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

DRAFT APPENDIX B: ECONOMICS

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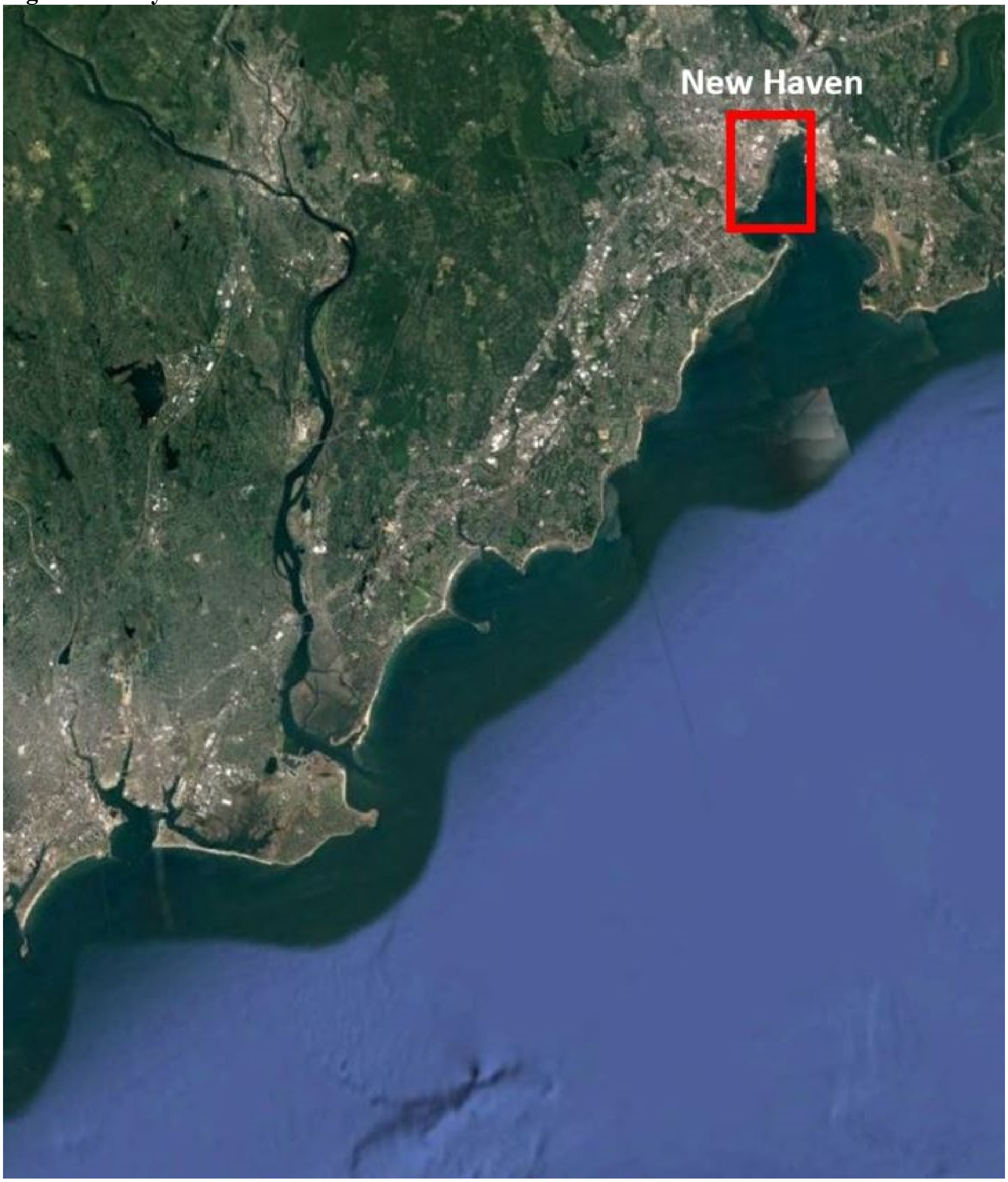
1.0 INTRODUCTION

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 reasonable maximizes net economic benefits. 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). The Tentatively Selected Plan for a non-structural solution was based on October 2020 dollars (2020 price levels, the year the study will be completed) and the FY20 Federal Discount Rate of 2.75 percent.

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 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)	123626	3405565
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 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. (Note that additional analysis of non-structural components will occur following public and agency review of the draft feasibility report and the Agency Decision Milestone.)

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. By the end of the fifty year period of analysis (2074), this alternative would potentially be exceeded by the 7.7-percent annual exceedance probability water level, considering the intermediate sea level change scenario.

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.

Alternative 3B: Enhanced I-95 Embankment

This alternative combines structural storm damage reduction features described in Alternative 3A including pumps and deployable structures, designed with a top elevation of 15.0 feet (NAVD88). In order to reduce the risk of structural failure of the I-95 embankment, this alternative entails a 6,425 liner foot system that parallels I-95 along the length of the Long Wharf area. The system includes 5,950 linear feet of pile-supported floodwall along the seaward side of I-95 from near the Howard Avenue overpass to 600 feet North of Canal Dock Road. The system also includes a combined 475 linear feet of deployable closure structures (i.e. floodgates). In addition to the closure structures described for alternative 3A, two deployable structures approximately 6-8 feet high, would be needed for protection at the exit 46 on and off ramps. The alignment was assumed to be as close to the grade break at the top of I-95 in order to minimize the height. Maximum wall height in that scenario is in the range of 6 to 8 feet. 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 would not be protected by this alternative and those structures and other residential properties may potentially be eligible for floodproofing which will be further analyzed by the study team following the Agency Decision Milestone

Alternative 4A: Shoreline Floodwall

This alternative uses an approximate 6,850 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 would not be protected by this alternative and those structures and other residential structures on the seaward side of I-95 may potentially be eligible for floodproofing which will be further analyzed by the study team following the Agency Decision Milestone.

Alternative 4B: Extended Shoreline Floodwall

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 3A	Existing Embankment	2, 3, 5	1, 4

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.

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 of structures included in the study

		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 ft. 12.5% of that is 0.34 ft.

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:

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

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.

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 $15.194M 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 Damage

	Expected Annual Damage		% increase	Equivalent Annual Damage
	Existing	Future		
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 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. The existing embankment with deployable floodwall, alternative 3A, would result in a lower amount of damage reduction, but would still generate a $9.3 million in annual benefit.

Table 15 New Haven Benefits *

Alternative	Description	With Project Dmg	Benefits from Structural Solution	Benefits from Non-Structural Solution	Total Plan Benefit
Alternative 3A	Existing Embankment	$ 6,337,000	$ 8,857,000	$ 468,000	$ 9,325,000
Alternative 3B	Enhanced Embankment	$ 1,449,000	$ 13,745,000	$ 468,000	$ 14,213,000
Alternative 4A	Shoreline Floodwall	$ 1,449,000	$ 13,745,000	$ 468,000	$ 14,213,000
Alternative 4B	Extended Shoreline Floodwall	$ 1,449,000	$ 13,745,000	$ 468,000	$ 14,213,000

**assumes additional non-structural component that elevates first floors to BFE+1Ft.*

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 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. The potential non-structural components by alternative are outlined in Table 16 below: (note that additional analysis of non-structural components will occur following public and agency review of the draft feasibility report and the Agency Decision Milestone.)

Table 16 New Haven Non-structural Elements

Alternative	Residential Structures Elevated	Commercial Structures Floodproofed	Total
Alternative 2	12	126	138
Alternative 3A	7	8	15
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. The remaining 12 residential structures and 121 commercial structures in the nonstructural plan yielded $2.2 million in annual benefits.

8.0 Project Costs

Detailed project costs were developed by the cost engineering team in conjunction with real estate. Operation, maintenance, repair, rehabilitation and replacement (OMRR&R) costs for non-structural are expected to be 'de-minimis' ($0). OMR&R cost for the structural alternatives were estimates at 1% of the Total Project First Cost. This cost will be refined during further study of the selected plan. See Appendix E – Cost Engineering for more information.

Table 17 New Haven Costs

Alternative	Total Project First Cost	IDC	Project Investment Cost	Average Annual Cost	O&M (0.01)	Total Average Annual Cost
Alternative 2	$ 47,449,000	$ 1,953,000	$ 49,402,000	$ 1,830,000	$ -	$ 1,830,000
Alternative 3A	$ 72,515,000	$ 2,985,000	$ 75,500,000	$ 2,797,000	$ 725,000	$ 3,522,000
Alternative 3B	$ 164,612,000	$ 6,776,000	$ 171,388,000	$ 6,348,000	$ 1,646,000	$ 7,995,000
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 20 below presents the summary of the economic analysis. 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 $6,220,000 with a benefit-to-cost ratio of 2.2 to one.

Table 18 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 3A	Existing Embankment	$ 9,330,000	$ 2,800,000	$ 5,800,000	3.3
Alternative 3B	Enhanced Embankment	$ 14,210,000	$ 6,350,000	$ 6,220,000	2.2
Alternative 4A	Shoreline Floodwall	$ 14,210,000	$ 7,410,000	$ 4,880,000	1.9
Alternative 4B	Extended Shoreline Floodwall	$ 14,210,000	$ 11,090,000	$ 240,000	1.3

10.0 Tentatively Selected Plan

Alternative 3B is the NED plan and the Tentatively Selected Plan. This plan reasonably maximizes the net annual benefits. Alternatives 3A, 3B, 4A and 4B all provide annual benefits of $14.2 million, but alternative 3B provides the highest net benefits due to a lower project cost. Compared to without project damage of $15.19 million, Alternative 3B carries a with-project residual risk (i.e. damages) of $1.4 million.

11.0 Regional Economic Development

USACE guidance requires that study alternatives be evaluated under all accounts the National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE) and Environmental Quality (EQ). NED effects have been addressed above. RED effects would be the impact of project spending, either direct or induced, on the local economy. It is expected that with increased Federal spending on home elevation, income and employment would show some modest temporary increase. The reduction in coastal storm damages will also help to maintain the current residential population and associated tax base.

Improving overall community resiliency of the study area in response to coastal storms is the primary effect on the OSE account. Please see the Integrated Project Report for discussion of the EQ account.

12.0 Risk and Uncertainty

Table 21 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.

Table 19 Risk and Uncertainty

Equivalent Annual Damge		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