NEW YORK-NEW JERSEY HARBOR AND TRIBUTARIES

NEW YORK DISTRICT

Interim Report Economics Appendix

US Army Corps of Engineers

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

NEW YORK STATE Department of Environmental Conservation

NYC Mayor's Office of Recovery & Resiliency

US Army Corps of Engineers®
New York District

New York – New Jersey Harbor and Tributaries Coastal Storm Risk Management Feasibility Study

Interim Report Economics Appendix

February 2019

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1 INTRODUCTION

Historical coastal storms including Hurricane Sandy have impacted the New York – New Jersey Harbor and Tributaries (NYNJHAT) area. In response to Public Law 113-2 (Disaster Relief Appropriations Act, 2013), the U.S. Army Corps of Engineers (USACE) investigated solutions from Virginia through New England that will reduce future flood risk in ways that support the long-term resilience and reduce the economic costs and risks associated with large-scale flood and storm events. In support of this goal, USACE completed in January 2015 the North Atlantic Coast Comprehensive Study (NACCS) which identified nine high risk areas on the Atlantic Coast for an in-depth analysis based on preliminary analyses.

The NYNJHAT study area encompasses the New York Metropolitan Area, including the most populous and densely populated city in the United States, and some of the largest cities in New Jersey. As the study area is highly urbanized, and with existing geography, topography, and proximity to tidally influenced areas, it is highly vulnerable to coastal storm damage. Combined with projections for climate change and sea level change, the vulnerability of this area to future flooding events and coastal storm damage is effectively increased.

1.1 Purpose of this Memorandum

The study objective is to identify and recommend alternatives that will manage coastal storm risk and reduce coastal storm damages to the existing development on the shorefront and in coastal floodplains. Given the broad area and types of data available within the NYNJHAT study area, the detailed approach to estimating benefits is limited to the data available. The desired model approach is to develop a full risk based HEC-FDA model.

This intern memorandum was initially envisioned as a summary of available data and a recommendation for the approach to estimate potential damages and benefits, where the data necessary to develop an FDA model was not available from desktop sources. As the data collection analysis continued it became apparent that sufficient data exists to develop HEC-FDA models for the entire study area. The deliverable therefore evolved into a summary of the data sources used in the model development and a tabulation of the preliminary model results.

1.2 Description of the Study Area

The shorelines of some of the NYNJHAT study area are characterized by low elevation areas, developed with residential and commercial infrastructure and are subject to tidal flooding during storms. The study area covers more than 2,150 square miles and comprises parts of 25 counties in New Jersey and New York, including Bergen, Passaic, Essex, Hudson, Union, Middlesex, and Monmouth Counties in New Jersey; and Rensselaer, Albany, Columbia, Greene, Dutchess, Ulster, Putnam, Orange, Westchester, Rockland, Bronx, New York, Queens, Kings, and Richmond Counties in New York. To include all tidally affected waters, the study area extends upstream of the Hudson River to the location of the Federal Lock and Dam in Troy, NY, the Passaic River to the Dundee Dam, and the Hackensack River to Oradell Reservoir.

1.3 Project Reaches

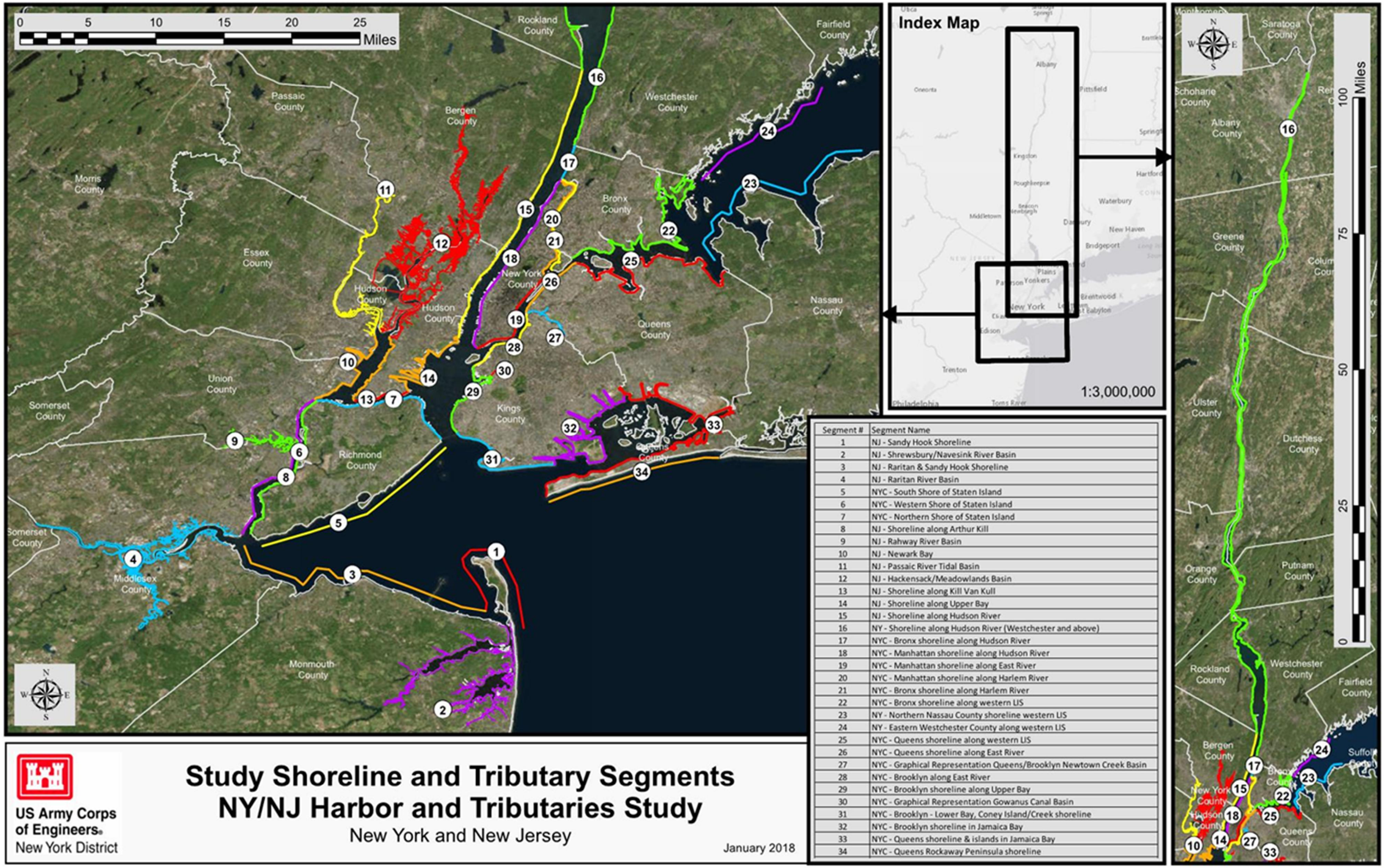
To ensure complete initial consideration, the study area will be divided into general reaches, by county and by waterbody, to allow for easier management in the NYNJHAT CSRM Study. The study reaches include all tidally influenced portions of rivers flowing into New York and New Jersey Harbor including the Hudson, East, Harlem, Raritan, Hackensack, Passaic, Shrewsbury, and Navesink Rivers. A map of the reaches is presented in Figure 1. A total of thirty-four study reaches, listed in Table 1, were identified within the NYNJHAT study area. While each of these reaches have been evaluated independently, it is important to consider a larger system perspective when considering measures and alternatives for the NYNJHAT study area.

Table 1: Study Area Reaches

Reach #	Reach Name	County
1	NJ - Sandy Hook Shoreline	Monmouth
2	NJ - Shrewsbury/Navesink River Basin	Monmouth
3	NJ - Raritan & Sandy Hook Shoreline	Monmouth / Middlesex
4	NJ - Raritan River Basin	Middlesex
5	NYC - South Shore of Staten Island	Richmond
6	NYC - Western Shore of Staten Island	Richmond
7	NYC - Northern Shore of Staten Island	Richmond
8A	NJ - Shoreline along Arthur Kill North	Union
8B	NJ - Shoreline along Arthur Kill South	Middlesex
9	NJ - Rahway River Basin	Union / Middlesex
10	NJ - Newark Bay	Union / Essex
11T	NJ - Passaic River Tidal Basin	Essex / Hudson
11MS	NJ - Passaic River Mainstem	Bergen
12RBDM	NJ - Hackensack/Meadowlands Basin RBDM	Bergen
12OP	NJ - Hackensack/Meadowlands Basin Overpeck Creek	Bergen
13	NJ - Shoreline along Kill Van Kull	Hudson
14	NJ - Shoreline along Upper Bay	Hudson
15	NJ - Shoreline along Hudson River	Hudson / Bergen
16	NY - Shoreline along Hudson River	Westchester / Putnam / Dutchess / Columbia / Rensselaer / Albany / Greene / Ulster / Orange / Rockland
17	NYC - Bronx shoreline along Hudson River	Bronx
18	NYC - Manhattan shoreline along Hudson River	New York
19	NYC - Manhattan shoreline along East River	New York
20A	NYC - Manhattan shoreline along Harlem River North	New York
20B	NYC - Manhattan shoreline along Harlem River South	New York
21A	NYC - Bronx shoreline along Harlem River North	Bronx

Table 1: Study Area Reaches

Reach #	Reach Name	County
21B	NYC - Bronx shoreline along Harlem River South	Bronx
22A	NYC - Bronx shoreline along western LIS - West	Bronx
22B	NYC - Bronx shoreline along western LIS - East	Bronx
23	NY - Northern Nassau County shoreline western LIS	Nassau
24	NY - Eastern Westchester County along western LIS	Westchester
25	NYC - Queens shoreline along western LIS	Queens
26	NYC - Queens shoreline along East River	Queens
27	NYC - Queens/Brooklyn Newtown Creek Basin	Queens / Kings
28	NYC - Brooklyn along East River	Kings
29	NYC - Brooklyn shoreline along Upper Bay	Kings
30	NYC - Graphical Representation Gowanus Canal Basin	Kings
31	NYC - Brooklyn – Lower Bay, Coney Island/Creek shoreline	Kings
32	NYC - Brooklyn shoreline in Jamaica Bay	Kings
33	NYC - Queens shoreline & islands in Jamaica Bay	Queens
34	NYC - Queens Rockaway Peninsula shoreline	Queens



Segment #	Segment Name
1	NJ - Sandy Hook Shoreline
2	NJ - Shrewsbury/Navesink River Basin
3	NJ - Raritan & Sandy Hook Shoreline
4	NJ - Raritan River Basin
5	NYC - South Shore of Staten Island
6	NYC - Western Shore of Staten Island
7	NYC - Northern Shore of Staten Island
8	NJ - Shoreline along Arthur Kill
9	NJ - Rahway River Basin
10	NJ - Newark Bay
11	NJ - Passaic River Tidal Basin
12	NJ - Hackensack/Meadowlands Basin
13	NJ - Shoreline along Kill Van Kull
14	NJ - Shoreline along Upper Bay
15	NJ - Shoreline along Hudson River
16	NY - Shoreline along Hudson River (Westchester and above)
17	NYC - Bronx shoreline along Hudson River
18	NYC - Manhattan shoreline along Hudson River
19	NYC - Manhattan shoreline along East River
20	NYC - Manhattan shoreline along Harlem River
21	NYC - Bronx shoreline along Harlem River
22	NYC - Bronx shoreline along western LIS
23	NY - Northern Nassau County shoreline western LIS
24	NY - Eastern Westchester County along western LIS
25	NYC - Queens shoreline along western LIS
26	NYC - Queens shoreline along East River
27	NYC - Graphical Representation Queens/Brooklyn Newtown Creek Basin
28	NYC - Brooklyn along East River
29	NYC - Brooklyn shoreline along Upper Bay
30	NYC - Graphical Representation Gowanus Canal Basin
31	NYC - Brooklyn - Lower Bay, Coney Island/Creek shoreline
32	NYC - Brooklyn shoreline in Jamaica Bay
33	NYC - Queens shoreline & islands in Jamaica Bay
34	NYC - Queens Rockaway Peninsula shoreline

Figure 1: Project Area Reaches

2 DATA COLLECTION

Available benefit models or coastal surge damage data within the NYNJHT study area have been collected. The data on structure damage and impacts to critical infrastructure have been drawn from sources including, but not limited to, prior USACE studies or studies by other Federal and Non-Federal governmental sources.

2.1 Stage Frequency Data

Locations (nodes) used for hydrologic modeling during the NACCS study have been assigned to each reach to be used as representative stage frequency data. These nodes provide water surface elevations for the 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, and 0.2% annual chance exceedance storm events for 1992 (the "2, 5, 10, 20, 50, 100, 200, and 500-year" events). The data was then adjusted for sea level rise for the base (2030) and future (2100) year of the study using USACE/NOAA Low Sea Level Change (SLC) Curve. Table 2 lists the nodes and gage (for the purposes of incorporating SLC) assigned to each reach. In some cases, a reach may contain multiple nodes, especially if it covers multiple counties.

Table 2: NACCS Node - Reach Assignment

Reach #	Reach Name	County	NACCS Stage Frequency Node	Assigned Gage for SLC
1	NJ - Sandy Hook Shoreline	Monmouth	3789	Sandy Hook
2	NJ - Shrewsbury/Navesink River Basin	Monmouth	11519	Sandy Hook
3	NJ - Raritan & Sandy Hook Shoreline	Monmouth	3538	Sandy Hook
3	NJ - Raritan & Sandy Hook Shoreline	Middlesex	11740	Sandy Hook
4	NJ - Raritan River Basin	Middlesex	11608	Sandy Hook
5	NYC - South Shore of Staten Island	Richmond	13809	Sandy Hook
6	NYC - Western Shore of Staten Island	Richmond	3967	Sandy Hook
7	NYC - Northern Shore of Staten Island	Richmond	13818	Battery Park
8A	NJ - Shoreline along Arthur Kill North	Union	3503	Battery Park
8B	NJ - Shoreline along Arthur Kill South	Middlesex	3967	Sandy Hook
9	NJ - Rahway River Basin	Union	4004	Battery Park
9	NJ - Rahway River Basin	Middlesex	4004	Battery Park
10	NJ - Newark Bay	Union	11754	Battery Park
10	NJ - Newark Bay	Essex	11754	Battery Park
11T	NJ - Passaic River Tidal Basin	Essex	4206	Battery Park
11T	NJ - Passaic River Tidal Basin	Hudson	4206	Battery Park
11MS	NJ - Passaic River Mainstem	Bergen	7412	Battery Park
12RBDM	NJ - Hackensack/Meadowlands Basin RBDM	Bergen	4281	Battery Park
12OP	NJ - Hackensack/Meadowlands Basin Overpeck Creek	Bergen	4281	Battery Park
13	NJ - Shoreline along Kill Van Kull	Hudson	13818	Battery Park
14	NJ - Shoreline along Upper Bay	Hudson	4176	Battery Park
15	NJ - Shoreline along Hudson River	Hudson	13862	Battery Park
15	NJ - Shoreline along Hudson River	Bergen	13862	Battery Park
16	NY - Shoreline along Hudson River	Westchester	13872	Battery Park
16	NY - Shoreline along Hudson River	Putnam	7976	Battery Park
16	NY - Shoreline along Hudson River	Dutchess	3575	Battery Park
16	NY - Shoreline along Hudson River	Columbia	3600	Battery Park
16	NY - Shoreline along Hudson River	Rensselaer	3600	Battery Park
16	NY - Shoreline along Hudson River	Albany	3600	Battery Park

Table 2: NACCS Node - Reach Assignment

Reach #	Reach Name	County	NACCS Stage Frequency Node	Assigned Gage for SLC
16	NY - Shoreline along Hudson River	Greene	3600	Battery Park
16	NY - Shoreline along Hudson River	Ulster	3575	Battery Park
16	NY - Shoreline along Hudson River	Orange	7976	Battery Park
16	NY - Shoreline along Hudson River	Rockland	7976	Battery Park
17	NYC - Bronx shoreline along Hudson River	Bronx	4573	Battery Park
18	NYC - Manhattan shoreline along Hudson River	New York	13862	Battery Park
19	NYC - Manhattan shoreline along East River	New York	11875	Battery Park
20A	NYC - Manhattan shoreline along Harlem River North	New York	4479	Battery Park
20B	NYC - Manhattan shoreline along Harlem River South	New York	13888	Battery Park
21A	NYC - Bronx shoreline along Harlem River North	Bronx	4479	Battery Park
21B	NYC - Bronx shoreline along Harlem River South	Bronx	13888	Battery Park
22A	NYC - Bronx shoreline along western LIS - West	Bronx	4349	Kings Point
22B	NYC - Bronx shoreline along western LIS - East	Bronx	4349	Kings Point
23	NY - Northern Nassau County shoreline western LIS	Nassau	13936	Kings Point
24	NY - Eastern Westchester County along western LIS	Westchester	13021	Kings Point
25A	NYC - Queens shoreline along western LIS - West	Queens	4349	Kings Point
25B	NYC - Queens shoreline along western LIS - East	Queens	4349	Kings Point
26	NYC - Queens shoreline along East River	Queens	11878	Battery Park
27	NYC - Queens/Brooklyn Newtown Creek Basin	Queens	11895	Battery Park
27	NYC - Queens/Brooklyn Newtown Creek Basin	Kings	11895	Battery Park
28	NYC - Brooklyn along East River	Kings	7673	Battery Park
29	NYC - Brooklyn shoreline along Upper Bay	Kings	11933	Battery Park
30	NYC - Gowanus Canal Basin	Kings	11930	Battery Park
31	NYC - Brooklyn - Lower Bay, Coney Island/Creek shoreline	Kings	14070	Sandy Hook
32	NYC - Brooklyn shoreline in Jamaica Bay	Kings	3963	Sandy Hook
33	NYC - Queens shoreline & islands in Jamaica Bay	Queens	14117	Sandy Hook
34	NYC - Queens Rockaway Peninsula shoreline	Queens	14196	Sandy Hook

2.2 Sea Level Change

Current USACE guidance requires incorporation of SLC into Civil Works projects. This is outlined in Engineer Regulation (ER) 1100-2-8162, *Incorporating Sea Level Change in Civil Works Programs* (31 Dec 2013), which supersedes Engineer Circular (EC) 1165-2-212, *Sea Level Change Considerations for Civil Works Programs*. The ER refers to additional specific guidance in Engineer Technical Letter (ETL) 1100-2-1, *Procedures to Evaluate Sea Level Change: Impacts Responses and Adaptation*, which contains details previously contained in attachments to the old EC.

ER 1100-2-8162 states:

> *"Planning studies and engineering designs over the project life cycle, for both existing and proposed projects, will consider alternatives that are formulated and evaluated for the entire range of possible future rates of SLC, represented here by three scenarios of "low," "intermediate," and "high" SLC.*
>
> *…Once the three rates have been estimated, the next step is to determine how sensitive alternative plans and designs are to these rates of future local mean SLC, how this sensitivity affects calculated risk, and what design or operations and maintenance measures should be implemented to adapt to SLC to minimize adverse consequences while maximizing beneficial effects."*

The various alternatives under consideration have significantly different implementation timelines. In order to provide the flexibility to analyze a range of implementation periods, SLC was calculated for conditions from the earliest anticipated base year of 2030 to year 2100, which would be at least 50 years after construction of any of the proposed risk management measures. ER 1100-2-8162 describes how SLC is to be computed and incorporated into levee/floodwall height calculations. To assist in the calculation of SLC mandated by ER 1100-2-8162, USACE has created a tool to assist with the calculations. The tool is located at the website http://www.corpsclimate.us/ccaceslcurves.cfm. This website uses information from ER 1100-2-8162 and National Oceanic and Atmospheric Administration (NOAA) Technical Report OAR CPO-1, Global Sea Level Rise Scenarios for the United States National Climate Assessment published in December 2012. Three gages were used for the NYNJHAT study area, Sandy Hook, Kings Point, and Battery Park. The assignment of gages to study area reaches is presented in Table 2 above.

The generated curves are based on USACE and NOAA equations at a low, intermediate, and high level. The output for the USACE and NOAA equations can be seen in Table 3. The program also plots a chart of the sea level curves as seen in Figure 2.

The inclusion of SLC affects the project benefits, design performance, and reliability.

Table 3: Sea Level Change, Sandy Hook

8531680, Sandy Hook, NJ NOAA's Historic Rate: 0.01280 feet/yr					
Year	**USACE Low NOAA Low**	**USACE Int NOAA Int Low**	**NOAA Int High**	**USACE High**	**NOAA High**
2016	0.07	0.12	0.23	0.28	0.36
2020	0.12	0.19	0.34	0.41	0.52
2025	0.18	0.28	0.49	0.59	0.74
2030	0.25	0.38	0.66	0.78	0.98
2035	0.31	0.48	0.84	1.00	1.25
2040	0.37	0.58	1.03	1.23	1.55
2045	0.44	0.69	1.24	1.48	1.87
2050	0.50	0.80	1.46	1.75	2.22
2055	0.57	0.92	1.70	2.04	2.59
2060	0.63	1.04	1.95	2.34	2.99
2065	0.69	1.17	2.22	2.67	3.42
2066	0.71	1.19	2.27	2.74	3.50

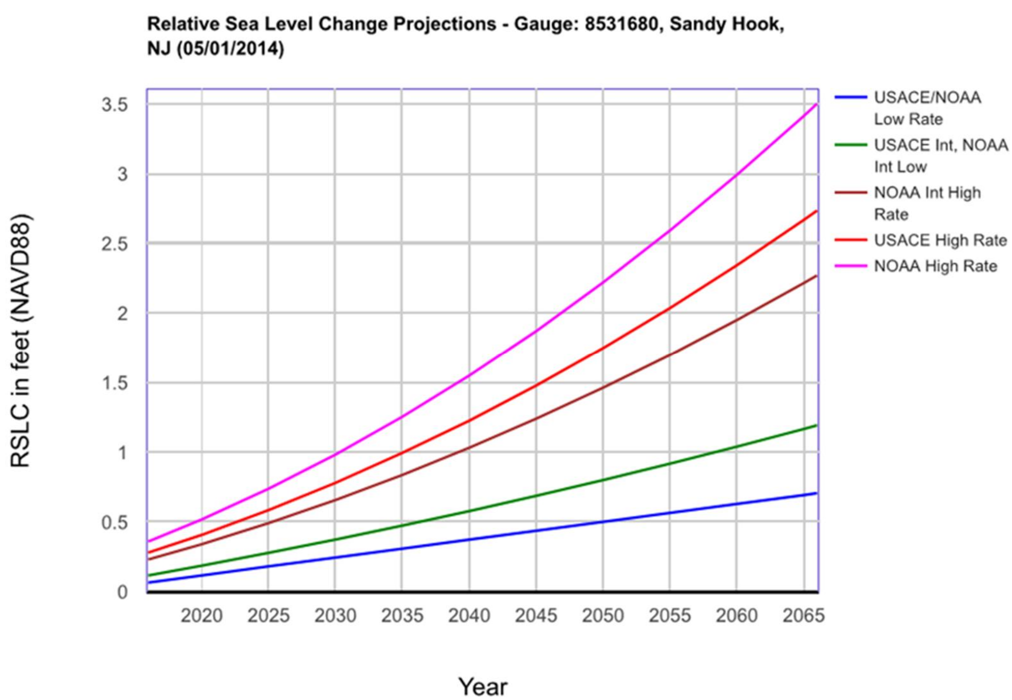


Figure 2. SLC Scenario Projections

2.3 Desktop Inventory Data

NYNJHAT Desktop inventory data has been assembled using parcel and elevation data from various sources. This "Desktop" Inventory has been created for each county and assigned to their respective reaches. Table 4 lists the sources of each county's data. In addition to assessed improvement values included in the data sources, building classification data was used to assign appropriate depth-damage functions for use in the damage estimation models. Where the data sources did not include certain structure characteristics required by the damage model (main floor height above ground and basement/foundation type), typical attributes drawn from detailed inventory surveys conducted in areas of similar building stock were assumed. Assessed improvement values were converted to replacement structure values by application of the current equalization rate for each municipality.

Table 4: Inventory Data Sources

County	Parcel Data Source	Elevation Data Source
New York State		
Albany	http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1300	*USGS 10m DEM
Columbia	Columbia County	**NYS Orthos Online 1m DEM
Dutchess	http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1300	*USGS 1m DEM
Greene	http://gis.greenegovernment.com/	*USGS 10m DEM
Orange	http://ocgis.orangecountygov.com/	**NYS Orthos Online 1m DEM
Putnam	Putnam County	**NYS Orthos Online 1m DEM
Rensselaer	http://www.rensco.com/gis-mapping/	*USGS 10m DEM
Rockland	http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1300	*USGS 10m DEM
Ulster	http://ulstercountyny.gov/ucis/gis-data	**NYS Orthos Online 1m DEM/Dutchess
Westchester	https://giswww.westchestergov.com/wcgis/DataWarehouse.htm	**NYS Orthos Online 1m DEM
New York City		
Bronx	http://www1.nyc.gov/site/planning/data-maps/open-data.page	***NACCS 1m DEM
Kings	http://www1.nyc.gov/site/planning/data-maps/open-data.page	***NACCS 1m DEM
New York	http://www1.nyc.gov/site/planning/data-maps/open-data.page	***NACCS 1m DEM
Queens	http://www1.nyc.gov/site/planning/data-maps/open-data.page	***NACCS 1m DEM
Richmond	http://www1.nyc.gov/site/planning/data-maps/open-data.page	***NACCS 1m DEM
New Jersey		
Bergen	https://njgin.state.nj.us/NJ_NJGINExplorer/	***NACCS 1m DEM
Essex	https://njgin.state.nj.us/NJ_NJGINExplorer/	***NACCS 1m DEM
Hudson	https://njgin.state.nj.us/NJ_NJGINExplorer/	***NACCS 1m DEM
Middlesex	https://njgin.state.nj.us/NJ_NJGINExplorer/	***NACCS 1m DEM
Monmouth	https://njgin.state.nj.us/NJ_NJGINExplorer/	***NACCS 1m DEM
Passaic	https://njgin.state.nj.us/NJ_NJGINExplorer/	***NACCS 1m DEM
Union	https://njgin.state.nj.us/NJ_NJGINExplorer/	***NACCS 1m DEM

*United States Geological Survey
**New York State
***North Atlantic Coast Comprehensive Study - United State Army Corp of Engineers

2.4 Floodplain Limits

Since the NYNJHAT study area is so extensive, the inventory data was limited to areas within maximum expected flood elevations for each reach. The maximum elevation has been selected as the 0.2% event ("500-year" storm) for each node in the year 2100 (assuming the intermediate / Curve I sea level rise scenario), plus two feet. Table 5 lists the maximum elevation inventory limit for each reach-node assignment.

Table 5: Maximum Elevation - Inventory Limit

Segment #	Reach Name	County	Limiting Elevation NAVD88 (ft.)
1	NJ - Sandy Hook Shoreline	Monmouth	20
2	NJ - Shrewsbury/Navesink River Basin	Monmouth	18
3	NJ - Raritan & Sandy Hook Shoreline	Monmouth	20
3	NJ - Raritan & Sandy Hook Shoreline	Middlesex	22
4	NJ - Raritan River Basin	Middlesex	22
5	NYC - South Shore of Staten Island	Richmond	21
6	NYC - Western Shore of Staten Island	Richmond	21
7	NYC - Northern Shore of Staten Island	Richmond	19
8A	NJ - Shoreline along Arthur Kill North	Union	19
8B	NJ - Shoreline along Arthur Kill South	Middlesex	21
9	NJ - Rahway River Basin	Union	20
9	NJ - Rahway River Basin	Middlesex	20
10	NJ - Newark Bay	Union	19
10	NJ - Newark Bay	Essex	19
11T	NJ - Passaic River Tidal Basin	Essex	19
11T	NJ - Passaic River Tidal Basin	Hudson	19
11MS	NJ - Passaic River Mainstem	Bergen	19
12RBDM	NJ - Hackensack/Meadowlands Basin RBDM	Bergen	17
12OP	NJ - Hackensack/Meadowlands Basin Overpeck Creek	Bergen	17
12U/S	NJ - Hackensack/Meadowlands Basin U/S area	Bergen	17
13	NJ - Shoreline along Kill Van Kull	Hudson	19
14	NJ - Shoreline along Upper Bay	Hudson	20
15	NJ - Shoreline along Hudson River	Hudson	17
15	NJ - Shoreline along Hudson River	Bergen	17
16	NY - Shoreline along Hudson River	Westchester	15
16	NY - Shoreline along Hudson River	Putnam	15
16	NY - Shoreline along Hudson River	Dutchess	15
16	NY - Shoreline along Hudson River	Columbia	18
16	NY - Shoreline along Hudson River	Rensselaer	18
16	NY - Shoreline along Hudson River	Albany	18
16	NY - Shoreline along Hudson River	Greene	18
16	NY - Shoreline along Hudson River	Ulster	15
16	NY - Shoreline along Hudson River	Orange	15
16	NY - Shoreline along Hudson River	Rockland	15
17	NYC - Bronx shoreline along Hudson River	Bronx	15
18	NYC - Manhattan shoreline along Hudson River	New York	17

Table 5: Maximum Elevation - Inventory Limit

Segment #	Reach Name	County	Limiting Elevation NAVD88 (ft.)
19	NYC - Manhattan shoreline along East River	New York	19
20A	NYC - Manhattan shoreline along Harlem River North	New York	16
20B	NYC - Manhattan shoreline along Harlem River South	New York	19
21A	NYC - Bronx shoreline along Harlem River North	Bronx	16
21B	NYC - Bronx shoreline along Harlem River South	Bronx	19
22	NYC - Bronx shoreline along western LIS	Bronx	20
23	NY - Northern Nassau County shoreline western LIS	Nassau	21
24	NY - Eastern Westchester County along western LIS	Westchester	21
25A	NYC - Queens shoreline along western LIS - West	Queens	20
25B	NYC - Queens shoreline along western LIS - East	Queens	20
26	NYC - Queens shoreline along East River	Queens	19
27	NYC - Queens/Brooklyn Newtown Creek Basin	Queens	19
27	NYC - Queens/Brooklyn Newtown Creek Basin	Kings	19
28	NYC - Brooklyn along East River	Kings	20
29	NYC - Brooklyn shoreline along Upper Bay	Kings	19
30	NYC - Gowanus Canal Basin	Kings	20
31	NYC - Brooklyn – Lower Bay, Coney Island/Creek shoreline	Kings	20
32	NYC - Brooklyn shoreline in Jamaica Bay	Kings	18
33	NYC - Queens shoreline & islands in Jamaica Bay	Queens	19
34	NYC - Queens Rockaway Peninsula shoreline	Queens	20

Structures in the Desktop Inventory have been eliminated if they are located on ground above the maximum elevation for their respective reach. Structures with zero value or categorized as outdoor recreational facilities (such as parks and sports fields), parking lots, vacant lots, agricultural land, or other parcels for which the data suggested no actual structure was present have also been removed from the study. Table 6 lists the number of structures in each reach in the desktop inventory and their total estimated values. The total structure replacement value for the 226,234 buildings identified in the study area was estimated to be $358 billion.

Table 6: Number and Value of Structures by Reach

Reach #	Reach Name	Residential		Non-Residential	
		# Structures	Value	# Structures	Value
1	NJ - Sandy Hook Shoreline	N/A	N/A	N/A	N/A
2	NJ - Shrewsbury/Navesink River Basin	8,960	$2,821,182,000	501	$909,254,000
3	NJ - Raritan & Sandy Hook Shoreline	14,055	$1,935,878,000	1,077	$444,958,000
4	NJ - Raritan River Basin	3,393	$797,439,000	518	$992,688,000
5	NYC - South Shore of Staten Island	12,699	$2,385,418,000	555	$5,310,693,000
6	NYC - Western Shore of Staten Island	2,631	$471,920,000	312	$6,081,582,000
7	NYC - Northern Shore of Staten Island	1,110	$606,174,000	473	$863,390,000
8A	NJ - Shoreline along Arthur Kill North	3,704	$793,849,000	750	$2,201,982,000
8B	NJ - Shoreline along Arthur Kill South	4,639	$723,888,000	390	$620,444,000
9	NJ - Rahway River Basin	2,818	$538,096,000	487	$1,505,559,000
10	NJ - Newark Bay	539	$124,016,000	467	$3,076,172,000
11T	NJ - Passaic River Tidal Basin	5,104	$1,191,160,000	2,123	$1,901,208,000
11MS	NJ - Passaic River Mainstem	3,611	$709,687,000	985	$2,210,468,000
12RBDM	NJ - Hackensack/Meadowlands Basin RBDM	6,230	$1,531,534,000	1,230	$2,885,216,000
12OP	NJ - Hackensack/Meadowlands Basin Overpeck Creek	1,606	$349,363,000	421	$812,496,000
13	NJ - Shoreline along Kill Van Kull	352	$105,440,000	18	$46,785,000
14	NJ - Shoreline along Upper Bay	2,840	$1,797,450,000	197	$1,138,307,000
15	NJ - Shoreline along Hudson River	10,703	$4,931,736,000	878	$1,277,797,000
16	NY - Shoreline along Hudson River	2,583	$843,683,000	957	$2,979,293,000
17	NYC - Bronx shoreline along Hudson River	0	$0	1	$1,790,000
18	NYC - Manhattan shoreline along Hudson River	1,998	$22,229,652,000	1,011	$24,318,556,000
19	NYC - Manhattan shoreline along East River	1,332	$17,408,665,000	495	$8,933,623,000
20A	NYC - Manhattan shoreline along Harlem River North	190	$578,241,000	94	$383,662,000
20B	NYC - Manhattan shoreline along Harlem River South	1,948	$7,091,513,000	782	$2,986,860,000
21A	NYC - Bronx shoreline along Harlem River North	351	$399,978,000	101	$744,059,000
21B	NYC - Bronx shoreline along Harlem River South	456	$989,783,000	278	$2,497,328,000
22A	NYC - Bronx shoreline along western LIS - West	5,571	2,196,707,000	772	6,699,072,000

Table 6: Number and Value of Structures by Reach

Reach #	Reach Name	Residential		Non-Residential	
		# Structures	Value	# Structures	Value
22B	NYC - Bronx shoreline along western LIS - East	3,851	1,749,245,000	316	3,017,754,000
23	NY - Northern Nassau County shoreline western LIS	N/A	N/A	N/A	N/A
24	NY - Eastern Westchester County along western LIS	N/A	N/A	N/A	N/A
25A	NYC - Queens shoreline along western LIS - West	2486	$5,329,972,000	728	$21,374,804,000
25B	NYC - Queens shoreline along western LIS - East	N/A	N/A	N/A	N/A
26	NYC - Queens shoreline along East River	1,464	$10,000,533,000	1,064	$5,680,715,000
27	NYC - Queens/Brooklyn Newtown Creek Basin	13	$27,154,000	281	$3,805,724,000
28	NYC - Brooklyn along East River	305	$2,160,771,000	164	$2,073,126,000
29	NYC - Brooklyn shoreline along Upper Bay	5	$2,716,000	0	$0
30	NYC - Gowanus Canal Basin	99	$131,136,000	59	$223,040,000
31	NYC - Brooklyn – Lower Bay, Coney Island/Creek shoreline	1,451	$1,197,998,000	196	$589,183,000
32	NYC - Brooklyn shoreline in Jamaica Bay	60,960	$49,845,052,000	8,526	$52,805,059,000
33	NYC - Queens shoreline & islands in Jamaica Bay	27,663	$8,181,039,000	1307	$34,980,967,000
34	NYC - Queens Rockaway Peninsula shoreline	N/A	N/A	N/A	N/A
Subtotal		*197,720*	*$152,178,068,000*	*28,514*	*$206,373,614,000*
Grand Total		**226,234 Structures** **$358,551,682,000**			

Price Level 2018
Reaches with N/A in the structure or value field are not covered by any measure under any plan.

2.5 Existing/Current Projects

The NYNJHAT study area encompasses many existing coastal flood risk management projects or areas that have been evaluated in detail for the implementation of such projects. The damage models for these existing projects have been collected and updated for consistency with NYNJHAT conditions. Updates include changing the stage frequency data, base and future year, and price index level of the inventory. These models were used in a comparison with the equivalent areas analyzed with the desktop inventory to refine and adjust some of the assumptions made in developing the desktop inventories. Table 7 presents a list of the existing project evaluations that have been collected and updated.

Table 7: Existing Projects in the Study Area

Existing Project Models	County
Highlands	Monmouth
Jamaica Bay South	Kings + Queens
Jamaica Bay North	Kings + Queens
Meadowlands	Bergen
Passaic Mainstem	Essex
Passaic Tidal	Essex + Hudson
Port Monmouth	Monmouth
Sea Bright	Monmouth
South Shore Staten Island	Richmond
Union Beach	Monmouth

2.6 Future Without Project Conditions

Modeling of the future without-project condition of the study area was refined by applying levees to reaches where coastal storm risk reduction measures have been constructed, or have been authorized. Table 8 presents details of the constructed and authorized projects that were incorporated into the future without project condition model via the input of levees consistent with those constructed or authorized. Note that the listed levee elevations were assigned only to sub-reaches within the listed reaches that were specifically delineated to match the spatial extents of each project.

Table 8: Projects Incorporated in the Future Without Project Condition

Affected Reach	County	Project	Levee Elevation Ft NAVD
3	Monmouth	Port Monmouth	13.0
3	Monmouth	Keansburg	14.0
3	Monmouth	Union Beach	14.0
3	Middlesex	Lawrence Harbor	13.0
5	Richmond	South Shore Staten Island	14.6
11	Essex	Passaic Tidal Protection Area	14.0
15	Hudson	Hoboken Rebuild by Design	15.0

3 STORM DAMAGE COMPUTATION

In accordance with current USACE practice for flood risk management projects, version 1.4.1 of HEC-FDA was selected as the appropriate software tool for computing the anticipated damages in these areas using the stage-frequency, structure value, and elevation data as described previously. HEC-FDA (Hydrologic Engineering Center - Flood Damage Analysis) is USACE-certified tool used to perform integrated hydrologic and economic evaluations of flood risk management plans. HEC-FDA uses Monte-Carlo simulation techniques to compute expected values of damage under without- and wit-project conditions while explicitly accounting for risk and uncertainty in key parameters, in accordance with current guidance.

Under this approach, key parameters including stage-frequency relationships, structure values, structure elevations, and inundation-damage functions are defined by probability distributions rather than fixed values. During each execution of the model, the program performs many iterations of the damage computations while sampling from the input probability distributions until an allowable tolerance in the overall mean damage is reached.

3.1 Inundation Damage Functions

The analysis required the assignment of appropriate depth-damage relationships to all structures in the inventory. A depth-damage function is a mathematical relationship between the depth of flood water above or below the first floor of a building and the amount of damage that can be attributed to that water. Depth-damage relationships are computed separately for structure and contents. Depth-damage relationships are based on the premise that water height, and its relationship to structure height (elevation), is the most important variable in determining the expected value of damage to buildings. Similar properties, constructed, furnished, and maintained alike, and exposed to the same flood stages and forces, may be assumed to incur damages in similar magnitudes or proportion to actual values. Depth-damage relationships are generally expressed with content damage as a percentage of content value, and structure damage as a percentage of structure value, for each foot of inundation.

While several sets of potentially applicable damage functions have been developed by the US Army Corps of Engineers for use in studies such as this one, the functions selected for this study were drawn from those developed for the NACCS study and published in 2015. The depth-damage functions were assigned according to the use and configuration of the individual inventory structures. The selected NACCS functions applied in these analyses are listed by structure type in Table 9 below.

Table 9: Depth-Damage Functions

Function	Applicable Structure
NACCS 1A-1	Prototype 1A-1, Apartments, 1 Story, No Basement
NACCS 1-A3	Prototype 1A-3, Apartments, 3 Stories, No Basement
NACCS 4A	Prototype 4A - Urban High Rise
NACCS 5A	Prototype 5A, Single-Story Residence, No Basement
NACCS 5B	Prototype 5B, Two-Story Residence, No Basement
NACCS 6A	Prototype 6A, Single-Story Residence, with Basement
NACCS 6B	Prototype 6B, Two-Story Residence, with Basement
NACCS 7A	Prototype 7A - Building on Open Pile Foundation
NACCS 7B	Prototype 7B - Building on Pile Foundation with Enclosure
NACCS 2 NP	Prototype 2, Commercial, Engineered, Nonperishable Contents
NACCS 2 P	Prototype 2, Commercial, Engineered, Perishable Contents
NACCS 3 NP	Prototype 2, Commercial, Non/Pre-Engineered, Nonperishable Contents
NACCS 3 P	Prototype 2, Commercial, Non/Pre-Engineered, Perishable Contents

4 ESTIMATION OF DAMAGES AND BENEFITS

The NYNJHAT study area is vulnerable to significant damages from coastal storm events that cause riverine and coastal flooding. Damages without project were evaluated using HEC-FDA version 1.4.1 and the results are summarized by reach in Table10.

4.1 Without Project Damages

Table 9 presents the total expected annual damages for each reach potentially covered by a flood risk reduction measure as part of one of the proposed alternative plans under conditions in 2030 and 2100, assuming intermediate projections of future sea level rise. Absent the implementation of any flood risk management project beyond those identified in the discussion of future without-project conditions, the area may be subject to expected annual damages of $5.1 billion in 2030, rising to $13.7 billion in 2100. The damage in any intervening years was calculated by interpolating between these two points in time.

Table 9 also presents the total equivalent annual damage for each reach for the initially assumed analysis period 2035 to 2085. Damage was calculated as both total present worth and equivalent annualized damage accounting for changes in expected damage over time – in this case due to sea level change between the base year and the final year of the analysis period. Without project equivalent annual damage has been computed for the 50-year period 2035 – 2085 only: For preliminary analyses it has been assumed that all components of the evaluated plans will be in place and accruing benefits by the year 2035, and be subject to an analysis period of 50 years. The total equivalent annual damage for the study area has been estimated to be approximately $7.1 billion.

Table 10: Summary of Without Project Damages (No Action Alternative)

Reach	Description	Annual Damages		
		2030 Expected	2100 Expected	Equivalent
2	NJ - Shrewsbury/Navesink River Basin	$73,554,550	$218,003,190	$108,224,000
3	NJ - Raritan & Sandy Hook Shoreline	$25,153,290	$66,060,990	$34,400,000
4	NJ - Raritan River Basin	$13,945,660	$33,928,440	$18,244,000
5	NYC - South Shore of Staten Island	$24,794,410	$49,852,740	$29,218,000
6	NYC - Western Shore of Staten Island	$69,364,910	$186,361,200	$96,152,000
7	NYC - Northern Shore of Staten Island	$25,869,230	$66,256,590	$34,862,000
8	NJ - Shoreline along Arthur Kill North	$63,635,250	$164,886,070	$86,341,000
9	NJ - Rahway River Basin	$33,945,320	$84,416,810	$44,970,000
10	NJ - Newark Bay	$48,579,560	$133,724,300	$68,325,000
11	NJ - Passaic River Tidal Basin	$74,669,960	$187,940,980	$99,611,000
12	NJ - Hackensack/Meadowlands Basin RBDM	$344,285,100	$933,901,240	$479,979,000
13	NJ - Shoreline along Kill Van Kull	$6,035,610	$16,894,520	$8,575,000
14	NJ - Shoreline along Upper Bay	$155,033,910	$402,264,020	$210,521,000
15	NJ - Shoreline along Hudson River	$34,362,010	$80,907,930	$44,125,000
16	NY - Shoreline along Hudson River	$42,048,850	$112,592,370	$58,170,000
17	NYC - Bronx shoreline along Hudson River	$122,460	$392,150	$189,000
18	NYC - Manhattan shoreline along Hudson River	$558,787,810	$1,386,949,790	$739,442,000
19	NYC - Manhattan shoreline along East River	$250,255,430	$595,784,960	$323,367,000
20A	NYC - Manhattan shoreline along Harlem River North	$800,530	$2,675,090	$1,271,000
20B	NYC - Manhattan shoreline along Harlem River South	$88,064,190	$231,357,790	$120,461,000
21A	NYC - Bronx shoreline along Harlem River North	$3,129,890	$12,132,150	$5,483,000
21B	NYC - Bronx shoreline along Harlem River South	$80,508,900	$200,401,010	$106,713,000
22A	NYC - Bronx shoreline along western LIS - West	$77,953,670	$178,961,570	$98,692,000
22B	NYC - Bronx shoreline along western LIS - East	$23,068,100	$52,245,760	$28,986,000
25A	NYC - Queens shoreline along western LIS - West	$1,338,330,190	$3,016,444,620	$1,677,165,000
26	NYC - Queens shoreline along East River	$300,268,990	$708,374,660	$386,002,000
27	NYC - Queens/Brooklyn Newtown Creek Basin	$43,705,680	$115,948,580	$60,131,000

Table 10: Summary of Without Project Damages (No Action Alternative)

Reach	Description	Annual Damages		
		2030 Expected	2100 Expected	Equivalent
28	NYC - Brooklyn along East River	$55,076,900	$139,828,060	$73,843,000
29	NYC - Brooklyn shoreline along Upper Bay	$60,350	$160,740	$83,000
30	NYC- Gowanus Canal Basin	$22,982,990	$50,452,570	$28,387,000
31	NYC - Brooklyn - Lower Bay, Coney Island/Creek shoreline	$57,651,070	$149,281,720	$78,191,000
32	NYC - Brooklyn shoreline in Jamaica Bay	$843,991,300	$3,062,186,310	$1,414,112,000
33	NYC - Queens shoreline & islands in Jamaica Bay	$358,009,500	$1,078,285,800	$532,042,000
Totals		*$5,138,045,570*	*$13,719,854,720*	*$7,096,277,000*

Price Level 2018. Analysis period for equivalent annual damage is 50 years (2035 – 2085), interest rate 2.875%

4.2 With - Project Damages and Benefits

For each reach, a suite of nonstructural, structural, and natural and nature based features were considered, as identified in the NACCS report. For this preliminary analysis, the storm risk management measures assigned to the reaches in each evaluated plan consisted of tide gates and surge barriers across the various bodies of water in the study area, and shore-based measures (SBM) constructed on land. Examples of shore-based measures include levees, berms, and floodwalls.

The frequency with which moveable gates and barriers may be closed to prevent storm damage is complex and driven by many factors including operation and maintenance costs, water quality issues, and navigation. For the preliminary analyses it was assumed that all moveable gates and barriers will be closed in the event of a 50% annual chance exceedance coastal storm ("2-Year storm"), while recognizing that the analysis may be refined in future to assume that larger gates/barriers may be closed for storms of 10% annual chance exceedance ("10-year") and greater.

For preliminary analyses it has been assumed that all components of the evaluated plans will be in place and accruing benefits by the year 2035, and will be subject to an analysis period of 50 years. In subsequent stages of the study the economic analysis will be driven by a detailed construction and commissioning schedule in which different components of each plan will come on stream and begin accruing benefits in different years.

The current analyses use an economic base year of 2030 for the entire project. In effect, this means that while the benefit calculations assume the project will be commissioned and come on stream in 2035, all damages, and benefits are discounted to the year 2030. The approach has been incorporated into the present worth analysis to allow more refined calculations of the benefits and costs as the project construction schedule and lifecycle are developed. At this point, the analysis may understate the present value of the benefits relative to the costs, but should not materially alter the comparison of the different plans.

The analysis interpolates without- and with-project expected annual damages in each year of the analysis period and calculates a total residual damage in each year, taking into account the assumed operating threshold for movable gates and barriers. The damages and benefits in each year are converted to a present worth using standard discounting formulae and summed for each lifecycle.

The total present worths of damages and benefits for each reach are converted to an equivalent annual damage or benefit using the capital recovery factor based on the current applicable interest rate. An example of the spreadsheet calculation for one reach is presented in Figure 3.

Figure 3 shows the calculation of present worth damages and benefits for the first 24 years of the period of analysis for Reach 7 with and without the construction of a barrier which will be closed for storm events of 50% annual chance exceedance and greater. For each year of the period of analysis, Figure 3 shows the expected annual without-project damages and the expected annual net residual damages (i.e. damages that occur during high frequency events that do not meet the criteria for closing the barrier, and very low frequency events during which the barrier is overtopped). The present worths of the consequent benefits in all years in the period of analysis are then summed and multiplied by the capital recovery factor derived from the current federal interest rate to generate the total equivalent annual benefit for this reach.

These equivalent annual values are summarized by reach and plan in Tables 11 through 15. These tables include a description of the assigned measure that is intended to reduce the risk of storm damage in each reach, and a glossary of the abbreviated terms follows at the end of this report. Plans 2 and 3a consist only of movable gates and barriers, Plans 3b and 4 comprise a combination of gates/barriers and shore-based measures, while Plan 5 includes shore-based measures only. For all gates and barriers in Plans 2 through 4 the operating threshold was assumed to be the 50% annual chance exceedance storm event. It should be noted that the results presented thus far do not include refinements to the residual damages due to drainage of interior runoff behind the assumed line of protection.

It should also be noted that this preliminary analysis may overstate the residual damages for plan alternatives in some reaches due to a simplifying assumption made for this phase of the study: It is currently assumed when evaluating plans in HEC-FDA that when the line of protection is overtopped during a storm event, the interior area will fill up to the same elevation as the exterior water surface. In reality, for surge barriers with large areas inland of the barrier, the post-overtopping interior water surface elevation will be governed by how much water can physically flow over the line of protection before the exterior water surface recedes below the design elevation.

The HEC-FDA program has the facility to more accurately model this scenario via the input of interior – exterior water surface elevation relationships for the structural measures assigned to each reach, but the required data is not available at this stage of the study.

A summary of the total equivalent annual damages and benefits for all evaluated plans is presented in Table 16, and Table 17 presents the same damages and benefits expressed as total present values discounted to the year 2030.

Discount Rate	2.875%	Plan								
Plan Base Year	2030	3a								
Plan Period of Analysis	50	2-Yr Res			Reach	7	VN-AK-TN Barrier			
Last year for benefits	2090		Measure	VN-AK-TN Barrier		Measure Complete	2035	Benefits Through Year		2085
Year	Project Year	pwf	WOP Damage	Residual HFF 2yr	Residual LFF	Net Residual	Benefit	PW WOP Damage	PW WP Damage	PW Benefit
2030	0	1.000	$ 25,869,230	$ 25,438,620	$ 2,195,850	$ -	$ -	$ -	$ -	$ -
2031	1	0.972	$ 26,446,192	$ 26,020,396	$ 2,228,012	$ -	$ -	$ -	$ -	$ -
2032	2	0.945	$ 27,023,155	$ 26,602,172	$ 2,260,173	$ -	$ -	$ -	$ -	$ -
2033	3	0.918	$ 27,600,117	$ 27,183,948	$ 2,292,335	$ -	$ -	$ -	$ -	$ -
2034	4	0.893	$ 28,177,079	$ 27,765,723	$ 2,324,497	$ -	$ -	$ -	$ -	$ -
2035	5	0.868	$ 28,754,041	$ 28,347,499	$ 2,356,659	$ -	$ -	$ -	$ -	$ -
2036	6	0.844	$ 29,331,004	$ 28,929,275	$ 2,388,820	$ 2,790,549	$ 26,540,455	$ 24,743,882	$ 2,354,131	$ 22,389,751
2037	7	0.820	$ 29,907,966	$ 29,511,051	$ 2,420,982	$ 2,817,897	$ 27,090,069	$ 24,525,504	$ 2,310,767	$ 22,214,737
2038	8	0.797	$ 30,484,928	$ 30,092,827	$ 2,453,144	$ 2,845,245	$ 27,639,683	$ 24,300,007	$ 2,267,989	$ 22,032,018
2039	9	0.775	$ 31,061,891	$ 30,674,603	$ 2,485,305	$ 2,872,593	$ 28,189,297	$ 24,067,958	$ 2,225,797	$ 21,842,162
2040	10	0.753	$ 31,638,853	$ 31,256,379	$ 2,517,467	$ 2,899,941	$ 28,738,911	$ 23,829,901	$ 2,184,192	$ 21,645,710
2041	11	0.732	$ 32,215,815	$ 31,838,154	$ 2,549,629	$ 2,927,290	$ 29,288,526	$ 23,586,353	$ 2,143,174	$ 21,443,179
2042	12	0.712	$ 32,792,777	$ 32,419,930	$ 2,581,791	$ 2,954,638	$ 29,838,140	$ 23,337,806	$ 2,102,742	$ 21,235,064
2043	13	0.692	$ 33,369,740	$ 33,001,706	$ 2,613,952	$ 2,981,986	$ 30,387,754	$ 23,084,730	$ 2,062,897	$ 21,021,833
2044	14	0.672	$ 33,946,702	$ 33,583,482	$ 2,646,114	$ 3,009,334	$ 30,937,368	$ 22,827,572	$ 2,023,637	$ 20,803,935
2045	15	0.654	$ 34,523,664	$ 34,165,258	$ 2,678,276	$ 3,036,682	$ 31,486,982	$ 22,566,757	$ 1,984,959	$ 20,581,798
2046	16	0.635	$ 35,100,627	$ 34,747,034	$ 2,710,437	$ 3,064,030	$ 32,036,596	$ 22,302,693	$ 1,946,863	$ 20,355,829
2047	17	0.618	$ 35,677,589	$ 35,328,810	$ 2,742,599	$ 3,091,378	$ 32,586,210	$ 22,035,762	$ 1,909,347	$ 20,126,416
2048	18	0.600	$ 36,254,551	$ 35,910,585	$ 2,774,761	$ 3,118,727	$ 33,135,825	$ 21,766,333	$ 1,872,406	$ 19,893,927
2049	19	0.584	$ 36,831,513	$ 36,492,361	$ 2,806,923	$ 3,146,075	$ 33,685,439	$ 21,494,752	$ 1,836,039	$ 19,658,713
2050	20	0.567	$ 37,408,476	$ 37,074,137	$ 2,839,084	$ 3,173,423	$ 34,235,053	$ 21,221,352	$ 1,800,242	$ 19,421,110
2051	21	0.551	$ 37,985,438	$ 37,655,913	$ 2,871,246	$ 3,200,771	$ 34,784,667	$ 20,946,445	$ 1,765,013	$ 19,181,432
2052	22	0.536	$ 38,562,400	$ 38,237,689	$ 2,903,408	$ 3,228,119	$ 35,334,281	$ 20,670,329	$ 1,730,346	$ 18,939,984
2053	23	0.521	$ 39,139,363	$ 38,819,465	$ 2,935,569	$ 3,255,467	$ 35,883,895	$ 20,393,287	$ 1,696,238	$ 18,697,049
2054	24	0.506	$ 39,716,325	$ 39,401,241	$ 2,967,731	$ 3,282,815	$ 36,433,509	$ 20,115,586	$ 1,662,685	$ 18,452,901
2055	25	0.492	$ 40,293,287	$ 39,983,016	$ 2,999,893	$ 3,310,164	$ 36,983,124	$ 19,837,480	$ 1,629,683	$ 18,207,796
2056	26	0.479	$ 40,870,249	$ 40,564,792	$ 3,032,055	$ 3,337,512	$ 37,532,738	$ 19,559,207	$ 1,597,227	$ 17,961,979
2057	27	0.465	$ 41,447,212	$ 41,146,568	$ 3,064,216	$ 3,364,860	$ 38,082,352	$ 19,280,994	$ 1,565,313	$ 17,715,681
2058	28	0.452	$ 42,024,174	$ 41,728,344	$ 3,096,378	$ 3,392,208	$ 38,631,966	$ 19,003,055	$ 1,533,934	$ 17,469,121
2059	29	0.440	$ 42,601,136	$ 42,310,120	$ 3,128,540	$ 3,419,556	$ 39,181,580	$ 18,725,593	$ 1,503,087	$ 17,222,506

Figure 3: Damages and Benefits Annualization Analysis Example

Table 11: Equivalent Annual Damages and Benefits: Plan 2

Reach	Measure	Annual Damage/Benefits Summary		
		WOP Damage	WP Damage	Benefits
2	Barrier	$108,224,000	$12,880,000	$95,344,000
3	Barrier	$34,400,000	$7,431,000	$26,969,000
4	Barrier	$18,244,000	$3,014,000	$15,229,000
5	Barrier	$29,218,000	$19,054,000	$10,165,000
6	Barrier	$96,152,000	$15,290,000	$80,862,000
7	Barrier	$34,862,000	$2,868,000	$31,994,000
8	Barrier	$86,341,000	$6,794,000	$79,547,000
9	Barrier	$44,970,000	$3,365,000	$41,605,000
10	Barrier	$68,325,000	$6,649,000	$61,676,000
11	Barrier	$99,611,000	$8,853,000	$90,758,000
12	Barrier	$479,979,000	$23,146,000	$456,834,000
13	Barrier	$8,575,000	$449,000	$8,126,000
14	Barrier	$210,521,000	$12,538,000	$197,983,000
15	Barrier	$44,125,000	$13,372,000	$30,753,000
16	Barrier	$58,170,000	$5,392,000	$52,779,000
17	Barrier	$189,000	$8,000	$181,000
18	Barrier	$739,442,000	$68,521,000	$670,921,000
19	Barrier	$323,367,000	$47,718,000	$275,649,000
20A	Barrier	$1,271,000	$335,000	$936,000
20B	Barrier	$120,461,000	$10,448,000	$110,014,000
21A	Barrier	$5,483,000	$608,000	$4,875,000
21B	Barrier	$106,713,000	$6,033,000	$100,680,000
22A	Barrier	$98,692,000	$10,114,000	$88,578,000
22B	PB Barrier	$28,986,000	$3,807,000	$25,179,000
25A	TN Barrier	$1,677,165,000	$48,142,000	$1,629,024,000
26	Barrier	$386,002,000	$33,982,000	$352,019,000
27	Barrier	$60,131,000	$7,172,000	$52,959,000
28	Barrier	$73,843,000	$6,868,000	$66,975,000
29	Barrier	$83,000	$10,000	$74,000
30	Barrier	$28,387,000	$1,123,000	$27,264,000
31	Barrier	$78,191,000	$1,667,000	$76,524,000
32	Barrier	$1,414,112,000	$120,710,000	$1,293,403,000
33	Barrier	$532,042,000	$101,627,000	$430,414,000
Totals		*$7,096,277,000*	*$609,988,000*	*$6,486,293,000*

Price level 2018, 50-year period of analysis, 2.875% interest rate

Table 12: Equivalent Annual Damages and Benefits: Plan 3a

Reach	Measure	Annual Damage/Benefits Summary		
		WOP Damage	WP Damage	Benefits
2	None	$108,224,000	$108,224,000	$0
3	None	$34,400,000	$34,400,000	$0
4	None	$18,244,000	$18,244,000	$0
5	None	$29,218,000	$29,218,000	$0
6	VN-AK-TN Barrier	$96,152,000	$15,290,000	$80,862,000
7	VN-AK-TN Barrier	$34,862,000	$2,868,000	$31,994,000
8	VN-AK-TN Barrier	$86,341,000	$6,794,000	$79,547,000
9	VN-AK-TN Barrier	$44,970,000	$3,365,000	$41,605,000
10	VN-AK-TN Barrier	$68,325,000	$6,649,000	$61,676,000
11	VN-AK-TN Barrier	$99,611,000	$8,853,000	$90,758,000
12	VN-AK-TN Barrier	$479,979,000	$23,146,000	$456,834,000
13	VN-AK-TN Barrier	$8,575,000	$449,000	$8,126,000
14	VN-AK-TN Barrier	$210,521,000	$12,538,000	$197,983,000
15	VN-AK-TN Barrier	$44,125,000	$13,372,000	$30,753,000
16	VN-AK-TN Barrier	$58,170,000	$5,392,000	$52,779,000
17	VN-AK-TN Barrier	$189,000	$8,000	$181,000
18	VN-AK-TN Barrier	$739,442,000	$68,521,000	$670,921,000
19	VN-AK-TN Barrier	$323,367,000	$47,718,000	$275,649,000
20A	VN-AK-TN Barrier	$1,271,000	$335,000	$936,000
20B	VN-AK-TN Barrier	$120,461,000	$10,448,000	$110,014,000
21A	VN-AK-TN Barrier	$5,483,000	$608,000	$4,875,000
21B	VN-AK-TN Barrier	$106,713,000	$6,033,000	$100,680,000
22A	VN-AK-TN Barrier	$98,692,000	$10,114,000	$88,578,000
22B	PB Barrier	$28,986,000	$3,807,000	$25,179,000
25A	TN Barrier	$1,677,165,000	$48,142,000	$1,629,024,000
26	VN-AK-TN Barrier	$386,002,000	$33,982,000	$352,019,000
27	VN-AK-TN Barrier	$60,131,000	$7,172,000	$52,959,000
28	VN-AK-TN Barrier	$73,843,000	$6,868,000	$66,975,000
29	VN-AK-TN Barrier	$83,000	$10,000	$74,000
30	VN-AK-TN Barrier	$28,387,000	$1,123,000	$27,264,000
31	SBQ Barrier	$78,191,000	$1,667,000	$76,524,000
32	SBQ Barrier	$1,414,112,000	$120,710,000	$1,293,403,000
33	SBQ Barrier	$532,042,000	$101,627,000	$430,414,000
Totals		*$7,096,277,000*	*$757,695,000*	*$6,338,586,000*

Price level 2018, 50-year period of analysis, 2.875% interest rate

Table 13: Equivalent Annual Damages and Benefits: Plan 3b

Reach	Measure	Annual Damage/Benefits Summary		
		WOP Damage	WP Damage	Benefits
2	None	$108,224,000	$108,224,000	$0
3	None	$34,400,000	$34,400,000	$0
4	None	$18,244,000	$18,244,000	$0
5	None	$29,218,000	$29,218,000	$0
6	AK-KVK Barrier	$96,152,000	$15,290,000	$80,862,000
7	AK-KVK Barrier	$34,862,000	$2,868,000	$31,994,000
8	AK-KVK Barrier	$86,341,000	$6,794,000	$79,547,000
9	AK-KVK Barrier	$44,970,000	$3,365,000	$41,605,000
10	AK-KVK Barrier	$68,325,000	$6,649,000	$61,676,000
11	AK-KVK Barrier	$99,611,000	$8,853,000	$90,758,000
12	AK-KVK Barrier	$479,979,000	$23,146,000	$456,834,000
13	AK-KVK Barrier	$8,575,000	$449,000	$8,126,000
14	SBM	$210,521,000	$12,538,000	$197,983,000
15	None	$44,125,000	$44,125,000	$0
16	SBM	$58,170,000	$2,981,000	$55,189,000
17	None	$189,000	$189,000	$0
18	SBM	$739,442,000	$49,024,000	$690,419,000
19	None	$323,367,000	$323,367,000	$0
20A	None	$1,271,000	$1,271,000	$0
20B	SBM	$120,461,000	$9,829,000	$110,632,000
21A	None	$5,483,000	$5,483,000	$0
21B	None	$106,713,000	$106,713,000	$0
22A	BR & WC Barriers & SBM	$98,692,000	$10,114,000	$88,578,000
22B	PB Barrier	$28,986,000	$3,807,000	$25,179,000
25A	FC Barrier & SBM	$1,677,165,000	$48,142,000	$1,629,024,000
26	SBM	$386,002,000	$16,607,000	$369,394,000
27	NC Gate	$60,131,000	$7,172,000	$52,959,000
28	None	$73,843,000	$73,843,000	$0
29	None	$83,000	$83,000	$0
30	GC Barrier	$28,387,000	$1,123,000	$27,264,000
31	SBQ Barrier	$78,191,000	$1,667,000	$76,524,000
32	SBQ Barrier	$1,414,112,000	$120,710,000	$1,293,403,000
33	SBQ Barrier	$532,042,000	$101,627,000	$430,414,000
Totals		*$7,096,277,000*	*$1,197,915,000*	*$5,898,364,000*

Price level 2018, 50-year period of analysis, 2.875% interest rate

Table 14: Equivalent Annual Damages and Benefits: Plan 4

Reach	Measure	Annual Damage/Benefits Summary		
		WOP Damage	WP Damage	Benefits
2	None	$108,224,000	$108,224,000	$0
3	None	$34,400,000	$34,400,000	$0
4	None	$18,244,000	$18,244,000	$0
5	None	$29,218,000	$29,218,000	$0
6	None	$96,152,000	$96,152,000	$0
7	None	$34,862,000	$34,862,000	$0
8	None	$86,341,000	$86,341,000	$0
9	None	$44,970,000	$44,970,000	$0
10	None	$68,325,000	$68,325,000	$0
11	None	$99,611,000	$99,611,000	$0
12	Hackensack Barrier	$479,979,000	$23,146,000	$456,834,000
13	None	$8,575,000	$8,575,000	$0
14	SBM	$210,521,000	$12,538,000	$197,983,000
15	None	$44,125,000	$44,125,000	$0
16	SBM	$58,170,000	$2,981,000	$55,189,000
17	None	$189,000	$189,000	$0
18	SBM	$739,442,000	$49,024,000	$690,419,000
19	None	$323,367,000	$323,367,000	$0
20A	None	$1,271,000	$1,271,000	$0
20B	SBM	$120,461,000	$9,829,000	$110,632,000
21A	None	$5,483,000	$5,483,000	$0
21B	None	$106,713,000	$106,713,000	$0
22A	BR & WC Barriers & SBM	$98,692,000	$10,114,000	$88,578,000
22B	PB Barrier	$28,986,000	$3,807,000	$25,179,000
25A	FC Barrier & SBM	$1,677,165,000	$48,142,000	$1,629,024,000
26	SBM	$386,002,000	$16,607,000	$369,394,000
27	NC Gate	$60,131,000	$7,172,000	$52,959,000
28	None	$73,843,000	$73,843,000	$0
29	None	$83,000	$83,000	$0
30	GC Barrier	$28,387,000	$1,123,000	$27,264,000
31	SBQ Barrier	$78,191,000	$1,667,000	$76,524,000
32	SBQ Barrier	$1,414,112,000	$120,710,000	$1,293,403,000
33	SBQ Barrier	$532,042,000	$101,627,000	$430,414,000
Totals		*$7,096,277,000*	*$1,592,483,000*	*$5,503,796,000*

Price level 2018, 50-year period of analysis, 2.875% interest rate

Table 15: Equivalent Annual Damages and Benefits: Plan 5

Reach	Measure	Annual Damage/Benefits Summary		
		WOP Damage	WP Damage	Benefits
2	None	$108,224,000	$108,224,000	$0
3	None	$34,400,000	$34,400,000	$0
4	None	$18,244,000	$18,244,000	$0
5	None	$29,218,000	$29,218,000	$0
6	None	$96,152,000	$96,152,000	$0
7	None	$34,862,000	$34,862,000	$0
8	None	$86,341,000	$86,341,000	$0
9	None	$44,970,000	$44,970,000	$0
10	None	$68,325,000	$68,325,000	$0
11	None	$99,611,000	$99,611,000	$0
12 RBDM	SBM	$390,818,000	$12,960,000	$377,859,000
12 OP U/S	None	$89,161,000	$89,161,000	$0
13	None	$8,575,000	$8,575,000	$0
14	SBM	$210,521,000	$12,538,000	$197,983,000
15	None	$44,125,000	$44,125,000	$0
16	SBM	$58,170,000	$2,981,000	$55,189,000
17	None	$189,000	$189,000	$0
18	SBM	$739,442,000	$49,024,000	$690,419,000
19	None	$323,367,000	$323,367,000	$0
20A	None	$1,271,000	$1,271,000	$0
20B	SBM	$120,461,000	$9,829,000	$110,632,000
21A	None	$5,483,000	$5,483,000	$0
21B	None	$106,713,000	$106,713,000	$0
22A	None	$98,692,000	$98,692,000	$0
22B	None	$28,986,000	$28,986,000	$0
25A	None	$1,677,165,000	$1,677,165,000	$0
26	SBM	$386,002,000	$16,607,000	$369,394,000
27	None	$60,131,000	$60,131,000	$0
28	None	$73,843,000	$73,843,000	$0
29	None	$83,000	$83,000	$0
30	None	$28,387,000	$28,387,000	$0
31	None	$78,191,000	$78,191,000	$0
32	None	$1,414,112,000	$1,414,112,000	$0
33	None	$532,042,000	$532,042,000	$0
Totals		*$7,096,278,000*	*$5,294,802,000*	*$1,801,476,000*

Price level 2018, 50-year period of analysis, 2.875% interest rate

Table 16: Summary of All Evaluated Plans

Plan	Equivalent Annual Damage/Benefits Summary		
	WOP Damage	WP Damage	Benefits
1 (No Action)	$7,096,278,000	$7,096,278,000	$0
2	$7,096,278,000	$609,988,000	$6,486,293,000
3a	$7,096,278,000	$757,695,000	$6,338,586,000
3b	$7,096,278,000	$1,197,915,000	$5,898,364,000
4	$7,096,278,000	$1,592,483,000	$5,503,796,000
5	$7,096,278,000	$5,294,802,000	$1,801,476,000

Price level 2018, 50-year period of analysis, 2.875% interest rate
Assumes completion of all project components by 2035.

Table 17: Summary of All Evaluated Plans: Present Values

Plan	Present Value of Damage/Benefits Summary (Values in $Billions)		
	WOP Damage	WP Damage	Benefits
1 (No Action)	$187.0	$187.0	$0.0
2	$187.0	$16.1	$170.9
3a	$187.0	$20.0	$167.0
3b	$187.0	$31.6	$155.4
4	$187.0	$42.0	$145.0
5	$187.0	$139.5	$47.5

Price level 2018, 50-year period of analysis, 2.875% interest rate
Assumes completion of all project components by 2035.
Economic base year 2030

Abbreviations and terms used in Tables 10-14

AK	Arthur Kill
Barrier	Used on its own to refer to a barrier from Sandy Hook - Queens
BR	Bronx River
FC	Flushing Creek
GC	Gowanus Creek
KVK	Kill Van Kull
NC	Newtown Creek
None	No structural measure assumed for this reach
PB	Pelham Bay
SBM	Shore-Based Measures
SBQ	South Brooklyn - Queens
TN	Throgs Neck
VN	Verrazano Narrows
WC	Westchester Creek