives. It will take 12 months to build each bulkhead. Implementation of nonstructural measures are assumed to be spread out over various construction timelines. However, given that each individual non-structural treatment is expected to take only 3 months (BPG 2020_Rev2), IDC is calculated accordingly for each floodproofing treatment.

For comparison to the benefits, which are average annual flood damages reduced, the first costs were stated in an average annual equivalent also based on the FY2022 discount rate of 2.25% and a 50-year period of analysis. The IDC was added to the first cost to derive the investment cost. Annual operation and maintenance (O&M) costs were also added to the structural alternatives. Table 35 shows the results of the costs computation.

Table 35: Cost for Alternatives (October 2021 price level, FY22 discount rate of 2.25%)

Plan Alternatives	Alternative Description	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annual Cost
FWOP	**No Action**			-	-	-	-
Alt 4 - NS_100YR	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 17, 23 NS_100YR	15,608,000	32,000	15,640,000	156,000	15,796,000	557,000
Alt 4 - NS_100YR Summary		63,986,000	534,000	64,520,000	640,000	65,160,000	2,297,000
Alt 4 - NS_50YR	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 17, 23 NS_50YR	10,380,000	21,000	10,401,000	104,000	10,505,000	370,000
Alt 4 - NS_50YR Summary		58,758,000	523,000	59,281,000	588,000	59,869,000	2,111,000
Alt 4 - NS_20YR	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 17, 23 NS_20YR	8,777,000	18,000	8,795,000	88,000	8,883,000	313,000
Alt 4 - NS_20YR Summary		57,155,000	520,000	57,675,000	572,000	58,247,000	2,054,000
Alt 5 - NS_100YR	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	154,000	19,217,000	191,000	19,408,000	684,000
	MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_100YR	406,339,000	838,000	407,177,000	4,063,000	411,240,000	14,500,000
Alt 5 - NS_100YR Summary		454,717,000	1,326,000	456,043,000	4,547,000	460,590,000	16,240,000
Alt 5 - NS_50YR	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_50YR	221,117,000	456,000	221,573,000	2,211,000	223,784,000	7,890,000
Alt 5 - NS_50YR Summary		269,495,000	958,000	270,453,000	2,695,000	273,148,000	9,631,000
Alt 5 - NS_20YR	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_20YR	126,357,000	260,000	126,617,000	1,264,000	127,881,000	4,509,000
Alt 5 - NS_20YR Summary		174,735,000	762,000	175,497,000	1,748,000	177,245,000	6,249,000
Alt 6 - NS_100YR	BH7: Patapsco North Seagirt Bulkhead	33,143,000	797,000	33,940,000	331,000	34,271,000	1,208,000
	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_100YR	406,339,000	838,000	407,177,000	4,063,000	411,240,000	14,500,000
Alt 6 - NS_100YR Summary		487,860,000	2,137,000	489,997,000	4,878,000	494,875,000	17,448,000
Alt 6 - NS_50YR	BH7: Patapsco North Seagirt Bulkhead	33,143,000	797,000	33,940,000	331,000	34,271,000	1,208,000
	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000

Plan Alternatives	Alternative Description	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annual Cost
	MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_50YR	221,117,000	456,000	221,573,000	2,211,000	223,784,000	7,890,000
Alt 6 - NS_50YR Summary		302,638,000	1,755,000	304,393,000	3,026,000	307,419,000	10,839,000
Alt 6 - NS_20YR	BH7: Patapsco North Seagirt Bulkhead	33,143,000	797,000	33,940,000	331,000	34,271,000	1,208,000
	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_20YR	126,357,000	260,000	126,617,000	1,264,000	127,881,000	4,509,000
Alt 6 - NS_20YR Summary		207,878,000	1,559,000	209,437,000	2,079,000	211,516,000	7,458,000
Alt 7 - NS_100YR	BH2: Martin State Airport West Bulkhead	22,698,000	188,000	22,886,000	227,000	23,113,000	815,000
	BH3: Martin State Airport East Bulkhead	8,092,000	17,000	8,109,000	81,000	8,190,000	289,000
	BH7: Patapsco North Seagirt Bulkhead	32,913,000	797,000	33,710,000	329,000	34,039,000	1,200,000
	BH10: Inner Harbor Anchorage Marina Bulkhead	195,438,000	4,700,000	200,138,000	1,954,000	202,092,000	7,125,000
	BH11: Inner Harbor Harborplace Bulkhead	144,554,000	3,477,000	148,031,000	1,446,000	149,477,000	5,270,000
	BH12: Inner Harbor Ritz Carlton Bulkhead	25,920,000	215,000	26,135,000	259,000	26,394,000	931,000
	BH13: Inner Harbor Harborview Bulkhead	7,411,000	15,000	7,426,000	74,000	7,500,000	264,000
	BH15: Locust Point Museum of Industry Bulkhead	29,286,000	334,000	29,620,000	293,000	29,913,000	1,055,000
	BH16: Locust Point American Sugar Bulkhead	15,871,000	82,000	15,953,000	159,000	16,112,000	568,000
	BH17: Locust Point Fort McHenry Bulkhead	17,108,000	88,000	17,196,000	171,000	17,367,000	612,000
	BH25: Middle Branch Wheelabrator Incinerator Plant	4,359,000	23,000	4,382,000	44,000	4,426,000	156,000
	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 23 NS_100YR	7,375,000	15,000	7,390,000	74,000	7,464,000	263,000
Alt 7 - NS_100YR Summary		559,403,000	10,453,000	569,856,000	5,595,000	575,451,000	20,289,000
Alt 7 - NS_50YR	BH2: Martin State Airport West Bulkhead	22,698,000	188,000	22,886,000	227,000	23,113,000	815,000
	BH3: Martin State Airport East Bulkhead	8,092,000	17,000	8,109,000	81,000	8,190,000	289,000
	BH7: Patapsco North Seagirt Bulkhead	32,913,000	797,000	33,710,000	329,000	34,039,000	1,200,000
	BH10: Inner Harbor Anchorage Marina Bulkhead	195,438,000	4,700,000	200,138,000	1,954,000	202,092,000	7,125,000
	BH11: Inner Harbor Harborplace Bulkhead	144,554,000	3,477,000	148,031,000	1,446,000	149,477,000	5,270,000
	BH12: Inner Harbor Ritz Carlton Bulkhead	25,920,000	215,000	26,135,000	259,000	26,394,000	931,000
	BH13: Inner Harbor Harborview Bulkhead	7,411,000	15,000	7,426,000	74,000	7,500,000	264,000
	BH15: Locust Point Museum of Industry Bulkhead	29,286,000	334,000	29,620,000	293,000	29,913,000	1,055,000
	BH16: Locust Point American Sugar Bulkhead	15,871,000	82,000	15,953,000	159,000	16,112,000	568,000
	BH17: Locust Point Fort McHenry Bulkhead	17,108,000	88,000	17,196,000	171,000	17,367,000	612,000
	BH25: Middle Branch Wheelabrator Incinerator Plant	4,359,000	23,000	4,382,000	44,000	4,426,000	156,000
	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 23 NS_50YR	2,258,000	5,000	2,263,000	23,000	2,286,000	81,000

Plan Alternatives	Alternative Description	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annual Cost
Alt 7 - NS_50YR Summary		554,286,000	10,443,000	564,729,000	5,544,000	570,273,000	20,107,000
Alt 7 - NS_20YR	BH2: Martin State Airport West Bulkhead	22,698,000	188,000	22,886,000	227,000	23,113,000	815,000
	BH3: Martin State Airport East Bulkhead	8,092,000	17,000	8,109,000	81,000	8,190,000	289,000
	BH7: Patapsco North Seagirt Bulkhead	32,913,000	797,000	33,710,000	329,000	34,039,000	1,200,000
	BH10: Inner Harbor Anchorage Marina Bulkhead	195,438,000	4,700,000	200,138,000	1,954,000	202,092,000	7,125,000
	BH11: Inner Harbor Harborplace Bulkhead	144,554,000	3,477,000	148,031,000	1,446,000	149,477,000	5,270,000
	BH12: Inner Harbor Ritz Carlton Bulkhead	25,920,000	215,000	26,135,000	259,000	26,394,000	931,000
	BH13: Inner Harbor Harborview Bulkhead	7,411,000	15,000	7,426,000	74,000	7,500,000	264,000
	BH15: Locust Point Museum of Industry Bulkhead	29,286,000	334,000	29,620,000	293,000	29,913,000	1,055,000
	BH16: Locust Point American Sugar Bulkhead	15,871,000	82,000	15,953,000	159,000	16,112,000	568,000
	BH17: Locust Point Fort McHenry Bulkhead	17,108,000	88,000	17,196,000	171,000	17,367,000	612,000
	BH25: Middle Branch Wheelabrator Incinerator Plant	4,359,000	23,000	4,382,000	44,000	4,426,000	156,000
	I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000
	I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000
	MAs 1, 23 NS_20YR	645,000	1,000	646,000	6,000	652,000	23,000
Alt 7 - NS_20YR Summary		552,673,000	10,439,000	563,112,000	5,527,000	568,639,000	20,049,000

9.3 BENEFIT-COST 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. The 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. Table 36 summarizes the equivalent annual benefits, average annual costs, first cost, net benefits, and the BCR for each alternative.

Table 36: Costs and Benefits of Alternatives (October 2021 price level, FY22 discount rate of 2.25%)

Alternative Description	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annualized Cost	Average Annualized Benefits	Average Annualized Net Benefits	BCR
No Action			-	-	-	-	-	-	-
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 17, 23 NS_100YR	$15,608,000	$32,000	$15,640,000	$156,000	$15,796,000	$557,000	$114,000	($443,000)	0.2
Alt 4 - NS_100YR Summary	$63,986,000	$534,000	$64,520,000	$640,000	$65,160,000	$2,297,000	$6,452,000	$4,155,000	2.8
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 17, 23 NS_50YR	$10,380,000	$21,000	$10,401,000	$104,000	$10,505,000	$370,000	$73,000	($297,000)	0.2
Alt 4 - NS_50YR Summary	$58,758,000	$523,000	$59,281,000	$588,000	$59,869,000	$2,111,000	$6,411,000	$4,341,000	3.0
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 17, 23 NS_20YR	$8,777,000	$18,000	$8,795,000	$88,000	$8,883,000	$313,000	$55,000	($258,000)	0.2
Alt 4 - NS_20YR Summary	$57,155,000	$520,000	$57,675,000	$572,000	$58,247,000	$2,054,000	$6,393,000	$4,398,000	3.1
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$154,000	$19,217,000	$191,000	$19,408,000	$684,000	$2,561,000	$1,877,000	3.7
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_100YR	$406,339,000	$838,000	$407,177,000	$4,063,000	$411,240,000	$14,500,000	$4,152,000	($10,348,000)	0.3
Alt 5 - NS_100YR Summary	$454,717,000	$1,326,000	$456,043,000	$4,547,000	$460,590,000	$16,240,000	$10,468,000	($5,772,000)	0.6
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_50YR	$221,117,000	$456,000	$221,573,000	$2,211,000	$223,784,000	$7,890,000	$3,300,000	($4,590,000)	0.4
Alt 5 - NS_50YR Summary	$269,495,000	$958,000	$270,453,000	$2,695,000	$273,148,000	$9,631,000	$9,638,000	$7,000	1.0
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_20YR	$126,357,000	$260,000	$126,617,000	$1,264,000	$127,881,000	$4,509,000	$2,291,000	($2,218,000)	0.5
Alt 5 - NS_20YR Summary	$174,735,000	$762,000	$175,497,000	$1,748,000	$177,245,000	$6,249,000	$8,629,000	$2,380,000	1.4
BH7: Patapsco North Seagirt Bulkhead	$33,143,000	$797,000	$33,940,000	$331,000	$34,271,000	$1,208,000	$155,000	($1,053,000)	0.1
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_100YR	$406,339,000	$838,000	$407,177,000	$4,063,000	$411,240,000	$14,500,000	$4,152,000	($10,348,000)	0.3
Alt 6 - NS_100YR Summary	$487,860,000	$2,137,000	$489,997,000	$4,878,000	$494,875,000	$17,448,000	$10,645,000	($6,803,000)	0.6

Alternative Description	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annualized Cost	Average Annualized Benefits	Average Annualized Net Benefits	BCR
BH7: Patapsco North Seagirt Bulkhead	$33,143,000	$797,000	$33,940,000	$331,000	$34,271,000	$1,208,000	$155,000	($1,053,000)	0.1
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_50YR	$221,117,000	$456,000	$221,573,000	$2,211,000	$223,784,000	$7,890,000	$3,300,000	($4,590,000)	0.4
Alt 6 - NS_50YR Summary	$302,638,000	$1,755,000	$304,393,000	$3,026,000	$307,419,000	$10,839,000	$9,793,000	($1,046,000)	0.9
BH7: Patapsco North Seagirt Bulkhead	$33,143,000	$797,000	$33,940,000	$331,000	$34,271,000	$1,208,000	$155,000	($1,053,000)	0.1
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 9, 10, 11, 12, 13, 14, 15, 16, 17, 22, 23 NS_20YR	$126,357,000	$260,000	$126,617,000	$1,264,000	$127,881,000	$4,509,000	$2,291,000	($2,218,000)	0.5
Alt 6 - NS_20YR Summary	$207,878,000	$1,559,000	$209,437,000	$2,079,000	$211,516,000	$7,458,000	$8,784,000	$1,326,000	1.2
BH2: Martin State Airport West Bulkhead	$22,698,000	$188,000	$22,886,000	$227,000	$23,113,000	$815,000	$18,000	($797,000)	0.0
BH3: Martin State Airport East Bulkhead	$8,092,000	$17,000	$8,109,000	$81,000	$8,190,000	$289,000	$0	($289,000)	0.0
BH7: Patapsco North Seagirt Bulkhead	$32,913,000	$797,000	$33,710,000	$329,000	$34,039,000	$1,200,000	$155,000	($1,045,000)	0.1
BH10: Inner Harbor Anchorage Marina Bulkhead	$195,438,000	$4,700,000	$200,138,000	$1,954,000	$202,092,000	$7,125,000	$2,866,000	($4,259,000)	0.4
BH11: Inner Harbor Harborplace Bulkhead	$144,554,000	$3,477,000	$148,031,000	$1,446,000	$149,477,000	$5,270,000	$1,754,000	($3,516,000)	0.3
BH12: Inner Harbor Ritz Carlton Bulkhead	$25,920,000	$215,000	$26,135,000	$259,000	$26,394,000	$931,000	$22,000	($909,000)	0.0
BH13: Inner Harbor Harborview Bulkhead	$7,411,000	$15,000	$7,426,000	$74,000	$7,500,000	$264,000	$2,000	($262,000)	0.0
BH15: Locust Point Museum of Industry Bulkhead	$29,286,000	$334,000	$29,620,000	$293,000	$29,913,000	$1,055,000	$91,000	($964,000)	0.1
BH16: Locust Point American Sugar Bulkhead	$15,871,000	$82,000	$15,953,000	$159,000	$16,112,000	$568,000	$141,000	($427,000)	0.2
BH17: Locust Point Fort McHenry Bulkhead	$17,108,000	$88,000	$17,196,000	$171,000	$17,367,000	$612,000	$81,000	($531,000)	0.1
BH25: Middle Branch Wheelabrator Incinerator Plant	$4,359,000	$23,000	$4,382,000	$44,000	$4,426,000	$156,000	$0	($156,000)	0.0
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 23 NS_100YR	$7,375,000	$15,000	$7,390,000	$74,000	$7,464,000	$263,000	$59,000	($204,000)	0.2
Alt 7 - NS_100YR Summary	$559,403,000	$10,453,000	$569,856,000	$5,595,000	$575,451,000	$20,289,000	$11,527,000	($8,762,000)	0.6
BH2: Martin State Airport West Bulkhead	$22,698,000	$188,000	$22,886,000	$227,000	$23,113,000	$815,000	$18,000	($797,000)	0.0
BH3: Martin State Airport East Bulkhead	$8,092,000	$17,000	$8,109,000	$81,000	$8,190,000	$289,000	$0	($289,000)	0.0
BH7: Patapsco North Seagirt Bulkhead	$32,913,000	$797,000	$33,710,000	$329,000	$34,039,000	$1,200,000	$155,000	($1,045,000)	0.1
BH10: Inner Harbor Anchorage Marina Bulkhead	$195,438,000	$4,700,000	$200,138,000	$1,954,000	$202,092,000	$7,125,000	$2,866,000	($4,259,000)	0.4
BH11: Inner Harbor Harborplace Bulkhead	$144,554,000	$3,477,000	$148,031,000	$1,446,000	$149,477,000	$5,270,000	$1,754,000	($3,516,000)	0.3
BH12: Inner Harbor Ritz Carlton Bulkhead	$25,920,000	$215,000	$26,135,000	$259,000	$26,394,000	$931,000	$22,000	($909,000)	0.0
BH13: Inner Harbor Harborview Bulkhead	$7,411,000	$15,000	$7,426,000	$74,000	$7,500,000	$264,000	$2,000	($262,000)	0.0

Alternative Description	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annualized Cost	Average Annualized Benefits	Average Annualized Net Benefits	BCR
BH15: Locust Point Museum of Industry Bulkhead	$29,286,000	$334,000	$29,620,000	$293,000	$29,913,000	$1,055,000	$91,000	($964,000)	0.1
BH16: Locust Point American Sugar Bulkhead	$15,871,000	$82,000	$15,953,000	$159,000	$16,112,000	$568,000	$141,000	($427,000)	0.2
BH17: Locust Point Fort McHenry Bulkhead	$17,108,000	$88,000	$17,196,000	$171,000	$17,367,000	$612,000	$81,000	($531,000)	0.1
BH25: Middle Branch Wheelabrator Incinerator Plant	$4,359,000	$23,000	$4,382,000	$44,000	$4,426,000	$156,000	$0	($156,000)	0.0
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 23 NS_50YR	$2,258,000	$5,000	$2,263,000	$23,000	$2,286,000	$81,000	$18,000	($63,000)	0.2
Alt 7 - NS_50YR Summary	$554,286,000	$10,443,000	$564,729,000	$5,544,000	$570,273,000	$20,107,000	$11,486,000	($8,621,000)	0.6
BH2: Martin State Airport West Bulkhead	$22,698,000	$188,000	$22,886,000	$227,000	$23,113,000	$815,000	$18,000	($797,000)	0.0
BH3: Martin State Airport East Bulkhead	$8,092,000	$17,000	$8,109,000	$81,000	$8,190,000	$289,000	$0	($289,000)	0.0
BH7: Patapsco North Seagirt Bulkhead	$32,913,000	$797,000	$33,710,000	$329,000	$34,039,000	$1,200,000	$155,000	($1,045,000)	0.1
BH10: Inner Harbor Anchorage Marina Bulkhead	$195,438,000	$4,700,000	$200,138,000	$1,954,000	$202,092,000	$7,125,000	$2,866,000	($4,259,000)	0.4
BH11: Inner Harbor Harborplace Bulkhead	$144,554,000	$3,477,000	$148,031,000	$1,446,000	$149,477,000	$5,270,000	$1,754,000	($3,516,000)	0.3
BH12: Inner Harbor Ritz Carlton Bulkhead	$25,920,000	$215,000	$26,135,000	$259,000	$26,394,000	$931,000	$22,000	($909,000)	0.0
BH13: Inner Harbor Harborview Bulkhead	$7,411,000	$15,000	$7,426,000	$74,000	$7,500,000	$264,000	$2,000	($262,000)	0.0
BH15: Locust Point Museum of Industry Bulkhead	$29,286,000	$334,000	$29,620,000	$293,000	$29,913,000	$1,055,000	$91,000	($964,000)	0.1
BH16: Locust Point American Sugar Bulkhead	$15,871,000	$82,000	$15,953,000	$159,000	$16,112,000	$568,000	$141,000	($427,000)	0.2
BH17: Locust Point Fort McHenry Bulkhead	$17,108,000	$88,000	$17,196,000	$171,000	$17,367,000	$612,000	$81,000	($531,000)	0.1
BH25: Middle Branch Wheelabrator Incinerator Plant	$4,359,000	$23,000	$4,382,000	$44,000	$4,426,000	$156,000	$0	($156,000)	0.0
I-95 Tunnel & Facility Bulkheads	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$3,777,000	$2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$2,561,000	$1,876,000	3.7
MAs 1, 23 NS_20YR	$645,000	$1,000	$646,000	$6,000	$652,000	$23,000	$0	($23,000)	0.0
Alt 7 - NS_20YR Summary	$552,673,000	$10,439,000	$563,112,000	$5,527,000	$568,639,000	$20,049,000	$11,468,000	($8,581,000)	0.6

The nonstructural MAs do not have the same hydrologic connection as the structural MAs; they are separable elements. None of the standalone nonstructural measures had positive net benefits in this point of the analysis. Hence, Alternatives 4 through 7 could be proposed as the NED Plan. Hence, the team decided to evaluate the nonstructural solution in each MA. As a result of the nonstructural MAs comparison in the various AEPs, the net benefits are positive and maximized in MA11-NS_50YR and MA14-NS_100YR. In addition, the BCR are near the unit with the maximum net benefits in the following MAs: MA9-NS_20YR, MA10-NS_20YR, MA12-NS_50YR, and MA15-NS_20YR. Table 37 Summarizes the nonstructural assessment in each MA.

Table 37: Nonstructural Assessment in each Model Area (October 2021 price level, FY22 discount rate of 2.25%)

Plan Alternatives	Alternative Description	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annual Cost	Average Annual Benefits	Average Annual Net Benefits	BCR
100YR Nonstructural Plans by MA	MA1: Martin State Airport	2,226,000	74,000	2,300,000	22,000	2,322,000	78,000	22,000	(56,000)	0.3
	MA9: Inner Harbor	18,644,000	618,000	19,262,000	186,000	19,448,000	652,000	308,000	(344,000)	0.5
	MA10: Inner Harbor Anchorage Marina	244,594,000	8,114,000	252,708,000	2,446,000	255,154,000	8,552,000	1,795,000	(6,757,000)	0.2
	MA11: Inner Harbor Harborplace	15,861,000	526,000	16,387,000	159,000	16,546,000	555,000	1,107,000	552,000	2.0
	MA12: Inner Harbor Ritz Carlton	1,113,000	37,000	1,150,000	11,000	1,161,000	39,000	12,000	(27,000)	0.3
	MA13: Inner Harbor Harborview	1,113,000	37,000	1,150,000	11,000	1,161,000	39,000	1,000	(38,000)	0.0
	MA14: Locust Point	5,565,000	185,000	5,750,000	56,000	5,806,000	195,000	575,000	380,000	2.9
	MA15: Locust Point Museum of Industry	3,896,000	129,000	4,025,000	39,000	4,064,000	136,000	46,000	(90,000)	0.3
	MA16: Locust Point American Sugar	278,000	9,000	287,000	3,000	290,000	10,000	77,000	67,000	7.7
	MA17: Locust Point Fort McHenry	7,463,000	248,000	7,711,000	75,000	7,786,000	261,000	55,000	(206,000)	0.2
	MA22: Patapsco South	37,061,000	1,229,000	38,290,000	371,000	38,661,000	1,296,000	117,000	(1,179,000)	0.1
	MA23: Patapsco South Fairfield	4,174,000	138,000	4,312,000	42,000	4,354,000	146,000	37,000	(109,000)	0.3
50YR Nonstructural Plans by MA	MA1: Martin State Airport	835,000	18,000	853,000	8,000	861,000	29,000	-	(29,000)	0.0
	MA9: Inner Harbor	15,861,000	343,000	16,204,000	159,000	16,363,000	548,000	280,000	(268,000)	0.5
	MA10: Inner Harbor Anchorage Marina	97,114,000	2,101,000	99,215,000	971,000	100,186,000	3,358,000	1,377,000	(1,981,000)	0.4
	MA11: Inner Harbor Harborplace	8,070,000	175,000	8,245,000	81,000	8,326,000	279,000	845,000	566,000	3.0
	MA12: Inner Harbor Ritz Carlton	557,000	12,000	569,000	6,000	575,000	19,000	11,000	(8,000)	0.6
	MA13: Inner Harbor Harborview	-	-	-	-	-	-	-	-	-
	MA14: Locust Point	4,452,000	96,000	4,548,000	45,000	4,593,000	154,000	497,000	343,000	3.2
	MA15: Locust Point Museum of Industry	2,226,000	48,000	2,274,000	22,000	2,296,000	77,000	42,000	(35,000)	0.5

Plan Alternatives	Alternative Description	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annual Cost	Average Annual Benefits	Average Annual Net Benefits	BCR
	MA16: Locust Point American Sugar	278,000	6,000	284,000	3,000	287,000	10,000	77,000	67,000	7.7
	MA17: Locust Point Fort McHenry	7,463,000	161,000	7,624,000	75,000	7,699,000	258,000	55,000	(203,000)	0.2
	MA22: Patapsco South	34,334,000	743,000	35,077,000	343,000	35,420,000	1,187,000	98,000	(1,089,000)	0.1
	MA23: Patapsco South Fairfield	1,113,000	24,000	1,137,000	11,000	1,148,000	38,000	18,000	(20,000)	0.5
20YR Nonstructural Plans by MA	MA1: Martin State Airport	557,000	6,000	563,000	6,000	569,000	19,000	-	(19,000)	0.0
	MA9: Inner Harbor	11,131,000	114,000	11,245,000	111,000	11,356,000	381,000	241,000	(140,000)	0.6
	MA10: Inner Harbor Anchorage Marina	54,818,000	563,000	55,381,000	548,000	55,929,000	1,875,000	1,025,000	(850,000)	0.5
	MA11: Inner Harbor Harborplace	4,730,000	49,000	4,779,000	47,000	4,826,000	162,000	424,000	262,000	2.6
	MA12: Inner Harbor Ritz Carlton	-	-	-	-	-	-	-	-	-
	MA13: Inner Harbor Harborview	-	-	-	-	-	-	-	-	-
	MA14: Locust Point	1,948,000	20,000	1,968,000	19,000	1,987,000	67,000	340,000	273,000	5.1
	MA15: Locust Point Museum of Industry	1,391,000	14,000	1,405,000	14,000	1,419,000	48,000	40,000	(8,000)	0.8
	MA16: Locust Point American Sugar	278,000	3,000	281,000	3,000	284,000	10,000	77,000	67,000	7.7
	MA17: Locust Point Fort McHenry	7,463,000	77,000	7,540,000	75,000	7,615,000	255,000	55,000	(200,000)	0.2
	MA22: Patapsco South	23,862,000	245,000	24,107,000	239,000	24,346,000	816,000	89,000	(727,000)	0.1
	MA23: Patapsco South Fairfield	-	-	-	-	-	-	-	-	-

9.4 RECOMMENDED NATIONAL ECONOMIC DEVELOPMENT PLAN

The NED Plan is limited to reasonably maximizing net benefits. The Tentatively Selected Plan (TSP) is the Total Benefits Plan that maximizes project benefits when considering the four P&G accounts per USACE Memo: Comprehensive Documentation of Benefits in Decision Document dated 05 January 2021. It is presented in Section 14 then optimized in Section 15 after the ADM.

According the USACE Planning and Guidance Notebook (ER 1105-2-103), 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 states:

…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 plans and identified a combination of plans based on the net benefits. Net benefits were positive for two structural measures:

- I-95 Tunnel & its Facility bulkheads in Locust Point.
- I-895 Tunnel & its Facility bulkheads in Patapsco.

Tunnels and their facilities are one entity.

In addition, two nonstructural measures had positive net benefits:

- MA 11 _NS50YR in Inner Harbor, Harbor Place.
- MA 14 NS_100YR in Locust Point.

Hence, the combination of these structural and nonstructural measures is identified as the NED Plan. Table 38 provides a summary of the NED plan.

The PDT decided to keep the MAs that yielded a BCR close to 1 (MA9-NS_20YR, MA10-NS_20YR, MA12-NS_50YR, and MA15-NS_20YR) in the proposed plan and to re-evaluate them based a reformulation of the nonstructural groupings with refined costs after the ADM as approved by the vertical team. Table 39 shows the Tentatively Selected Plan (TSP). The final Total Benefits Plan that maximizes project benefits when considering the four P&G accounts is described in Section 15.

Table 38: National Economic Development Plan (October 2021 price level, FY22 discount rate of 2.25%)

NED Plan	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annualized Cost	Average Annualized Benefits	Average Annualized Net Benefits	BCR
I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,055,697	3,970,939	2,915,242	3.8
I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	684,782	2,673,936	1,989,154	3.9
MA11: Inner Harbor Harborplace_NS50YR	8,070,000	175,000	8,245,000	81,000	8,326,000	279,000	845,000	566,000	3.0
MA14: Locust Point_NS100YR	5,565,000	185,000	5,750,000	56,000	5,806,000	195,000	575,000	380,000	2.9
Alt-5B	62,013,000	862,000	62,875,000	621,000	63,496,000	2,214,000	8,065,000	5,850,000	3.6

Table 39: Alternative 5A: Tentatively Selected Plan (October 2021 price level, FY22 discount rate of 2.25%)

Preliminary TSP Plan	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annualized Cost	Average Annualized Benefits	Average Annualized Net Benefits	BCR
I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,055,697	3,970,939	2,915,242	3.8
I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	684,782	2,673,936	1,989,154	3.9
MA11: Inner Harbor Harborplace_NS50YR	8,070,000	175,000	8,245,000	81,000	8,326,000	279,000	845,000	566,000	3.0
MA14: Locust Point_NS100YR	5,565,000	185,000	5,750,000	56,000	5,806,000	195,000	575,000	380,000	2.9
MA9: Inner Harbor_NS20YR	11131000	114000	11245000	111000	11356000	381000	241000	(140000)	0.6
MA10: Inner Harbor Anchorage Marina_NS20YR	54818000	563000	55381000	548000	55929000	1875000	1025000	(850000)	0.5
MA12: Inner Harbor Ritz Carlton_NS50YR	557000	12000	569000	6000	575000	19000	11000	(8000)	0.6
MA15: Locust Point Museum of Industry_NS20YR	1391000	14000	1405000	14000	1419000	48000	40000	(8000)	0.8
Alt-5A	129,910,000	1,565,000	131,475,000	1,300,000	132,775,000	4,537,000	9,382,000	4,844,000	2.07

9.5 ECONOMIC RISK ANALYSIS

The benefits displayed in Tables 38 and 39 above have uncertainties associated with them. There are uncertainties in the G2CRM inputs used and, in the model, 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 15 July 2019. Section 8 Policy and Required Procedures (d) states:

> *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 probability distributions for the expected mean annual damages for the future without project condition and the future with project condition for each alternative will be provided to aid decision makers such as the NFS, 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.

10. 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 Baltimore Coastal 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 and health and safety of the Baltimore Metropolitan community were examined.

10.1 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 Section 4.5). Since there is uncertainty in modeling life loss, the future without project condition was modeled to serve as a baseline. 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 from each alternative.

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 were separated into two categories. One category was people under 65 years old and the second category was people over 65 years old. 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.

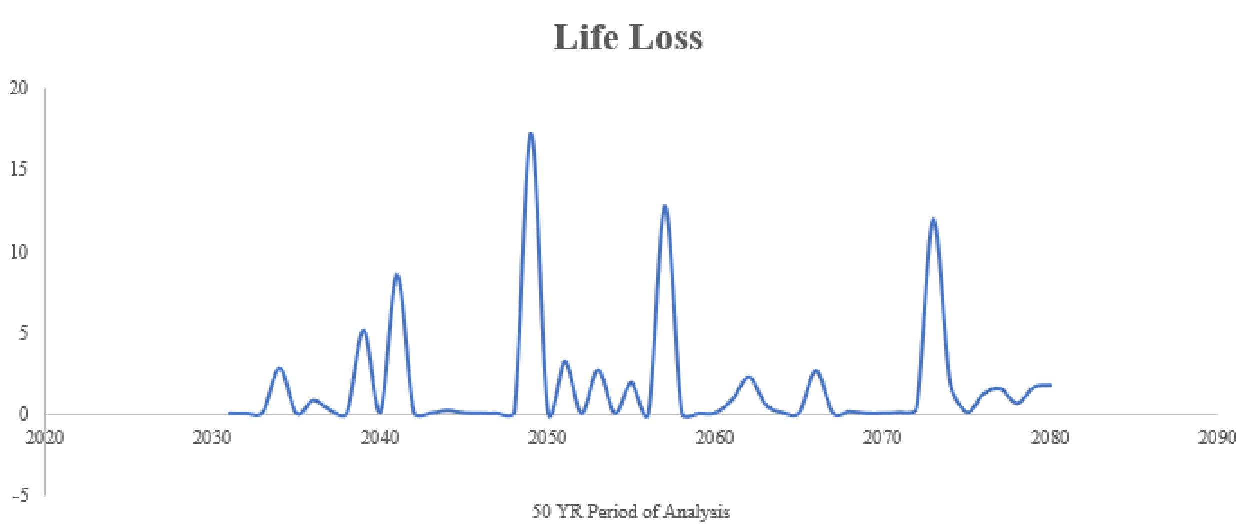
Each type of structure has an associated storm surge lethality. The surge over the foundation height is the minimum for a lethality zone (safe, compromised, chance). The surge over foundation height are age specific. There is one surge height for people under 65 years old and another surge height for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

The model cycles through every active structure for each storm scenario. For each structure, the model defaults the lethality function to safe and checks for the maximum lethality function such that the modeled area stage is greater than the sum of the first flood elevation of the structure and the lethality function's surge above the foundation. This is checked separately for under and over age 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 future without project condition and when comparing the alternatives between each other.

Based on Figure 42, life loss is predominant around the year 2050 but occurred along the life cycle in the future without project condition. The curve pattern shows that life loss is unpredictable.

Figure 42: Life Loss Trends Over a 50-Year Period of Analysis



A population of 89,066 was modeled in the structure inventory. An annualized percent life loss of 0.0034% would occur under the future without project condition. Comparative analysis of the future with project condition resulted in a reduction of 0.001% loss of life when compared to the future without project condition. Loss of life was identified in the Inner Harbor (MAs 9, 10, 11, 12, and 13). More discussion on life loss can be found in Section 15.

10.2 HEALTH AND SAFETY

The health and safety of people living in the community within the project area were considered for 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 Census Bureau data, the Baltimore Metropolitan area has a high disability population under 65 years old and a high African American population. The per capita income is low on average, but the project would be implemented in areas where the majority of the population are not considered low income.

The Environmental Protection Agency's Environmental Justice (EJ) Screen tool shows a high population over 64 years old in the Inner Harbor and EJ communities in the Westport neighborhoods in MA 20 where no plans have been proposed. But most of the structures are on high ground. Inundated unoccupied lands are slated for redevelopment and should be constructed in accordance with FEMA flood protection requirements. Similarly, the Cherry Hill neighborhood also in MA 20 is identified as an EJ community, but areas with potential flooding impacts are a public park that is separated from the community by a road and a steep hill. The NED Plan would enhance job opportunities in the Brooklyn MA 20 and Curtis Bay MA 22 communities since it will maintain close transportation across harbor and marine terminals, warehouses, and heavy industries.

The PDT will continue to investigate the inclusion of critical infrastructure protection and nonstructural measures in the communities that would most likely need additional support before, during, and after coastal flooding events. These vulnerable areas will be further examined in the Recommended Plan.

11. 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 employment, income, and output of the regional economy are considered part of the Regional Economic Development (RED) account. The input-output macroeconomic model RECONS (Regional Economic System) was used to address the impacts of the construction spending associated with the project alternatives.

11.1 RECONS METHODOLOGY

The certified RECONS 2.0 model was used to develop the Baltimore Coastal Study Regional Economic Development (RED) account. This model was developed by 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.

This RED analysis, using RECONS, employs input-output economic analysis, which measures the interdependence among industries and workers in an economy. The RED effects of each alternative were examined. The total cost for each alternative was input into the RECONS model.

This analysis uses a matrix representation of a region's economy to predict the effect of changes to various industries with the implementation of a project. 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.

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 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.

11.2 RECONS RESULTS

Of the total expenditures, 99% would be captured within the study area. The remainder of the expenditures would be captured at 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 GRP (value added) are summarized in Tables 40 through 48 for each alternative. Nonstructural alternatives with 1%, 2% and 5% risk reductions were combined with structural alternatives. Hence, for Alternative 4, three sub-alternatives Alternative 4 NS_100, Alternative 4 NS50YR, and Alternative 4 NS_20YR were developed. Among these three sub-alternatives, Alternative 4 NS_100 had the highest costs and Alternative 4 NS_20 had the lowest costs. For simplicity, the RED summary is presented using the minimum and maximum costs for each alternative.

Table 40: RECONS - Alternative 4 - Minimum Cost $62,667,000

RECONS - Alternative 4 - Min Cost $62,667,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$58,522,000	341	$45,472,000	$49,685,000
Secondary Impact		$52,203,000	273	$18,488,000	$32,276,000
Total Impact	$58,522,000	$110,725,000	613	$63,960,000	$81,961,000
State					

Direct Impact		$58,522,000	354	$45,472,000	$49,685,000
Secondary Impact		$52,397,000	273	$18,588,000	$32,392,000
Total Impact	$58,522,000	$110,919,000	628	$64,060,000	$82,077,000
US					
Direct Impact		$59,068,000	419	$49,090,000	$49,976,000
Secondary Impact		$100,038,000	481	$32,850,000	$56,239,000
Total Impact	$59,068,000	$159,106,000	900	$81,940,000	$106,215,000

Table 41: RECONS – Alternative 4 - Maximum Cost $69,029,000

RECONS – Alternative 4 - Max Cost $69,029,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$68,287,000	377	$53,059,000	$57,976,000
Secondary Impact		$60,914,000	302	$21,573,000	$37,661,000
Total Impact	$68,287,000	$129,201,000	679	$74,632,000	$95,637,000
State					
Direct Impact		$68,287,000	392	$53,059,000	$57,976,000
Secondary Impact		$61,140,000	303	$21,689,000	$37,797,000
Total Impact	$68,287,000	$129,427,000	695	$74,748,000	$95,773,000
US					
Direct Impact		$68,924,000	465	$57,281,000	$58,315,000
Secondary Impact		$116,730,000	533	$38,331,000	$65,623,000
Total Impact	$68,924,000	$185,654,000	997	$95,612,000	$123,938,000

Table 42: RECONS – Alternative 5 - Minimum Cost $162,898,000

RECONS - Alternative 5 -Min Cost $162,898,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$161,147,000	890	$125,212,000	$136,814,000
Secondary Impact		$143,747,000	712	$50,908,000	$88,875,000
Total Impact	$161,147,000	$304,894,000	1,602.2	$176,120,000	$225,689,000
State					
Direct Impact		$161,147,000	926	$125,212,000	$136,814,000
Secondary Impact		$144,280,000	714	$51,184,000	$89,196,000
Total Impact	$161,147,000	$305,427,000	1,639.9	$176,396,000	$226,010,000
US					
Direct Impact		$162,651,000	1,096.2	$135,175,000	$137,615,000
Secondary Impact		$275,466,000	1,257.4	$90,455,000	$154,860,000
Total Impact	$162,651,000	$438,117,000	2,353.5	$225,630,000	$292,475,000

Table 43: RECONS - Alternative 5 - Maximum Cost $411,320,000

RECONS - Alt 5 -Max Cost $411,320,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$406,897,000	2,247.2	$316,162,000	$345,458,000
Secondary Impact		$362,964,000	1,798.4	$128,544,000	$224,410,000
Total Impact	$406,897,000	$769,861,000	4,045.6	$444,706,000	$569,868,000

State					
Direct Impact		$406,897,000	2,337.6	$316,162,000	$345,458,000
Secondary Impact		$364,309,000	1,803.1	$129,240,000	$225,221,000
Total Impact	$406,897,000	$771,206,000	4,140.7	$445,402,000	$570,679,000
US					
Direct Impact		$410,697,000	2,767.8	$341,319,000	$347,480,000
Secondary Impact		$695,556,000	3,174.9	$228,401,000	$391,023,000
Total Impact	$410,697,000	$1,106,253,000	5,942.7	$569,720,000	$738,503,000

Table 44: RECONS - Alternative 5A - Cost $96,230,000

RECONS - Alt 5A - Cost $96,230,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$86,358,719	676.8	$62,539,309	$60,780,705
Secondary Impact		$83,681,824	435.4	$29,526,119	$51,023,246
Total Impact	$86,358,719	$170,040,544	1,112.1	$92,065,428	$111,803,951
State					
Direct Impact		$86,411,257	707.0	$63,082,683	$61,034,674
Secondary Impact		$84,766,796	441.2	$29,816,670	$51,584,315
Total Impact	$86,411,257	$171,178,053	1,148.2	$92,899,352	$112,618,990
US					
Direct Impact		$92,639,635	777.1	$66,506,752	$64,432,397
Secondary Impact		$166,124,266	777.6	$53,286,953	$91,102,765
Total Impact	$92,639,635	$258,763,901	1,554.7	$119,793,705	$155,535,162

Table 45: RECONS - Alternative 6 - Minimum Cost $263,909,000

RECONS - Alt 6 -Min Cost $263,909,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$261,071,000	1442	$202,854,000	$221,651,000
Secondary Impact		$232,883,000	1154	$82,476,000	$143,985,000
Total Impact	$261,071,000	$493,954,000	2596	$285,330,000	$365,636,000
State					
Direct Impact		$261,071,000	1500	$202,854,000	$221,651,000
Secondary Impact		$233,746,000	1157	$82,922,000	$144,505,000
Total Impact	$261,071,000	$494,817,000	2657	$285,776,000	$366,156,000
US					
Direct Impact		$263,509,000	1776	$218,995,000	$222,948,000
Secondary Impact		$446,279,000	2037	$146,546,000	$250,886,000
Total Impact	$263,509,000	$709,788,000	3813	$365,541,000	$473,834,000

Table 46: RECONS - Alternative 6 - Maximum Cost $512,331,000

RECONS - Alt 6 -Max Cost $512,331,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					

Direct Impact		$506,822,000	2799	$393,804,000	$430,295,000
Secondary Impact		$452,100,000	2240	$160,112,000	$279,520,000
Total Impact	$506,822,000	$958,922,000	5039	$553,916,000	$709,815,000
State					
Direct Impact		$506,822,000	2912	$393,804,000	$430,295,000
Secondary Impact		$453,775,000	2246	$160,979,000	$280,530,000
Total Impact	$506,822,000	$960,597,000	5158	$554,783,000	$710,825,000
US					
Direct Impact		$511,555,000	3448	$425,140,000	$432,814,000
Secondary Impact		$866,369,000	3955	$284,492,000	$487,050,000
Total Impact	$511,555,000	$1,377,924,000	7402	$709,632,000	$919,864,000

Table 47: RECONS - Alternative 7 - Minimum Cost $673,419,000

RECONS - Alt 7 -Min Cost $673,419,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$666,178,000	3679	$517,625,000	$565,590,000
Secondary Impact		$594,250,000	2944	$210,454,000	$367,407,000
Total Impact	$666,178,000	$1,260,428,000	6624	$728,079,000	$932,997,000
State					
Direct Impact		$666,178,000	3827	$517,625,000	$565,590,000
Secondary Impact		$596,452,000	2952	$211,594,000	$368,735,000
Total Impact	$666,178,000	$1,262,630,000	6779	$729,219,000	$934,325,000
US					
Direct Impact		$672,399,000	4532	$558,813,000	$568,900,000
Secondary Impact		$1,138,775,000	5198	$373,942,000	$640,189,000
Total Impact	$672,399,000	$1,811,174,000	9729	$932,755,000	$1,209,089,000

Table 48: RECONS - Alternative 7 - Maximum Cost $667,312,000

RECONS - Alt 7 -Max Cost $667,312,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$660,137,000	3646	$512,931,000	$560,460,000
Secondary Impact		$588,861,000	2918	$208,546,000	$364,075,000
Total Impact	$660,137,000	$1,248,998,000	6563	$721,477,000	$924,535,000
State					
Direct Impact		$660,137,000	3792	$512,931,000	$560,460,000
Secondary Impact		$591,043,000	2925	$209,675,000	$365,391,000
Total Impact	$660,137,000	$1,251,180,000	6718	$722,606,000	$925,851,000
US					
Direct Impact		$666,301,000	4490	$553,745,000	$563,741,000
Secondary Impact		$1,128,448,000	5151	$370,551,000	$634,383,000
Total Impact	$666,301,000	$1,794,749,000	9641	$924,296,000	$1,198,124,000

In summary, Tables 40 through 48 above show that the construction stimulus in the Baltimore Metropolitan area for each alternative would generate full-time equivalent jobs, labor income, and output at the local, state, and federal levels.

12. 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. U.S. Geologic Survey (USGS) topographic quadrangles, U.S. Department of Agriculture (USDA) web soil surveys, FEMA floodplain mapping, and U.S. Fish and Wildlife Service's (USFWS) National Wetland Inventory (NWI) were used to access the presence of wetlands, soil types, historical resources, archeological sites, and aesthetics in the study area. The environmental quality (EQ) account uses a qualitative assessment to assess potential effects of structural and nonstructural measures on environmental and cultural resources in the Baltimore Coastal study area. The analysis does not include quantitative EQ benefits. More information on EQ benefits can be found in the Baltimore Coastal Study IFR/EA.

13. COMPARISON OF FOUR ACCOUNTS

The NED was developed using G2CRM, which showed that Alternative 5A had positive net benefits. Detailed costs and benefits were presented in Section 6. For simplicity, the average annual net benefits will be used for comparison in this section.

The OSE was estimated in Section 9 using G2CRM. 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 10 using RECONS. The expenditures for each alternative were used to capture the direct and indirect impacts at the local, state and national levels. 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 more jobs and value are added to the economy. 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 GRP for each alternative.

The EQ account qualitatively assessed the effects of the alternatives on environmental and cultural resources in the study area.

Table 49 presents a comparative summary of the four accounts as required by the *Comprehensive Documentation of Benefits in Decision Document*. Nonstructural solutions were evaluated for the 1%, 2%, and 5% AEP. Hence, the final plans evaluated were:

- Alt 4-NS_20YR, Alt 4-NS_50YR, Alt 4-NS_100YR
- Alt 5-NS_20YR, Alt 5-NS_50YR, Alt 5-NS_100YR
- Alt 6-NS_20YR, Alt 6-NS_50YR, Alt 6-NS_100YR

- Alt 7-NS_20YR, Alt 7-NS_50YR, Alt 7-NS_100YR
- Alt 5A

For simplicity, Table 49 uses ranges: Alt 4, Alt 5, Alt 6, and Alt 7 to present the P&G accounts.

Table 49: Summary of the four P&G Accounts

PLAN SUMMARY		Alt 4	Alt 5	Alt 5A	Alt 6	Alt 7
Description		Critical Infrastructure	Critical Infrastructure with NS Plan	Critical Infrastructure with Select NS Plan	Critical Balanced	Mid-Tier
Total Cost of the Project		$58.2M-$65.2M	$177.2M-$460.6M	$96.2M	$211.5M-$494.9M	$568.9M-$575.9M
Comprehensive Benefits		High net benefits, low community resilience.	High net benefits at 5% AEP while maintaining historic neighborhood character, access to water, and community resilience.	Maximizes net benefits while maintaining historic neighborhood character, access to water, and community resilience.	Lower net benefits with negative benefits at Seagirt Marine Terminal. Similar EQ and OSE benefits to Alt 5.	Negative net benefits. Detrimental community and visual impacts.
National Economic Development (NED)	**Net Benefits**	$124.0M-$129.5M	$-171.5M-$71.0M	$356.0M	$-203.0M-$39.6M	$-261.4M-$-256.0M
Regional Economic Development (RED)	**Local-US Jobs**	900-997	2,354-5,943	1,112.1	3,813-7,402	9729-9,641
	Local-US Outputs	$159.1M-$185.7M	$438.1M-$1,106.2M	$171.1M	$709.8M-$1,377.9M	$1,811.2M-$1,794.7M
	Employment Income	$81.9M-$95.6M	$292.5M-$738.5M	$155.5M	$365.5M-$709.6M	$932.8-$924.3M
Environmental Quality (EQ)		▲Increased community resilience; No significant impacts. Minor wetland buffer impacts.				

			Alt 4			Alt 5			Alt 5A			Alt 6			Alt 7		
			Under 65	**Over 65**	**Total**	**Under 65**	**Over 65**	**Total**	**Under 65**	**Over 65**	**Total**	**Under 65**	**Over 65**	**Total**	**Under 65**	**Over 65**	**Total**
Other Social Effects (OSE)	**Life Loss**	**No Action**	**0.0**	**0.0**	**0.0**	**5.3**	**82.7**	**88.0**	**5.3**	**82.5**	**87.8**	**5.3**	**82.7**	**88.0**	**5.3**	**78.9**	**84.2**
		Project	**0.0**	**0.0**	**0.0**	**5.3**	**82.7**	**88.0**	**5.3**	**82.5**	**87.8**	**5.3**	**82.7**	**88.0**	**4.6**	**58.3**	**62.9**
		Benefits	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-0.7**	**-20.6**	**-21.3**
	Social Vulnerability and Resilience					▲Maintain historical character and cultural identity.											**▼Long term negative impacts to aesthetics and water access. Block roads during deployment.**
	Economic Vitality		▲ Ensure connectivity between communities and access to jobs.														

14. TENTATIVELY SELECTED PLAN

The PDT evaluated the optimization of plans. The OSE and EQ accounts were the same across alternative plans. Since RECONS uses expenditures to forecast future jobs and value added to the economy, the higher the cost, the more jobs and value are added to the economy. Hence, RED should not be the driving factor in selection of the Comprehensive Benefits Plan. The TSP was identified as Alternative 5A which is the combination of floodwalls around the I-895 and -95 Tunnels, and nonstructural solutions in the Inner Harbor and Locust Point. Alternative 5A had positive net benefits.

Table 50: Alt-5A: Total Benefits Plan (October 2021 price level, FY22 discount rate of 2.25%)

TSP	First Cost	IDC	Investment Cost	O&M	Total Cost	Average Annualized Cost	Average Annualized Benefits	Average Annualized Net Benefits	BCR
I-95 Tunnel & Facility Bulkheads	29,315,000	334,000	29,649,000	293,000	29,942,000	1,056,000	3,777,000	2,721,000	3.6
I-895 Tunnel & Facility Bulkheads	19,063,000	168,000	19,231,000	191,000	19,422,000	685,000	2,561,000	1,876,000	3.7
MA11: Inner Harbor Harborplace_NS50YR	8,070,000	175,000	8,245,000	81,000	8,326,000	279,000	845,000	566,000	3.0
MA14: Locust Point_NS100YR	5,565,000	185,000	5,750,000	56,000	5,806,000	195,000	575,000	380,000	2.9
MA9: Inner Harbor_NS20YR	11131000	114000	11245000	111000	11356000	381000	241000	(140000)	0.6
MA10: Inner Harbor Anchorage Marina_NS20YR	54818000	563000	55381000	548000	55929000	1875000	1025000	(850000)	0.5
MA12: Inner Harbor Ritz Carlton_NS50YR	557000	12000	569000	6000	575000	19000	11000	(8000)	0.6
MA15: Locust Point Museum of Industry_NS20YR	1391000	14000	1405000	14000	1419000	48000	40000	(8000)	0.8
Alt-5A	129,910,000	1,565,000	131,475,000	1,300,000	132,775,000	4,537,000	9,075,000	4,537,000	2.0

Alternative 5A benefits were greater than the cost. It is identified as the Total Benefits Plan and has been recommended to be the TSP, presented in the summary Table 50. The two tunnels have their support facilities respectively in Patapsco North MA 8 and in Locust Point MA 18. Each tunnel and its facility are not separable elements. As noted in Section 8.4, nonstructural alternatives MA 9 NS_20YR, MA 10 NS_20YR, MA 11 NS_50YR, MA 12 NS_50YR, MA 14 NS_100YR and MA 15 NS_20YR were included in the selected plan because either their net benefits are positive or are near positive. Nonstructural measures will be further re-evaluated based on geographical neighborhood with refined costs from the TSP to the ADM as described in Section 15 below.

15. OPTIMIZATION OF THE TSP

After the ADM, engineering data and other discipline data were reevaluated. It is important to note that the economic results above pictured the data obtained up to the TSP milestone. The top elevation of PSEs were reassessed as well as nonstructural measures according to revised hydraulic data. To manage flood risk to structures over a 50-year period of analysis (2031 to 2080), the top elevation for each PSE was updated from 12.2 ft to 12.5 ft NAVD88 as shown in Table 51.

Table 51: Hydrology & Hydraulics Analysis used to scale the finish elevation of protective system elements.

Year		1992	2031	2031	2031	2080	2080	2080	2130	2130	2130
USACE Sea Level Rise Scenarios		None	Low	Medium	High	Low	Medium	High	Low	Medium	High
Sea Level Rise, ft		0	0.36	0.5	0.93	0.86	1.55	3.73	1.36	3.06	8.43
Recurrence Interval	Percent Chance Exceedance	Water Surface Elevations plus Sea Level Rise, ft (Level of Performance 12.5 ft)									
5000	0.02	17.5	17.9	18.0	18.5	18.4	19.1	21.3	18.9	20.6	26.0
2000	0.05	16.5	16.9	17.0	17.5	17.4	18.1	20.3	17.9	19.6	25.0
1000	0.1	15.6	15.9	16.1	16.5	16.4	17.1	19.3	16.9	18.6	24.0
500	0.2	14.4	14.7	14.9	15.3	15.2	15.9	18.1	15.7	17.4	22.8
200	0.5	12.4	12.8	12.9	13.3	13.3	14.0	16.1	13.8	15.5	20.8
100	1	11.0	11.4	11.5	11.9	11.9	12.5	14.7	12.4	14.1	19.4
50	2	9.6	10.0	10.1	10.6	10.5	11.2	13.4	11.0	12.7	18.1
20	5	8.1	8.5	8.6	9.1	9.0	9.7	11.9	9.5	11.2	16.6
10	10	7.4	7.7	7.9	8.3	8.2	8.9	11.1	8.7	10.4	15.8
5	20	6.9	7.2	7.4	7.8	7.7	8.4	10.6	8.2	9.9	15.3
2	50	6.3	6.7	6.8	7.3	7.2	7.9	10.1	7.7	9.4	14.8
1	100	5.2	5.5	5.7	6.1	6.0	6.7	8.9	6.5	8.2	13.6

Flooding will occur during these conditions (WSEL greater than or equal to 12.5 feet NAVD88)

No flooding will occur during these conditions (WSEL less than 12.5 feet NAVD88)

In addition, the I-895 Tunnel located in MA24, and its four ventilation buildings split between two MAs (MA8 and MA24) were regrouped into one MA: MA8. The I-95 Tunnel located in MA19 and its two ventilation buildings split between two MAs (MA18 and MA19) were regrouped into one MA: MA18. Economic benefits were assessed for the regrouped model areas (MA8 and MA18). MAs that contained nonstructural measures included: MA9, MA10, MA11, MA12, MA14, and MA15. MA11 and MA14 yielded positive net benefits.

For the remaining of the project, the PDT has decided to update the study area as well as the formulation to structural solutions at the tunnel's areas and the nonstructural solutions in model areas 9, 10, 11, 12, 14, and 15. The total damage in the updated study area is $3.3 billion as shown in the distribution damages by model areas and by occupancy type Table 52.

The tunnels make up to 69% of damages; 31% at the tunnel I-895 (MA8) and 38% at the tunnel I-95 (MA18). High rise buildings come to a second position with 12% of total damages.
In the nonstructural model areas, most damages are happened in sub-MA24NS and sub-MA25NS; 13% and 10% damages respectively in these two sub-MAs. The discussion of sub-MAs can be found below in this section.

Table 52: Distribution of Damages by MA and Occupancy Type

Type of Solutions	MA	COM1	COM2	COM3	COM4	COM5	COM8	EDU1	GOV1	HRISE	IND2	IND3	IND5	RES1-1SNB	RES3B	RES4	Tunnel	Damage by MA	% Damage by MA
STRUCTURAL	**MA8**	-	8	-	-	-	-	-	44	3,976	14	-	-	-	-	-	1,020,566	**1,024,608**	**31%**
	MA18	-	182	-	-	-	-	-	-	-	-	-	-	-	-	-	1,267,439	**1,267,621**	**38%**
NONSTRUCTURAL	**MA1NS**	202	-	-	333	-	1,202	-	-	10,003	-	-	-	-	-	-	-	**11,740**	**0%**
	MA3NS	58	175	-	-	-	-	-	2,513	-	35	-	-	-	-	-	-	**2,782**	**0%**
	MA4NS	-	-	-	-	-	-	62,306	-	25,298	-	-	-	-	-	-	-	**87,604**	**3%**
	MA5NS	-	-	-	2,805	-	-	-	-	-	-	-	-	-	-	-	-	**2,805**	**0%**
	MA6NS	-	-	-	-	-	-	-	-	-	209	-	-	-	-	-	-	**209**	**0%**
	MA7NS	-	-	-	17,810	-	-	-	-	9,759	1,387	-	-	-	-	-	-	**28,957**	**1%**
	MA8NS	-	-	-	-	-	-	-	-	566	-	-	-	-	924	-	-	**1,490**	**0%**
	MA9NS	-	-	-	25	-	-	-	-	7,517	-	-	-	-	-	-	-	**7,542**	**0%**
	MA10NS	-	-	-	-	-	-	-	-	345	-	-	-	-	-	-	-	**345**	**0%**
	MA11NS	-	-	-	-	-	-	29	-	-	-	-	-	-	-	-	-	**29**	**0%**
	MA12NS	42	-	-	425	-	-	53	-	-	-	-	-	-	-	-	-	**520**	**0%**
	MA13NS	-	11	-	-	-	-	-	-	25	-	-	-	-	-	-	-	**36**	**0%**
	MA14NS	-	-	-	657	-	4,354	-	-	10,091	365	-	-	-	-	-	-	**15,467**	**0%**
	MA15NS	27	-	-	-	-	-	-	-	-	-	-	-	-	-	387	-	**414**	**0%**
	MA16NS	-	57	-	110	-	-	-	-	-	-	-	-	-	-	-	-	**167**	**0%**

MA17NS	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	**7**	**0%**
MA18NS	152	12,129	-	7,962	302	-	-	-	-	5,525	-	-	-	-	-	-	**26,071**	**1%**
MA19NS	-	-	-	-	-	2,274	-	-	16,548	-	-	-	-	-	-	-	**18,822**	**1%**
MA20NS	39,110	-	-	1,133	-	-	-	-	12,680	106	41	-	-	-	-	-	**53,070**	**2%**
MA21NS	77	-	-	-	-	-	-	2,715	2,247	98	-	-	-	-	-	-	**5,137**	**0%**
MA22NS	5,107	77	-	3,988	-	-	851	-	1,988	3,638	-	-	-	-	-	-	**15,649**	**0%**
MA23NS	1,663	-	207	1,135	-	-	-	-	-	-	-	-	-	-	-	-	**3,006**	**0%**
MA24NS	93,502	-	-	-	-	16,381	5,254	582	299,264	-	-	-	12,326	-	-	-	**427,308**	**13%**
MA25NS	83	37,934	3,624	72,429	-	20,261	-	1,192	-	189,246	-	11	-	-	-	-	**324,780**	**10%**
Damage by Occupancy Type	**140,023**	**50,573**	**3,831**	**108,819**	**302**	**44,472**	**68,493**	**7,046**	**400,307**	**200,623**	**41**	**11**	**12,326**	**924**	**387**	**2,288,005**	**3,326,186**	**100%**
% Damage by Occupancy Type	**4%**	**2%**	**0%**	**3%**	**0%**	**1%**	**2%**	**0%**	**12%**	**6%**	**0%**	**0%**	**0%**	**0%**	**0%**	**69%**		

Note: Numbers are in $000s

Baltimore District emergency management reanalyzed the evacuation order. The minimum, the likelihood, and the maximum remaining population rates of 0, 0.5, and 1 that were used when the water level reach 2 feet were found inaccurate. The correct rates of 0.1, 0.16, and 0.50 are then used for life loss calculations in G2CRM. Other G2CRM updated inputs are described in Section 15.3. Table 53 and 54 present the FWOP and the FWP damage and life loss results for the new study area.

Table 53: FWOP Damage and Life Loss on the Updated Study Area

Alternative	FWOP Damage			FWOP Life Loss		
	Structure	Content	Total	Under 65	Over 65	Total
I-895 Tunnel & Facility (MA8)	1,024,481	127	1,024,608	-	-	-
I-95 Tunnel & Facility (MA18)	1,267,559	62	1,267,621	-	-	-
Nonstructural Treatments	776,885	257,071	1,033,956	3	5	8

Damages in $000 and life loss rounded to whole number.

Table 54: FWP Damage and Life Loss on the Updated Study Area

Alternative	FWP Damage					FWP Life Loss			
	Structure	Content	Total	Damage Reduced	% Damage Reduced	Under 65	Over 65	Total	Life Loss Benefits
I-895 Tunnel & Facility (MA8)	214,920	43	214,963	809,645	79%	-	-	-	-
I-95 Tunnel & Facility (MA18)	336,418	50	336,468	931,153	73%	-	-	-	-
Nonstructural Treatments	261,650	95,694	357,344	676,612	65%	3	5	8	0

Damages in $000 and life loss rounded to whole number.

Damages are reduced by 79%, 73%, and 65% respectively at I-895 tunnel, I-95 tunnel, and with nonstructural solutions.
Each type of structure has an associated storm surge lethality and contains population during daytime and nighttime under and over 65 years of age. Hence, life loss computation is evaluated on a per-structure and a per-storm basis. As a result, life loss is not occurred at the tunnels but on the buildings. The total life loss of 8 in FWOP and FWP denotes that the nonstructural solutions for this study will not have any impact on the RP.

In the remaining of the analysis, the model areas for the nonstructural solutions are regrouped in small geographical areas or community basis called sub-MAs. This decision was made to re-evaluate MAs 9, 10, 12, and 15 in the TSP since some sub-MAs can yield positive net benefits. Six MAs that included nonstructural measures were further broken down into clusters or sub-MAs based on neighborhoods. The neighborhoods included Harbor East, Little Italy, Harbor Point, Fells Point, Perkins Homes, Inner Harbor, Jonestown, Washington Hill, Butcher's Hill, Patterson Place, Patterson Park, Downtown West, Otterbein, and Canton. A total of 25 sub-MAs were identified and labeled as MA1NS, MA2NS…MA24NS, and MA25NS. Figure 43 shows Baltimore City neighborhoods based on Census Bureau-designed areas, and Figure 44 shows the boundaries of the sub-MAs within the larger MAs.

Figure 43: Names of Neighborhood in Inner Harbor and Locus Point

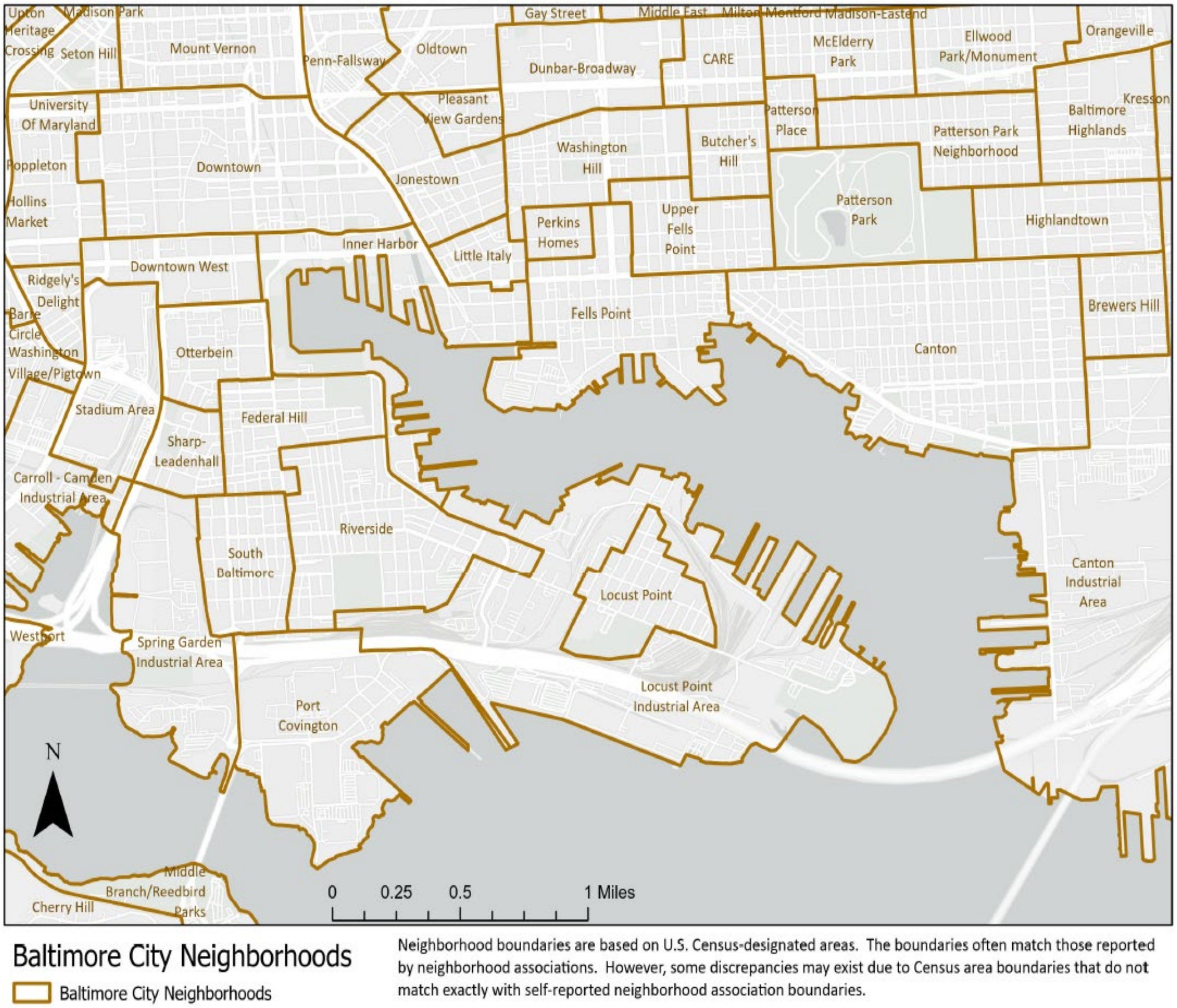
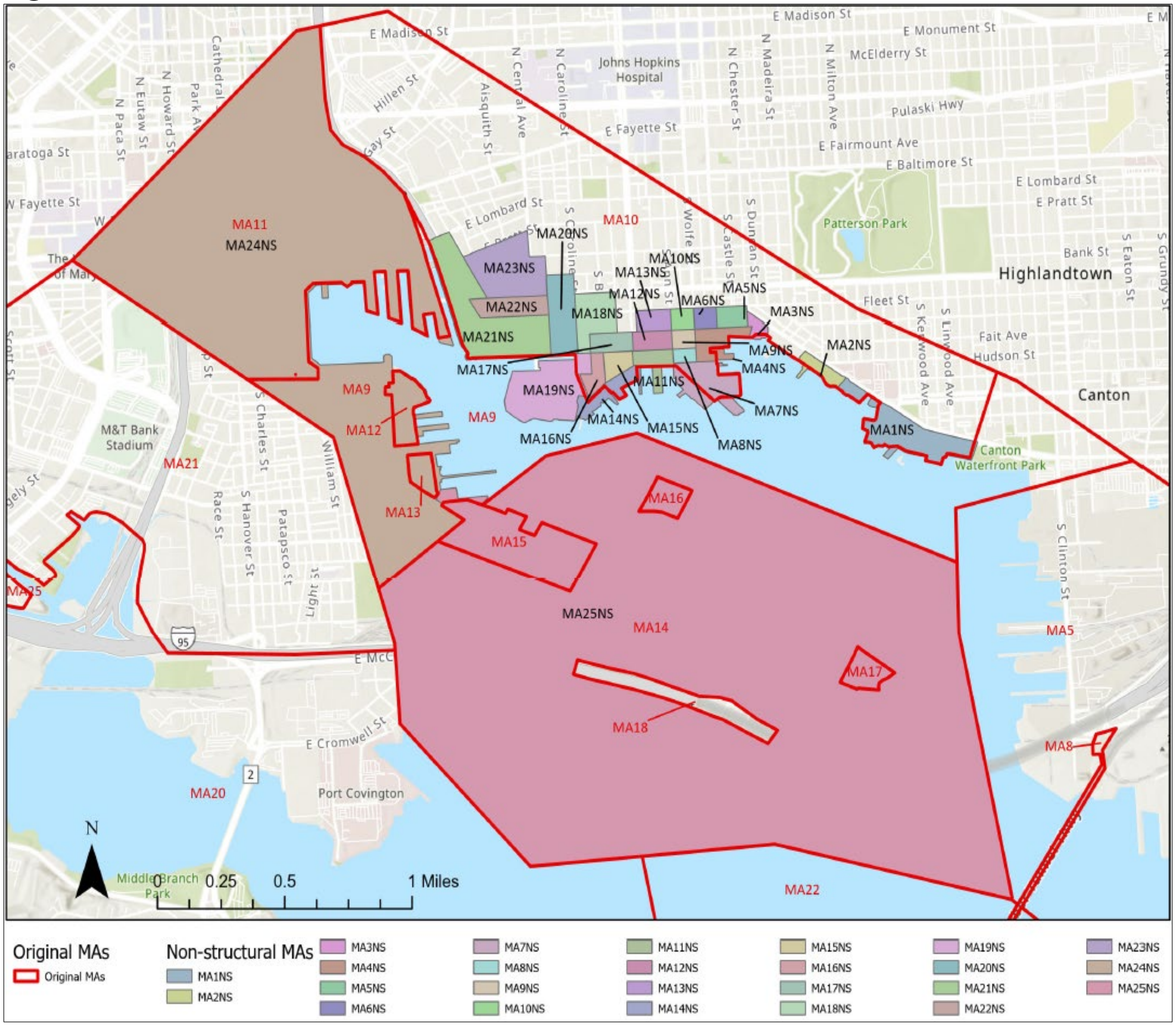


Figure 44: Model Areas and Sub-Model Areas in Inner Harbor and Locus Point



Fells Point has the densest concentration of structures at risk to flooding, which were subdivided into commercial, industrial, and residential. In general, structures associated with industrial properties are clustered together, rowhouses used as commercial businesses are clustered together, and residential rowhouses in contiguous blocks are clustered together. Several MAs were combined since there were only a few potentially vulnerable structures in some MAs. Google street view, windshield survey, and a site visit were used to categorize the structures and to regroup them.

Structures' square footage with the combination of their occupancy type were used to regroup them into commercial, industrial, and residential structures for the purpose of assigning non-structural floodproofing costs. These three types of structures were considered in developing the cost of nonstructural treatments. Table 55 shows a snapshot of the categorization.

Table 55: Initial Categorization of Structures for Cost Estimating

Occupancy Type	Structure Category		
RES1-1SNB	Residential		
RES1-1SWB	Residential		
RES1-2SNB	Residential		
RES1-2SWB	Residential		
RES3A	Residential		
RES3B	Residential	Commercial > 10000 sf	
RES4	Commercial		
COM1	Residential < 9100sf	Commercial >9100sf	
COM10	Residential		
COM2	Residential <1400sf	Commercial < 10000sf	Industrial >10000sf
COM3	Residential < 4000 sf	Commercial < 9000sf	Industrial > 9000sf
COM4	Commercial - mostly Fells Point	Industrial - mostly Locust Point	
COM5	Commercial		
COM8	Commercial		
COM9	Residential		
EDU1	Commercial		
GOV1	Commercial		
HRISE	Residential <8000sf		
IND2	Commercial	Industrial	
IND3	Industrial		
IND5	Commercial		

Within those categories, the nonstructural treatment costs were based on the measure outlined in Table 56. Note that all measures in each category might not be applicable for a structure that falls into the category.

An updated Total Project Cost Summary (TPCS) was developed by USACE Baltimore District cost engineers in the FY23 for the current price level, October 2022. The values of the structures appreciated by 23% from 2022 to 2023. Since the structure depreciated replacement values in the inventory that were used in G2CRM to compute the future without project and future with project damages still reflect FY22 costs, RS Means book historical cost indexes for the City of Baltimore were used to escalate the benefits from 2022 to 2023.

Table 56: Measures per Structure Category for Cost Estimating

Residential - Rowhouse	**Commercial -** Office/Condo/Residential Tower/Federal Building	**Industrial -** Warehouse
1) Install certified flood proof bulkhead doors on existing basement entrance and replace original doors on top for preservation of historical aesthetics.	1) Install certified flood proof doors at two single door locations and one double door location.	1) Dry flood proof office area in the structure up to the height of approximately 3 ft. above the finished floor. a. Door openings: Flood proof doorways. i. Install flood proof doors at five single door locations (3 ft. wide each) ii. Install flood proof barrier at one garage door opening. b. Pumping: i. Assume six skimmer/sump pumps for use inside the building and portable generators with suitable capacity to run the pumps. c. Sewage check valve: i. Assume one check valve to be placed on sanitary line to prevent backflow during flood event. d. Exterior wall utility penetrations: i. Replace seal at utility penetration locations to ensure watertightness.
2) Acquire certified temporary flood barriers for use on the two single doors on the first floor.	2) Install stoplog closures and associated framing on the building exterior for the following number and size of openings.	2) Wet flood proof open area in structure. a. Installation of flood louvers in exterior wall i. Assume 10 flood louvers total, 2 ft. by 1 ft. each, installed in existing masonry wall b. Pumping i. Assume 1 skimmer/sump pump and portable emergency generator with suitable capacity to run the pump.
3) Replace seals on existing utility penetrations of the house.	3) Install interior skimmer pumps and sufficient emergency generation capacity (assume one pump per stoplog closure) to reduce the risk of damage due to seepage during a high-water event.	3) Elevate exterior mechanical and electrical equipment a. Elevate all exterior mechanical and electrical equipment (assumed five units total) on elevated platform above the DFE. i. Assume one platform, 10 ft. x 25 ft., 4 ft. height
4) Install skimmer pumps on basement interior to remove seepage which may occur, with portable generation capacity required to operate the pumps.	4) Relocate existing electrical panel and meter from the basement to the first floor or higher.	
5) Install a backflow preventer on the existing sewage line connection.	5) Install a backflow preventer on all existing sewage line connections.	
6) Relocate the existing electrical meter and switch panel to the first floor or higher.		
7) Raise exterior HVAC unit.		
8) Masonry tuckpointing on 10% of the building exterior up to the finished first floor elevation.		
9) Full masonry unit and mortar replacement of the building exterior up the finished first floor elevation.		

15.1 RE-EVALUATION OF SEA LEVEL CHANCE IMPACT ON TUNNELS

MAs 8 and 18 were re-evaluated under the no, low, intermediate, and high SLC scenarios in accordance with ER 1100-2-8162 (*Incorporating Sea Level Changes in Civil Works Program* dated 31 Dec 2013). The results of the future without project under all three SLC conditions and no SLC for bulkheads in MA8 and MA18 are presented in Table 57.

Table 57: Sea Level Change Scenarios on Future Without Project Condition Damages

FWOP Present Value Damages by Sea Level Change Curve					**% Change from Intermediate SLC Curve**		
Model Area	**No**	**Low**	**Intermediate**	**High**	**No**	**Low**	**High**
MA8: I-895 Tunnel & Facility	16,259	115,046	138,756	256,816	-88%	-17%	85%
MA18: I-95 Tunnel & Facility	8,591	229,427	276,693	509,225	-97%	-17%	84%
All MAs	**24,850**	**344,474**	**415,449**	**766,041**	**-94%**	**-17%**	**85%**

Note: $ in 000s

The three right columns in Table 57 show the percent change from the intermediate SLC as compared to no SLC, low SLC, and high SLC. Both tunnels are almost equally affected by various SLC curves. For the I-895 Tunnel, the future without project damages were reduced by 88% under no SLC, by 17% under low SLC and increased by 85% under high SLC. For the I-95 Tunnel, the future without project damages were reduced by 97% under no SLC, by 17% under low SLC and increased by 85% under high SLC.

Table 58 presents costs, benefits, and the BCR under the three SLC curves and the no SLC curve in MAs 8 and 18.

Table 58: Net Benefits and Benefit-to-Cost Ratios Under Various Sea Level Change Curves for Model Areas 8 and 18 (October 2022 price level, FY23 discount rate of 2.5%)

Plan Alternatives	Alternative Description	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	Change from Intermediate in Net Benefits	BCR
MA8: I-895 Tunnel & Facilities Bulkheads Inner Harbor	I-895_100YR Intermediate SLC	$685,000	$3,725,000	$3,040,000	-	5.4
	I-895_100YR Low SLC	$685,000	$3,435,000	$2,750,000	-10%	5.0
	I-895_100YR High SLC	$685,000	$7,041,000	$6,356,000	109%	10.3
	I-895_100YR No SLC	$685,000	$2,260,000	$1,575,000	-48%	3.3
MA18: I-95 Tunnel & Facilities Bulkheads Ft. McHenry	I-95_100YR Intermediate SLC	$1,056,000	$6,360,000	$5,304,000	-	6.0
	I-95_100YR Low SLC	$1,056,000	$5,679,000	$4,623,000	-13%	5.4
	I-95_100YR High SLC	$1,056,000	$9,848,000	$8,792,000	66%	9.3
	I-95_100YR No SLC	$1,056,000	$4,204,000	$3,148,000	-41%	4.0

For the I-895 Tunnel, the net benefits were reduced by 48% under no SLC, by 10% under low SLC and increased by 109% under high SLC. For the I-95 Tunnel, the net benefits were reduced by 41% under no SLC, by 13% under low SLC and increased by 66% under high SLC.

The future without project damages decreased or increased substantially for various SLC curves, and the decrease in damages followed approximately the same trend.

Under the no, low, intermediate, and high SLC scenarios, the net benefits remained positive for both alternative. This indicates that the PSEs can manage the flood risk under the three SLC curves. The strong net benefits and BCR under high SLC shows the risk is reduced considerably during extreme storm events.

15.2 OPTIMIZATION OF THE TSP BASED ON ANNUAL EXCEEDANCE PROBABILITIES

The USACE may select a project based on the AEP that maximizes net benefits. This ensures that the top elevation of the designed bulkheads or nonstructural measures are selected effectively to reduce the maximum flood damages in communities. It is critical to recognize that figures, tables, and any results above were accurate at the time they were produced.

15.2.1 STRUCTURAL MITIGATION WITH VARIOUS FLOODWALL HEIGHTS

The performance of bulkheads in MAs 8 and 18 were analyzed for depth thresholds of a 2-, 1-, 0.5-, 0.2-, and a 0.1-percent (50-, 100-, 200, 500-, and a 1,000-year frequency events) risk reduction to assess which AEP the maximum net benefits would occur. Hence, the top of protection associated to the various AEPs are respectively 12.03, 13.04, 14.24, 15.56, and 16.17 ft. Table 59 shows the expected water level and the top of protection in each AEP. Table 60 presents the economic results for the structural plan floodwall heights optimization.

The comparison of various AEPs is based on the net benefits. Since the net benefits are derived from annualized average costs and annualized average benefits, it is necessary to indicate that the quantities for the floodwall materials were not updated after the TSP milestone (1% AEP for both tunnels). A Micro-Computer Aided Cost Estimating System (second generation) (MII) estimate, a Cost and Schedule Risk Analysis (CSRA), and TPCS were not provided by the cost estimator for the other AEPs. On the other hand, the tops of bulkheads were modeled for various AEPs and used to run simulations in G2CRM. Hence, the benefits computed reflected modeling results that accounted for uncertainties.

Based on the net benefits presented in Table 60, the maximum average annualized net benefits of \$3,040,000 were obtained for protection of the I-895 Tunnel and its ventilation buildings while the maximum average annualized net benefits of \$5,304,000 were obtained for the I-95 Tunnel and its ventilation buildings. Hence, the optimization of floodwall heights was achieved under the 1% AEP with the total cost and the average annualized cost of \$19,422,000 and \$550,000 respectively in MA8. For the I-95 Tunnel, the optimization of floodwall heights was achieved under the 1% AEP with the total cost and the average annualized cost of \$29,942,000 and \$5,304,000 respectively in MA18.

When comparing economic model results presented in Table 60, there is a high reduced average annualized flood damages of \$600,000 (=\$3,725,000 - \$4,325,000) from the 1% AEP to the 0.5%

AEP in MA8. There is a much higher reduced average annualized flood damages of $2,235,000 (=$8,595,000 - $6,360,000) from the 1% AEP to the 0.5% AEP in MA18 by raising the floodwalls from 12.5 ft (1% AEP) to 14.0 ft (0.5% AEP).

Since the cost of the structural plans in 2-, 0.5-, 0.2-, and a 0.1-percent percent AEPs were not developed, the analysis recommends evaluating the cost of the 0.5% AEP (200YR) during the Preconstruction Engineering and Design (PED) Phase. The maximum net benefits to manage flood risk at the tunnels would occur in the 0.5% AEP with a 14.0-ft high floodwall. If this is the case, both alternatives should manage flood risk under a 200-year event flood and not a 100-year event flood.

Table 59: Expected Water Level and Top of Protection of Bulkhead for each AEP

Exceedance Annual Probability (%)	2	1	0.5	0.2	0.1
Expected Value AEP	6.66	7.94	9.33	11.30	12.51
WSEL + SLC (intermediate) through 2080	**11.2**	**12.5**	**14.0**	**15.9**	**17.1**

Table 60: Optimization of Floodwall Heights (October 2022 price level, FY23 discount rate of 2.5%)

Plan Alternatives	Alternative Description	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA8: I-895 Tunnel & Facilities Bulkheads Inner Harbor	2%AEP (50YR) – 11.2 ft.	$14,000,000	$494,000	$2,741,000	$2,247,000	5.5
	1%AEP (100YR) – 12.5 ft.	$19,422,000	$685,000	$3,725,000	$3,040,000	5.4
	0.5%AEP (200YR) – 14.0 ft.	$36,500,000	$1,287,000	$4,325,000	$3,038,000	3.4
	0.2%AEP (500YR) – 15.9 ft.	$38,000,000	$1,340,000	$4,325,000	$2,985,000	3.2
	0.1%AEP (1000YR) – 17.1 ft.	$40,000,000	$2,948,000	$4,325,000	$1,377,000	1.5
MA18: I-95 Tunnel & Facilities Bulkheads Ft. McHenry	2%AEP (50YR) – 11.2 ft.	$20,000,000	$705,000	$4,419,000	$3,714,000	6.3
	1%AEP (100YR) – 12.5 ft.	$29,942,000	$1,056,000	$6,360,000	$5,304,000	6.0
	0.5%AEP (200YR) – 14.0 ft.	$95,000,000	$3,350,000	$8,595,000	$5,245,000	2.6
	0.2%AEP (500YR) – 15.9 ft.	$110,000,000	$3,878,000	$8,907,000	$5,029,000	2.3
	0.1%AEP (1000YR) – 17.1 ft.	$120,000,000	$4,231,000	$8,907,000	$4,676,000	2.1

The following graphs (Figures 45 and 46) present the costs and benefits comparison for each iteration. The economic and engineering variables were derived from the Monte Carlo simulation and a total of 100 iterations were executed by G2CRM for the analysis. These graphs indicate that the variability of benefits around the cost of protecting the tunnels seems to be similar for both alternatives.

Figure 45: I-895 Tunnel Costs and Benefits Comparison by Iteration for 1% AEP

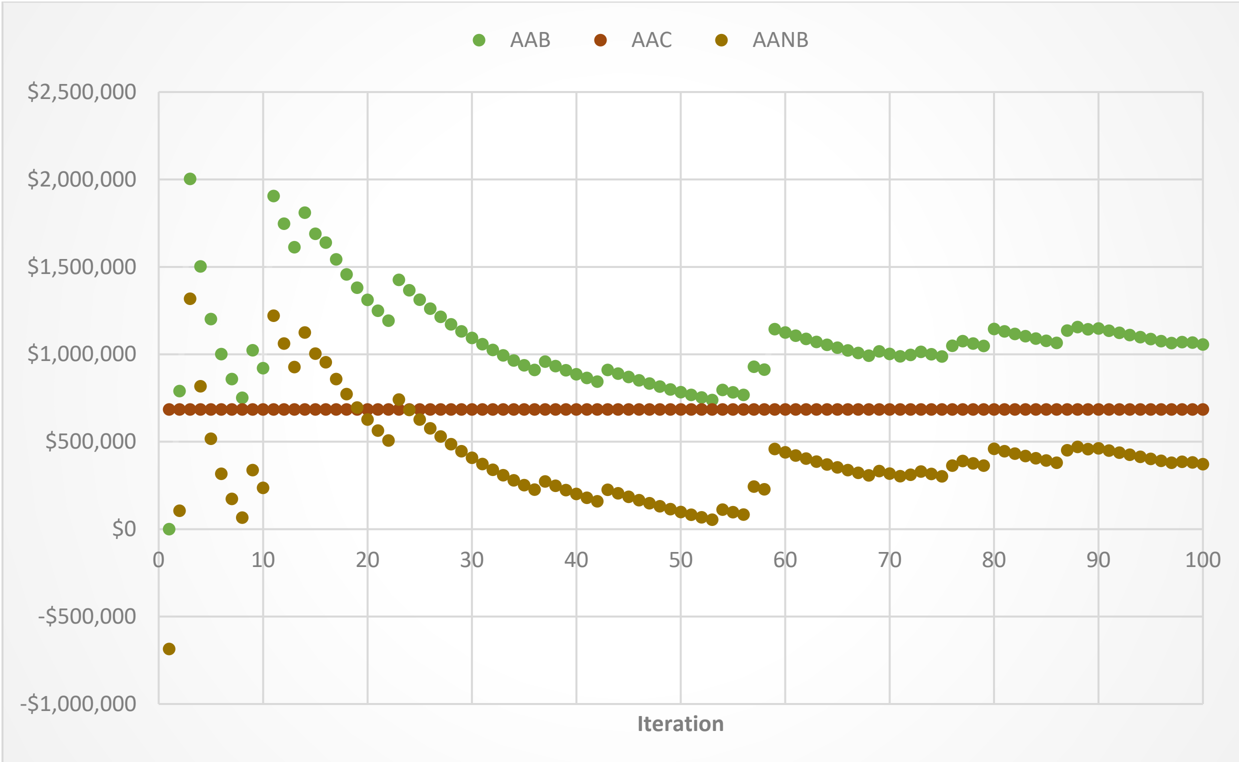
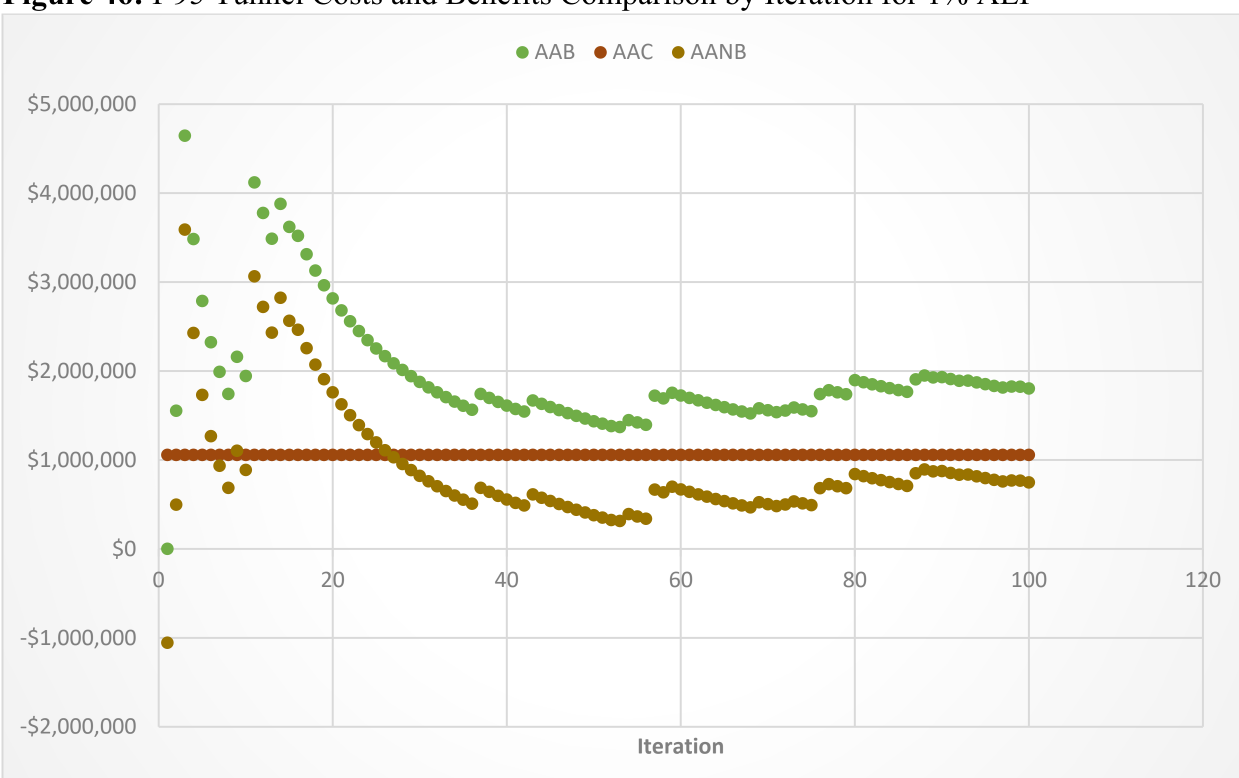


Figure 46: I-95 Tunnel Costs and Benefits Comparison by Iteration for 1% AEP



15.2.2 NONSTRUCTURAL MITIGATION

The aggregation used to the TSP milestone was based on flood depths relative to first floor elevations in each MA in compliance with Planning Bulletin (PB) 2019-03. The method used is not biased to structure size, value, or any other economic factors. To treat the structures more equitable relative to communities, the structures were also aggregated to sub-MAs or clusters. The aggregation method based on communities and the three types of structures, commercial, industrial, and rowhouse is not exact. This method resulted in some fringe situations since some neighborhoods or streets were split between structures included and excluded within the aggregation. The cost estimates prepared for the study only included dry and wet floodproofing treatments. Other treatments such as relocation, acquisition, or elevation were not included in the cost estimates. During the PED phase, field work will be conducted on each selected structure to determine if dry or wet floodproofing would be a suitable option.

PB 2019-03 requires that USACE analyses formulate, evaluate, and present a plan that reasonably maximizes net NED benefits. Three depths of flooding thresholds were used with the aggregation method to maximize net benefits. Each MA and sub-MA were analyzed within the 1% AEP (100YR), 2% AEP (50YR), and 5% AEP (20YR) flood frequencies. The aggregation optimization analysis followed the same assumptions previously described in this appendix. The G2CRM was re-run to reflect the nonstructural mitigation for each aggregation.

The nonstructural costs were updated by cost engineering for accuracy. The TPCS was developed for floodproofing treatments for the MAs (developed prior to the TSP), and the sub-MAs (developed after the ADM). The nonstructural solution includes 252, 429, and 749 structures in the 5%, 2%, and 1% AEP, respectively. In general, the updated floodproofing costs are higher compared to the previous costs used prior to the TSP. A flat nonstructural treatment cost of $290,000 was used prior to the TSP for each structure regardless of the structure category.
Based on MA aggregations, positive net benefits were found in MA11, MA14 and MA15. Tables 61, 62, and 63 show the cost, benefits, and BCR for the MAs in the 1%, 2%, and 5% AEP.

Table 61: Nonstructural Benefits and the Benefit-to-Cost Ratio in Model Areas - 1% AEP (October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

NS - MA	First Cost	IDC	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA9	$15,608,000	$32,000	$15,640,000	$551,000	$138,000	($413,000)	0.25
MA10	$65,595,000	$135,000	$65,730,000	$2,318,000	$828,000	($1,490,000)	0.36
MA11	$36,468,000	$75,000	$36,543,000	$1,288,000	$981,000	($307,000)	0.76
MA12	$1,105,000	$2,000	$1,107,000	$39,000	$6,000	($33,000)	0.15
MA14	$5,123,000	$11,000	$5,134,000	$181,000	$715,000	$534,000	4.0
MA15	$2,495,000	$5,000	$2,500,000	$88,000	$48,000	($40,000)	0.55

Table 62: Nonstructural Benefits and the Benefit-to-Cost Ratio in Model Areas – 2% AEP (October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

NS - MA	First Cost	IDC	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA9	$13,398,000	$28,000	$13,426,000	$473,000	$114,000	($359,000)	0.24
MA10	$51,649,000	$106,000	$51,755,000	$1,825,000	$757,000	($1,068,000)	0.41
MA11	$29,837,000	$62,000	$29,899,000	$1,054,000	$898,000	($156,000)	0.85
MA14	$4,270,000	$9,000	$4,279,000	$151,000	$620,000	$469,000	4.1
MA15	$1,390,000	$3,000	$1,393,000	$49,000	$46,000	($3,000)	0.94

Table 63: Nonstructural Benefits and the Benefit-to-Cost Ratio in Model Areas – 5% AEP (October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

NS - MA	First Cost	IDC	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA9	$9,946,000	$21,000	$9,967,000	$351,000	$106,000	($245,000)	0.30
MA10	$27,209,000	$56,000	$27,265,000	$961,000	$540,000	($421,000)	0.56
MA11	$17,681,000	$36,000	$17,717,000	$625,000	$462,000	($163,000)	0.74
MA14	$2,277,000	$5,000	$2,282,000	$80,000	$464,000	$384,000	5.8
MA15	$1,390,000	$3,000	$1,393,000	$49,000	$46,000	($3,000)	0.94

Among the five MAs analyzed for nonstructural solutions, only MA14 had positive average annualized net benefits after ADM. The maximum average annualized net benefits of $534,000 were obtained in the 1% AEP with a total of 18 structures that would receive nonstructural treatments.

MA11 - 2% AEP was selected as the NED plan at TSP but the reassessment shows negative net benefits because structures found in this MA are commercial, which are expensive to protect against flood events.

When examining the benefits for the sub-MAs, MA4NS, MA20NS, and MA25NS yielded positive net benefits. In sub-MA MA24NS, the net benefits are negative $38,000 for a total of 29 structures with a BCR close to a unit, 0.97. There is a great chance to have a positive net benefit. Due to time constraints to re-evaluate costs and benefits, the PDT decided to keep this sub-MA for further analysis at the final Integrated Feasibility Report and Environmental Assessment. Tables 64 to 66 show nonstructural economic results in sub-MAs developed after the ADM milestone.

Table 64: Nonstructural Benefits and Benefit-to-Cost Ratio in Sub-Model Areas - 1% AEP (October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

NS - MA	First Cost	IDC	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA1NS	$7,768,000	$17,000	$7,785,000	$274,000	$93,000	(181,000)	0.34
MA3NS	$1,272,000	$3,000	$1,275,000	$45,000	$12,000	(33,000)	0.27
MA4NS	$2,324,000	$5,000	$2,329,000	$82,000	$229,000	147,000	2.8
MA5NS	$1,272,000	$3,000	$1,275,000	$45,000	$10,000	(35,000)	0.22
MA6NS	$650,000	$1,000	$651,000	$23,000	$11,000	(12,000)	0.48

NS - MA	First Cost	IDC	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA7NS	$10,800,000	$23,000	$10,823,000	$382,000	$124,000	(258,000)	0.32
MA8NS	$1,923,000	$4,000	$1,927,000	$68,000	$18,000	(50,000)	0.26
MA9NS	$2,573,000	$5,000	$2,578,000	$91,000	$46,000	(45,000)	0.51
MA10NS	$1,110,000	$2,000	$1,112,000	$39,000	$5,000	(34,000)	0.13
MA11NS	$488,000	$1,000	$489,000	$17,000	$10,000	(7,000)	0.59
MA12NS	$1,598,000	$3,000	$1,601,000	$56,000	$14,000	(42,000)	0.25
MA13NS	$163,000	$0	$163,000	$6,000	$2,000	(4,000)	0.33
MA14NS	$5,548,000	$12,000	$5,560,000	$196,000	$36,000	(160,000)	0.18
MA15NS	$1,435,000	$3,000	$1,438,000	$51,000	$12,000	(39,000)	0.24
MA16NS	$650,000	$1,000	$651,000	$23,000	$14,000	(9,000)	0.61
MA17NS	$325,000	$0	$325,000	$11,000	$5,000	(6,000)	0.45
MA18NS	$3,448,000	$8,000	$3,456,000	$122,000	$95,000	(27,000)	0.78
MA19NS	$5,548,000	$12,000	$5,560,000	$196,000	$32,000	(164,000)	0.16
MA20NS	$8,075,000	$17,000	$8,092,000	$285,000	172,000	($113,000)	0.60
MA21NS	$5,548,000	$12,000	$5,560,000	$196,000	$50,000	(146,000)	0.26
MA22NS	$10,475,000	$22,000	$10,497,000	$370,000	$85,000	(285,000)	0.23
MA23NS	$5,414,000	$5,000	$5,419,000	$191,000	$37,000	(154,000)	0.19
MA24NS	$41,059,000	$89,000	$41,148,000	$1,451,000	$1,289,000	(162,000)	0.89
MA25NS	$8,417,000	$17,000	$8,434,000	$297,000	$938,000	641,000	3.2

Table 65: Nonstructural Benefits and Benefit-to-Cost Ratio in Sub-Model Areas - 2% AEP (October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

NS - MA	First Cost	IDC	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA1NS	$6,727,000	$14,000	$6,741,000	$238,000	$89,000	($149,000)	0.37
MA3NS	$1,295,000	$3,000	$1,298,000	$46,000	$12,000	($34,000)	0.26
MA4NS	$2,324,000	$5,000	$2,329,000	$82,000	$227,000	$145,000	2.8
MA5NS	$1,121,000	$2,000	$1,123,000	$40,000	$7,000	($33,000)	0.18
MA6NS	$348,000	$0	$348,000	$12,000	$6,000	($6,000)	0.50
MA7NS	$10,961,000	$23,000	$10,984,000	$387,000	124,000	($263,000)	0.32
MA8NS	$1,992,000	$4,000	$1,996,000	$70,000	18,000	($52,000)	0.26
MA9NS	$2,688,000	$5,000	$2,693,000	$95,000	46,000	($49,000)	0.48
MA10NS	$1,121,000	$2,000	$1,123,000	$40,000	5,000	($35,000)	0.13
MA11NS	$522,000	$1,000	$523,000	$18,000	10,000	($8,000)	0.56
MA12NS	$522,000	$1,000	$523,000	$18,000	7,000	($11,000)	0.39
MA14NS	$5,606,000	$12,000	$5,618,000	$198,000	36,000	($162,000)	0.18
MA15NS	$1,121,000	$2,000	$1,123,000	$40,000	7,000	($33,000)	0.18
MA16NS	$522,000	$1,000	$523,000	$18,000	11,000	($7,000)	0.61
MA17NS	$174,000	$0	$174,000	$6,000	2,000	($4,000)	0.33
MA18NS	$3,517,000	$7,000	$3,524,000	$124,000	95,000	($29,000)	0.77
MA19NS	$4,485,000	$10,000	$4,495,000	$158,000	30,000	($128,000)	0.19
MA20NS	$5,606,000	$12,000	$5,618,000	$198,000	161,000	($37,000)	0.81

NS - MA	First Cost	IDC	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA21NS	$2,242,000	$5,000	$2,247,000	$79,000	28,000	($51,000)	0.35
MA22NS	$6,727,000	$14,000	$6,741,000	$238,000	64,000	($174,000)	0.27
MA23NS	$4,408,000	$9,000	$4,417,000	$156,000	34,000	($122,000)	0.22
MA24NS	$33,705,000	$69,000	$33,774,000	$1,191,000	1,153,000	($38,000)	1.0
MA25NS	$6,219,000	$12,000	$6,231,000	$220,000	819,000	$599,000	3.7

Table 66: Nonstructural Benefits and Benefit-to-Cost Ratio in Sub-Model Areas - 5% AEP (October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

NS - MA	First Cost	IDC	Total Cost	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA1NS	$3,364,000	$7,000	$3,371,000	$119,000	$28,000	($91,000)	0.24
MA3NS	$1,295,000	$3,000	$1,298,000	$46,000	$12,000	($34,000)	0.26
MA4NS	$2,324,000	$5,000	$2,329,000	$82,000	$225,000	$143,000	2.7
MA5NS	$1,121,000	$2,000	$1,123,000	$40,000	$7,000	($33,000)	0.18
MA6NS	$348,000	$0	$348,000	$12,000	$6,000	($6,000)	0.50
MA7NS	$9,318,000	$20,000	$9,338,000	$329,000	$113,000	($216,000)	0.34
MA8NS	$1,818,000	$2,000	$1,820,000	$64,000	$15,000	($49,000)	0.23
MA9NS	$2,340,000	$5,000	$2,345,000	$83,000	$41,000	($42,000)	0.49
MA11NS	$174,000	$0	$174,000	$6,000	$4,000	($2,000)	0.67
MA12NS	$174,000	$0	$174,000	$6,000	$2,000	($4,000)	0.33
MA14NS	$3,364,000	$7,000	$3,371,000	$119,000	$28,000	($91,000)	0.24
MA16NS	$522,000	$1,000	$523,000	$18,000	$11,000	($7,000)	0.61
MA17NS	$174,000	$0	$174,000	$6,000	$2,000	($4,000)	0.33
MA18NS	$3,198,000	$7,000	$3,205,000	$113,000	$76,000	($37,000)	0.67
MA19NS	$2,242,000	$5,000	$2,247,000	$79,000	$25,000	($54,000)	0.32
MA20NS	$3,364,000	$7,000	$3,371,000	$119,000	146,000	$27,000	1.2
MA24NS	$20,181,000	$43,000	$20,224,000	$713,000	$616,000	($97,000)	0.86
MA25NS	$3,989,000	$8,000	$3,997,000	$141,000	$627,000	$486,000	4.4

The maximum average annualized net benefits of $147,000 were obtained in a 1% AEP with a total of 2 structures that will receive floodproofing protections in MA4NS. In MA20NS, the maximum annualized net benefits of $27,000 were obtained in the 5% AEP with a total of 2 structures that would receive floodproofing treatments. In MA24NS, the maximum annualized net benefits were obtained in the 2% AEP with a total of 29 structures that would receive floodproofing treatments. In MA25NS, the maximum annualized net benefits of $641,000 were obtained in the 1% AEP with a total of 21 structures that would receive floodproofing treatments. Hence, for the combined structures in the four sub-MAs that yielded positive net benefits, the total count of structures is 54 as shown in Table 66.

Table 67: Summary of sub-Model Areas with Positive Net Benefits

Summary of Sub-MAs with Positive Net Benefits
Cost Category

	Commercial	Industrial	Residential	Total
MA4NS_100YR	2	0	0	2
MA20NS_20YR	2	0	0	2
MA24NS_50YR	29	0	0	29
MA25NS_100YR	2	19	0	21
Total	**35**	**19**	**0**	**54**

Table 68 shows a summary on the nonstructural analysis in the selected sub-MAs. The total cost for the nonstructural plan is $46,770,000 and the total benefits is $69,941,000.

Table 68: Summary Costs, Benefits, and Benefit-to-Cost Ratio in Sub-Model Areas with Positive Net Benefits (October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

Total Benefits Plan	First Cost	IDC	Total Cost	Average Annualized Cost	Average Annualized Benefits	Average Annualized Net Benefits	BCR
MA4NS_100YR	$2,324,000	$5,000	$2,329,000	$82,000	$229,000	$147,000	2.8
MA20NS_20YR	$2,324,000	$5,000	$2,329,000	$82,000	$146,000	$64,000	1.8
MA24NS_50YR	$33,705,000	$69,000	$33,774,000	$1,191,000	$1,153,000	($38,000)	1.0
MA25NS_100YR	$8,417,000	$17,000	$8,434,000	$297,000	$938,000	$641,000	3.2
Total	$46,770,000	$96,000	$46,866,000	$1,652,000	$2,466,000	$814,000	1.5

15.2.3 PARTICIPATION RATE SENSITIVITY ANALYSIS

Participation rates provide information on the number of property owners that might participate in the nonstructural plan and the cost associated to these rates. Hence, participation rate sensitivity analysis was performed during optimization. The highest and lowest benefit to the structures within the nonstructural aggregation were examined as well as the costs of the treatments. Table 69 presents the results of the 100% participation rate, the 80% best-case scenario, and the 80% worst-case scenario. The 80% best case scenario includes 80% of structures that bring the highest net benefits. The 80% worst case scenario includes 80% of structures with the lowest net benefits. The participation rate analysis is used to illustrate the uncertainty involved in a nonstructural voluntary program.

Table 69: Best- and Worst-Case Scenarios
(October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

Total Benefits Plan	Total Cost	Average Annualized Cost	Average Annualized Benefits	Average Annualized Net Benefits	BCR
80% Worst Case Scenario	$31,045,000	$1,095,000	$893,000	($202,000)	0.8
80% Best Case Scenario	$28,311,000	$998,000	$1,953,000	$955,000	2.0
100% Full Participation	$46,770,000	$1,652,000	$2,466,000	$814,000	1.5

For the 80% worst case scenario, the average annualized net benefits are negative $202,000 and a BCR of 0.8 with a total cost of $31,045,000. For the 80% best case scenario, the average annualized net benefits are $955,000 and a BCR of 2.0 with a total cost of $28,311,000.

The interval in which the average annualized net benefits in both scenarios indicates that the nonstructural solutions are feasible by taking contingency into consideration. People have lived and established businesses in these communities for many decades. Some local factors would certainly increase the participation rate. Family connections within the region will lead to an unwillingness to relocate and may therefore increase the participation rate for nonstructural solutions. The study needs to have strong public outreach to help educate the community on the long-term benefits of flood risk mitigation to be successful and live up to the expected participation rates presented above.

15.3 RECOMMENDED PLAN – ALTERNATIVE 5A

The optimization laid out in Sections 15.1 and 15.2 was done right after the ADM level. Table 70 shows the Recommended Plan at that time, with October 1, 2022, price level and FY23 discount rate of 2.5%.

Table 70: Recommended Plan (October 1, 2022, Price level – FY23 Discount Rate of 2.5%)

Recommended Plan	First Cost	IDC	Investment Cost	O&M	Total Costs	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
I-895 Tunnel & Facility	$19,063,000	$168,000	$19,231,000	$191,000	$19,422,000	$685,000	$3,725,000	$3,040,000	5.4
I-95 Tunnel & Facility	$29,315,000	$334,000	$29,649,000	$293,000	$29,942,000	$1,056,000	$6,360,000	$5,304,000	6.0
MA4NS_100YR	$2,324,000	$5,000	$2,329,000	-	$2,329,000	$82,000	$229,000	$147,000	2.8
MA20NS_20YR	$2,324,000	$5,000	$2,329,000	-	$2,329,000	$82,000	$146,000	$64,000	1.8
MA24NS_50YR	$33,705,000	$69,000	$33,774,000	-	$33,774,000	$1,191,000	$1,153,000	-$38,000	1.0
MA25NS_100YR	$8,417,000	$17,000	$8,434,000	-	$8,434,000	$297,000	$938,000	$641,000	3.2
Alt-5A	$95,148,000	$598,000	$95,746,000	$484,000	$96,230,000	$3,393,000	$12,551,000	$9,158,000	3.7

The total cost of Alternative 5A was $96.2 million with the average annualized net benefits of $9.2 million and total benefits of $356 million over a 50-year period of analysis.

Many updates have been done on G2CRM inputs after the ADM.
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. The Advanced Circulation Model (ADCIRC) is a high-fidelity model that predicts water levels and currents based on input parameters including subsurface bathymetry, wind velocity, atmospheric pressure, and storm tracks. The results of ADCIRC are in the form of water level hydrographs and are reported in save points. As noted, three comprehensive save points 5944, 10930, and 13228 were previously selected in the ADCIRC domain. During the Agency Technical Review (ATR) of the final Integrated Feasibility Report and Environmental Assessment (IFR/EA), the ADCIRC save point 13228 was replaced by its analogue STWAVE point, 1946, that includes the wave actions. Extra tropical storms were also added to the season storm file. The NACCS industrial depth-damage curve, (IND6) used for the tunnels was replaced by appropriated depth-damage curves described in Section 7. Ground elevations of the tunnels were updated as well. The discrepancy was found in water levels when comparing CHS AEP curve and AEP curve generated by G2CRM. To address the discrepancy between CHS and G2CRM AEP curves, the vertical conversion from Mean Lower Low Water (MLLW) to Mean Sea Level (MSL) was adjusted by adding 1.18 feet to the previous -0.81 value used in H5 metadata file. As a result, the correction of the water level within G2CRM model increased structure damages and the numbers of structures eligible to receive nonstructural solutions. The tunnel I-895 BCR is then multiplied by 3.5 while the BCR for the tunnel I-95 was multiplied by 3.8. Table 71 shows structures per sub-MAs that yielded positive net benefits. The total count of structures that will receive nonstructural solutions is now 109 after comparing nonstructural alternatives in the various 5%, 2%, and 1% AEPs. After the ADM, the structural inventory was further refined to remove residential structures from the analysis for floodproofing applications due to safety and structural concerns, following emerging recommendations from the USACE Nonstructural Summit held in July 2023. Therefore, only commercial, and industrial properties were analyzed for inclusion in the Recommended Plan.

Table 71: Summary of sub-Model Areas with Positive Net Benefits

	Summary of Sub-MAs with Positive Net Benefits			
	Cost Category			
	Commercial	Industrial	Residential	Total
MA1NS_20YR	4	0	0	4
MA4NS_100YR	2	0	0	2
MA5NS_100YR	1	0	0	1
MA7NS_20YR	11	0	0	11
MA9NS_20YR	1	0	0	1
MA14NS_20YR	5	0	0	5
MA18NS_20YR	2	4	0	2
MA19NS_20YR	3	0	0	3
MA20NS_20YR	3	0	0	3
MA21NS_50YR	2	0	0	2
MA22NS_50YR	7	0	0	7
MA24NS_50YR	29	0	0	29
MA25NS_100YR	10	25	0	35
Total	**80**	**29**	**0**	**109**

The Recommended Plan Revision developed with October 1, 2023, price level and the FY24 discount rate of 2.75% is presented in Table 72 below. It is the combination of structural and nonstructural plans.

Table 72: Recommended Plan Revision (October 1, 2023, Price level – FY24 Discount Rate of 2.75%)

Recommended Plan	First Cost	IDC	Investment Cost	O&M	Total Costs	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
I-895 Tunnel & Facility (MA8)	$35,358,000	$343,000	$35,701,000	$3,510,000	$39,211,000	$1,452,000	$29,990,000	$28,538,000	20.7
I-95 Tunnel & Facility (MA18)	$42,131,000	$528,000	$42,659,000	$1,620,000	$44,279,000	$1,640,000	$34,491,000	$32,851,000	21.0
MA1NS_20YR	$4,761,000	$11,000	$4,772,000	-	$4,772,000	$177,000	$195,000	$18,000	1.1
MA4NS_100YR	$2,380,000	$5,000	$2,385,000	-	$2,385,000	$88,000	$1,701,000	$1,613,000	19.3
MA5NS_100YR	$1,190,000	$3,000	$1,193,000	-	$1,193,000	$44,000	$73,000	$29,000	1.7
MA7NS_20YR	$13,092,000	$30,000	$13,122,000	-	$13,122,000	$486,000	$709,000	$223,000	1.5
MA9NS_20YR	$1,190,000	$3,000	$1,193,000	-	$1,193,000	$44,000	$207,000	$163,000	4.7
MA14NS_20YR	$5,951,000	$13,000	$5,964,000	-	$5,964,000	$221,000	$322,000	$101,000	1.5
MA18NS_20YR	$4,117,000	$9,000	$4,126,000	-	$4,126,000	$153,000	$351,000	$198,000	2.3
MA19NS_20YR	$3,571,000	$8,000	$3,579,000	-	$3,579,000	$133,000	$487,000	$354,000	3.7
MA20NS_20YR	$3,571,000	$8,000	$3,579,000	-	$3,579,000	$133,000	$500,000	$367,000	3.8
MA21NS_50YR	$2,380,000	$5,000	$2,385,000	-	$2,385,000	$88,000	$96,000	$8,000	1.1
MA22NS_50YR	$8,331,000	$19,000	$8,350,000	-	$8,350,000	$309,000	$380,000	$71,000	1.2
MA24NS_50YR	$34,515,000	$78,000	$34,593,000	-	$34,593,000	$1,281,000	$11,275,000	$9,994,000	8.8
MA25NS_100YR	$22,755,000	$51,000	$22,806,000	-	$22,806,000	$845,000	$7,870,000	$7,025,000	9.3
Alt-5A	**$185,293,000**	**$1,114,000**	**$186,407,000**	**$5,130,000**	**$191,537,000**	**$7,094,000**	**$88,647,000**	**$81,553,000**	**12.5**

The total cost of Alternative 5A is $191.5 million dollars with the average annualized net benefits of $81.6 million dollars and total benefits of $2.4 billion dollars over a 50-year period of analysis.

The cost estimates for the nonstructural features were completed at a parametric level to obtain Class 3 level designs. Site specific assessments failed to be conducted for each of the structures during the feasibility phase. Due to multiple factors including limited design information, high-cost contingency/uncertainty, and lack of time and funding to develop the expected class level cost for the nonstructural plan, the nonstructural plan has been removed from the Recommended Plan. Hence, the Final Recommended Plan includes only the critical infrastructure plan of Alt-5A. This structural plan, as shown in Table 73, consists of the construction of the floodwalls and closure structures around the Fort McHenry Tunnel (I-95) and its ventilation buildings, and the construction of the floodwalls and closure structures around the Baltimore Harbor Tunnel (I-895) and its ventilation buildings.

Table 73: Final Recommended Plan (October 1, 2023, Price level – FY24 Discount Rate of 2.75%)

Recommended Plan	First Cost	IDC	Investment Cost	O&M	Total Costs	Average Annualized Costs	Average Annualized Benefits	Average Annualized Net Benefits	BCR
I-895 Tunnel & Facility (MA8)	$35,358,000	$343,000	$35,701,000	$3,510,000	$39,211,000	$1,452,000	$29,990,000	$28,538,000	20.7
I-95 Tunnel & Facility (MA18)	$42,131,000	$528,000	$42,659,000	$1,620,000	$44,279,000	$1,640,000	$34,491,000	$32,851,000	21.0
Alt-5A	**$77,489,000**	**$871,000**	**$78,360,000**	**$5,130,000**	**$83,490,000**	**$3,092,000**	**$64,481,000**	**$61,389,000**	**20.9**

The total cost of the Final Recommended Plan is now $83.5 million dollars with the average annualized net benefits of $61.4 million dollars and total benefits of $1.7 billion dollars over a 50-year period of analysis.

15.3.1 UPDATED RECONS FOR THE FINAL RECOMMENDED PLAN

The Regional Economic Development (RED) account on the Final RP is summarized in Table 74.

Table 74: RECONS – Summary of RED on RP

RECONS – Alt-5A RP Cost $83,490,000					
Area	**Local Capture**	**Output**	**Jobs***	**Labor Income**	**Value Added**
Local					
Direct Impact		$74,926,000	522.3	$54,260,000	$52,734,000
Secondary Impact		$72,603,000	336.2	$25,617,000	$44,268,000
Total Impact	$74,926,000	$147,529,000	858.5	$79,877,000	$97,002,000
State					
Direct Impact		$74,971,000	545.5	$54,731,000	$52,954,000
Secondary Impact		$73,544,000	340.7	$25,869,000	$44,755,000
Total Impact	$74,971,000	$148,516,000	886.2	$80,600,000	$97,709,000
US					
Direct Impact		$80,375,000	600.1	$57,702,000	$55,902,000
Secondary Impact		$144,131,000	601.4	$46,232,000	$79,042,000
Total Impact	$80,375,000	$224,506,000	1,201.6	$103,934,000	$134,944,000

The construction stimulus in the Baltimore Metropolitan study area for the RP would generate at the local level 858.5 full-time jobs, $79.9 million dollars labor income, and $147.5 million dollars outputs.

At the State level, the construction stimulus would generate 886.2 full-time jobs, $80.6 million dollars labor income, and $148.5 million dollars outputs.

At the federal level, the construction stimulus in the Baltimore Metropolitan area would generate 1,201.6 full-time jobs, $103.9 million dollars labor income, and $224.5 million dollars outputs.

15.3.2 RESIDUAL RISK

The risk that remains in the study area after the proposed coastal storm risk management project is implemented is residual risk. It includes the consequence of capacity exceedance as well as consideration of the project flood risk reduction. Hence, given the hydrological, environmental, and economic constraints, the residual risk cannot be mitigated. Three metrics; Average Annual Damages (AAD), Life Loss, and Number of Structures at risk were used to assess the residual risk as shown in below Table 75.

After the ADM, the PDT has decided to update the study area boundary to the tunnel's areas and the model areas where the project would propose nonstructural solutions. This limited study boundary is an interim response to the study authority. The Recommended Plan only was re-analyzed following the water level correction. Hence, the risk associated with other measures in the final array of alternatives were not re-evaluated. Another authority might be used in the future to re-analyze the entire Baltimore Metropolitan study area since the current scope cannot accommodate additional time and funding. Residual risk in the entire study area will be much higher than the one presented below in the updated study area.

The total FWOP damage in the updated study area is $3.3 billion as shown in Table 52 with the AAD of $123.2 million, and the life loss is 8 (Table 54). The total damage reduced by the intervention is $1.7 billion with the AAD of $64.5 million (Table 73).

***Table 75**: Residual Risk*

Alt-5A Critical Infrastructure Plan	
	Structural
Average Annual Damages (2.75% interest rate; 50-year analysis; $ in FY2024 price levels)	
Future without Project	123,205,000
Less: Risk Reduction	64,481,000
Residual Risk	**58,724,000**
RR as % of FWOP	*48%*
Life Loss	
Future without Project	8
Less: Risk Reduction	0
Residual Risk	
RR as % of FWOP	*100%*
Number of Structures at Risk[1]	
Future without Project	191
Less: Risk Reduction	8
Residual Risk	**183**
RR as % of FWOP	*96%*

[1] A structure is at risk if expected inundation damage is greater than 5% of its value

In Table 75, the residual risk is listed as percentages and dollars. Using the intermediate sea level change, the average annual damages remaining in the study area with the implementation of the Recommended Plan is $58.7 million, which represent a 48-percent of the future without project condition or potential flood damages remaining. This is the residual risk.

The life loss statistics with high level of uncertainty at inundated structures were assessed using G2CRM. The results should be viewed as more qualitative as opposed to a quantitative assessment of life loss even though the results are stated in numerical values. Since there are not life loss benefits with respect to the intervention, the life loss residual risk remains a 100-percent on the study area.

The last metric used to assess residual risk is the number of structures at risk of inundation damages. A structure is at risk if its expected damages is greater than 5% of its structure and contents value. The number of structures continue to be at risk after the implementation of the Recommended Plan is 183, an equivalent of a 96-percent of the total number of structures.

16. REFERENCES

Chen, W., & Lalas, P. (2012). *Leakage repairs for transit tunnels*. North American Tunneling 2012 Proceedings, Indianapolis, IN (pp. 371–381).

Cialone, M. A., Massey, T. C., Anderson, M. E., Grzegorzewski, A. S., Jensen, R. E., Cialone, A., Mark, D.J., Pevey, K.C., Gunkel, B.L., McAlpin, T. O., Nafal-Caraballo, N.C., Melby, J.A., & Ratcliff, J.L. (2015). *North Atlantic Coast Comprehensive Study (NACCS) Coastal Storm Model Simulations: Waves and Water Levels* (Report No. ERDC/CHL TR-15-14). United States Army Corps of Engineers Engineer Research and Development Center (USACE ERDC). Retrieved from: https://apps.dtic.mil/sti/pdfs/ADA621343.pdf

Colorado Department of Transportation (CDOT). (2020). *Risk and Resilience Analysis Procedure – a manual for calculating risk to CDOT assets from flooding, rockfall, and fire debris flow.* Denver, CO: CDOT. Retrieved from: https://www.codot.gov/programs/planning/assets/cdot-rnr-analysis-procedure-8-4-2020-v6.pd

de Moel, H., & Aerts, J. C. J. H. (2011). Effect of uncertainty in land use, damage models and inundation depth on flood damage estimates. *Natural Hazards, 58*(1), 407–425. https://doi.org/10.1007/s11069-010-9675-6

Federal Highway Administration (FHWA). (2005, March). FHWA tunnel leak assessment (Boston Central Artery Interim Report).

Habermann, N., & Hedel, R. (2018). Damage functions for transport infrastructure. International *Journal of Disaster Resilience in the Built Environment, 9*(4/5), 420–434. https://doi.org/10.1108/IJDRBE-09-2017-0052

Martello, M. V. & Whittle, A. J. (2023). Estimating coastal flood damage costs to transit infrastructure under future sea level rise. *Communications Earth & Environment.* https://doi.org/10.1038/s43247-023-00804-7

Martello, M. V., Whittle, A. J., & Lyons-Galante, H.R. (2023). Depth-Damage Curves for Rail Rapid Transit Infrastructure. *Journal of Flood Risk Management.* https://doi.org/10.1111/jfr3.12856

Nadal-Caraballo, N.C. & Melby, J.A. (2014). *North Atlantic Coast Comprehensive Study Phase 1: Statistical Analysis of Historical Extreme Water Levels with Sea Level Change* (Report No. ERDC/CHL TR-14-7). United States Army Corps of Engineers Engineer Research and Development Center (USACE ERDC). Retrieved from: https://apps.dtic.mil/sti/pdfs/ADA611642.pdf

Nazarchuk, A. (2008). Water intrusion in underground structures (MEng thesis). Department of Civil & Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA. http://hdl.handle.net/1721.1/43880

Vanneuville, W., De Maeyer, P., Maeghe, K., & Mostaert, F. (2003). Model the effects of a flood in the Dender catchment, based on a risk methodology. *Bulletin of the Society of Cartography, 37*(2), 59–64.

Gerl, T., Kreibich, H., Franco, G., Marechal, D., & Schröter, K. (2016). A review of flood loss models as basis for harmonization and benchmarking. *PLoS One, 11*(7), e0159791. https://doi.org/10.1371/journal.pone.0159791

United States Army Corps of Engineers (USACE) Coastal Hydraulics Laboratory (USACE CHL). (202). *Coastal Hazards System, V2.0*. USACE. Retrieved from: https://chs.erdc.dren.mil/

USACE. 2021. USACE Generation II Coastal Risk Model (G2CRM) User's Manual v4.556.3.

USACE. 2011. Coastal Storm Risk Management National Economic Development Manual. IWR Report 2011-R-09.