Raritan Bay and Sandy Hook Bay
Highlands, New Jersey
Coastal Storm Risk Management
Feasibility Study

Appendix C
Economics

May 2020

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May 2020

BOROUGH OF HIGHLANDS, NEW JERSEY
FINAL FEASIBILITY STUDY
APPENDIX C - ECONOMICS

U.S. Army Corps of Engineers New York District

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INTRODUCTION

REPORT PURPOSE AND SCOPE

1. This report was prepared to document procedures and results of the economic storm damage analysis for the Borough of Highlands, New Jersey Feasibility Study. This report presents the findings of economic assessments for the without-project and with–project future conditions.
2. Economic analyses include the development of stage versus damage relationships and annual damages over a 50-year analysis period, from year 2026 to year 2076. Damage assessments include tidal inundation and wave damages.

CONDITIONS

3. Estimates of without-project damages are based on October 2019 (FY20) price levels and a 50-year period of analysis. Damages have been annualized over the 50-year period of analysis using the 2020 fiscal year federal water resource studies discount rate of 2.75%.
4. Included in this economics report are:
    - Description of the Study Areas,
    - Identification of the without-project future conditions,
    - Summary of the flood damage analysis methodologies,
    - Summary of the wave damage analysis methodologies,
    - Summary of the report findings.

STUDY AUTHORIZATION

5. A combined beach erosion control and storm damage protection study for Raritan Bay and Sandy Hook Bay, New Jersey, including the Borough of Highlands, was authorized by a resolution of the U.S. House of Representatives Committee on Public Works and Transportation and adopted August 1, 1990. The resolution states that:

"Resolved by the Committee of Public Works and Transportation of the U.S. House of Representatives, that the Board of Engineers for Rivers and Harbors is requested to review the report of the Chief of Engineers on the Raritan Bay and Sandy Hook Bay, New Jersey, published as House Document 464, Eighty-seventh Congress, Second Session, and other pertinent reports, to determine the advisability of modifications of the recommendations contained therein to provide erosion control and storm damage prevention for the Raritan Bay and Sandy Hook Bay ."

6. The project, including incomplete construction, was re-authorized by the Water Resources Development Act of 1996 (Public Law 104-303, approved October 12, 1996, 110 Stat. 3658).

PRIOR STUDIES

7. The existing Federal project was authorized by the Flood Control Act of October 12, 1962 in accordance with House Document 464, Eighty-seventh Congress, Second Session. This project resulted in shore protection improvements in certain municipalities; however, improvements in the Borough of Highlands were not considered economically feasible and therefore, were not recommended.

8. A Reconnaissance Study Report for Raritan Bay and Sandy Hook Bay was completed in March 1993. The Raritan Bay and Sandy Hook Bay study area is a 21-mile stretch located between Sandy Hook and the mouth of the Raritan River. The area has been subject to storm damage and major flooding.

9. The purpose of the Reconnaissance Study was to identify and evaluate possible solutions to storm damage problems, to determine if there was local support for a potential project, to make recommendations with regard to the continuation of the study, and to develop a scope of study and cost estimate for a feasibility study.

10. The Reconnaissance Report focused on the community of Port Monmouth, a section of Middletown Township, and identified potential Federal interest for the communities of Middletown Township, Highlands, Union Beach, Keyport, and Cliffwood Beach. Considering the complexity of coastal processes and interior drainage in the area, and lack of hard data, a pre-feasibility study within a greater level of detail was undertaken to verify interest in conducting feasibility level studies.

11. The pre-feasibility study for the Borough of Highlands was completed in February 1999 and determined that there likely was Federal interest in a coastal storm risk management project. The State of New Jersey supported the findings and is participating as the cost share partner

for the Feasibility Study. The State of New Jersey is sharing the non-Federal cost of the study with the Borough of Highlands.

DESCRIPTION OF THE STUDY AREA

LOCATION

12. The study area is contained within the Borough of Highlands in northeast Monmouth County in the State of New Jersey. The land area consists of approximately 0.7 square miles located between the Sandy Hook Bay and the Navesink River. Monmouth County is located along the Atlantic Coastal Plain Physiographic Province and is bordered by four (4) counties: Middlesex to the north, Mercer and Burlington to the west and Ocean to the south. It is situated 26 miles south from New York City, with parts of Highlands Borough sitting on the highest point of land on the Atlantic coastline.

13. Overall, the Borough of Highlands is approximately 2,000 feet wide. It is characterized by primarily low, flat terrain for about 1,500 feet inland from Sandy Hook Bay, after which the ground rises dramatically to an elevation of 240-feet North American Vertical Datum of 1988 (NAVD88). Shorelines in the eastern portion near Sandy Hook and the Shrewsbury River and in the southwestern portion near Middletown consist of low-lying marsh. The Highlands Borough business district as well as the central sections are protected by assorted public and private bulkheads, seawalls and revetments.

ACCESSIBILITY

14. Vehicle: The study area is convenient to major population centers, including New York City, through a network of modern highways, routes, tunnels and bridges. New Jersey State Route 36 runs east/west through Highlands providing direct access from the major corridors to the business district, shorefront and throughout the borough. Local routes connect with New Jersey State Highway Route 36, extending access to/from central Highlands and the shore points.
15. Rail and Bus: The community is serviced by New Jersey Transit (NJT) and Academy Bus Line which provide bus access to major commercial centers such as Philadelphia, Newark and New York City. The NJT buses provide connecting service throughout Monmouth County, to major airports, NJT Coast Line, Amtrak, Greyhound Lines, the Metropolitan Transportation Authority (MTA), Port Authority Trans-Hudson (PATH) trains, and the Port Authority of New York and New Jersey.

16. Ferry: The Highlands high speed ferry service provides water transportation from Highlands to New York City's Pier 11 (Wall Street) in 40 minutes and West 34th Street in 55 minutes. The passenger ferry service is operated by SeaStreak, a wholly-owned subsidiary of Sea

Containers Ltd., and provides service on a daily basis. The Highlands Terminal is located at Conners Hotel on Shore Drive. Parking lots are available to ferry commuters with additional parking at the municipal parking lots located on Shore Drive and on South Second Street.

RECREATION AND TOURISM

17. Beaches: Highlands' beaches consist of three small recreational areas. Additionally, the nearby Gateway National Recreation Area at Sandy Hook is composed of long stretches of beaches and dunes. South Bay Avenue Beach is situated along the Shrewsbury River in Highlands while the Miller Street Beach is located along the bay coastline. Snug Harbor Beach is positioned along the bay and is the largest of the three beaches with approximately 150 feet of beachfront. Snug Harbor also offers courts for tennis, volleyball and basketball.

18. Restaurants and "Bed & Breakfast" Inns: Highlands boasts a variety of seafood restaurants; most located along Bay Avenue in the business district. Charter boats from the Borough provide locals and tourists the ability to enjoy recreational fishing. Commercial fishermen catch clams, lobsters and salt-water fish, selling directly to wholesalers and retailers in the local fish markets. Historic homes have been converted into bed & breakfast Inns, attracting locals and tourists alike to the area.

19. Parks: Highlands also has several recreational parks including the Mt. Mitchell Scenic Overlook Park and the nearby Hartshorne Woods Park. The Monmouth County Park System (MCPS) has incorporated the former Highlands Army Air Defense military reservation into its Hartshorne Woods Park. MCPS is currently considering restoration of the buildings and artillery gun batteries that were not intentionally destroyed when the U.S government stopped using the site.

POPULATION

20. State, County & Borough: As shown in Table 1, the population for the Borough of Highlands increased from 3,916 in 1970 to 5,005 in 2010 (28%). This is lower than the county-wide growth rate of 36% during the same period.

TABLE 1 – HISTORICAL AND PROJECTED POPULATIONS
BOROUGH OF HIGHLANDS, NJ

Area Name	Census 1970	Census 1980	Census 1990	Census 2000	Census 2010	Projected 2025
New Jersey	7,171,112	736,5011	773,0188	841,4350	8,791,894	9,446,200
Monmouth County	461,849	503,173	553,124	615,301	630,380	694,189
Highlands	**3,916**	**5,187**	**4,849**	**5,097**	**5,005**	**5,168**

Source: Monmouth County Division of Planning Aug 6, 2012

21. These population growth trends have slowed, with county-wide growth of 2.5% between 2000 and 2010, while the population has actually decreased in Highlands. The population of Monmouth County is expected to increase at a rate of 10.1% between 2010 and 2025. In comparison, the Borough of Highlands is expected to experience minimal growth (3.3%) through 2025.

22. Density: The Borough of Highlands is heavily developed with a population density nearly six times the state average. The population per square mile (2010, US Census) for the State of New Jersey is 1,195.5 persons. The Monmouth County population density is 1337 persons per square mile, while the population density for the Borough of Highlands yields 7820 persons per square mile.

23. Ethnicity: Table 2 shows the ethnic composition of the Borough of Highlands. Whites comprise the majority of the local population (95%). African-Americans, Asian and "Other" comprise 1.0%, 0.3%, and 3.2 %, respectively.

TABLE 2 – ETHNICITY STATISTICS, BOROUGH OF HIGHLANDS		
Ethnicity Composition	**Total**	**%**
White	4,659	95.5
African Americans	49	1.0
Asian	16	0.3
Other	156	3.2
Total Persons:	***5,005***	***100***

Source- 2013-2017 American Community Survey 5-Year Estimates

24. Age: Table 3 provides a comparison between the ages of Highlands, Monmouth County and New Jersey residents for census year 2010. The most notable difference is the low proportion of children and adolescents in Highlands (16%) in comparison to Monmouth County (26%). A higher than typical proportion of Highlands residents, 3,564 persons (71.2%), are within the ages of 20 to 64 years, classified as working age. The median age for Highlands is similar to the State and county values.

TABLE 3 - 2010 POPULATION AND HOUSEHOLD STATISTICS BOROUGH OF HIGHLANDS, MONMOUTH COUNTY, NEW JERSEY						
	Borough of Highlands		Monmouth County		New Jersey	
	Total	%	Total	%	Total	%
Total Population Sex and Age	5,005		630,380		8,791,894	
Male	2,522	50.3	306,654	48.6	4,279,600	48.7
Female	2,483	49.6	323,726	51.4	4,512,294	51.3
Under 5 years	252	5.0	34,755	5.5	541,020	6.2
5 years to 19 years	545	10.9	130,723	20.7	1,750,183	19.9
20 years to 64 years	3,564	71.2	378,211	60.0	5,665,670	64.4
65 years and over	644	12.9	86,691	13.8	835,021	9.5
Median Age	45.1		41.3		39.0	
Total Households	2,623		233,983		3,214,360	
Family Households	1,160	44.2	163,389	69.8	2,226,606	69.3
Non-Family Households	1,463	55.8	70,954	30.3	987,754	30.7

Source- 2010 US Census

25. Households: Family households make up a lower percentage of the total households in the Borough of Highlands (44%) than the average in Monmouth County (69.8%) or the State (69.3%). The average household size is 1.9 persons in Highlands, compared to 2.8 for both the County and the State.

INCOME AND EMPLOYMENT

26. Income: Incomes in Highlands are low to moderate in comparison to Monmouth County. The median household income level for the county ($91,807) is $15,332 higher than the State ($76,475). Residents in the Borough of Highlands represent a high proportion of residents below the poverty line. The medium value of owner-occupied housing units in the Borough of Highlands, as reported by the 2010 Census, was 11% less than in the State overall, and 25% less than for Monmouth County, as shown in Table 4.

TABLE 4 – COMPARISON OF INCOMES FROM American Community Survey				
Indicator	**Highlands**	**Monmouth**	**New Jersey**	**United States**
Per Capita Income	$50,288	$46,311	$34,858	$27,334
Median Household Income	$60,817	$91,807	$76,475	$57,652
Individual Below Poverty Line (% of Population)	7.2%	7.6%	10.7%	14.6%
Median Value of Owner Occupied Housing Unit	$319,200	$424,800	$357,900	$188,900

Source-2013-2017 American Community Survey 5-Year Estimates

27. Labor Force: As shown in Table 5, the Borough of Highlands' unemployment rate (4.6%) is higher than the unemployment rates for Monmouth County (6%) and for State of New Jersey (7%). The total employed population over 16 years of age in the Borough of Highlands numbered 2,847. Education, health and social services occupations employed 18.0% of the working population. Management professional, scientific administrative and waste management was the second largest employment sector (17.7%), followed by finance, insurance, real estate, rental and leasing (15.7%), and retail trade (9.5%). Construction accounts for 6.9% of employment, and farming and related occupations account for 0.4%.

TABLE 5 – 2011 EMPLOYMENT DATA, BOROUGH OF HIGHLANDS, MONMOUTH COUNTY, NEW JERSEY			
Employment Status	**Borough of Highlands**	**Monmouth County**	**New Jersey***
Population Aged 16 years or over	4,422	507,976	7,197,215
In Labor Force	2,983	334,798	4,724,242
Employed	2,847	314,470	4,388,024
Unemployed	136	19,969	328,167
% Unemployment	4.6%	6%	7%

Source-2013-2017 American Community Survey 5-Year Estimates

ECONOMY AND LAND USE

28. The Borough of Highlands was incorporated in 1900. At that time the local economy was based around three main water-dependent industries: fishing, boating and clamming. In its early years the community supported a prosperous clamming industry. While overuse and pollution nearly devastated the industry, clamming recently began making a successful comeback. Although most of the clams harvested in the area of Raritan and Sandy Hook Bays are not fit for immediate consumption, clams may be purified at a depuration plant, or transplanted to cleaner water for a minimum of 30 days. The J. T. White depuration plant in Highlands is one of two facilities operating in Monmouth County.

29. The economy of Monmouth County has undergone extensive growth in recent years with much of the development concentrated along the major transportation routes. The majority of non-residential development has been for office and research facilities. According to the U.S. Census Bureau, there were 21 business establishments in the Borough of Highlands in 2012 with a total of 198 employees having an average annual payroll of $21,394.

30. The majority of land in the project area contains residential (approximately 70% of Borough area) and commercial and marine development (approximately 30% of Borough area) within the low-lying areas along the Sandy Hook Bayshore (NJ Future 2014). Commercial development is concentrated along Route 36, Bay Avenue and Linden Avenue.

HOUSING UNITS

31. As presented in Table 6, of the total residential housing units reported by the U.S. Census Bureau for 2010, there were 1,398 detached single family houses, 214 attached single family houses, 1,299 multi-family units, and 128 mobile homes located within the Borough. About half of the units were built before 1969 (1,661 total) with some dating to 1939 and earlier. The next growth period in housing in this area was during the 1970's and 1980's, when 1,137 new units were built. Between 1990 and 2000, 94 new units were constructed, and between 2000 and 2010, 147 new housing units were built in the Borough.

TABLE 6 –SUMMARY OF HOUSING UNITS-2006- 2010 HIGHLANDS, NEW JERSEY	
Land Use/Category	**Community Total Number**
Single Family Residential (detached)	1,398
Single Family Residential (attached)	214
Multi-Family Residential (2 to 4 units)	477
Multi-Family Residential (5 to 9 units)	139
Multi-Family Residential (> 10 units)	683
Mobile/Trailer Residential	128
Total Housing Units	**3,039**
Vacant /Seasonal Housing Units	605
Total Occupied Units:	***2,434***

Source: U.S. Census Bureau, 2010 Census

DESCRIPTION OF THE PROBLEM

32. The majority of development in the Borough of Highlands is located between the waters of Sandy Hook Bay or the Shrewsbury River, and a bluff extending up to 240 feet NAVD88. Sandy Hook acts as a barrier preventing the Atlantic Ocean waves and storm surges from breaking on the shore of the Highlands. This low lying area is vulnerable to severe tidal inundation and wave damage. Most of the development is located below the +9-foot NAVD88 contour placing it within the regulated 100-year floodplain.

33. In addition to tidal inundation, the topography in the Highlands creates significant flooding due to the ponding of rainfall and runoff. In the center of the Borough, a topographic depression is developed as elevations slope gently away from the shoreline forming an area where floodwaters pond during periods of heavy rain. This problem is most pronounced when heavy rainfall coincides with abnormally high tides or storm surge. The Borough maintains numerous storm drains and two pump stations which help to reduce the severity of this interior flooding. Nevertheless, flooding in the Borough is pervasive, potentially affecting nearly all of the developed properties.

STORM HISTORY

34. A series of coastal storms have impacted the Borough of Highlands over the years, causing evacuations and extensive damage from both flooding and wave overtopping of low-lying bulkheads. According to the Federal Insurance and Mitigation Administration (FIMA), there are a total of 1,050 flood insurance policies in force within the Borough, with a total insured value of approximately $198,000,000 as of July 2016.

35. Both extra-tropical storms (nor'easters) and hurricanes have impacted the Raritan and Sandy Hook bayshore areas. These storms produce wind and wave-driven surges that cause extensive flooding within the study area. Storm surges also frequently block existing storm water outlets, resulting in prolonged and extensive interior flooding.

36. Some of the most damaging storms that have impacted the Borough of Highlands include the following:

    - <u>Hurricane of September 14, 1944</u> – This hurricane caused damage losses estimated at over $2,500,000 (1944 dollars) in the bayshore area. Peak tide height reached +7.3 feet NAVD88 in the area from Highlands to Keyport and 12.0 inches of rain were recorded in New Brunswick. At Highlands, the storm caused damage to streets, sewers, water lines and bulkheads. About 150 homes, 20 hotels, numerous stores and the sewage and water treatment facility were inundated. Several pavilions were also destroyed by waves.

- Extra-tropical Storm of November 25, 1950 - This storm, which produced tides of +8.0 feet NAVD88 at Keyport, caused over $2,000,000 (1950 dollars) of damage in the bayshore area. According to newspaper accounts, there were two deaths, one in Union Beach and another in Keansburg. Rainfall totaled approximately 2.5 inches. The accompanying high tide in the New York Harbor area was up to 2 feet above the previous maximum recorded during the 1944 hurricane.

  At Leonardo, Atlantic Highlands, and Highlands, boats and piers were severely damaged by tide and wave action in Sandy Hook Bay. The entire downtown section of Highlands was flooded resulting in the evacuation of residents and heavy damage to many commercial establishments. The beaches and many streets in the area were also damaged.

- Extra-tropical Storm of November 6-7, 1953 – Total estimated damage for this storm was estimated at $1,630,000 (1953 dollars). At Long Branch (Atlantic Coast), the strongest wind was measured at 78 miles per hour from the east. Total rainfall was estimated at 1.25 inches. Flooded tracks near South Amboy and other places resulted in loss of railway service along the entire north shore. The State Legislature of New Jersey organized the "Legislative Commission to Study Sea Storm Damage" as a result of the severe damage from the storm. The Commission found that direct damage to public property in the bayshore area was approximately $374,000 (1953 dollars).

- Hurricane Donna (September 12, 1960) – Total estimated damage for this Hurricane on the bayshore was $6,000,000 (1960 dollars). More than half of the total damages included damage to homes which were flooded or destroyed. Another one-third of the loss was the result of structural and stock damage to stores, restaurants and waterfront concession. Tides produced by the hurricane reached +7.6 feet NAVD88 with wind gusts up to 79 mph. A total of 4.5 inches of rainfall was reported at Morgan. In Highlands water was 4 to 5 feet deep on the main street and a large number of stores and homes were flooded. Newspapers carried reports of raw sewage floating in the streets. A recently constructed bulkhead was flanked by the tide and the street behind the bulkhead was washed out.

- Nor'easter of March6-8, 1962 – During this storm, maximum water levels at the Battery and at Willets Point were +6.6 and +8.1 feet NAVD88, respectively. Damage to beaches, bluffs, buildings and erosion control structures on the bayshore were estimated at nearly $1,200,000.

- January 23, 1966 – Strong winds occurring during high tide caused flooding on the bay shore. Many residents had to be rescued from their homes during this event.

- November 11, 1977 – At the time of its occurrence, this storm was identified by many as the worst storm in recent history. The 7 inches of rain that fell in a 24 hour period caused homes to be flooded and left most local roadways closed.

- March 29, 1984. – This Northeaster caused widespread damage along the entire Mid-Atlantic coast. Water levels reached a peak of +6.0 feet NAVD88 at Sandy Hook, with a peak surge of 6.1 feet above predicted tides. Most of the low-lying streets of Highlands were under water through the day with water levels 3 to 4 feet above the roadways. More than 300 residents were evacuated, many by boat. The northern section of Highlands was most severely affected; the area bounded to the south by Bay Avenue was almost completely inundated. More than 80 cars were submerged.

- Nor'easter of December 11-12, 1992 – Gale force winds in combination with high tides caused the worst flooding in decades on the bay shore. Thousands of homes were damaged or destroyed and hundreds of residents were evacuated as floodwaters inundated local neighborhoods. A section of bulkhead at the end of Snug Harbor at Highlands was destroyed, possibly contributing to the severe inundation damages suffered by the low-lying town. Other bulkheads suffered moderate damage. In a garage attached to the second house on Water Witch Way, landward of the bulkhead, the water level reached 4 to5 feet above the ground elevation. This level of inundation appeared to be typical of all the homes in the town within five blocks of the water front. Widespread flooding resulted in vast amounts of furniture, debris and personal belongings stacked along the sidewalks awaiting removal. In one instance, flooding also prevented emergency response to a fire which destroyed a five-unit residential building.

  Nearly $5,300,000 in flood insurance claims were paid for damage within the Highlands as a result of the 1992 storm. Nearly 600 Highlands residents registered for emergency assistance and 249 housing assistance grants were issued. A total of 283 small business administration loan applications were filed as the Borough struggled to recover from this major disaster.

- Hurricane Sandy October 29, 2012 – As the storm traveled up the Atlantic coastline after originating in the Caribbean, three weather systems combined to form a super storm. The storm became the largest Atlantic hurricane of record with winds spanning approximately 1,100 miles. The size and the energy of the storm caused unprecedented damage along the northern Atlantic coastline including damage to infrastructure, businesses and residences from flooding, wave action and erosion. The addition of the full moon tide over several tidal cycles caused damage to more than 40,000 residences in New Jersey.

  The 12-17 foot storm surge caused damage to approximately 1,200 of the 1,500 homes and almost all of the businesses in the downtown area. The preliminary evaluation estimated that approximately 800 of the 1,200 damaged structures would require being elevated almost 14 feet. The waterfront trailer park was wiped out by the storm surge and wave action.

Widespread damage was also caused to many of the borough facilities and infrastructure including, Highlands Borough Hall, Highlands fire house, Highlands first aid building, the DPW garage, community center, pumping stations, electrical facilities, park facilities, and roadways. Preliminary estimates for repairs for damage to the municipal properties were in excess of $15 million.

WITHOUT-PROJECT FUTURE CONDITIONS

37. The Borough of Highlands without-project future conditions have been identified as:

- worsening tidal flooding and wave impacts as continued sea level rise contributes to future storm damage; and
- reconstruction of substantially damaged buildings to levels above the regulated Base Flood Elevation in accordance with floodplain management regulations.

38. It is expected that storms will continue to occur into the future, causing damage in this area. 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 Sandy Hook, a 0.014-foot per year increase is anticipated, resulting in a 0.7-foot increase over the 50-year period of analysis for the project. In future years this will result in more frequent and higher stages of flooding.

39. According to the FEMA Flood Insurance Rate Map (FIRM), virtually all of Highlands Borough has been classified as a "Special Flood Hazard Area" inundated by the 100-year flood. In order to regulate land development in the floodplain, the Borough of Highlands has adopted and enforces various ordinances and regulations. Highlands Flood Damage Prevention Ordinance (0-99-11 Part 7, Article XXIV of the Zoning Ordinance, adopted August 18, 1999) has a primary purpose to prevent construction and development from increasing flooding as well as to ensure public safety and reduce property damage. The ordinances and regulations call for elevating buildings above the adopted Base Flood Elevation (BFE) for both new construction projects and substantial improvements to existing structures.

40. The overall future condition of the study area is uncertain whether or not action is taken. However, the most likely scenario can be extrapolated. Due to the Zoning Ordinance, several structures have been demolished or elevated above the BFE for the area (+12ft NAVD88). Further, the prevention of future construction limits economic analysis to existing structures.

FLOOD DAMAGE

GENERAL

41. In order to address the storm damage problem in Highlands, various alternatives were developed to provide additional coastal storm risk management. These alternatives were developed in coordination with the New Jersey Department of Environmental Protection (NJDEP), the non-Federal Sponsor, and in conjunction with input from local municipalities and other interested parties.

42. The following basic steps were used in the analysis of inundation damage:
    - Assignment of evaluation reaches,
    - Inventory structures within the 500-year floodplain,
    - Estimate depreciated structure replacement costs,
    - Assign generalized stage vs. damage relationships to each structure,
    - Calculate aggregated stage versus damage relationships, and
    - Calculate average annual damages.

43. Flood damage calculations were performed using the Hydrologic Engineering Center's Flood Damage Analysis (HEC-FDA) computer program version 1.4. 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 the existing without- project and future without-project conditions.

ECONOMIC REACHES

44. In order to conduct economic benefit analyses of alternative plans and to simplify the stage versus damage and subsequent interior drainage analyses, the study area was divided into eleven economic reaches. To more accurately define proposed levee and floodwall limits two economic reaches (five and seven) were further divided into additional sub reaches. Economic reach selection was determined by the criteria below. Reach description and structure counts are provided in Table 7.
    - <u>Interior drainage areas</u>: High ground between drainage areas was identified and the structures within these areas were assigned to reaches corresponding to the drainage areas. This delineation simplified the HEC-FDA stage versus damage modeling and will simplify corresponding alignment of the reaches with the interior drainage modeling.

- Existing shorefront: Some structures along the shorefront are susceptible to wave attack damage in addition to flood damage during major storms. The existing shore structures provide varying levels of coastal storm risk management to these buildings. Reach boundaries were assigned at significant changes in the existing level of performance. These structures were assigned to be separate databases for analysis of wave damage.
- Potential study area limits: Certain areas of the community may be outside some of the area to directly benefit from the project. Identifying those areas as separate reaches facilitates eventual modeling of the benefit cost ratio (BCR) differences between the alternatives.

45. The study area has been divided into eleven economic reaches. To define these reaches, the study area was first divided into segments (typically about 100 feet wide) by overlaying Location Identifiers (LIDs), or 'stations,' upon the study area map. Beginning with LID 1 in Atlantic Highlands Corporate limits, LIDs were drawn at approximately 500-foot intervals eastward to Shrewsbury River Bridge, providing a total of 20 LIDs. Economic Reaches were further defined by its bounding LIDs.

46. By using LIDs to divide the study area into a series of smaller units, unique characteristics of individual segments of the study area were taken into account during plan formulation. This allowed for the evaluation of different levels of flood risk management alternatives for different portions of the study area. A map of the economic reaches described above is presented in Figure1.

Figure 1:
Economic Reach Delineation

TABLE 7 – OVERVIEW OF ECONOMIC REACHES AND STRUCTURES IN STUDY AREA				
Economic Reach	**Description**	**Number of Structures**		
		Res.	**Non-Res.**	**Total**
1.0	Reach 1 – Station 0+00 to 1+00 The westernmost reach (approx. 500 feet) extended from Atlantic Highlands Corporate limits to Willow Street.	17	0	17
2.0	Reach 2 – Station 1+01 to 2+00 From Willow Street extending (approx. 285 feet) to east end of Bulkhead located in front of Bay view Garden Apartments.	57	2	59
3.0	Reach 3 – Station 2+01 to 3+00 Extended eastward (approx. 1,330 feet) from Bulkhead (Retaining Wall at Sta. 2+00) to West of Gravelly Point Road.	22	3	25
4.0	Reach 4 – Station 3+01 to 6+00 Reach extending (approx. 1,110 feet) from West of Gravelly Point Road to Snug Harbor Avenue.	108	2	110
5.0	Reach 5- Station 6+01 to 12+00 Reach extending (approx. 2,400 feet) from Snug Harbor Avenue to Sea Drift Avenue.	228	13	241
5.1	Reach 5.1- Station 12+01 to 13+00 Reach Extending (approx. 690 feet) from Sea Drift Avenue to Atlantic Street.	24	2	26
6.0	Reach 6 – Station 13+01 to 16+99 Reach extending (approx. 1.275 feet) from Atlantic St. to Miller St.	230	16	246
7.0	Reach 7 – Station 17+00 to 20+00 Reach extending (approx. 2,420 feet) from Miller Street to New Jersey State Highway 36 Highlands Bridge*.	*126*	*28*	*154*
7.1	Reach 7.1 – Station 18+00 to 19+00 North of Shrewsbury Avenue (approx. 930 feet) between Jackson Avenue and South Street.	*12*	*2*	*14*
7.2	Reach 7.2 – Station 20+00 Optional alignment (approx. 480 feet) East of Veterans Memorial Park	*2*	*9*	*11*
7.3	Reach 7.3 – Station 20+00 End alignment (approx. 400 feet)	*0*	*2*	*2*
	Total:	***826***	***79***	***905***

INVENTORY METHODOLOGY

47. To accomplish the damage analysis, the development of a structural data base was needed to assist in predicting flood damages. The structural base data was originally generated through inspection of structures in the project area obtained through a "windshield survey", which was conducted in late 2003. Topographic mapping with a 2-foot contour interval used as a base map. Table 8 (below) indicates the physical characteristics obtained for the building inventory during the windshield survey.

TABLE 8 – PHYSICAL CHARACTERISTICS OBTAINED FOR BUILDING INVENTORY			
1)	Structure ID		
2)	Map Number	10)	Quality of Construction
3)	Type	11)	Current Condition
4)	Usage	12)	Ground Elevation*
5)	Size	13)	Main Floor Elevation
6)	Story	14)	Low Opening
7)	Basement Type	15)	Reach
8)	Number of Garage Openings	16)	Notes/Description (as required)
9)	Exterior Construction		

*Note: * Ground elevations collected in NGVD29, subsequently converted to NAVD88.*

48. Each structure (or distinct usage type where multiple usages occur within a single building) was assigned a unique structure identification number (SRID) using Geographical Information System (GIS) database map. A GIS query was used to determine the structure footprint sizes which were adjusted for porches, decks, etc. according to observations in the field. The data collected was used to categorize the structure population into groups having common physical features. For each structure, data was also gathered pertaining to its damage potential including ground, main floor elevations, and lowest opening elevations.

49. After the Sandy storm, Highlands enforced restrictions on new developments in the flood zone and issued 195 permits for elevations and demolitions of damaged and vulnerable structures. The structure inventory was revised accordingly for the analysis and there remained a total of 905 structures.

50. Tables 9 and 10 summarize the finding of the structure inventory survey by structure type and the floodplain.

TABLE 9 – SUMMARY OF STRUCTURE INVENTORY BY STRUCTURE TYPE							
Economic Reach	**Damage Categories**						***Totals by Reach***
	Apartment	**Commercial**	**Industrial**	**Municipal**	**Residential**	**Utility**	
1.0	0	0	0	0	17	0	*17*
2.0	0	2	0	0	57	0	*59*
3.0	5	3	0	0	17	0	*25*
4.0	0	2	0	0	108	0	*110*
5.0	0	12	0	0	228	1	*241*
5.1	0	2	0	0	24	0	*26*
6.0	1	8	4	3	229	1	*246*
7.0	1	26	0	0	125	2	*154*
7.1	0	2	0	0	12	0	*14*
7.2	0	5	3	0	2	0	*11*
7.3	0	3	0	0	0	0	*2*
Totals:	***7***	***65***	***7***	***3***	***817***	*4*	*905*

TABLE 10 – SUMMARY OF STRUCTURE INVENTORY BY FLOODPLAIN								
BUILDINGS WITH GROUND ELEVATIONS AT OR BELOW FLOOD LEVEL								
Economic Reach	**2-Yr**	**5-Yr**	**10-Yr**	**25-Yr**	**50-Yr**	**100-Yr**	**200-Yr**	**500-Yr**
1.0	0	9	14	17	17	17	17	17
2.0	12	21	37	48	55	59	59	59
3.0	2	2	3	12	24	25	25	25
4.0	47	104	109	109	110	110	110	110
5.0	212	228	231	232	238	241	241	241
5.1	13	16	17	18	24	26	26	26
6.0	147	197	213	245	246	246	246	246
7.0	130	148	151	152	154	154	154	154
7.1	47	104	109	109	114	114	114	114
7.2	0	4	6	7	11	11	11	11
7.3	0	0	2	2	2	2	2	2
Total	***572***	***738***	***794***	***853***	***905***	***905***	***905***	***905***

Based on base year water surface elevations – see Table 12

STRUCTURE VALUES

51. The depreciated replacement value of each building in the floodplain was updated from August 2003 to October 2019 price level utilizing a limited survey update of 300 structures randomly selected from the original structure inventory. Square foot building costs were

then calculated for these structures using 2016 RSMeans (adjusted to 2019 levels). The original analysis combined the physical characteristics obtained in the inventory with standard unit prices per square foot. Updated costs for the remaining structures in the inventory were determined based upon cost adjustment factors derived from the partial survey update. Depreciation was then calculated based on the quality and condition of each structure. The estimated structure values were subsequently updated to October 2019 price levels using the appropriate quarterly index published in EM 1110-2-1304. The total depreciated replacement value of all structures within the study area is estimated to be $265,900,000. Depreciated structure values by economic reach are summarized in Table 11. The original inventory was also revised to remove buildings destroyed by Hurricane Sandy and those subsequently demolished, based on information provided by Borough officials and a review of publicly available information.

TABLE 11 –DEPRECIATED STRUCTURE REPLACEMENT VALUE BY ECONOMIC REACHES

Economic Reach	Depreciated Replacement Value
1	$2,000,000
2	$9,000,000
3	$30,400,000
4	$28,300,000
5	$59,800,000
5.1	$14,900,000
6	$63,100,000
7	$47,600,000
7.1	$4,200,000
7.2	$2,800,000
7.3	$3,800,000
TOTAL All Reaches:	***$265,900,000***

October 2019 Price Level

STAGE FREQUENCY DATA

52. Stage-Frequency curves for the analysis of project damages and benefits were taken from the North Atlantic Coast Comprehensive Study location ID 3555. All future year stages include 0.7 feet sea level rise, calculated in accordance with current guidance (EC 1165-2-2111). Note that the waves arrive at the shoreline at a 45-degree angle of incidence and waves are in a non-breaking condition at the shoreline. Accordingly non-wave setup is included in these still water flood levels.

53. In accordance with ER 1100-2-8162, potential relative sea level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence. Fluvial studies that include backwater profiling should also include potential relative sea level change in the starting water surface elevation for such profiles, where appropriate. Table 12 presents the summary of stage frequency data for base and future years. The base year was adjusted from 2021 in the draft report to 2026 for this final report and the water surface profiles were updated accordingly. The historic / low scenario was used for updating WSP because "it provides a useful minimum baseline for projecting future change in mean sea level to enable the analysis".

TABLE 12 SUMMARY OF STAGE VERSUS FREQUENCY DATA, EXISTING AND FUTURE CONDITION Feet, NAVD88

Condition	2-Yr / 50% ACE	5-Yr / 20% ACE	10-Yr / 10% ACE	20-Yr / 5% ACE	50-Yr / 2% ACE	100-Yr / 1% ACE	200-Yr / 0.5% ACE	500-Yr / 0.2% ACE
Base year	6.1	7.2	8.0	8.9	10.2	11.5	13.1	15.1
Future	6.7	7.8	8.6	19.5	10.8	12.1	13.7	15.7

ACE = Annual Chance Exceedance

54. The frequency of exceedance of stages in the Sandy Hook Bay was originally developed from a simulation of recorded and possible storm tide conditions developed from the period 1933-2003; the 70 year period of record. The historic rate of future sea-level rise is determined directly from gauge data gathered in the vicinity of the study area. Subsequently, tide conditions at Sandy Hook (National Oceanic and Atmospheric Administration (NOAA) Station #8531680) best represent the conditions experienced in Highlands. Therefore the NACCS 75-year record (1932 to 2006) of tide data gathered at Sandy Hook, NJ was used in the analysis to construct stage versus frequency confidence bands based on the order statistics approach within the Hydraulic Engineering Center Flood Damage Assessment Program.

INUNDATION DAMAGE FUNCTIONS

55. Based on the type, usage and value of each structure inventoried, Generalized Depth-Percent Damage functions were used to calculate inundation damage for each structure in the analysis. Using structure and ground elevation data these depth versus damage relationships were converted to corresponding stage (from NGVD 29 to NAVD88) versus damage relationships. Damages for individual structures at various stages were

aggregated according to structure type (residential, apartment, commercial, etc.) and location (reach).

56. Two separately developed sets of damage functions formed the basis of the curves used in the analysis. The Passaic River Basin Study (PRB) damage functions were originally developed in 1982 as part of the Passaic River Basin Feasibility Study. The Functions were later updated in 1995. PRB functions were developed for specific residential and non-residential (commercial, industrial, municipal, and utility) structure types.

57. The U.S. Army Corps of Engineers (USACE), generic depth-percent damage functions were developed for residential structures with and without basements and published in Electronic Guidance Memoranda 01-03 (December 4, 2000) and 04-01 (October 10, 2003).

58. For a single family residential structure (except for bi-level and raised ranch residences) the USACE damage functions have been used. For all other single and multi-family residence structures, Passaic River Basin damage functions were assigned. Residential content values for the damage functions assigned were determined in accordance with current guidelines found in Engineering Manual EM 1110-2-1619. For Passaic River Basin functions, content value was assumed to be 43.5% of the structure value, while for single-family residences assigned the generic USACE functions, content values were assumed to be 100% of the structure value, in accordance with EGM 01-03 and 04-01.

59. The generic USACE depth-damage curves may be used for this study since these curves are intended for nation-wide use and no rationale is required to demonstrate applicability in an individual floodplain (ER 1105-2-100). Since the non-residential development in the study area is relatively limited, the development of location-specific functions was not warranted, and the PRB functions were considered appropriate for use since the study areas are nearby (approximately 30 miles apart) and have similar building stock.

60. Three categories of damage were considered; damage to structure, content and other for each building. Other damage includes emergency costs, such as evacuation, debris cleanup and temporary housing. Components of other costs that were estimated, debris pick up and disposal and vehicular damage, where accounted for separately.

61. In addition to damage to structures and associated contents, the study attempted to capture damages to motor vehicles 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. To expedite this component of the analysis, the following 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:

1. It was assumed that 1.5 vehicles are associated with each housing unit in the Borough of Highlands, based on U.S. Census Bureau data.
2. 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.
3. Sedans were assumed to be the predominant vehicle type in the study area; hence the Sedan depth-damage function in Table 4 of EGM 09-04 was applied to all vehicles in the inventory.
4. 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 residential unit. For other residential structures, it was assumed that damage to motor vehicles is included in the "other" component of the assigned Passaic River Basin depth-damage functions.
5. The probability that vehicle owners would move their vehicles to higher ground before a flood was assumed to be 80%. In the absence of specific documented warning times in advance of flood events, this adjustment factor was derived from the average of the percentages given in Table 5 of EGM 09-04, revised slightly upwards to account for the fact that the frequent flooding experienced in the study area may influence residents' knowledge of the appropriate time to evacuate.
6. It was assumed that no vehicles remain outside non-residential structures during a flood event.
7. Certain assumptions made in calculating vehicle values introduce uncertainty. It is difficult to know with certainty the warning times which vary by storm. It is also noted that some cars may be evacuated to the town parking lots, which may still flood at a relatively high frequency. The number of cars and car values are based on general US Census averages and may be different with the actuals of the floodplain. While care was taken in estimating these values, a 30% coefficient of variation was used in the HEC-FDA program to account of this uncertainty.

62. A summary of the assumed distribution and value of vehicles included in the analysis is presented in Table 13:

TABLE 13: DISTRIBUTION OF MODELED MOTOR VEHICLE VALUES	
Reach	**Modeled Value***
1	$57,400
2	$178,400
3	$9,600
4	$315,500
5	$656,400
0.1	$60,500
6	$707,400
7	$353,700
7.1	$38,200
7.2	$0
7.3	$0
Project Total	*$2,377,100*

**Values adjusted for the probability that vehicles will be removed by owners prior to a flood event.*
October 2019 Price Level

63. The final category of benefits evaluated for this study was the cost to clear and dispose of storm damage debris subsequent to each damaging storm event. The estimation of debris costs utilized a matrix developed by the FEMA Modelling Task Force, debris removal costs from the NACCS Emergency Costs Report, and outputs from the Passaic Tidal Protection Area HEC-FDA model run for structures only. Table 14 shows an excerpt from the FEMA matrix, which categorized flood damage into four levels according to water depth: Affected, Minor, Major, and Destroyed. For each level, the matrix assigned a debris weight per 1,000 square feet of building area. Since wave damage was not incorporated into the damages for the Passaic Tidal Protection Area, the "Destroyed" category was not used.

Table 14 Tons of Debris by Flood Depth, as Estimated by FEMA MOTF Matrix		
Building Damage Level	**Water Depth Ft**	**Tons of Debris per 1,000 Sq Ft**
Affected	>0 to 2	2.05
Minor	>2 to 5	4.1
Major	>5	6.8

64. Structures in one of the output files from the without-project analysis in HEC-FDA were categorized into Residential and Nonresidential. For each flood event, structures were further categorized into one of three FEMA building damage levels according to water depth. Each structure's total footprint square footage was divided by 1000 and multiplied by a debris weight

according to the criteria in Table 14. The resulting debris weight was multiplied by an average tipping fee for the Northeast and Mid-Atlantic states, provided by the NACCS Emergency Costs Report. The resulting values were aggregated into reaches and grouped by flood event to be aligned with the appropriate stages and depths for each reach, at each flood event. This enabled reach-specific direct depth-damage functions to be derived and input to HEC-FDA to represent the cost of debris removal in each reach.

65. The tipping fee used to derive the debris functions was $71.14/ton for both residential and non-residential structures. This estimate was taken from the Emergency Costs section of the North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk. The estimated tipping fee produced by the study was derived from data focused on New York and New Jersey the areas that were most impacted by Hurricane Sandy and accurately represents cleanup charges for the study area.

AVERAGE ANNUAL INUNDATION DAMAGES

66. The 905 structures in the updated Highlands inventory were split into two data bases for analysis. A total of 841 structures were identified as outside of the wave damage area and were analyzed for flood damage only (the remaining 64 were analyzed for wave damage in addition to inundation). For these buildings, the stage versus damage data was combined with stage versus frequency data using the HEC-FDA program. The HEC-FDA program quantifies uncertainty in discharge-frequency, stage-discharge, and stage-damage functions and incorporates it into economic and performance analyses of alternatives. The process applies a procedure (Monte Carlo simulation) that computes the expected value of damage while accounting for uncertainty in the basic value. The HEC-FDA program presents results for expected annual damages and equivalent annual damages.

67. Under current USACE guidance, risk and uncertainty must be incorporated into flood damage reduction studies. The following areas of uncertainty were incorporated into the HEC-FDA program:

- stage frequency
- first floor elevation
- depreciated structure value
- content-to-structure value ratio
- other-to-structure value ratio

68. The HEC-FDA program allows uncertainty in stage-frequency to be calculated using equivalent record length, for which USACE Engineering Manual, EM 1110-2-1619, Table 4-5, was consulted. For the Borough of Highlands HEC-FDA models, an equivalent

record length of 75 years was assumed.

69. A first floor standard deviation of 0.6 feet was selected based on recommendations in the USACE Engineering Manual, EM 1110-2-1619, Table 6-5, and the 2-foot contour intervals provided in the project topographic mapping.

70. The analysis recognizes that estimates of depreciated structure value based on windshield inventories contain inherent uncertainty. Structure values are assumed to have a coefficient of variation of 10%. Engineering Manual EM 1110-2-1619 suggests that in lieu of better site-specific information, content-structure value ratios based on large samples of Flood Insurance Administration (FIA) claims records can be used (Table 6-4 in Engineering Manual EM 1110-2-1619). A coefficient of variation of 25% was applied to the content to value ratio. Since the damage functions present other damage as a percent of structure value, the other-to-structure value ratio was estimated to have a coefficient of variation of 10%.

71. The economic analysis includes the existing benefits afforded by high shorefront elevations and bulkheads. Since damages are limited until the storm surge overtops the existing bulkhead or high ground, the analysis of existing conditions considers a levee as part of existing conditions along the shorefront. This levee allows the existing level of performance to be taken into account when calculating project damages. The high ground elevation along the shorefront varies, but inundation will occur when waters overtop the bulkheads at the lowest elevations, identified as +5 feet NAVD88. Under existing conditions, it is assumed that no damages result until water levels exceed the crest of this structure.

72. For this final report, aggregated stage-damage functions represent total storm damages as the sum of damage inflicted to structure, content and other components of a given building. Public emergency costs have not yet been analyzed. Damages are represented by the output generated from the HEC-FDA models included in the attachments. Expected annual damages for each category due to inundation only for the without-project/existing condition, and for the without-project/future year conditions for all 905 structures in the inventory are provided in Tables 15 and 16. Equivalent annual inundation damages are provided in Table 17.

73. During the course of this analysis, from plan formulation to selection of the NED plan, the price levels have changed. Planning Guidance Notebook, ER 1105-2-100, requires that unit prices be updated to current price levels. Price level escalations would impact all categories and alternatives in a similar fashion and would therefore not change plan selection.

TABLE 15 SUMMARY OF WITHOUT-PROJECT CONDITION/BASE YEAR ANNUAL INUNDATION DAMAGE BY DAMAGE CATEGORIES AND DAMAGE REACHES									
Damage Reach	Damage Categories								Total *
	Apartment	Commercial	Debris	Industrial	Municipal	Residential	Utility	Auto	
1	$0	$0	$400	$0	$0	$75,700	$0	$6,700	$82,800
2	$0	$2	$1,800	$0	$0	$346,400	$0	$22,400	$392,000
3	$159,000	$2,400	$600	$0	$0	$253,000	$0	$300	$415,300
4	$0	$16,400	$5,300	$0	$0	$1,568,500	$0	$78,300	$1,668,500
5	$0	$1,063,900	$21,800	$0	$0	$4,130,700	$8,800	$241,500	$5,466,700
5.1	$0	$56,400	$1,500	$0	$0	$243,900	$0	$15,100	$316,900
6	$24,000	$1,148,100	$36,900	$112,000	$852,800	$5,382,100	$100	$195,900	$7,751,900
7	$0	$98,000	$0	$0	$0	$120,700	$0	$11,200	$229,900
7.1	$86,400	$3,806,200	$36,300	$0	$0	$4,973,800	$49,500	$144,200	$9,096,400
7.2	$0	$60,600	$0	$10,800	$0	$63,500	$0	$0	$134,900
7.3	$0	$21,100	$0	$0	$0	$0	$0	$0	$21,100
Total	*$269,400*	*$6,294,500*	*$104,600*	*$122,800*	*$852,800*	*$17,158,300*	*$58,400*	*$715,600*	***$25,576,400***

** Does Not Include Wave Damage*

TABLE 16 SUMMARY OF WITHOUT-PROJECT CONDITION/FUTURE YEAR ANNUAL INUNDATION DAMAGE BY DAMAGE CATEGORIES AND DAMAGE REACHES									
Damage Reach	Damage Categories								Total *
	Apartment	Commercial	Debris	Industrial	Municipal	Residential	Utility	Auto	
1	$0	$0	$600	$0	$0	$113,400	$0	$9,700	$123,700
2	$0	$30,400	$2,800	$0	$0	$517,600	$0	$30,400	$581,200
3	$247,400	$3,300	$800	$0	$0	$373,800	$0	$500	$625,800
4	$0	$24,200	$8,500	$0	$0	$2,137,600	$0	$103,900	$2,274,200
5	$0	$1,417,000	$31,900	$0	$0	$5,356,200	$10,800	$294,500	$7,110,400
5.1	$0	$84,400	$2,200	$0	$0	$321,700	$0	$19,100	$427,400
6	$32,700	$1,475,400	$48,400	$139,100	$1,058,400	$6,729,700	$100	$244,100	$9,727,900
7	$0	$140,500	$0	$0	$0	$169,200	$0	$13,800	$323,500
7.1	$,,1,000	$4,751,600	$47,300	$0	$0	$6,075,500	$71,400	$171,900	$11,228,700
7.2	$0	$96,300	$0	$16,400	$0	$100,600	$0	$0	$213,300
7.3	$0	$31,000	$0	$0	$0	$0	$0	$0	$31,000
Total	*$391,100*	*$8,054,100*	*$142,500*	*$155,500700*	*$1,058,400*	*$21,895,300*	*$82,300*	*$887,900*	***$32,667,100***

** Does Not Include Wave Damage* *Incorporating historical rate of sea level rise of 0.7 ft*

TABLE 17 SUMMARY OF WITHOUT PROJECT CONDITION EQUIVALENT ANNUAL INUNDATION DAMAGE									
Damage Reach	Damage Categories								Total *
	Apartment	Commercial	Debris	Industrial	Municipal	Residential	Utility	Auto	
1	$0	$0	$500	$0	$0	$90,000	$0	$7,800	$98,300
2	$0	$24,800	$2,200	$0	$0	$411,500	$0	$25,400	$463,900
3	$192,600	$2,700	$700	$0	$0	$298,900	$0	$400	$495,300
4	$0	$19,400	$6,500	$0	$0	$1,785,000	$0	$88,000	$1,898,900
5	$0	$1,198,200	$25,600	$0	$0	$4,596,800	$9,600	$261,700	$6,091,900
5.1	$0	$67,100	$1,700	$0	$0	$273,500	$0	$16,600	$358,900
6	$27,300	$1,272,600	$41,300	$122,300	$931,000	$5,894,600	$100	$214,200	$8,503,400
7	$0	$114,200	$0	$0	$0	$139,200	$0	$12,200	$265,600
7.1	$95,700	$4,165,800	$40,400	$0	$0	$5,392,800	$57,800	$154,700	$9,907,200
7.2	$0	$74,100	$0	$12,900	$0	$77,600	$0	$0	$164,600
7.3	$0	$24,800	$0	$0	$0	$0	$0	$0	$24,800
Total	*$315,600*	*$6,963,700*	*$118,900*	*$135,200*	*$931,000*	*$18,959,900*	*$67,500*	*$781,000*	***$28,272,800***

** Does Not Include Wave Damage. Damage calculated at 2.75% Interest rate, 50-year period of analysis, Price level October 2019*

74. The term annual chance exceedance (ACE) is used to characterize flood events in the Borough and their chance of being equaled or surpassed each year. A 10 year ACE event can happen in any given year as can a 100 year or 500 year event. Table 18 below presents the breakdown of structures in the floodplain at these different ACE events. Rarer events cause damage to more structures. Future total damages to structures in the floodplain are estimated to be over $150,000,000 for the rarest event (see Table 19).

Table 18. Number of Structures at Selected Annual Chance Exceedance Events*

Damage Category	10 Year	100 Year	500 Year
Apartment	2	3	3
Commercial	54	59	59
Industrial	3	4	4
Municipal	3	3	3
Residential	624	756	767
Utility	2	4	4
Total	688	829	840

*Does not include wave vulnerable structures

Table 19. Dollar Damages at Selected Annual Chance Exceedance Events*

Damage Category	10 Year	100 Year	500 Year
Apartment	$ 273	$ 1,413	$ 4,240
Commercial	$ 12,024	$ 20,960	$ 25,530
Industrial	$ 136	$ 289	$ 371
Municipal	$ 1,588	$ 2,264	$ 2,547
Residential	$ 33,041	$ 79,673	$ 123,632
Utility	$ 147	$ 296	$ 320
Total	$ 47,209	$ 104,895	$ 156,639

*In $1000's at FY20 price levels. Does not include wave vulnerable structures

WAVE DAMAGES

GENERAL

75. Shorefront areas in the Borough of Highlands are exposed to waves which can break against some buildings with enough force to destroy the structure. The Flood Insurance Rate Maps (FIRMs) for Highlands at study initiation in 2003 identified approximately 218 structures within the V Zone, a designation reflecting potential high velocity wave impacts. These structures, plus an additional 28 front or second row buildings, were screened for possible wave attack damages. Of the 246 structures initially considered, 89 structures along the Highlands shoreline were originally deemed susceptible to wave attack based on current topography. Following the Post-Sandy inventory update, 64 structures remained from the original 89. The structures were subjected to a modified form of structural damage analysis that incorporated inundation damage with wave damage. This analysis used life-cycle simulation to account for the impact of regulatory rebuilding limitations, which reduces the potential for repetitive building failure.

WAVE FAILURE CRITERIA

76. The shorefront area of Highlands has historically been susceptible to attack by wind driven waves from Raritan Bay and Lower New York Harbor. In order to simplify the stage vs. damage analysis while accounting for waves from both sources, the wave heights in the analysis were all assumed to be depth limited. This means that the wave generation (or wave height) is limited by water depth. Therefore, using FEMA's "Ways of Estimating Wave Heights in Coastal Hazard Areas" (April 1981), wave height transmission beyond manmade structures were assumed limited by the water depth leeward of protective structures. Review of available wave data indicates that the depth limited waves at the buildings are typically smaller than the arriving waves, verifying the approach of using depth limited waves.

77. A controlling elevation was established to determine the limiting water depth between the bay and the structure. It was selected as the highest elevation that occurs in the path of the incoming wave from the shoreline to the structure. This lowest still water depth that occurs as a result of the controlling elevation will limit the wave height arriving at the structure. In some cases, bulkheads also limit wave impact areas. These structures were considered effective until overtopped by still water.

78. Several studies of wave damage and structural stability have related wave height to building failure. The analysis for the nearby Sea Bright to Ocean Township study calculated that a 2.2-foot breaking wave is sufficient to incur 100% damage to most structures. Building failure (100% damage) was found to occur at a minimum still water depth of 2.8 feet over the controlling elevation. This reflects the critical 2.2-foot breaking wave occurring at 78% of the still water depth.

WAVE TRANSMISSION

79. The landward limit of the wave damage analysis was determined based on the depth limited arriving wave height and wave transmission beyond the first row of buildings. The wave transmission was calculated using procedures described in using FEMA's "Ways of Estimating Wave Heights in Coastal High Hazard Areas." The density of the number of structures per reach fronting the shoreline was used to determine the transmission coefficient. This coefficient was applied to the incoming first row wave heights to determine the wave heights approaching the second row of structures. From the resulting calculations, it was established that no second row structures are likely to fail from wave attack.

DEPTH - DAMAGE FUNCTIONS

80. After considering limits on wave transmission, it was determined in the original study that 43 of the 89 structures in the wave zone dataset were subject to failure within the expected range of still water elevations, and custom damage functions were developed for each of the those buildings to blend inundation functions with the wave failure results. Following the Post-Sandy inventory update, only 27 structures remained that were assigned the adjusted depth-damage functions.

81. The wave failure point used to modify the inundation damage curves assumes 100% damage when still water surface elevations exceed 2.8 feet above the controlling ground elevation. Controlling elevations were identified and used to calculate the resultant still water level at which failure would occur due to wave attack. The depth-percent damage functions for each of the affected structures were adjusted to transition from partial inundation damage to 100% damage at the failure depth (relative to main floor). The data was imported into the HEC-FDA program to aggregate stage damage relationships by reach and to calculate average annual damage.

EXISTING CONDITIONS DAMAGES

82. Existing without project condition damages were calculated using both the inundation only and the combined inundation and wave attack depth damage functions for each affected structure. Total existing condition base year average annual damage to structures in the area susceptible to wave damage is calculated to be $1,770,160. Of this total, $706,000 is attributable to inundation, and $422,000 is attributable to wave damage. The most significant center of wave damage is Reach 7, with $217,000 of average annual structure damage attributable to waves. The remaining reaches in the study area containing wave-vulnerable structures are Reaches 4 and 5, each with approximately $95,000 in annual wave damage to structures.

FUTURE CONDITIONS DAMAGES

83. In both with and without project future conditions, structures that experience substantial damage as defined by the National Flood Insurance Program must be rebuilt to meet V-Zone requirements, which generally results in elevation of the structure such that the lowest horizontal structural member is at or above the applicable base flood elevation plus the freeboard stipulated in the local floodplain management ordinance. This will reduce the potential for repetitive building failure and future damages. Conversely, continued sea level rise will increase the potential for future damages.

84. Previous flood risk reduction studies for the Borough of Highlands project area were conducted prior to Hurricane Sandy and included a risk-based lifecycle analysis to determine equivalent annual damages due to waves taking into account changes in development conditions due to potential future storms and the effects of sea level rise. A total of four post-storm developments and two sea level conditions were evaluated to simulate the combined effect on future annual damage.

85. For the current study, it has been assumed that Hurricane Sandy represented a worst-case wave damage scenario, and since the updated structure inventory reflects all structures demolished or elevated following the storm, the assumption that the number of structures susceptible to future wave damages will change over time is no longer considered valid. Therefore, the future wave damages and equivalent annual damage for structures in the wave zone may be computed using the current updated inventory in HEC-FDA and the additional risk-based lifecycle model is no longer required to capture the effect of the inventory changing over time in response to wave damages.

86. The wave damage results generated by HEC-FDA are presented in Table 20, along with a summary of the total structure value in each reach. The effects of baseline sea

level rise were incorporated by projecting the current historic rate of sea level rise to the future year, in accordance with the current guidance as per the calculation of inundation damages for structures outside the wave zone, as described above

TABLE 20 SUMMARY OF ANNUAL EQUIVALENT DAMAGES WITHIN THE WAVE ATTACK ZONE			
Reach	**Number of Structures**	**Total Depreciated Structure Replacement Value***	**Equivalent Annual Damage**
1	0	$0	$0
2	0	$0	$0
3	7	$16,018,000	$0
4	10	$4,875,000	$184,180
5	19	$3,449,000	$250,260
5.1	1	$2,289,000	$0
6	18	$3,921,000	$37,360
7	9	$7,035,000	$437,750
TOTALS:	***64***	***$37,587,000***	***$909,550***

*Damage attributable to wave damages, above the inundation damages presented in Table 17.
2.75% Discount Rate, 50-year Period of Analysis, Price Level October 2019

78. Of the $909,550 in equivalent annual wave damages, $500,000 (55%) is attributed to residential structures, while almost all of the remaining wave damage ($372,000) is attributed to commercial buildings.

79. Total estimated without project damages are summarized in Table 21 below:

TABLE 21 WITHOUT PROJECT SUMMARY OF TOTAL EQUIVALENT ANNUAL DAMAGE			
Reach	**Inundation Damage**	**Wave Damage**	**Total Damage**
1	$98,350	$0	$98,350
2	$463,920	$0	$463,920
3	$495,320	$0	$495,320
4	$1,898,900	$184,180	$2,083,080
5	$6,091,810	$250,260	$6,342,070
5.1	$358,900	$0	$358,900
6	$8,503,390	$37,360	$8,540,750
7	$9,907,260	$437,750	$10,345,010
7.1	$265,530	$0	$265,530
7.2	$164,650	$0	$164,650
7.3	$24,830	$0	$24,830
TOTALS:	***$28,272,860***	***$909,550***	***$29,182,410***

2.75% Interest Rate, October 2019 price level

WITH-PROJECT DAMAGES AND BENEFITS

NATIONAL ECONOMIC DEVELOPMENT PLAN

80. For this study, management measures were formulated into an array of Alternative Plans (herein called Alternatives). These alternatives include several combinations of the flood risk management measures including hard structural measures, beachfill and dune measures, an offshore barrier, nonstructural measures, and combinations thereof.

81. For comparison purposes, the alternatives were developed for a still water level (SWL) for a 2% flood (50-year return period) storm surge of elevation +8.1 ft. NAVD88, plus an anticipated sea level rise of +0.7 ft. (over the 50-year period of analysis), for a design storm surge elevation of +8.8 ft. NAVD88. A minimum inland crest elevation, where minimal surface wind wave action is anticipated, was set at elevation +10 ft. NAVD88, which is the design storm surge elevation of +8.8 ft. NAVD88, plus a value of +1.1 ft. for the height of small surface, wind generated inland waves.

82. Five initial alternatives were developed, in addition to the No Action Plan:

- No Action: A no-action plan means that no additional federal actions would be taken to provide for coastal storm risk management. It provides the base against which the with-project benefits are measured.

- Alternative 1- Hard Structural Plan: Alternative 1 consists of hard structural measures along the 8,000 ft of shorefront including vinyl coated, steel sheet pile floodwall driven in front of the existing bulkhead, tie-ins, closure gates, stone scour protection, interior storm water diversion pipes, gated interior outlets, and three pump stations with a total capacity of 180 cubic feet per second (cfs).

- Alternative 2 - Nonstructural Plan: This strategy consists of raising or relocating structures prone to flooding; using ring walls around vulnerable structures and streets; and utilizing wet and dry flood proofing of structures.

- Alternative 3 - Offshore Closure Plan: This strategy combines structural measures raised bulkheads and ground surfaces with an offshore breakwater that extends across Sandy Hook Bay.

- Alternative 4 – Dune and Beach Fill Plan: This strategy consists of structural measures and beach and dune fill in a portion of the project area where ever possible, in contrast to the hard structural measures in Alternative 1.

- Alternative 5 - Hybrid Plan: This strategy consists of structural measures formulated to be consistent with the land type that currently exists. It raises or caps existing bulkheads, calls for reinforced dunes where there are currently beaches, and includes raising of ground surfaces and streets where there is open, publicly owned space.

83. The first costs, net benefits, and benefit to cost ratios (BCR) for Alternatives 1 to 5 are provided in Table 22.

TABLE 22 INITIAL ALTERNATIVES COSTS AND BENEFITS

Alt. No.	First Cost	Avg. Annual Cost	Avg. Annual Benefit	Net Benefit	BCR
1	$50,077,000	$2,697,400	$3,142,600	$463,200	1.2
2	$127,769,900	$6,475,500	$4,791,800	-$1,683,800	0.8
3	$139,757,200	$7,185,400	$3,123,500	-$4,061,400	0.4
4	$44,638,200	$2,441,600	$3,121,200	$679,700	1.3
5	$38,787,600	$2,080,400	$3,121,200	$1,040,500	1.5

** 4.125% Interest Rate, October 2010 price level*

84. Based on the low Benefit to Cost Ratios, Alternative 2 (Non-Structural) and Alternative 3 (Off-Shore Barrier with Sector Gate) are removed from further consideration. This leaves Alternatives 1 (the Pre-Feasibility Alternative), 4 (the Dune and Beachfill Alternative), and 5 (similar to Alternative 1, but adjusted to minimize and avoid environmental impacts) for consideration. Of the three alternatives, Alternative 5 has the highest net benefits. Accordingly, Alternative 5 was developed further with five (5) variants, 5a to 5e.

85. In relation to Alternative 5, 5A to 5e can be briefly described as:

5A: Alt. 5 without the buoyant swing gate, retains the removable flood walls in Reach 4

5B: Alt. 5 without the removable flood walls and the addition of nonstructural treatments for 12 structures in Reach 4, target elevation of +10.9 ft NAVD88

5C: Alt. Alt. 5 without the removable flood walls and the addition of nonstructural treatments for 12 structures in Reach 4, target elevation of +12.1 ft NAVD88

5D: Alt.5 without the removable flood walls in Reach 4, target elevation of 12.8 ft NAVD88 removes the need for nonstructural treatments in Reach 4

5E: Alt. 5 without buoyant swing gate, without removable flood walls, target elevation 12.8 ft NAVD88 (known also as the “no moving parts” alternative)

86. Alternative plans 5A to 5E provide risk management to a water surface elevation of +9.9 ft NAVD88, including the historic rate of sea level change, over the 50 year period of analysis. Because they were all developed to the same design event (50 yr. or 2% annual chance flood), they perform the same level of risk reduction, providing $9,376,000 (October 2014 price levels) in damages reduced annually. Any differentiation would be achieved through examination of annual costs against the annual benefits, with the lowest annual cost determining the Tentatively Selected Plan (Table 23).

TABLE 23
AVERAGE ANNUAL PERFORMANCE OF ALTERNATIVES 5A to 5E

Alternative	Cost	Benefit	Net Benefit	B/C ratio
5A	$3,705,000	$9,376,000	$5,671,000	2.5
5B	$3,859,000	$9,376,000	$5,517,000	2.4
5C	$3,740,000	$9,376,000	$5,636,000	2.5
5D	$3,677,000	$9,376,000	$5,699,000	2.5
5E	**$3,489,000**	**$9,376,000**	**$5,887,000**	**2.7**

87. With the highest net benefits, Alternative 5E was identified as the Tentatively Selected Plan (TSP) for National Economic Development (NED) Plan, to be further studied and refined in a process referred to as Optimization. Alternative 5E assumed a continuous I-Wall composed of driven or vibrated sheetpile with various options for dune fill and a limited section of Toe Stone.

88. As part of the optimization process the TSP was evaluated using HEC-FDA to compute residual with-project equivalent annual damages with three different levels of performance as follows:

- TSP 8.7: Stillwater design elevation +8.7 feet NAVD88
- TSP 9.7: Stillwater design elevation +9.7 feet NAVD88
- TSP 11.0: Stillwater design elevation +11.0 feet NAVD88

89. The residual with-project damages and subsequent benefits with the three alternatives in place are presented in Tables 24 and 25:

TABLE 24: TSP DESIGN LEVELS OF PERFORMANCE RESIDUAL EQUIVALENT ANNUAL DAMAGE			
Reach	**TSP +8.7 NAVD88**	**TSP +9.7 NAVD88**	**TSP +11.0 NAVD88**
1	$43,500	$30,200	$19,400
2	$189,200	$134,300	$90,100
3	$336,700	$310,700	$232,400
4	$544,900	$445,700	$276,300
5	$1,356,700	$913,600	$547,200
5.1	$353,900	$99,800	$67,600
6	$1,581,400	$1,001,400	$595,000
7	$1,970,700	$1,189,300	$664,600
7.1	$185,600	$50,800	$32,300
7.2	$164,700	$165,200	$165,200
7.3	$24,800	$25,100	$25,100
TOTALS:	***$6,752,100***	***$4,366,100***	***$2,715,200***

Interest rate 2.75%, Price Level October 2019

TABLE 25: TSP DESIGN LEVELS OF PERFORMANCE EQUIVALENT ANNUAL BENEFITS			
Reach	**TSP +8.7 NAVD88**	**TSP +9.7 NAVD88**	**TSP +11.0 NAVD88**
1	$54,700	$68,200	$78,900
2	$274,300	$329,600	$373,800
3	$118,700	$184,600	$262,900
4	$1,409,300	$1,637,300	$1,806,800
5	$4,880,200	$5,428,400	$5,794,800
5.1	$223,500	$259,100	$291,300
6	$6,907,100	$7,539,400	$7,945,700
7	$8,374,300	$9,155,700	$9,680,500
7.1	$188,500	$214,800	$233,200
7.2	$0	$0	$0
7.3	$0	$0	$0
TOTALS:	***$22,430,600***	***$24,817,100***	***$26,467,900***

Interest rate 2. 75%, Price Level October 2019

RESIDUAL INTERIOR DAMAGE

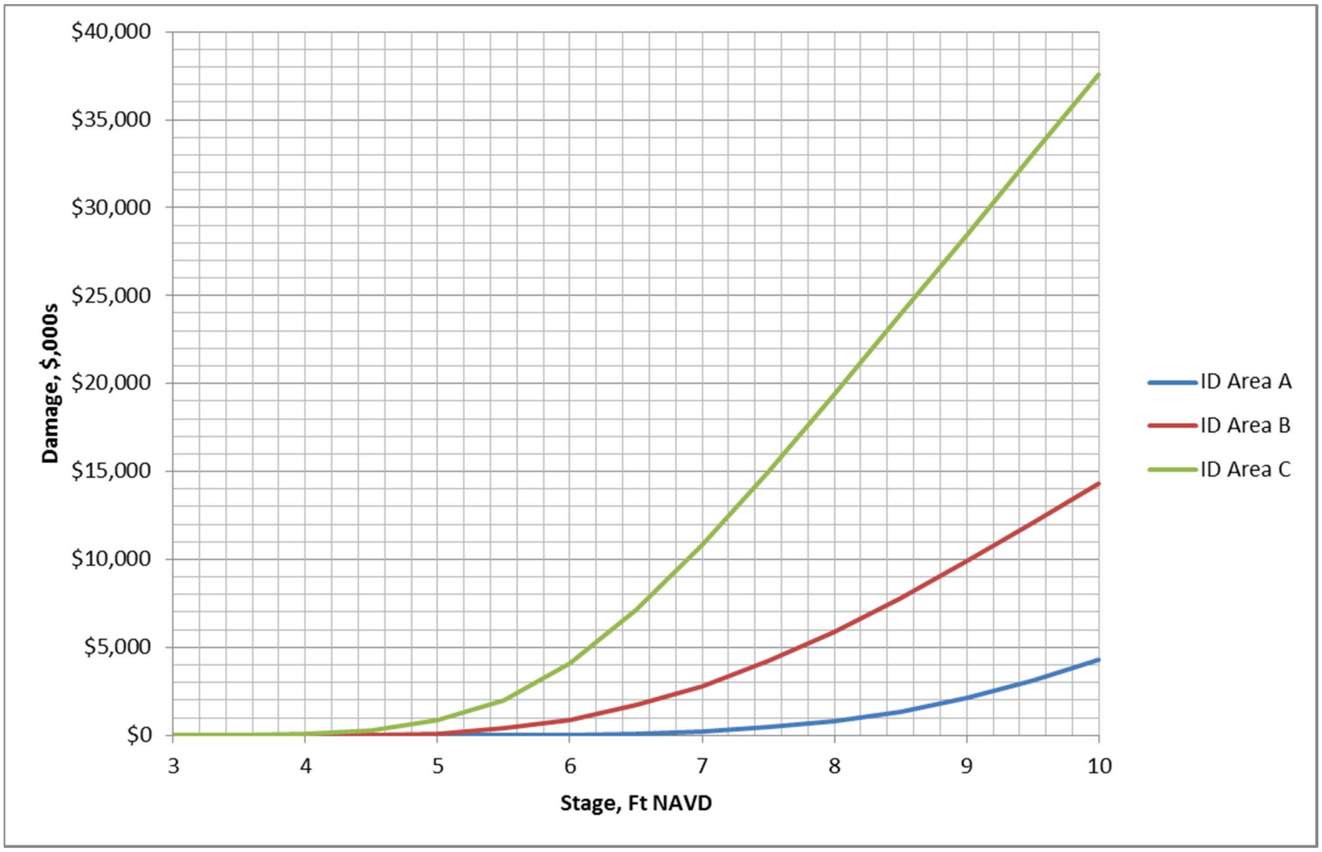
90. In addition to potential damage from storm surges over topping the levees and floodwalls, runoff from rainfall in the interior of the protected area may also cause damages. The drainage analysis subdivided the protected area into three interior drainage areas A, B, and C as shown in Figure 2.

Figure 2:
Interior Drainage Area Delineation

91. Interior flood risk management alternatives were formulated independently of the project alignment and several facilities at each location were evaluated for hydrologic and economic impacts. The economic assessments for interior drainage features utilized the structure inventory and HEC-FDA model developed for the study.

92. In accordance with current USACE guidance, interior drainage alternatives were evaluated in comparison with the minimum facility (MF), which in this study is provided by a series of storage ponds for all three drainage areas. The existing stage-damage relationships for each of the three interior drainage areas is presented for illustrative purposes in Figure 3:

Figure 3:
Interior Drainage Areas: Stage-Damage Relationships



93. The interior drainage alternatives subsequently evaluated were as follows:

Alternative 1:

Area A: 160 cfs pump station (single pump)

Area B: 600 cfs Pump station (150 cfs plus 450 cfs pumps)

Area C: 300 cfs Pump station (50 cfs plus 250 cfs pumps)

Alternative 2:

Area A: 8 acre-foot ponding area (no pumping or additional outlets)

Area B: diversion of entire upper basin into pressurized pipe

Area C: 150 cfs pump station (100 cfs and 50 cfs pumps) plus 4 additional 36" pipe outlets

94. A summary of the base year, future year, and equivalent annual residual damages for all the evaluated interior features are presented by drainage area in Table 24, while a more detailed breakdown of equivalent annual damages by area and alternative is presented in Table 26.

TABLE 26: RESIDUAL INTERIOR DRAINAGE DAMAGE			
MINIMUM FACILITY			
ID AREA	**Base Year**	**Future Year**	**EAD**
A	$144,710	$202,780	$166,800
B	$1,279,160	$1,407,890	$1,328,120
C	$3,940,390	$4,130,760	$4,012,790
Total	***$5,364,260***	***$5,741,430***	***$5,507,710***
ALTERNATIVE 1			
ID AREA	**Base Year**	**Future Year**	**EAD**
A	$2,870	$4,100	$3,340
B	$31,230	$32,350	$31,660
C	$523,240	$514,820	$520,040
Total	***$557,340***	***$551,270***	***$555,040***
ALTERNATIVE 2			
ID AREA	**Base Year**	**Future Year**	**EAD**
A	$39,480	$66,070	$49,590
B	$310,540	$386,360	$339,380
C	$821,320	$949,350	$870,010
Total	***$1,171,340***	***$1,401,780***	***$1,285,980***

Interest rate 2.75%, Price Level October 2019

TABLE 27:
INTERIOR DRAINAGE ALTERNATIVES – EQUIVALENT ANNUAL RESIDUAL DAMAGES BY AREA AND ALTERNATIVE

Drainage Area A

Alt.	Damage Categories							Total *
	Apartment	Commercial	Industrial	Municipal	Residential	Utility	Auto	
MF	$3,150	$330	$0	$0	$147,240	$0	$15,990	$166,780
1	$0	$0	$0	$0	$2,430	$0	$900	$3,330
2	$490	$60	$0	$0	$43,330	$0	$5,690	$49,590

Drainage Area B

Alt.	Damage Categories							Total *
	Apartment	Commercial	Industrial	Municipal	Residential	Utility	Auto	
MF	$0	$145,850	$0	$0	$1,097,980	$2,440	$81,290	$1,328,060
1	$0	$600	$0	$0	$26,020	$20	$5,020	$31,660
2	$0	$18,790	$0	$0	$292,410	$470	$27,690	$339,370

Drainage Area C

Alt.	Damage Categories							Total *
	Apartment	Commercial	Industrial	Municipal	Residential	Utility	Auto	
MF	$15,860	$1,022,330	$29,980	$177,050	$2,665,680	$3,690	$97,190	$4,012,670
1	$730	$63,900	$4,630	$15,190	$418,690	$30	$16,870	$520,040
2	$2,000	$144,790	$7,700	$29,950	$660,120	$150	$25,280	$870,020

**Debris damages not included (negligible)* *Interest rate 2. 75%, Price level October 2019*

95. The interior drainage formulation resulted in Alternative 2 being selected for Areas A and B, and Alternative 1 selected for Area C. While full details of the interior drainage plan formulation and costs are presented in the Engineering Appendix, a summary of the optimization is presented in Table 28:

TABLE 28: INTERIOR DRAINAGE ALTERNATIVE FORMULATION						
Interior Drainage Plan/Area		**Total Annual Cost including O&M**	**Minimum Facility Annual Residual Damages**	**Interior Drainage Annual Residual Damages**	**Interior Drainage Annual Benefits**	**Annual Net Benefits**
Alternative 1	A	$379,400	$158,000	$3,100	$154,900	-$224,500
	B	$936,100	$1,241,400	$28,700	$1,212,700	$276,600
	C	$615,000	$3,881,500	$498,700	$3,382,800	**$2,767,800**
Alternative 2	A	$51,500	$158,000	$46,700	$111,300	**$59,800**
	B	$146,800	$1,241,400	$312,600	$928,800	**$782,000**
	C	$514,400	$3,881,500	$839,400	$3,042,100	$2,527,700

Interest rate 2.875%, Price level October 2016

SUMMARY OF DAMAGES AND BENEFITS

96. Table 29 presents a summary of the total benefits of the optimized TSP options in combination with the benefits of the selected interior drainage alternatives.

Table 23 Summary of Damages and Benefits			
Without Project Damage Total	$29,182,500		
With Project Damage	**Small**	**Medium**	**Large**
Line of Protection	$6,752,200	$4,365,300	$2,714,400
Interior Drainage	$909,000	$909,000	$909,000
Total	$7,661,200	$5,274,300	$3,623,400
Total Benefits	**$21,521,300**	**$23,908,200**	**$25,559,100**

Interest rate 2. 75%, Price level October 2019

PROJECT PERFORMANCE AND RISK ANALYSIS

97. ER 1105-2-101 "Risk Analysis for Flood Damage Reduction Studies (USACE, January 3, 2006) stipulates that the risk analysis for a flood risk reduction project should quantify the performance of the plan and evaluate the residual risk, including the consequences of exceedance of the project's capacity. The guidance specifically stipulates, along with the basic economic performance of a project, the engineering performance of the project is to be reported in terms of:

- The annual exceedance probability
- The long-term risk of exceedance
- The conditional non-exceedance probability

The overall economic performance (expected and probabilistic values of damages and benefits) of all the evaluated alternatives under the low sea level rise condition has been computed by HEC-FDA and the results are presented in Table 30.

98. The annual exceedance probability of a project is the likelihood that a target stage is exceeded by flood waters in any year and can be considered as an indication of the level of risk management provided by the NED Plan. The target stage is the point at which significant damage is incurred in the with-project condition, the significant damage elevation was defined as the water surface elevation which results in damages equal to 5% of damages incurred by the 1% annual chance exceedance event ("100-year" event) in the without-project condition

99. The target stage for each reach was used in HEC-FDA to calculate the base year median and expected annual exceedance probability for the NED Plan. The median value reflects the basic as-designed performance of the plan without the application of uncertainty to the basic discharge-frequency and stage-discharge functions, while the expected value is computed from the results of the Monte Carlo simulations which take into account uncertainty in hydrologic/hydraulic functions and project features such as diversion structures. Hence the difference between the two is an indication of the uncertainty associated with the project performance.

100. The long-term risk of exceedance is the probability that the design stage will be exceeded at least once in the specified durations of 10, 30, and 50 years, and the conditional non-exceedance probability measures the likelihood that the project will not be exceeded by a specified hydrologic event. For this analysis the base year conditional

non-exceedance probability has been computed for each alternative for the 10%, 4%, 2%, 1%, 0.4% and 0.2% annual chance exceedance events (10-, 25-, 50-, 100-, 250- and 500-year floods). These indicators of project performance and reliability for the alternatives evaluated under the low sea level rise scenario are presented in Table 31.

Table 30 Expected and Probabilistic Values of Damages and Benefits						
Alternative	**Equivalent Annual Damage (Project Alignment Only)**			**Probability that Damage Reduced Exceeds the Indicated Values**		
	Without Project	**With Project**	**Damage Reduced**	**75%**	**50%**	**25%**
8.7' NAVD	$29,182,390	$6,751,950	$22,430,450	$21,070,040	$21,908,660	$22,812,770
9.7' NAVD	$29,182,390	$4,366,150	$24,816,240	$23,020,780	$24,234,280	$25,561,580
11' NAVD	$29,182,390	$2,715,190	$26,467,200	$23,823,620	$25,872,280	$27,747,840

Interest rate 2.75%, Price level October 2019

Table 31 Project Performance Analysis - Line of Protection				
Performance and Reliability Criteria		**11 ft NAVD**	**13 ft NAVD**	**14 ft NAVD**
Annual Exceedance Probability of Target Stage	Median	5.0%	3.0%	1.3%
	Expected	5.0%	3.0%	1.5%
Long Term Exceedance Probability	10 Years	43%	25%	14%
	30 Years	81%	57%	35%
	50 Years	94%	76%	52%
Conditional Non-Exceedance Probability	10%	97%	100%	100%
	4%	31%	73%	98%
	2%	10%	38%	74%
	1%	7%	17%	41%
	0.40%	0%	2%	8%
	0.20%	0%	0%	1%

SENSITIVITY TEST: SEA LEVEL RISE

101. Current USACE guidance requires that potential relative sea level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence. The base level of potential relative sea-level change is considered the historically recorded changes for the study site, which is estimated to be an increase of 0.0134 feet/year. All economic analyses for which results are tabulated in previous sections of this report were based on this historic rate of sea level change. However, in accordance with Engineering Regulation ER 1100-28162 (incorporating Sea Level changes in Civil Works Program, 31 Dec 2013), proposed projects that are subject to coastal storm surges must be also evaluated for a range of possible sea level rise rates: In addition to the historical rate ("low") which is a 0.7 ft. increase over the period of analysis, the project was also evaluated using "intermediate" and "high" rates derived from modified NRC Curves I and III, which for this study are estimated to cause increases of 1.1ft. and 2.6ft., respectively over the fifty year period-of-analysis. The results of all analyses under all three sea level rise conditions are presented in Table 32.

Table 32
Impacts of Sea Level Rise on Damages and Benefits

Damages/ Benefits	**Condition/ Alternative**	**Historic "Low"**	**Curve I "Intermediate"**	**Curve III "High"**
Equivalent Annual Damages	Without	$29,182,500	$32,108,000	$47,042,000
	8.7' NAVD	$6,752,200	$8,103,000	$20,439,000
	9.7' NAVD	$4,365,300	$5,114,000	$11,327,000
	11' NAVD	$2,714,400	$3,066,000	$5,674,000
Annual Benefits	8.7 NAVD	$22,430,300	$24,005,000	$26,603,000
	9.7 NAVD	$24,817,200	$26,994,000	$35,715,000
	11' NAVD	$26,468,100	$29,042,000	$41,368,000

Interest rate 2.75%, Price level October 2019

Sea Level Rise projections based on observed trends at the Sandy Hook, NJ, NOAA tide gage and guidance in EC 1165-2-211.

IDENTIFICATION OF THE RECOMMENDED PLAN

102. Recommended Plan

In the process of optimization, different project sizes are considered to find the optimal dimensions to maximize net benefits. Using the TSP as a starting point, two additional versions of the project were developed: one smaller than the TSP and one larger than the TSP. For analysis purposes, the performance of the three versions were measured based on stillwater design elevations. Table 33 shows the elevation heights of the optimized alternatives in relation to the stillwater design elevations evaluated in HEC-FDA.

Table 33 Height of Alternatives for Optimization

Size	Project Height	Stillwater Design Elevation
Small	+11 ft NAVD88	+8.7 ft NAVD88
Medium (TSP)	+12.5 ft NAVD88	+9.7 ft NAVD88
Large	+14 ft NAVD88	+11 ft NAVD88

The height of +11 ft NAVD88 was chosen for the small plan because it is the elevation of the existing bulkhead built by the State in Reach 2 of the study area. Building a project lower than +11 ft NAVD88 would not fully leverage the benefits of the existing State bulkhead.

The height of 14 ft NAVD88 was chosen for the large plan because it is the ground elevation of the new condominium development (Harborside at Hudson's Ferry) at the western end of the project. Project heights above +14 ft NAVD88 were not considered because the additional height requires additional length (approximately 2,000 linear feet) to circumvent the edge of the condominium development to tie into high ground. Evaluation of the extension cannot include benefits to the development because it was constructed after 1991, in accordance with Section 308 of the Water Resources Development Act of 1990.[1] In this situation, only the cost of the extension could be counted, which would lead only to a decrease in the net benefits.

[1] https://www.epw.senate.gov/wrda90.pdf

103. The first costs, net benefits, and benefit to cost ratios (BCR) for the optimized alternatives are provided in Table 34.

Table 34. Performance of Optimized Alternatives Against RSLC			
	Small	Medium	Large
Annual Cost	$4,919,000	$5,325,000	$5,376,000
Historic SLR			
Annual Benefits	$21,521,000	$23,908,000	$25,559,000
Net Benefits	$16,602,000	$18,583,000	$20,183,000
BCR	4.4	4.5	4.8
Intermediate SLR			
Annual Benefits	$23,096,000	$26,085,000	$28,133,000
Net Benefits	$18,177,000	$20,760,000	$22,757,000
BCR	47	4.9	5.2
High SLR			
Annual Benefits	$25,694,000	$34,806,000	$40,459,000
Net Benefits	$20,775,000	$29,481,000	$35,083,000
BCR	5.2	6.5	7.5

** Interest rate 2.75%, Price level October 2019*

***Annual Cost based on FY17 price level to be updated to FY20*

104. Risk in benefits analysis

Uncertainty has been defined for key input parameters in the economic analysis thus uncertainty in the expected benefits have been calculated assuming the low sea level rise scenario for the line of protection benefits. HEC-FDA calculated the distribution of equivalent annual damage reduced by the Recommended Plan in terms of the probability that the benefits exceed a value for these likelihood scenarios: 75%, median and 25%. There is a .75 probability that the equivalent annual damage reduced is greater than $22,000,000, a .50 probability benefits are greater than $24,000,000 and a .25 probability that benefits exceed $25,000,000. With the Recommended Plan in place, it is very likely that damages reduced will exceed $20,000,000. Table 35 summarizes the benefits and probability distribution of the plan.

Table 35. Economic Summary or Recommended Plan with Uncertainty

	Annual Benefits	Annual Cost	Net Benefits	BCR	Probability Distribution Quartiles		
					0.75	0.5	0.25
Mean	$24,038	$6,477	$17,561	3.7			
EAB					$22,561	$24,233	$25,727
ENB					$16,084	$17,756	$19,250
BCR					3.5	3.7	4.0

Note: EAB= Equivalent Annual Benefits; ENB= Equivalent Net Benefits; BCR=Benefits-Costs Ratio. Annual costs (including interest during construction) and benefits estimated at FY20 discount rate of 2.75%. This table displays line of protection results only.

105. Economic justification in USACE studies is typically based upon the historic or low rate of RSLC, to be conservative on the estimate of benefits. Upon the historic rate of RSLC, the large alternative (+11’ NAVD88) provides the most net benefits and is therefore identified as the NED plan, or the Recommended Plan. Under the intermediate and high scenarios of RSLC, the large alternative still has the highest net benefits, confirming its identification as the Recommended Plan.

106. Risk to Life Safety.

The potential risks associated with flooding were estimated by structure count and dollar damage at different ACE events were presented in the Future Without Condition section of this appendix. At any storm event level there is the added risk of life loss. As part of the risk assessment framework, a discussion of the hazards with and without the project, with project performance and consequences follows.

Communities in the Highlands borough have historically experienced flooding from the Sandy Hook Bay and Shrewsbury Rivers. Residents and business owners are familiar with damages incurred as a result of flooding. Due to vulnerability to flash floods and other high water events, emergency vehicles may experience difficulty when trying to reach residents in distress. Hurricane Sandy of 2012, with its sustained winds and surge was linked to one death in Monmouth County. It is expected that the area will continue to experience water events that threaten the livelihood of residents and business owners.

A future storm of equal or greater magnitude and duration as Sandy can strain existing flood protection structures and weaken the effectiveness of an implemented damage reduction project. USACE barriers are designed and built to regulation with respect to materials used and design dimensions that help to mitigate these risks.

Performance

The main component of the project consist of I-Wall floodwalls. While no structure provides full protection from flooding, only 10% of the entire USACE floodwall portfolio are expected to have poor performance due to instability according to the USACE Levee Portfolio Report. The proposed system for Highlands Borough would not be within this 10%. The project is designed to tie into existing bulkhead of up to a height of 14 feet and is expected to be resistant to seepage and malfunctions up to the 50 year event at a minimum.

The risk of having this project in place with its floodwalls and drainage systems, is commensurate with the benefits. For example, the project has a detention basin component which will reduce local flooding from runoff that exceeds the capacity of the pump station. The failure of a pump station is a minimal risk associated with this project. A failed pump station can result in slowly rising flood levels allowing the population at risk to safely evacuate which is unlikely to lead to loss of life.

Consequences

It is the unexpected, high surge breach that can be catastrophic and incur loss of life because the population at risk needs sufficient warning time to safely evacuate. Sudden inundation can limit access in or out of the flood plain. The line of protection spans the entire border of the Highlands area +10000 feet of floodwall. Residents in the interior area may be subject to residual flooding even with the project in place. It is important that residents adhere to local evacuation directives and actions to reduce risk since loss of life can be further prevented by evacuating people before expected flood events. Highlands residents generally understand the implications of staying in harm's way when a storm is forecasted to affect the area. Because there is typically two to seven days' notice prior to major storms (e.g., hurricanes and tropical storms) residents are given sufficient warning to evacuate. However, residents typically have only a few hours warning before the arrival smaller storms and rain events that cause flash flooding on the Bay and River. The population at risk should evacuate prior to storms to avoid being stranded, which could pose a danger for their welfare. Flood awareness and emergency evacuation play a part in risk management for communities within a floodwall plan. These measures reduce the potential for property damage and life loss. Table 36 presents a matrix of plan components and their performance on loss and risk.

Table 36. Life safety measure and plan evaluation matrix.

Measure	Metric		
	Economic Damage	Expected Life Loss	Evacuation Life Loss Risk
No Action	High	High	High
I-Wall	Medium	Low	Low
Pump Station	Low	Low	Low
Detention Pond	Low	Low	Low