Rahway River Basin, New Jersey

Coastal Storm Risk Management Feasibility Study

Draft
Economic Appendix

New Jersey
Department of
Environmental Protection

U.S. Army Corps
of Engineers
New York District

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1 Introduction

This report was prepared to document procedures and results of the economic flood damage analysis for the Rahway River Basin, New Jersey Coastal Storm Risk Management Feasibility Study. Economic analyses include the development of stage versus damage relationships and annual damages over a 50-year analysis period, from year 2021 to year 2071. Damage assessments include inundation damages to structure and contents and vehicles.

Flood damage calculations were performed using Version 1.4.1 of the Hydrologic Engineering Center's Flood Damage Analysis computer program (HEC-FDA, May 2016). This program applies Monte Carlo Simulation to calculate expected damage values while explicitly accounting for uncertainty in the input data. HEC-FDA models were prepared for existing without-project conditions, and for the each alternative plan.

Estimates of without-project damages and with-project damages are based on October 2016 price levels and a 50-year period of analysis. Damages have been annualized over the 50-year project life using the 2017 fiscal year Federal water resource studies discount rate of 2.875%.

2 Description of Study Area

2.1 Location and Setting

The study area is the tidally influenced lower portion of the Rahway River Basin, located in northeastern New Jersey. The Rahway River Basin lies within the metropolitan area of Greater New York City and occupies approximately 15 percent of Essex County, 35 percent of Union County, and 10 percent of Middlesex County. The basin is 83.3 square miles (53,300 acres) in area and is roughly crescent-shaped. Its greatest width is approximately 10 miles in the east-west direction, from the City of Linden to the City of Plainfield. Its greatest length is approximately 18 miles in a north–south direction, from West Orange to Metuchen. The tidal influence on the Rahway River extends roughly 5 miles from the Arthur Kill into the City of Rahway.

The Rahway River consists of the mainstem Rahway River and four branches. The West Branch flows south from Verona through South Mountain Reservation and downtown Millburn. The East Branch originates in West Orange and Montclair and travels through South Orange and Maplewood. These two branches converge near Route 78 in Springfield to form the Rahway River which flows through the municipalities of Springfield, Union, Cranford and Clark. The Rahway River then travels through Rahway, entering from Clark at Rahway River Park. The river receives the waters of Robinsons Branch at Elizabeth Avenue between West Grand Avenue and West Main Street and the waters of the South Branch at East Hazelwood Avenue and Leesville Avenue. Finally the river leaves Rahway to enter the city limits of Linden and Carteret before flowing into the Arthur Kill.

The study area is developed and contains residential, commercial and industrial structures within the floodplain. It is largely suburban and urban with little available open space and lies within the

10th Congressional District, which is currently represented by Donald Payne (D-NJ). The local commercial and industrial facilities in the area represent an important regional commercial resource.

The study area encompasses portions of the Cities of Linden and Rahway in Union County and the Borough of Carteret and Woodbridge Township in Middlesex County. The tidal influence on the Rahway River extends roughly five miles from the Arthur Kill into the City of Rahway.

The City of Rahway is located in southern Union County, New Jersey. According to the United States Census Bureau, Rahway has a total area of 4.028 square miles. Of this area, 3.897 square miles is land and 0.131 square miles (3.26%) is water. Rahway is bordered to the northwest by Clark, the northeast by Linden and to the south by Woodbridge Township in Middlesex County.

Woodbridge Township has a total area of 24.507 square miles (63.473 km2), including 23.213 square miles of land and 1.294 square miles of water (5.28%). The City of Linden has a total area of 11.407 square miles, including 10.675 square miles of land and 0.732 square miles of water (6.42%). The Borough of Carteret has a total area of 5.000 square miles, including 4.418 square miles of land and 0.582 square miles of water (11.65%).

Rahway has a medium household income of $60,374 and a per capita income of $29, 939 (Census 2015). The 2010 U.S. Census listed the Rahway City's population as 27,346. Population under age 5 is 5.9% and 65years and over is 13.5% (US Census 2010). The racial makeup is 52.3% white, 30.9% black, 23.5% Hispanic, and 4.3% Asian (US Census 2010).

3 Problem Identification

The primary problem encountered in the study area is tidal flooding with elevated water levels associated with tidal surge on the Rahway River and tributaries within the study area.

3.1 Storm History

3.1.1 Hurricane Sandy: 22-29 October 2012

Hurricane Sandy initially formed as a tropical depression in the southwestern Caribbean. Sandy weakened somewhat and then made landfall as a post-tropical cyclone near Brigantine, New Jersey with 70-kt maximum sustained winds. Because of its extensive size Sandy drove a very severe storm surge into the New Jersey and New York coastlines.

The highest storm surge measured by a National Ocean Service (NOS) tide gauge in New Jersey was 8.57 feet above normal tide levels at the northern end of Sandy Hook in the Gateway National Recreation Area. Since the station failed and stopped reporting during the storm, it is likely that the actual storm surge was higher. Farther south, the NOS tide gauges in Atlantic City and Cape May measured storm surges of 5.82 feet and 5.16 feet, respectively.

The following inundations, expressed above ground level, were prevalent along the coast due to the storm tide:

Monmouth and Middlesex Counties	4 to 9 feet
Union and Hudson Counties	3 to 7 feet
Essex and Bergen Counties	2 to 4 feet
Ocean County	3 to 5 feet
Atlantic, Burlington, and Cape May Counties	2 to 4 feet

The highest storm surge occurred in areas that border Lower New York Bay, Raritan Bay, and the Raritan River. The highest high-water mark measured by the USGS was 8.9 feet above ground level at the U.S. Coast Guard Station on Sandy Hook. This high-water mark agrees well with data from the nearby NOS tide gauge, which reported 8.01 feet above mean higher high water (MHHW) before it failed. Elsewhere, a high-water mark of 7.9 feet above ground level was measured in Keyport on the southern side of Raritan Bay and a mark of 7.7 feet was measured in Sayreville near the Raritan River.

As storm surge from Sandy was pushed into New York and Raritan Bays, seawater surge occurred within the Hudson River and the coastal waterways and wetlands of northeastern New Jersey, including Newark Bay, the Passaic and Hackensack Rivers, Kill Van Kull, and Arthur Kill. Significant inundations occurred along the Hudson River in Weehawken, Hoboken, and Jersey City, where many high-water marks indicated that inundations were between 4 and 6.5 feet above ground level. Inundations of 4 to 6 feet were also measured across Newark Bay in Elizabeth and the area around Newark Liberty International Airport.

Discussions between USACE and the Middlesex Office of Emergency Management (OEM) revealed that municipalities within the lower portion of the Rahway River Basin and general area suffered tidally induced flood damages from Sandy. It is estimated that Hurricane Sandy caused tens of millions of dollars of damage in the study area. The City of Rahway sustained an estimated $35 million in damages with approximately $15 million of it to city property and another $20 million to private property. Damages included costly repairs to the existing Corps levee pump stations. Damages for the Borough of Carteret are estimated at $53.1M. Woodbridge Township suffered damages estimate at $7M with 200 structures damaged, including 40 destroyed. The PSE&G power plant in Woodbridge was destroyed. Blue Acres at the NJDEP is in the process of buying out 175 structures in the township. During Hurricane Sandy, bulk fuel tanks were damaged and fuel flowed into the Arthur Kill. The storm temporarily shut down oil refineries in the study area leading to shortages of fuel in northern New Jersey. No deaths linked with Hurricane Sandy have been identified within the study area.

3.1.2 Tropical Cyclone Irene: 27-28 August 2011

Irene made its United States landfall near Little Egg Inlet, New Jersey on Sunday, August 28, 2011 as a hurricane with maximum sustained winds of 75 mph. At this point Irene had weakened to a tropical storm. Tropical Storm Irene produced about three to 13 inches of rain on the watersheds within the New York District's civil works boundaries in northern New Jersey and southern New York in about a 16 hour period between Saturday, August 27 and Sunday, August 28. Tropical

Storm Irene rainfall total for the Rahway River basin was about 10 inches. Irene generated a storm surge of 4 to 6 feet along the New Jersey coast and a surge of 3 to 6 feet in the New York City and Long Island areas.

3.1.3 Other Storm Events

Various other storms, tropical storms, northeasters and hurricanes caused tidal inundation and damage in recent decades. These include:

- Storm of 15-16 April 2007
- Tropical Storm Floyd on 15-16 Sep 1999
- Storm of Oct 19 1996
- Northeaster Storm of 11-12 Dec, 1992
- Halloween Northeaster of 31 Oct 1991
- Hurricane Gloria on 27 Sep 1985
- Coastal Storm of 29-30 Mar 1984
- Tropical Storm Doria 26-28 Aug 1971
- Coastal Storm of 6-8 Mar 1962
- Hurricane of 12 Sep 1960 (Donna)
- Storm of 6-7 Nov 1953
- Storm of 25 Nov 1950
- Hurricane of 14 Sep 1944

4 Without-Project Condition Flood Damages

Without-project condition flood damages were modeled in HEC-FDA for the years 2021 and 2071. Tidal inundation is expected to increase gradually over time, in direct relation to the anticipated rise in relative sea level. Based upon long-term trends measured at the Bergen Point gage, a 0.0152 foot per year increase is anticipated, resulting in an average 0.76 foot increase over the 50-year period of economic analysis. In future years this will result in more frequent and higher stages of flooding.

4.1 Delineation of Damage Reaches

In order to conduct economic damage analyses for the without-project condition and alternative plans, the study area has been separated into five streams containing a total of 27 damage reaches, as depicted in Table 1. Streams, reach locations and the upstream and downstream limits of the reaches in the HEC-FDA model were selected to be consistent with the hydrologic/hydraulic modeling and were mostly located at the location of bridges, existing levees, and alternative hydraulic structures such as new levees and floodwalls, so that the effects of these features could be evaluated in detail.

Table 1
Rahway CSRM Damage Reaches

Stream	Damage Reach	Bank	Downstream Station	Upstream Station
Carteret & Woodbridge	A-CW-4-L	Left	20876.51	23622.28
	B-CW-4-R	Right	23243.43	23622.28
	C-CW-2-L	Left	19201.06	19883.70

	D-CW-2-R	Right	14731.32	17565.28
	U-CW-1B-L	Left	10548.64	19201.06
	U-CW-1B-R	Right	10548.64	14731.00
	U-CW-1-L	Left	5.52	10548.64
	U-CW-1-R	Right	5.52	10548.64
	U-CW-3-L	Left	19883.70	20876.51
	U-CW-3-R	Right	17565.28	23243.43
Millburn-Clark	A-MB-1-L	Left	28472.74	29222.75
	A-MB-1-R	Right	28472.74	29222.75
	A-MB-2-L	Left	29222.75	30056.00
	A-MB-2-R	Right	29222.75	30056.00
Rahway	A-RR-1-L	Left	24509.34	27042.00
	A-RR-2-L	Left	27042.00	27392.85
	CH-RR-3-L	Left	27392.85	28188.89
	CH-RR-3-R	Right	27392.85	28188.89
	E-RR-1-R	Right	24509.34	27042.00
	N-RR-2-R	Right	27042.00	27392.85
Robinsons Branch	A-RB-L	Left	175.45	8840.25
	A-RB-R	Right	175.45	8840.25
South Branch	B-SB-2-R	Right	872.00	2283.30
	E-SB-1-L	Left	210.79	2499.70
	U-SB-1-R	Right	210.80	872.00
	U-SB-2-L	Left	2499.70	11400.90
	U-SB-3-R	Right	2283.30	11400.90

4.2 Structure Inventory

A database of residential and nonresidential structures in the study area was compiled for the modeling of flood damages. The structure inventory data was generated through analysis of Geographic Information System (GIS) data, county assessor data, and street-level imagery available through Google Earth®. Street-level imagery was examined for each structure in the inventory to obtain structure type, condition, exterior construction, main floor elevation, low opening elevation, number of garages, and the presence of a basement. Structure ground elevations were obtained from a digital elevation model of the study area.

Each structure (or distinct use type where multiple usages occur within a single building) was assigned a unique structure identification number following the identification of all structures for inventory using GIS mapping. GIS also was used to determine each structure's footprint size, main floor area, and to assign each structure to its proper river station cross section. The final structure inventory contains the information listed below.

- Structure ID #
- Map Number
- Type of structure
- Use of structure
- Exterior Construction
- Quality of Construction
- Current Condition
- Ground Elevation

- Building Footprint Area
- Number of Stories
- Basement Type
- Number of Garages
- Foundation Height
- Location of Low Openings
- Assigned Reach
- Notes/Description (as required)

4.2.1 Summary of Structure Types and Values

In total 2,502 structures in the study area were identified to be located within the 0.2% Annual Chance Exceedance (ACE) tidal floodplain, though 195 of the structures were constructed after 1991. In accordance with Section 308 of WRDA 1990 (33 USC 2318), structures in the 1% ACE floodplain that were built after 1990 were selected for exclusion from the benefit pool. After examination of the structures via Google Earth in aerial and street view, it was concluded that the structures are not necessary for conducting a water-dependent activity, and were excluded from further analysis. The remaining 2,307 structures formed the inventory upon which all analyses were conducted.

Table 2 shows the numbers of structures in each of the 27 damage reaches, with subtotals for each type of structure category.

Table 3 provides additional information for the structure categories and damage reaches – total value. As shown in the table, the inventory valuation (depreciated replacement value as of October 2016) totals over $1.75 billion, with a total residential (non-apartment) valuation of over $350 million.

Table 2
Structure Inventory Summary by Damage Reach (Numbers of Structures)

Stream	Damage Reach	Residential	Apartments	Commercial	Industrial	Utility	Municipal	TOTAL
Carteret & Woodbridge	A-CW-4-L	15		5	1	1		22
	B-CW-4-R			1	12		1	14
	C-CW-2-L	91		10	7		1	109
	D-CW-2-R	162		4	30		1	197
	U-CW-1B-L	133		6	111		8	258
	U-CW-1B-R	32						32
	U-CW-1-L				68	26	7	101
	U-CW-1-R	131	1	9	223	1	2	367
	U-CW-3-L	2		2	1		2	7
	U-CW-3-R	48		8	10	17	3	86
Millburn-Clark	A-MB-1-L	4		1	4			9
	A-MB-1-R	15	1	2				18
	A-MB-2-L	106		2		1		109
	A-MB-2-R	17	3			1		21
Rahway	A-RR-1-L	157	5	4	2		6	174
	A-RR-2-L	59		4	2	1	3	69
	CH-RR-3-L	4		2				6
	CH-RR-3-R	10	1	2				13
	E-RR-1-R	118	6	9	1	2	10	146
	N-RR-2-R		1	5				6
Robinsons Branch	A-RB-L	85	8	8			3	104
	A-RB-R	64	3	6			3	76
South Branch	B-SB-2-R	14	1		3		1	19
	E-SB-1-L	174		9	1		4	188
	U-SB-1-R			1				1
	U-SB-2-L	45		25	27		2	99
	U-SB-3-R	28	5	11	11		1	56
TOTALS		1,514	35	136	514	50	58	2,307

Table 3
Structure Inventory Summary by Damage Reach (Value $000)

Stream	Damage Reach	Residential	Apartments	Commercial	Industrial	Utility	Municipal	TOTAL
Carteret & Woodbridge	A-CW-4-L	3,831		6,825	1,517	121,639		133,812
	B-CW-4-R			351	13,603		59	14,013
	C-CW-2-L	20,335		24,501	24,496		36	69,368
	D-CW-2-R	21,716		1,237	153,580		107	176,641
	U-CW-1B-L	27,276		11,285	54,487		27,426	120,474
	U-CW-1B-R	5,300						5,300
	U-CW-1-L					82,772	2,113	84,885
	U-CW-1-R	28,110	1,525	35,832	20,708	109	11,530	97,814
	U-CW-3-L	474		7,652	74,320		377	82,823
	U-CW-3-R	14,022		10,510	70,537	25,650	6,240	126,959
Millburn-Clark	A-MB-1-L	1,266		453	21,282			23,001
	A-MB-1-R	4,421	2,654	2,022				9,097
	A-MB-2-L	23,927		598		910		25,435
	A-MB-2-R	4,192	25,499			3,777		33,468
Rahway	A-RR-1-L	36,970	2,557	11,237	443		12,624	63,832
	A-RR-2-L	24,714		1,728	140	591	119	27,292
	CH-RR-3-L	2,502		6,672				9,174
	CH-RR-3-R	3,043	2,098	1,255				6,396
	E-RR-1-R	39,606	102,918	73,397	296	232	9,909	226,358
	N-RR-2-R		3,332	108,546				111,878
Robinsons Branch	A-RB-L	25,618	15,030	10,076			95	50,819
	A-RB-R	18,034	3,858	5,883			1,389	29,164
South Branch	B-SB-2-R	3,117	847		3,743		256	7,963
	E-SB-1-L	40,182		3,865	1,375		3,095	48,517
	U-SB-1-R			347				347
	U-SB-2-L	9,092		14,633	76,685		1,973	102,383
	U-SB-3-R	11,065	6,875	37,245	8,262		84	63,531
TOTALS		368,815	167,194	376,148	525,477	235,679	77,431	1,750,744

Price level October 2016

Table 4 provides a general summary of the proportions of structures found in each damage category type and their average depreciated structure replacement values. The table shows that the largest proportion (66%) of structures are of residential (one- or two-family) use, though residential structures account for only 21% of the inventory's depreciated structure replacement value. Conversely, commercial structures account for 6 % of the number of structures, though the value of those structures is 21% of the inventory's depreciated structure replacement value.

Table 4
Proportions of Structures by Damage Category

		Pct of Total	Average Value
Residential	No. of Structures	65.6%	$ 244,000
	Value	21.1%	
Apartment	No. of Structures	1.5%	$ 4,777,000
	Value	9.5%	
Commercial	No. of Structures	5.9%	$ 2,766,000
	Value	21.5%	
Industrial	No. of Structures	22.3%	$ 1,022,000
	Value	30%	
Utility	No. of Structures	2.2%	$ 4,714,000
	Value	13.5%	
Municipal	No. of Structures	2.5%	$ 1,335,000
	Value	4.4%	

Price level October 2016

4.2.2 Residentially-Owned Motor Vehicles

The HEC-FDA inventory also includes estimates of the numbers and values of residentially-owned motor vehicles likely to be exposed to flood risk. To expedite this component of the analysis, a number of simplifying assumptions were made during the estimation of the number and value of vehicles likely to be present in the study area during flood events:

- It was assumed that on average, 1.73 vehicles are associated with each housing unit in the municipalities covered by the study area, based on U.S. Census bureau data.
- The average depreciated value of a vehicle in the study area is $10,000, a value which has been accepted for use in similar studies for USACE elsewhere in the country.
- Sedans were assumed to be the predominant vehicle type in the study area; hence the Sedan depth-damage function in Table 4 of Economic Guidance Memorandum (EGM) 09-04 was applied to all vehicles in the inventory.
- The total number of housing units was estimated by assuming that each structure covered by one of the generic USACE residential depth-damage functions contained a single unit, and that the number of units in an apartment building was derived by dividing the

building's total square footage by 1,200 (1,000 square feet for the assumed average apartment size plus an additional 200 square feet to account for hallways and other common areas).

- The probability that vehicle owners would move their vehicles to higher ground before a flood was assumed to be 73%. In the absence of any specific information regarding local warning times in advance of flood events this figure was derived by taking an average of the percentages given in Table 5 of EGM 09-04.

A summary of the HEC-FDA inventory's distribution and value of vehicles by damage reach is shown in Table 5

Table 5
Distribution of Motor Vehicles in Study Area

Stream	Damage Reach	Number	Value	* Modeled Value
Carteret & Woodbridge	A-CW-4-L	38	380,000	103,000
	B-CW-4-R	55	550,000	149,000
	C-CW-2-L	171	1,710,000	462,000
	D-CW-2-R	291	2,910,000	785,000
	U-CW-1B-L	251	2,510,000	677,000
	U-CW-1B-R	55	550,000	149,000
	U-CW-1-L	0	0	0
	U-CW-1-R	433	4,330,000	1,168,000
	U-CW-3-L	3	30,000	9,000
	U-CW-3-R	93	930,000	252,000
Millburn-Clark	A-MB-1-L	7	70,000	19,000
	A-MB-1-R	54	540,000	145,000
	A-MB-2-L	197	1,970,000	532,000
	A-MB-2-R	140	1,400,000	378,000
Rahway	A-RR-1-L	358	3,580,000	967,000
	A-RR-2-L	116	1,160,000	313,000
	CH-RR-3-L	7	70,000	19,000
	CH-RR-3-R	33	330,000	89,000
	E-RR-1-R	346	3,460,000	934,000
	N-RR-2-R	0	0	0
Robinsons Branch	A-RB-L	254	2,540,000	687,000
	A-RB-R	151	1,510,000	406,000
South Branch	B-SB-2-R	31	310,000	84,000
	E-SB-1-L	344	3,440,000	929,000
	U-SB-1-R	0	0	0
	U-SB-2-L	78	780,000	210,000
	U-SB-3-R	114	1,140,000	308,000
TOTALS		3,620	36,200,000	9,774,000

* value adjusted for the probability that vehicles will be removed by owners prior to a flood event.

4.2.3 Inundation Damage Functions

The computation of annual flood damages in this analysis is based on the application of depth-damage functions to the structures in the study area to compute damage incurred by structures, their contents and other associated features during flood events of different probability of occurrence. The primary source of depth-damage functions for this study were the generic depth-damage functions for residential structures developed for use in U.S. Army Corps of Engineers flood damage reduction studies in 2000 and 2003, and the depth-damage functions for non-residential structures that were developed by the U.S. Army Corps of Engineers specifically for the Passaic River Basin flood damage reduction study during the 1980s.

Damage functions for single-family residential structures (and two- or multi-family structures with similar physical characteristics) without basements were applied in accordance with: Economic Guidance Memorandum (EGM) 01-03, "Generic Depth-Damage Relationships", December 4, 2000.

Damage functions for single-family residential structures (and two- or multi-family structures with similar physical characteristics) with basements were applied in accordance with: Economic Guidance Memorandum (EGM) 04-01," Generic Depth-Damage Relationships for Residential Structures with Basements", October 10, 2003. Passaic River Basin Damage functions for non-residential structures (plus apartment buildings and large multi-family structures) were applied in accordance with previous experience with similar flood risk reduction projects in northern New Jersey.

A total of 41 different depth-damage functions were applied to cover the diversity of structure types and usages in the study area; all six generic residential depth-damage functions presented in EGMs 01-03 and 04-01 are represented in the study area, with over 40 percent of all residential structures assigned the damage function for two-story residences with basements, and over 85 percent of all residential structures featuring a subgrade basement. The non-residential and apartment structures in the study area are represented by 28 different Passaic River Basin damage functions, with some such functions being assigned to more than one non-residential usage.

The value of contents for each structure was effectively assumed to be equal to 100% of the structure value, in accordance with the appropriate guidance. In addition to damage to structures and associated contents, the Passaic River Basin damage functions for non-residential structures incorporate a third ("other") component for damage to features external to the main structure such as vehicles, storage yards, plant machinery, and landscaping. The value of these features was assumed to be equal to 100% of the structure value, and for most damage functions incorporating this component the percentage of the "other" value realized in damage at each depth is small compared to the corresponding structure or contents damage.

While the generic residential damage functions do not include a component for other damages, the study attempted to capture damages to motor vehicles associated with residences that could be left in the study area during flood events, using USACE guidance found in *Economic*

Guidance Memorandum 09-04, "Generic Depth-Damage Relationships for Vehicles", June 22, 2009.

4.2.4 Existing Levees

Two existing levees are included under without-project and all alternative conditions:

- Rahway Existing Levee: Located on the right descending bank, between the beginning (downstream) Station of 24509.34 and ending (upstream) Station of 27042. The levee has a top elevation of 12.6 ft. NAVD88. This stationing corresponds to the HEC-FDA damage reach named E-RR-1-R.
- South Branch Existing Levee: Located on the left descending bank, between the beginning (downstream) Station of 210.79 and ending (upstream) Station of 2499.697. The levee has a top elevation of 12.6 ft. NAVD88. This stationing corresponds to the HEC-FDA damage reach named E-SB-1-L.

4.2.5 Risk and Uncertainty Parameters

This study has been conducted in accordance with Engineering Manual EM 1110-2-1619, "Risk-Based Analysis for Flood Damage Reduction Studies (USACE, August 1, 1996), which requires that primary elements of the damage estimation computations are explicitly subjected to probabilistic analyses. Estimates of annual flood damage were computed for this study using version 1.4 of the Hydrologic Engineering Center's Flood Damage Analysis computer program (HEC-FDA), which applies Monte Carlo simulation techniques to calculate expected damage values while explicitly accounting for uncertainty in the input data.

Uncertainty was incorporated into the following components of the flood damage calculations:

- Discharge-frequency functions
- Stage-discharge functions
- Stage-frequency functions
- Structure first floor elevation
- Structure depreciated replacement value
- Content/other value-structure value ratios
- Depth-damage functions

Uncertainty associated with the discharge-frequency relationship was applied in HEC-FDA using order statistics and equivalent record lengths. For this analysis, equivalent record lengths of up to 75 years were used to generate uncertainty bands for all reaches for all conditions.

Uncertainty associated with the main floor elevation of single-family (and similar two-family) residential structures was applied using a normal distribution with a standard deviation of 0.6 feet, in accordance with guidance in Table 6-5 of EM 1110-2-1619 for inventories compiled by visual

survey and topographic mapping with two-foot contour intervals. The uncertainty associated with the main floor elevation of non-residential, larger residential and apartment structures that were assigned Passaic River Basin damage functions was applied using a normal distribution with a standard deviation of 1.0 feet, in accordance with previous practice when using this set of damage functions.

The depreciated structure replacement value was subjected to uncertainty via the application of a normal probability distribution with a coefficient of variation of 10% for all structures, in accordance with previously accepted practice for similar USACE flood damage reduction studies. For non-residential and apartment structures the ratios between content value and structure value, and between other value and structure value, was subjected to uncertainty via the application of normal distributions with a coefficient of variation of 25% and 10% respectively, also in accordance with previously accepted practice for similar USACE flood damage reduction studies. These ratios are not applicable to the generic damage functions for residential structures.

4.2.6 Without-Project Expected Annual Damages

Table 6 provides a summary of the numbers of study area structures experiencing damage at selected annual chance exceedance events (year 2071), broken down by damage category. Note that the numbers of structures in the table were compiled without the application of risk and uncertainty to water surface elevations or structure elevations in the HEC-FDA model.

Table 6
Summary of Damaged Structures by Flood Event

Damage Category	Annual Chance Exceedance (ACE) Event						
	50% (2-yr)	20% (5-yr)	10% (10-yr)	4% (25-yr)	2% (50-yr)	1% (100-yr)	> 1% (>100-yr)
Residential	40	88	129	231	395	569	1,205
Apartment	8	10	10	11	12	17	25
Commercial	8	13	20	30	42	55	105
Industrial	2	219	231	248	301	354	463
Utility	4	4	8	16	29	34	46
Municipal	4	4	6	10	15	26	42
Total	**66**	**338**	**404**	**546**	**794**	**1,055**	**1,886**

Using HEC-FDA, Average Annual Damages (AAD) were calculated for the without-project base year (2021) and the future condition, and Equivalent Annual Damages (EAD) were calculated for the 50-year period of analysis, using the 2017 fiscal year USACE project evaluation and federal plan formulation discount rate of 2.875%. Table 7 shows that the total equivalent annual damage resulting in these calculations is approximately $17.5 million for the study area.

Table 7
Without-project Expected Annual Damages by Category and Damage Reach

Stream	Damage Reach	Res	Aptmnts	Autos	Comm	Indus	Util	Mun	TOTAL
Carteret & Woodbridge	A-CW-4-L	189,500	0	5,500	116,700	252,400	59,400	0	623,500
	B-CW-4-R	0	0	200	1,700	145,400	0	200	147,600
	C-CW-2-L	88,400	0	1,800	45,700	77,900	0	100	213,900
	D-CW-2-R	80,600	0	8,400	5,800	3,217,200	0	200	3,312,300
	U-CW-1B-L	660,700	0	29,600	24,900	228,100	0	7,100	950,400
	U-CW-1B-R	9,000	0	300	0	0	0	0	9,300
	U-CW-1-L	0	0	0	0	561,900	309,300	1,400	872,700
	U-CW-1-R	342,400	100	24,300	154,500	2,468,700	700	10,400	3,001,000
	U-CW-3-L	300	0	0	13,700	10,500	0	25,300	49,800
	U-CW-3-R	34,500	0	700	19,300	143,900	282,400	900	481,600
Millburn-Clark	A-MB-1-L	2,300	0	0	1,400	29,400	0	0	33,100
	A-MB-1-R	156,200	131,200	19,800	225,300	0	0	0	532,500
	A-MB-2-L	157,000	0	5,500	6,700	0	35,100	0	204,200
	A-MB-2-R	11,500	2,600	500	0	0	500	0	15,000
Rahway	A-RR-1-L	536,500	53,100	26,900	1,429,500	55,700	0	25,100	2,126,800
	A-RR-2-L	87,600	0	4,800	154,300	15,000	500	3,100	265,100
	CH-RR-3-L	700	0	0	669,200	0	0	0	669,900
	CH-RR-3-R	9,000	1,600	300	4,100	0	0	0	15,000
	E-RR-1-R	65,500	212,000	5,400	298,000	2,000	1,300	4,200	588,600
	N-RR-2-R	0	5,500	0	164,300	0	0	0	169,800
Robinsons Branch	A-RB-L	324,000	51,700	11,500	285,100	0	0	1,700	673,900
	A-RB-R	319,800	15,100	7,200	38,800	0	0	700	381,600
South Branch	B-SB-2-R	37,500	0	1,100	0	21,900	0	700	61,300
	E-SB-1-L	145,100	0	5,000	32,700	9,200	0	2,600	194,500
	U-SB-1-R	0	0	0	8,200	0	0	0	8,200
	U-SB-2-L	39,400	0	1,100	98,400	968,500	0	100	1,107,500
	U-SB-3-R	44,700	200	1,200	343,900	423,400	0	4,200	817,500
TOTALS		3,342,200	473,200	161,000	4,142,000	8,631,000	689,200	87,900	17,526,400

Price level October 2016, 2.875 % discount rate

5 Evaluation of Alternatives

Five alternatives were evaluated for the Rahway CSRM study. Alternatives 1 & 2 are comprised entirely of structural measures, which include channel work, levees, floodwalls, and tide gates. Alternatives 3A and 3B are comprised of nonstructural measures, which include dry flood proofing (e.g., sealing basement windows on residential properties), wet flood proofing, elevation (raising buildings), barriers (ring floodwalls/ring berms), and pump replacements. Relocations and acquisitions (buyouts) were not considered in this analysis. Alternative 3A includes nonstructural treatments for structures located within the 10% ACE floodplain, and Alternative 3B includes nonstructural treatments for structures located within the 2% ACE floodplain. Alternative 4 is comprised of a combination of structural and non-structural measures.

5.1 Organization of Economic Reaches

Six economic reaches were defined for the analysis of alternatives, and include a combination of damage reaches defined previously in this appendix. It should be noted that each damage reach has been assigned to an economic reach. The listing of economic reaches and their associated damage reaches is provided Table 8 below.

Table 8
Organization of Economic Reaches

Economic Reach	Subcategory	Damage Reach	Damage Reach Stream
Reach A	Alt 1 Levee	A-CW-4-L	Carteret & Woodbridge
	Alt 1 Levee	A-RR-1-L	Rahway River
	Alt 1 Levee	A-RR-2-L	Rahway River
	Alt 1 Levee	N-RR-2-R	Rahway River
	Existing Levee	E-RR-1-R	Rahway River
	No Levee	A-MB-1-L	Millburn-Clark
	No Levee	A-MB-1-R	Millburn-Clark
	No Levee	A-MB-2-L	Millburn-Clark
	No Levee	A-MB-2-R	Millburn-Clark
	No Levee	CH-RR-3-L	Rahway River
	No Levee	CH-RR-3-R	Rahway River
	No Levee	A-RB-L	Robinsons Branch
	No Levee	A-RB-R	Robinsons Branch
Reach B	Alt 1 Levee	B-CW-4-R	Carteret & Woodbridge
	Alt 1 Levee	B-SB-2-R	South Branch
Reach C	Alt 1 Levee	C-CW-2-L	Carteret & Woodbridge
Reach D	Alt 1 Levee	D-CW-2-R	Carteret & Woodbridge
Reach E	Existing Levee	E-SB-1-L	South Branch
Reach U	No Levee	U-CW-1B-L	Carteret & Woodbridge
	No Levee	U-CW-1B-R	Carteret & Woodbridge
	No Levee	U-CW-1-L	Carteret & Woodbridge
	No Levee	U-CW-1-R	Carteret & Woodbridge
	No Levee	U-CW-3-L	Carteret & Woodbridge
	No Levee	U-CW-3-R	Carteret & Woodbridge
	No Levee	U-SB-1-R	South Branch
	No Levee	U-SB-2-L	South Branch
	No Levee	U-SB-3-R	South Branch

5.2 Alternative 1: Floodwalls, Levees, with Channel Modification

Alternative 1 consists of a combination of four (4) levee/floodwall segments, two (2) closure gates, interior drainage structures, and channel modification. This alternative, at present conditions, is likely to have a 1 percent chance of annual exceedance in the protected areas. The design height of the levees and floodwalls is at elevation 12.6 feet, NAVD88, consistent with existing levees in the study area.

5.2.1 Levee / Floodwall Segments

Alternative 1 is separated into levee/floodwall segments A through D, which correspond to the economic reaches defined in Section 5.1 of this appendix.

Segment A

Segment A includes floodwalls along both banks of the Rahway River that begin just upstream of Rahway River Station 27932.85. The right bank floodwall continues downstream to tie-in at a bridge raising bridge and road raising at Rahway River Station 27107.37. The left bank floodwall continues downstream to Rahway River Station 26210.85 where it ties in to Essex Street, requiring the road to be raised by approximately 1.5 feet for a distance of approximately 150 feet.

The Rahway River left bank floodwall resumes its course just downstream of Rahway River Station 25887.58, and ties to high ground at the recently modified East Milton Avenue Bridge. A left bank levee section starts downstream of the bridge, and continues downstream for approximately 1,510 feet until it ties into high ground just downstream of the Rahway River / South Branch confluence.

The line of protection for Segment A ends with a floodwall approximately 580 feet long located between the Route 1 exit and Route 1 itself.

Segment A also includes a 6,450 foot long channel modification in order to mitigate for the impact of bank encroachments caused by existing levees in the Rahway River and the additional encroachments that would be incurred by Segment A levees and floodwalls. The upstream and downstream ends of channel modification are: 500 ft. upstream of W. Grand Avenue Bridge upstream of the confluence with Robinson's Branch and approximately 100 ft. downstream of Lawrence Street Bridge downstream of the confluence with the South Branch, respectively.

Segment B

Segment B consists of a combination of levee and floodwall. A floodwall is to be located on the right bank of South Branch just downstream of South Branch Station 2283.30, and continuing downstream for approximately 5,700 feet toward South Branch Station 872.0. A levee protects from Carteret & Woodbridge overland flow, and is located near the intersection of Randolph Avenue and Edgar Road.

Segment C

Segment C includes a levee on the left bank of the Carteret & Woodbridge River beginning about 200 feet downstream of Carteret & Woodbridge Station 19883.37, and ending about 350 feet upstream of Carteret & Woodbridge Station 19201.06. The levee is 890 ft. long with an average height above ground of approximately 7.5 feet, and levee is located on the left bank of the Rahway River, approximately one mile downstream of the confluence with the South Branch.

Segment D

Segment D includes a 3,360 linear feet of levee on the right bank of the Carteret & Woodbridge River beginning about 100 feet downstream of Carteret & Woodbridge Station 19883.37, and ending about 150 feet downstream of Carteret & Woodbridge Station 14731.32. The average levee height is approximately 7.5 feet above ground level.

5.2.2 Residual Damages and Benefits

Using HEC-FDA, Average Annual Damages were calculated for the base year and future years with Alternative 1 in place, and Equivalent Annual Damages were calculated for the 50-year period of analysis, using the 2017 fiscal year USACE project evaluation and formulation discount rate of 2.875%. A summary of equivalent annual damages and flood damage reduction benefits by damage reach for Alternative 1 is presented in Table 9, and a summary of equivalent annual damages and flood damage reduction benefits by economic reach for Alternative 1 is presented in Table 10.

Table 9
Summary of Damages and Benefits for Alternative 1: Damage Reaches

Stream	Damage Reach	Without Project Damages	With Alternative 1 Damages	Damage Reduction Benefits
Carteret & Woodbridge	A-CW-4-L	623,500	155,000	468,500
	B-CW-4-R	147,600	108,200	39,400
	C-CW-2-L	213,900	168,900	45,000
	D-CW-2-R	3,312,300	968,700	2,343,600
	U-CW-1B-L	950,400	950,700	-300
	U-CW-1B-R	9,300	9,200	100
	U-CW-1-L	872,700	872,700	0
	U-CW-1-R	3,001,000	2,980,000	21,000
	U-CW-3-L	49,800	48,300	1,500
	U-CW-3-R	481,600	478,100	3,500
Millburn-Clark	A-MB-1-L	33,100	17,200	15,900
	A-MB-1-R	532,500	434,600	97,900
	A-MB-2-L	204,200	170,100	34,100
	A-MB-2-R	15,000	11,500	3,500
Rahway	A-RR-1-L	2,126,800	279,600	1,847,200
	A-RR-2-L	265,100	49,500	215,600
	CH-RR-3-L	669,900	542,000	127,900
	CH-RR-3-R	15,000	13,700	1,300
	E-RR-1-R	588,600	586,700	1,900
	N-RR-2-R	169,800	175,300	-5,500
Robinsons Branch	A-RB-L	673,900	606,300	67,600
	A-RB-R	381,600	363,600	18,000
South Branch	B-SB-2-R	61,300	38,300	23,000
	E-SB-1-L	194,500	192,300	2,200
	U-SB-1-R	8,200	7,800	400
	U-SB-2-L	1,107,500	952,600	154,900
	U-SB-3-R	817,500	759,600	57,900
TOTAL		17,526,500	11,940,300	5,586,200

Price Level: October 2016, Discount Rate: 2.875%

Table 10
Summary of Damages and Benefits for Alternative 1: Economic Reaches

Economic Reach	Subcategory	Without Project Damages	With Alternative 1 Damages	Damage Reduction Benefits	Reach Benefits
Reach A	Alt 1 Levee	3,185,200	659,300	2,525,800	2,893,900
	Existing Levee	588,600	586,700	1,900	
	No Levee	2,525,300	2,159,000	366,200	
Reach B	Alt 1 Levee	208,800	146,500	62,400	62,400
Reach C	Alt 1 Levee	213,900	168,900	45,000	45,000
Reach D	Alt 1 Levee	3,312,300	968,700	2,343,600	2,343,600
Reach E	Existing Levee	194,500	192,300	2,200	2,200
Reach U	No Levee	7,297,900	7,059,000	239,000	239,000
TOTAL		17,526,500	11,940,300	5,586,200	5,586,200

5.2.3 Cost Estimate

A summary of the costs and benefits for Alternative 1 is presented in Table 11.

Table 11
Alternative 1 Costs and Benefits

First Cost	106,506,651
Interest During Construction	6,911,507
Total Investment Cost	113,418,157
Annual Investment Cost	4,304,001
Annual O&M Cost	456,695
Total Annual Cost	4,760,697
Annual Benefits	5,586,200
Net Benefits	825,500
BCR	1.2

Price Level: October 2016, Discount Rate: 2.875%

5.3 Alternative 2: Tidal Surge Barrier

The main feature of Alternative 2 is a surge barrier consisting of tide gates and a pumping station at the New Jersey Turnpike Bridge. A surge barrier is a specific type of floodgate designed to prevent a storm surge from flooding the area behind the barrier up to a specified design height. The barrier would be upstream of the bridge, i.e. to the west of the Turnpike, spanning across the width of the river from Carteret to Linden. Additional channel modification, levees and floodwalls in both Carteret and Linden, and closure structures complete the plan. This alternative is likely to have a 1% chance of annual exceedance.

The surge barrier is located approximately 775 ft. upstream of the New Jersey Turnpike with a design elevation of 13 feet NAVD88. It includes:

(1) Six tainter gates allowing navigable passage,

(2) A pumping station with four pumps at a total capacity of 2.7 million gpm,

(3) Levee tie-ins to high ground (the turnpike) on the left and right banks, and

(4) Channel modification at the surge barrier for a length of approximately 2,000 ft.

Gates will be open during normal tide conditions and fluvial events. During tidal events, the gates will close during a rising tide as long as the headwater (landside) has a lower water surface elevation than the tailwater (ocean-side).

Levees on the left and right banks of the surge barrier will tie into the New Jersey Turnpike, and the alternative also includes approximately 2,000 feet of channel modifications.

5.3.1 Residual Damages and Benefits

Using HEC-FDA, Average Annual Damages were calculated for the base year and future years with Alternative 2 in place, and Equivalent Annual Damages were calculated for the 50-year period of analysis, using the 2017 fiscal year USACE project evaluation and formulation discount rate of 2.875%. A summary of equivalent annual damages and flood damage reduction benefits by damage reach for Alternative 2 is presented in Table 12, and a summary of equivalent annual damages and flood damage reduction benefits by economic reach for Alternative 2 is presented in Table 13.

Table 12
Summary of Damages and Benefits for Alternative 2: Damage Reaches

Stream	Damage Reach	Without Project Damages	With Alternative 2 Damages	Damage Reduction Benefits
Carteret &Woodbridge	A-CW-4-L	623,500	300,800	322,700
	B-CW-4-R	147,600	81,000	66,600
	C-CW-2-L	213,900	150,600	63,300
	D-CW-2-R	3,312,300	1,311,800	2,000,500
	U-CW-1B-L	950,400	436,100	514,300
	U-CW-1B-R	9,300	8,400	900
	U-CW-1-L	872,700	869,500	3,200
	U-CW-1-R	3,001,000	2,998,800	2,200
	U-CW-3-L	49,800	67,700	-17,900
	U-CW-3-R	481,600	286,300	195,300
Millburn-Clark	A-MB-1-L	33,100	32,800	300
	A-MB-1-R	532,500	280,400	252,100
	A-MB-2-L	204,200	179,900	24,300
	A-MB-2-R	15,000	14,600	400
Rahway	A-RR-1-L	2,126,800	824,700	1,302,100
	A-RR-2-L	265,100	128,300	136,800
	CH-RR-3-L	669,900	326,500	343,400
	CH-RR-3-R	15,000	13,200	1,800
	E-RR-1-R	588,600	361,500	227,100
	N-RR-2-R	169,800	166,900	2,900
Robinsons Branch	A-RB-L	673,900	588,700	85,200
	A-RB-R	381,600	376,800	4,800
South Branch	B-SB-2-R	61,300	35,300	26,000
	E-SB-1-L	194,500	106,800	87,700
	U-SB-1-R	8,200	4,200	4,000
	U-SB-2-L	1,107,500	639,100	468,400
	U-SB-3-R	817,500	590,800	226,700
TOTAL		17,526,500	11,181,100	6,345,400

Price Level: October 2016, Discount Rate: 2.875%

Table 13
Summary of Damages and Benefits for Alternative 2: Economic Reaches

Economic Reach	Subcategory	Without Project Damages	With Alternative 2 Damages	Damage Reduction Benefits	Reach Benefits
Reach A	Alt 1 Levee	3,185,200	1,420,700	1,764,500	2,703,900
	Existing Levee	588,600	361,500	227,100	
	No Levee	2,525,300	1,812,800	712,300	
Reach B	Alt 1 Levee	208,800	116,200	92,600	92,600
Reach C	Alt 1 Levee	213,900	150,600	63,300	63,300
Reach D	Alt 1 Levee	3,312,300	1,311,800	2,000,500	2,000,500
Reach E	Existing Levee	194,500	106,800	87,700	87,700
Reach U	No Levee	7,297,900	5,900,900	1,397,100	1,397,100
TOTAL		17,526,500	11,181,100	6,345,400	6,345,400

5.3.2 Cost Estimate

A summary of the costs and benefits for Alternative 2 is presented in Table 14.

Table 14
Alternative 2 Costs and Benefits

First Cost	988,808,637
Interest During Construction	119,775,589
Total Investment Cost	1,108,584,226
Annual Investment Cost	42,068,650
Annual O&M Cost	4,943,657
Total Annual Cost	47,012,307
Annual Benefits	6,345,400
Net Benefits	-40,666,907
BCR	0.1

Price Level: October 2016, Discount Rate: 2.875%

5.4 Alternative 3A: Nonstructural Treatment (10% Annual Chance Exceedance (ACE) Floodplain)

A nonstructural alternative is one in which the physical mechanism and extent of flooding is largely unchanged (no riverine structures are constructed or modified to substantially constrain, impede or redirect floodwater) but the existing buildings within the floodplain are instead adapted or the regulatory framework that governs new development is modified to reduce the damage incurred during flood events. For this study, only nonstructural measures which directly affect existing buildings have been incorporated into the analysis.

Under Alternative 3A, nonstructural treatments were applied to structures located within the study area 10% ACE floodplain using a spreadsheet matrix which considered physical characteristics including building configuration, usage, footprint size, foundation type, and existing main floor elevation in order to select and cost the most appropriate/feasible treatment for each structure.

The nonstructural analysis considered 10 different treatment measures for application, which can be described under the following broad categories:

- Elevation: the structure is physically raised so that the main floor of the structure is at or above the specified design protection level.
- Dry Floodproof: all openings are sealed or fitted with moveable watertight barriers and the exterior walls are treated to make them waterproof to the design protection level.
- Wet Floodproof: wet floodproofing is generally applied to structures with a main floor elevation already above the design protection level but which still incur significant damages due to the presence of basements and vulnerable utilities. Treatments include the vacating or filling of basements, removal of utilities, and the provision of equivalent facilities above the design protection level. Wet floodproofing also includes a number of minor treatments such as the raising of exterior air conditioning units and the provision of louvers in crawlspace walls to allow the equalization of hydrostatic pressure.
- Ringwall: the structure (and in some cases, groups of closely adjacent structures) is encircled by a small floodwall constructed to the design protection elevation.

The design protection level for this analysis was based on the 2071 water surface elevation with a 1% annual chance of being equaled or exceeded (the “100-year flood”) plus one foot. While nonstructural measures reduce the risk of damage to individual structures and their contents, they are assumed not to reduce damages to exterior items such as vehicles and landscaping. It should also be noted that except for ringwalls and dry floodproof measures, some residual structure damage can still be incurred below the design level of protection following the implementation of nonstructural measures. The structures identified for nonstructural treatments under Alternative 3A are summarized in Table 15.

Table 15
Nonstructural Measures Applied to Structures in 10% ACE Floodplain

Damage Reduction Measure	Residential	Non Residential	Total
Dry Flood Proofing		2	2
Elevate Structure	136	4	140
Ringwall Around Structure	35	69	104
Wet Flood Proofing	3	4	7
TOTAL	**174**	**79**	**253**

5.4.1 Residual Damages and Benefits

Using HEC-FDA, Average Annual Damages were calculated for the base year and future years with Alternative 3A in place, and Equivalent Annual Damages were calculated for the 50-year period of analysis, using the 2017 fiscal year USACE project evaluation and formulation discount rate of 2.875%.

Analysis Procedures for Ringwalls

With-project damages for structures located behind ringwalls were calculated by changing the above-first floor elevation at which damages begin for each structure relative to the assigned ringwall height. For example, structure 5312 has a ground elevation of 9.34, a foundation height of 0.5 feet (first floor elevation 9.84 feet NAVD88), and is located behind a ringwall will have a top elevation of 14.4 feet NAVD88. Under with-project conditions, the "begin damage" elevation for structure 5312 is set to 4.56 (14.4 – (9.34 + 0.5)) to simulate a floodwall with an elevation of 4.56 feet above first floor. FDA output for the analysis of Structure 5312 (analysis year 2071 static data – no R&U parameters) is provided below in Table 16.

Table 16
Structure 5312 Floodwall Simulation for With-Ringwall Damage Estimate

Event	Stage	First Floor Depth	Without Project Damage	With Ringwall Damage
2 Yr	8.75	-1.09	0	0
5 Yr	9.98	0.14	54	0
10 Yr	10.68	0.84	279	0
25 Yr	11.48	1.64	515	0
50 Yr	12.43	2.59	744	0
100 Yr	13.39	3.55	946	0
250 Yr	14.71	4.87	1,237	1,237
500 Yr	16.42	6.58	1,392	1,392

As shown in the table generated from HEC-FDA output, without-project damages begin when the ground-level of Structure 5312, as flooding encroaches on the structure's foundation (located -0.5 feet below the main floor). With a ringwall in place, damages begin to accrue when the height of the ringwall is exceeded – 4.56 feet above the main floor elevation. Note that with-ringwall 4 damages for the 250 year event and the 500 year event are identical to without-project damages for those analysis years and frequency events – proving that the approach for simulating a levee is valid.

A summary of equivalent annual damages and flood damage reduction benefits by damage reach for Alternative 3A is presented in Table 17, and a summary of equivalent annual damages and flood damage reduction benefits by economic reach for Alternative 3A is presented in Table 18.

Table 17
Summary of Damages and Benefits for Alternative 3A: Damage Reaches

Stream	Damage Reach	Without Project Damages	With Alternative 3A Damages	Damage Reduction Benefits
Carteret & Woodbridge	A-CW-4-L	623,500	179,800	443,700
	B-CW-4-R	147,600	147,600	0
	C-CW-2-L	213,900	205,400	8,500
	D-CW-2-R	3,312,300	1,018,500	2,293,800
	U-CW-1B-L	950,400	374,900	575,500
	U-CW-1B-R	9,300	9,300	0
	U-CW-1-L	872,700	747,000	125,700
	U-CW-1-R	3,001,000	2,318,800	682,200
	U-CW-3-L	49,800	49,800	0
	U-CW-3-R	481,600	240,000	241,600
Millburn-Clark	A-MB-1-L	33,100	33,100	0
	A-MB-1-R	532,500	56,300	476,200
	A-MB-2-L	204,200	159,100	45,100
	A-MB-2-R	15,000	15,000	0
Rahway	A-RR-1-L	2,126,800	291,800	1,835,000
	A-RR-2-L	265,100	63,800	201,300
	CH-RR-3-L	669,900	83,100	586,800
	CH-RR-3-R	15,000	15,000	0
	E-RR-1-R	588,600	416,000	172,600
	N-RR-2-R	169,800	169,800	0
Robinsons Branch	A-RB-L	673,900	353,200	320,700
	A-RB-R	381,600	263,700	117,900
South Branch	B-SB-2-R	61,300	53,900	7,400
	E-SB-1-L	194,500	138,400	56,100
	U-SB-1-R	8,200	8,200	0
	U-SB-2-L	1,107,500	912,200	195,300
	U-SB-3-R	817,500	525,300	292,200
TOTAL		17,526,500	8,849,000	8,677,500

Price Level: October 2016, Discount Rate: 2.875%

Table 18
Summary of Damages and Benefits for Alternative 3A: Economic Reaches

Economic Reach	Subcategory	Without Project Damages	With Alternative 3A Damages	Damage Reduction Benefits	Reach Benefits
Reach A	Alt 1 Levee	3,185,200	705,100	2,480,000	4,199,300
	Existing Levee	588,600	416,000	172,600	
	No Levee	2,525,300	978,600	1,546,700	
Reach B	Alt 1 Levee	208,800	201,400	7,400	7,400
Reach C	Alt 1 Levee	213,900	205,400	8,500	8,500
Reach D	Alt 1 Levee	3,312,300	1,018,500	2,293,800	2,293,800
Reach E	Existing Levee	194,500	138,400	56,100	56,100
Reach U	No Levee	7,297,900	5,185,500	2,112,500	2,112,500
TOTAL		17,526,500	8,849,000	8,677,500	8,677,500

5.4.2 Cost Estimate

A summary of the costs and benefits for Alternative 3A is presented in Table 19.

Table 19
Alternative 3A Costs and Benefits

First Cost	623,323,356
Interest During Construction	10,290,951
Total Investment Cost	633,614,307
Annual Investment Cost	24,044,450
Annual O&M Cost	2,875,748
Total Annual Cost	26,920,198
Annual Benefits	8,677,500
Net Benefits	-18,242,698
BCR	0.3

Price Level: October 2016, Discount Rate: 2.875%

5.5 Alternative 3B: Nonstructural Treatment (2% Annual Chance Exceedance (ACE) Floodplain)

Under Alternative 3B, nonstructural treatments were applied to structures located within the study area 2% ACE floodplain using a spreadsheet matrix which considered physical characteristics including building configuration, usage, footprint size, foundation type, and existing main floor elevation in order to select and cost the most appropriate/feasible treatment for each structure.

The methodology and assumptions used to assign nonstructural treatments to individual structures under Alternative 3B were identical to those for Alternative 3A, though the structure population used for the analysis of Alternative 3B was comprised of 581 structures. The structures identified for nonstructural treatments are summarized in Table 20.

Table 20
Nonstructural Measures Applied to Structures in 2% ACE Floodplain

Damage Reduction Measure	Residential	Non Residential	Total
Dry Flood Proofing	11	37	48
Elevate Structure	287	5	292
Ringwall Around Structure	76	110	186
Wet Flood Proofing	51	4	55
TOTAL	**425**	**156**	**581**

5.5.1 Residual Damages and Benefits

Using HEC-FDA, Average Annual Damages were calculated for the base year and future years with Alternative 3B in place, and Equivalent Annual Damages were calculated for the 50-year period of analysis, using the 2017 fiscal year USACE project evaluation and formulation discount rate of 2.875%. A summary of equivalent annual damages and flood damage reduction benefits by damage reach for Alternative 3B is presented in Table 21, and a summary of equivalent annual damages and flood damage reduction benefits by economic reach for Alternative 3B is presented in Table 22.

Table 21
Summary of Damages and Benefits for Alternative 3B: Damage Reaches

Stream	Damage Reach	Without Project Damages	With Alternative 3B Damages	Damage Reduction Benefits
Carteret & Woodbridge	A-CW-4-L	623,500	131,500	492,000
	B-CW-4-R	147,600	147,600	0
	C-CW-2-L	213,900	156,100	57,800
	D-CW-2-R	3,312,300	851,100	2,461,200
	U-CW-1B-L	950,400	326,300	624,100
	U-CW-1B-R	9,300	9,300	0
	U-CW-1-L	872,700	657,500	215,200
	U-CW-1-R	3,001,000	2,293,300	707,700
	U-CW-3-L	49,800	49,800	0
	U-CW-3-R	481,600	219,800	261,800
Millburn-Clark	A-MB-1-L	33,100	30,500	2,600
	A-MB-1-R	532,500	54,100	478,400
	A-MB-2-L	204,200	92,600	111,600
	A-MB-2-R	15,000	13,300	1,700
Rahway	A-RR-1-L	2,126,800	207,400	1,919,400
	A-RR-2-L	265,100	41,900	223,200
	CH-RR-3-L	669,900	64,600	605,300
	CH-RR-3-R	15,000	15,000	0
	E-RR-1-R	588,600	394,100	194,500
	N-RR-2-R	169,800	169,800	0
Robinsons Branch	A-RB-L	673,900	333,500	340,400
	A-RB-R	381,600	177,400	204,200
South Branch	B-SB-2-R	61,300	35,600	25,700
	E-SB-1-L	194,500	124,400	70,100
	U-SB-1-R	8,200	8,200	0
	U-SB-2-L	1,107,500	885,200	222,300
	U-SB-3-R	817,500	350,400	467,100
TOTAL		17,526,500	7,840,000	9,686,500

Price Level: October 2016, Discount Rate: 2.875%

Table 22
Summary of Damages and Benefits for Alternative 3B: Economic Reaches

Economic Reach	Subcategory	Without Project Damages	With Alternative 3B Damages	Damage Reduction Benefits	Reach Benefits
Reach A	Alt 1 Levee	3,185,200	550,500	2,634,600	4,573,300
	Existing Levee	588,600	394,100	194,500	
	No Levee	2,525,300	780,900	1,744,200	
Reach B	Alt 1 Levee	208,800	183,200	25,700	25,700
Reach C	Alt 1 Levee	213,900	156,100	57,800	57,800
Reach D	Alt 1 Levee	3,312,300	851,100	2,461,200	2,461,200
Reach E	Existing Levee	194,500	124,400	70,100	70,100
Reach U	No Levee	7,297,900	4,799,700	2,498,200	2,498,200
TOTAL		17,526,500	7,840,000	9,686,500	9,686,500

5.5.2 Cost Estimate

A summary of the costs and benefits for Alternative 3B is presented in Table 23.

Table 23
Alternative 3B Costs and Benefits

First Cost	973,143,314
Interest During Construction	104,626,626
Total Investment Cost	1,077,769,939
Annual Investment Cost	4
Annual O&M Cost	4,495,920
Total Annual Cost	45,395,226
Annual Benefits	9,686,500
Net Benefits	-35,708,726
BCR	0.2

Price Level: October 2016, Discount Rate: 2.875%

5.6 Alternative 4: Levee Segment D & Nonstructural Treatment (10% Annual Chance Exceedance (ACE) Floodplain)

Alternative 4 provides a combination of non-structural and structural measures. The structural measure is Levee Segment D (a component of Alternative 1), located on the right bank of the Carteret & Woodbridge River between the beginning (downstream) Station of 14731.32 and ending (upstream) Station of 17565.28. The levee would be constructed with a top elevation of 12.6 ft. NAVD88. This stationing corresponds to the HEC-FDA damage reach named D-CW-2-R, which includes a total of 197 structures and 291 residentially-owned automobiles.

Non-structural treatments were developed for a total of 149 structures, as outlined in Table 24 below.

Table 24
Nonstructural Measures Applied – Alternative 4

Damage Reduction Measure	Residential	Non Residential	Total
Dry Flood Proofing		2	2
Elevate Structure	124	6	130
Ringwall Around Structure		13	13
Wet Flood Proofing	1	3	4
TOTAL	**125**	**24**	**149**

Numbers of structures by stream and damage reach are provided in the Table 25 below. In total, Alternative 4 provides risk reduction to 342 structures – 149 through non-structural treatments, and 197 through Levee Segment D – Levee segment D also provides risk reduction to 291 residentially-owned automobiles.

Table 25
Numbers of Structures by Alternative 4 Treatment

Stream	Damage reach	Alt 4 Action	Structures	Reach Structures
Carteret-Woodbridge	A-CW-4-L	Elevate Structure	4	6
		Elevate-Demolish and Rebuild	1	
		Wet Floodproofing	1	
	C-CW-2-L	Elevate Structure	1	1
	D-CW-2-R	Levee Segment D @ Elevation 12.6 Ft. NAVD88	197 Structures 291 Autos	197 Structures 291 Autos
	U-CW-1-R	Elevate Structure	21	24
		Elevate-Demolish and Rebuild	1	
		Wet Floodproofing	2	
	U-CW-1B-L	Elevate Structure	43	43
	U-CW-3-R	Ringwall	1	1
Millburn-Clark	A-MB-1-R	Elevate Structure	7	8
		Ringwall	1	
	A-MB-2-L	Elevate Structure	3	3
Rahway River	A-RR-1-L	Elevate Structure	31	38
		Elevate-Demolish and Rebuild	1	
		Ringwall	6	
	A-RR-2-L	Elevate Structure	3	3
Robinsons Branch	A-RB-L	Elevate Structure	7	8
		Wet Floodproofing	1	
	A-RB-R	Dry Floodproofing	1	5
		Elevate Structure	4	
South Branch	B-SB-2-R	Elevate Structure	3	3
	U-SB-2-L	Dry Floodproofing	1	4
		Ringwall	3	
	U-SB-3-R	Ringwall	2	2
TOTALS	**Non-Structural Treatment**			**149**
	Structures Located Behind Levee Segment D			**197**
	Autos Located Behind Levee Segment D			**291**
	Structures Addressed through Alternative 4			**346**

5.6.1 Residual Damages and Benefits

Using HEC-FDA, Average Annual Damages were calculated for the base year and future years with Alternative 4 in place, and Equivalent Annual Damages were calculated for the 50-year period of analysis, using the 2017 fiscal year USACE project evaluation and formulation discount rate of 2.875%. A summary of equivalent annual damages and flood damage reduction benefits by damage reach for Alternative 4 is presented in Table 26, and a summary of equivalent annual damages and flood damage reduction benefits by economic reach for Alternative 4 is presented in Table 27.

Table 26
Summary of Damages and Benefits for Alternative 4: Damage Reaches

Stream	Damage Reach	Without Project Damages	With Alternative 4 Damages	Damage Reduction Benefits
Carteret & Woodbridge	A-CW-4-L	623,500	453,700	169,800
	B-CW-4-R	147,600	147,600	0
	C-CW-2-L	213,900	205,400	8,500
	D-CW-2-R	3,312,300	962,000	2,350,300
	U-CW-1B-L	950,400	379,400	571,000
	U-CW-1B-R	9,300	9,300	0
	U-CW-1-L	872,700	872,700	0
	U-CW-1-R	3,001,000	2,352,200	648,800
	U-CW-3-L	49,800	49,800	0
	U-CW-3-R	481,600	239,900	241,700
Millburn-Clark	A-MB-1-L	33,100	33,100	0
	A-MB-1-R	532,500	264,300	268,200
	A-MB-2-L	204,200	192,800	11,400
	A-MB-2-R	15,000	15,000	0
Rahway	A-RR-1-L	2,126,800	1,254,500	872,300
	A-RR-2-L	265,100	219,200	45,900
	CH-RR-3-L	669,900	669,900	0
	CH-RR-3-R	15,000	15,000	0
	E-RR-1-R	588,600	588,600	0
	N-RR-2-R	169,800	169,800	0
Robinsons Branch	A-RB-L	673,900	607,200	66,700
	A-RB-R	381,600	342,200	39,400
South Branch	B-SB-2-R	61,300	53,600	7,700
	E-SB-1-L	194,500	194,500	0
	U-SB-1-R	8,200	8,200	0
	U-SB-2-L	1,107,500	915,600	191,900
	U-SB-3-R	817,500	541,100	276,400
TOTAL		17,526,500	11,756,600	5,769,900

Price Level: October 2016, Discount Rate: 2.875%

Table 27
Summary of Damages and Benefits for Alternative 4: Economic Reaches

Economic Reach	Subcategory	Without Project Damages	With Alternative 4 Damages	Damage Reduction Benefits	Reach Benefits
Reach A	Alt 1 Levee	3,185,200	2,097,200	1,088,000	1,473,700
	Existing Levee	588,600	588,600	0	
	No Levee	2,525,300	2,139,600	385,700	
Reach B	Alt 1 Levee	208,800	201,200	7,700	7,700
Reach C	Alt 1 Levee	213,900	205,400	8,500	8,500
Reach D	Alt 1 Levee	3,312,300	962,000	2,350,300	2,350,300
Reach E	Existing Levee	194,500	194,500	0	0
Reach U	No Levee	7,297,900	5,368,100	1,929,800	1,929,800
TOTAL		17,526,500	11,756,600	5,769,900	5,769,900

5.6.2 Cost Estimate

A summary of the costs and benefits for Alternative 4 is presented in Table 28.

Table 28
Alternative 4 Costs and Benefits

First Cost	180,535,678
Interest During Construction	11,041,013
Total Investment Cost	191,576,691
Annual Investment Cost	7,269,969
Annual O&M Cost	466,278
Total Annual Cost	7,736,246
Annual Benefits	5,769,900
Net Benefits	-1,966,346
BCR	0.7

Price Level: October 2016, Discount Rate: 2.875%

5.6.3 Additional Ringwall Analyses for Plan Formulation Evaluations

Individual ringwall performance metrics were developed to aid in refinement of Alternative 4. Alternative 4 calls for seven ringwalls to provide coastal storm risk reduction to a total of 13 structures, as outlined in Table 29 below.

Table 29
Alternative 4 Ringwall Groups and Structures

Ringwall Group	Stru	Ringwall Elevation	Damage Reach
R001	5405	14.4	U-SB-3-R
R001	5406	14.4	U-SB-3-R
R002	5312	14.4	U-SB-2-L
R003	5381	14.4	U-SB-2-L
R003	5382	14.4	U-SB-2-L
R004	5751	14.4	U-CW-3-R
R005	1173	14.4	A-RR-1-L
R006	1175	14.4	A-RR-1-L
R006	1370	14.4	A-RR-1-L
R006	1371	14.4	A-RR-1-L
R006	1372	14.4	A-RR-1-L
R006	1373	14.4	A-RR-1-L
R007	5093	16.0	A-MB-1-R

To analyze performance of the ringwalls, a separate HEC-FDA model was developed that analyzed only the 13 structures for which ringwalls were specified under Alternative 4. The results of the model for the 13 structures are shown below in Table 30.

Table 30
Ringwall Risk Reduction Performance Under Alternative 4

Damage Reach & Stream	Ringwall Groups	Without Project Damages ($)	Alternative 4 Damages ($)	Alternative 4 Benefits ($)
U-SB-3-R South Branch	R001	397,200	122,900	274,300
U-SB-2-L South Branch	R002, R003	268,300	64,600	203,700
U-CW-3-R Carteret-Woodbridge	R004	254,300	9,600	244,700
A-RR-1-L Rahway River	R005, R006	574,300	40,100	534,200
A-MB-1-R Milburn-Clark	R007	132,100	7,200	124,900
TOTAL		**1,626,200**	**244,400**	**1,381,800**

Damage reaches in the HEC-FDA model were used to isolate the without-project and Alternative 4 (with ringwall) damages for the following Ringwall Groups:

- R001 (damage reach U-SB-3-R);
- R004 (damage reach U-CW-3-R); and
- R007 (damage reach A-MB-1-R).

With- and without-project damages for structures within Ringwall Groups R002, R003, R005, and R006 were isolated by developing additional separate HEC-FDA models that contain structures within:

- R002 (Structure No. 5312 evaluated); and
- R005 (Structure No. 1173 evaluated).

As such, damages for Ringwall Group R003 were isolated by subtracting the results of Ringwall Group R002 (which includes ONE structure from damage reach U-SB-2-L) from the overall ringwall total for damage reach U-SB-2-L. Similarly, damages for Ringwall Group R006 were isolated by subtracting the results of Ringwall Group R005 (which includes ONE structure from damage reach A-RR-1-L) from the overall ringwall total for damage reach A-RR-1-L.

Isolated damages under with- and without-project conditions are provided for each of the ringwall groups in Table 31 below.

Table 31
Individual Ringwall Risk Reduction Performance under Alternative 4

Ringwall Group	Damage Reach & Stream	Without Project Damages	Alternative 4 Damages	Alternative 4 Benefits
R001	U-SB-3-R South Branch	397,200	122,900	274,300
R002	U-SB-2-L South Branch	122,600	33,400	89,200
R003	U-SB-2-L South Branch	145,700	31,200	114,500
R004	U-CW-3-R Carteret-Woodbridge	254,300	9,600	244,700
R005	A-RR-1-L Rahway River	522,900	35,300	487,600
R006	A-RR-1-L Rahway River	51,400	4,800	46,600
R007	A-MB-1-R Milburn-Clark	132,100	7,200	124,900
	TOTAL	**1,626,200**	**244,400**	**1,381,800**

5.7 Alternative 4a: Levee Segment D & Nonstructural Treatment without Ringwalls (10% Annual Chance Exceedance (ACE) Floodplain)

Alternative 4a provides a combination of non-structural and structural measures, similarly to Alternative 4. The structural measure is Levee Segment D, just as it is in Alternative 4. The levee would be constructed with a top elevation of 12.6 ft. NAVD88. The difference between Alternative 4 and Alternative 4a is that the ringwalls have been removed in Alternative 4a.

Non-structural treatments were developed for a total of 136 structures, as outlined in Table 32 below.

Table 32
Nonstructural Measures Applied – Alternative 4a

Damage Reduction Measure	Residential	Non Residential	Total
Dry Flood Proofing		2	2
Elevate Structure	124	6	130
Wet Flood Proofing	1	3	4
TOTAL	**125**	**11**	**136**

Numbers of structures by stream and damage reach are provided in the Table 33 below. In total, Alternative 4a provides risk reduction to 333 structures – 136 through non-structural treatments, and 197 through Levee Segment D – Levee segment D also provides risk reduction to 291 residentially-owned automobiles.

Table 33
Numbers of Structures by Alternative 4a Treatment

Stream	Damage reach	Alt 4a Action	Structures	Reach Structures
Carteret-Woodbridge	A-CW-4-L	Elevate Structure	4	6
		Elevate-Demolish and Rebuild	1	
		Wet Floodproofing	1	
	C-CW-2-L	Elevate Structure	1	1
	D-CW-2-R	Levee Segment D @ Elevation 12.6 Ft. NAVD88	197 Structures 291 Autos	197 Structures 291 Autos
	U-CW-1-R	Elevate Structure	21	24
		Elevate-Demolish and Rebuild	1	
		Wet Floodproofing	2	
	U-CW-1B-L	Elevate Structure	43	43
Millburn-Clark	A-MB-1-R	Elevate Structure	7	8
			1	
	A-MB-2-L	Elevate Structure	3	3
Rahway River	A-RR-1-L	Elevate Structure	31	38
		Elevate-Demolish and Rebuild	1	
			6	
	A-RR-2-L	Elevate Structure	3	3
Robinsons Branch	A-RB-L	Elevate Structure	7	8
		Wet Floodproofing	1	
	A-RB-R	Dry Floodproofing	1	5
		Elevate Structure	4	
South Branch	B-SB-2-R	Elevate Structure	3	3
	U-SB-2-L	Dry Floodproofing	1	4
			3	
TOTALS	**Non-Structural Treatment**			**136**
	Structures Located Behind Levee Segment D			**197**
	Autos Located Behind Levee Segment D			**291**
	Structures Addressed through Alternative 4a			**333**

5.7.1 Residual Damages and Benefits

Using HEC-FDA, Average Annual Damages were calculated for the base year and future years with Alternative 4a in place, and Equivalent Annual Damages were calculated for the 50-year period of analysis, using the 2017 fiscal year USACE project evaluation and formulation discount rate of 2.875%. A summary of equivalent annual damages and flood damage reduction benefits by damage reach for Alternative 4a is presented in Table 34, and a summary of equivalent annual damages and flood damage reduction benefits by economic reach for Alternative 4a is presented in Table 35.

Table 34
Summary of Damages and Benefits for Alternative 4a: Damage Reaches

Stream	Damage Reach	Without Project Damages	With Alternative 4a Damages	Damage Reduction Benefits
Carteret & Woodbridge	A-CW-4-L	623,500	453,700	169,800
	B-CW-4-R	147,600	147,600	0
	C-CW-2-L	213,900	205,400	8,500
	D-CW-2-R	3,312,300	962,000	2,350,300
	U-CW-1B-L	950,400	379,400	571,000
	U-CW-1B-R	9,300	9,300	0
	U-CW-1-L	872,700	872,700	0
	U-CW-1-R	3,001,000	2,352,200	648,800
	U-CW-3-L	49,800	49,800	0
	U-CW-3-R	481,600	484,600	-3000
Millburn-Clark	A-MB-1-L	33,100	33,100	0
	A-MB-1-R	532,500	389,200	143,300
	A-MB-2-L	204,200	192,800	11,400
	A-MB-2-R	15,000	15,000	0
Rahway	A-RR-1-L	2,126,800	1,788,700	338,100
	A-RR-2-L	265,100	219,200	45,900
	CH-RR-3-L	669,900	669,900	0
	CH-RR-3-R	15,000	15,000	0
	E-RR-1-R	588,600	588,600	0
	N-RR-2-R	169,800	169,800	0
Robinsons Branch	A-RB-L	673,900	607,200	66,700
	A-RB-R	381,600	342,200	39,400
South Branch	B-SB-2-R	61,300	53,600	7,700
	E-SB-1-L	194,500	194,500	0
	U-SB-1-R	8,200	8,200	0
	U-SB-2-L	1,107,500	1,119,300	-11,800
	U-SB-3-R	817,500	541,100	2,100
TOTAL		17,526,500	13,138,400	4,388,100

Price Level: October 2016, Discount Rate: 2.875%

Table 35
Summary of Damages and Benefits for Alternative 4a: Economic Reaches

Economic Reach	Subcategory	Without Project Damages	With Alternative 4a Damages	Damage Reduction Benefits	Reach Benefits
Reach A	Alt 1 Levee	3,185,200	2,631,400	553,800	
	Existing Levee	588,600	588,600	0	814,600
	No Levee	2,525,300	2,264,500	260,800	
Reach B	Alt 1 Levee	208,800	201,200	7,700	7,700
Reach C	Alt 1 Levee	213,900	205,400	8,500	8,500
Reach D	Alt 1 Levee	3,312,300	962,000	2,350,300	2,350,300
Reach E	Existing Levee	194,500	194,500	0	0
Reach U	No Levee	7,297,900	6,090,800	1,207,100	1,207,100
TOTAL		17,526,500	13,138,400	4,388,100	4,388,100

5.7.2 Cost Estimate

A summary of the costs and for Alternative 4a is presented in Table 36.

Table 36
Alternative 4a Costs and Benefits

First Cost	65,502,480
Interest During Construction	3,215,681
Total Investment Cost	68,718,161
Annual Investment Cost	2,607,723
Annual O&M Cost	47,610
Total Annual Cost	2,655,332
Annual Benefits	4,388,100
Net Benefits	1,732,768
BCR	1.7

Price Level: October 2016, Discount Rate: 2.875%

6 Comparison of Alternatives

A summary of all damages, benefits, costs, and subsequent benefit-cost ratios for the two structural plans, two nonstructural plans, and two combination plan evaluated for the Rahway River Basin Coastal Storm Risk Management Study is presented in Table 37.

This study has been conducted in accordance with ER 1105-2-101, "Risk Analysis for Flood Damage Reduction Studies (USACE, January 3, 2006), which stipulates that the risk analysis for a flood protection project should quantify the performance of all alternatives and evaluate the residual risk, including the consequences of the project's capacity exceedance. Table 38 quantifies the performance of all alternatives in accordance with ER 1105-2-101.

Table 37
Summary of Benefits and Costs

	Inundation Damages						
	Without Project	With Project	Annual Benefits	First Cost	Annual Cost	Net Benefits	BCR
Alternative 1 Levee/Floodwall with Channel Modification	17,526,500	11,940,300	5,586,200	$106,506,651	$4,760,697	$825,503	1.2
Alternative 2 Tidal Surge Barrier	17,526,500	11,181,100	6,345,400	$988,808,637	$47,012,307	-$40,666,907	0.1
Alternative 3A Nonstructural Treatment (10% Annual Chance Exceedance Floodplain)	17,526,500	8,849,000	8,677,500	$623,323,356	$26,920,198	-$18,242,698	0.3
Alternative 3B Nonstructural Treatment (2% Annual Chance Exceedance Floodplain)	17,526,500	7,840,000	9,686,500	$973,143,314	$45,395,226	-$35,708,726	0.2
Alternative 4 Levee Segment D and Nonstructural Treatment (10% Annual Chance Exceedance Floodplain)	17,526,500	11,756,600	5,769,900	$180,535,678	$7,736,246	-$1,966,346	0.7
Alternative 4a Levee Segment D and Nonstructural Treatment without Ringwalls (10% Annual Chance Exceedance Floodplain)	$17,526,500	$13,138,400	$4,388,100	$66,900,321	$2,650,871	$1,737,229	1.7

Price Level: October 2016, Discount Rate: 2.875%
Annual Cost includes First Cost, IDC, and O&M

6.1 Tentatively Selected Plan

The Tentatively Selected Plan (TSP) is Alternative 4a. The benefit and costs for 4a are summarized in Table 38.

Table 38
TSP Benefit-Cost Summary

	TSP
First Cost	$66,900,321
Interest During Construction	$1,598,186
Total Investment Cost	$68,498,507
Annual Investment Cost	$2,599,387
O&M	$51,484
Annual Cost	$2,650,871
Without Project Damages	$17,526,500
With Project Damages	$13,138,400
Annual Benefits	$4,388,100
Net Benefits	$1,737,229
Benefit Cost Ratio	1.7

6.2 Project Performance and Risk Analysis

This study has been conducted in accordance with ER 1105-2-101, "Risk Analysis for Flood Damage Reduction Studies (USACE, January 3, 2006), which stipulates that the risk analysis for a flood protection project should quantify the performance of all alternatives and evaluate the residual risk, including the consequences of the project's capacity exceedance. Table 39 quantifies the performance of all alternatives in accordance with ER 1105-2-101.

Table 39
Expected and Probabilistic Values of Damage Reduced by Alternative

	Equivalent Annual Damages			Probability that Damage Reduced Exceeds the Indicated Values		
	Without Project	With Project	Damage Reduced	75%	50%	25%
Alternative 1 Levee/Floodwall with Channel Modification	17,526,500	11,940,300	5,586,200	3,837,100	5,409,000	7,201,600
Alternative 2 Tidal Surge Barrier	17,526,500	11,181,100	6,345,400	4,148,100	6,288,500	8,598,500
Alternative 3A Nonstructural Treatment (10% Annual Chance Exceedance Floodplain)	17,526,500	8,849,000	8,677,500	6,030,800	8,591,400	11,190,100
Alternative 3B Nonstructural Treatment (2% Annual Chance Exceedance Floodplain)	17,526,500	7,840,000	9,686,500	6,538,400	9,532,400	12,662,600
Alternative 4 Levee Segment D and Nonstructural Treatment (10% Annual Chance Exceedance Floodplain)	17,526,500	11,756,600	5,769,900	4,265,800	5,799,800	7,222,800
Alternative 4a Levee Segment D and Nonstructural Treatment without Ringwalls (10% Annual Chance Exceedance Floodplain)	17,526,500	13,138,400	4,388,100	3,567,300	4,485,900	5,266,100

Price Level: October 2016, Discount Rate: 2.875%