Fairfield and New Haven Counties, CT Coastal Storm Risk Management Feasibility Study

APPENDIX B: ECONOMICS

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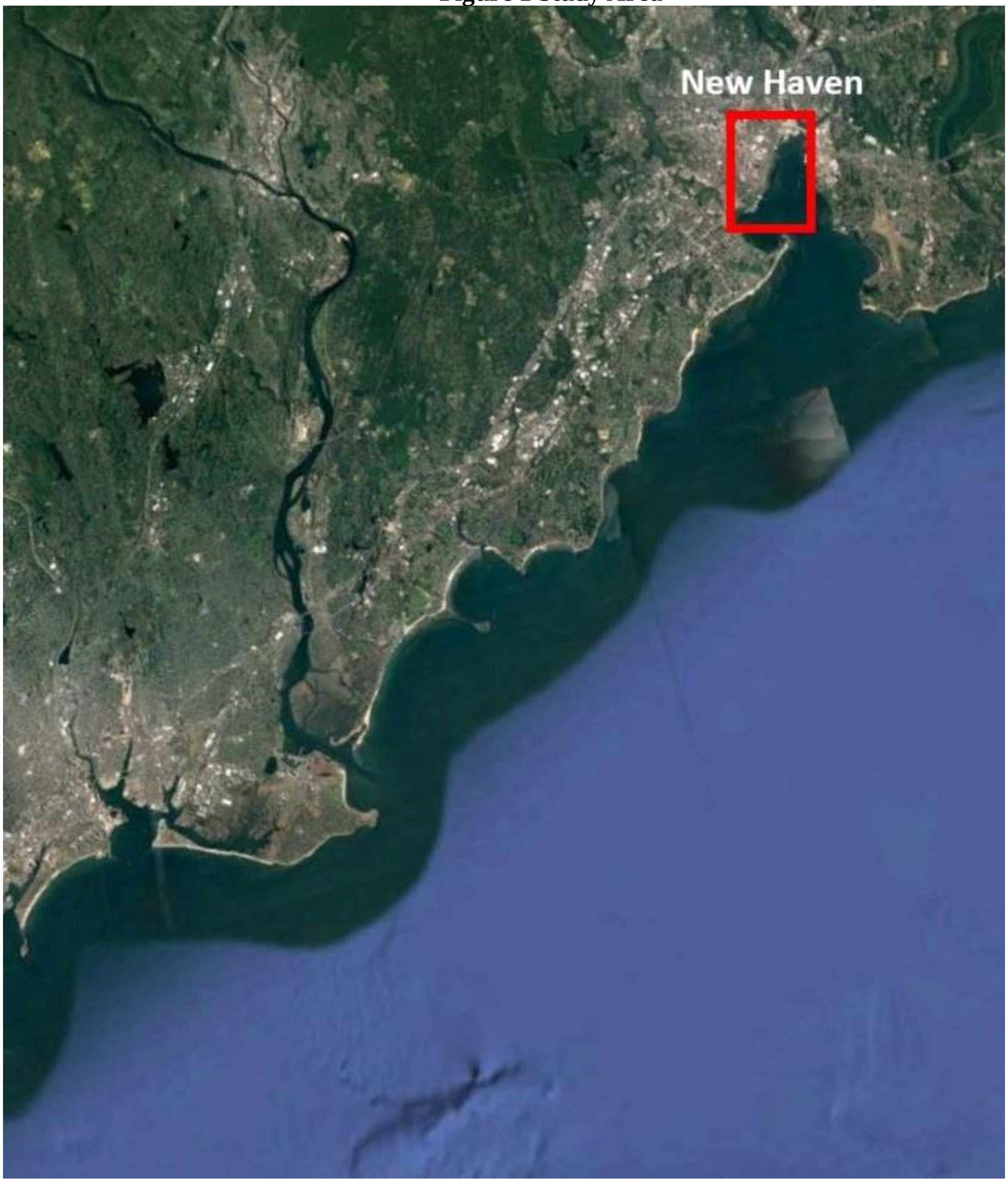
1.0 INTRODUCTION

The purpose of this appendix is to evaluate the economic feasibility of providing coastal storm damage risk reduction along part of the New Haven, Connecticut coast. This appendix will provide details for major decision points along the study timeline beginning with defining the original study areas through the Agency Decision Milestone and the selection of the National Economic Development (NED) alternative. The NED plan is the plan that reasonably maximizes net economic benefits consistent with protecting the Nation's environment. The analysis includes an evaluation of existing coastal storm damages, evaluation of alternatives, and calculation of coastal storm damage reduction benefits. Structural and non-structural plans were screened for cost-effectiveness based on with and without-project damages and calculation of benefit-cost ratios. The economic analysis is consistent with Federal water resources policies and practices, including Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G, 1983) and the Corps Planning Guidance Notebook (ER-1105-2-100, 22 April 2000, as amended). The economic analysis for the Recommended Plan is based on October 2020 dollars (FY21 study completion and approval) and the FY20 Federal Discount Rate of 2.75 percent. (Note: The discount rate will be updated to the FY21 discount rate when published in October 2020.)

2.0 DESCRIPTION OF STUDY AREA

The study area, shown in Figure 1 below, is located along the coastline of southern Connecticut in New Haven, extending approximately 1.5 miles along Long Island Sound. The study area was identified based on elevation data, structure density, and discussions with city and state officials regarding high damage-prone areas and history of coastal storm damages. The Long Wharf, New Haven area is a socio-economic center of southern Connecticut comprised largely of industrial and commercial users. A key component of choosing the study area was the lack of existing coastal protection and USACE's ability to construct projects to alleviate coastal storm damage risk while contributing to the NED objective.

Figure 1 Study Area



The study area is further divided into individual damage areas, or reaches, based on geographic, hydrological, and economic considerations. The use of damage reaches throughout the study enables the project delivery team to better formulate alternatives. The reaches for New Haven are given in Figure 2 below.

Figure 2 New Haven Damage Reaches

3.0 SOCIOECONOMIC SETTING

3.1 Population and Housing

Table 1 displays the 2000 and 2010 populations and the projected change in population from 2015 to 2025. New Haven's population growth rate is projected to exceed Connecticut as a whole. The median housing value is less than $200,000 in New Haven. We assume no structure growth in the area because already heavily developed and recent population estimates suggest growth rates will be slow to non-existent.

Table 1: Population and Housing

	New Haven	CT
Population (2000 Census)	123,626	3,405,565
Population (2010 Census)	129,779	3,574,097
Population percent change 2000-2010	5.0%	4.9%
Estimated % change in population 2015-2025 (2012 Connecticut State Data Center)	7.1%	2.8%
Median housing value (2015 ACS)	191,800	270,500
Percent of housing for seasonal, recreational, or occasional use (2010 Census)	4.2	25.4

3.2 Age and race

New Haven's demographics skew significantly younger than Connecticut as a whole. New Haven is majority non-white and far less homogenous than the rest of the state.

Table 2 Age and Race

	New Haven	CT
Median age (2016 ACS)	30.7	40.6
Percent 65 and older (2016 ACS)	10.5%	15.5%
Percent white, non-latino (2016 ACS)	30.8	68.7

3.3 Income and Employment

Table 3 shows the median household income levels, poverty rates and unemployment rates as of 2015. Median income stands at $37,000 in New Haven, which is well below the state average. Compared to the rest of Connecticut, New Haven is relatively impoverished with more than a quarter of the population living below the poverty line.

Table 3 Income and Employment

	New Haven	CT
Median household income (2015 ACS)	$37,192	$99,992
Percent with below poverty income in last 12 months (2015 ACS)	26.6%	10.50%
Unemployment rate (2015 ACS)	12.7%	8.8%

The largest industries in New Haven-Milford, CT Metro Area are Healthcare & Social Assistance, Educational Services, and Retail trade. Residents are primarily employed in the education, healthcare, and professional services fields. (Table 4).

Table 4 Occupation Data

	New Haven	Connecticut
Civilian employed population 16 years and over	59,236	1,793,688
Agriculture, forestry, fishing and hunting, and mining	183	7,209
Construction	1,974	101,497
Manufacturing	4,717	190,713
Wholesale trade	1,150	45,110
Retail trade	5,410	193,853
Transportation and warehousing, and utilities	2,060	66,516
Information	1,075	42,374
Finance and insurance, and real estate and rental and leasing	2,230	163,765
Professional, scientific, and management, and administrative services	5,361	206,042
Educational services, and health care and social assistance	24,704	474,976
Arts, entertainment, and recreation, and accommodation and food services	6,253	153,754
Other services, except public administration	2,479	81,588
Public administration	1,640	66,291

4.0 FLOOD HISTORY

A list of Connecticut's storm events and amounts awarded in Public Assistance Grants since 1990, including nor'easters and other coastal storms, is shown Table 5 below. Hurricanes, tropical storms and nor'easters produce heavy winds and precipitation and storm surges which cause flooding, beach erosion and structural damage.

Table 5 Major Storm History for the State of Connecticut

Disaster and Emergency Declaration (Disaster Number)	Declaration Type	Date	Total Public Assistance Grants Dollars Obligated
Connecticut Hurricane Bob (DR-916)	Major Disaster Declaration	8/29/1991	not available
Connecticut Coastal Flooding, Winter Storm (DR-972)	Major Disaster Declaration	12/16/1992	not available
Connecticut Severe Winds and Blizzard, Record Snowfall (EM-3098)	Emergency Declaration	3/15/1993	not available
Connecticut Blizzard (DR-1092)	Major Disaster Declaration	1/23/1996	not available
Connecticut Tropical Storm Floyd (DR-1302)	Major Disaster Declaration	9/22/1999	$1,875,868.51
Connecticut Snowstorm (EM-3176)	Emergency Declaration	3/10/2003	$8,932,169.87
Connecticut Snow (EM-3192)	Emergency Declaration	1/14/2004	$9,529,091.70
Connecticut Snow (EM-3200)	Emergency Declaration	2/16/2005	$12,467,305.96
Connecticut Hurricane Katrina Evacuation (EM-3246)	Emergency Declaration	9/12/2005	$668,487.86
Connecticut Severe Storms and Flooding (DR-1619)	Major Disaster Declaration	12/15/2005	$3,698,478.50
Connecticut Snow (EM-3266)	Emergency Declaration	5/1/2006	$9,911,219.22
Connecticut Severe Storms and Flooding (DR-1700)	Major Disaster Declaration	5/10/2007	$4,843,030.23
Connecticut Severe Storms and Flooding (DR-1904)	Major Disaster Declaration	4/22/2010	$9,441,670.90
Connecticut Snowstorm (DR-1958)	Major Disaster Declaration	3/2/2011	$13,744,523.80
Connecticut Hurricane Irene (EM-3331)	Emergency Declaration	8/26/2011	not available
Connecticut Tropical Storm Irene (DR-4023)	Major Disaster Declaration	9/1/2011	$43,035,875.60
Connecticut Severe Storm (EM-3342)	Emergency Declaration	10/30/2011	not available
Connecticut Severe Storm (DR-4046)	Major Disaster Declaration	11/16/2011	$87,384,912.85
Connecticut Hurricane Sandy (EM-3353)	Emergency Declaration	10/27/2012	not available
Connecticut Hurricane Sandy (DR-4087)	Major Disaster Declaration	10/29/2012	$64,446,199.77
Connecticut Severe Winter Storm (EM-3361)	Emergency Declaration	2/9/2013	not available
Connecticut Severe Winter Storm and Snowstorm (DR-4106)	Major Disaster Declaration	3/20/2013	$31,772,536.00
Connecticut Severe Winter Storm and Snowstorm (DR-4213)	Major Disaster Declaration	4/7/2015	$9,603,757.08

From: https://www.fema.gov/disasters

4.1 Major Recent Flooding Events

Connecticut's Natural Hazard Mitigation Plan Update describes the three most recent major flooding events: Winter Storm Nemo in 2013, Hurricane Sandy in 2012, and Hurricane Irene in 2011.

Winter Storm Nemo (DR-4106/EM-3361) left approximately three feet of snow across Connecticut. Storm surges caused beach erosion and flooding along the coast. Roads were closed throughout the state, and tens of thousands lost power.

Hurricane Sandy (DR-4087/EM-3353) created storm surges that resulted in $360 million in damages to coastal residents and business owners (https://www.ctpost.com/news/article/Sandy-storm-damage-tops-360M-in-state-4037538.php). More than 360,000 people were evacuated, roads were closed, commuter rail and Amtrak service was canceled, and at least three deaths were reported in coastal towns.

Tropical Storm Irene (DR-4023/EM-3331) was particularly devastating to Connecticut's coastal towns, as a storm surge occurred during high tide. The storm resulted in $235 million in damages, left more than 800,000 without power, and resulted in two storm-related deaths.

(https://www.nbcconnecticut.com/weather/stories/All-Eyes-on-Irene-128351438.html; http://www.nydailynews.com/new-york/hurricane-irene-year-storm-cost-15-8-damage-florida-new-york-caribbean-article-1.1145302).

4.2 Flood Claims

From 1978 to 2017 over $500 million in National Flood Insurance Claims were issued in the State of Connecticut; 49% of these funds were issued in Fairfield County and 33% in New Haven (https://www.fema.gov/policy-claim-statistics-flood-insurance). Table 5 (above) shows the amount of public assistance grants distributed in Connecticut's federal disaster and emergency declarations. In addition to public assistance, FEMA also provided assistance on an individual basis through its Individual and Households Program (IHP). FEMA's National Emergency Management Information System (NEMIS) reports total IHP funds granted to individuals for flood-loss damages for all declared major disasters for the years 2006-2016. Two severe storms, in 2007 and 2010, resulted in over $6.5 million funds issued to Connecticut's residents for home and personal property repair and replacement due to flood damage. Hurricanes Irene (2011) and Sandy (2012) each resulted in more than $5 million (total $10.7 million) in funding to property owners for flood-related damages.

5.0 SCOPE OF THE STUDY

The study area, which is characterized by low, flat terrain, is highly susceptible to flooding from the tidal surges associated with hurricanes, tropical storms, and nor'easters. Increases in relative sea level rise is expected to, in turn, increase the potential for future coastal flooding. Because the Connecticut Coast is highly developed and densely populated, this area is subject to significant risk of damages from coastal flooding, including destruction of buildings and damages to roads and utilities.

The Feasibility Study plan formulation considered a range of structural and nonstructural measures ("alternatives") to reduce the risk of storm damage in the study areas. Coastal storm risk management measures were developed to address problems and to capitalize upon opportunities described in the main report. They were derived from a variety of sources including prior studies, the public scoping process, and the Project Delivery Team (PDT).

Through an iterative planning process, potential coastal storm risk management measures were identified, evaluated, and compared. Net benefits and benefit-to-cost ratios (BCR) were reviewed to determine the viability of each alternative based on an economic justification.

5.1 New Haven Alternatives

The suite of alternatives developed for the New Haven focus area consists of the plans outlined in Table 6 below. Combinations of non-structural and structural measures were considered for each alternative.

Alternative 2: Non-Structural Floodproofing

The Nonstructural alternative for the Long Wharf focused study area consists of providing non-structural storm risk management benefits through a combination of elevating or floodproofing eligible structures within the study area. 138 structures were initially found to be eligible for potential floodproofing or elevation of the first floor. The majority of these structures are large commercial properties. There are 12 residential structures within the study area that are potential candidates for elevating the first floor. There are 126 commercial structures within the study area that are potential candidates for either wet or dry floodproofing. Most of the buildings are large commercial buildings that would be extremely difficult, if not impossible to properly floodproof. This option would not reduce the risk of coastal storm damage to the rail and highway infrastructure.

Alternative 3A: Existing I-95 Embankment

This alternative uses deployable closure structures under I-95 to reduce the flood event frequency. Deployable closure structures would be used to prevent floodwaters from passing through where Long Wharf Drive, Canal Dock Road pass under I-95 and where Brewery Street passes under the Oak Street Connector. For costing purposes a post and panel type system was assumed, however a more detailed analysis will be required during the design phase of the project. These systems would need to be stored near the openings and installed by a work crew prior to a storm event. The structure to close Long Wharf Drive would be roughly 60 foot wide and 3-4 foot high. Canal Dock Road would require a roughly 190 foot wide structure 4-5 foot high and Brewery Street would be approximately 65 feet wide and 1-2 foot high. Foundations for the system will require significant coordination with the existing utilities in the streets as well as coordination with Connecticut DOT to tie the structures effectively into the I-95 walls or embankment. This option would provide protection only up to a flood elevation of approximately elevation 10.5' NAVD88 after which water would start flooding across I-95 near where the Long Wharf drive crosses under I-95. Pumps will be required to move any stormwater out of the protected area.

Alternative 3A would rely heavily on the existing I-95 embankment to perform as a flood control structure during a coastal storm event. The existing embankment was not designed to perform in such a manner as communicated by the Federal Highways and the Connecticut Department of Transportation. Additionally, the use of lightweight fills in the construction of the embankment (along with questionable side slope stability) casts uncertainty on the non-Federal acceptability of this alternative.

Further analysis of Alternative 3A following release of the draft report in December 2019 revealed that this alternative fails to meet study objectives and avoid study constraints (effectiveness criteria). The alternative also fails to meet the efficiency and acceptability criteria as detailed in Table 9 of the main report. A risk-informed decision was made to not carry Alternative 3A forward as a viable option and an economic benefit/cost analysis was not conducted on this alternative.

Alternative 3B: Enhanced I-95 Embankment

Alternative 3B consists of five road closure structures (one at Long Wharf Drive approximately 60 feet wide by 8 feet high; one at Canal Dock Road approximately 190 feet wide by 7 feet high; one at Brewery Street approximately 65 feet wide by 3 feet high; two at Exit 46, (approximately 160 feet wide and 5 feet high); one pumping station which would handle approximately 900 cubic feet of water per second (cfs); and enhancement of the I-95 embankment with approximately 5,800 linear feet of "T-wall" type floodwall along with 475 feet of deployable closure structures. The proposed floodwall would be built to a height +15 feet NAVD88. This elevation was selected considering future annual exceedance probability water levels under the low, intermediate and high sea level change scenarios. By the end of the project's 50 year period of economic analysis in 2074, the floodwall will have a 0.8-percent annual exceedance probability (AEP) under the low sea level change scenario, a 1.2-percent annual exceedance probability under the intermediate sea level change scenario and a 3.5-percent annual exceedance probability under the high sea level change scenario. These levels of residual risk are considered to be low and tolerable. Project performance, as represented by Annual Exceedance Probability and Long-Term Exceedance Probability at the 90 percent level of assurance, consistent with ER 1105-2-101, is presented for all alternatives in Table 7-1 of Appendix C, Coastal Engineering. Performance of the recommended plan is further discussed in Section 8 of the Coastal Engineering Appendix over the project's 50 year period of economic analysis and 100 year adaptation horizon relative to the three sea level change scenarios. Please refer to the Coastal Engineering Appendix for further information on AEP and sea level change.

<u>Alternative 4A: Shoreline Floodwall</u>

This alternative uses an approximate 6,700 foot long pile supported floodwall along Long Wharf Drive (rather than along I-95). Due to the low elevations in the area, the floodwall would be as high as 9 feet above existing grade and would reduce the risk of coastal storm damage to the commercial and transportation facilities extending to the same endpoints as Alternative 3B. At least 4 deployable structures would be required, one at Brewery Street (described in option 3A), one crossing Long Wharf Drive roughly 65 feet wide and 7 feet high, one at the Canal Dock Boathouse Access approximately 35 feet long and 9 feet high and one at the Long Wharf Park parking area which would be roughly 50 foot wide and 5 feet high. Additional access doors and/or structures would be needed to make the Long Wharf Park access convenient to pedestrians and other users. This alternative would restrict access and views of Long Wharf Park and would require some tree removal. Pumps will be required to move any stormwater out of the protected area as described in alternatives 3A and 3B.

This Alternative would protect the commercial and railroad areas behind I-95 from storms and waves up to approximately elevation 15' NAVD88. By the end of the fifty year period of analysis (2074), this alternative would potentially be exceeded by the 0.4-percent annual exceedance probability water level, considering the intermediate sea level change scenario. The Long Wharf Maritime Center and other structures on the seaward side of I-95 were analyzed during the study to determine if they may be eligible for floodproofing. Due to first floor elevations and building contents, the study team determined it would not be economically feasible to floodproof these structures under this study authority.

<u>Alternative 4B: Extended Shoreline Floodwall</u>

This alternative consists of all the structures in alternative 4A except the Long Wharf Drive closure structure and extends the wall around the Long Wharf Maritime Center extending the floodwall approximately 3,000 feet. Due to the low elevations in the area, the floodwall would be as high as 13 feet above existing grade. Part of this alignment would be along an existing seawall alignment and would pose difficult construction and design issues due to the available space to work around the existing wall.

In addition to the deployable closure structures in 4A, closure structures would be needed at the entrance to the Tank Farm, (55 foot long 9 foot high), crossing East Street (90 feet long, 5 foot high) and crossing Water Street at the intersection with East Street (90 feet wide, 5 foot high). At least one additional pump would be needed in the Long Wharf Maritime Center to handle stormwater behind the floodwalls. This additional pump station would require a pumping capacity of approximately 100 cfs.

This Alternative would protect the commercial and railroad areas behind I-95 from storms and waves up to approximately elevation 15 feet (NAVD88).

Table 6 New Haven Alternatives

Alternative	Description	Reaches Protected Structural Solution	Reaches Protected Nonstructural Solution
Alternative 2	Nonstructural	none	all
Alternative 3B	Enhanced Embankment	2, 3, 5	1, 4
Alternative 4A	Shoreline Floodwall	2, 3, 5	1, 4
Alternative 4B	Extended Shoreline Floodwall	2, 3, 4, 5	1

6.0 ECONOMIC ANALYSIS METHODS

6.1 HEC-FDA

The USACE flood damage analysis tool, Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) Version 1.4.2, was used to model all existing and future (2074) inundation damages in with- and without-project scenarios. Alternatives were evaluated based on the 2020 Federal Discount Rate of 2.75 percent and a period of analysis of 50 years. Damages under future with- and without-project conditions were estimated based on the frequency and extent of flooding damages experienced in each structure.

HEC-FDA requires the following inputs to calculate flood damages to structures: flood depth, depth/damage relationships, structure values, content value percentages, first floor elevations, and flood stage-probabilities.

6.2 INPUTS TO THE HEC-FDA MODEL

6.2.1 Structure Inventory

The structure inventory was compiled using geospatial data available from the state of Connecticut. All processing was done with ArcGIS 10.3 using NAD_1983_StatePlane_Connecticut_FIPS_0600_Feet as the horizontal projection and NAVD88 feet as the vertical datum. Structure attribute data including depreciated replacement cost, structure style, and number of stories are available through Vision Government Solutions' Computer Assisted Mass Appraisal (CAMA) system. This system provides costs per square foot for varying types and grades of construction and then allows the assessor to make decisions for each property as to what type and quality a structure is, and how much depreciation the structure has. As an example if the assessor deems a house to be of "Custom" design and very good quality, but appears to have depreciated approximately ten years, CAMA system applies the cost per square foot for a Custom style home, then subtracts a percentage for depreciation. This method of structure valuation has been approved for former studies in the New England area. Analysis of new construction is done to establish construction costs, including builder's profit, while older homes were used to establish the amount of depreciation indicated by the current market.

The inventoried structures were classified as one of 12 structure types that were assigned based upon the categories of depth-damage functions used in the North Atlantic Coastal Comprehensive Study (NACCS). Table 7 lists the 12 structure types. Table 8 shows the average and total structure value for those structures included in each of the study areas.

Table 7 NACCS structure types included in the study

NACCS Prototype Code	Style Description
NACCS 1A-1	Apartments, 1 Story, No Basement
NACCS 1A-3	Apartments, 3 Stories, No Basement
NACCS 2 NP	Commercial, Engineered, Nonperishable
NACCS 2 P	Commercial, Engineered, Perishable
NACCS 3 NP	Commercial, Non- or Pre-Engineered, Nonperishable
NACCS 4A	Urban High Rise
NACCS 4B	Beach High Rise
NACCS 5A	Single-Story Residence, No Basement
NACCS 5B	Two-Story Residence, No Basement
NACCS 6A	Single-Story Residence, with Basement
NACCS 6B	Two-Story Residence, with Basement
NACCS 7A	Building on Open Pile Foundation
NACCS 7B	Building on Pile Foundation with Enclosure

Table 8 Mean structure value (2020 Price Level)

		New Haven
Asset Inventory Value	$	782,788,000
Mean Structure Value	$	2,093,000
Residential		247
Commercial		122
Apartment		5
Total Structures		374

No future growth or development in the study area was projected for this analysis, therefore structure inventory and values were the same for the existing (2024) and future (2074) year scenarios. The HEC-FDA model does not adjust structure values over the modeling period. Much of the coastal floodplain in the study area is already developed, and there are limited opportunities for new expansion. There are a few vacant parcels spread throughout the study reach, most of which are behind the barrier beaches and strictly regulated in terms of development and the ability to withstand coastal storms.

6.2.2 Residential and Non-Residential Content-to-Structure Value Ratios

The content value used for residential structures was 43.5% of structure value (as per EM 1110-2-1619, 1 Aug 1996 Table 6-4). Content to structure value ratios for commercial structures follows the URS Group's April, 2009 draft report to USACE, "Expert Opinion Elicitation for the Development of Nonresidential Depth-Damage Functions". This is the most up-to-date, comprehensive analysis of content to structure ratios, and provides the most conservative content to structure value ratio estimates compared with other documents and guidance. Table 9 duplicates Table 5-2 of URS Group's report, which lists the most likely content to structure value ratio by structure type. These were the content to structure values used for commercial structures in the study.

Table 9 Most Likely Value CSVR by Structure Type

Prototype	Content Value ($/sq ft)	Pre-Engineered ($/sq ft)	Pre-Engineered CSVR	Engineered ($/sq ft)	Engineered CSVR
Retail-Furniture	$14.00	$80.00	18%	$100.00	14%
Retail-Electronics	$65.00	$80.00	81%	$100.00	65%
Retail-Clothing	$29.00	$80.00	36%	$100.00	29%
Hotel	$15.00	$80.00	19%	$100.00	15%
Fast Food	$24.00	$140.00	17%	$160.00	15%
Non-Fast Food	$40.00	$155.00	26%	$175.00	23%
Hospital	$70.00	$230.00	30%	$250.00	28%
Medical Office	$21.00	$136.70	15%	$156.70	13%
Protective Services	$66.00	$75.00	88%	$95.00	69%
Correctional Facility	$57.50	$215.00	27%	$235.00	24%
Recreation	$28.30	$95.00	30%	$115.00	25%
Religious Facilities	$9.63	$120.00	8%	$140.00	7%
Schools	$11.00	$150.00	7%	$170.00	6%
Service Station	$66.00	$80.00	83%	$100.00	66%
Office One-Story	$18.50	$136.70	14%	$156.70	12%
Convenience Store	$65.00	$105.00	62%	$125.00	52%
Grocery	$85.00	$80.00	106%	$100.00	85%
Apartment	$10.90	$90.00	12%	$110.00	10%
Industrial Light	$40.10	$85.00	47%	$105.00	38%
Warehouse, Refrig	$42.70	$100.00	43%	$120.00	36%
Warehouse, Non-Refrig	$37.44	$80.00	47%	$100.00	37%

Source: URS Most Likely Value CSVR by Structure Type

6.2.3 First Floor Elevations

Using shapefiles with parcel polygons from each of the town tax assessors' offices, a layer was created with points linking parcels to specific structures based on property id numbers. The points were geolocated to the specific structure location using an aerial-view base map. Each of the structure location points were intersected with a Digital Elevation Model (LiDAR) to determine the ground elevation (in feet NAVD88) of the structure. After determining structures' ground elevation, street view imagery of the structures (through photos provided by the tax assessor and/or Google maps street view) was used to determine the height of each structure's first floor elevation and lowest opening relation to the ground.

6.2.4 Depth-Damage Relationships.

Depth-damage relationships developed for the North Atlantic Coastal Comprehensive study were used for all structures in the inventory. These depth-damage functions estimate the likely degree of damage to structure and contents at each elevation of flooding relative to the first floor, expressed as a percentage of structure and content value, based on actual damages experienced during Hurricane Sandy in the northeast.

6.2.5 Flood Stage-Probabilities

Stage-probability relationships were provided for the existing without-project condition and future without-project conditions (2074). Water surface profiles were provided for eight annual chance exceedance (ACE) events: 50% (2-year), 20% (5-year), 10% (10-year), 4% (25-year), 2% (50-year), 1% (100-year), 0.5% (200-year), and 0.2% (500-year). Water surface profiles were based on historic and modeled storm surge and rainfall events. See Appendix C – Coastal Engineering for more information.

To account for sea level rise (SLR), the mean sea level trend at Bridgeport, CT was selected to represent the project site because it was the closest long term gauge to the project location. An increase of 0.93 feet, based on the intermediate rate of SLR determined by the project coastal engineer, was added to the stage-probability estimates for 2074 future conditions. Water surface elevations used in the HEC-FDA model for both the existing conditions and future conditions with SLR are presented in Tables 10 and 11 below.

Table 10 New Haven Water Surface Profiles, 2024 (in feet NAVD88)

Station	Chance Exceedance Event							
	50.0%	20.0%	10.0%	4.0%	2.0%	1.0%	0.4%	0.2%
10	6.62	7.82	8.69	9.56	10.82	12.01	13.46	15.46
20	0.001	0.01	8.69	9.56	10.82	12.01	13.46	15.46
30	0.001	0.01	8.69	9.56	10.82	12.01	13.46	15.46
40	6.62	7.82	8.69	9.56	10.82	12.01	13.46	15.46
50	0.001	0.01	8.69	9.56	10.82	12.01	13.46	15.46

Table 11 New Haven Water Surface Profiles, 2074 (in feet NAVD88)

Station	Chance Exceedance Event							
	50.0%	20.0%	10.0%	4.0%	2.0%	1.0%	0.4%	0.2%
10	7.55	8.75	9.62	10.49	11.75	12.94	14.39	16.39
20	0.001	0.01	9.62	10.49	11.75	12.94	14.39	16.39
30	0.001	0.01	9.62	10.49	11.75	12.94	14.39	16.39
40	7.55	8.75	9.62	10.49	11.75	12.94	14.39	16.39
50	0.001	0.01	9.62	10.49	11.75	12.94	14.39	16.39

6.3 UNCERTAINTY SURROUNDING THE INPUTS

Uncertainty factors are included in depth/damage relationships, structure values, content value percentages, first floor elevations and flood stage-probabilities. Uncertainty surrounding these variables was quantified and entered into the HEC-FDA model in order to estimate the uncertainty surrounding the stage-damage relationships developed for each study area reach.

Uncertainty in depreciated replacement value is incorporated in the model by assuming depreciated structure values fall under a normal distribution with a 20% standard deviation. Twenty percent was used because the difference in depreciated value is approximately 20% if a structure identified to be in average condition is actually in fair condition as per Marshall and Swift. Likewise the difference in depreciated value is approximately 20% if a structure identified to be in average condition is actually in good condition. (source: Santa Paula Creek Flood Control Project, General Reevaluation Report 1995)

Uncertainty in content to structure value ratio is incorporated in the model by assuming content to structure value ratios fall under a normal distribution with a 25.3% standard deviation, as per recommended guidance EM 110-2-1619.

Uncertainty in first-floor elevation is incorporated in the model by assuming first-floor elevations fall under a normal distribution with a 1.75 ft standard deviation. Uncertainty in first-floor elevation arises from several sources; these sources of uncertainty are discussed in turn.

1) While the use of high resolution ground-based light detection and ranging (LiDAR) datasets greatly improve the precision of Digital Surface Models (DSMs), these data still imperfectly identify distinct objects and spaces. This is especially the case in densely populated and urban areas, which constitute much of the study area. A study by Bodoque and colleagues (2016) finds an average difference of 0.54 m ± 0.32 (1.77 ft ± 1.05) between LiDAR and actual elevation values.

   https://pdfs.semanticscholar.org/1986/a1baaf10cf7b5d4810d97b65fd9ff7983dd7.pdf

2) The location where elevations were estimated is subject to measurement error. It is unlikely that each point where elevation was calculated is the precise point of entry in a given structure. To capture this source of uncertainty, we calculated the standard deviation of the difference in the elevation captured at a polygon's centroid versus the structure location (1.36 ft)

3) In general, the first floor elevation was calculated using the number of steps to the lowest first floor entry. A conservative estimate of 8 inches per step, or 3 steps=2 feet was used based on Connecticut building code standards which state that the maximum riser height will be 8 and ¼ inches (https://www.cga.ct.gov/2013/rrdata/pr/2013REG2013-038A-RC.PDF). In cases where the pre-existing stairs are 9 inches, often the case in older buildings, the building code allows for risers up to 9 inches. Newer buildings, on the other hand, tend to have lower stair rises of 7 inches. Because stair risers may be one inch above or below the 8 inches calculated for each step to determine first floor elevation, first floor elevation is allowed to vary by 1/8 = 12.5%. The average first floor elevation from ground is 2.7 feet 12.5% of that is 0.34 feet.

To obtain one value representing the combined uncertainty in first floor elevation, the square root of the sum of squares of each of these three uncertainty measures is estimated:

$$Uncertainty_{FFE} = \sqrt{1.05^2 + 1.36^2 + 0.34^2} = 1.75 \text{ ft}$$

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Uncertainty in depth-damage curves – A triangular probability density function was used to determine the uncertainty surrounding the damage percentage associated with each depth of flooding. Each individual depth-damage curve has its own unique maximum, minimum and most likely depth-damage percentages, taken directly from the depth-damage functions derived in the NACCS. The specific range of values regarding probability distributions for the depth-damage curves can be found in the final NACCS report.

Uncertainty in flood-stage probabilities – A 50-year equivalent record length was used to quantify the uncertainty surrounding the stage-probability relationships for each study area reach. Based on this equivalent record length, the HEC-FDA model calculated the confidence limits surrounding the stage-probability functions.

6.4 HEC-FDA MODEL CALCULATIONS

The HEC-FDA model was utilized to evaluate flood damages using risk-based analysis. Using the aforementioned data inputs and their respective uncertainty estimates, the HEC-FDA model performs Monte Carlo simulation to estimate stage-damage and stage probability relationships. The Monte Carlo simulation randomly selects values of the input variables from within the established distributions over a defined number of iterations (here we use 1000 iterations). With each iteration, a different value for each input is independently selected and thus each iteration has unique stage-damage and stage probability relationships. The damage estimates from each iteration are summed and then divided by the number of iterations to determine the expected value and standard probability distribution of the with and without project expected annual damages and equivalent annual damages in the current and future scenarios.

6.4.1 HEC-FDA Calculation Procedures

Procedurally, with-project damages for structural alternatives were computed by using HEC-FDA's levee feature. The levee feature in HEC-FDA was used to enter NAVD88 elevation for top of protection of each levee for reaches protected by a structural solution. Damages for the non-structural alternative were computed by changing the height of the first floor elevation in the structure inventory.

7.0 NATIONAL ECONOMIC DEVELOPMENT (NED) FLOOD DAMAGE AND BENEFIT CALCULATIONS

7.1 WITHOUT PROJECT CONDITIONS

In the absence of a Federal project, coastal Connecticut is subject to significant risk of coastal storm damages including destruction of buildings, erosion, flooding, and loss of structures, as well as damages to roads and utilities. Table 12 shows the number of structures predicted to be damaged by each annual chance exceedance event for the years 2024 and 2074 using the intermediate sea level rise scenario.

Table 12 Number of structures and damage by Annual Exceedance Probability

Base Year	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Structures Affected	1	1	10	18	34	57	97	123
Total Damage (000s)	$28	$118	$22,008	$62,920	$129,853	$180,181	$228,306	$297,570
Future	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Structures Affected	1	11	18	29	50	78	108	132
Total Damage (000s)	$106	$24,347	$65,390	$113,062	$170,943	$212,275	$260,760	$321,045

For the without-project alternative, the expected annual damages (EAD) were calculated in HEC-FDA for each study area reach to obtain the total without-project EAD under existing (2024) and future (2074) conditions. Table 13 shows the Expected Annual Damages in 2024 and 2074 and the percentage increase between the two. The HEC-FDA model was used to calculate the without project average annual equivalent damages of $15.19M using the FY 2020 interest rate of 2.75 percent; the results are also displayed in Table 13 below. The future without project condition serves as the base condition to use as a comparison for all other alternatives. The FY 2020 Federal discount rate was used to screen alternatives.

Table 13 Without-Project (WOP) Damage

	Expected Annual Damage		% increase	Equivalent Annual
	Existing	Future		Damage
New Haven	$10,990,000	$22,043,000	101%	$15,194,000

Table 14 below presents equivalent annual damages by reach. Damage is concentrated in Reach 5, which encompasses a large area of the city's downtown commercial center. Reach 4 incurs no damage due to higher elevation of the structures.

Table 14 WOP Damage by Reach

New Haven	
Reach	**Equivalent Annual Damage**
1	$ 580,000
2	$ 54,000
3	$ 269,000
4	$ -
5	$ 14,290,000

7.2 WITH PROJECT CONDITIONS

7.2.1 Structural Alternatives

The future with-project conditions would result in significant reductions of annual damage. Alternative 3B – Enhanced Embankment would reduce average annual damage by 94 percent, resulting in an annual benefit of $14.2 million. Because Reach 4 incurs no damage in the model due to the elevation of structures in that area, there is no incremental benefit to extending the embankment to protect Reach 4.

Tables 15 and 16 below present summaries of project benefits by Alternative and by Reach.

Table 15 Summary of Benefits

Alternative	Description	Without Project Annual Damages	With Projects Annual Damages	Annual Benefits
Alternative 3B	Enhanced Embankment	$15,194,000	$980,280	$14,213,000
Alternative 4A	Shoreline Floodwall	$15,774,000	$1,561,000	$14,213,000
Alternative 4B	Extended Shoreline Floodwall	$15,774,000	$1,561,000	$14,213,000

Table 16 Commercial and Residential Damages & Benefits by Reach for Recommended Plan

Annual Damages				
Plan Name	Reach	Commercial Structures	Residential Structures	TOTAL
Without Project	Reach 1	$ 550,710	$ 29,730	$ 580,440
	Reach 2	47,470	6,260	53,730
	Reach 3	240,590	28,100	268,690
	Reach 4	-	-	-
	Reach 5	13,679,970	610,750	14,290,720
		$ 14,518,740	$ 674,840	$ 15,193,580
With-Project Enhanced Embankment	Reach 1	$ 69,820	$ 7,550	$ 77,370
	Reach 2	23,260	1,810	25,070
	Reach 3	66,190	25,240	91,430
	Reach 4	-	-	-
	Reach 5	728,390	58,020	786,410
		$ 887,660	$ 92,620	$ 980,280

Annual Benefits

Benefits	Reach 1	$ 480,890	$ 22,180	$ 503,070
	Reach 2	24,210	4,450	28,660
	Reach 3	174,400	2,860	177,260
	Reach 4	-	-	-
	Reach 5	12,951,580	552,730	13,504,310
Total Benefits to Structures (Rounded)		$ 13,631,080	$ 582,220	$ 14,213,300

7.2.2 Non-Structural Alternatives

The Nonstructural alternative for the Long Wharf focused study area consists of providing non-structural storm risk management benefits through a combination of elevating or floodproofing eligible structures within the study area. 138 structures were initially found to be eligible for potential floodproofing or elevation of the first floor. The majority of these structures are large commercial properties. There are 126 commercial structures within the study area that are potential candidates for either wet or dry floodproofing. Most of the buildings are large commercial buildings that would be extremely difficult, if not impossible to properly floodproof. This option would not reduce the risk of coastal storm damage to the rail and highway infrastructure. The potential non-structural components by alternative are outlined in Table 16 below.

Table 17 New Haven Non-structural Elements

Alternative	Residential Structures Elevated	Commercial Structures Floodproofed	Total
Alternative 2	12	126	138
Alternative 3B	7	8	15
Alternative 4A	7	8	15
Alternative 4B	7	8	15

The non-structural alternatives were initially shown to generate annual benefits of over $11 million, representing a 73 percent reduction in damage. Further analysis revealed that 80 percent of base year damages in the without-project scenario accrued to just five high-value structures. It was determined that effectively floodproofing these buildings was not feasible so they were removed from the inventory. Following the Agency Decision Milestone, the study team analyzed the structures potentially eligible for elevation or floodproofing and determined that based on first floor elevations and building contents, it was not cost justified to include a non-structural component as part of the recommended plan.

8.0 PROJECT COSTS

Detailed project costs were developed by the cost engineering team in conjunction with real estate. Annual operation, maintenance, repair, rehabilitation and replacement (OMRR&R) costs for all alternatives were estimated at 1% of the Total Project First Cost.

Interest during construction (IDC) was calculated using the 2020 Federal discount rate of 2.75 percent and a construction period of 36 months, with interest compounded at the end of the period.

Table 18 New Haven Costs (2020 Price Level; FY20 Discount Rate of 2.75%)

Alternative	Total Project First Cost	IDC	Project Investment Cost	Average Annual Cost	Annual O&M	Total Average Annual Cost
Alternative 2	$ 47,449,000	$ 1,953,000	$ 49,402,000	$ 1,830,000	$ -	$ 1,830,000
Alternative 3B	$ 133,141,000	$ 5,481,000	$ 138,622,000	$ 5,135,000	$ 1,331,000	$ 6,466,000
Alternative 4A	$ 192,265,000	$ 7,915,000	$ 200,180,000	$ 7,415,000	$ 1,923,000	$ 9,337,000
Alternative 4B	$ 287,675,000	$ 11,842,000	$ 299,517,000	$ 11,094,000	$ 2,877,000	$ 13,971,000

9.0 ECONOMIC SUMMARY

Table 19 below presents the summary of the economic analyses. The National Economic Development Plan (NED) is the plan that reasonably maximizes net annual benefits. The net annual benefits are equal to a plan's annual benefits minus its annual costs. The benefit to cost ratios are calculated by dividing the annual benefits by the annual cost. Benefit to cost ratio (BCR) is used in the feasibility study to determine whether an alternative is a sound investment (i.e. an alternative has a BCR greater than unity). All alternatives examined had a BCR >1.

Alternative 3B, maximizes net benefits and is the NED plan. This alternative provides net benefits of $8,271,000 with a benefit-to-cost ratio of 2.3 to one.

Table 19 Net Benefits and BCR Calculations

Alternative	Description	AAE Benefit	AAE Cost	Net Benefits	BCR
Alternative 2	Nonstructural	$ 2,210,000	$ 1,830,000	$ 380,000	1.2
Alternative 3B	Enhanced Embankment	$ 14,737,000	$ 6,466,000	$ 8,271,000	2.3
Alternative 4A	Shoreline Floodwall	$ 14,213,000	$ 9,337,000	$ 4,876,000	1.5
Alternative 4B	Extended Shoreline Floodwall	$ 14,213,000	$ 13,971,000	$ 242,000	1.0

Note: Alternative 3B in this table includes an additional $0.5 million in NED benefits discussed below.

10.0 RECOMMENDED PLAN

Alternative 3B is the NED plan and the Recommended Plan. This plan reasonably maximizes the net annual benefits. Compared to without project damage of $15.19 million, Alternative 3B carries a with-project residual risk (i.e. damages) of $1.4 million.

Following the Agency Decision milestone endorsing Alternative 3B as the recommended plan and initiating the final phase of the study, additional economic analysis was performed to capture the transportation delay benefits and infrastructure benefits of Alternative 3B. The benefit analysis is discussed in Section 12.1 below. This resulted in the addition of $0.5 million in NED benefits to Alternative 3B increasing the annual benefit from $14.2 million to $14.7 million.

11.0 REGIONAL ECONOMIC DEVELOPMENT

Economic activity lost in the New Haven region due to flooding can be transferred to another area or region in the national economy, and is therefore not included in the NED account. However, the impacts of project spending on the employment, income, and output of the regional economy are considered part of the Regional Economic Development (RED) account. These regional impacts associated with construction spending for the NED Plan are calculated using the USACE Regional Economic System (RECONS) certified regional economic model. The RECONS model uses IMPLAN® modeling system software developed by Minnesota IMPLAN Group, Inc. to trace the economic ripple, or *multiplier*, effects of project spending in the study area. The model is based on data collected by the U. S. Department of Commerce, the U.S. Bureau of Labor Statistics, and other federal and state government agencies. RECONS uses categories defined by the U.S. Office of Management and Budget's North American Industry Classification System (NAICS). Nationally developed input-output tables represent the relationships between the many different sectors of the economy to allow an estimate of changes in economic activity on the larger economy as a whole, brought about by spending in the project area.

There are two types of effects estimated by the RECONS model—direct and secondary effects. These effects, or impacts, are described as follows:

- Direct effects are the change in dollars or number of jobs that are created because of the direct construction spending made through payroll and direct purchases from businesses for goods and services.

- Secondary impacts measure the change in dollars or employment caused by the next round of spending as businesses make further purchases and pay their employees—these are often called the multiplier effect.

Estimates are provided for local, state, and national levels of geographic impact areas based on Flood Risk Management construction spending of $133 million in the New Haven County area of Connecticut. Of this total expenditure, $103 million will be captured within the local impact area. The remainder of the expenditures will be captured within the state and national impact area. The direct and secondary impacts are measured in output, jobs, labor income, and gross regional product (value added) as summarized in table 20 below.

The regional economic effects are shown for the local, state, and national impact areas. The expenditures of $133 million support a total of 843 full-time equivalent jobs, $62.2 million in labor income, $86.8 million in the gross regional product, and $163.3 million in economic output in the local impact area. More broadly, these expenditures support almost 1,503 full-time equivalent jobs, $107.7 million in labor income, $157.4 million in the gross regional product, and $303.2 million in economic output in the nation. Further breakdown by industry for local, state and National economic impacts is presented in Tables 21 – 23.

Table 20 Overall Summary of Regional Economic Development (RED) Impacts

Area	Local Capture ($000)	Output ($000)	Jobs*	Labor Income ($000)	Value Added ($000)
Local					
Direct Impact		$103,040	459.9	$40,259	$49,855
Secondary Impact		$60,254	383.3	$21,900	$36,931
Total Impact	**$103,040**	**$163,295**	**843.2**	**$62,159**	**$86,786**
State					
Direct Impact		$108,264	490.3	$43,998	$55,143
Secondary Impact		$66,063	402.8	$24,736	$41,067
Total Impact	**$108,264**	**$174,328**	**893.0**	**$68,734**	**$96,210**
US					
Direct Impact		$127,911	587.6	$52,251	$64,101
Secondary Impact		$175,261	915.0	$55,397	$93,298
Total Impact	**$127,911**	**$303,172**	**1,502.6**	**$107,647**	**$157,399**

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

Table 21 Regional Economic Development - Local Impacts

	Output ($000)	Jobs*	Labor Income ($000)	Value Added ($000)
Direct Impacts				
Sand and gravel mining	$482	1.1	$89	$350
Construction of new highways and streets	$1,328	6.9	$493	$561
Construction of new commercial structures, including farm structures	$1,330	9.1	$625	$716
Construction of other new nonresidential structures	$33,142	211.3	$14,956	$17,145
Construction of new single-family residential structures	$1,330	7.4	$475	$782
Cement manufacturing	$0	0.0	$0	$0
Iron and steel mills and ferroalloy manufacturing	$465	0.4	$35	$59
All other industrial machinery manufacturing	$14	0.1	$4	$5
Switchgear and switchboard apparatus manufacturing	$76	0.2	$20	$27
Wholesale trade	$2,417	7.4	$778	$1,700
Air transportation	$4	0.0	$1	$2
Rail transportation	$404	1.8	$128	$40
Water transportation	$13	0.0	$1	$3
Truck transportation	$728	3.8	$263	$321
Insurance carriers	$959	2.0	$233	$504
Commercial and industrial machinery and equipment rental and leasing	$2,711	10.6	$910	$1,728
Architectural, engineering, and related services	$16,777	94.7	$8,758	$8,801
Environmental and other technical consulting services	$876	9.9	$704	$511
Office administrative services	$6,476	46.0	$5,372	$5,626
Employment and payroll of federal govt, non-military	$10,973	47.4	$6,414	$10,973
Private Labor	$22,537	0.0	$0	$0
Direct Impact	**$103,040**	**459.9**	**$40,259**	**$49,855**
Secondary Impact	**$60,254**	**383.3**	**$21,900**	**$36,931**
Total Impact	**$163,295**	**843.2**	**$62,159**	**$86,786**

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

Table 22 Regional Economic Development - State Impacts

	Output ($000)	Jobs*	Labor Income ($000)	Value Added ($000)
Direct Impacts				
Sand and gravel mining	$699	2.1	$128	$508
Construction of new highways and streets	$1,330	6.9	$503	$567
Construction of new commercial structures, including farm structures	$1,330	9.1	$633	$722
Construction of other new nonresidential structures	$33,250	212.0	$15,284	$17,337
Construction of new single-family residential structures	$1,330	7.4	$493	$784
Cement manufacturing	$0	0.0	$0	$0
Iron and steel mills and ferroalloy manufacturing	$537	0.5	$40	$69
All other industrial machinery manufacturing	$43	0.2	$13	$15
Switchgear and switchboard apparatus manufacturing	$254	0.6	$77	$106
Wholesale trade	$2,417	7.4	$812	$1,738
Air transportation	$4	0.0	$1	$2
Rail transportation	$404	1.8	$138	$46
Water transportation	$13	0.0	$2	$4
Truck transportation	$728	3.8	$274	$327
Insurance carriers	$1,144	2.4	$337	$707
Commercial and industrial machinery and equipment rental and leasing	$3,312	13.0	$1,547	$2,381
Architectural, engineering, and related services	$16,777	94.7	$8,930	$8,968
Environmental and other technical consulting services	$977	11.0	$862	$606
Office administrative services	$6,476	50.0	$5,372	$5,626
Employment and payroll of federal govt, non-military	$14,630	67.5	$8,552	$14,630
Private Labor	$22,610	0.0	$0	$0
Direct Impact	**$108,264**	**490.3**	**$43,998**	**$55,143**
Secondary Impact	**$66,063**	**402.8**	**$24,736**	**$41,067**
Total Impact	**$174,328**	**893.0**	**$68,734**	**$96,210**

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

Table 23 Regional Economic Development - National Impacts

	Output ($000)	Jobs*	Labor Income ($000)	Value Added ($000)
Direct Impacts				
Sand and gravel mining	$727	2.6	$171	$528
Construction of new highways and streets	$1,330	7.0	$504	$567
Construction of new commercial structures, including farm structures	$1,330	9.2	$633	$722
Construction of other new nonresidential structures	$33,250	213.2	$15,284	$17,337
Construction of new single-family residential structures	$1,330	8.1	$493	$784
Cement manufacturing	$5,418	8.3	$832	$2,204
Iron and steel mills and ferroalloy manufacturing	$4,876	4.6	$438	$900
All other industrial machinery manufacturing	$833	3.0	$244	$300
Switchgear and switchboard apparatus manufacturing	$1,220	3.0	$371	$507
Wholesale trade	$2,422	8.9	$823	$1,742
Air transportation	$20	0.0	$5	$10
Rail transportation	$404	1.8	$138	$217
Water transportation	$13	0.0	$2	$4
Truck transportation	$1,341	7.4	$505	$602
Insurance carriers	$1,164	2.4	$343	$720
Commercial and industrial machinery and equipment rental and leasing	$5,288	20.7	$2,470	$3,828
Architectural, engineering, and related services	$21,725	122.7	$11,820	$11,898
Environmental and other technical consulting services	$1,330	15.0	$1,173	$825
Office administrative services	$6,650	67.3	$5,516	$5,777
Employment and payroll of federal govt, non-military	$14,630	82.5	$10,486	$14,630
Private Labor	$22,610	0.0	$0	$0
Direct Impact	**$127,911**	**587.6**	**$52,251**	**$64,101**
Secondary Impact	**$175,261**	**915.0**	**$55,397**	**$93,298**
Total Impact	**$303,172**	**1502.6**	**$107,647**	**$157,399**

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

Improving overall community resiliency of the study area in addition to managing coastal storm risk to existing rail infrastructure and the I-95 corridor is the primary effect on the OSE account. Please see the Integrated Feasibility Report/EA for discussion of the EQ account.

12.0 RISK AND UNCERTAINTY

Table 24 displays the distribution of equivalent annual damage reduced in terms of the probability that the damage reduced exceeds the given value for the probabilities of 0.75, 0.50, and 0.25. There is a 75% probability that benefits will exceed $6.38M; there is a 50% probability that benefits will exceed $11.27M; and a 25% probability that benefits will be greater than $16.89M. Given net benefits of $7.6 million, it is more likely than not that the project will outperform expectations in terms of damage reduction. With an estimated annual project cost of $7.1 million, the probability of the BCR remaining above one is approximately 75 percent.

Table 24 Risk and Uncertainty

Equivalent Annual Damage		Probability Damage Reduced Exceeds Indicated Values		
With Project	**Damage Reduced**	**0.75**	**0.50**	**0.25**
$ 2,866,000	**$ 12,327,000**	**$ 6,382,000**	**$ 11,274,000**	**$ 16,887,000**

12.1 Additional Benefit Categories

Plans presented in the Draft Report were evaluated based on damages to structures and contents, the primary NED benefit category. Other potential sources of benefit such as damage to vehicles, debris removal, damage to utilities, and travel time delays for rail lines and the segment of Interstate-95 running through downtown New Haven were not evaluated for the Draft Report. However, following reviews of the Draft Report a decision was made at the Agency Decision Milestone meeting to perform a limited analysis of railroad and highway damages for the recommended plan. The analysis is described in the following sections.

12.1.1 Railroad and Highway Damages

The Study area includes a section of Interstate-95 and significant infrastructure located within the New Haven Rail Yard. The rail yard is a 74-acre facility that serves as a repair and layover facility for major rail freight and passenger lines serving the northeast. The freight rail runs two to five trains per day carrying 7.5 million metric tons of freight annually. Passenger rail includes the Metro-North Railroad, Shore Line East and Amtrak Acela Express. I-95 is the principal highway connecting New York City with much of New England, including the Connecticut coast, Rhode Island and the Boston Metro Area.

The 2017 Long Wharf Flood Protection Report, prepared for the City of New Haven by GZA GeoEnvironmental, Inc., provided the basis for inundation damages to the railroad and highway in the study area. The report indicates the rail yard is susceptible to coastal flooding when still water elevations reach approximately 9 feet NAVD88. The section of Interstate-95, along Long Wharf, is constructed on an elevated embankment but has several low points making it vulnerable to flooding at an approximate elevation of 10 feet NAVD88.

The length of highway was estimated using Google Earth measurements while the length of railroad track was calculated in ArcMap from the Homeland Infrastructure Foundation-Level data. Replacement cost for highway segments was obtained from the National Asphalt Pavement Association. Railroad structural components such as track, ties and interlockings and heavy duty rail bumpers were valued using RSMeans Building Construction Costs 2019, 77th Annual Edition. Prices were updated to 2020 values using an average of the Construction Cost Index and Implicit Price Deflator. The replacement value for the limited highway and railway components located in Long Wharf was estimated at slightly less than $13.8 million. These values were entered into the HEC-FDA model and damages were calculated using the depth-damage function for road and railroad developed for transportation infrastructure in the report entitled, *Development of Depth-Emergency Costs and Infrastructure Damage Relationships for Selected South Louisiana Parishes* dated March 2012. Although this function was developed for the Louisiana coastal area, it is appropriate to use in the current study because rail and electrical components in the northeast have similar characteristics and would be impacted at similar depths. The damage function chosen was developed for short-term, salt water inundation.

Additional benefits of reducing flood damages to rail and highway structural components are close to $300,000 annually and are presented in the table below.

Table 25 Additional Rail and Highway Benefits

Description	Without Project Annual Damages	With Projects Annual Damages	Annual Benefits
Rail Damages	$ 319,740	$ 41,680	$ 278,060
Interstate-95 Damages	18,830	6,590	12,240
Total	$ 338,570	$ 48,270	$ 290,300

12.1.2 Value of Time

The value of time (VOT) calculation was used to determine economic impacts caused by increased travel time when public transportation is shut down or detours are in place due to flooded roadways and railways. The calculation follows guidance from USACE Engineering Regulation - ER 1105-2-100, Appendix D.

A monetary value was attributed to lost productive hours using the average hourly household median income of $76,106 for Connecticut (US Census Bureau) and an alternate route mapped out on Google Earth. Trips were assumed to be 75% work-related and 25% for other purposes. The roadway detour from I-95 to the nearest secondary roads was estimated to increase the travel distance by 0.61 miles with an increased travel time by slightly less than 30 minutes per trip due to congestion and lower speed limits off the highway. Offloading rail passengers from train to alternate public transportation was estimated to increase travel time by approximately 1.5 hours based on distance between available stations. Table 26 presents the value of time saved according to percentage of family income and the length of delay. Value of time saved is $19.69/hour for work trips and $23.60/hour for other trips.

Table 26 Value of Time saved per Hour by Trip Length and Purpose

	Value of Time Saved	Value of Time Saved
	$/hour	**% of hourly family income**
Low Time Savings (0-5 min)		
Work Trips	2.34	6.4%
Social/Recreation Trips	0.48	1.3%
Other Trips	0.04	0.1%

Medium Time Savings (5-15 min)		
Work Trips	11.78	32.2%
Social/Recreation Trips	8.45	23.1%
Other Trips	5.31	14.5%
High Time Savings (over 15 minutes)		
Work Trips	19.69	53.8%
Social/Recreation Trips	21.95	60.0%
Other Trips	23.6	64.5%
All time savings	27.48	75.1%

According to CT Department of Transportation, the I-95 corridor carries approximately 152,500 vehicles through the Long Wharf corridor each day. Ridership on the various rail lines amounts to approximately 92,000 passengers per day. The total number of daily travelers was used to determine the amount of additional time spent to detour onto secondary roads if I-95 or rail lines were closed due to flooding.

Other travel costs incurred by delay are considered vehicle operational costs. Operational costs are expenditures spent on operating and maintaining a vehicle for additional usage. Costs include fuel, maintenance, repairs, and depreciation to vehicle value. Operating cost used in this model is $0.56 per mile based on owning and operating an auto sourced from the American Automobile Association.

Table 27 Value of Time Calculation for Roadway and Rail Closures

	Roadway		Railroad
additional travel time			
hours	0.46		1.5
minutes	27.59		90.0
passengers/vehicle (work)	1		1
Weekdays			
vehicles/travelers per day	152,500		91,490
vehicles/travelers per year (261 Days)	39,802,500		23,878,890
Trip Type			

Work @ $19.69/hour	75%		75%
Other @ $23.60/hour	25%		25%
Weekends			
vehicles/travelers per day	152,500		91,490
vehicles/travelers per year (104 Days)	15,860,000		9,514,960
Trip Type			
Work	0		0
Social/Recreational @ $21.95/hour	50%		50%
Other @ $23.60/hour	50%		50%
Op Cost ($/m)	0.5646		0
Total Value of Time (rounded)			
Weekdays	$378,278,000		$740,275,000
Weekends	$166,102,000		$325,055,000
Total Value of Time	$544,380,000		$1,065,330,000
Vehicle Operating Costs			
Weekdays	$13,708,000		0
Weekends	$5,462,000		0
Total Operating Costs	$19,170,000		0
TOTAL Annual Impacts	$563,550,000		$1,065,330,000
Total Daily Impacts	$1,565,417		$2,959,251

Impacts were calculated using highway, rail and flood elevation data from the HEC-FDA methodology. Based on past flooding of I-95 in other areas of New England, a conservative assumption was made that I-95 would be closed for 3 days and rail service would be down for 5 days at the .01 and .004 Annual Exceedance storm events, and 5 days and 10 days for highway and rail respectively at the .002 Annual Exceedance event. Additional benefits for reducing the economic impacts of travel detours amount to $234,000 annually with $178,000 annually for rail passengers and $56,000 annually for motorists using I-95.

Table 28 Additional Benefits for Value of Time

Description	Without Project Annual Damages	With Project Annual Damages	Annual Benefits
VOT - Rail Passengers	$ 207,148	$ 29,593	$ 177,555
VOT - I95 Vehicles	64,182	7,827	56,355
Total	$ 271,330	$ 37,420	$ 233,910

Additional benefits for protecting I-95 and rail service account for 3.6% of total NED benefits as presented in Table 29 below.

Table 29 Percent Allocation of Annual NED Benefits

Reduced Inundation to Structures	$14,213,000	96.4%
Reduced Inundation to Rail and Highway Components	290,000	2.0%
Value of Time Benefits for reduced Detours	234,000	1.6%
Total Annual Benefits	$14,737,000	100%

12.1.3 Life Safety

Although life loss was not specifically calculated, it is reasonable to expect that the recommended plan will improve prospects for life safety. Most flooding deaths occur in vehicles trapped along inundated roadways. The proposed floodwall alternative would reduce water levels, which would decrease risk to motorists. The study area is located in downtown New Haven which is primarily a commercial working area. The Connecticut Office of Emergency Management has an evacuation plan and emergency mitigation toolkits. It is reasonable to expect that residents and workers would have sufficient warning time prior to flooding to evacuate the area.

13.0 NED Plan Sensitivity to Sea Level Rise

Current USACE guidance requires that potential relative sea level change (SLC) must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence. In accordance with Engineering Regulation ER 1100-2-8162 (incorporating Sea Level changes in Civil Works Program, 31 Dec 2013), Planning studies are evaluated over the project life cycle for the entire range of possible future rates of SLC. The range consists of a “low” rate based on historic change at the project area, and an “intermediate” and “high” rate based on curves for local mean sea level change published by the National Resource Council.

Optimization analyses that evaluated floodwalls at 13 and 14 feet were completed earlier in the study. Elevations above 15 feet were not considered given constraints in local topography. There is no high ground above 15 feet in the immediate vicinity of the recommended plan. Increasing the wall height would therefore require substantial improvements to areas outside the project footprint such as added lengths of floodwall and additional closure structures. Working within the intermediate SLC scenario the enhanced embankment with a crest elevation at 15 feet NAVD88 was identified as the alternative that maximized NED benefits. All economic results presented in previous sections of this report were based on this intermediate rate of sea level change. In addition to the intermediate rate, which is an increase of 0.93 feet over the 50-year period of analysis, the project was also evaluated using the "low" and "high" rates of change. The low and high curves cause increases of 0.47 feet and 2.6 feet, respectively over the fifty year period-of-analysis.

Because any analysis of a higher wall was eliminated earlier in the study, the cost for the wall was held constant across the three SLC scenarios. The probability of the floodwall being overtopped shifts across the SLC scenarios, with a higher likelihood of exceedance under higher SLC scenarios. By the end of the period-of-analysis in 2074, the wall is not projected to be overtopped at the 0.004 AEP event for the low and intermediate scenarios. However, the wall is expected to be overtopped under the 0.002 AEP event when the static WSELs are 15.93 FT NAVD for the low curve and 16.39 FT NAVD for the intermediate curve; yielding $1.1 million in residual damages for the intermediate scenario compared to $1.0 million in the low scenario. There is an average of 0.46 feet difference between the WSELs for low and intermediate SLC scenarios. The intermediate scenario provides $1.4 million more benefits and a slightly higher BCR when compared to the low scenario.

For the high SLC scenario, the WSELs average 1.6 feet higher for all storm frequencies when compared to those in the intermediate scenario; yielding significantly more benefits before the wall is overtopped. The WSEL for the 0.01 AEP is 14.6 FT NAVD; slightly lower than floodwall crest elevation. Static water surface elevations of 16.05 FT and 18.05 FT NAVD were used in the model for the 0.004 and 0.002 AEP; overtopping the wall and leaving slightly more than double residual damages of $2.3 million.

The results of all analyses under all three sea level change conditions are presented in Table 30. The without project damages by storm frequency are presented in Table 31 below.

Table 30 Impacts of Sea level Change on Net Benefits and BCR

Sea Level Change Scenarios	Historic "Low"	Curve I "Intermediate"	Curve III "High"
Without Project Equivalent Annual Damages	14,388,000	15,823,000	44,325,000
Residual Damages for Recommended Plan	1,008,000	1,086,000	2,283,000
Annual Benefits of Recommended Plan	13,380,000	14,737,000	42,042,000
Average Annual Costs	6,466,000	6,466,000	6,466,000
Net Benefits Revised for SLC Scenarios	6,914,000	8,271,000	35,576,000
BCR with Revised Benefits based on SLC	2.1	2.3	6.5

Table 31 Comparison of Without Project Damages by Storm Frequency and Sea Level Change

Annual Exceedence Probability	Intermediate SLC		Low SLC				High SLC			
	Residual Damages ($)	# Structures Impacted	Residual Damages ($)	$ Variance to Intermediate	# Structures Impacted	variance in # structures	Residual Damages ($)	$ Variance to Intermediate	# Structures Impacted	variance in # structures
0.5	105,500	1	67,700	(37,800)	1	0	45,184,100	45,078,600	16	15
0.2	24,347,000	11	1,142,800	(23,204,200)	7	-4	108,477,000	84,130,000	28	17
0.1	65,389,700	18	42,578,300	(22,811,400)	16	-2	161,394,200	96,004,500	37	19
0.04	113,062,000	29	83,335,600	(29,726,400)	22	-7	196,392,800	83,330,800	61	32
0.02	181,777,800	50	161,812,400	(19,965,400)	37	-13	238,893,300	57,115,500	96	46
0.01	224,121,300	78	208,348,907	(15,772,393)	67	-11	265,229,700	41,108,400	105	27
0.004	273,147,600	108	257,159,016	(15,988,584)	103	-5	325,310,900	52,163,300	128	20
0.002	333,896,700	132	322,466,225	(11,430,475)	126	-6	381,642,200	47,745,500	156	24

14.0 FINAL NED SUMMARY

The Fairfield and New Haven Counties, CT Coastal Storm Risk Management Analysis evaluated the economic feasibility of providing coastal storm damage risk reduction along the coast Connecticut. The NED plan consists of augmenting the existing Interstate-95 embankment in New Haven by adding approximately 5,800 linear feet of floodwall with a top elevation of +15 feet North Atlantic Vertical Datum of 1988 (NAVD88). An additional 475 linear feet of deployable flood gates (closure structures) with five deployable road closure structures and one pump station would also be constructed.

The NED Plan yielded annual benefits of approximately $14.7 million compared to an annual cost of $6.5 million; yielding net annual benefits of $8.3 million and a BCR of 2.3 for the project. Residual damages amounted to approximately $1.6 million in annual damages compared to potential annual damages of $16.4 million if the project is not constructed. Table 32 below presents the benefit-cost analysis for the NED plan at the FY20 Price Level and discount rate. Table 33 shows that the project retains a positive BCR of 2.2 at the FY21 Price Level and Federal discount rate of 2.5%

Table 32 Summary of NED Plan 2020
(2020 Price Level and FY20 Federal Discount Rate 2.75%)

Investment Costs	
First Costs (includes Constr., PED, S&A)	$ 132,744,000
Real Estate Costs	397,000
Total Project Costs	133,141,000
Interest During Construction	5,481,000
Total Investment Costs	$138,622,000
Annual Investment Costs	5,135,000
Annual OMRR&R	1,331,000
Total Annual Economic Costs	**$ 6,466,000**
Inundation Reduction Benefits	
Commercial & Residential Structures	$14,213,000
Rail and Highway Components	290,000
Value of Time	234,000
Total Annual Benefits	**$14,737,000**
Net Benefit and BCR	
Annual Net Benefit	**$8,271,000**
BCR	**2.3**

Table 33 Summary of NED Plan 2021
(2021 Price Level and FY21 Federal Discount Rate 2.5%)

Investment Costs	
First Costs (includes Constr., PED, S&A)	$ 136,726,000
Real Estate Costs	409,000
Total Project Costs	137,135,000
Interest During Construction	5,120,000
Total Investment Costs	$142,255,000
Annual Investment Costs	5,022,000
Annual OMRR&R	1,371,000
Total Annual Economic Costs	**$ 6,393,000**
Inundation Reduction Benefits	
Commercial & Residential Structures	$13,529,000
Rail and Highway Components	276,000
Value of Time	223,000
Total Annual Benefits	**$14,028,000**
Net Benefit and BCR	
Annual Net Benefit	**$7,635,000**
BCR	**2.2**