US Army Corps of Engineers®
New York District

Economic Appendix
NED Damage & Benefits Analysis

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

Draft

Appendix D

September 2022

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Purpose

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.

The study objective is to evaluate alternative plans that will manage coastal storm risk and reduce coastal storm damages to the existing development on the shorefront and in coastal floodplains and recommend a selected plan.

The economic analyses have been focused on National Economic (NED) benefits in the form of damages to structure and contents avoided. However, this Appendix also includes assessments under other accounts such as Regional Economic Development (RED) and Other Social Effects (OSE). Navigational benefits have not been evaluated since any related issues are anticipated to be mitigated as part of the detailed design phase.

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, more than 900 miles of tidally influenced shoreline, and includes parts of 22 counties in two states that contribute to the economic analysis.

In New York State the economic analysis covers parts of New York, Kings, Queens, Brooklyn, and Richmond Counties in the City of New York, and parts of Albany, Rensselaer, Columbia, Greene, Dutchess, Ulster, Putnam, Orange, Westchester, and Rockland Counties upstream on the Hudson River. In New Jersey the analysis covers parts of Monmouth, Middlesex, Hudson, Bergen, Union, Essex, and Passaic Counties.

To include all tidally affected waters, the study area extends upstream on 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 Overview of Alternatives

The study evaluated six alternatives, including the without-project condition (Alternative 1) and five with-project alternatives:

- Alternative 1: No action
- Alternative 2: NY-NJ Harbor-Wide Storm Surge Gates/Beach Restoration Features
- Alternative 3A: Upper Bay-Newark Bay Storm Surge Gate and Jamaica Bay Storm Surge Gate Plan
- Alternative 3B: Newark Bay, Jamaica Bay, Newtown Creek, Gowanus Creek, Flushing Creek, and Multiple Shore-Based Measures
- Alternative 4: Single Water Body Barriers/Floodwalls/Levees: Jamaica Bay, Hackensack River, Newtown Creek, Gowanus Creek, Flushing Creek, Bronx River, Westchester Creek Surge Gates, and Shore-Based Measures
- Alternative 5: Perimeter Only Solutions (Multiple Shore-Based Measures)

The coverage and specific components of each evaluated plan are described in more detail in subsequent sections of this Appendix.

1.4 Economic Analysis Parameters

For the analysis of all alternatives, construction was assumed to start in 2030 and a base year of 2044 was used for all economic calculations. Since the with-project alternatives vary greatly in scale and cost, their construction durations and periods of benefits accrual will also vary. The key years and time periods associated with each alternative, applied in accordance with current USACE planning guidance, are presented in Table 1. For detailed descriptions of the scheduling of each alternative, see Appendix A-2, Cost Engineering.

Table 1. Timelines for Evaluated Alternatives

Alternative	Start of Construction	Construction Duration, Years	Construction Complete	Base Year	First Year of Full Benefits	Last Year of Full Benefits	Years of Full Benefits
2	2030	32	2062	2044	2063	2094	32
3A	2030	24	2054	2044	2055	2094	40
3B	2030	14	2044	2044	2045	2094	50
4	2030	14	2044	2044	2045	2094	50
5	2030	5	2035	2044	2036	2085	50

All economic analyses associated with the evaluation of these plans used the FY2022 interest rate of 2.25% and were based on a price level of February 2022.

2 Problem Identification

The study area is vulnerable to damage from storm surge, wave attack, erosion, and intense rainfall events that can also cause riverine or inland flooding. These forces constitute a threat to human life and increase the risk of flood damages to public and private property and infrastructure. The study area encompasses the New York Metropolitan Area, including the most populous and densely populated city in the United States and the three largest cities in New Jersey (Trenton, Jersey City and Paterson). This region is the hub of financial centers and international trade, qualifying it as one of the most important economic regions in the world. The City of New York alone had a Gross Metropolitan Product (GMP) of $1.6 trillion in 2016. The study area is highly urbanized, and with existing geography, topography, and proximity to tidally influenced areas, is highly vulnerable to coastal storm damage. Projections of climate change and sea level change effectively increase the risk/vulnerability of this area to future flooding events and coastal storm damage.

Coastal storms have played important roles in shaping the present-day shoreline through erosion and movement of sand. Development of housing and waterfront properties along the coastline has placed many property owners in areas of high vulnerability due to the lack of shoreline stabilization, erosion of supportive and protective landforms, and surge during coastal storms.

Historic sea level change has exacerbated flooding over the past century, and potential sea level change in the future will only increase the magnitude, frequency, and extent of the problem. Since 1900, relative sea level has risen by more than a foot within the study area due to global climate change and local land subsidence (NPCC2, 2013). According to the NYS 2100 Commission Report (2013), experts project sea level to rise in New York City and Long Island by as many as six feet under certain scenarios within the next 90 years. As sea levels continue to rise, coastal storms will cause flooding over a larger area and at increased heights than they otherwise would have in the past.

The States of New Jersey and New York, in their respective state hazard mitigation plans, have documented the numerous, historic instances of flooding, Presidential disaster declarations, and damage estimates. Coastal storms have and will continue to cause flooding and severe impacts to the NYNJHT study area. It is projected that the frequency and intensity of these coastal storms will increase (NPCC2, 2013). Between 1996 and 2013, 22 major coastal flooding events were recorded for the study area (NOAA NCDC, 2013).

In October 2012, Hurricane Sandy damaged or destroyed at least 650,000 houses and left approximately 8.5 million customers without power during the storm and its aftermath. Preliminary estimates from the event exceeded $50 billion in damages (NOAA, 2013), with 24 states impacted by the storm. Hurricane Sandy caused devastation in the study area, damaging property and disrupting millions of lives. As a result of the storm, 48 people lost their lives in New York and 12 people lost their lives in New Jersey. Some of the highest storm surges and greatest inundation, which reached record levels, occurred in New York and New Jersey. Storm surge caused flooding at 10 feet above ground level in some locations. The storm exposed vulnerabilities associated with inadequate coastal storm risk management measures and lack of defense to critical transportation and energy infrastructure. Environmental impacts to the study area were also significant.

Table 2 presents a summary of development in terms of the number of identified structures and their estimated values in selected floodplains. This table aims to give an idea of the magnitude of the problem and the impact of future sea level change, using events whose frequencies form the upper and lower bounds of the range in which most estimates of Hurricane Sandy's frequency lie. Table 2 indicates that, in the year in which a proposed plan is scheduled to begin construction, more than 130,000 structures with a value of $188 billion in the study area lie within the 1% annual chance exceedance ("100-year") floodplain, and that if sea levels were to rise by two feet, then that floodplain would expand to impact an additional 30,000 structures with an additional $66 billion in exposed value. For the 2% ("500-year") floodplain, sea level change of the same magnitude would result in 38,000 vulnerable structures added to the total of 185,000 in 2030, with the exposed value increasing from $227 billion to $271 billion.

Conditions vary with location in the study area but, under the projections incorporated in this economic analysis, the intermediate scenario is for relative sea level to rise by two feet between the years 2102 and 2117. Under the high sea level rise scenario, a rise of two feet will occur by 2063. For detailed descriptions of the development of the inventory of vulnerable structures, and of the source and application of the selected sea level change scenarios, see Sections 4 and 5 of this Appendix. Additional technical discussions of sea level rise are contained in the Engineering Appendix.

.

Table 2. Impact of Future Sea Level Change on Building Exposure

Project Region	County	1% Floodplain (2030)		0.2% Floodplain (2030)		1% Floodplain with 2 Ft SLC		0.2% Floodplain with 2 Ft SLC	
		#	Value	#	Value	#	Value	#	Value
NJ	Bergen	10,019	$14,808	12,795	$17,186	12,218	$16,907	14,251	$18,447
NJ	Essex	4,176	$2,956	6,435	$3,868	5,701	$3,619	7,661	$4,324
NJ	Hudson	12,613	$18,111	12,626	$18,134	12,626	$18,134	12,628	$18,134
NJ	Middlesex	4,090	$3,214	7,380	$5,260	5,847	$4,346	9,750	$6,857
NJ	Monmouth	16,161	$6,276	20,865	$8,563	19,072	$7,734	23,323	$10,189
NJ	Passaic	20	$54	105	$131	41	$79	179	$178
NJ	Union	2,800	$3,476	4,934	$4,839	4,158	$4,403	6,536	$5,848
NYC	Bronx	3,982	$4,325	8,443	$9,888	6,682	$6,919	11,924	$15,258
NYC	Kings	34,465	$46,712	57,962	$77,391	49,302	$65,838	72,448	$95,453
NYC	New York	3,112	$24,073	5,555	$42,762	4,654	$36,277	7,169	$55,917
NYC	Queens	27,974	$56,092	37,488	$84,739	33,698	$78,780	42,992	$93,220
NYC	Richmond	11,422	$6,537	8,443	$11,200	6,682	$9,081	11,924	$13,505
NYS	Albany	22	$51	61	$143	55	$126	114	$374
NYS	Columbia	88	$153	101	$156	100	$156	113	$165
NYS	Dutchess	46	$29	68	$43	71	$44	86	$54
NYS	Greene	184	$84	231	$107	222	$104	273	$127
NYS	Orange	104	$120	133	$140	139	$142	159	$160
NYS	Putnam	46	$15	54	$18	58	$20	76	$31
NYS	Rensselaer	74	$86	183	$193	164	$162	302	$2,437
NYS	Rockland	345	$193	525	$308	584	$352	830	$500
NYS	Ulster	210	$85	238	$109	248	$112	273	$120
NYS	Westchester	363	$635	425	$774	447	$845	502	$924
Totals		**132,316**	**$188,085**	**185,050**	**$285,953**	**163,769**	**$254,180**	**223,513**	**$342,221**

Price Level: February 2022

2.1 Future Without-Project conditions

The future without-project condition is the baseline condition against which all alternatives are compared to evaluate their effectiveness and cost efficiency. The National Economic (NED) Benefits for the project are the difference in expected damages to structures and their contents without and with a selected alternative in place.

In the absence of measures to reduce the risk of coastal storm damage, the study area will continue to experience flooding and associated damages to structures and their contents, plus disruption to commerce, transportation, and other infrastructure. Sea level change will further exacerbate the impact of inundation due to storm surges as under all three evaluated projections (low, intermediate, and high) the frequency of potentially damaging events will increase.

Modeling of the future without-project condition of the study area was refined by accounting for coastal storm damage risk reduction projects in the study area that have already been constructed or are authorized for construction and are expected to be complete in advance of the start of construction of the evaluated alternatives.

Table 3 presents details of the constructed and authorized Federal projects that were incorporated into the future without-project condition in the HEC-FDA damage models, along with their authorized levels of protection.

Most of these projects were accounted for in the damage models by assigning levees with elevations consistent with those constructed or authorized to sub-reaches (see Section 3.1) specifically delineated to match the spatial extent of each project. For the relatively small number of structures covered by the Laurence Harbor project, which essentially involved a program of nonstructural protection measures including acquisitions, the project was incorporated in the damage analysis by raising the minimum damage level for structures in the project area to the authorized level of protection. The structures covered by the Jamaica Bay High Flood Frequency Risk Reduction Features were incorporated in the analysis similarly since the authorized project does not provide a high level of protection compared to other authorized or completed projects with levees.

Table 3. Projects Incorporated in the Future Without-Project Condition

Affected Economic Reach (Sub-reach)	County	Project	Level of Protection (Ft NAVD)
3 (3.2)	Monmouth	Port Monmouth	13.0
3 (3.3)	Monmouth	Keansburg	14.0
3 (3.4)	Monmouth	Union Beach	14.0
3	Middlesex	Laurence Harbor	13.0
5 (5.1)	Richmond	South Shore of Staten Island	14.6
11 (11A)	Essex	Passaic Tidal Protection Area	14.0
15 (15A)	Hudson	Hoboken Rebuild by Design	15.0
33	Queens	Jamaica Bay High Frequency Flood Risk Reduction Features	7.0

In addition to the Federal projects listed in Table 3, the analysis of future without-project conditions also accounted for resilience projects in planning or construction affecting numerous facilities owned by the Port Authority of New York and New Jersey.

3 Economic Reaches

3.1 Economic Reach Delineation

Economic reaches are segments of the study area shoreline and floodplain that may be considered distinct units when evaluating storm damages and benefits. Division of the study area into units of this nature facilitates the analysis of components of storm damage reduction plans independently as well as contributary elements in the larger system. For the initial phase of the study, the study area was divided into 34 project reaches by county boundaries and water bodies, and included 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.

The initial reach delineation also reflected the locations and extents of storm damage reduction measures that were provisionally identified for the interim phase of the study. The reach delineation was further refined and adjusted to incorporate the modifications and additions to the storm damage reduction components of the evaluated plans that arose as the plans were developed in more detail. Where reaches included the locations of existing or authorized coastal storm damage reduction projects (See Section 2), sub-reaches were also delineated to cover the extents of projects, where these projects involved a large number of structures or a high level of protection, as described in Section 2.1. Damages were calculated at the sub-reach level to fully reflect the different future without-project conditions, but the overall economic analysis was conducted at the aggregated economic reach level.

The result of this exercise was an array of project reaches was expanded to 52 economic reaches which contributed to the analysis of storm damages and storm damage reduction benefits.

3.2 Final Economic Reaches

A complete list of all economic reaches that contributed to the economic analysis of the plans is presented in Table 4, and a graphical depiction of the economic reaches and sub-reaches is presented in Figure 1- Figure 6.

Table 4. NYNJHAT Study Economic Reaches and Sub-reaches

Reach # (*Sub-reach*)	Economic Reach Name/Location	County
2	NJ – Shrewsbury/Navesink River Basin	Monmouth
3	NJ - Raritan & Sandy Hook Shoreline	Middlesex
3.1	*Area in Reach 3 east of Sub-reach 3.2*	*Monmouth*
3.2	*Port Monmouth Existing/Authorized Project*	*Monmouth*
3.3	*Keansburg Existing/Authorized Project*	*Monmouth*
3.4	*Union Beach Existing/Authorized Project*	*Monmouth*
3.5	*Area in Reach 3 west of Union Beach Sub-reach*	*Monmouth*
4	NJ - Raritan River Basin	Middlesex
5	NYC - South Shore of Staten Island	Richmond
5.1	*South Shore of Staten Island Existing/Authorized Project*	*Richmond*
5.2	*Area in Reach 5 not in SSSI Project Sub-reach*	*Richmond*
6	NYC - Western Shore of Staten Island	Richmond
7W	NYC - Northern Shore of Staten Island	Richmond
7E	NYC - North Eastern Shore of Staten Island	Richmond
8N	NJ - Shoreline along Arthur Kill North	Union
8S	NJ - Shoreline along Arthur Kill South	Middlesex
9	NJ - Rahway River Basin	Union
10	NJ - Newark Bay	Essex
11	NJ - Passaic River Basin	Hudson / Essex / Passaic
11A	*Passaic Tidal Protection Area Existing/Authorized Project*	*Essex*
12	NJ - Hackensack/Meadowlands Basin/Overpeck Creek	Bergen/Hudson
12RBDM	NJ - Hackensack/Meadowlands Basin RBDM	Bergen
12RBDMSU	NJ - Hack/Meadowlands SBM Upper Area	Bergen
12RBDMSM	NJ - Hack/Meadowlands SBM Middle Area	Bergen
12RBDMSL	NJ - Hack/Meadowlands SBM Lower Area	Bergen
13	NJ - Shoreline along Kill Van Kull	Hudson
14	NJ - Shoreline along Upper Bay	Hudson

Reach # (*Sub-reach*)	Economic Reach Name/Location	County
14S	NJ - Jersey City SBM	Hudson
15	NJ - Shoreline along Hudson River (excluding 15A)	Bergen / Hudson
15A	*Rebuild by Design Hoboken Existing/Authorized Project*	*Hudson*
16	NY - Shoreline along Hudson River	Westchester / Putnam / Dutchess / Columbia / Rensselaer / Albany / Greene / Ulster / Orange / Rockland
16SP	NY - Hudson Stony Point Perimeter SBM	Rockland
16SS	NY - Hudson Stony Point Shore SBM	Rockland
16SO	NY - Hudson Ossining SBM	Westchester
16ST	NY - Hudson Tarrytown SBM	Westchester
16SYN	NY - Hudson Yonkers N SBM	Westchester
16SYS	NY - Hudson Yonkers S SBM	Westchester
17	NYC - Bronx Shoreline along Hudson River	Bronx
18	NYC - Manhattan shoreline along Hudson River	New York
18S	NYC - West Side SBM	New York
19	NYC - Manhattan shoreline along East River	New York
19S	NYC - West Side SBM -East River Section	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
21B	NYC - Bronx shoreline along Harlem River South	Bronx
22A	NYC - Bronx shoreline along western LIS - West	Bronx
22AS	NYC - Bronx shoreline along western LIS - Barriers and SBM	Bronx
22PB	NYC - Bronx shoreline along western LIS - Pelham Barrier	Bronx
25A	NYC - Queens shoreline along western LIS - West	Queens
25AS	NYC - Queens shoreline along western LIS - Astoria SBM	Queens
25AF	NYC - Queens shoreline along western LIS - Flushing Creek Barrier SBM	Queens
26	NYC - Queens shoreline along East River	Queens
26S	NYC - Queens shoreline Long Island City SBM	Queens
27	NYC - Queens/Brooklyn Newtown Creek Basin	Queens
28	NYC - Brooklyn along East River	Kings
29	NYC - Brooklyn shoreline along Upper Bay	Kings
30	NYC - 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

The list of economic reaches in Table 4 includes only those for which storm damages and benefits were quantified for contribution to the overall economic analysis. It does not include a small number of the initially identified project reaches which lie outside the line of protection for all alternative plans, or for which the estimation of damages and benefits was initially considered not appropriate: Reach 1, covering the Sandy Hook Peninsula is federal property and at the time the inventory was initially developed it was considered to have very limited impact on the NED benefit analysis and was not included in tax databases used to develop the desktop inventory. It was therefore excluded from the assessment.

While it was initially anticipated that Reach 22B, Reach 23, Reach 24, and Reach 25B (all of which lie on Long Island Sound west of Throgs Neck), would be covered by alternative layouts, as plan formulation evolved it became apparent that none of the evaluated alternatives included risk reduction measures for these locations and hence they were also excluded from the desktop inventory and the benefit analysis. However, in some of these reaches, features to mitigate adverse effects (induced flooding) resulting from the construction of a project have been proposed.

Figure 1 depicts the overall study area and includes an index to Figures 5 through 6 which show clusters of reaches in detail. Reaches shown in Figure 2 are those in New Jersey on the south shore of Sandy Hook Bay and Raritan Bay, the Shrewsbury and Raritan River Basins, and on the New Jersey side of the Arthur Kill. Figure 3 includes all remaining reaches in New Jersey, including those along the Hudson River, Newark Bay, and in the Passaic and Hackensack River Basins. Figure 4 includes reaches in New York City covering Manhattan and the Bronx, while Figure 5 covers Staten Island, Brooklyn, and Queens, including Jamaica Bay and the Rockaway Peninsula. Figure 6 covers the southern part of the Hudson River valley in New York State, including several smaller reaches that were initially identified as locations for standalone structural risk reduction measures. The northern extent of the study area in New York State is shown as an insert in Figure 1.

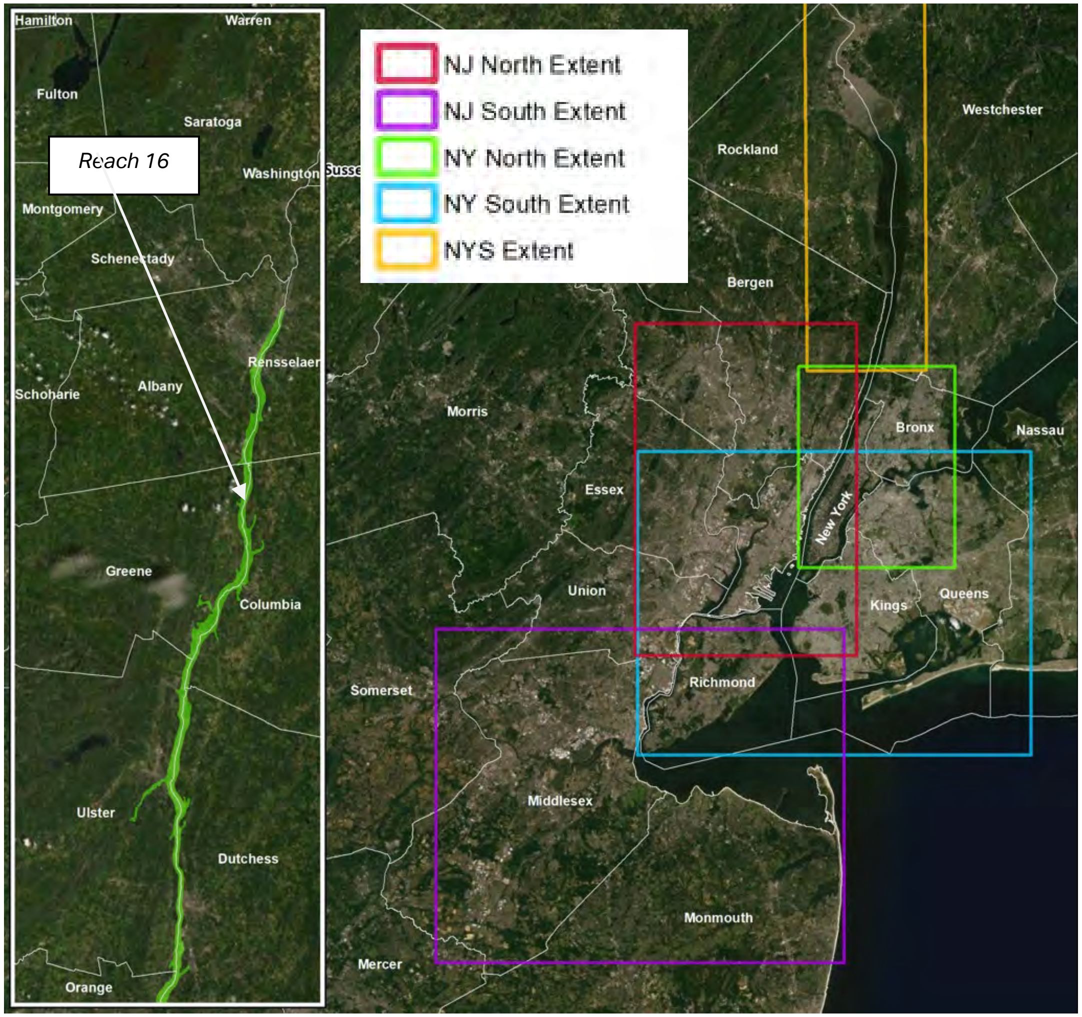


Figure 1. NYNJHAT Study Area with Key to Economic Reach Maps

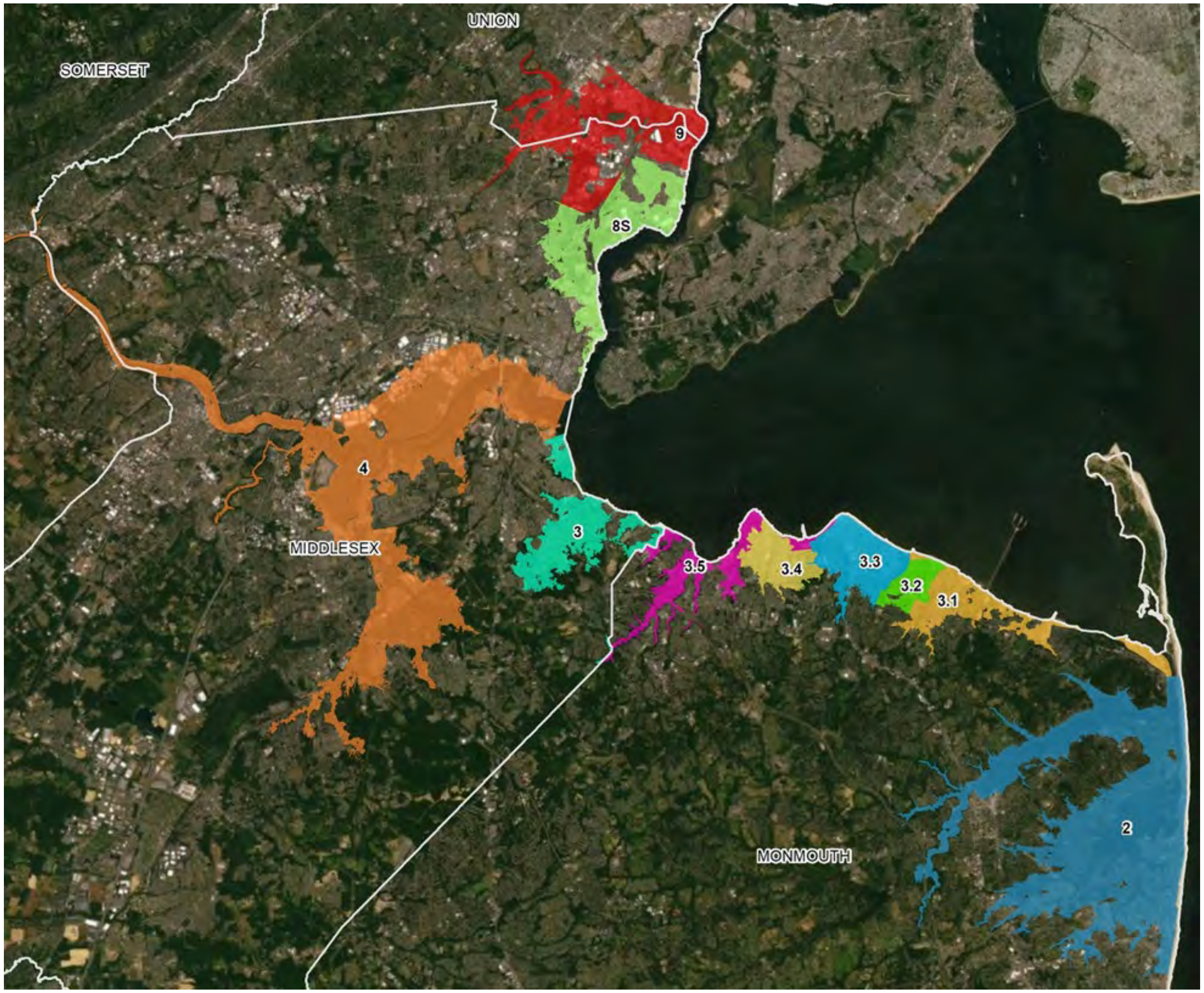


Figure 2. NYNJHAT Economic Reaches and Sub-reaches, New Jersey South

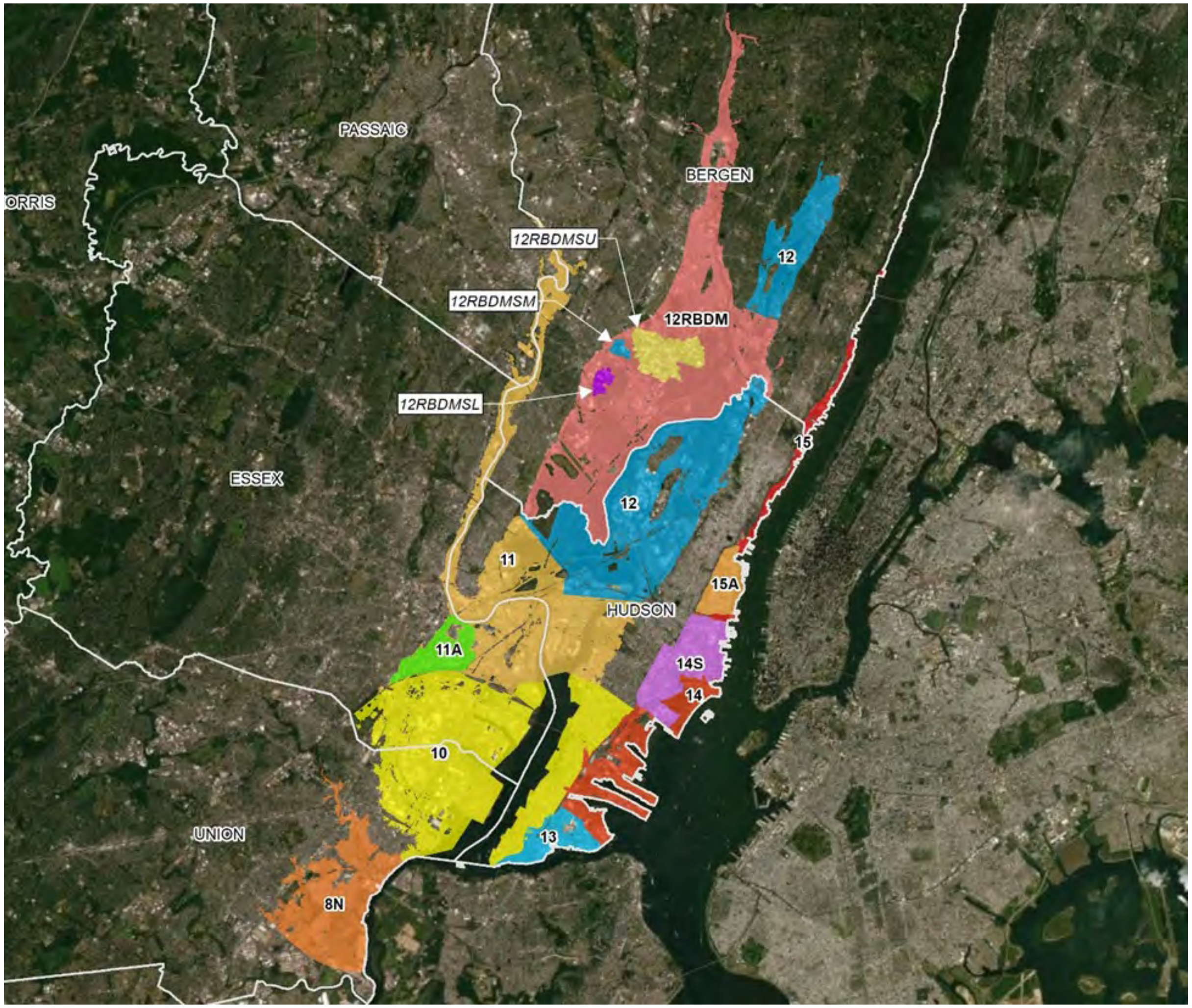


Figure 3. NYNJHAT Economic Reaches and Sub-reaches, New Jersey North

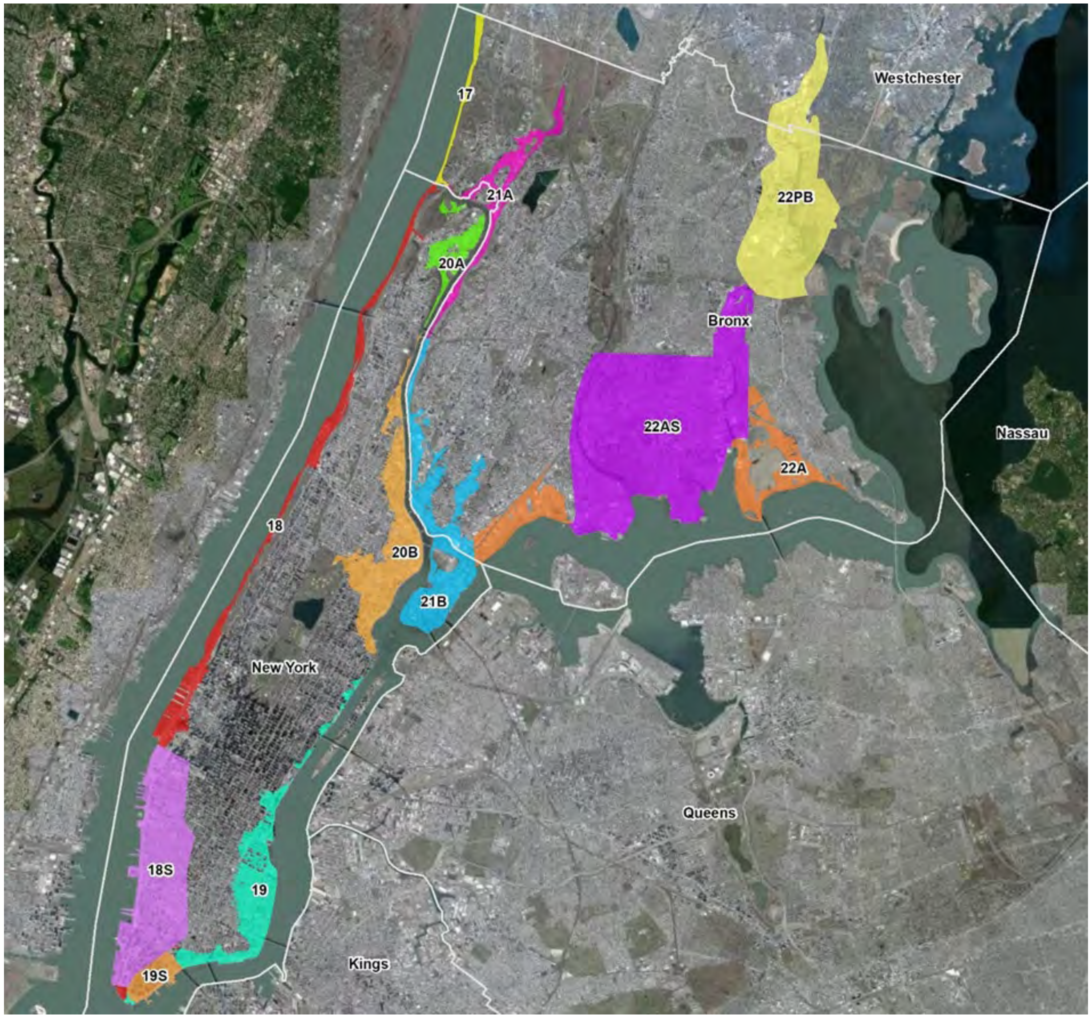


Figure 4. NYNJHAT Economic Reaches and Sub-reaches, New York City North

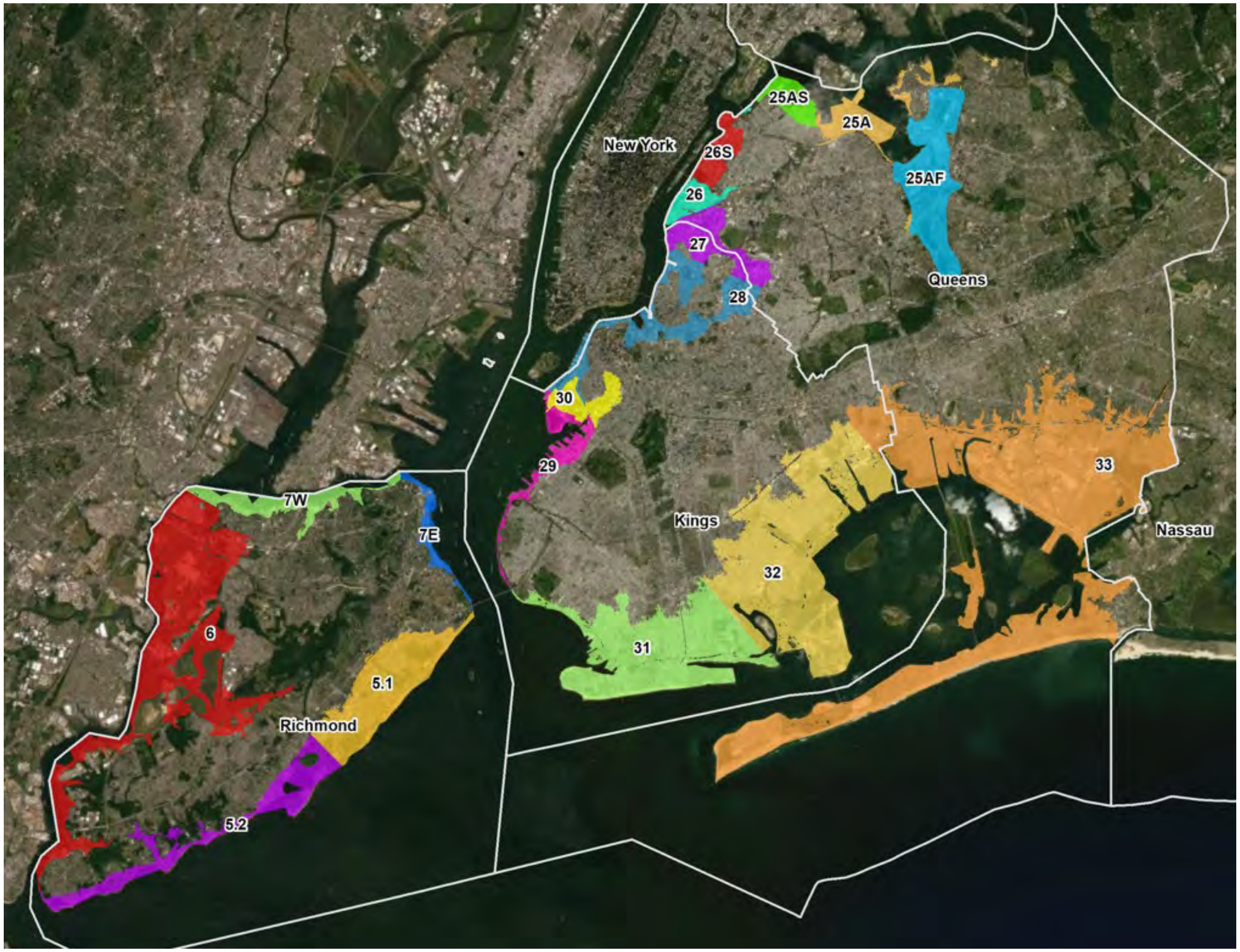


Figure 5. NYNJHAT Economic Reaches and Sub-reaches, New York City South

Figure 6. NYNJHAT Economic Reaches and Sub-reaches, New York State

4 Inventory Database Development

The structure inventory for the economic analysis was developed in two phases: for the interim report of February 2019, a preliminary inventory was derived for the interim report solely from building classification and physical characteristic data contained in publicly available tax parcel and elevation data. This database was referred to in the Interim Report as the "Desktop Inventory" since it was a purely office-based exercise and involved no fieldwork to populate or verify the data. In the subsequent feasibility phase of the study, the inventory was refined by incorporating more detailed GIS data and conducting field surveys of targeted groups and structure categories.

4.1 Desktop Inventory

The desktop inventory data was generated using parcel and elevation data from various sources. The desktop inventory was created for each impacted county and assigned to their respective reaches. Table 5 presents the data sources used to compile the desktop inventory.

Table 5. 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

County	Parcel Data Source	Elevation Data Source
New York State		
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 Corps of Engineers

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 that associated with the 500-year (0.2% Annual Chance Exceedance) storm for each node (See section below on stage-frequency data) plus the year 2100 Curve I sea level rise (see SLC section), plus two feet. The elevation limit varied by reach, depending on the assigned stage-frequency node, and all were within the range of 15 to 20 feet NAVD88.

Structures in the Desktop Inventory were eliminated if they are located on the 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 were also removed from the inventory.

Where the building classification and physical characteristics from tax/parcel sources did not include certain structure attributes required for the estimation of flood damages (most notably the main floor height above ground and the basement/foundation type), typical attributes drawn from detailed inventory surveys conducted in areas of the similar building stock in the same region were assumed. 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 were collected and updated for consistency with NYNJHAT conditions. Updates included revising 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 inventory. Table 6 presents a list of the existing project evaluations that have been collected and updated.

Table 6. Existing/Prior Projects in the Study Area

Existing Project Models	County
Highlands	Monmouth
Jamaica Bay South	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

The assessed improvement values of developed parcels in the study area were converted to replacement structure values by the application of municipal equalization rates, in order to align more closely with current policy and guidance for the estimation of flood damages for Federal flood and storm risk reduction studies.

In addition to assessed improvement values included in the data sources, building classification and usage data were used to assign appropriate depth-damage functions for use in the damage analysis models.

4.2 Refinement of Inventory Data

4.2.1 Incorporation of Structure Polygon Data

As described above, the desktop inventory was derived from parcel data sources presented in Table 5. In addition to building characteristic and value data, GIS software tools were also used to overlay the spatial extents of parcels with elevation data also listed in Table 5 and the ground elevation of structures contributing to the economic analysis was assumed to be represented by the centroid of each parcel. To refine the inventory data and enhance the accuracy of the analysis, a substantial exercise was undertaken using GIS software tools to match the parcels with individual structure footprints from publicly available GIS data. The data used for this exercise was sourced from the New Jersey Department of Environmental Protection Bureau of GIS, New York City Open Data Building Footprints, and Microsoft Building Footprints. For every structure in the inventory matched with footprint data, the elevation at the centroid of the polygon was extracted and taken as a more accurate representation of the ground elevation than the centroid of the host parcel. For parcels where building footprint data was not found, the original desktop data was retained for use in the analysis. A detailed description of the data building polygon data sources follows:

New Jersey: The New Jersey Department of Environmental Protection (NJDEP) has compiled a statewide building inventory for New Jersey within the 1% annual chance floodplain boundaries published by the Federal Emergency Management Agency (FEMA), and within a 200-foot buffer around the 1% floodplain boundaries. The effort involved extensive quality review, editing, and then the combination of existing datasets, including the 2013 NJDEP post-Hurricane Sandy dataset and the 2018 Microsoft Bing computer-generated dataset, which is described below. Footprint polygons with an area of less than 500 square feet were removed.

In locations where the Study reach extended beyond the boundary of the NJDEP dataset, a national building polygon dataset created by Microsoft was used to provide coverage. The Microsoft dataset is licensed under the Open Data Commons Open Database License (ODbL). This dataset used Microsoft Bing imagery (multiple sources and years) to approximate building polygons.

New York City: Building footprint polygon data for the City of New York is provided by the NYC Department of Information Technology and Telecommunication (NYC DOITT). Building footprints represent the full perimeter outline of each building as viewed directly from above. The data was captured using aerial photography, researching Department of Buildings (DOB) records, and other image sources. Using orthoimagery, the planimetric base layers were updated citywide starting in March 2015 and were published in May 2016. The features captured are all buildings with a footprint greater than 400 square feet. Structures smaller than 400 square feet are typically detached garages or other ancillary/storage structures that are usually not included in estimates of flood damage or nonstructural risk management plans. While there are probably some structures of this nature in the overall dataset which are of usages other than garages/storage, it was assumed that there were not sufficient numbers or values to influence the plan formulation and that constraints of time and budget precluded a detailed examination of the full study area-wide dataset to confirm.

New York State: the Microsoft Bing dataset was the primary data source. Where needed, corrections were made to create or edit polygons.

4.2.2 Field Survey of Structures

The goal of the field survey was to refine and verify the assumptions applied during the development of the desktop inventory, to provide data to establish typical costs associated with nonstructural protection plans, and generally to improve the accuracy of the project benefits estimate. The structures selected for inclusion in the sampling plan were grouped into the following categories:

High Damage Structures: The current damage analysis models were examined and output was post-processed to calculate the probability-weighted annual average damage under baseline (year 2030) conditions for all structures in the inventory, and the approximately 2,600 structures with the highest annual average damage were identified for field verification since these structures are likely to have a significant influence on the analysis of damages.

Value Comparison Structures: The purpose of surveying these structures was to collect data for the estimation of depreciated structure replacement value using published square foot cost reference data. This allowed the comparison of values provided by each tax database with the depreciated replacement values calculated based on the field investigation. The subsequent analysis assessed how reliably the tax database values represent depreciated replacement values and derived appropriate adjustment factors as needed.

Prior to extracting the sample clusters, structures that did not experience any damage at the 500-year event, structures with a current assumed value of less than $25,000, and the approximately 2,600 maximum damage structures were temporarily removed from the dataset, to ensure that the sampling plan contained no duplicates, and to reduce the possibility that the sample would contain structures that contribute negligibly to the overall damage analysis.

The sample plan aimed to survey at least 50 structures in each county, up to a total of 2,000 across the study area in this category. For counties with fewer than 100 structures in the revised base dataset, suitable structures for field survey were selected manually, up to a maximum of 50. The remainder of the target sample total was pro-rated across the other counties in clusters of 10 structures, with a minimum of 50 structures per county. Each cluster was selected by randomly generating a seed structure in an Excel spreadsheet and using GIS to gather nine adjacent structures. Ultimately, due to a restricted number of suitable structures and limitations of the available building polygon data in some of the counties in New York State upstream of the Hudson River, approximately 1,800 structures were selected for field survey in this category.

Structures in the 10% Annual Chance Exceedance Floodplain: One of the key structure attributes required for the damage analysis is the height above ground level of the main (first) floor of each structure. As mentioned above, the desktop inventory assumed typical main floor heights for structure types based on inventory data collected for other flood risk management projects in the New York/New Jersey area. The survey plan aimed to collect sufficient data to evaluate if these assumed values are representative of the broader inventory, and to determine whether or not the building height above grade is correlated in any way with the floodplain in which it stands. Specifically, the structures located in high-frequency floodplains may be found to have greater main floor heights than structures likely to experience flooding less frequently. While many of the structures in the high value and value comparison clusters are located in areas likely to flood with high frequency, an additional 1,200 structures in the 10% annual chance exceedance ("10-year") floodplain were targeted for the field survey specifically for this assessment. These were selected from a subset of the sampling dataset which included only structures in that floodplain.

This set of structures was also anticipated to contribute to the accuracy of data used to develop plans involving nonstructural risk management measures for low-lying portions of the study area. A significant number of structures in the other survey categories were also located in this floodplain, such that in total, approximately two-thirds of the structures surveyed were thus located.

Structures constructed after 1991: A sub-sample of structures constructed after 1991 was also drawn from the base sampling dataset, to confirm the assumption that more recent buildings were constructed in compliance with the requirements of the National Flood Insurance Program. An additional 100 structures were randomly selected from a subset of the full dataset which included only structures recorded as built after 1991, distributed across New Jersey, New York City, and New York State approximately in proportion to the total distribution of structures in the full sampling dataset.

The field survey was conducted using a "windshield" approach by which surveyors toured the locations on foot or by car on public roads recording structure attributes without entering any private property. Key attributes collected during the survey were:

- Type and usage
- Number of stories
- Foundation/Basement type
- Exterior construction material
- Structure condition
- Main floor height above grade

Ground elevations and footprint areas were determined from the GIS analysis but were adjusted due to observations made during the windshield survey where appropriate.

The final total of surveyed structures was adjusted slightly from the total targeted in the original plan, since structures were found when visited in the field to be missing or new, or were found to contain substantially different attributes within the same footprint.

The breakdown of all field-surveyed structures by county and sample category is presented in Table 7.

Table 7. Summary of Field Survey Distribution

State/City	County	Survey Category				
		Post-1991	10% Floodplain	Value Comparison	High Damage	Total
New Jersey	Bergen	5	99	112	286	502
New Jersey	Essex	13	32	41	53	139
New Jersey	Hudson	15	167	50	429	661
New Jersey	Middlesex	8	25	81	83	197
New Jersey	Monmouth	8	207	175	24	414
New Jersey	Union	3	19	51	75	148
New York City	Bronx	10	29	92	84	215
New York City	Kings	0	181	396	683	1,260
New York City	New York	0	4	55	391	450
New York City	Queens	10	270	214	379	873
New York City	Richmond	11	130	184	101	426
New York State	Albany	0	0	50	2	52
New York State	Columbia	0	0	43	2	45
New York State	Dutchess	0	0	49	0	49
New York State	Greene	0	2	31	1	34
New York State	Orange	5	0	21	4	30
New York State	Passaic	0	0	32	0	32

State/City	County	Survey Category				
		Post-1991	10% Floodplain	Value Comparison	High Damage	Total
New York State	Putnam	0	0	48	1	49
New York State	Rensselaer	1	0	30	0	31
New York State	Rockland	0	0	0	1	1
New York State	Ulster	5	1	18	6	30
New York State	Westchester	2	1	28	15	46
	Total	***96***	***1,167***	***1,801***	***2,620***	***5,684***

While 1,801 structures were surveyed specifically for the value comparison, the structures surveyed in the 10% floodplain and for the assessment of post-1991 construction were also added to the pool of structures for this analysis. The structures identified for the survey due to their high damages were not added to the value comparison pool: since they are largely unusually high-value structures, they were omitted from the damage comparison analysis in case they skewed the resulting adjustment factors.

As an additional refinement to the inventory, structures from existing inventories developed to a similar level of detail were used to populate the database in two parts of the study area likely subject to flooding from high-frequency events where gaps in the desktop inventory where identified. Hence, approximately 900 structures in Broad Channel in Jamaica Bay and 320 structures in the Meadowlands area were added, bringing the total number of structures in the inventory for which detailed survey attributes are available to almost 6,900.

4.2.3 Analysis and Application of Survey Data

The recorded attributes were applied in conjunction with the footprint areas to develop depreciated structure replacement values for all surveyed structures, using unit costs provided by RSMeans Square Foot Building Costs. The two sets of values were then subjected to statistical analysis in the form of a difference of means test which generated a value adjustment factor when the test statistic rejects the null hypothesis, which is a 90% certainty that the values are 10% different. The analysis also generated a value uncertainty factor to be applied in the damage models (see Section 5).

The analysis was conducted separately for each county in the study area, and the results are presented in Table 8 below. While the depreciated structure replacement values were generally found to be higher than the associated assessed/equalized tax values, the analysis indicated that a value adjustment factor should be applied for eight of the 22 counties.

Table 8. Summary of Statistical Value Comparison Analysis

State/City	County	Null Hypothesis Rejected	Value Adjustment Factor	Uncertainty Factor
NY	Albany	No	N/A	N/A
NJ	Bergen	Yes	161%	59%
NYC	Bronx	No	N/A	N/A
NY	Columbia	No	N/A	N/A
NY	Dutchess	No	N/A	N/A
NJ	Essex	No	N/A	N/A
NY	Greene	Yes	206%	79%
NJ	Hudson	No	N/A	N/A
NYC	Kings	No	N/A	N/A
NJ	Middlesex	Yes	170%	44%
NJ	Monmouth	Yes	164%	51%
NYC	New York	No	N/A	N/A
NY	Orange	No	N/A	N/A
NJ	Passaic	No	N/A	N/A
NY	Putnam	No	N/A	N/A
NYC	Queens	No	N/A	N/A
NY	Rensselaer	Yes	265%	56%
NYC	Richmond	Yes	148%	48%
NY	Ulster	Yes	237%	89%
NJ	Union	Yes	135%	54%
NY	Westchester	No	N/A	N/A

A similar statistical analysis was conducted for structures in the 10% annual chance exceedance floodplain, the results of which indicated that building heights above grade inside the 10% floodplain did not vary significantly from those in lower frequency floodplains, and hence no adjustments were made to the original assumptions. While a detailed statistical analysis was not conducted for buildings constructed after 1991, it was observed that post-1991 development was generally in compliance with floodplain regulations in place at the time and additional inventory adjustments were not required.

4.3 Summary of Refined Inventory

The structure inventory was revised to incorporate the results of the survey and subsequent analyses. Since significant time elapsed between the compilation of the original desktop inventory, the field survey and subsequent refinements, and the use of the inventory in the economic benefit analyses, it was necessary to update the inventory to a current price level.

For this purpose, a uniform price level update factor of 1.26 was applied to the inventory to bring structure values to a February 2022 price level from January 2018. This factor was derived from the Engineering News-Record Historical Building Cost Index database.

Table 9 lists the number of structures in each reach in the refined inventory and their total estimated values, with all refinements and updates described in the preceding sections incorporated. For the economic analyses, the total structure replacement value for the approximately 272,000 buildings identified in the study area was estimated to be $394 billion.

Table 9. Number and Value of Structures by Economic Reach

Economic Reach		Residential		Non-Residential	
		# Structures	Value	# Structures	Value
2	NJ – Shrewsbury/Navesink River Basin	9,790	$5,769,175,000	1,067	$1,888,037,000
3*	NJ - Raritan & Sandy Hook Shoreline	14,948	$4,020,217,000	1,489	$940,882,000
4	NJ - Raritan River Basin	3,852	$1,707,503,000	805	$2,833,390,000
5*	NYC - South Shore of Staten Island	14,968	$4,464,414,000	686	$4,644,395,000
6	NYC - Western Shore of Staten Island	3,522	$879,985,000	549	$4,314,824,000
7W	NYC - Northern Shore of Staten Island	1,160	$351,107,000	464	$595,094,000
7E	NYC - North Eastern Shore of Staten Island	206	$518,154,000	247	$803,080,000
8N	NJ - Shoreline along Arthur Kill North	4,071	$1,002,734,000	1,303	$2,630,297,000
8S	NJ - Shoreline along Arthur Kill South	5,174	$1,553,510,000	754	$1,178,636,000
9	NJ - Rahway River Basin	3,041	$1,041,013,000	1,117	$1,963,281,000
10	NJ - Newark Bay	592	$156,261,000	932	$3,260,996,000
11*	NJ - Passaic River Basin	9,054	$2,649,789,000	3,708	$4,157,966,000
12	NJ - Hackensack/Meadowlands Basin/Overpeck Creek	2,001	$957,842,000	682	$2,974,706,000
12RBDM	NJ - Hackensack/Meadowlands Basin RBDM	5,904	$2,484,674,000	1,936	$8,502,044,000
12RBDMSU	NJ - Hack/Meadowlands SBM Upper Area	16	$1,518,000	608	$2,162,479,000
12RBDMSM	NJ - Hack/Meadowlands SBM Middle Area	0	$0	44	$244,667,000
12RBDMSL	NJ - Hack/Meadowlands SBM Lower Area	0	$0	36	$484,595,000
13	NJ - Shoreline along Kill Van Kull	114	$32,879,000	130	$136,130,000
14	NJ - Shoreline along Upper Bay	156	$900,932,000	97	$2,287,340,000
14S	NJ - Jersey City SBM	2,376	$2,059,862,000	508	$2,640,491,000
15*	NJ - Shoreline along Hudson River	8,325	$6,384,909,000	1,135	$2,464,999,000
16	NY - Shoreline along Hudson River	2,563	$1,041,371,000	1,271	$4,222,904,000
16SP	NY - Hudson Stony Point Perimeter SBM	33	$7,434,000	6	$12,648,000
16SS	NY - Hudson Stony Point Shore SBM	1	$145,000	0	$0

Economic Reach		Residential		Non-Residential	
		# Structures	Value	# Structures	Value
16SO	NY - Hudson Ossining SBM	0	$0	3	$8,259,000
16ST	NY - Hudson Tarrytown SBM	17	$34,344,000	24	$41,404,000
16SYN	NY - Hudson Yonkers N SBM	4	$104,146,000	42	$297,278,000
16SYS	NY - Hudson Yonkers S SBM	0	$0	10	$19,316,000
17	NYC - Bronx Shoreline along Hudson River	0	$0	3	$2,256,000
18	NYC - Manhattan shoreline along Hudson River	47	$1,175,564,000	122	$3,597,547,000
18S	NYC West Side SBM	2,225	$18,262,695,000	1,003	$13,442,558,000
19	NYC - Manhattan shoreline along East River	1,546	$10,885,031,000	397	$4,160,372,000
19S	NYC West Side SBM -East River Section	107	$2,100,754,000	176	$2,421,541,000
20A	NYC - Manhattan shoreline along Harlem River North	208	$690,228,000	117	$479,326,000
20B	NYC - Manhattan shoreline along Harlem River South	2,284	$7,240,329,000	841	$3,557,880,000
21A	NYC - Bronx shoreline along Harlem River North	415	$357,980,000	114	$873,249,000
21B	NYC - Bronx shoreline along Harlem River South	526	$1,048,636,000	332	$3,172,217,000
22A	NYC - Bronx shoreline along western LIS - West	1,826	$1,013,363,000	391	$3,353,530,000
22AS	NYC - Bronx shoreline along western LIS - Barriers and SBM	5,162	$1,603,779,000	715	$3,410,403,000
22PB	NYC - Bronx shoreline along western LIS - Pelham Barrier	838	$580,425,000	179	$2,657,567,000
25A	NYC - Queens shoreline along western LIS - West	2,237	$3,951,743,000	277	$20,748,073,000
25AS	NYC - Queens shoreline along western LIS - Astoria SBM	62	$133,802,000	193	$609,000,000
25AF	NYC - Queens shoreline along western LIS - Flushing Creek Barrier SBM	722	$1,728,617,000	546	$3,719,705,000
26	NYC - Queens shoreline along East River	478	$4,089,509,000	627	$3,108,824,000
26S	NYC - Queens shoreline Long Island City SBM	1,458	$2,357,053,000	655	$2,182,776,000
27	NYC - Queens/Brooklyn Newtown Creek Basin	1,310	$2,580,002,000	1,049	$6,546,775,000
28	NYC - Brooklyn along East River	3,355	$14,849,664,000	2,176	$16,283,192,000
29	NYC - Brooklyn shoreline along Upper Bay	196	$382,637,000	472	$4,461,302,000
30	NYC- Gowanus Canal Basin	1,575	$2,637,808,000	1,252	$3,679,083,000
31	NYC - Brooklyn - Lower Bay, Coney Island/Creek shoreline	34,745	$25,597,725,000	3,754	$12,785,593,000

Economic Reach		Residential		Non-Residential	
		# Structures	Value	# Structures	Value
32	NYC - Brooklyn shoreline in Jamaica Bay	35,127	$10,915,922,000	2,312	$14,795,383,000
33	NYC - Queens shoreline & islands in Jamaica Bay	43,800	$11,519,218,000	2,120	$44,104,117,000
Subtotals		*232,137*	*$163,826,402,000*	*39,476*	*$229,862,407,000*
Grand Total		**271,613**			
		$393,688,809,000			

Price Level February 2022. Reaches not contributing to the analyses of damages and benefits not shown.
*Aggregated for whole reach including sub-reaches.

5 Storm Damage Criteria

5.1 Flood Damage Analysis Tool

Computation of the expected flood and coastal storm damages in the study area under without- and with-project conditions was conducted using version 1.4.2 of Hydrologic Engineering Center - Flood Damage Analysis (HEC-FDA). HEC-FDA is a USACE-certified software tool which performs integrated hydrologic and economic evaluations of flood risk management plans using the structure inventory, stage-frequency, and depth damage relationships.

HEC-FDA uses Monte-Carlo simulation techniques to compute expected damage under without- and with-project conditions while explicitly accounting for risk and uncertainty in key parameters used to determine flood inundation damage to structures and their contents, in accordance with current USACE planning guidance. Under this approach, key parameters 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.

The basic data inputs required by HEC-FDA are the structure inventory, stage-frequency relationships (and their future variation to account for sea level change), and depth-damage functions. The development and refinement of the inventory have been described in detail in Section 4. Stage-frequency relationships (or water surface profiles) are obtained from hydraulic/hydrologic modeling and describe the elevation of increments of flooding in terms of their probability of occurrence. Depth-damage functions describe the damage incurred by structures at increments of flood depth above the main floor. While the development and refinement of the inventory are discussed in Section 4, the stage-frequency and depth-damage relationships are described in the following sections.

5.2 Stage-Frequency Relationships

Representative stage-frequency relationships used in the analysis of flood and storm damages were taken from the hydrologic modeling undertaken during the NACCS study; each reach was assigned to one or more NACCS modeling nodes as presented in Table 10 below. In some cases, a reach may contain multiple nodes, especially if it impacts multiple counties. In such cases, sub-reaches were delineated as appropriate in the flood damage models, with results combined for the presentation of analysis results by economic reach. These nodes provide water surface elevations for the events of with annual exceedance probabilities of 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, and 0.2% (2, 5, 10, 20, 50, 100, 200, and 500-year storms) for 1992. Water surface elevations were subsequently adjusted for sea level change for input to the analyses as discussed in Section 5.2.

Each economic reach was also assigned to one of three tide/sea level gages operated by the National Oceanic and Atmospheric Agency (NOAA), for the purposes of incorporating the impacts of sea level change into the analyses. These three gages are located at:

- Sandy Hook, on the spit located in Monmouth County, New Jersey, in Lower New York Bay
- The Battery, on the southernmost point of the island of Manhattan, New York
- Kings Point, on the north shore of Long Island in Nassau County, New York, east of the Throgs Neck Bridge.

The assignment of NOAA gages by economic reach is also presented in Table 10.

Table 10. NACCS Node and NOAA Gage Assignments

Reach #	Economic Reach	County	NACCS Stage Frequency Node	Assigned Gage for SLC
2	NJ – Shrewsbury/Navesink River Basin	Monmouth	3789	Sandy Hook
3*	NJ - Raritan & Sandy Hook Shoreline	Monmouth	11519	Sandy Hook
3	NJ - Raritan & Sandy Hook Shoreline	Middlesex	3538	Sandy Hook
4	NJ - Raritan River Basin	Middlesex	11740	Sandy Hook
5*	NYC - South Shore of Staten Island	Richmond	11608	Sandy Hook
6	NYC - Western Shore of Staten Island	Richmond	13809	Sandy Hook
7W	NYC - Northern Shore of Staten Island	Richmond	3967	The Battery
7E	NYC - North Eastern Shore of Staten Island	Richmond	13818	The Battery
8N	NJ - Shoreline along Arthur Kill North	Union	3503	The Battery
8S	NJ - Shoreline along Arthur Kill South	Middlesex	3967	Sandy Hook
9	NJ - Rahway River Basin	Union	4004	The Battery
9	NJ - Rahway River Basin	Middlesex	4004	The Battery
10	NJ - Newark Bay	Essex	11754	The Battery
10	NJ - Newark Bay	Union	11754	The Battery
11	NJ - Passaic River Basin	Hudson	4206	The Battery
11*	NJ - Passaic River Basin	Essex	4206	The Battery
11	NJ - Passaic River Basin	Bergen	7412	The Battery
12	NJ - Passaic River Basin	Passaic	7412	The Battery
12	NJ - Hackensack/Meadowlands Basin	Bergen	4281	The Battery
12	NJ - Hackensack/Meadowlands Basin	Hudson	4206	The Battery
12RBDM	NJ - Hackensack/Meadowlands Basin RBDM	Bergen	4281	The Battery
12RBDMSU	NJ - Hack/Meadowlands SBM Upper Area	Bergen	4281	The Battery
12RBDMSM	NJ - Hack/Meadowlands SBM Middle Area	Bergen	4281	The Battery

Reach #	Economic Reach	County	NACCS Stage Frequency Node	Assigned Gage for SLC
12RBDMSL	NJ - Hack/Meadowlands SBM Lower Area	Bergen	4281	The Battery
13	NJ - Shoreline along Kill Van Kull	Hudson	13818	The Battery
14	NJ - Shoreline along Upper Bay	Hudson	4176	The Battery
14S	NJ - Jersey City SBM	Hudson	4176	The Battery
15	NJ - Shoreline along Hudson River	Bergen	13862	The Battery
15*	NJ - Shoreline along Hudson River	Hudson	13862	The Battery
16	NY - Shoreline along Hudson River	Westchester	13872	The Battery
16	NY - Shoreline along Hudson River	Putnam	7976	The Battery
16	NY - Shoreline along Hudson River	Dutchess	3575	The Battery
16	NY - Shoreline along Hudson River	Columbia	3600	The Battery
16	NY - Shoreline along Hudson River	Rensselaer	3600	The Battery
16	NY - Shoreline along Hudson River	Albany	3600	The Battery
16	NY - Shoreline along Hudson River	Greene	3600	The Battery
16	NY - Shoreline along Hudson River	Ulster	3575	The Battery
16	NY - Shoreline along Hudson River	Orange	7976	The Battery
16	NY - Shoreline along Hudson River	Rockland	7976	The Battery
16SP	NY - Hudson Stony Point Perimeter SBM	Rockland	7976	The Battery
16SS	NY - Hudson Stony Point Shore SBM	Rockland	7976	The Battery
16SO	NY - Hudson Ossining SBM	Westchester	13872	The Battery
16ST	NY - Hudson Tarrytown SBM	Westchester	13872	The Battery
16SYN	NY - Hudson Yonkers N SBM	Westchester	13872	The Battery
16SYS	NY - Hudson Yonkers S SBM	Westchester	13872	The Battery
17	NYC - Bronx Shoreline along Hudson River	Bronx	4573	The Battery
18	NYC - Manhattan shoreline along Hudson River	New York	13862	The Battery

Reach #	Economic Reach	County	NACCS Stage Frequency Node	Assigned Gage for SLC
18S	NYC - West Side SBM	New York	13862	The Battery
19	NYC - Manhattan shoreline along East River	New York	11875	The Battery
19S	NYC - West Side SBM -East River Section	New York	11875	The Battery
20A	NYC - Manhattan shoreline along Harlem River North	New York	4479	The Battery
20B	NYC - Manhattan shoreline along Harlem River South	New York	13888	The Battery
21A	NYC - Bronx shoreline along Harlem River North	Bronx	4479	The Battery
21B	NYC - Bronx shoreline along Harlem River South	Bronx	13888	The Battery
22A	NYC - Bronx shoreline along western LIS - West	Bronx	4349	Kings Point
22AS	NYC - Bronx shoreline along western LIS - Barriers and SBM	Bronx	4349	Kings Point
22PB	NYC - Bronx shoreline along western LIS - Pelham Barrier	Bronx	4349	Kings Point
25A	NYC - Queens shoreline along western LIS - West	Queens	4349	Kings Point
25AS	NYC - Queens shoreline along western LIS - Astoria SBM	Queens	4349	Kings Point
25AF	NYC - Queens shoreline along western LIS - Flushing Creek Barrier SBM	Queens	4349	Kings Point
26	NYC - Queens shoreline along East River	Queens	11878	The Battery
26S	NYC - Queens shoreline Long Island City SBM	Queens	11878	The Battery
27	NYC - Queens/Brooklyn Newtown Creek Basin	Queens	11895	The Battery
27	NYC - Queens/Brooklyn Newtown Creek Basin	Kings	11895	The Battery
28	NYC - Brooklyn along East River	Kings	7673	The Battery
29	NYC - Brooklyn shoreline along Upper Bay	Kings	11933	The Battery
30	NYC - Gowanus Canal Basin	Kings	11930	The Battery
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

*Including sub-reaches for existing/authorized projects

5.3 Sea Level Change

Current USACE guidance requires the 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* (15 June 2019). 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."

For this study, the low sea level change scenario was taken to be a linear projection of the current historic rate of change observed at each of the three gages, and the intermediate and high sea level scenarios were represented by modified NRC Curves I and III respectively.

Using the formulae and constants provided in ER-1100-2-8162, and the most recent observed trends in relative sea level rise from NOAA, sea level change increments for low, intermediate, and high sea level change scenarios for all three gages were calculated for a period covering 130 years following the currently assumed start of construction for all evaluated alternatives. The resulting curves are plotted and presented in Figure 7 below.

The various alternatives under consideration have significantly different completion schedules. Hence, in order to provide the flexibility to analyze a range of implementation periods, the impacts of sea level change were estimated for increments of sea level change, which can occur in different future years depending on the gage and scenario under consideration, rather than for fixed future years representing the completion schedules of plan alternatives which are subject to change as the study progresses.

Water surface elevations under an intermediate sea level change scenario in 2030, when all alternatives are assumed to begin construction, were used as a baseline and flood inundation damages were calculated for that condition and for subsequent increments of sea level change of 1, 2, 4, and 6 feet. This allows for lifecycle damages and benefits to be calculated for all plans using a common template, covering a period ending significantly more than 50 years after the anticipated completion of any plan, even accounting for plausible future changes in the completion schedules.

The years in which these sea level change increments are projected to be achieved are tabulated for each scenario by gage in Table 11 and by economic reach in Table 12

Table 11. Occurrence Years of Sea Level Change Increments by Gage

Gage	Scenario	Sea Level Change Increment			
		1 Ft	2 Ft	4 Ft	6 Ft
The Battery	Low	2144			
	Intermediate	2077	2112		
	High	2046	2063	2089	2110
Sandy Hook	Low	2109			
	Intermediate	2070	2102		
	High	2044	2061	2086	2107
Kings Point	Low	2171			
	Intermediate	2080	2117		
	High	2046	2063	2090	2112

Table 12. Occurrence Years of Sea Level Change Increments by Economic Reach

Economic Reach	Low SLC	Intermediate SLC		High SLC			
	1 Ft	1 Ft	2 Ft	1 Ft	2 Ft	4 Ft	6 Ft
2	2109	2070	2102	2044	2061	2086	2107
3*	2109	2070	2102	2044	2061	2086	2107
4	2109	2070	2102	2044	2061	2086	2107
5*	2109	2070	2102	2044	2061	2086	2107
6	2109	2070	2102	2044	2061	2086	2107
7W	2144	2077	2112	2046	2063	2089	2110
7E	2144	2077	2112	2046	2063	2089	2110
8N	2144	2077	2112	2046	2063	2089	2110
8S	2109	2070	2102	2044	2061	2086	2107
9	2144	2077	2112	2046	2063	2089	2110
10	2144	2077	2112	2046	2063	2089	2110
11*	2144	2077	2112	2046	2063	2089	2110
12	2144	2077	2112	2046	2063	2089	2110
12RBDM	2144	2077	2112	2046	2063	2089	2110

Economic Reach	Low SLC	Intermediate SLC		High SLC			
	1 Ft	1 Ft	2 Ft	1 Ft	2 Ft	4 Ft	6 Ft
12RBDMSU	2144	2077	2112	2046	2063	2089	2110
12RBDMSM	2144	2077	2112	2046	2063	2089	2110
12RBDMSL	2144	2077	2112	2046	2063	2089	2110
13	2144	2077	2112	2046	2063	2089	2110
14	2144	2077	2112	2046	2063	2089	2110
14S	2144	2077	2112	2046	2063	2089	2110
15*	2144	2077	2112	2046	2063	2089	2110
16	2144	2077	2112	2046	2063	2089	2110
16SP	2144	2077	2112	2046	2063	2089	2110
16SS	2144	2077	2112	2046	2063	2089	2110
16SO	2144	2077	2112	2046	2063	2089	2110
16ST	2144	2077	2112	2046	2063	2089	2110
16SYN	2144	2077	2112	2046	2063	2089	2110
16SYS	2144	2077	2112	2046	2063	2089	2110
17	2144	2077	2112	2046	2063	2089	2110
18	2144	2077	2112	2046	2063	2089	2110
18S	2144	2077	2112	2046	2063	2089	2110
19	2144	2077	2112	2046	2063	2089	2110
19S	2144	2077	2112	2046	2063	2089	2110
20A	2144	2077	2112	2046	2063	2089	2110
20B	2144	2077	2112	2046	2063	2089	2110
21A	2144	2077	2112	2046	2063	2089	2110
21B	2144	2077	2112	2046	2063	2089	2110
22A	2171	2080	2117	2046	2063	2090	2112
22AS	2171	2080	2117	2046	2063	2090	2112
22PB	2171	2080	2117	2046	2063	2090	2112
25A	2171	2080	2117	2046	2063	2090	2112
25AS	2171	2080	2117	2046	2063	2090	2112
25AF	2171	2080	2117	2046	2063	2090	2112
26	2144	2077	2112	2046	2063	2089	2110
26S	2144	2077	2112	2046	2063	2089	2110
27	2144	2077	2112	2046	2063	2089	2110
28	2144	2077	2112	2046	2063	2089	2110
29	2144	2077	2112	2046	2063	2089	2110
30	2144	2077	2112	2046	2063	2089	2110
31	2109	2070	2102	2044	2061	2086	2107
32	2109	2070	2102	2044	2061	2086	2107
33	2109	2070	2102	2044	2061	2086	2107

*Including sub-reaches for existing/authorized projects.

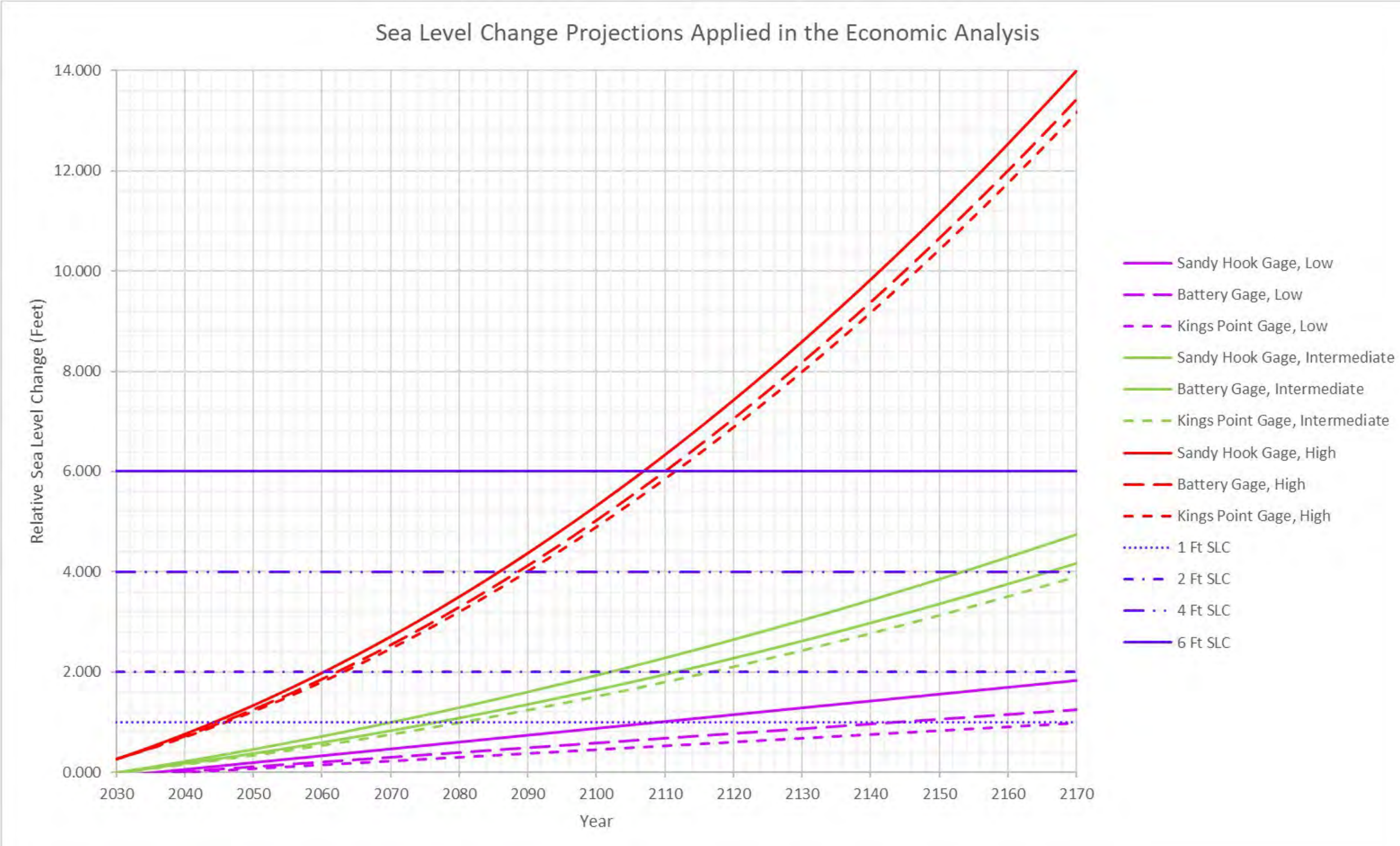


Figure 7. Sea Level Change Projections Applied in the Economic Analysis

5.4 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. Depth-damage relationships are computed separately for structures and their 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.

Depth-damage functions which express inundation damage as a percentage of the structure or content value for increments of flood depth above the main floor, and hence can be applied to multiple structures of similar use or configuration, are referred to as indirect damage functions and are by far the most commonly applied functions in studies of this nature. Damage functions that express damage as a specific dollar value at each flood depth increment are referred to as direct damage functions and are developed for use with specific individual structures. These structures are typically those for which no indirect or generic depth damage function is appropriate, or for which dollar values of damage are known with a high degree of precision.

While several sets of potentially applicable indirect 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 as part of the NACCS study and published in 2015. The depth-damage functions were assigned according to the use and configuration of the individual inventory structures as interpreted from tax parcel data or observed in the field in the case of sample survey structures. The NACCS functions applied in these analyses are presented by structure type in Table 13 below.

Table 13. Inundation 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

Function	Applicable Structure
NACCS 5B	Prototype 5B, Two-Story Residence, With 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

In addition to the depth-damage functions listed in Table 13, the damage models included direct damage functions for facilities owned and operated by the Port Authority of New York and New Jersey, since the Port Authority provided detailed information regarding the planned or implemented level of protection at each facility, along with estimates of damage should the protection be overtopped. These estimates were based on documented repair costs following Superstorm Sandy or estimates by a third-party specialist consultant. The data received from the Port Authority comprised a list of facilities and estimated damages resulting from the overtopping of new protection measures that were anticipated to be completed by 2022. This data enabled the derivation of custom direct damage functions for each affected facility. The Port Authority Facilities and the planned or constructed protection elevations for which custom damage functions were derived are presented in Table 14 below.

Table 14. Port Authority Facilities with Protection in the Future Without Project Condition

Port Authority Department	Facility	County	Protection Elevation (Ft NAVD88)
Airports	JFK Airport	Queens	17.0
Airports	LaGuardia Airport	Queens	13.0
Airports	Newark Airport	Essex	15.0
PATH	Exchange Place Station	Hudson	17.0
PATH	Grove Street Station	Hudson	16.0
PATH	Hoboken Station	Hudson	17.0
PATH	Newport Station	Hudson	16.0
PATH	World Trade Center Station	New York	14.5
PATH	Harrison Car Maintenance Facility	Hudson	15.5
PATH	Substation 2	Hudson	15.3
PATH	Substation 7	Hudson	13.3
PATH	Substation 8	Hudson	15.3
PATH	Substation 9	Hudson	14.3

Port Authority Department	Facility	County	Protection Elevation (Ft NAVD88)
PATH	Substation 14	Hudson	15.5
Ports	Port Jersey	Hudson	14.0
Ports	Port Elizabeth/Port Newark	Essex/Union	14.0
Ports	Brooklyn Marine Terminal	Kings	15.0
Ports	Howland Hook	Richmond	15.0
Ports	NYNJ Float Rail Bridges	Hudson	11.0
TB&T	Holland Tunnel	Hudson/New York	15.0
WTC	Non-PATH Structures and Facilities	New York	14.4

6 Without-Project Annual Damages

6.1 Analysis Approach and Assumptions

As outlined in Section 5, HEC-FDA integrates hydraulic and hydrologic data with vulnerable structure attributes and depth-damage relationships to calculate expected damages for each evaluated alternative while incorporating uncertainty in key parameters. During this analysis, uncertainty in the form of probability distributions was applied to structure values, structure main floor elevations, water surface profiles, and depth-damage relationships.

The key assumptions that were made in the analysis of the without-project condition were:

- It was assumed that damages within the normal tidal zone cannot contribute to the analyses, and therefore damages were truncated below the high astronomic tide (HAT) stage. In each reach, this was assumed to be one foot below the 50% annual chance exceedance water surface elevation, and truncation points with a corresponding crest elevation were applied in HEC-FDA.
- It was assumed that there will be substantial local efforts, whether structural or nonstructural, to mitigate the impacts of sea level change, and hence the HAT truncation points in the future without-project conditions were raised to match the sea level change increments.
- The structure inventory is assumed to be static over the analysis period. I.e. no changes are assumed to development in terms of the numbers, physical attributes, and values of the structures. While this assumption does not account for future condemnation of frequently damaged structures or any new development, the challenges and limitations of projecting future inventory changes over a study area of this extent are too significant to assign any reasonable level of accuracy to predicted inventory modifications.

The data on structure type, elevation, and value were combined with the damage criteria in HEC-FDA to generate relationships between water surface elevations and dollar damages to create stage-damage curves for each structure type and each reach in the study area. In addition to estimating the expected or mean stage-damage curves, HEC-FDA also evaluated the confidence band for each curve. The confidence bands reflect the potential impact of data limitations including uncertainty in building elevation and value, and the variance in depth-damage relationships. An example of a stage damage curve extracted from HEC-FDA showing confidence bands is presented in Figure 8.

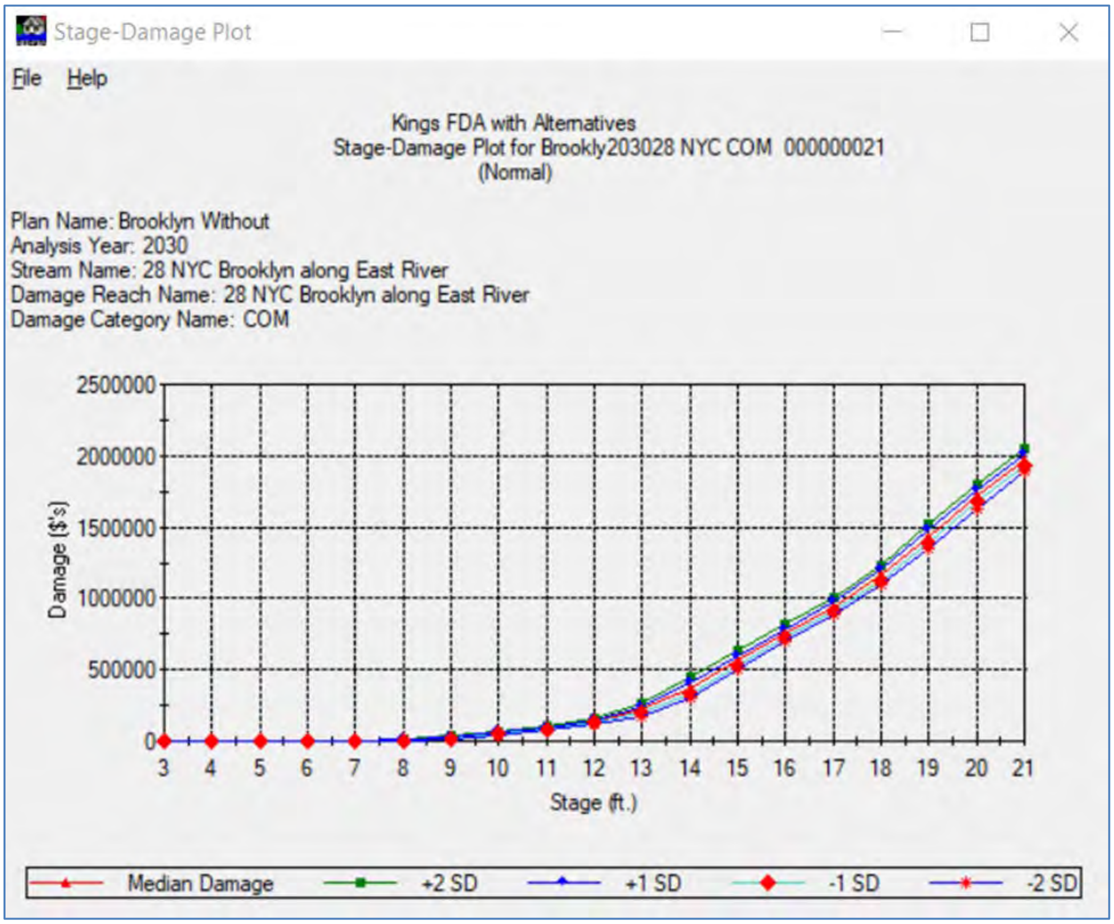


Figure 8. Example Stage-Damage Curve with Confidence Bands

To quantify the true impact of flooding in a way that facilitates comparisons with the costs of measures to mitigate them, stage-damage curves are combined with flood stage-frequency relationships in HEC-FDA to compute damage in average annual terms.

The output from HEC-FDA has been post-processed in a lifecycle spreadsheet (see Section 7.2) and used to determine the annual NED benefits for each alternative in comparison with the no-action (without-project) alternative.

6.2 Without-Project Analysis Results

Expected Annual damages were calculated using HEC-FDA for a baseline condition and for subsequent increments of sea level change of 1, 2, 4, and 6 feet. The baseline condition was taken to be 2030 when all alternatives are assumed to begin construction. The output from HEC-FDA was input to a spreadsheet in which the damages accruing from each increment of sea level change were used to calculate lifecycle damages for each economic reach in present worth and annualized form.

The lifecycle spreadsheet format facilitates the calculation of lifecycle damages while allowing for the fact that the year of occurrence of each sea level change increment will vary from reach to reach since the reaches are assigned to one of three different gages, each with unique sea level change parameters. This approach captures the non-linearity of the intermediate and high sea level change scenarios and also simplifies the estimation of future damages since it reduces the total number of conditions that would be otherwise required to be set up in the HEC-FDA models.

The lifecycle spreadsheet template covers a range of years extending well past 50 years from the estimated completion year of all evaluated alternatives. For any given reach under any sea level change scenario, the damages for each sea level change increment are input into the template in the year in which they are estimated to occur, and expected damages for every year between increments are interpolated. The spreadsheet then applies the appropriate present worth factor in each year and produces a total over the appropriate analysis period. The total is then annualized by application of the capital recovery factor associated with the FY2022 discount rate of 2.25%.

Without-project damages for all economic reaches included in the analyses are presented in Table 15 below. Expected annual damages are presented for all sea level rise increments, and the equivalent annual damage is presented for the 50-year period following the project base year of 2044 which is considered to be the most representative of the alternative project timelines.

Table 15. Without-Project Damages

Economic Reach	Expected Annual Damage at Increments of Sea Level Rise (Feet)					Equivalent Annual Damage	Assigned Gage
	Baseline*	1	2	4	6	2045-2094	
2	$129,682,000	$256,214,000	$433,398,000	$1,015,947,000	$1,939,890,000	$249,653,000	SH
3	$55,586,000	$92,762,000	$140,812,000	$298,902,000	$682,211,000	$90,339,000	SH
4	$48,105,000	$78,733,000	$121,329,000	$253,991,000	$450,342,000	$77,109,000	SH
5	$21,485,000	$32,646,000	$48,869,000	$114,453,000	$329,409,000	$32,141,000	SH
6	$21,719,000	$36,688,000	$62,220,000	$173,710,000	$430,881,000	$36,476,000	SH
7W	$12,561,000	$25,144,000	$43,756,000	$94,999,000	$160,004,000	$22,424,000	BT
7E	$8,725,000	$16,180,000	$28,083,000	$84,680,000	$209,664,000	$14,616,000	BT
8N	$49,126,000	$90,991,000	$144,003,000	$292,514,000	$509,473,000	$81,455,000	BT
8S	$21,883,000	$39,425,000	$65,704,000	$154,155,000	$306,299,000	$38,727,000	SH
9	$40,271,000	$80,241,000	$138,238,000	$265,046,000	$416,715,000	$71,539,000	BT
10	$59,306,000	$105,509,000	$185,729,000	$576,699,000	$1,474,531,000	$96,167,000	BT
11	$248,493,000	$414,275,000	$598,329,000	$1,064,781,000	$1,620,153,000	$375,105,000	BT
12	$220,717,000	$425,415,000	$672,204,000	$1,144,716,000	$1,606,266,000	$378,113,000	BT
12RBDM	$781,651,000	$1,328,473,000	$1,938,612,000	$3,350,703,000	$4,928,067,000	$1,199,437,000	BT
12RBDMSU	$371,908,000	$586,290,000	$767,544,000	$1,075,714,000	$1,335,960,000	$532,545,000	BT
12RBDMSM	$22,996,000	$39,356,000	$58,885,000	$104,988,000	$142,871,000	$35,565,000	BT
12RBDMSL	$64,414,000	$116,408,000	$162,131,000	$237,353,000	$304,310,000	$103,469,000	BT
13	$5,801,000	$11,962,000	$23,391,000	$56,951,000	$81,406,000	$10,756,000	BT
14	$98,099,000	$163,511,000	$249,422,000	$616,133,000	$1,234,811,000	$148,780,000	BT
14S	$157,079,000	$293,590,000	$478,750,000	$1,006,486,000	$1,691,523,000	$263,166,000	BT
15	$71,402,000	$117,547,000	$182,679,000	$444,312,000	$921,878,000	$107,401,000	BT
16	$44,599,000	$93,544,000	$164,098,000	$360,781,000	$614,191,000	$82,863,000	BT
16SP	$661,000	$1,217,000	$1,779,000	$3,835,000	$8,023,000	$1,082,000	BT
16SS	$4,000	$9,000	$18,000	$31,000	$59,000	$8,000	BT

Economic Reach	Expected Annual Damage at Increments of Sea Level Rise (Feet)					Equivalent Annual Damage	Assigned Gage
	Baseline*	1	2	4	6	2045-2094	
16SO	$466,000	$1,021,000	$1,634,000	$2,491,000	$3,629,000	$890,000	BT
16ST	$677,000	$1,514,000	$2,589,000	$5,473,000	$11,062,000	$1,324,000	BT
16SYN	$1,330,000	$3,219,000	$6,955,000	$18,797,000	$40,037,000	$2,862,000	BT
16SYS	$213,000	$503,000	$1,217,000	$5,297,000	$9,154,000	$456,000	BT
17	$119,000	$283,000	$567,000	$1,059,000	$1,305,000	$250,000	BT
18	$32,298,000	$61,233,000	$111,585,000	$290,588,000	$542,375,000	$55,389,000	BT
18S	$146,125,000	$278,841,000	$492,430,000	$1,207,374,000	$2,319,318,000	$251,091,000	BT
19	$120,707,000	$231,606,000	$385,405,000	$830,366,000	$1,495,009,000	$207,074,000	BT
19S	$171,470,000	$319,901,000	$501,503,000	$892,200,000	$1,239,039,000	$285,745,000	BT
20A	$921,000	$1,989,000	$4,103,000	$18,290,000	$49,104,000	$1,787,000	BT
20B	$243,385,000	$369,654,000	$504,098,000	$884,376,000	$1,418,311,000	$339,507,000	BT
21A	$3,362,000	$7,181,000	$13,117,000	$36,182,000	$80,880,000	$6,371,000	BT
21B	$14,147,000	$25,408,000	$48,464,000	$151,166,000	$352,041,000	$23,322,000	BT
22A	$59,861,000	$111,760,000	$190,779,000	$453,461,000	$859,774,000	$97,551,000	KP
22AS	$19,268,000	$36,312,000	$63,457,000	$165,622,000	$349,737,000	$31,687,000	KP
22PB	$4,494,000	$7,975,000	$13,145,000	$34,870,000	$100,178,000	$7,017,000	KP
25A	$18,735,000	$34,566,000	$62,419,000	$194,490,000	$525,705,000	$30,361,000	KP
25AS	$8,223,000	$13,693,000	$21,928,000	$51,554,000	$99,564,000	$12,192,000	KP
25AF	$44,284,000	$82,067,000	$146,933,000	$404,904,000	$880,660,000	$71,975,000	KP
26	$136,345,000	$238,843,000	$362,158,000	$646,124,000	$1,032,590,000	$215,143,000	BT
26S	$20,260,000	$35,034,000	$61,082,000	$180,986,000	$421,155,000	$32,068,000	BT
27	$74,675,000	$141,999,000	$244,741,000	$598,176,000	$1,230,173,000	$127,617,000	BT
28	$220,430,000	$408,949,000	$794,981,000	$2,417,019,000	$4,310,295,000	$374,032,000	BT
29	$39,819,000	$65,142,000	$108,666,000	$274,646,000	$648,566,000	$59,998,000	BT
30	$84,204,000	$157,711,000	$270,050,000	$632,311,000	$1,100,323,000	$142,016,000	BT

Economic Reach	Expected Annual Damage at Increments of Sea Level Rise (Feet)					Equivalent Annual Damage	Assigned Gage
	Baseline*	**1**	**2**	**4**	**6**	**2045-2094**	
31	$480,256,000	$911,867,000	$1,541,263,000	$3,555,712,000	$6,466,401,000	$892,575,000	SH
32	$53,321,000	$111,562,000	$217,352,000	$690,735,000	$1,904,953,000	$111,536,000	SH
33	$254,108,000	$533,907,000	$911,028,000	$1,967,358,000	$3,491,495,000	$517,584,000	SH
Totals	*$4,809,776,000*	*$8,639,870,000*	*$13,793,632,000*	*$29,403,507,000*	*$52,381,770,000*	*$7,948,356,000*	

Price Level February 2022, Discount Rate 2.25% BT: Battery Gage, SH: Sandy Hook Gage KP: Kings Point Gage
*Intermediate sea level change scenario, 2030

7 With-Project Annual Damages and Benefits

7.1 Overview of Plan Measures and coverage

The alternatives evaluated in this analysis are comprised principally of storm surge barriers (SSBs) and shore-based measures (SBMs), supplemented by risk reduction features (RRFs) and induced flooding-mitigation features (IFFs). What follows is a brief description of the form and function of each of these components, with a description of the analysis approach to follow in subsequent sections. For detailed descriptions of the scheduling of each alternative, see Appendix A-1, Engineering.

Storm surge barriers take the form of moveable gates of a varying design constructed in-water, i.e. across bays, rivers, and other waterways. When open they are designed to allow the passage of all shipping that currently uses New York and New Jersey harbors and associated tributaries. Due to their size and complexity, it is assumed that SSBs can only be closed when flood stages reach a pre-defined threshold, to minimize operational and maintenance costs, navigational disruption, and water quality issues.

Shore-based measures are principally flood risk reduction structures constructed on land in the form of floodwalls, levees, seawalls, deployable barriers, and composite structures, although they may also take the form of smaller movable in-water barriers which may be operated with higher frequency than larger SSBs.

While the line of protection for each evaluated alternative is comprised of SSBs and SBMs, the analyses also accounted for the effects of risk reduction features and induced flooding-mitigation features.

The analyses at the current stage of the study were based on the assumption that the storm surge barriers featured in Alternatives 2 through 4 would be closed when the water surface elevation reaches 7 feet NAVD at the Battery, at the southernmost point of Manhattan. Under this operating scenario, there remain some developed areas behind the barriers with ground elevations sufficiently low that they would be subject to flooding prior to the closure of the barriers. To mitigate damages in areas behind barriers that remain at risk from high-frequency flooding, risk reduction features have been proposed to supplement the structural plans. The RRFs were applied universally to residual and are sufficient to mitigate the risk but were not subject to incremental justification.

The form of RRFs is similar to SBMs (structural measures constructed on land, deployable gates, and movable in-water barriers which may be operated with higher frequency than larger SSBs) but are constructed with significantly lower crest elevations. RRFs may also incorporate nonstructural risk management measures in areas of affected reaches where the construction of floodwalls or other structural measures is not feasible or appropriate. These nonstructural measures comprise nonstructural measures such as elevation and floodproofing of individual structures, and also ringwalls for structures too large or otherwise unsuitable for elevation or floodproofing. Total costs for each alternative for the purposes of this analysis included the cost of structural RRFs plus supplemental nonstructural measures where identified. A separate component of the overall NYNJHAT study evaluated a comprehensive stand-alone nonstructural plan for the 1% ACE floodplain, and stand-alone nonstructural plans for a smaller floodplain area in each reach that could be implemented independent of any structural measures. These plans were developed and screened for potential benefit and cost viability based on aggregate values for each economic reach. See Appendix A-1 for a more detailed description of these analyses.

Hydrodynamic modeling of Alternatives 2 through 4 revealed that the construction of SSBs across some bays and other waterways would result in induced flooding impacting areas outside each alternative's line of protection. In order to mitigate these impacts, induced flooding-mitigation features have been proposed for construction in affected reaches. The form of IFFs is similar to SBMs (structural measures constructed on land, deployable gates, and movable in-water barriers which may be operated with higher frequency than larger SSBs), and benefits have been computed for IFFs where they have been proposed for economic reaches contributing to the NED benefits analysis.

The components of each evaluated plan that have been assumed for the analysis of damages and benefits are tabulated by reach in Table 16. For the purposes of the analysis, all reaches protected by SSBs are assumed to incorporate RRFs unless stated otherwise in subsequent sections of this Appendix. The key years and time periods associated with each alternative, applied in and applied in the economic analysis, are presented in Table 17. For detailed descriptions of the scheduling of each alternative, see Appendix A-2, Cost Engineering.

Table 16. Analyzed Measures by Economic Reach

Reach #	Alternative 2	Alternative 3A	Alternative 3B	Alternative 4	Alternative 5
2	SH-TN SSBs	HL-SRB IFFs	None	None	None
3	SH-TN SSBs	RB-SHB IFF	None	None	None
4	SH-TN SSBs	Raritan Basin-IFF	None	None	None
5	SH-TN SSBs	SSSI-IFF	None	None	None
6	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	None	None
7W	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	NSSI IFF	None
7E	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
8N	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	Elizabeth IFF	None
8S	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	None	None
9	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	None	None
10	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	Newark Bay IFF	None
11	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	K-N-JC IFFs	None
12RBDM	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	Hackensack SSB	None
12RBDMSU	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	Hackensack SSB	HS Upper SBM
12RBDMSM	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	Hackensack SSB	HS Middle SBM
12RBDMSL	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	Hackensack SSB	HS Lower SBM
13	SH-TN SSBs	VN-AK-TN SSBs	AK-KVK Barrier	Bergen Point IFF	None
14	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
14S	SH-TN SSBs	VN-AK-TN SSBs	Jersey City SBM	Jersey City SBM	Jersey City SBM
15	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
16	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
16SP	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
16SS	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
16SO	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
16ST	SH-TN SSBs	VN-AK-TN SSBs	None	None	None

Reach #	Alternative 2	Alternative 3A	Alternative 3B	Alternative 4	Alternative 5
16SYN	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
16SYS	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
17	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
18	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
18S	SH-TN SSBs	VN-AK-TN SSBs	NYC West Side SBM	NYC West Side SBM	NYC West Side SBM
19	SH-TN SSBs	VN-AK-TN SSBs	Kips Bay IFF	None	None
19S	SH-TN SSBs	VN-AK-TN SSBs	NYC West Side SBM	NYC West Side SBM	NYC West Side SBM
20A	SH-TN SSBs	VN-AK-TN SSBs	Inwood IFF	None	None
20B	SH-TN SSBs	VN-AK-TN SSBs	NYC Harlem SBM	NYC Harlem SBM	NYC Harlem SBM
21A	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
21B	SH-TN SSBs	VN-AK-TN SSBs	Bronx IFF	None	None
22A	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
22AS	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
22PB	Pelham Bay SSB	Pelham Bay SSB	None	None	None
25A	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
25AS	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
25AF	SH-TN SSBs	VN-AK-TN SSBs	Flushing Creek SSB	Flushing Creek SSB	None
26	SH-TN SSBs	VN-AK-TN SSBs	NC Barrier SBM	NC Barrier SBM	None
26S	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
27	SH-TN SSBs	VN-AK-TN SSBs	Newtown Creek SSB	Newtown Creek SSB	None
28	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
29	SH-TN SSBs	VN-AK-TN SSBs	None	None	None
30	SH-TN SSBs	VN-AK-TN SSBs	Gowanus Canal SSB	Gowanus Canal SSB	None
31	SH-TN SSBs	Jamaica Bay SSB	Jamaica Bay SSB	Jamaica Bay SSB	None
32	SH-TN SSBs	Jamaica Bay SSB	Jamaica Bay SSB	Jamaica Bay SSB	None
33	SH-TN SSBs	Jamaica Bay SSB	Jamaica Bay SSB	Jamaica Bay SSB	None

Notes:

1. Table 16 includes only those reaches for which damages and benefits were quantified for contribution to the overall economic analysis.
2. RRFs are located within reaches protected by SSBs and hence are not identified separately.

Guide to Abbreviations:

Abbreviation	**Full Name**
SH-TN	Sandy Hook – Throgs Neck
VN-AK-TN	Verrazano Narrows – Arthur Kill – Throgs Neck
AK-KVK-	Arthur Kill – Kill Van Kull
HS	Hackensack
HL-SRB	Highlands – Shrewsbury River Barrier
RB-SHB	Raritan Bay – Sandy Hook Bay
SSSI	South Shore Staten Island
NSSI	North Shore Staten Island
K-N-JC	Kearny – Newark – Jersey City

Table 17. Lifecycle Analysis Timelines for Evaluated Alternatives

Alternative	Start of Construction	Construction Duration, Years	Construction Complete	Base Year	First Year of Full Benefits	Last Year of Full Benefits	Years of Full Benefits
2	2030	32	2062	2044	2063	2094	32
3A	2030	24	2054	2044	2055	2094	40
3B	2030	14	2044	2044	2045	2094	50
4	2030	14	2044	2044	2045	2094	50
5	2030	5	2035	2044	2036	2085	50

For the analysis of all alternatives, construction was assumed to start in 2030 and a base year of 2044 was used for all economic calculations. Since the evaluated alternatives vary greatly in scale and cost, their construction durations and periods over which benefits accrue will also vary.

All economic analyses conducted during the evaluation of the four plans used the FY2022 interest rate of 2.25% and were based on a price level of February 2022.

7.1.1 Prior Screening of Measures

At prior stages of the formulation and evaluation of the alternatives, several features additional to those included in Table 16 were proposed for various plans, but eliminated after the initial analyses indicated that they would be extremely unlikely to be cost-effective. The eliminated features are presented in Table 18, along with a comparison of annual without-project damages and annualized costs. The comparison indicates that even if each feature could be anticipated to reduce the without-project annual damage in the affected reach by 100%, a BCR greater than 0.5 could not be expected from any of these features. All of these features functioned as stand-alone measures in the alternatives in which they were originally proposed, and did not connect to other structural protection measures.

Table 18. Features Eliminated During Initial Screening

Reach	Feature Name	Annual Without Project Damages	Annual Costs	Eliminated from Alternative
16SP	Stony Point Perimeter SBM	$1,082,000	$7,425,000	3B, 4, 5
16SS	Stony Point Shore SBM	$8,000	$6,896,000	3B, 4, 5
16SO	Ossining SBM	$890,000	$4,579,000	3B, 4, 5
16ST	Tarrytown SBM	$1,324,000	$13,681,000	3B, 4, 5
16SYN	Yonkers North SBM	$2,862,000	$16,785,000	3B, 4, 5

Reach	Feature Name	Annual Without Project Damages	Annual Costs	Eliminated from Alternative
16SYS	Yonkers South SBM	$456,000	$16,433,000	3B, 4, 5
22AS	Bronx River/Westchester Creek SSBs	$31,687,000	$78,428,000	3B, 4
22PB	Pelham Bay SSB	$7,017,000	$32,947,000	3B, 4
25AS	Astoria SBM	$12,192,000	$71,878,6000	3B, 4, 5
26S	Long Island City SBM	$32,068,000	$59,871,000	3B, 4, 5

Price Level February 2022, Discount Rate 2.25%. Costs from 2019 cost estimate updated to 2022 using ENR Construction Cost Index.

7.2 Benefits Analysis Concept and Approach

7.2.1 Overview Of Approach

The general approach for all damage avoided benefits is to evaluate the risk of damage in dollar terms for the with-project condition (residual risk) and subtract that risk from the without-project damage. The analysis of residual risk is slightly different depending on the type of measure in each reach. In general, measures such as the shore based measures, including measures to prevent induced flooding, are evaluated based on truncating damages below the level of design. For the storm surge barriers, the analysis is more complex, considering the flood risk prior to gate closing and interior flood elevations that managed through the risk reduction features, as well as flood risks from less frequent events.

7.2.2 Calculation of Benefits for SSBs

Because the storm surge barriers(SSBs) have been designed to limit the overtopping during events far exceeding the future 1% ACE event with freeboard under intermediate SLC conditions, it is expected that there will be a very limited residual risk due to overtopping, and SSBs, when combined with risk reduction features, have been assumed to be completely effective in managing flood risk due to coastal storm surge. This may slightly overstate the performance of the SSBs during the later years of the period of analysis under a high sea level rise scenario, where the overtopping of the structure could exceed the available flood storage and pumping capacity of the system.

7.2.3 Calculation of Benefits for SBMs

Shore based measures are stand-alone features and do not operate in conjunction with any other measure in any given reach. Since the design criteria were evolving at the time during the planning process when the analytical models were compiled, the design elevation for SBMs was assumed to be equal to the 2030 1% annual chance exceedance water surface elevation in each reach, plus three feet to account for future sea level change. On subsequent comparison with the engineering design elevations of SBMs that were used for cost estimating purposes, it was found that the assumed elevations in the damage models were on average within 0.6 feet of the engineering elevations. This was considered to be sufficiently close for this stage of the study and the differences are not believed to impact benefit and cost comparisons.

7.2.4 Calculation of Benefits for IFFs

Induced flooding-mitigation features were assumed to be similar to SBMs for the purposes of this analysis and hence benefits were computed for IFFs on a first-added basis, with design protection elevations equal to the 2030 1% annual chance exceedance water surface elevation in each affected reach, plus three feet to account for future sea level change. An additional initial assumption is that IFFs provide protection to the full length of each reach in which they are located. This assumption can be revisited and refined in later stages of the study.

7.2.5 Calculation of Benefits for RRFs

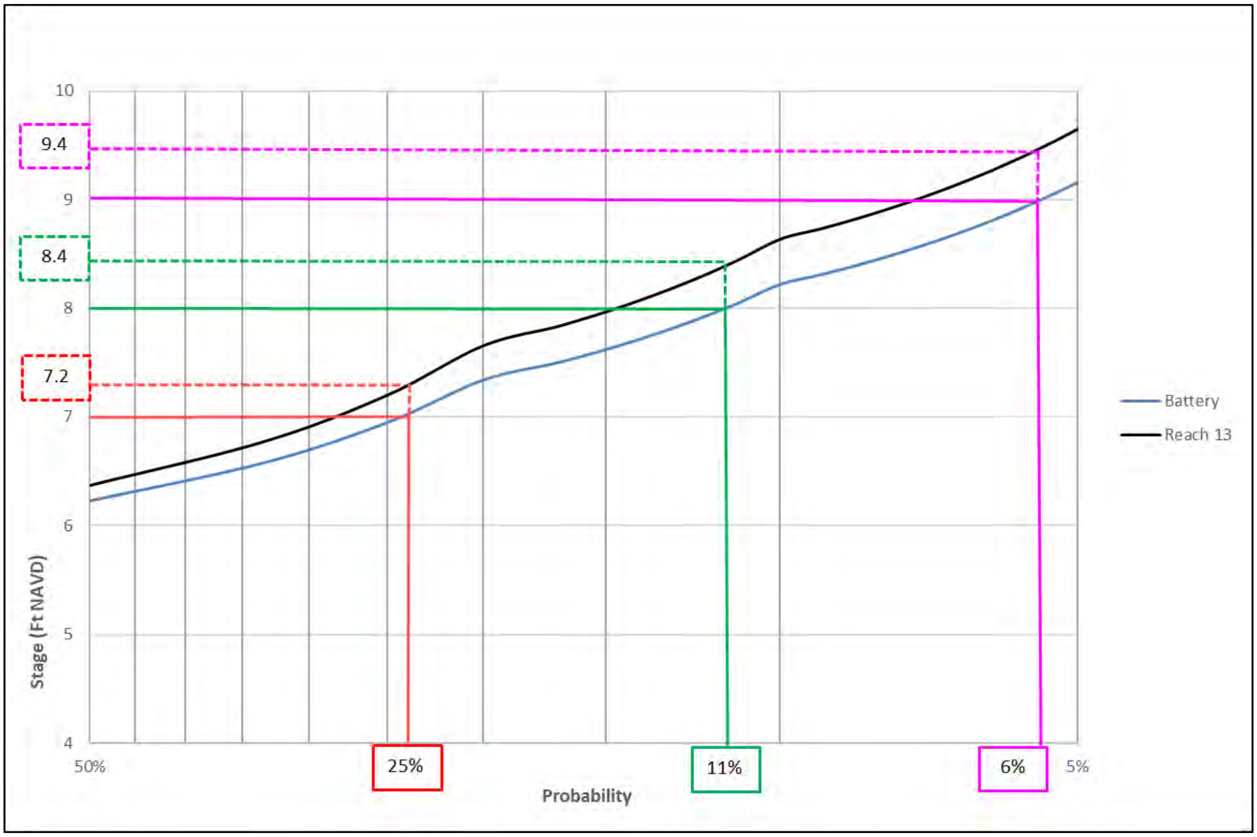
Benefits have been computed for risk reduction features as both a first (addressing storm tides prior to navigation gate closure) and second added (addressing interior flooding after the navigation gate is closed) measure and the design elevation used in the analysis models for each reach varied with the location of the reach.

As outlined above, current analyses were based on the assumption that the storm surge barriers featured in Structural Plans 2 through 4 would be closed when the water surface elevation reaches 7 feet at the Battery. Since there is significant variation across the study area in the frequency at which the water surface elevation reaches 7 feet NAVD, the floodplains affected by these features, and hence the modeled design level of design for RRFs, have been derived by using the water surface elevation in each reach which occurs at the same frequency as that which generates the 7 feet NAVD stage at the Battery.

An example of the derivation of the equivalent stage for a single economic reach is shown in Figure 9: At the Battery, a 7-foot water surface elevation in the baseline condition is expected to have an annual chance exceedance probability of 25%, while in Reach 13, which is assigned to a different NACCS node with a different stage-frequency profile, the same annual chance exceedance event produces a stage of 7.2 feet, which is taken as the protection elevation for RRFs in this reach. This exercise was repeated to determine the analyzed level of protection for RRFs in each reach.

In the future, as sea level change increases, the frequency which generates a stage of 7 feet NAVD at the Battery will increase, and the barrier closure stage may need to be raised to reduce operations and maintenance costs and to minimize obstructions to shipping caused by more frequent operation of the barriers. This would enlarge the areas behind the line of protection subject to high-frequency flooding, and necessitate the corresponding expansion of risk reduction features, either by modifying structural features or by providing nonstructural risk management measures to more buildings. Figure 9 also illustrates the derivation of stages equivalent to sea level rise increments of one and two feet above 7 feet at the Battery for the same example reach. These stages may be used to support RRF adaptation for future sea level change scenarios in which raising SSB operating thresholds are considered.

Figure 9. Derivation of Equivalent Floodplain Stages



Hackensack Basin/Meadowlands RBDM Area

For the section of the study area in New Jersey located in the Hackensack River Basin covering Economic Reaches 12 through 12RBDMSL, the approach to calculating the benefits of RRFs has been refined to account for the local conditions specific to that area:

For Alternatives 2, 3A, and 3B the plans include a storm surge barrier of limited elevation to address the risk of storm surge flooding in the Hackensack Meadowlands prior to the closure of the larger SSBs across the main navigation channels. Operational analysis of the Hackensack SSB to address flood risk prior to gate closure has not been performed, the SSB would be closed significantly below the closure criteria for the main navigation barriers. For this analysis, it is assumed that it is closed at a low enough elevation to prevent significant tidal flooding of development within the Meadowlands and that all of the first added RRF benefits are applicable to these alternatives.

With regards to the interior flooding after the barrier closure, the likely operation of the Hackensack SSB as an RRF will be to close the gates well below the 5-foot action level used for developing the interior flood frequency curve. It is expected that the interior flood levels will be maintained below the elevation of 5 ft NAVD which corresponds to the height of the existing Berms in the area of the RBDM project (ref RBDM Report Econ). For this reason, it is assumed that there would be no interior flood damages in the RBDM reaches.

In Alternative 4, by contrast, the SSB on the Hackensack is assumed to be operated in a manner similar to the main navigation gates. This is consistent with the formulation assumption associated with all other gates, including Jamaica Bay, Newtown Creek, Gowanus Canal, and Flushing Creek. Unlike the other SSBs, however, the Hackensack SSB does not have linear RRFs to prevent damage prior to the gate closure. Therefore, for the Hackensack SSB in Alternative 4, the first added RRFs are not included as a project benefit.

With regards to the interior flooding after the barrier closure in Alternative 4, there are no RRFs to minimize interior flooding between elevations 5 and elevation 7 in all of the Meadowlands. The area would be subject to continued interior flooding unless additional pumping capacity was added.

The benefits analysis concept is illustrated in Figure 10 below, and a brief explanatory key is provided in Table 19.

The benefits of RRFs (whether in structural form or comprising nonstructural), when considered on a first-added basis, correspond to Area A in Figure 10. Where RRFs or nonstructural plans are intended to supplement the protection provided by structural plans, they reduce the risk to structures in low-lying areas (i.e., the 7-foot equivalent floodplains) behind the gates from potential flooding before the barriers are closed and from flooding caused by interior runoff after the gates have closed. In this scenario, RRFs/nonstructural have been evaluated on a second added basis (i.e., they include benefits from when the barriers are closed in addition to pre-closure flooding). The benefits for RRFs/nonstructural evaluated using this approach correspond to Area A plus Area B in Figure 10. Area C in Figure 10 represents the benefits of storm surge barriers implemented on a first-added basis.

Table 19. Key to Benefits Analysis Concept Figure

Alternative Feature	Damages/Benefits	Component of Figure S
No Action	Without-Project Damages	Area A + Area B + Area C
Risk Reduction Features	Benefits as First Added	Area A
Storm Surge Barriers	Benefits as First Added	Area C
Risk Reduction Features	Benefits as Second Added	Area A + Area B
Complete Project	Total Benefits	Assumed = 100% of WoP

An example extract from the lifecycle spreadsheet used to post-process the output from HEC-FDA and to compute damages and benefits is presented in Figure 11 to Figure 13 below. The example shows the calculation of without-project and with-project damages, and hence the benefits, for the SBM proposed in Reach 19S in Alternative 3B, under the intermediate sea level change scenario. Visible in the figures are the analysis parameters including the discount rate, completion year, and final year of benefits accrual for the alternative. The assigned gage is shown and the present worth factor and sea level change increment are shown for each year of the analysis period. The yellow cells in the otherwise green columns are the without and with-project damages output from HEC-FDA for increments of zero and one foot under this projection, in the year that they are estimated to occur. The intervening green cells interpolate the damages for each individual year, which then have yearly benefits calculated and present worth factors applied in the white columns. At the bottom of the worksheet total present worths are calculated over the analysis period and the capital recovery factor is applied to derive annualized damages and benefits.

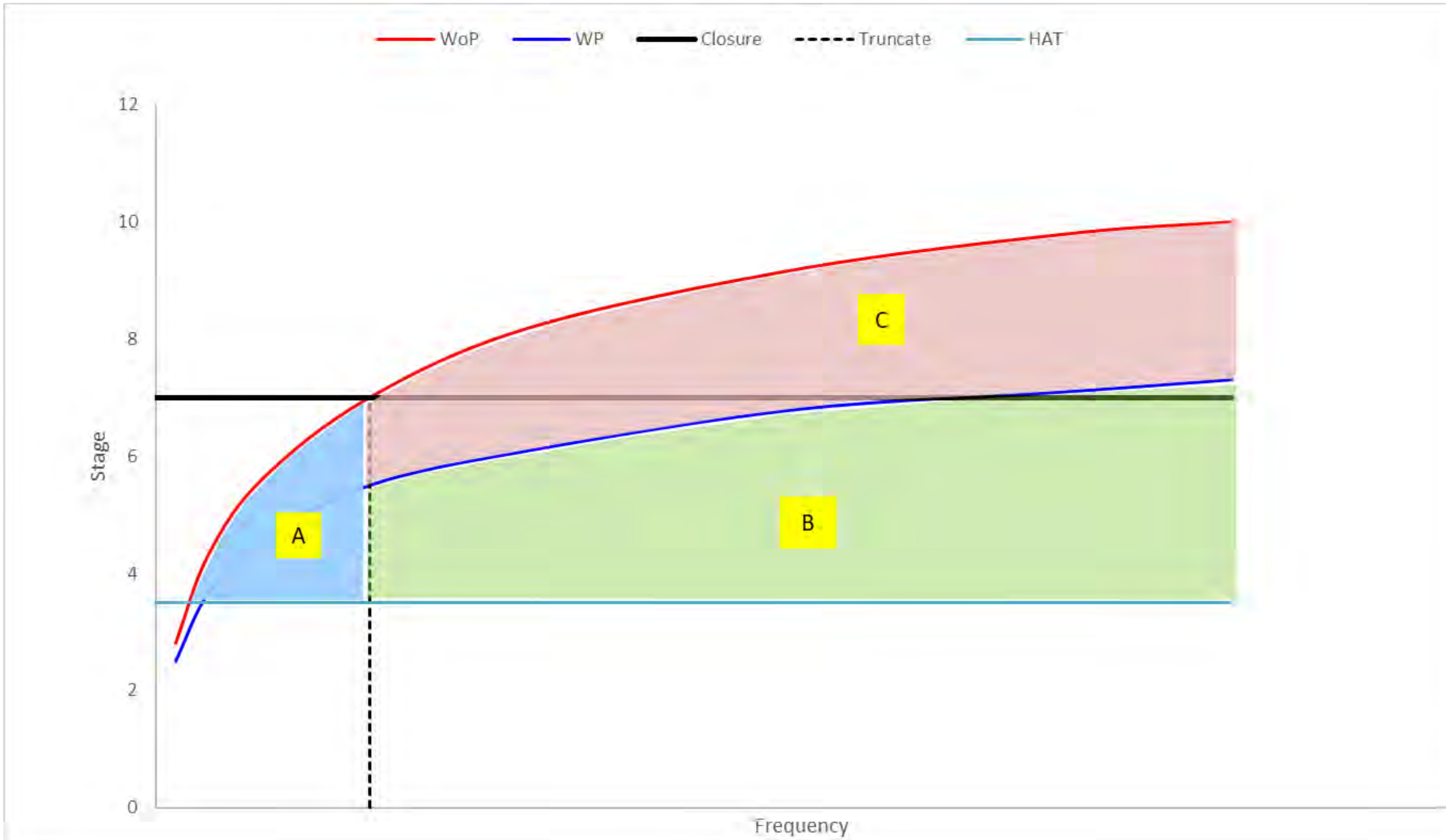


Figure 10: Benefits Analysis Concept

Discount Rate	2.250%		Gage	Battery					19S				
CRF	0.03352		Gage #	2									
Plan Period of Analysis	50	2044	SLR Scenario	SLR Scenario				Reach	19S		Measure	NYC West Side SBM	
Plan	**3b**	Element Base Year	Intermediate	Intermediate	Intermediate	Intermediate	Measure Complete	2044			Last Year for Benefits	2094	
Year	2030 PWF	PWF	SLR Increment from 2030 Intermediate	WOP Damage	WP Damage: Storm Surge Barrier (With Project damages from FOA 7 foot closure levees with exterior-interior relationships)	WP Damage: Shore-Based Measures	PW WOP Damage	PW WP Damage: Shore-Based Measures	PW WP Damage: Storm Surge Barriers	PW Benefits: Shore-Based Measures	PW Benefits: Storm Surge Barriers (SSB First Added)	PW Benefits: RRF (as Second Added)	Total Project Benefits
2018	1.306	1.783					$ -	$ -	$ -	$ -	$ -	$ -	$ -
2029	1.023	1.396					$ -	$ -	$ -	$ -	$ -	$ -	$ -
2030	1.000	1.365	0.00	$ 171,469,519	$ 171,469,519	$ 6,813,009	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2031	0.978	1.335	0.02	$ 174,627,626	$ 174,627,626	$ 6,891,369	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	0.956	1.306	0.03	$ 177,785,734	$ 177,785,734	$ 6,969,729	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2033	0.935	1.277	0.05	$ 180,943,841	$ 180,943,841	$ 7,048,090	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	0.915	1.249	0.07	$ 184,101,948	$ 184,101,948	$ 7,126,450	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	0.895	1.222	0.09	$ 187,260,055	$ 187,260,055	$ 7,204,810	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2036	0.875	1.195	0.11	$ 190,418,162	$ 190,418,162	$ 7,283,170	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2037	0.856	1.169	0.13	$ 193,576,269	$ 193,576,269	$ 7,361,530	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2038	0.837	1.143	0.14	$ 196,734,376	$ 196,734,376	$ 7,439,891	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2039	0.819	1.118	0.16	$ 199,892,484	$ 199,892,484	$ 7,518,251	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2040	0.801	1.093	0.18	$ 203,050,591	$ 203,050,591	$ 7,596,611	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2041	0.783	1.069	0.20	$ 206,208,698	$ 206,208,698	$ 7,674,971	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2042	0.766	1.046	0.22	$ 209,366,805	$ 209,366,805	$ 7,753,331	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2043	0.749	1.023	0.24	$ 212,524,912	$ 212,524,912	$ 7,831,692	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2044	0.732	1.000	0.26	$ 215,683,019	$ 215,683,019	$ 7,910,052	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2045	0.716	0.978	0.28	$ 218,841,127	$ 218,841,127	$ 7,988,412	$ 214,025,552	$ 7,812,628	$ 214,025,552	$ 206,212,924	$ -	$ -	$ 206,212,924
2046	0.700	0.956	0.30	$ 221,999,234	$ 221,999,234	$ 8,066,772	$ 212,336,592	$ 7,715,661	$ 212,336,592	$ 204,620,930	$ -	$ -	$ 204,620,930
2047	0.685	0.935	0.32	$ 225,157,341	$ 225,157,341	$ 8,145,132	$ 210,618,328	$ 7,619,179	$ 210,618,328	$ 202,999,149	$ -	$ -	$ 202,999,149
2048	0.670	0.915	0.34	$ 228,315,448	$ 228,315,448	$ 8,223,493	$ 208,872,868	$ 7,523,208	$ 208,872,868	$ 201,349,661	$ -	$ -	$ 201,349,661
2049	0.655	0.895	0.36	$ 231,473,555	$ 231,473,555	$ 8,301,853	$ 207,102,241	$ 7,427,770	$ 207,102,241	$ 199,674,471	$ -	$ -	$ 199,674,471
2050	0.641	0.875	0.38	$ 234,631,662	$ 234,631,662	$ 8,380,213	$ 205,308,400	$ 7,332,890	$ 205,308,400	$ 197,975,510	$ -	$ -	$ 197,975,510
2051	0.627	0.856	0.40	$ 237,789,770	$ 237,789,770	$ 8,458,573	$ 203,493,223	$ 7,238,589	$ 203,493,223	$ 196,254,634	$ -	$ -	$ 196,254,634
2052	0.613	0.837	0.42	$ 240,947,877	$ 240,947,877	$ 8,536,933	$ 201,658,518	$ 7,144,887	$ 201,658,518	$ 194,513,631	$ -	$ -	$ 194,513,631

Figure 11. Example Extract from Lifecycle Benefits Spreadsheet (Part 1)

Discount Rate	2.250%		Gage	Battery									
CRF	0.03352		Gage #	2					19S				
Plan Period of Analysis	50	2044	SLR Scenario	SLR Scenario				Reach	19S		Measure	NYC West Side SBM	
Plan	**3b**	Element Base Year	Intermediate	Intermediate	Intermediate	Intermediate	Measure Complete	2044			Last Year for Benefits	2094	
Year	2030 PWF	PWF	SLR Increment from 2030 Intermediate	WOP Damage	WP Damage: Storm Surge Barrier (With Project damages from 1D4: 7 foot closure levees with exterior-interior relationships)	WP Damage: Shore-Based Measures	PW WOP Damage	PW WP Damage: Shore-Based Measures	PW WP Damage: Storm Surge Barriers	PW Benefits: Shore-Based Measures	PW Benefits: Storm Surge Barriers (SSB First Added)	PW Benefits: RRF (as Second Added)	Total Project Benefits
2052	0.613	0.837	0.42	$ 240,947,877	$ 240,947,877	$ 8,536,933	$ 201,658,518	$ 7,144,887	$ 201,658,518	$ 194,513,631	$ -	$ -	$ 194,513,631
2053	0.599	0.819	0.45	$ 244,105,984	$ 244,105,984	$ 8,615,294	$ 199,806,023	$ 7,051,804	$ 199,806,023	$ 192,754,219	$ -	$ -	$ 192,754,219
2054	0.586	0.801	0.47	$ 247,264,091	$ 247,264,091	$ 8,693,654	$ 197,937,410	$ 6,959,358	$ 197,937,410	$ 190,978,052	$ -	$ -	$ 190,978,052
2055	0.573	0.783	0.49	$ 250,422,198	$ 250,422,198	$ 8,772,014	$ 196,054,286	$ 6,867,566	$ 196,054,286	$ 189,186,720	$ -	$ -	$ 189,186,720
2056	0.561	0.766	0.51	$ 253,580,305	$ 253,580,305	$ 8,850,374	$ 194,158,193	$ 6,776,444	$ 194,158,193	$ 187,381,749	$ -	$ -	$ 187,381,749
2057	0.548	0.749	0.53	$ 256,738,413	$ 256,738,413	$ 8,928,735	$ 192,250,614	$ 6,686,006	$ 192,250,614	$ 185,564,607	$ -	$ -	$ 185,564,607
2058	0.536	0.732	0.55	$ 259,896,520	$ 259,896,520	$ 9,007,095	$ 190,332,973	$ 6,596,268	$ 190,332,973	$ 183,736,705	$ -	$ -	$ 183,736,705
2059	0.525	0.716	0.58	$ 263,054,627	$ 263,054,627	$ 9,085,455	$ 188,406,636	$ 6,507,242	$ 188,406,636	$ 181,899,394	$ -	$ -	$ 181,899,394
2060	0.513	0.700	0.60	$ 266,212,734	$ 266,212,734	$ 9,163,815	$ 186,472,915	$ 6,418,939	$ 186,472,915	$ 180,053,976	$ -	$ -	$ 180,053,976
2061	0.502	0.685	0.62	$ 269,370,841	$ 269,370,841	$ 9,242,175	$ 184,533,067	$ 6,331,372	$ 184,533,067	$ 178,201,695	$ -	$ -	$ 178,201,695
2062	0.491	0.670	0.64	$ 272,528,948	$ 272,528,948	$ 9,320,536	$ 182,588,298	$ 6,244,550	$ 182,588,298	$ 176,343,748	$ -	$ -	$ 176,343,748
2063	0.480	0.655	0.67	$ 275,687,056	$ 275,687,056	$ 9,398,896	$ 180,639,764	$ 6,158,484	$ 180,639,764	$ 174,481,280	$ -	$ -	$ 174,481,280
2064	0.469	0.641	0.69	$ 278,845,163	$ 278,845,163	$ 9,477,256	$ 178,688,573	$ 6,073,182	$ 178,688,573	$ 172,615,392	$ -	$ -	$ 172,615,392
2065	0.459	0.627	0.71	$ 282,003,270	$ 282,003,270	$ 9,555,616	$ 176,735,785	$ 5,988,652	$ 176,735,785	$ 170,747,134	$ -	$ -	$ 170,747,134
2066	0.449	0.613	0.74	$ 285,161,377	$ 285,161,377	$ 9,633,976	$ 174,782,415	$ 5,904,901	$ 174,782,415	$ 168,877,514	$ -	$ -	$ 168,877,514
2067	0.439	0.599	0.76	$ 288,319,484	$ 288,319,484	$ 9,712,337	$ 172,829,434	$ 5,821,936	$ 172,829,434	$ 167,007,498	$ -	$ -	$ 167,007,498
2068	0.429	0.586	0.79	$ 291,477,591	$ 291,477,591	$ 9,790,697	$ 170,877,772	$ 5,739,764	$ 170,877,772	$ 165,138,008	$ -	$ -	$ 165,138,008
2069	0.420	0.573	0.81	$ 294,635,699	$ 294,635,699	$ 9,869,057	$ 168,928,314	$ 5,658,388	$ 168,928,314	$ 163,269,926	$ -	$ -	$ 163,269,926
2070	0.411	0.561	0.83	$ 297,793,806	$ 297,793,806	$ 9,947,417	$ 166,981,911	$ 5,577,815	$ 166,981,911	$ 161,404,096	$ -	$ -	$ 161,404,096
2071	0.402	0.548	0.86	$ 300,951,913	$ 300,951,913	$ 10,025,777	$ 165,039,370	$ 5,498,048	$ 165,039,370	$ 159,541,322	$ -	$ -	$ 159,541,322
2072	0.393	0.536	0.88	$ 304,110,020	$ 304,110,020	$ 10,104,138	$ 163,101,465	$ 5,419,090	$ 163,101,465	$ 157,682,375	$ -	$ -	$ 157,682,375
2073	0.384	0.525	0.91	$ 307,268,127	$ 307,268,127	$ 10,182,498	$ 161,168,933	$ 5,340,945	$ 161,168,933	$ 155,827,987	$ -	$ -	$ 155,827,987
2074	0.376	0.513	0.93	$ 310,426,234	$ 310,426,234	$ 10,260,858	$ 159,242,474	$ 5,263,616	$ 159,242,474	$ 153,978,858	$ -	$ -	$ 153,978,858
2075	0.367	0.502	0.96	$ 313,584,341	$ 313,584,341	$ 10,339,218	$ 157,322,758	$ 5,187,103	$ 157,322,758	$ 152,135,655	$ -	$ -	$ 152,135,655
2076	0.359	0.491	0.98	$ 316,742,449	$ 316,742,449	$ 10,417,578	$ 155,410,421	$ 5,111,409	$ 155,410,421	$ 150,299,012	$ -	$ -	$ 150,299,012
2077	0.351	0.480	**1.01**	$ 319,900,556	$ 319,900,556	$ 10,495,939	$ 153,506,067	$ 5,036,535	$ 153,506,067	$ 148,469,532	$ -	$ -	$ 148,469,532
2078	0.344	0.469	1.04	$ 325,089,199	$ 325,089,199	$ 10,651,612	$ 152,563,194	$ 4,998,763	$ 152,563,194	$ 147,564,431	$ -	$ -	$ 147,564,431
2079	0.336	0.459	1.06	$ 330,277,842	$ 330,277,842	$ 10,807,285	$ 151,587,488	$ 4,960,215	$ 151,587,488	$ 146,627,273	$ -	$ -	$ 146,627,273
2080	0.329	0.449	1.09	$ 335,466,486	$ 335,466,486	$ 10,962,958	$ 150,580,848	$ 4,920,943	$ 150,580,848	$ 145,659,905	$ -	$ -	$ 145,659,905

Figure 12. Example Extract from Lifecycle Benefits Spreadsheet (Part 2)

Discount Rate	2.250%		Gage	Battery					19S				
CRF	0.03352		Gage #	2									
Plan Period of Analysis	50	2044	SLR Scenario		SLR Scenario			Reach	19S		Measure	NYC West Side SBM	
Plan	**3b**	Element Base Year	Intermediate	Intermediate	Intermediate	Intermediate	Measure Complete	2044			Last Year for Benefits	2094	
Year	2030 PWF	PWF	SLR Increment from 2030 Intermediate	WOP Damage	WP Damage: Storm Surge Barrier (With Project damages from FDA: 7 foot closure levees with exterior-interior relationships)	WP Damage: Shore-Based Measures	PW WOP Damage	PW WP Damage: Shore-Based Measures	PW WP Damage: Storm Surge Barriers	PW Benefits: Shore-Based Measures	PW Benefits: Storm Surge Barriers (SSB First Added)	PW Benefits: RTF (as Second Added)	Total Project Benefits
2076	[illegible]	0.491	0.98	$ 316,742,449	$ 316,742,449	$ 10,417,578	$ 155,410,421	$ 5,111,409	$ 155,410,421	$ 150,299,012	$ -	$ -	$ 150,299,012
2077	[illegible]	0.480	**1.01**	$ 319,900,556	$ 319,900,556	$ 10,495,939	$ 153,506,067	$ 5,036,535	$ 153,506,067	$ 148,469,532	$ -	$ -	$ 148,469,532
2078	[illegible]	0.469	1.04	$ 325,089,199	$ 325,089,199	$ 10,651,612	$ 152,563,194	$ 4,998,763	$ 152,563,194	$ 147,564,431	$ -	$ -	$ 147,564,431
2079	[illegible]	0.459	1.06	$ 330,277,842	$ 330,277,842	$ 10,807,285	$ 151,587,488	$ 4,960,215	$ 151,587,488	$ 146,627,273	$ -	$ -	$ 146,627,273
2080	[illegible]	0.449	1.09	$ 335,466,486	$ 335,466,486	$ 10,962,958	$ 150,580,848	$ 4,920,943	$ 150,580,848	$ 145,659,905	$ -	$ -	$ 145,659,905
2081	[illegible]	0.439	1.11	$ 340,655,129	$ 340,655,129	$ 11,118,631	$ 149,545,109	$ 4,880,997	$ 149,545,109	$ 144,664,112	$ -	$ -	$ 144,664,112
2082	[illegible]	0.429	1.14	$ 345,843,772	$ 345,843,772	$ 11,274,304	$ 148,482,040	$ 4,840,427	$ 148,482,040	$ 143,641,613	$ -	$ -	$ 143,641,613
2083	[illegible]	0.420	1.17	$ 351,032,415	$ 351,032,415	$ 11,429,977	$ 147,393,344	$ 4,799,279	$ 147,393,344	$ 142,594,065	$ -	$ -	$ 142,594,065
2084	[illegible]	0.411	1.19	$ 356,221,059	$ 356,221,059	$ 11,585,650	$ 146,280,664	$ 4,757,598	$ 146,280,664	$ 141,523,066	$ -	$ -	$ 141,523,066
2085	[illegible]	0.402	1.22	$ 361,409,702	$ 361,409,702	$ 11,741,323	$ 145,145,583	$ 4,715,427	$ 145,145,583	$ 140,430,156	$ -	$ -	$ 140,430,156
2086	[illegible]	0.393	1.25	$ 366,598,345	$ 366,598,345	$ 11,896,996	$ 143,989,625	$ 4,672,809	$ 143,989,625	$ 139,316,816	$ -	$ -	$ 139,316,816
2087	[illegible]	0.384	1.28	$ 371,786,989	$ 371,786,989	$ 12,052,669	$ 142,814,259	$ 4,629,783	$ 142,814,259	$ 138,184,476	$ -	$ -	$ 138,184,476
2088	[illegible]	0.376	1.30	$ 376,975,632	$ 376,975,632	$ 12,208,342	$ 141,620,898	$ 4,586,387	$ 141,620,898	$ 137,034,511	$ -	$ -	$ 137,034,511
2089	[illegible]	0.367	1.33	$ 382,164,275	$ 382,164,275	$ 12,364,015	$ 140,410,904	$ 4,542,660	$ 140,410,904	$ 135,868,244	$ -	$ -	$ 135,868,244
2090	[illegible]	0.359	1.36	$ 387,352,918	$ 387,352,918	$ 12,519,688	$ 139,185,587	$ 4,498,637	$ 139,185,587	$ 134,686,950	$ -	$ -	$ 134,686,950
2091	[illegible]	0.351	1.39	$ 392,541,562	$ 392,541,562	$ 12,675,361	$ 137,946,207	$ 4,454,351	$ 137,946,207	$ 133,491,855	$ -	$ -	$ 133,491,855
2092	[illegible]	0.344	1.41	$ 397,730,205	$ 397,730,205	$ 12,831,034	$ 136,693,975	$ 4,409,836	$ 136,693,975	$ 132,284,139	$ -	$ -	$ 132,284,139
2093	[illegible]	0.336	1.44	$ 402,918,848	$ 402,918,848	$ 12,986,707	$ 135,430,059	$ 4,365,123	$ 135,430,059	$ 131,064,935	$ -	$ -	$ 131,064,935
2094	[illegible]	0.329	1.47	$ 408,107,492	$ 408,107,492	$ 13,142,380	$ 134,155,578	$ 4,320,243	$ 134,155,578	$ 129,835,335	$ -	$ -	$ 129,835,335
2095	[illegible]	0.321	1.50	$ 413,296,135	$ 413,296,135	$ 13,298,053	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2096	[illegible]	0.314	1.53	$ 418,484,778	$ 418,484,778	$ 13,453,726	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2097	[illegible]	0.307	1.56	$ 423,673,421	$ 423,673,421	$ 13,609,399	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2098	[illegible]	0.301	1.59	$ 428,862,065	$ 428,862,065	$ 13,765,072	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2099	[illegible]	0.294	1.62	$ 434,050,708	$ 434,050,708	$ 13,920,745	$ -	$ -	$ -	$ -	$ -	$ -	$ -
						Lifecycle Totals	**$ 8,525,036,950**	**$ 289,387,707**	**$ 8,525,036,950**	**$ 8,235,649,244**	**$ -**	**$ -**	**$ 8,235,649,244**
					Reach	**19S**							
					Annualized for Period of analysis		**$285,745,000**						
								$9,700,000					
									$285,745,000				
										$276,045,000			
											$0		
												$0	
													$276,045,000

Figure 13. Example Extract from Lifecycle Benefits Spreadsheet (Part 3)

7.3 NED Benefit Analysis Results

The results of the analyses are summarized in Table 20 below, which presents the total annual without-project damages, with-project damages, benefits, net benefits, and benefit to cost ratios for each evaluated alternative. The table shows that, based on National Economic Development Benefits, the Tentatively Selected Plan is **Alternative 3B**, the Upper Bay-Newark Bay Surge Gate and Jamaica Bay Surge Gate Plan, with net annual benefits of approximately $4.0 billion.

Table 20. Summary of Analysis Results by Evaluated Plan

Intermediate Sea Level Change Scenario Annual Damages/Benefits/Costs, Billions						
Alternative	**Without Project**	**With Project**	**Benefits**	**Cost**	**Net Benefits**	**BCR**
2	$7.948	$3.366	$4.582	$5.035	-$0.453	0.91
3A	$7.948	$1.562	$6.386	$3.207	$3.179	2.0
3B	**$7.948**	**$1.689**	**$6.259**	**$2.553**	**$3.706**	**2.5**
4	$7.948	$2.943	$5.005	$2.094	$2.911	2.4
5	$7.948	$6.035	$1.914	$0.864	$1.050	2.2

Price Level February 2022, Discount Rate 2.25%, 50-year period of analysis

While Alternative 2 covers a greater proportion of the study area than Alternative 3A, it accrues lower total annual benefits than Alternative 3A due to the different anticipated timelines and scheduled completion dates of these alternatives. Every alternative is anticipated to begin construction in 2030 and to accrue benefits for a period of analysis up to 50 years following the project completion year. In accordance with current USACE planning guidance, the period of analysis for each alternative does not extend past 50 years after the common economic base year of 2044. Alternative 2 has a construction duration of 32 years, with anticipated completion in 2062, while Alternative 3A has a construction duration of 24 years, with anticipated completion in 2054, as presented in Table 21.

Table 21. Comparison of Timelines for Plans 2 and 3A

Alternative	Start of Construction	Construction Duration, Years	Construction Complete	Base Year	First Year of Full Benefits	Last Year of Full Benefits	Years of Full Benefits
2	2030	32	2062	2044	2063	2094	32
3A	2030	24	2054	2044	2055	2094	40

Therefore to remain in compliance with current USA planning guidance, Alternative 2 has 32 years of function over which it can accrue benefits for this analysis, while Alternative 3 has 40 years of function.

In order to compare the alternatives fairly, it was assumed that standalone structural features common to several different alternatives would be completed to the same schedule regardless of the plans in which they were incorporated. Hence, it was assumed that since the Jamaica Bay Barrier does not tie into any other structural component, it could be completed and function as a standalone measure in 2044 in Alternative 3A, hence accruing10 years of advance benefits. Similarly, it was assumed the Hackensack Barrier could also be completed in 2044 under Alternative 3A and operating for 10 years in advance of the full project completion, and also accruing advance benefits over that period. The completion years of both these components in Alternative 3A were assumed based on their schedule as components of Alternative 4, for which the full project is anticipated to be complete by 2044.

Also, the total with-project damages for Alternative 2 are greater than for Alternative 3A since they include damages accruing over 18 years of the 50-year analysis period prior to completion of the project (i.e. the years 2045 through 2062), while for Alternative 2 the corresponding period prior to project completion is only 10 years (2045 through 2054) for reaches not accruing benefits until the full project is complete.

Table 22 below presents annual without-project damages, with-project damages, and benefits for the Tentatively Selected plan for all economic reaches that contributed to the analysis.

Table 22. Annual Damages and Benefits for Alternative 3B by Economic Reach

Intermediate Sea Level Change Scenario			
Economic Reach	Equivalent Annual Damage		Annual Benefits
	Without Project	With Project	
2	$249,653,000	$249,653,000	$0
3	$90,339,000	$90,339,000	$0
4	$77,109,000	$77,109,000	$0
5	$32,141,000	$32,141,000	$0
6	$36,476,000	$0	$36,476,000
7W	$22,424,000	$0	$22,424,000
7E	$14,616,000	$14,616,000	$0
8N	$81,455,000	$0	$81,455,000
8S	$38,727,000	$0	$38,727,000
9	$71,539,000	$0	$71,539,000
10	$96,167,000	$0	$96,167,000

Intermediate Sea Level Change Scenario			
Economic Reach	Equivalent Annual Damage		Annual Benefits
	Without Project	With Project	
11	$375,105,000	$0	$375,105,000
12	$378,113,000	$72,053,000	$306,060,000
12RBDM	$1,199,437,000	$0	$1,199,437,000
12RBDMSU	$532,545,000	$0	$532,545,000
12RBDMSM	$35,565,000	$0	$35,565,000
12RBDMSL	$103,469,000	$0	$103,469,000
13	$10,756,000	$0	$10,756,000
14	$148,780,000	$148,780,000	$0
14S	$263,166,000	$17,725,000	$245,441,000
15	$107,401,000	$107,401,000	$0
16	$82,863,000	$82,863,000	$0
16SP	$1,082,000	$1,082,000	$0
16SS	$8,000	$8,000	$0
16SO	$890,000	$890,000	$0
16ST	$1,324,000	$1,324,000	$0
16SYN	$2,862,000	$2,862,000	$0
16SYS	$456,000	$456,000	$0
17	$250,000	$250,000	$0
18	$55,389,000	$55,389,000	$0
18S	$251,091,000	$28,862,000	$222,229,000
19	$207,074,000	$17,004,000	$190,070,000
19S	$285,745,000	$9,700,000	$276,045,000
20A	$1,787,000	$508,000	$1,279,000
20B	$339,507,000	$12,988,000	$326,519,000
21A	$6,371,000	$6,371,000	$0
21B	$23,322,000	$5,619,000	$17,703,000
22A	$97,551,000	$97,551,000	$0
22AS	$31,687,000	$31,687,000	$0
22PB	$7,017,000	$7,017,000	$0
25A	$30,361,000	$30,361,000	$0
25AS	$12,192,000	$12,192,000	$0
25AF	$71,975,000	$0	$71,975,000
26	$215,143,000	$8,310,000	$206,833,000
26S	$32,068,000	$32,068,000	$0
27	$127,617,000	$0	$127,617,000
28	$374,032,000	$374,032,000	$0
29	$59,998,000	$59,998,000	$0
30	$142,016,000	$0	$142,016,000

Intermediate Sea Level Change Scenario			
Economic Reach	Equivalent Annual Damage		Annual Benefits
	Without Project	With Project	
31	$892,575,000	$0	$892,575,000
32	$111,536,000	$0	$111,536,000
33	$517,584,000	$0	$517,584,000
Totals	***$7,948,356,000***	***$1,689,209,000***	***$6,259,147,000***

Price Level February 2022, Discount Rate 2.25%, 50-year period of analysis

7.4 Summary of Tentatively Selected Plan

The result of the analysis of NED benefits is that Alternative 3B is recommended as the Tentatively Selected Plan. Alternative 3B includes SSBs covering Newark Bay, Jamaica Bay, Gowanus Creek, Flushing Creek, and SBMs located in Jersey City, Manhattan's Lower West Side and Financial District, Harlem, and Newtown Creek. If the construction of Alternative 3B were to begin in 2030, the full project would be expected to be complete in 2044, and the for the purposes of this analysis the last year of full benefits would be 2094. The key economic data, based on intermediate sea level rise scenario and derived using a discount rate of 2.25% and based on a price level of February 2022, is summarized as follows:

Annual Without -Project Damages	$7.948 Billion
Annual With-Project Damages	$1.689 Billion
Annual Benefits	$6.259 Billion
Annual Cost	$2.553 Billion
Annual Net Benefits	$3.983Billion
Benefit to Cost Ratio	2.5

8 Sensitivity Analyses

Table 23 and Table 24 present a summary of each plan under two additional sea level change scenarios. Table 25 presents the results of analyses under all three evaluated scenarios in a single table for comparison. The sea level change scenarios applied in these analyses are described in detail in Section 5.2 above and were developed in accordance with ER 1100-2-8162. Under a low sea level rise scenario, in which historic sea level trends are projected linearly over the period of analysis, Alternative 3B would remain the Tentatively Selected Plan. However, under a high sea level change scenario, in which the rate of rising is expected to accelerate over the analysis period, Alternative 3A would become the Tentatively Selected Plan.

Table 23. Summary of Analysis Results by Evaluated Plan, Low Sea Level Change Scenario

Annual Damages/Benefits/Costs, Billions						
Alternative	Without Project	With Project	Benefits	Cost	Net Benefits	BCR
2	$5.899	$2.686	$3.213	$5.035	-$1.822	0.6
3A	$5.899	$1.198	$4.701	$3.207	$1.494	1.5
3B	$5.899	$1.237	$4.662	$2.553	$2.109	1.8
4	$5.899	$2.380	$3.519	$2.094	$1.425	1.7
5	$5.899	$4.369	$1.530	$0.864	$0.666	1.8

Price Level February 2022, Discount Rate 2.25%, 50-year period of analysis

Table 24. Summary of Analysis Results by Evaluated Plan, High Sea Level Change Scenario

Annual Damages/Benefits/Costs, Billions						
Alternative	Without Project	With Project	Benefits	Cost	Net Benefits	BCR
2	$16.892	$5.439	$11.453	$5.035	$6.418	2.3
3A	$16.892	$2.568	$14.325	$3.207	$11.118	4.5
3B	$16.892	$4.134	$12.758	$2.553	$10.205	5.0
4	$16.892	$6.018	$10.874	$2.094	$8.780	5.2
5	$16.892	$13.735	$3.157	$0.864	$2.293	3.7

Price Level February 2022, Discount Rate 2.25%, 50-year period of analysis

Table 25. Comparison of Results for All Evaluated Sea Level Change Scenarios

Annual Net Benefits in Billions						
Alternative	Low Sea Level Change		Intermediate Sea Level Change		High Sea Level Change	
	Net Benefits	BCR	Net Benefits	BCR	Net Benefits	BCR
2	-$1.822	0.6	-$0453	0.91	$6.418	2.3
3A	$1.494	1.5	$3.179	2.0	$11.118	4.5
3B	$2.109	1.8	$3.709	2.5	$10.205	5.0
4	$1.425	1.7	$2.911	2.4	$8.780	5.2
5	$0.666	1.8	$1.050	2.2	$2.293	3.7

Price Level February 2022, Discount Rate 2.25%, 50-year period of analysis

While the economic analyses have been conducted primarily using the current FY discount rate of 2.25% for federal water resources projects, Table 26 and Table 27 present a summary of each plan using two additional discount rates: the alternatives have been evaluated using a discount rate of 2.5%, to reflect a possible increase in the coming fiscal year, and using a rate of 7%[1], which has been used for the evaluation of most federal programs since 1992. Table 28 presents the results of analyses under all three applied interest rates in a single table for comparison.

Table 26. Summary of Analysis Results by Evaluated Plan, 2.5% Discount Rate

Intermediate Sea Level Change Scenario Annual Damages/Benefits/Costs, Billions						
Alternative	Without Project	With Project	Benefits	Cost	Net Benefits	BCR
2	$7.899	$3.460	$4.440	$5.243	-$0.804	0.8
3A	$7.899	$1.615	$6.285	$3.394	$2.890	1.9
3B	$7.899	$1.678	$6.221	$2.725	$3.496	2.3
4	$7.899	$2.930	$4.970	$2.235	$2.734	2.2
5	$7.899	$5.953	$1.946	$0.932	$1.014	2.1

Price Level February 2022, Discount Rate 2.50%, 50-year period of analysis

[1] Net benefits at 7% are not fully realized at this stage. Future stages of the study will evaluate the construction sequencing in more detail such that several of the features in the TSP will likely be completed prior to the base year so that benefits may accrue sooner than assumed for this analysis. Also, there may be additional benefit streams (e.g., oil storage tanks, etc.) that would promote economic justification of the TSP at the 7% discount rate.

Table 27. Summary of Analysis Results by Evaluated Plan, 7.0% Discount Rate

Intermediate Sea Level Change Scenario Annual Damages/Benefits/Costs, Billions						
Alternative	**Without Project**	**With Project**	**Benefits**	**Cost**	**Net Benefits**	**BCR**
2	$7.204	$4.875	$2.329	$11.887	-$9.558	0.2
3A	$7.204	$2.538	$4.666	$9.011	-$4.345	0.5
3B	$7.204	$1.524	$5.680	$8.079	-$2.399	0.7
4	$7.204	$2.737	$4.466	$6.645	-$2.178	0.7
5	$7.204	$4.560	$2.644	$3.169	-$0.525	0.8

Price Level February 2022, Discount Rate 7.0%, 50-year period of analysis

Table 28. Comparison of Results for All Evaluated Discount Rates

Intermediate Sea Level Change Scenario Annual Net Benefits in Billions						
Alternative	**2.25% Discount Rate**		**2.5% Discount Rate**		**7.0% Discount Rate**	
	Net Benefits	**BCR**	**Net Benefits**	**BCR**	**Net Benefits**	**BCR**
2	-$0.453	0.91	-$0.804	0.8	-$9.558	0.2
3A	$3.179	2.0	$2.890	1.9	-$4.345	0.5
3B	**$3.706**	**2.5**	$3.496	2.3	-$2.399	0.7
4	$2.911	2.4	$2.235	2.2	-$2.178	0.7
5	$1.050	2.2	$1.014	2.1	-$0.525	0.8

Price Level February 2022, 50-year period of analysis

9 Evaluation of Other Benefit Accounts

9.1 Regional Economic Development

The regional benefit associated with construction is the indirect and induced economic output that would be produced for an assumed construction cost. This analysis uses the USACE RECONS 2.0 input/output model, developed by the Institute for Water Resources (IWR), to estimate the regional economic impacts of proposed construction work activities.

Alternatives 2-5 have common work activities associated with the Construction of Earth, Concrete, and Mechanical Levees and Floodwalls as defined in the RECONS model. Conceptualized annual costs are used as construction expenditures (see Table 20 in section 7.3 of this report). Of total expenditures, a portion will be captured within the local impact area and the remainder of the expenditures will be captured within the state and the nation. Direct expenditures capture direct impacts on the area's employment and income based on the goods and services necessary to complete the construction of the alternative. Construction will also generate secondary economic activity often called multiplier effects. This would be realized through companies that supply materials or services to companies engaged in construction. Local restaurateurs, for example, will have higher disposable income because of an increase in clientele, and as a result, they will spend their dollars to purchase appliances, do home repairs and otherwise put money back into the economy. It should be noted that the extent of the multiplier effect is dependent upon how consumers respond to the additional income, in today's climate consumers might be inclined to save for an emergency rather than spend.

Summarized in the following tables are the impacts of each alternative measured in output, jobs, labor income, and gross regional (value added) product. Only Regional economic effects are shown for the local impact area. In summary, estimated annual expenditures[2] of approximately $5 billion for Alternative 2 will support a total of 44 thousand full-time equivalent jobs and a lump sum of $3.4 billion in labor income to the local economy. Spending $3 billion annually for Alternative 3A will add $2.5 billion in local labor income and 33,000 jobs. Alternative 3B expenditures of $2 billion will generate $1.8 billion in labor income and 24,000 jobs. Spending $2 billion each year of construction for Alternative 4 generates $1.5 billion in income and 21,000 jobs and $863 million in spending for Alternative 5 will generate $690 million and 9,400 jobs.

[2] At the time of this analysis conceptual costs were used. Expenditure values used in the analysis approximate current cost estimates and may be refined as more data becomes available.

Table 29. Regional Economic Development Impacts

Alternative 2

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$3,510,126,000	32,604	$2,686,309,000	$2,304,541,000
Secondary Impact		$2,212,966,000	11,809	$711,626,000	$1,289,467,000
Total Impact	$3,510,126,000	$5,723,092,000	44,414	$3,397,936,000	$3,594,008,000

Alternative 3A

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$2,369,059,000	25,138	$1,946,600,000	$1,682,776,000
Secondary Impact		$1,593,607,000	8,487	$518,577,000	$933,793,000
Total Impact	$2,369,059,000	$3,962,667,000	33,625	$2,465,177,000	$2,616,570,000

Alternative 3B

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$1,713,781,000	18,185	$1,408,174,000	$1,217,323,000
Secondary Impact		$1,152,818,000	6,139	$375,139,000	$675,508,000
Total Impact	$1,713,781,000	$2,866,599,000	24,324	$1,783,313,000	$1,892,831,000

Alternative 4

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$1,507,863,000	16,000	$1,238,976,000	$1,071,056,000
Secondary Impact		$1,014,302,000	5,402	$330,065,000	$594,342,000
Total Impact	$1,507,863,000	$2,522,165,000	21,401	$1,569,040,000	$1,665,399,000

Alternative 5

Area	Local Capture	Output	Jobs*	Labor Income	Value Added
Local					
Direct Impact		$663,583,000	7,041	$545,250,000	$471,352,000
Secondary Impact		$446,375,000	2,377	$145,255,000	$261,559,000
Total Impact	$663,583,000	$1,109,958,000	9,418	$690,506,000	$732,911,000

Construction expenditures are expected to produce these regional impacts for the duration of construction. Table 30 displays annual employment contribution of each alternative for the expected construction durations. Alternative 2 will provide $3.4 billion in local labor income and create 44,000 jobs each year for thirty-two years.

Table 30. Summary of Annual Employment Contribution

	Alternative 2	Alternative 3A	Alternative 3B	Alternative 4	Alternative 5
Annual Local Labor Income	$3,398,000,000	$2,465,000,000	$1,783,000,000	$1,569,000,000	$691,000,000
Construction Duration	32	24	14	14	5
Annual Job Creation	44,414	33,625	24,324	21,401	9,418

9.2 Life Safety

9.2.1 Hazards and consequences

Much of the damages from Hurricane Sandy forces were due to storm surge, wind, and tidal action. The center of Sandy made landfall near Brigantine, New Jersey, around 7:30 p.m. on October 29th, 2012, with 70-knot maximum sustained winds. The pressure gradient between Sandy's extremely low pressure and high pressure to its north created enhanced wind speeds from the northeast which contributed to record setting surge[3]. The recorded sustained winds reflect a Category 1 type storm with relatively little damage according to the Saffir-Simpson scale however, because of its tremendous size, Sandy drove a catastrophic storm surge into the New Jersey and New York coastlines. The tropical storm force winds extended across approximately 1,000 miles (in diameter), making Sandy one of the largest Atlantic tropical storms ever recorded. The worst flooding occurred along the New Jersey shore and around the New York City metropolitan area where inundations were measured up to 9 ft above ground level in coastal areas.

9.2.2 Life Loss – Hurricane Sandy

Storm surge and wind from the Sandy storm caused deaths both directly and indirectly. Directly-caused deaths were attributed to storm surge causing flooding in homes. There were 117 deaths related to Sandy in the United States. Most deaths occurred in New York (fifty-three) and New Jersey (thirty-four)[4]. In addition to storm surge forces, the area saw gusty winds that resulted in downed trees and power lines. Hurricane Sandy caused a massive power outage in the Northeast leaving residents without power for days even months after the storm. According to U.S. Department of Energy, Office of Electricity Delivery and Reliability, approximately 4.5 million electricity meters were without service in New York and

[3] Ibid, page 13.

[4] Centers for Disease Control and Prevention. Deaths Associated with Hurricane Sandy — October–November 2012. MMWR 2013;62: (20);393-397

New Jersey one day after the storm had exited the area. This led to unsafe conditions where street light outages led to under-regulated traffic creating hazardous driving conditions. Power outages also caused the disruption of critical services for individuals dependent on electricity powered medical equipment such as ventilators and oxygen concentrators.

The speed, intensity, and duration of the storm were catastrophic because people did not get out of harm's way in time. The decision to evacuate would hinge on whether evacuation orders were given and with enough lead time for those at risk to prepare and respond. In after-action reporting, the National Weather Service acknowledged that hurricane watches and warnings dissemination decisions were not timely made. It is reasonable to believe that the lack of hurricane warnings adversely influenced public perceptions of storm intensity and potential perils. Other factors play a role in whether the population at risk (PAR) decides to evacuate, such as whether there were shelter options available and how to access those options. Example factors include whether a household had knowledge of where to seek shelter and whether they had the ability to reach those places. Some residents did not evacuate because, after experiencing years of hurricanes with little or no damage, they developed a false sense of security, so when orders to evacuate were eventually given, they decided to stay. Whatever the reason behind a decision not to evacuate, of the 375,000 people who live in low-lying areas[5] in New York that were ordered to evacuate, only an estimated 32% evacuated. The same evacuation rate was estimated for coastal populations in New Jersey.

9.2.3 Population at Risk (PAR)

Hurricane Sandy presented significant consequences to people who live along the Atlantic coast. For ease of assessment, the population at risk for the NYNJHAT study is represented by people inhabiting the 1-percent floodplain extent along the shoreline, however, the extent of the Sandy storm reached further inland than delineated by the floodplain. The PAR represents those who are in the area that are in the path of inundation before any warnings are given and individuals who will be exposed to storm hazard forces if they do not get out of harm's way. The coastal PAR, especially those inhabiting low-lying areas, are vulnerable to drowning in floodwaters which is the primary cause of death among people directly exposed to storm surges and tides. Others will be impacted by being hit by falling trees, debris, and other objects during high winds, tornadoes, and hurricane forces in general.

The ability to evacuate to a safe location outside the inundation area is an important factor in determining life loss. The PAR will seek to escape either horizontally on the roads or vertically to higher ground to get out of harm's way. A safe location may mean the upper floors of a multi-story building out of the reach of floodwaters. Certain households in the study area

---

[5] Partial definition of Zone A which was the naming convention during the Sandy storm. Subsequent zone classifications for NYC now use a numbered system.

occupy two or more storied structures where occupants are able to escape to the upper floors. Others, however, occupy one story or mobile homes and are not able to egress vertically. For people who do not evacuate and occupy structures located on low-lying terrain, the number of people remaining in harm's way will increase depending on the depths of flooding.

9.2.4 Life Loss Alternatives Screening

The ability to escape to shelter is an important determinant of life loss, but possibilities to reach safe locations will also depend on water depth and the rise rate of the water. The exposed population will decrease as people escape inundation volumes. The damage and danger that flood waters might cause can be related to the force of the flood flows as they travel down a floodplain[6]. Escape will work optimally in tandem with inundation flow management to reduce life loss where efforts to reduce the risk to life safety to the exposed population will consider depths of flooding and velocity of flow. To reduce the risk of storm damage, structural and nonstructural risk reduction measures were considered for the NYNJHAT study. The alternative concepts span the spectrum of predominantly in-water structures (surge barriers) that provide coastal storm risk management (CSRM) for most of the study area (Alternative 2), to solely land-based measures, also known as secondary measures consisting of floodwalls and levees at localized areas of high risk (Alternative 5). In between are the regional hybrid combinations of smaller barriers and land-based measures (3A to 4).

Storm surge barriers are primary measures whereas shoreline (land-based) measures are secondary and include strategically placed deployable floodwalls, closure gates, levees, berms, seawalls, revetments, and bulkheads.

Table 31 summarizes the conceptual design risk management for the various coastal storm risk management measures considered for the NYNJHAT study as conceptualized in the NACCS. The design criteria include a "+3 feet" allowance for the structural measures to account for uncertainty associated with future sea level change forecasts. Of the measures considered, storm surge barriers were assumed to be designed to a 0.2 percent annual chance flood elevation.

Table 31. Risk Reduction Measures

Risk Reduction Measures	
Measure Type	**Criteria**
Structural (not barriers)	1 percent flood elevation + 3-foot sea level change allowance
Storm Surge Barriers	0.2 percent flood elevation + 3-foot sea level change allowance

[6] Smith, G.P., (2015). *Expert Opinion: Stability of People, Vehicles and Buildings in Flood Water*. Water Research Laboratory. University of New South Wales. page 2

Risk Reduction Measures	
Measure Type	**Criteria**
Natural and Nature-Based Features[1]	10 percent flood elevation
Nonstructural (Floodproofing and Buyouts)	1 percent flood elevation + 3-foot sea level change allowance

[1] Beaches and dunes are considered NNBF.

Storm surge barriers are superior to other measures due to the extent of potential protection (0.2-percent annual chance elevation) and the ability to manage the rate of water rise in exposed areas. Each alternative except Alternative 5 has a storm surge barrier measure that will provide primary risk reduction to the PAR. The measure that holds back storm surge however will be absolutely and relatively catastrophic for areas within the immediate vicinity of the breach (especially in low-lying, densely populated areas) if the structure were to malfunction.

There is a limited portfolio of storm surge gates in the world from which to evaluate performance, however, the European Climate Adaptation Platform Climate surveyed existing surge gates/barriers in Europe. Overall, they have found gates to be effective against storm surges and the risks of technical failure are limited when the barriers are tested regularly[7]. If a surge barrier were to fail to operate, secondary features are planned to be installed to prevent storm damage.

A semi-quantitative risk assessment (SQRA) to determine the most likely ways a shore-based (secondary features) might fail (levee risk) and how likely that failure is to occur was performed for the South Shore of Staten Island Coastal Storm Risk Management Project (within the study area). The analysis considered 165 failure modes of land-based measures to include, but are not limited to, failures due to piping and internal erosion of soil embankments or foundations, stability of embankments and flood walls, interactions between concrete structures and embankments, overtopping and breach of embankments, erosion and scour of slopes and, failure due to operational issues such as inability to access and operate gates and closures. Inundation scenarios considered include breach prior to overtopping as from a defect within the system, overtopping with the breach as the levee overtops then breaches, component failure, and the scenario where floods exceed the capacity of the levee but the levee does not breach.

Of the various failure modes evaluated, five were considered to be risk-drivers and are summarized in Table 32.

[7] Retrieved from: https://climate-adapt.eea.europa.eu/metadata/adaptation-options/storm-surge-gates-flood-barriers/#success_factors

Table 32. Failure Mode Summary

Risk-Driving Failure Modes
Freeflow Overtopping of Levee Embankment
Concentrated Leak Erosion through Levee Embankment
Structural Failure of Road Closure Gate due to Structure Impact
Backward Erosion Piping through Buried Rock Seawall Foundation
Wave Overtopping of Buried Seawall

The SQRA found that the primary risk-driver potential failure modes for shoreline-based measures were wave overtopping of the structure followed by freeflow (i.e., still water) overtopping of a levee embankment, where both circumstances occurred at flood loading events that exceeded design criteria. Evaluated erosion failure modes considered did not progress scour of a shoreline-based structures to a full breach due to the assumed short duration of a coastal storm event.

Where flooding from a storm event exceeds the capacity of the levee design it is likely that enough warning time for evacuations would be given due to advanced forecasting techniques. It is reasonable to assume that the majority of the population at risk (PAR) will mobilize in response to evacuation orders due to their past experience with Hurricane Sandy and therefore minimize the possibility of life loss.

Risk estimates for the buried seawall are plotted as boxes (see Figure Figure 14) representing order-of-magnitude estimates for the annual exceedance probability on the vertical axis and estimated life loss on the horizontal axis. These estimates are displayed to represent each risk-driving potential failure mode, total levee risk, overtopping without breach, and total flood risk. Project risk increases as the plotting position moves up and to the right on the graph. Societal risk (the dashed line on the plot) is the probability of adverse consequences, and risks that plot above the societal life risk line are considered unacceptable and are not being properly managed. As the figure shows, the performance of the project plots just below what is acceptable to society as far as life loss, and further measures can be taken to improve the effectiveness of the project. The goal is to manage the rate of water rise during a storm event so that people in the exposed area can evade inundation.

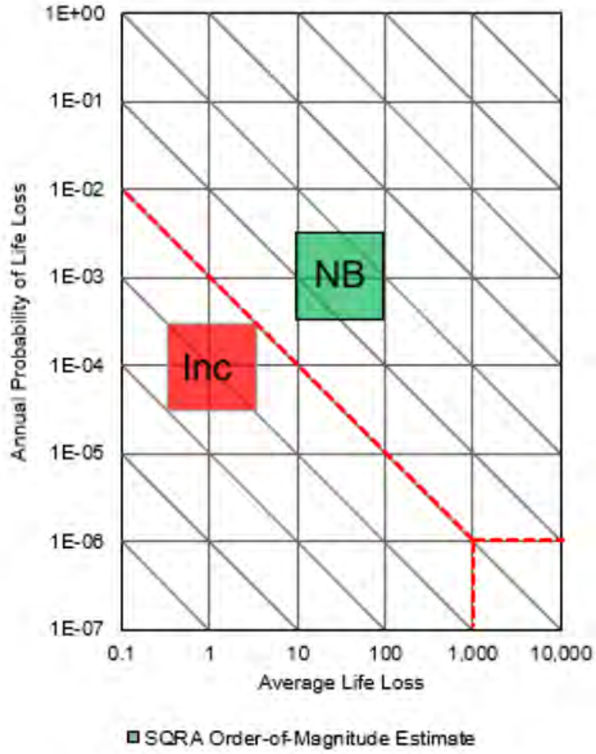


Figure 14. SQRA Plot

Regulating the rate of rise will act to decrease the likelihood of life loss, giving the exposed population an opportunity to flee from a rising water situation and get out of harm's way. The storm surge barrier and secondary measures (floodwalls, levees, etc.) assessed above reduce the risks to life safety by regulating hazard flows. Nonstructural risk management solutions, on the other hand, will reduce the risks to individuals located in the floodplain without altering the nature or extent of the hazard. Nonstructural measures considered for the NYNJHAT project include ringwalls, floodproofing, and elevations on a voluntary basis.

Floodproofing may leave a high level of residual risk to individuals because access to and from the structure may be blocked by floodwater which would present a danger to emergency rescue operations. There is also the threat that floodproofing may fail, causing as much then would have occurred without the floodproofing. A particular building might only benefit from this method when flood levels are three feet or less than the first-floor elevation. Current practices of elevating structures are informed by local zoning rules, i.e., raising the structure to the base flood elevation plus freeboard as dictated by the relevant ordinances. The effectiveness of such individualized methods of reducing the risk to life safety will be determined by the depths of inundation associated with the storm. In G.P. Smith's expert elicitation, several fragility curves were estimated to determine the stability of people and structures at various depths of flooding and flow velocities. He found that fit adults seeking to escape through floodwaters can become unstable when flow depths exceed 1.2 m (3.9 ft) and school-age children and the elderly members of the community may become vulnerable to toppling over in flood waters deeper than 0.5 m (1.6 ft). The study also highlighted that depending on building materials, residential buildings are at risk of failure once flood flows are greater than 1.0 m (3.3 ft) deep in combination with flow speeds greater than 3.6 km/h (1 m/s)[8]. For the New York-New Jersey study area, flood depths recorded for the Sandy storm were as high as 9 feet (2.7 m) above ground elevation in some areas as depicted in Figure 15.

CSRM and structural measures are intended to reduce risks however, the perils associated with hurricanes will continue to be a risk to life safety. The speed and depth of flow in any local part of the floodplain are also dependent on the volume of flow passing and the shape of the floodplain. For example, the most extreme observed natural flows occur in steep channels or at large flow structures like dam spillways[9]. A site-specific analysis of life loss will therefore be performed using the Hydrologic Engineering Center-LifeSim model during subsequent phases of the NYNJHAT study.

Evacuation of individuals out of the exposed area will be the most effective at reducing the risk of life loss. Ability to evacuate whether horizontally on roads or vertically to higher ground is informed by physical ability and knowledge about the threat. The Other Social Effects appendix discusses the presence of socially vulnerable individuals in the area who may experience difficulty evacuating. For example, people over the age of sixty represented a majority of the deaths in the study area. This group may have a mobility issues that limit their ability to escape even with access to a safe location. One study described the attributes of residences where deaths occurred and of the seventeen recorded structures two were two-storied the other fifteen were one-storied. The deaths in those structures occurred to individuals who were over the age of sixty[10].

---

[8] Ibid G.P. Smith (2015)

[9] Ibid Smith (2015)

[10] Zhang, F., Orton, P.M., Madajewicz, M. et al. Mortality during Hurricane Sandy: the effects of waterfront flood protection on Staten Island, New York. Nat Hazards 103, 57–85 (2020). https://doi.org/10.1007/s11069-020-03959-0

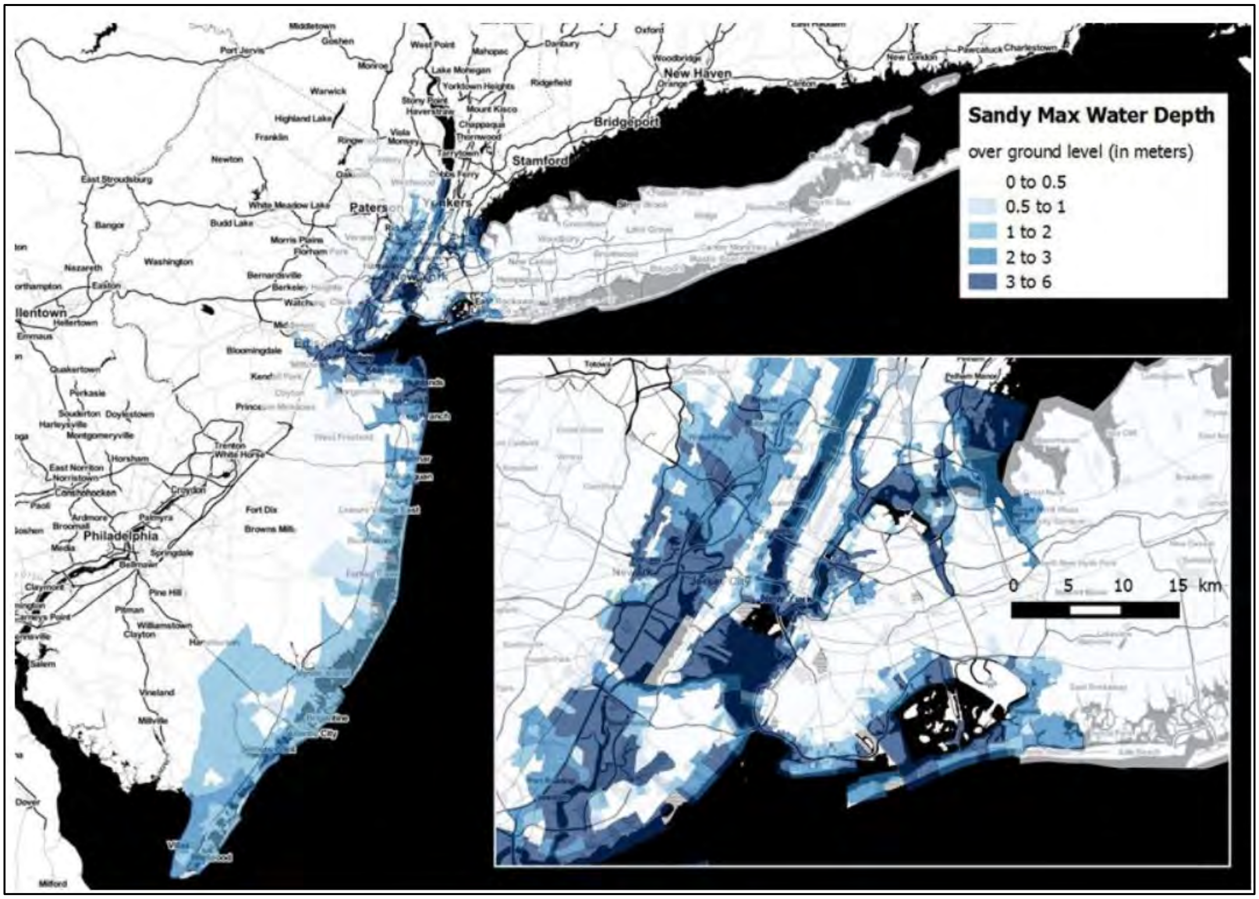


Figure 15. Hurricane Sandy flood depths in New York and New Jersey (FEMA, 2012)[11]

Differentiation between the several barrier alternatives is not yet made, however, the more densely populated the exposed area, the higher the likelihood of life loss. As more data becomes available, an evaluation of critical infrastructure and shelter options will be presented.

9.3 Critical Infrastructure: Above Ground Storage Tanks

9.3.1 Assessing Damage to Aboveground Storage Tanks:

The port of New York and New Jersey is a significant the fourth busiest in the United States and a hub in the trade and distribution of liquid bulk commodities, with an estimated 420 million barrels of liquid bulk arriving at the port in 2020, much of it primarily gasoline, diesel, and fuel oil (exclusive of additional shipments via pipeline; USACE, 2020). Receiving and storing these primarily petroleum-based commodities are approximately 2,300 aboveground storage tanks, many of which are located in the coastal zone adjacent to Arthur

[11] Burton, Christopher, Rufat, Samuel, Tate, Eric. (2018). Social Vulnerability: Conceptual Foundations and Geospatial Modeling.

Kill, Kill Van Kull, and Newark Bay. These storage tanks are susceptible to damage during coastal flood events, which could potentially result in the loss of contents and related environmental damage. There are several recent examples of such damage within the past decade in the US. During Hurricane Katrina, the floatation failure of a large aboveground storage tank led to the spillage of approximately 25,000 barrels of crude oil (Reible et al., 2006). Within the study area, damage to aboveground storage tanks during Hurricane Sandy (2012) resulted in a spill of 9,400 barrels of diesel and other fuel in New Jersey, though the spills were quickly contained (Reuters Staff, 2012; Hutchins, 2012). Similarly, damage to aboveground storage tanks in the Houston area during Hurricane Harvey led to the spillage of approximately 11,000 barrels of gasoline into the Houston Ship Channel and adjacent smaller creeks (USACE, 2021).

Recent research suggests there are several potential failure mechanisms for these Aboveground Storage Tanks (ASTs), though floatation failure is the primary mechanism for flooding at depths of less than 10 feet and wind speeds of less than 160 mph (Kameshwar & Padgett, 2018a; Kameshwar & Padgett, 2018b). Here, we assess damage to ASTs within the subset of the study area considering floatation failure as the primary damage mechanism. Consistent with the approach outlined by the Coastal Texas study, we assume that storage tanks within the study area are unanchored, that floatation failure results in the complete loss of contents, and that damages to pipelines and related interconnections are negligible relative to the consequences of floatation failure (USACE, 2021). As such, the relationship between flood depth and damage to AST structures and their contents is governed by the probability of floatation failure.

Floatation failure (when an AST floats away from its foundation during a flood) results when the buoyant forces acting on the tank exceed the resisting forces (i.e., the self-weight of the tank and any additional anchoring force, if any). Because the buoyant forces are a function of the volume of water displaced by a given AST, the size and shape of the tank factor inform the likelihood of AST failure at a given flood depth (Bernier et al., 2017). Additionally, the self-weight of the tank is informed by the weight of its contents, which is a function of the specific density of the commodity within the AST and the fill level of the AST. If the dimensions of the tank (diameter and height), its contents, and fill level are known, then a critical surge height can be determined, either directly by structural analysis or via a logistic regression function presented by Kameshwar & Padgett, (2018b). Below such a critical surge height, the likelihood of AST floatation is 0%, and above which floatation failure is a certainty (i.e., failure probability = 100%).

Realistically, the fill level cannot be known in advance of a flood event and is therefore considered to be an uncertain quantity. As such, for a given AST, its likelihood of failure given a certain depth of flooding can only be estimated probabilistically. If we assume the fill level is uniformly distributed between empty and 95% full (similar to the Coastal Texas study; USACE, 2021; Kameshwar & Padgett, 2018a) we can observe how the failure probability changes when compared to an AST with a known fill level, as shown in Figure 16 below.

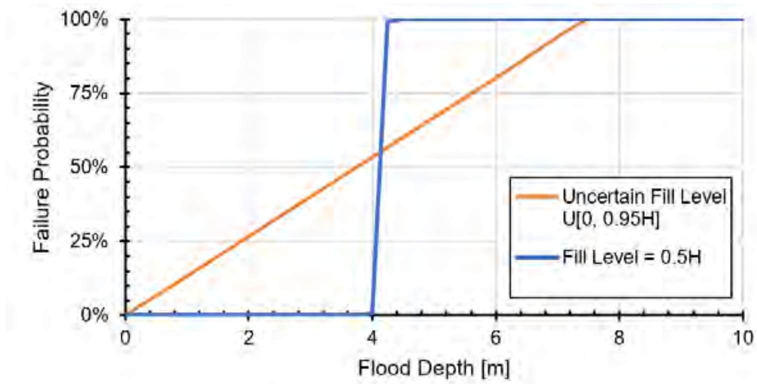


Figure 16: Floatation failure probability vs. flood depth for a sample aboveground storage tank (AST; D = 15 m, H = 10 m, ρ = 0.75) with an uncertain and known fill level

Rather than generate individualized depth-damage functions for each AST within the study area, we instead develop generalized depth-damage curves for the study area to describe AST structure and content loss for use in HEC-FDA. Because AST failure probability is informed by several AST characteristics (diameter, height, commodity, fill level) that vary by location, we did not assume the depth-damage functions generated for the Coastal Texas study were applicable to the current study area.

Additionally, we also expand upon the analysis framework presented in the Coastal Texas study to generate content loss depth-damage curves inclusive of oil spill cleanup costs by employing the EPA Basic Oil Spill Cost Estimation Model (BOSCEM; Etkin, 2004). The EPA BOSCEM, a refinement of a prior oil spill cost estimation model (Etkin, 1999) is an empirically (i.e., historically) informed parametric model for estimation of cleanup, socioeconomic, and environmental costs associated with oil spills. Both versions of the model remain well-cited within the academic literature and are often used as a benchmark for newer oil spill cost models (REFS). The EPA BOSCEM estimates the cost of a spill considering the volume of a spill (considering economies of scale in cleanup efforts), the type of oil/petroleum commodity spilled, as well as characteristics of the spill response and location to develop estimates of spill costs. For the purposes of this evaluation, we only consider the cleanup costs of a spill (i.e., the direct recovery costs associated with cleaning up the spilled contents of a given AST) and assume the default EPA BOSCEM spill cost values well-characterize cleanup methods and locations (mechanical recovery at 10% effectiveness for a spill on open shore/water).

Additionally, we adjust spill cost estimates from 2004Q1 to 2020Q2[12] price levels using the USACE CWCCIS by applying an inflation adjustment factor of 165.22% (USACE, 2022).

9.3.2 AST Characterization

ASTs in a subset of the study area were cataloged via a desktop survey given publicly available satellite imagery, documenting the location and diameter of ASTs in municipalities bordering Arthur Kill, Kill Van Kul, and the Port of Newark. A total of 2,281 ASTs were identified within the study area subset. Figure 17 shows a representative sample of the ASTs found in the study area in Linden and Carteret, NJ, wherein tank farms are situated in low-lying areas of reclaimed marshland adjacent to coastal waterways. We obtain estimates of the elevation of each AST [ft, NAVD88] via The National Map Bulk Query Service v2.0 (USGS, 2022).

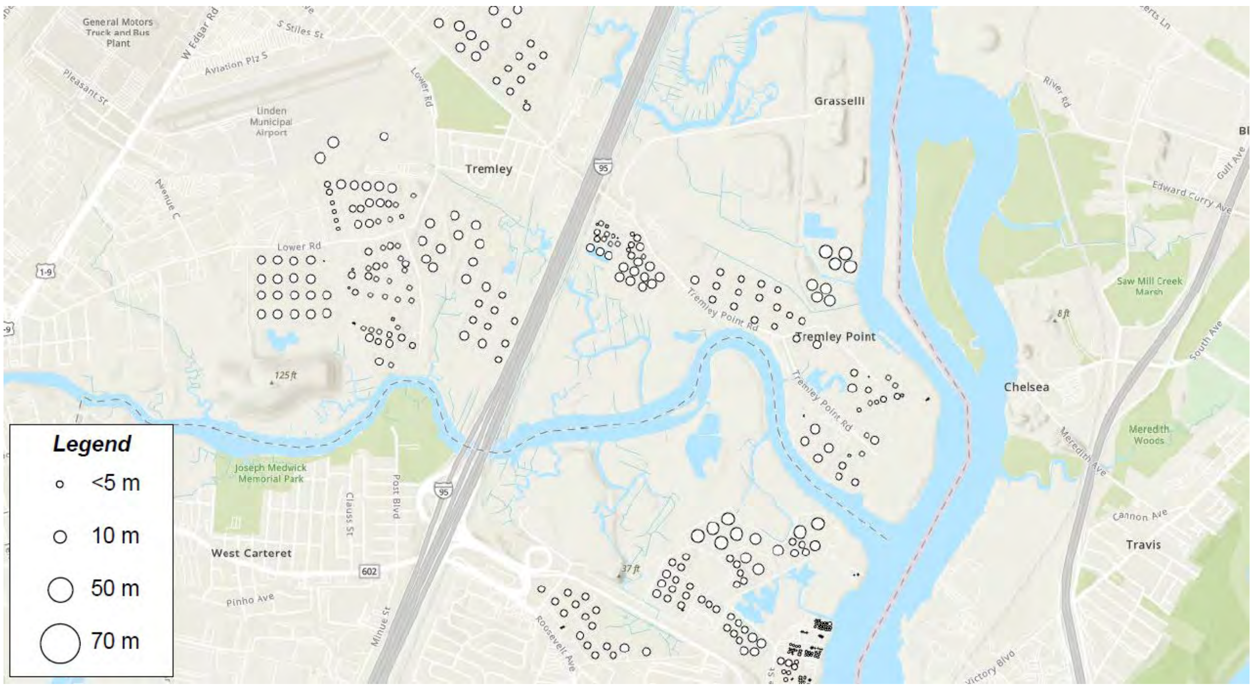


Figure 17: Subset of aboveground storage tanks (ASTs) identified within the study area in Linden and Carteret, NJ.

A histogram of AST diameters in the municipalities bordering Arthur Kill, Kill Van Kull, and Port of Newark is provided in Figure 18. AST diameters ranged from 2 meters to 78 meters; the most common diameter in the study area was 3 meters and the average diameter was 17.4 meters.

---

[12] We escalate to 2020Q2 price levels rather than 2022Q4 price levels as to allow for inflation-adjusted comparison of AST content replacement costs, which were based on a 5-year average of commodity prices from 2017Q3 to 2022Q4 (2020Q2 is the midpoint of this 5-year period).

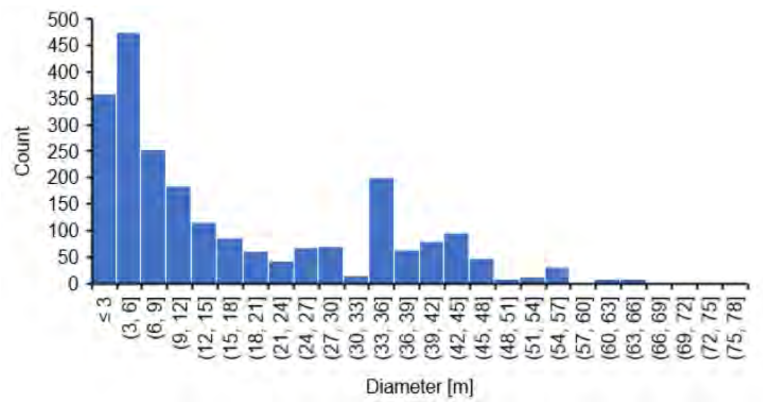


Figure 18: Histogram of aboveground storage tank (AST) diameters in municipalities bordering Arthur Kill, Kill Van Kull, and Port of Newark.

Because limited information is available on ASTs within the study area, it was not possible to obtain records of AST heights directly. Due to the limitations of the study, field measurements of ASTs were not feasible. Fortunately, Kameshwar & Padgett (2018b) provide estimated lower and upper bounds of AST height to diameter ratios, which were applied to develop upper and lower bound estimates of AST heights. While these ratios were developed based on the dimensions of the AST population in the Houston shipping channel, we assume that AST design and construction practices are consistent enough across the U.S. that these equations also adequately describe the AST population within the study area. As such, for a given AST whose diameter is known, we consider its height to be an uncertain quantity uniformly distributed between the lower and upper bound specified by Kameshwar & Padgett (2018b). Figure 19 below summarizes the height to diameter ratio lower and upper bounds assumed in the study area.

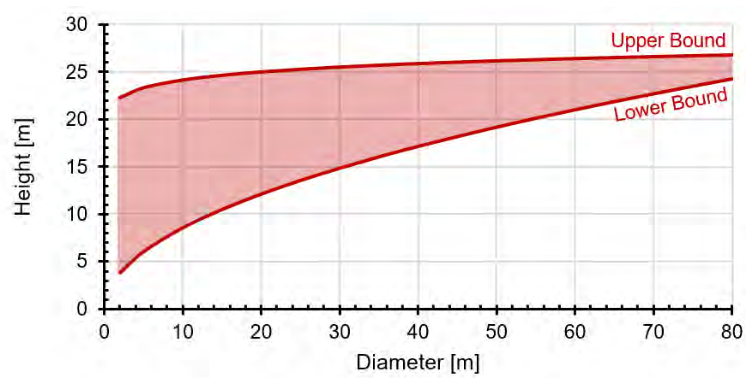


Figure 19: Aboveground storage tank (AST) height to diameter ratio lower and upper bounds assumed in study area (after Kameshwar & Padgett, 2018b)

As previously mentioned, the fill level of a given AST during a flood event is an unknown quantity. Similar to prior studies (Bernier et al. 2017; Kameshwar & Padgett, 2018a; Kameshwar & Padgett, 2018b; USACE, 2021) we consider this quantity to be uncertain and uniformly distributed between 0% and 95% of AST height (i.e., the tank is equally likely to be anywhere between empty and 95% full during a flood event). We also considered additional fill level probability distributions (triangular and beta distributions) though chose to apply the uniform distribution, as there was no physical basis to consider alternative distributions which were less conservative than the assumption already established in the literature.

In addition to the uncertainty surrounding the fill level of a given AST, absent a comprehensive inventory of each AST (which was not available and infeasible to collect given the scope of the study) the type of commodity being held within a given AST is also uncertain. As such, we obtained an estimate of the distribution of liquid bulk commodities arriving at the port in NY Harbor, Newark Bay, and NY and NJ Channels as provided by USACE waterborne tonnages data (USACE, 2020). The resulting distribution of liquid bulk commodities by volume is summarized in the pie chart shown in Figure 20. The relative distribution of petroleum commodities shown was found to be largely consistent with prior analysis performed by USDOT (2018). At 86.4% by volume, petroleum products make up the majority of the liquid bulk passing through the port at NY Harbor, with gasoline and diesel fuel accounting for 38% and 22% by volume respectively. Figure 20 also provides a breakdown of liquid bulk commodities by specific density and by long-term average price (found by averaging commodity prices over a 5-year span[13] from 2017 to 2022; US EIA, 2022; US BLS, 2022; Fernández, 2022; index mundi, 2022). The average price per gallon of liquid bulk commodities arriving at the port in NY Harbor was found to be $1.75/gallon. The specific density of the liquid being stored in a given AST is an important factor in determining its flood damage potential, as all else being equal, tanks storing lighter liquids will be more likely to float away during a storm.

[13] Commodity prices are heavily dependent on supply and demand that results from both local and global events. While the aforementioned five-period does include the COVID19 pandemic, the Russo-Ukrainian War is currently still ongoing, and the impacts on commodity prices remains to be fully realized.

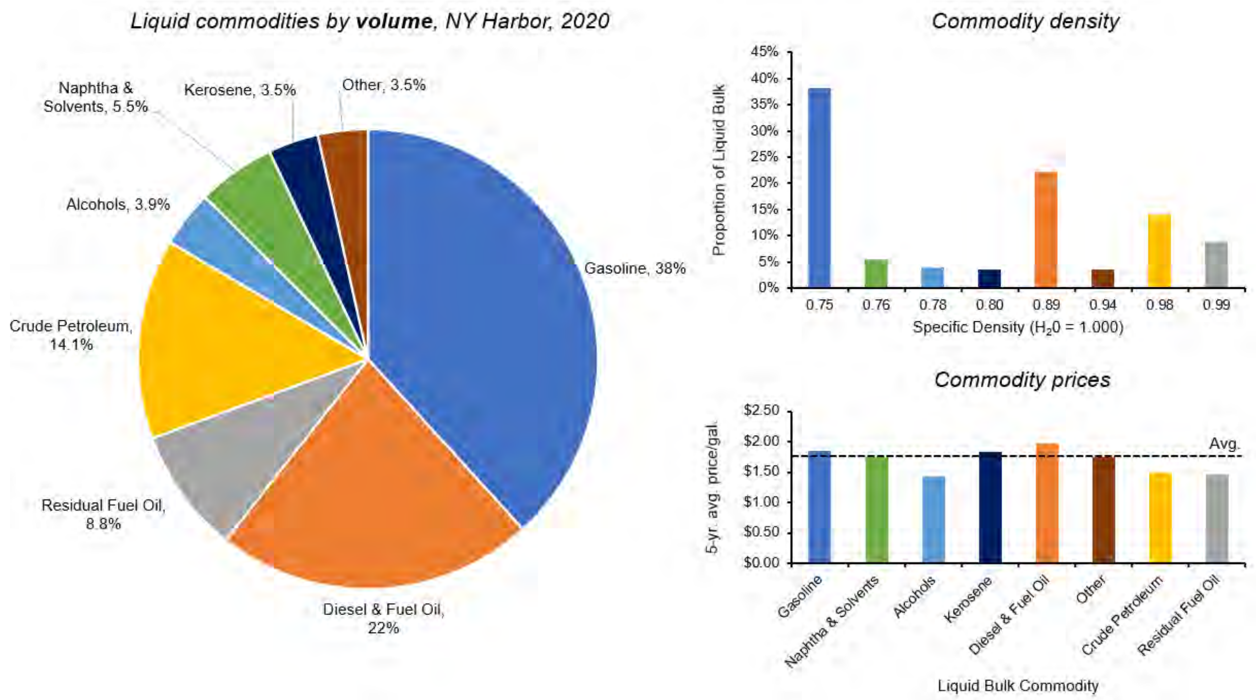


Figure 20: Summary of liquid bulk commodities arriving at port in NY Harbor.
Left: Distribution of liquid bulk commodities by volume. Top Right: Distribution of liquid bulk commodities by specific density. Bottom Right: Long-term 5-year average price of liquid bulk commodities.

9.3.3 Replacement Cost Estimates

Estimates of replacement costs are crucial for the application of percent depth damage curves. Kameshwar & Padgett (2018b) provide a relation between AST capacity and replacement cost [2016 USD] for fixed and floating head ASTs. While most ASTs within the storage area were fixed head construction, we averaged the fixed and floating head replacement cost estimates to obtain a generalized AST capacity to replacement cost relationship. Replacement cost estimates were further adjusted from 2016 to 2022 price levels using the appropriate cost escalation factor recommended by the USACE CWCCIS (EM1110-2-1304; USACE, 2022) and reduced by 50% to account for estimated tank structure depreciation (assuming straight-line depreciation and that on average, tanks are halfway through their expected useful life). Figure 21 provides the resulting replacement cost vs. capacity relationship. Using the expected AST height given the lower and upper bounds found via the height to diameter ratio presented above (Kameshwar & Padgett, 2018b) we obtain a capacity estimate for each AST in the study area. Using this capacity estimate, we obtain a replacement cost estimate for each AST in the study area. Similarly, we develop a contents replacement cost estimate for each AST, assuming a maximum fill capacity of 95%[14] and

[14] Note that we develop contents depth-damage curves for ASTs relative to this 95% fill capacity.

applying the average liquid bulk commodity price for the study area ($1.75/gallon). The structures and contents replacement values can be input directly into the HEC-FDA model.

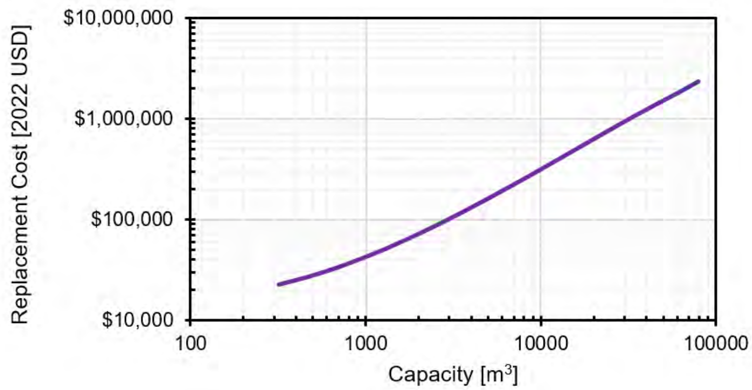


Figure 21: Aboveground storage tank (AST) structure replacement cost [2022 USD] vs. storage capacity (after Kameshwar & Padgett, 2018b)

9.3.4 Depth-Damage Curve Synthesis

Using the information characterizing the ASTs in the study area presented above and the logistic regression function presented by Kameshwar & Padgett, (2018b) we performed several Monte Carlo simulations (n = 10,000 trials) to determine the minimum, maximum, and expected depth-damage curve for AST structures, contents, and spill costs (inclusive of contents). Each trial within a given Monte Carlo simulation consisted of the following steps:

- Obtain a sample AST diameter (randomly sampled from the population if not specified).
- Estimate an AST height (uniformly distributed between lower and upper bounds as described above).
- Generate a fill level (randomly sampled from the uniform distribution described above).
- Assume a liquid bulk commodity (randomly sampled from liquid bulk commodity distribution). Obtain specific density, and long-term commodity price.
- Estimate AST structure failure probability for a predefined set of flood depths.
- Estimate AST content loss probability (failure probability x tank fill percentage).
- Estimate AST probabilistic spill cost (failure probability x tank fill volume x cleanup cost*) *as determined by the EPA BOSCEM

Expected depth-damage relationships were determined by evaluating the probability and consequences of floatation failure considering all ASTs within the study area. The Monte Carlo simulation was also performed for AST diameters of 3 m and 78 m to develop minimum and maximum depth-damage curves that still accounted for uncertainty in AST height, fill level, and commodity type. Figure 22 provides the resulting structure and content depth-damage curves and compares these curves to those employed by the Coastal Texas study (USACE, 2021). We note general agreement between the curves across both studies, particularly for flood depths less than 10 ft.

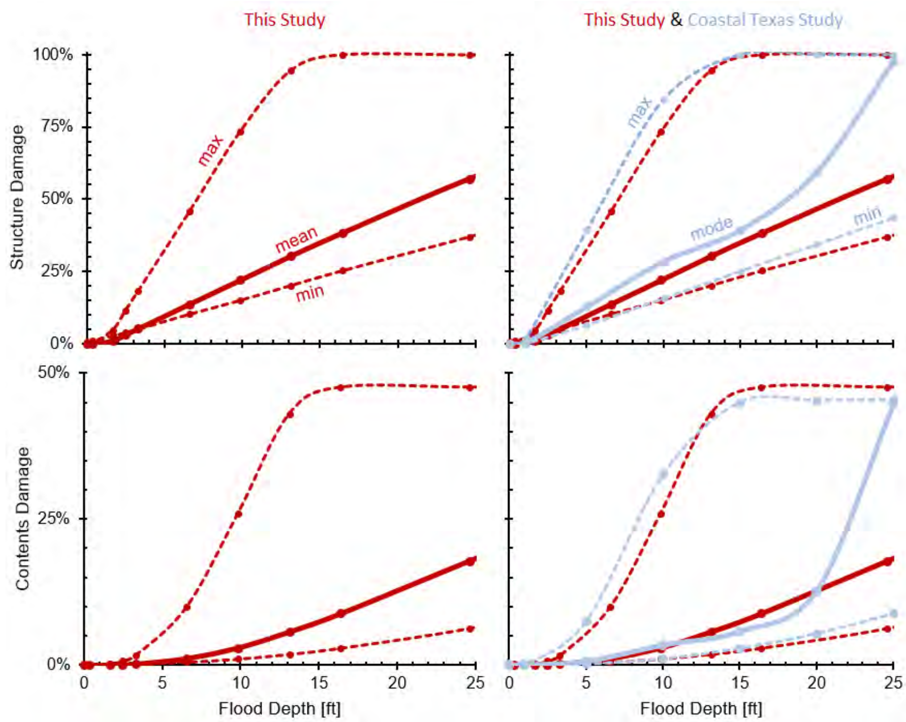


Figure 22: Structure and contents depth-damage functions for aboveground storage tanks (ASTs) developed for this study (left, red) compared to equivalent functions developed for the Coastal Texas Study (right, blue) USACE (2021)

Applying the EPA BOSCEM and adjusting for inflation, we also generated per-tank estimates of spill cleanup costs (including the cost of spilled contents) relative to tank content replacement costs. Consistent with prior assessments, we assume floatation failure leads to the complete spillage of contents (Bernier et al., 2017; Kameshwar & Padgett, 2018a; Kameshwar & Padgett, 2018b; USACE, 2021). Figure 23 compares the depth-damage curve for contents to the resulting depth-damage curves for spill cleanup and content costs. We note that the consideration of cleanup costs leads to a damage estimate that is on average approximately 140 times the cost of the spilled AST contents. While significant, these results are well within the expectations of the EPA BOSCEM and are similar in magnitude to the cleanup costs associated with the spill of 25,000 gallons of crude oil during Hurricane Katrina (Reible et al., 2006). The spill of an estimated $1.62M in crude oil (based on Aug. 2005 WTI spot price; US EIA, 2022) cost an estimated $90M to clean and resulted in a $330M settlement (2005 USD; Palardy, 2017).

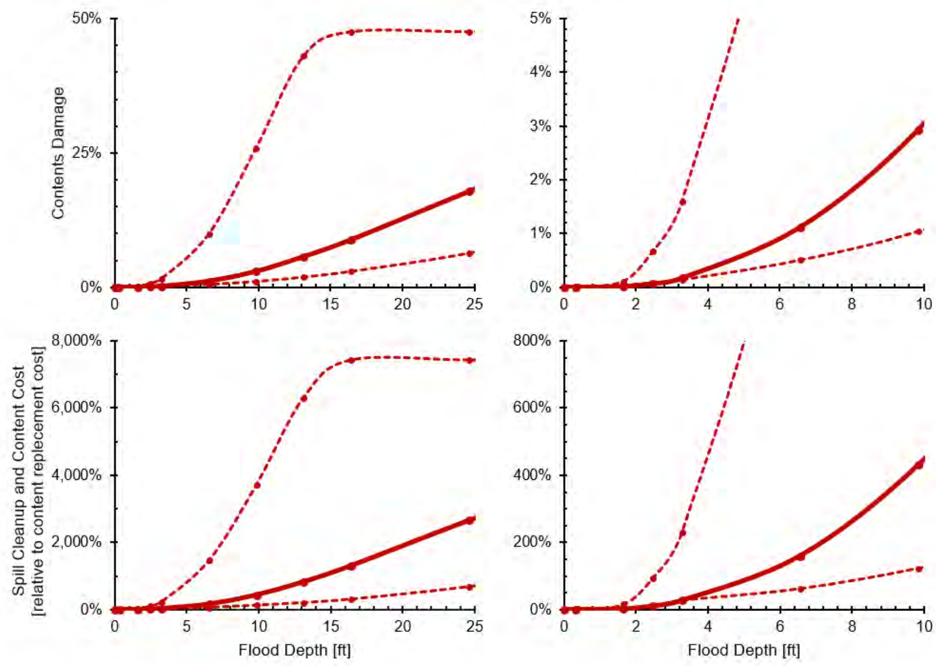


Figure 23: Comparison of depth-damage curves for aboveground storage tank (AST) contents and spill cleanup (including contents cost) as estimated via the EPA Basic Oil Spill Cost Estimation Method (EPA BOSCEM; Etkin, 2004)

9.4 References

Bernier, C., Elliott, J. R., Padgett, J. E., Kellerman, F., & Bedient, P. B. (2017). Evolution of Social Vulnerability and Risks of Chemical Spills during Storm Surge along the Houston Ship Channel. *Natural Hazards Review*, *18*(4), 04017013. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000252

Etkin, D. S. (1999). Estimating cleanup costs for oil spills. In *International oil spill conference* (Vol. 1999, No. 1, pp. 35-39). American Petroleum Institute.

Etkin, D. S. (2004, April). Modeling oil spill response and damage costs. In *Proceedings of the fifth biennial freshwater spills symposium* (Vol. 15, p. 15).

Fernández, L. (2022). *Price of naphtha worldwide from 2017 to 2022(in U.S. dollars per metric ton)* [Data set]. Statista. https://www.statista.com/statistics/1171139/price-naphtha-forecast-globally/

index mundi. (2022). *Commodity Prices* [Data set]. index mundi. https://www.indexmundi.com/commodities/

Kameshwar, S., & Padgett, J. E. (2018a). Storm surge fragility assessment of above ground storage tanks. *Structural Safety*, *70*, 48–58. https://doi.org/10.1016/j.strusafe.2017.10.002

Kameshwar, S., & Padgett, J. E. (2018b). Fragility and resilience indicators for portfolio of oil storage tanks subjected to hurricanes. *Journal of Infrastructure Systems*, *24*(2), 04018003. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000418

Reible, D.D., Haas, C.N., Pardue, J.H., Walsh, W.J. (2006, March). The Aftermath of Katrina. *The Bridge, National Academy of Engineering. 36*(1). pp.5-13. Retrieved from: https://www.nae.edu/File.aspx?id=7393&v=932df41

Palardy, A. P. (2017). *Assessing Risk of Aboveground Storage Tanks to Sea Level Rise and Coastal Inundation Along Chelsea Creek-an Application of a Transdisciplinary Framework*. University of Massachusetts Boston.

United States Army Corps of Engineers (USACE). (2020). *Waterborne tonnage for principal U.S. ports and all 50 states and U.S. territories; Waterborne tonnages for domestic, foreign, imports, exports and intra-state waterborne traffic* [Data set]. USACE. https://usace.contentdm.oclc.org/digital/collection/p16021coll2/id/7447

United States Army Corps of Engineers (USACE). (2021). *Coastal Texas Protection and Restoration - Feasibility Study Final Feasibility Report: Appendix E-1: Economics for the Coastal Storm Risk Management - Upper Texas Coast.* USACE. Retrieved from: https://www.swg.usace.army.mil/Portals/26/CTX_MR_Appendix%20E-1_CSRM%20Economics_1.pdf

United States Army Corps of Engineers (USACE). (2022). CWCCIS [Civil Works Construction Cost Index System] Indices. USACE. Retrieved from: https://www.usace.army.mil/Cost-Engineering/cwccis/

United States Bureau of Labor Statistics (US BLS). (2022). *Producer Price Index by Commodity: Chemicals and Allied Products: Ethanol (Ethyl Alcohol)* [Data set]. FRED, Federal Reserve Bank of St. Louis. https://fred.stlouisfed.org/series/WPU06140341

United States Department of Transportation (USDOT). (2018). *Port Performance Freight Statistics Program: Annual Report to Congress.* USDOT. Retrieved from: https://www.bts.dot.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/port-performance/216906/port-performance-2017-revised-2-12-18.pdf

United States Energy Information Administration (US EIA). (2022). *Cushing, OK WTI Spot Price FOB* [Data set]. US EIA. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RWTC&f=M

United States Energy Information Administration (US EIA). (2022). *U.S. Residual Fuel Oil Wholesale/Resale Price by Refiners* [Data set]. US EIA. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPPR_PWG_NUS_DPG&f=M

United States Geological Survey (USGS). (2022). *The National Map Bulk Point Query Service (v2.0).* USGS. https://apps.nationalmap.gov/bulkpqs/