CLIMATE ASESSMENT

APPENDIX

NEW JERSEY BACK BAYS
COASTAL STORM RISK MANAGEMENT
FEASIBILITY STUDY

PHILADELPHIA, PENNSYLVANIA

APPENDIX K

December 2024

NJBB
NEW JERSEY BACK BAYS STUDY

U.S. Army Corps of Engineers
Philadelphia District

Contents

1.0 Introduction 4
2.0 Key Findings 5
3.0 International, National and State Level Findings on Climate Change 9
3.1 National Climate Change Summary (National Climate Assessment, NCA) 9
3.2 State Climate Summary NOAA, New Jersey 11
3.3 USACE Climate Guidance 12
4.0 Scaled Analysis and Decision Making 14
5.0 Sea level change at the Atlantic City Steel Pier 19
5.1 Future Sea-level Change Impacts to the Project/Study Area 21
5.2 High Frequency Flooding 24
6.0 Section 113 (b) analysis for Sea level change 39
7.0 Vulnerability Assessment and Climate and Hydrology Assessment Tool (CHAT) Climate 40
8.0 Council on Environmental Quality (CEQ) Guidance on GHG 47
9.0 Critical Elevation Analysis 52
10.0 Conclusion 54
References 56

Figure 1 Trigger Hazard matrix 8
Figure 2 Image from ETL 1100-2-1 illustrating potential sea level change to 2100. 13
Figure 3 Tiering with the Corps 6 Step Planning Process 14
Figure 4 New Jersey STAP sea level change estimates 16
Figure 5 Sea Level Change and Rate at the Atlantic City Tide Gauge 19
Figure 6 SLC curves at Atlantic City, NJ with NJ Science Technology Advisory Panel (STAP) 2019 values 21
Figure 7 Sea Level Tracker 1911-2150 22
Figure 8 Strategies for dealing with sea level change and climate change 23
Figure 9 Datums within the Study Area 24
Figure 10 Increase in days of High Frequency Flooding at the Atlantic City tide gauge 26
Figure 11: NWS Real-Time Flood Monitoring Network. 27
Figure 12: Floodplain associated with NWS Stages at Atlantic City, NJ. 30
Figure 13: Floodplain associated with NWS Stages at Wildwood, NJ 30
Figure 14: Floodplain associated with NWS Stages at Cape May, NJ 31
Figure 15: Historic High-Frequency Flooding at Atlantic City, NJ 32
Figure 16: Impact of SLC on Historic High-Frequency Flooding 33
Figure 17: Future High-Frequency Flooding – USACE-Low SLC 35

Figure 18: Future High-Frequency Flooding – USACE-Intermediate SLC 36
Figure 19: Future High-Frequency Flooding – USACE-High SLC 37
Figure 20 Existing Conditions in Ocean City New Jersey 38
Figure 21 Sea Level in 2080 in Ocean City New Jersey 38
Figure 22 Vulnerability Assessment Tool outputs at the HUC 4 level 41
Figure 23 Watersheds and Stream Segment locations from CHAT 43
Figure 24 Toms River Maximum of Mean Monthly Stream Flow 44
Figure 25 Toms River Annual Maximum of 1-Day Precipitation 44
Figure 26 Toms River Annual Maximum 1-Day Temperature 44
Figure 27 Great Egg Maximum of Mean Monthly Stream Flow 46
Figure 28 Great Egg Maximum 1-Day Precipitation 46
Figure 29 Great Egg Annual Maximum 1-Day Temperature 46
Figure 30 Annual Global CO2 emissions 48
Figure 31 Annual US CO2 emissions 48
Figure 32 Total Global Greenhouse Gas Emissions 49
Figure 33 Co2 in ppm, Mauna Lau Observatory 50
Figure 34 First Floor Elevation in Long Beach Island 52
Figure 35 Sea Level Change against Critical Elevations 53

Table 1 Potential adaptation approaches by project type, addressing purpose and magnitude. 13
Table 2 Primary physical processes sensitive to SLC by project type. 18
Table 3 Minor, Moderate, Major storm water elevations 29
Table 4 High-Frequency Flood Occurrences (Per Year) 34
Table 5 Sea Level Change Against Critical Elevations Output 53

1.0 Introduction

The recommended plan for the NJBB study area plan includes the following major components:

- Elevation of ~6,421 residential structures within the 20% AEP (5-year) floodplain to the 1% base flood elevation in 2080 accounting for intermediate rates of sea level change ‘
- Floodproofing up to +3’ to 4.5’ above existing ground elevation of ~ 279 Critical Infrastructure elements (Police, Fire, ambulance, hospital, pharmacy)
- Nature Based Solutions (NBS) with dredged material to restore degraded salt marsh habitat at approximately 7 locations in the back bay area

USACE Climate Change

The USACE Climate Preparedness and Resilience Statement identified that USACE will continue to consider potential climate change impacts when undertaking long-term planning, setting priorities, and making decisions that affect its resources, programs, policies, and operations.

Climate change has the potential to affect all of the missions of the U.S. Army Corps of Engineers. To ensure continued effective and efficient water operations in both the short (5-10 years) and longer term (10—50 years), nationally consistent but regionally tailored water management adaptation strategies and polices are needed. For climate change analysis the analysis timeframe would likely need to exceed these durations and consider the projects service life that extends beyond the period of economic analysis. As defined by ER 1110-2-8159, Life Cycle Design and Performance, project service life is the length of time a project will remain in use to provide its intended function. This will often exceed the time period used for economic analysis of project benefits and costs as the basis for project authorization. Major Civil Works projects can have an indefinite service life. Several cycles of component rehabilitation or replacement may be required to maintain the project’s service life. Minimum project service life is considered 100 years for major infrastructure projects such as locks, dams and levees. For this reason, some component s of this assessment will look beyond the 50 year period of economic analysis.

Corps Mission Statement

The mission of the (USACE) Responses to Climate Change Program is;

“To develop, implement, and assess adjustments or changes in operations and decision environments to enhance resilience or reduce vulnerability of USACE projects, systems, and programs to observed or expected changes in climate.”

This Appendix reviews existing international, regional, and statewide reports and analyses related to climate change. It also evaluates climate change according to USACE Engineering and Construction Bulletins (ECB's), Engineering Regulations (ER's) Engineering Technical Letters (ETL's) and guidance for projected impacts from climate change using USACE developed tools related to sea level change, inland hydrology, temperature and vulnerability assessments.

Corps Climate Action Plan

Executive Order 14008 established the Climate Policy Office within the Executive Office of the President and establishes a National Climate Task Force and for agencies to develop a climate action plan to ensure data driven resilience**.** and adaptation measures, and to create climate-ready installations and operations. The USACE Climate Action Plan consists of 5 Actions and 3 Topics outlined and briefly discussed below. This USACE Climate Action Plan details the USACE commitment to integrate the best available observed and forward looking climate information into its missions, programs, and management functions, as allowed within relevant authorities. This plan describes how climate effects and vulnerabilities are and will be considered in USACE decision making for managing procurement, real property, and public lands and waters. The USACE Climate Action Plan consists of five priority adaptation actions, items required by the White House Council on Environmental Quality in its 3 March 2021 Interim Instructions for Preparing Draft Climate Action Plans Under Executive Order 14008.

Action 1: MODERNIZE USACE programs and policies to support climate-resilient investments

Action 2: MANAGE USACE lands and waters for climate preparedness and resilience
Action 3: ENABLE state, local, and tribal government preparedness
Action 4: PROVIDE actionable climate information, tools, and projections
Action 5: PLAN for climate change-related risks to USACE missions and operations

The Climate Adaptation Plan can be read in its entirety at the following link. https://usace.contentdm.oclc.org/digital/collection/p16021coll11/id/5381. A Progress Report on the Climate Action Plan was written in 2022. https://www.usace.army.mil/corpsclimate/.

2.0 Key Findings

The New Jersey Back study was evaluated for its exposure and vulnerability to a number of factors related to climate change. The area and its surroundings will experience changes to precipitation patterns, stream discharge, temperature, drought, and sea level change, but may only be vulnerable to climate change factors related to sea level, high frequency flooding, increase in stream discharge and related compound flooding. Continued increases in carbon dioxide concentrations from historic level are likely to increase sea level in the study area with negative impacts to coastal communities.

- The historic relative sea level trend at the Steel Pier, Atlantic City tide gauge is 4.21 millimeters/year with a 95% confidence interval of +/- 0.15 mm/yr. based on monthly mean sea level data from 1911 to 2023 which is equivalent to a change of 1.38 feet in 100 years. This will exacerbate storm surge flooding, high frequency flooding and storm damages in the coastal areas of NJ now and in the future. (https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8534720)
- The USACE Sea Level Analysis Tool indicates that long term trends in sea level change at this location show a 4.24 mm/yr. record for the life of the gauge from 1911-2024, but a 5.24 mm/yr. increase in the more recent 40 year time period from 1984-2024, indicating recent increases in the rate of relative sea level change at this location (https://climate.sec.usace.army.mil/slat/)
- The NOAA State Climate Report indicates that sea level along the New Jersey coast has risen by more than 16 inches, double the global average since 1911. This is likely due to regional geologic factors related to subsidence, and glacial isostatic adjustment of the earth's crust.
- Based on the USACE projected sea level calculations for low, intermediate and high sea level change scenarios, the Atlantic City Tide Gauge from the USACE Sea Level Tracker, MSL projected to increase by 2.5', 3.5,' 6.6' in 2100 for the low, intermediate and high scenario from the 1911 level.
- The Atlantic City Tide Gauge appears to be tracking the intermediate sea level change curve (green Line) when the 5 year moving average is plotted on mean sea level (MSL.) in the USACE Sea Level Tracker.
- Future Without Project Average Annual Damages (FWOP-AAD) are $2,066,197,000 for the low sea level change scenario, $2,645,467,000 for the intermediate scenario and $3,807,011,000 for the high sea level change scenario. This indicates that the study area is sensitive to increases in sea level during the period of economic analysis (2030-2080).
- High Frequency Flooding Events (HFF) defined by NOAA as water elevations above +1.75 MHHW are likely to increase in the future as a result of sea level change. The National Weather Service data and analysis by our H&H section indicates that High Frequency Flooding could increase to over 300 days a year for the intermediate sea level change curve by 2100.
- In its 2022 NOAA National Center for Environmental Information for NJ, NOAA reports that annual average temperatures have risen more than 3.5°F in New Jersey since the beginning of the 20th century. Additionally, all the 10 hottest

calendar years on record for the state have occurred since 1990, and six have occurred since 2010.

- Global average concentrations of CO_2 in the atmosphere are at their highest in over the past 800,000 years and global temperatures has increased by to approximately 0.7 Celsius higher than the 1961-1990 baseline.
- Carbon Dioxide measurements at the Manau Lau observatory have recorded and increase in concentration of this gas from 315 ppm in 1959 to 421 ppm in 2023 (https://gml.noaa.gov/ccgg/trends/data.html) which are driving temperature and sea level change increases. Forecasting this data in the Time Series Model shows the potential for these levels to increase within the range of 461 to 759 ppm within a 95% confidence interval by 2100 with a midpoint of 607 ppm. Carbon Dioxide levels at these concentrations would likely see the impacts of climate change related to heat, sea level change, high frequency flooding, precipitation, and drought increase.

Engineering and Construction Bulletin ECB- 2018-14 titled Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects has a useful section for categorizing triggers and risks for inland hydrology that is also useful for Coastal Storm Risk Management (CSRM) studies Figure 2. It outlines triggers, hazards, harm and likelihood for each of the features in the selected plan. It is useful as a summary of study risks and what the future of climate change will hold for the selected plan .

	Trigger	Hazard	Harm	Qualitative Likelihood
Feature				
Nonstructural Housing Elevation	Increase water levels driven by precipitation increases, sea level change, in singular or combined events	Future floods could exceed modeled flood in HEC-FDA, established Firth Floor Elevations	Damages underestimated, properties not properly elevated, increase in NS elevations to accommodate future Sea Level Change (SLC), future adaptation required	Likely future scenario with climate change/SLC
Nonstructural - Floodproofing	Increase water levels driven by precipitation increases, sea level change, in singular or combined events	Future Sea level change, Flooding, Precipitation could overtop the fixed +3' design for floodproofing	Once +3' is reached the floodproofing measure will be ineffective due to restriction of floodproofing over 3'	Likely future scenario with climate change/SLC
Nature Based Systems (NBS saltmarsh)	Increase water levels driven by precipitation increases, sea level change, in singular or combined events	NBS systems and saltmarsh are highly dependent on water levels, increase in water level will make them more susceptible to erosion/inundation	Natural and built systems would erode, loss of habitat, loss of storm buffering capacity	Highly likely with SLC

Figure 1 Trigger Hazard matrix

Table one indicates that the recommended features will likely be impacted by climate change, specifically related to rising sea level, and considerable adaptation strategies will have to be employed to accommodate these stressors. Home elevations, that are part of the recommended flood risk management plan will all be impacted in the future. Current plans for home elevation are taking an anticipatory approach to sea level change by increasing base flood elevations to accommodate 50 years of intermediate change. Floodproofing cannot be implemented over +3 to 4.5' feet above ground elevations, so any floodproofed structure would lose storm risk management capabilities over time with increases in water levels since the floodproofing cannot be increased above +3 feet above ground surface. Every increase in sea level change reduces the effective height of a fixed measure.

3.0 International, National and State Level Findings on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. The IPCC provides regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation (https://www.ipcc.ch/))

The IPCC is now in its sixth assessment cycle, in which the IPCC is producing the Sixth Assessment Report (AR6) with contributions by its three Working Groups and a Synthesis Report, three Special Reports, and a refinement to its latest Methodology Report. The IPCC Sixth Assessment Report, Summary for Policy Makers, was released in August of 2021.

Key Findings concluded that human influence has warmed the atmosphere, ocean and land, widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. Global surface temperature will continue to increase until at least mid-century under all emissions scenarios. Global warming of 1.5°C and 2°C above pre-industrial levels will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades.

3.1 National Climate Change Summary (National Climate Assessment, NCA)

The Global Change Research Act of 1990 mandates that the U.S. Global Change Research Program (USGCRP) deliver a report to Congress and the President no less than every four years that "1) integrates, evaluates, and interprets the findings of the Program…; 2) analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and 3) analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years." This report is titled the National Climate Assessment and was most recently published in November of 2018 as the 4rth National Climate Assessment. The Fifth assessment is due in March of 2023. https://nca2018.globalchange.gov/

The most recent NCA drew 5 key messages in its analysis and projections for the Northeast United States, these include;

Key Message 1 Changing Seasons Affect Rural Ecosystems, Environments, and Economies

The seasonality of the Northeast is central to the region's sense of place and is an important driver of rural economies. Less distinct seasons with milder winter and earlier spring conditions are already altering ecosystems and environments in ways that adversely impact tourism, farming, and forestry. The region's rural industries and livelihoods are at risk from further changes to forests, wildlife, snowpack, and streamflow.

Key Message 2 Changing Coastal and Ocean Habitats, Ecosystems Services, and Livelihoods

The Northeast's coast and ocean support commerce, tourism, and recreation that are important to the region's economy and way of life. Warmer ocean temperatures, sea level change, and ocean acidification threaten these services. The adaptive capacity of marine ecosystems and coastal communities will influence ecological and socioeconomic outcomes as climate risks increase.

Key Message 3 Maintaining Urban Areas and Communities and Their Interconnectedness

The Northeast's urban centers and their interconnections are regional and national hubs for cultural and economic activity. Major negative impacts on critical infrastructure, urban economies, and nationally significant historic sites are already occurring and will become more common with a changing climate.

Key Message 4 Threats to Human Health
Changing climate threatens the health and well-being of people in the Northeast through more extreme weather, warmer temperatures, degradation of air and water quality, and sea level change. These environmental changes are expected to lead to health related impacts and costs, including additional deaths, emergency room visits and hospitalizations, and a lower quality of life. Health impacts are expected to vary by location, age, current health, and other characteristics of individuals and communities.

Key Message 5 Adaptation to Climate Change Is Underway
Communities in the Northeast are proactively planning and implementing actions to reduce risks posed by climate change. Using decision support tools to develop

and apply adaptation strategies informs both the value of adopting solutions and the remaining challenges. Experience since the last assessment provides a foundation to advance future adaptation efforts

Overall, the NCA anticipates changes in precipitation, air temperature, ocean temperature, sea level change, and extreme heat to dominate the region as a result of climate change.   The Northeast has been seen increases in rainfall intensity, with increases in intensity exceeding those in other regions of the contiguous United States. Further increases in rainfall intensity are expected, with increases in total precipitation expected during the winter and spring but with little change in the summer. Increases in annual average temperatures across the Northeast range from less than 1°F (0.6°C) in West Virginia to about 3°F (1.7°C) or more in New England since 1901.

3.2 State Climate Summary NOAA, New Jersey

In its 2022 NOAA National Center for Environmental Information for NJ, NOAA reports that Annual average temperatures have risen more than 3.5°F in New Jersey since the beginning of the 20th century. Under a higher emissions pathway, historically unprecedented warming is projected during this century. Heat waves are projected to be more intense, while cold waves are projected to be less intense. Precipitation has been highly variable, with wetter than average conditions over the last decade, and the highest number of extreme events occurred during 2005–2014. Winter and spring precipitation and extreme precipitation events are projected to increase in the future. Sea level along the New Jersey coast has risen by more than 16 inches, double the global average, since 1911. Global average sea level is projected to rise another 1 to 4 feet by 2100. Sea level change poses substantial risks, including greater vulnerability to severe coastal flooding.

The NOAA State Climate Report indicates that sea level along the New Jersey coast has risen by more than 16 inches, double the global average, since 1911. Sea level change poses substantial risks, including greater vulnerability to severe coastal flooding (https://statesummaries.ncics.org/chapter/nj/). Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities. USACE is considering the upper bound of upper bound for 21st century GMSL is about 2 m (6.5 feet). Even greater rises are projected along the New Jersey coast because of land subsidence. Sea level along the coast of New Jersey has also risen faster than the global average. Observations beginning in 1911 show sea level has risen at an average rate of 1.6 inches per decade, about double the global rate, over the period of record at Atlantic City. Sea level change has caused an increase in tidal floods associated with nuisance-level impacts.

3.3 USACE Climate Guidance

Engineering Pamphlet 1100-2-100 describes how USACE missions, operations, programs, and projects must be resilient to coastal climates Table 1. The Pamphlet (EP) addresses adaptation to changing sea levels. It includes a broadly applicable method encompassing four USACE mission areas and also provides insight into use for multipurpose projects. Adequately incorporating potential Sea Level Change (SLC) into the planning, engineering, and operations process should improve the resilience1of project systems and maximize performance over time. USACE guidance in Engineering Pamphlet 11-2-100 has multiple adaptation approaches to sea level change depending on the project type shown in the figure below. For all project types of the options are categorized as Protect, Accommodate and Retreat with options for each business line. All adaptation approaches for the New Jersey back Bay study in the phase of sea level change were considered, and the study team is considering a combination of protecting and accommodating the study area to sea level change.

The Protect approach includes upgrading and strengthen existing structures, expand design footprint and cross section of existing structures, levee construction, floodwall construction, surge barriers and add secondary structures and gates and dune/beach construction. The accommodation approach includes elevating and flood proof buildings. Retreat and relocation will be considered in the face of un-mitigatable sea level change, where protecting and accommodating are no longer effective and the greatest threat from sea level change becomes evident in the near future.

Project Type	Protect	Accommodate	Retreat
Navigation	• Upgrade and strengthen existing primary structures • Expand design footprint and cross section of existing structures, including raising for clearance and access • Add secondary structures • Add structures to protect backshore Improve resilience of backshore facilities	• Upgrade drainage systems Increase maintenance and dredging • Adjust channel location and dimensions • Modify operational windows Flood proof interior infrastructure • Add sediment to shoreline or underwater morphology	• Relocate interior harbor infrastructure due to relative sea level rise or fall • Abandon harbor/port • Re-purpose project area
Coastal Storm Damage Reduction	• Upgrade and strengthen existing structures • Expand design footprint and cross section of existing structures • Add secondary structures • Dune/beach construction	• Increase maintenance of shoreline protection features • Sediment management • Beach nourishment/ vegetation • Upgrade drainage systems • Upgrade and modify infrastructure • Flood proof buildings Implement	• Relocate buildings and infrastructure • Land-use planning and hazard mapping • Modify land use

		building setbacks • Modify building codes	
Flood Risk Reduction	• Upgrade and strengthen existing structures • Expand design footprint and cross section of existing structures • Construct levees or implement flood proofing measures • Add secondary structures • Dune/beach construction	• Increase maintenance of flood risk protection features • Upgrade and modify infrastructure • Improve natural shoreline resilience (vegetation} • Flood proof buildings • Implement building setbacks	• Relocate buildings and infrastructure • Land-use planning and hazard mapping • Modify land use
Ecosystems	• Construct drainage systems • Construct shoreline protection structures, dikes or cells • Construct tidal gates, install saltwater intrusion barriers	• Accept changes to ecosystems • Sediment management • Change water extraction • Freshwater injection /diversion • Modify land use • Migrate landward	• Allow/facilitate habitat conversion • Forbid hard defenses • Ecosystem migration • Abandon ecosystem

Table 1 Potential adaptation approaches by project type, addressing purpose and magnitude.

Engineering Pamphlet 1100-2-1 indicates that a credible upper bound for sea level change is 2 meters by 2100 Figure 2. As shown in Figure 2, IPCC (2001, 2007, 2013) gives a range of sea level change, but at the high end there is an unknown additional potential contribution from major ice sheets, which is not shown for these IPCC ranges.

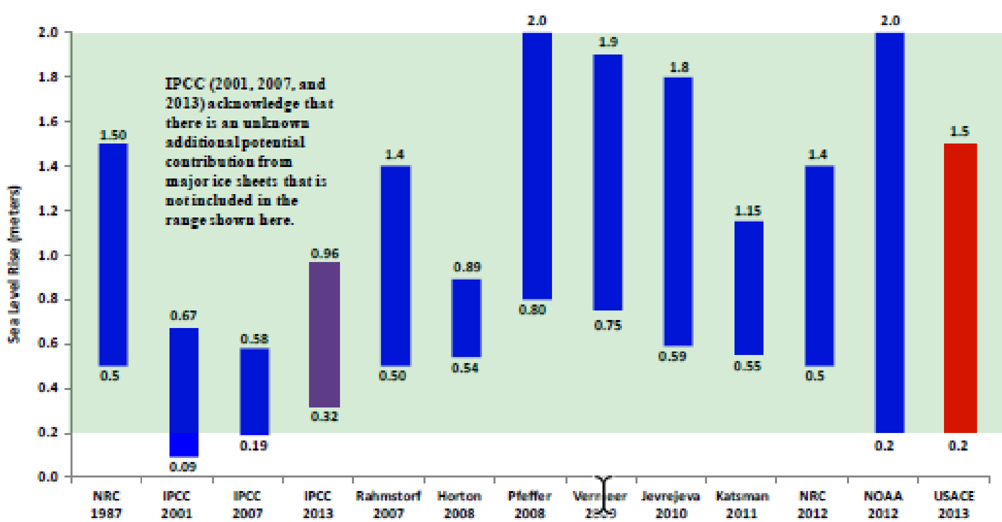


Figure 2 Image from ETL 1100-2-1 illustrating potential sea level change to 2100.

4.0 Scaled Analysis and Decision Making

USACE guidance in 1100-2-1 recommends a tiered approach to dealing with sea level change and a study's assessment of SLC impacts on the project and the project alternatives. The three primary tiers include: (1) establishing a strategic decision context, (2) determining project area exposure and vulnerability, and (3) developing and evaluating alternatives for addressing sea level change at the project site. Figure 3

The tiered decision making approach is nested with the Corps six step planning process and requires team member to make decision of increasing magnitude and complexity as the study progresses. Tier -1 of the strategic decision making involved the discussion of non-performance, stationarity and loading on existing coastal systems, While Step -2 in the decision context and in the Corp Planning process requires the team to establish project area boundaries based on 100 year high rate of SLC, and evaluate thresholds and tipping points triggered by SLC. Step 3 in the decision making process and 3, 4, 5 and 5 of the planning process require decisions of protection, accommodation or retreat from SLC and plan approaches as Anticipatory, Adaptative or Reactive.

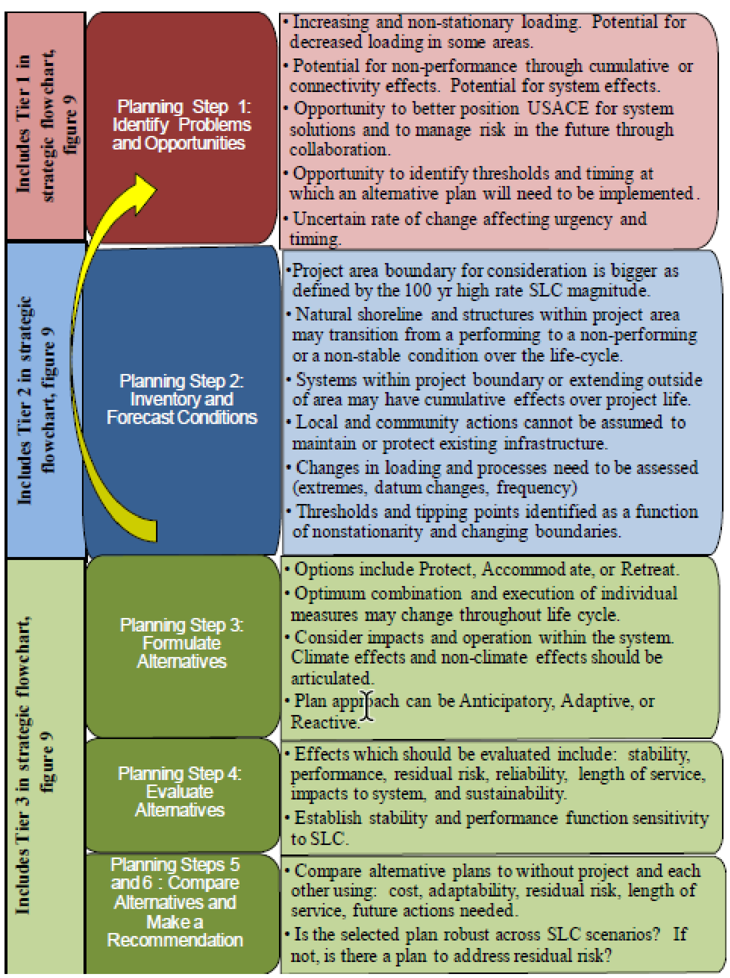


Figure 3 Tiering with the Corps 6 Step Planning Process

Tier 1 – Establish Strategic Decision Context.

The first step in the process outlined in Figure 3 is to establish a broad understanding of how SLC may impact the study area and a strategic decision context for the incorporation of SLC into USACE project planning has multiple purposes. For this study an anticipatory, adaptation approach was taken and sea level were incorporated into design and modeling efforts based on potential Intermediate RSLC projections.

Tier -1 of the EP specifically asks these following questions for the PDT at the beginning stages of the study.

(a) How vulnerable is existing infrastructure to SLC?
(b) What are the critical thresholds of coastal evolution past which infrastructure is unacceptably impacted?
(c) What are thresholds and tipping points for human response to SLC?
(d) How will SLC affect the loading or behavior of the engineered shore protection measures?
(e) If the infrastructure fails, what might be the impacts on the protected area?

The National Oceanographic and Atmospheric Association (NOAA) has a sea level change viewer that can be used to evaluate vulnerability to SLC based on different elevations above MHHW located at https://coast.noaa.gov/SLC/#. The user can use the vertical slider to simulate water level rise, the resulting inundation footprint, and relative depth. Water levels are relative to local Mean Higher High Water Datum. Areas that are hydrologically connected to the ocean are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may also flood. They are determined solely by how well the elevation data captures the area's drainage characteristics. The mapping may not accurately capture detailed hydrologic/hydraulic features such as canals, ditches, and stormwater infrastructure. A more detailed analysis may be required to determine the area's actual susceptibility to flooding. NOAA indicates that there is not 100% confidence in the elevation data and/or mapping process. It is important not to focus on the exact extent of inundation, but rather to examine the level of confidence that the extent of inundation is accurate (see mapping confidence tab).

The study area was evaluated for 3 different scenarios compared to the existing MHHW level for an assumed 2', 4', and 6' of sea level change. The NOAA mapping indicates that the area is vulnerable to sea level change depending on location for water level elevation from 2-6' above MHHW, with most barrier islands inundated at MHHW + 6, with little change beyond barrier created by the Garden State Parkway.

Based on the analysis of the USACE sea level change curve, the Sea Level Tracker, the Atlantic City Tide Gauge and STAP projections the study area is likely to see between + 2-6 feet of sea level change in the distant future. The low beaches and infrastructure, roads, stormwater systems will likely be impacted by this amount f rise.

The New Jersey Science Technology Advisory Panel Low and high emissions scenarios correspond to global-mean warming by 2100 of 2°C and 5°C above early Industrial (1850-1900) levels, respectively, or equivalently, about 1°C and 4°C above the current global mean temperature. Moderate (Mod.) emissions are interpolated as the midpoint between the high- and low emissions scenarios and approximately correspond to the warming expected under current global policies. Rows correspond to different projection probabilities. There is at least a 95% chance of SLC exceeding the values in the 'Low End' row, while there is less than a 5% chance of exceeding the values in the 'High End' row. There is at least a 66% chance that SLC will fall within the values in the 'Likely Range'. The New Jersey STAPP has likely range of sea level change that they list as having a greater than 83% - to less than 17% chance between 1.7'- 6.3' for different emission scenarios to 2100 . Reaching these elevations would take considerable time at the at the current rate of relative sea level change at the Atlantic City Tide gauge.

		2030	2050	2070			2100			2150		
				Emissions								
	Chance SLR Exceeds			Low	Mod.	High	Low	Mod.	High	Low	Mod.	High
Low End	> 95% chance	0.3	0.7	0.9	1	1.1	1.0	1.3	1.5	1.3	2.1	2.9
Likely Range	> 83% chance	0.5	0.9	1.3	1.4	1.5	1.7	2.0	2.3	2.4	3.1	3.8
	~50 % chance	0.8	1.4	1.9	2.2	2.4	2.8	3.3	3.9	4.2	5.2	6.2
	<17% chance	1.1	2.1	2.7	3.1	3.5	3.9	5.1	6.3	6.3	8.3	10.3
High End	< 5% chance	1.3	2.6	3.2	3.8	4.4	5.0	6.9	8.8	8.0	13.8	19.6

Figure 4 New Jersey STAP sea level change estimates

Increasing sea level will increase storm magnitude and the frequency of high tide flooding (HTF). It may eventually overwhelm existing coastal storm protection systems, including bulkheads, berm and dune systems, and interior drainage efficiency, potentially lead to life safety issues. Coastal transportation evacuation routes off of barrier islands will also be impacted with increase in sea level change. Coastal dune systems and beaches will likely be impacted as well as existing federal beach nourishment projects that align the New Jersey Coast.

Tier 2 – Project Area Vulnerability to SLC.

The purpose for conducting the "Project Area Vulnerability" phase is to provide a relatively low-level examination of the project area, which will raise the awareness of how SLC may alter project stability or performance in the future. Three estimates are required by the guidance: a baseline estimate representing the minimum expected SLC, an intermediate estimate, and a high estimate representing the maximum expected SLC. From Equation B-3 in Appendix B, the baseline, intermediate, and high SLC values were estimated for the project area.

Existing low lying infrastructure related to drainage, evacuation routes, municipal bulkheads and cause ways are more vulnerable to sea level change than project features. Huma thresholds and tipping points could be more related to High Frequency

Flooding discussed in Section 8 since it may impact the shore communities ability to function for a majority of the year in decades to come. The increased sea level change is likely to negatively affect shore protection features that are lower in elevation like beach berms, salt marsh features and low lying natural environments.

Tier -2 of the EP specifically asks these following questions for the PDT at the beginning stages of the study.

(a) How will SLC affect other coastal forces, such as storm surges or storm waves?
(b) Will changes to the local mean sea level change the frequency or severity of flooding?
(c) What are the dominant forces and are they impacted by SLC?
(d) What are the expected human responses?
(e) How might riverine, estuarine, or barrier island back bay processes change?

Engineering Pamphlet 1100-1-2 has a table that outlines the potential impacts to coastal processes by project type. The New Jersey Back Bay study area has a multitude of project types including Navigation, Ecosystem Restoration As well as Coastal Storm Risk Management. There are three navigation inlets within the NJBB study area, Manasquan Inlet, Barnegat Inlet, Absecon Inlet and Cape May Inlet There is also an Ecosystem Restoration project that is part of the Cape May Meadows to Cape May Point project, as well as numerous CSRM projects along the ocean front shoreline with dunes, beaches and seawalls with the potential to be impacted by climate change and sea level change. Table 3 outlines the potential impacts to these projects from sea level change. Sea level change has the potential to impact all project types, with impacts coming from wave attack, inundation, erosion and management practices affecting most business lines, water quality and salinity impacting ecosystem restoration and harbor, basin and channel hydrodynamics impacting navigation projects.

All Processes	Navigation	Coastal Storm Damage Reduction	Flood Risk Reduction	Ecosystems
Wave Attack				
wave runup and overtopping	X	X	X	X
wave transformation	X	X	X	X
depth-limited wave	X	X	X	X
wave and storm surge	X	X	X	X
rubblemound damage rate	X	X		
ship wake impacts	X			X
Inundation				
wave runup and overtopping	X	X	X	X
wave and storm surge	X	X	X	X
tailwater effects		X	X	X
hydrologic regime			X	X
Short- and Long-Term Erosion				
wave runup and overtopping	X	X	X	X
depth-limited wave	X	X	X	X
wave and storm surge	X	X	X	X
shoreline change rates (storm event, seasonal, longterm)	X	X	X	X
Inland Waterways/Drainage Hydraulics				
seasonal and extreme backwater profiles			X	X
canal/drainage system profiles	X		X	X
groundwater flow characteristics			X	X
Harbor, Basin, Channel Hydrodynamics				
harbor resonance	X			
vessel excursion and movement	X			
wave transmission (diffraction, overtopping, permeability)	X			
water quality circulation characteristics	X			X
Morphological Change and Shoaling				
foundation scour	X	X		
adjacent shoreline change	X	X		X
disposal site dispersiveness	X			
sediment transport and deposition (subaqueous and subaerial)	X	X		X
subsidence/uplift	X	X	X	X
Water Quality Changes (surface and ground)				
salinity	X			X
nutrients and dissolved oxygen				X
circulation	X			X
mixing of ocean/estuarine/river water	X			X
Management Practices				
catchment management	X	X	X	X
dredging and material placement	X	X		X
groundwater or fluid withdrawal	X	X	X	X
beach nourishment	X	X	X	X
shoreline stabilization measures	X	X		X

Table 2 Primary physical processes sensitive to SLC by project type.

5.0 Sea level change at the Atlantic City Steel Pier

The historic relative sea level trend at the Atlantic City tide gauge is 4.17 millimeters/year with a 95% confidence interval of +/- 0.14 mm/yr. based on monthly mean sea level data from 1911 to 2022 which is equivalent to a change of 1.37 feet in 100 years Figure 5 . This figure shows monthly mean sea levels without the regular seasonal fluctuations from coastal ocean temperatures, salinity, wind, atmospheric pressure, and ocean currents.

Based on the projected sea level calculations for low, intermediate, and high sea level change scenarios the Atlantic City Tide Gauge from the USACE Sea level Tracker, MSL projected to increase by 2.5', 3.5,' 6.6' in 2100 for the low, intermediate and high scenario from the 1911 level.

An initial analysis of the potential impacts from sea level change indicate that sea level rates have the ability to impact future without project damages, with higher rates of sea level change increasing average annual damages. Section 5.4 of the main report has a discussion comparing the TSP under the three USACE SLC scenarios (Low, Intermediate and High curves). The results indicate that with Future Without Project Average Annual Damages (FWOP-AAD) are $2,066,197,000 for the low scenario, $2,645,467,000 for the intermediate scenario and $3,807,011,000 for the high scenario. The TSP, which was formulated under the Intermediate SLC curve does not change based on the SLC curve selected, but with the net benefits and benefits costs ratio being the greatest under the high sea level curve. This is likely due to increase depth damage curve damages with additional water causing additional inundation and wave damages to study area structures. The CHAT and Section 113 (b) analysis indicate increases in precipitation, run-off, and riverine discharge for streams flowing into the NJBB study area. This is discussed in Section 9 and 11 of this document.

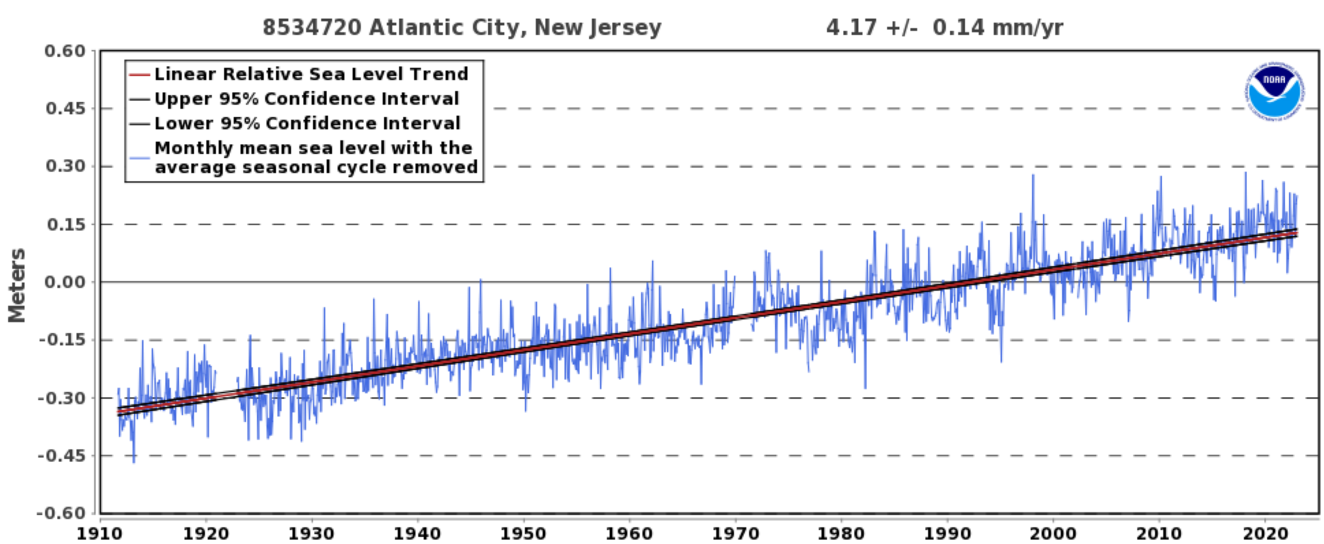


Figure 5 Sea Level Change and Rate at the Atlantic City Tide Gauge

Tier 3 - Alternative Development, Evaluation and Adaptability
This step involves Develop measures to address the identified problems and opportunities. Identify each measure's implementation strategy (anticipatory, adaptive, reactive, or combinations) and develop qualitative and quantitative performance metrics for later use in comparing the plans.

Tier -3 of the EP specifically asks these following questions for the PDT at the beginning stages of the study.

(a) What are the critical thresholds of coastal evolution past which infrastructure is unacceptably impacted?
(b) What are tipping points past which project stability and/or performance will be adversely affected?
(c) How can the project be adapted for changing water levels and through what range of water levels?
(d) Does the selected plan include thresholds where the existing project alternative ceases to be optimal and another becomes more beneficial?

EP 1100-2-1 identifies three strategies to dealing with future sea level change, Anticipatory, Reactive and Adaptative. The anticipatory strategy implements features and design parameters that decrease the vulnerability to future SLC and/or enhance the project adaptability before impacts are incurred. This strategy can either implement features now or facilitate the next adaptive management strategy should it be needed in the future. The reactive strategy may be planned or ad-hoc and is not implemented until required by the impacts of SLC are evident. The major risks of this strategy are that impacts will already be occurring by the time SLC becomes apparent, and it may be more difficult to take the action at the time of the response due to lack of preparation. The adaptive management strategy uses sequential decisions and implementation based on learning and new knowledge. For this strategy, implementation of the alternative measure occurs prior to SLC impacts and requires advance planning to maintain the ability to adapt to SLC. An example of adaptive management is designing berms, seawalls, or barriers to accommodate future additional height, with design and construction tied to a threshold prior to the time that the future impact is expected to occur.

The NJBB study utilized a combination of adaptive and anticipatory strategies in its design and evaluation of SLC by adding additional freeboard to hard structures and evaluating first floor elevations using the intermediate rate of rise to 2080. Anticipatory and Adaptive measures included increasing first floor elevations for nonstructural features projected to 2080 while accounting for future intermediate rates of sea level change, additional freeboard for levee and floodwall features. The study team also performed a Section 113b analysis for the determination if coastal and riverine damages were exacerbated or driven by climate change and considered future hydrologic and hydraulic changes impacts to the study are based on precipitation and sea level changes.

5.1 Future Sea-level Change Impacts to the Project/Study Area

Sea Level Tracker

The Sea Level Tracker allows users to visualize observed changes in sea level and to compare trends to projected changes per USACE Engineer Regulation (ER) 1100-2-8162 and Engineer Technical Letter (ETL) 1100-2-1, Figure 6. The tool shows the historical, observed changes in mean sea level (MSL) as measured and reported by the National Oceanic Atmospheric Administration (NOAA), mapped against SLC projections from sources such as USACE, NOAA, and the Coastal Assessment Regional Scenario Working Group (CARSWG). Taken together, the tool enables the comparison of actual SLC with SLC projections (as described in ER 1100-2-8162), along with observed monthly water levels and the computation of SLC trends based on historical data. In addition, the tool allows users to map these trends and projections against elevation levels that represent critical thresholds for infrastructure or other elevations of interest to the user. Finally, the tool enables users to visualize the indirect impacts of SLC on extreme water levels (EWLs) as calculated by USACE and NOAA. Working together, these components can help users align SLC scenarios with existing and planned engineering efforts, estimating when and how the sea level may impact critical infrastructure and planned development activities.

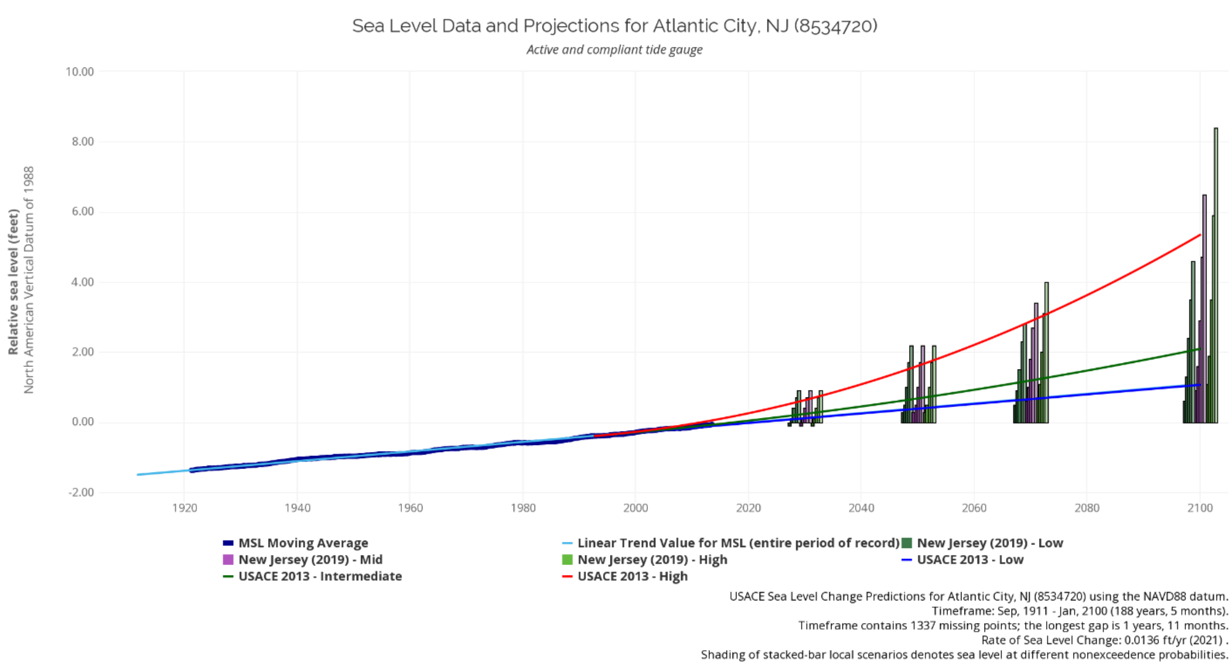


Figure 6 SLC curves at Atlantic City, NJ with NJ Science Technology Advisory Panel (STAP) 2019 values

Sea Change-level Change Summary

Based on the projected sea level calculations for low, intermediate and high sea level change scenarios the Atlantic City Tide Gauge from the USACE Sea Level Tracker, MSL is projected to increase by 2.5’, 3.5,’ 6.6’ in 2100 for the low, intermediate and high scenario from the 1911 level.

Critical Elevation Analysis

Identifying thresholds beyond which performance is adversely affected is an important way to understand current and future vulnerability. Thresholds can take a wide range of forms, including physical, economic, social, and environmental thresholds. A tipping point is a point or level at which new properties emerge in an ecological, economic, or other system, invalidating predictions based on mathematical relationships that apply at lower levels. It is especially important to note these tipping points, because the performance of the system can deteriorate rapidly once these thresholds are exceeded. Understanding thresholds can inform the urgency of action, the range of feasible actions, any necessary transition points from one type of measure to another, and the selection of extreme conditions for design, as well as larger system effects

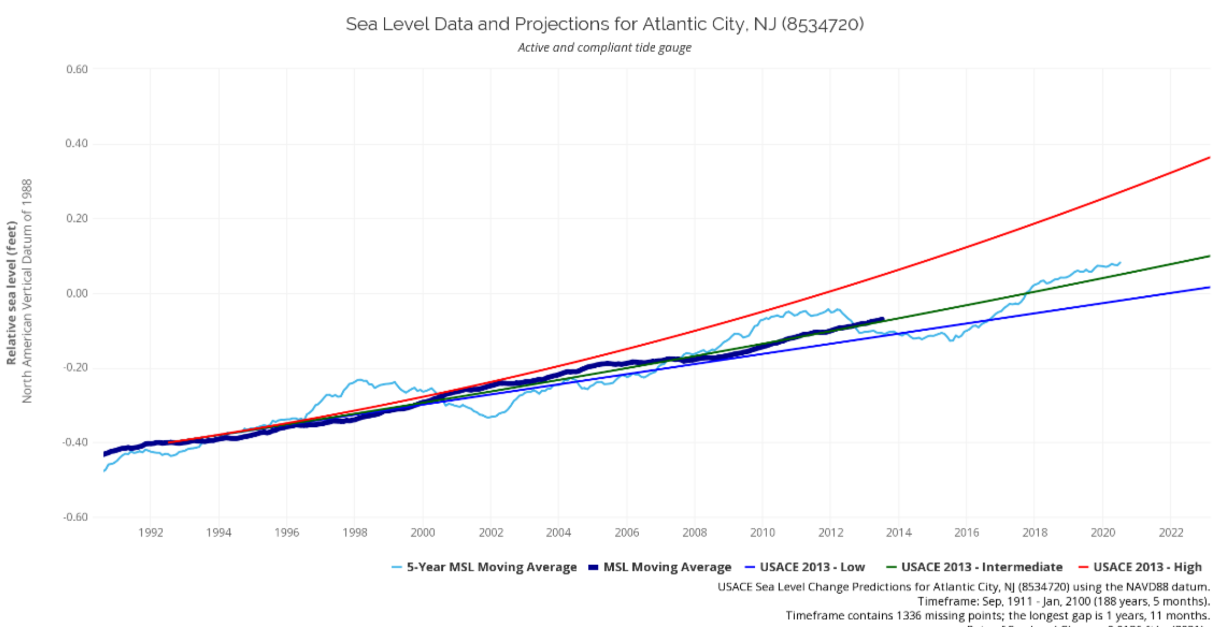


Figure 7 Sea Level Tracker 1911-2150

Critical elevations were evaluated against future sea level change scenarios in the sea level tracker for the Atlantic City tide gauge. The 19 year and 5 year moving average was plotted for mean sea level, with NOAA 1% high EWL to the USACE 2013 intermediate curve. Features likely to be sensitive to this amount of sea level change are home elevation and FFE, Critical Infrastructure and floodproofing and NBS. Due to the number of home elevations, their variety and locations within the study area, determining the exact threshold tipping point will be difficult. Similar situations existing for floodproofing and NBS systems. This information is discussed in Section 9.0.

Adaptation Strategies and Long Term Planning

As discussed, USACE planning requires long term strategies to be develop for dealing with sea level change and climate change to be part of the planning process. These strategies are considered Anticipatory, Adaptative or reactive, with a final strategy being considered a combination of the three.

The anticipatory strategy implements features and design parameters that decrease the vulnerability to future SLC and/or enhance the project adaptability before impacts are incurred. This strategy can either implement features now or facilitate the next adaptive management strategy should it be needed in the future. The adaptive management strategy (Brown et al. 2011) uses sequential decisions and implementation based on learning and new knowledge. The reactive strategy may be planned or ad-hoc and is not implemented until required by the impacts of SLC. The major risks of this strategy are that impacts will already be occurring by the time SLC becomes apparent, and it may be more difficult to take the action at the time of the response due to lack of preparation. No one strategy is likely to be adapted over another, and an overall strategy might incorporate all three approaches. Even if it wasn't part of the original strategy, a study team may have to adapt a reactive strategy for a climate or sea level change risk that was not anticipated at the beginning of a study in order to repair or rehabilitate a feature damaged during an isolated event.

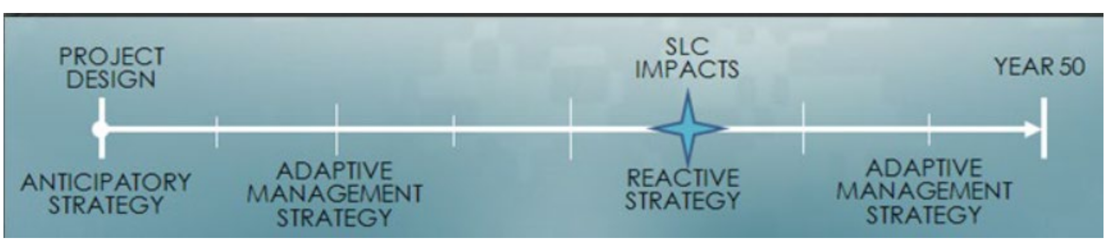


Figure 8 Strategies for dealing with sea level change and climate change

As part of the feasibility planning process the team developed an anticipatory strategy for sea level change based on rates of sea level change at the Atlantic City Tide Gauge. This allowed for additional freeboard for floodwall, levee, floodgate and SSB feature for still water elevations that will increase as a result of sea level change.

Anticipatory strategies are useful during the planning and design phases, but will likely need to morph into adaptive and reactive strategies as the design proceeds to construction and long term asset management in the face of future climate changes begins the impact project features during the ~100 year project service life.

Adaptive Strategies

Trigger points, thresholds and adaptive planning will have to be developed for the final analysis, along with pathways for implementation and funding, through Post Authorizations Change analysis, Section 216 Review of Completed Works or spin-ff, new start feasibility studies. Determining critical elevation thresholds for home elevations and critical floodproofing would require grouping elevations of structures against future rates of rise, which was not accomplished for this draft report.

5.2 High Frequency Flooding

NOAA defines High Tide Flooding (HTF) as occurring when coastal water levels exceed about 0.5 m (about 1.75 ft) above the mean higher high water (MHHW) in its 2021 report titled 2021 Annual State of High Tide Flooding and Annual Outlook. At these levels, HTF impacts are typically minor. NOAA reports that HTF is one of the most tangible signs of sea level change and anticipates it to increase over the next few decades as the earth continues to warm and sea level continue to rise. More severe moderate and major HTF occurring at 2.75 ft and 4 above MHHW, respectively.

The study area is sensitive to this phenomenon, but the current recommendations do not reduce the risk from high tide flooding, and they were more formulated for extreme events that have water levels about high tide events and contain associated with storm events.

Mean High High Water is approximately 2' above NAVD 88 at the Atlantic City Tide gauge, and a height of 1.75' above MHHW would place high tide flood events beginning at approximately +3.75' NAVD 88, Figure **9**. This is an elevation that will produce nuisance flooding of streets and roadways in certain locations, residential first floor elevations, dune heights and beach berm heights. But it may increase water levels during extreme storm events by superimposing additional water that was not experienced in the past on top of surge.

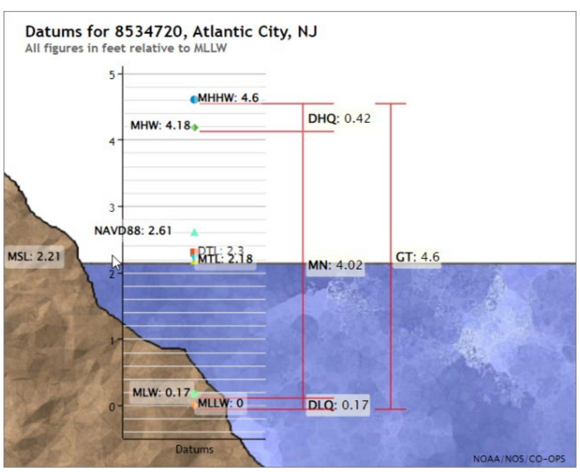


Figure 9 Datums within the Study Area

Water level of approximately +1.75’ above MHHW would likely impact streets and low lying communities within the study area. NOAA’s High tide flooding mapper shows some communities almost 100% inundated with shallow water during minor High Tide Flood Events. West Wildwood is inundated at +1.75 above MHHW. Other communities show minor flooding of streets during these events.

The NOAA report closes by stating that tide gauges continue to measure an increase in RSL, which is driving greater frequency of HTF along U.S. coastlines. NOAA continues by saying that an individual HTF event typically causes minor impacts, which are not overly damaging or of lasting concern if viewed as singular events. However, the cumulative repercussions from rising frequencies and durations of floods are beginning to damage infrastructure and cause other economic and ecosystem impacts within coastal communities, which are largely responsible for finding and funding solutions. Thus, HTF is a growing concern to coastal residents, emergency managers, community planners, and resource managers alike. NOAA intends to continue providing next-year outlooks and projections for the coming decades to support both preparedness and planning.

The study area of the NJBB will likely be impacted by future HTF since the main measures being selected (nonstructural elevations), will not prevent water from entering municipalities and damaging low lying areas.

Despite the TSP effectiveness at reducing and managing the risk to coastal storm events there are still residual damages associated with HTF. RSLC will render the existing network of bulkheads along the study area’s shoreline less effective at preventing HTF, leaving the study area susceptible to greater depths and frequency of HTF. Since the TSP’s SSBs and nonstructural management measures do not reduce water levels during a HTF event, the NJBB CSRM Study is exploring additional complementary management measures to address HFF, such as NS, NNBFs, bulkheads, critical infrastructure plans, and municipal partnership considerations.

The image below shows an output from NOAA's Climate Explorer page for Atlantic City, NJ and the projected increase in HTF to 2100 based on 2 emissions scenarios from the Fourth National Climate Assessment, Figure 10. NCA4 focuses on RCP 8.5 as a “higher” scenario, associated with more warming, and RCP 4.5 as a “lower” scenario, with less warming. This report indicates that by 2100 The Atlantic City Gauge are projected record HTF elevations greater than 3.75’ NAVD approximately 270-365 days a year. . https://crt-climate-explorer.nemac.org/

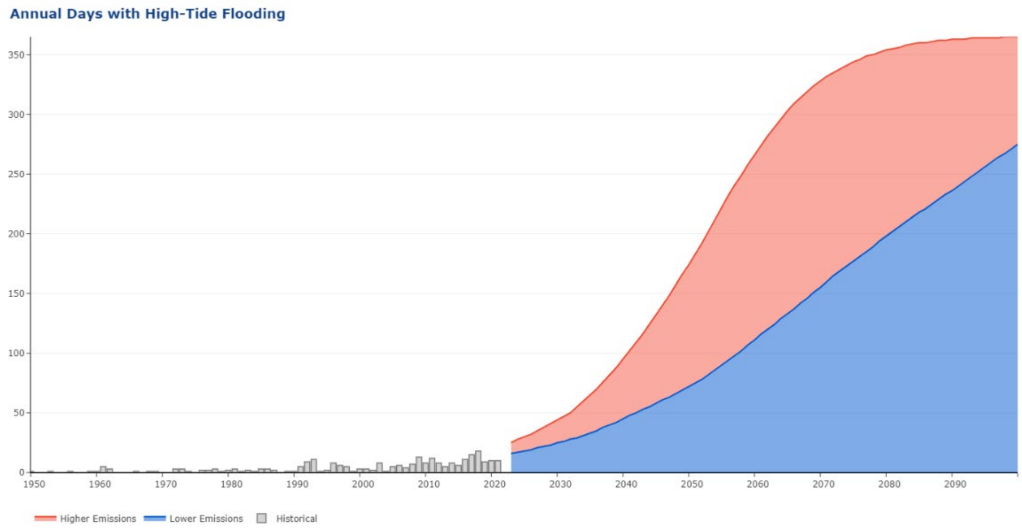


Figure 10 Increase in days of High Frequency Flooding at the Atlantic City tide gauge

High-Frequency Flooding Analysis

High-frequency flooding, also known as nuisance flooding, recurrent flooding, or sunny-day flooding, are flood events caused by tides and/or minor storm surge that occur more than once per year. High-frequency flooding mostly affects low-lying and exposed assets or infrastructure, such as roads, public storm-, waste- and fresh-water systems (Sweet et. al 2018) and is likely more disruptive (a nuisance) than damaging. However, the cumulative effects of high-frequency flooding may be a serious problem to residents who live and work in these low-lying areas. The number of high-frequency flood days is accelerating in the study area in response to RSLC.

Flooding from rainfall and inadequate stormwater systems are closely related to high-frequency flooding but are treated separated in this study. It is common for municipalities in the study area to have gravity-based stormwater systems that are unable to drain water when tidal level exceeds the elevation of the storm drain. When this happens, water starts ponding around the drain and may flood many of the same low-lying areas as high-frequency flooding. The frequency and impact of rainfall flooding will increase as the probability of the tide level exceeding storm drains will increases in response to RSLC. Some municipalities are addressing this problem by installing pump stations that are capable of draining water during elevated water levels.

National Weather Service Flood Stages

The National Weather Service (NWS) with the help of NOAA and USGS provide real time flood status of stream gages and tidal stations (Figure 11). The National Weather Service (NWS) has established three coastal flood severity thresholds: minor, moderate, and major flood stages. The NWS minor and moderate flood stages are the most representative of high-frequency flooding events right now. However, all three flood stages will be evaluated here since NWS major flood stage could eventually occur at frequency consistent with high-frequency flooding in the future in response to RSLC.

The definition of minor, moderate, and major flooding is provided herein by NWS. The definitions are taken from the NWS website for Atlantic City, NJ so that impacts are specific to Ocean and Atlantic County. However, impacts experienced described at this station are generally representative of the entire study area.

- **Minor Flooding** - Minimal or no property damage, but possibly some public threat;
- **Moderate Flooding** - widespread flooding of roadways begins due to high water and/or wave action with many roads becoming impassable in the coastal communities of Ocean County and Atlantic County. Lives may be at risk when people put themselves in harm's way. Some damage to vulnerable structures may begin to occur;
- **Major Flooding** - flooding starts to become severe enough to begin causing structural damage along with widespread flooding of roadways in the coastal communities of Ocean County and Atlantic County. Vulnerable homes and businesses may be severely damaged or destroyed as water levels rise further above this threshold. Numerous roads become impassable and some neighborhoods may be isolated. The flood waters become a danger to anyone who attempts to cross on foot or in a vehicle.

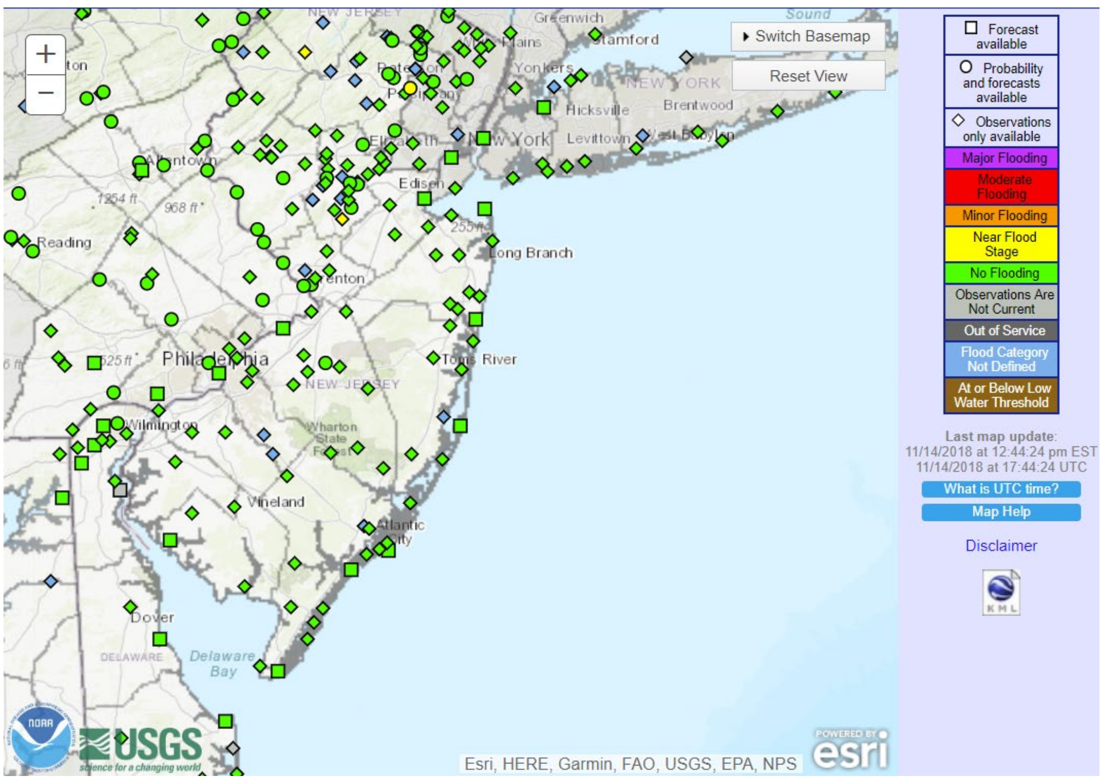


Figure 11: NWS Real-Time Flood Monitoring Network

An example of the flood inundation area associated with the three NWS Flood stages is shown in **Figure 12**, **Figure 13**, and **Figure 14** at Atlantic City, Wildwood, and Cape May.

The impact of minor flooding can be seen to be very limited to a few particularly low-lying areas. The impact of moderate flooding is more widespread impacting some streets and properties and major flooding is widespread impacting several streets and blocks near the bay shoreline.

There are 17 NWS stations in the study area with documented flood stages. The flood stages are reported on the NWS website in feet MLWW:

https://water.weather.gov/ahps/region.php?state=nj

The NWS flood stages are converted to feet NAVD88 for floodplain mapping Table 3. NWS minor flood stages are typically 1 to 1.5 feet above MHHW. Moderate and major flood stages are an additional 1 and 2 feet, respectively, above the minor flood stage. The NWS minor flood stage elevations are pretty consistent across the study area, 3.2 to 3.7 feet NAVD88, with the exception of Barnegat Bay where the tidal range is smaller.

Location	Gage	Minor	Moderate	Major
Belmar	BLMN4	3.7	4.7	5.7
Manasquan	MSNN4	3.2	4.2	5.2
Mantaloking	MTLN4	1.4	2.4	3.4
Bayshore	BASN4	1.4	2.4	3.4
Barnegat Light	BGLN4	2.3	3.3	4.3
Ship Bottom	SBTN4	2.1	3.1	4.1
Tuckerton	TKTN4	2.6	3.6	4.6
Atlantic City Marina	ATLN4	3.3	4.3	5.3
Atlantic City	ALCN4	3.5	4.5	5.5
Atlantic City (ocean front)	ACYN4	3.4	4.4	5.4
Margate	MGTN4	3.3	4.3	5.3
Ocean City	ONCN4	3.2	4.2	5.2
Sea Isle City	SICN4	3.3	4.3	5.3
Avalon	AVLN4	3.5	4.5	5.5
Stone Harbor	SHBN4	3.4	4.4	5.4
Cape May	CMAN4	3.7	4.7	5.7
Cape May Harbor	CAPN4	3.4	4.4	5.4

Note: Locations are sorted from North to South. Grey-shaded locations are in Barnegat Bay. All elevations are in NAVD 88.

Table 3 Minor, Moderate, Major storm water elevations

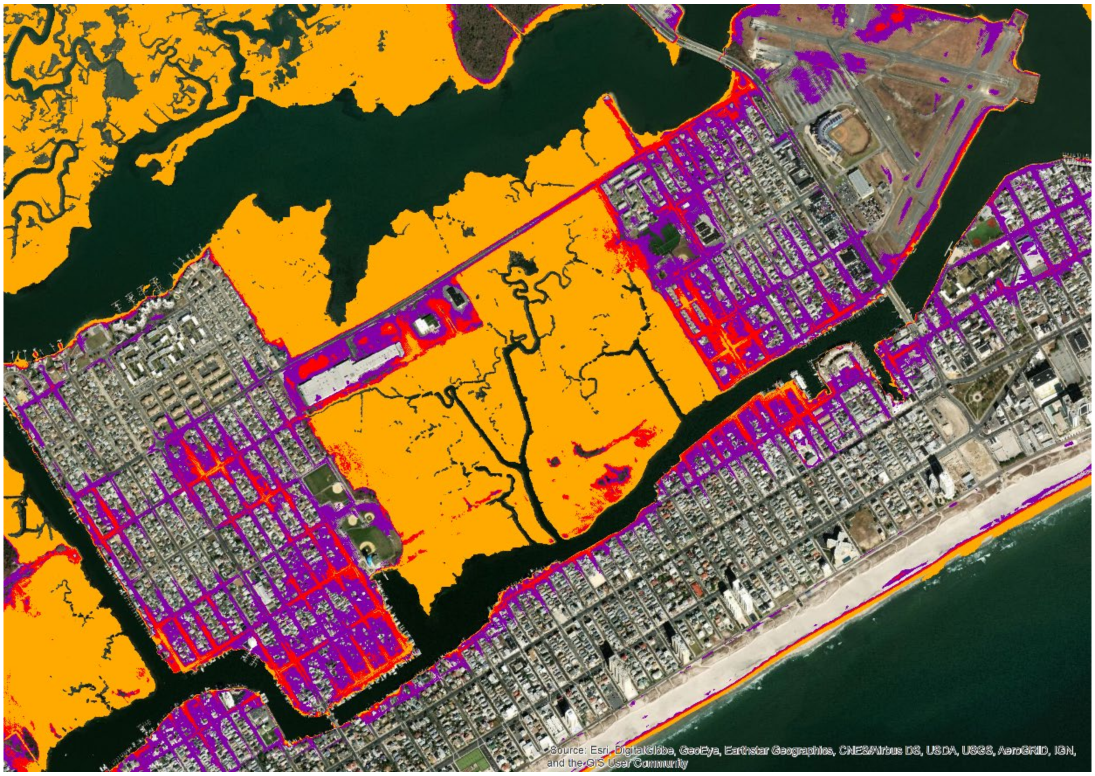


Figure 12: Floodplain associated with NWS Stages at Atlantic City, NJ

Figure 13: Floodplain associated with NWS Stages at Wildwood, NJ

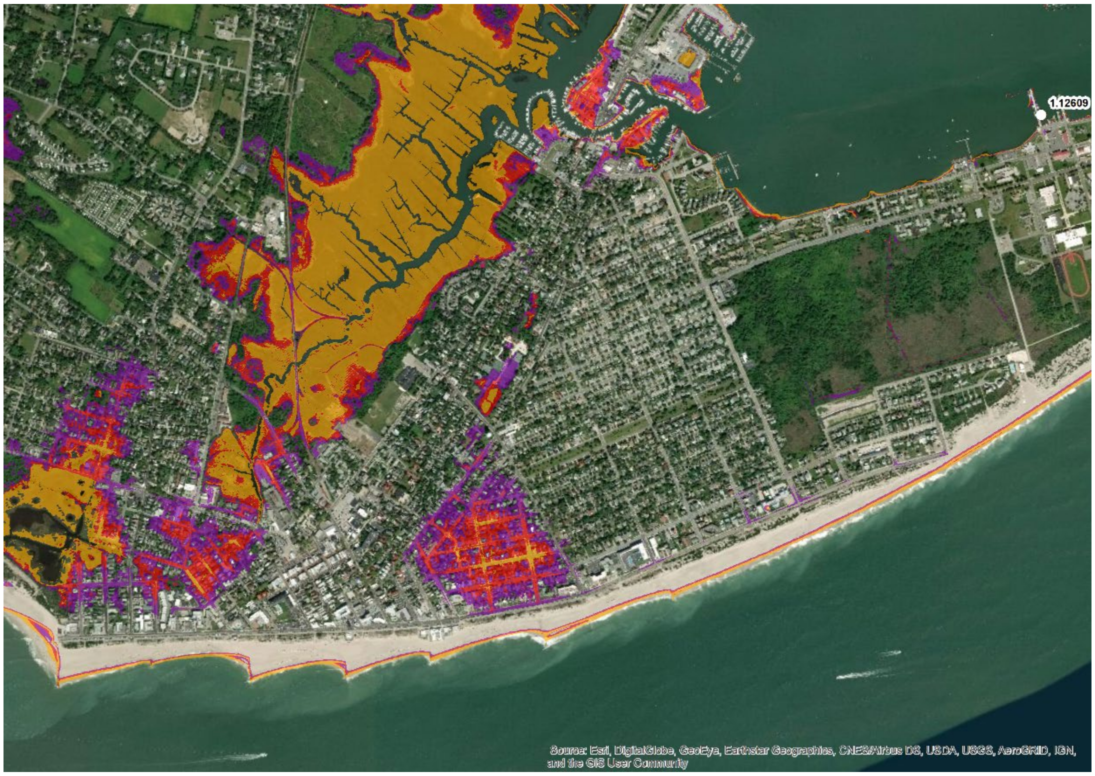


Figure 14: Floodplain associated with NWS Stages at Cape May, NJ

Historical High-Frequency Flooding at Atlantic City, NJ

Atlantic City, NJ has the longest tidal record (1911-Present) out of any of NOAA or USGS stations and is therefore best suited for investigating how often high-frequency flooding has occurred in the past and how rate of flooding has been affected by historic RSLC. Hourly verified data from NOAA CO-OPS station at Atlantic City, NJ was downloaded from 1911-2018. The number of days in which the daily maximum water level equaled or exceeded the NWS flood stages was calculated. The top panel of Figure 15 shows historic record of water levels and a dot for any day in which the NWS flood stages were exceeded. The bottom panel of Figure 15 shows a histogram of the total number of days in a given year that the NWS flood stages were exceeded. It is readily observed from Figure 15 that annual rate of NWS minor flooding has increased over time, with a dramatic increase in the 1990’s. The annual rate of NWS moderate flooding has a seen a small but visible increase and with little or no increase in NWS major flooding.

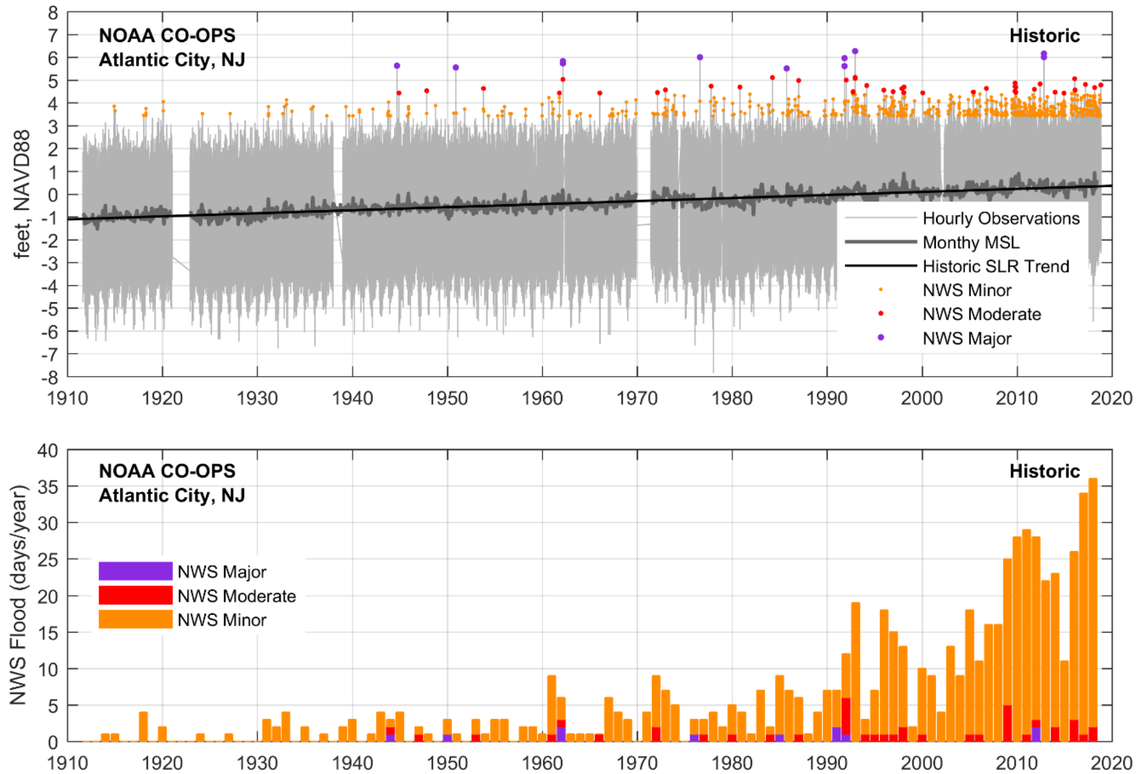


Figure 15: Historic High-Frequency Flooding at Atlantic City, NJ

To isolate the impact of historic RSLC on the frequency of flooding, the analysis was repeated with the historic SLC trend removed so that the mean sea level remained the same as in 1910 over the period of record. Figure 16 shows that if no RSLC had occurred since 1910, the frequency of NWS minor flooding would still be a couple times per year, significantly lower than today, and that primary driver of the increase in high-frequency flooding over the last 100 years has been RSLC not changes in the tidal range or meteorological conditions.

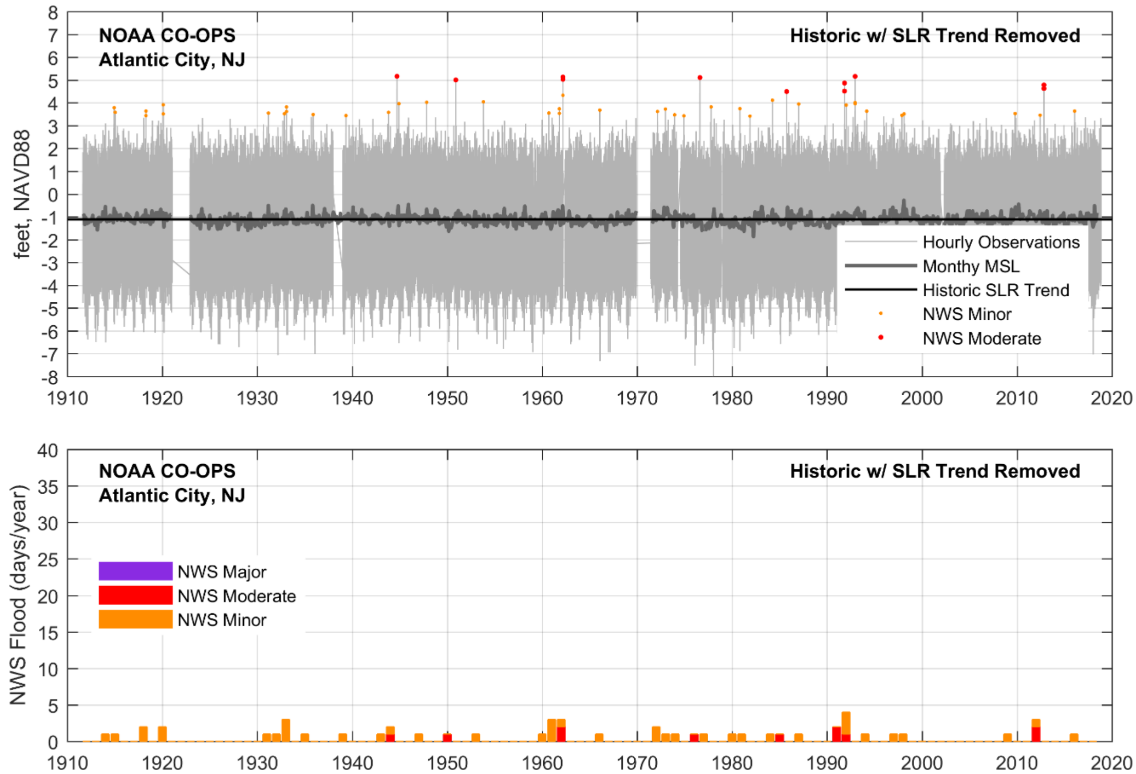


Figure 16: Impact of SLC on Historic High-Frequency Flooding

Future High-Frequency Flooding at Atlantic City, NJ

The previous section showed the dramatic impact RSLC has had on frequency of flooding over the last 100 years. This section shows how the rate of high-frequency flooding will be affected by future RSLC. To complete this analysis the last 25 years of the NOAA tidal record (1992-2017, skipping 2002 which had data gaps) was assumed to repeat over and over again until 2130. However, the three USACE SLC projections were added to the observed water levels. The top panel of Figure 17 shows the hourly water level observations and future projections with the USACE-Low SLC scenario applied and a dot for any day in which the NWS flood stages were exceeded. The middle and bottom panel of Figure 17 shows a histogram of the total number of days in a given year that the NWS flood stages were exceeded. The bottom panel shows the same information as the middle panel, but zooms in on NWS flood days (per year) between 0 and 40. The results in Figure 17 show that Atlantic City is experiencing an acceleration in NWS minor flood days that will only get worse in the future. It also indicates that the increase already underway in NWS minor flooding will begin to occur in the future for the NWS moderate and major flooding. A significant increase in NWS moderate and major flooding appears to occur after 2030 and 2080 respectively.

The same analysis was repeated for the USACE-Intermediate and USACE-High RSLC scenarios in Figure 18 and Figure 19. Annual NWS flood days from the analyses are tabulated in Table 4 It is difficult to say or know what the tipping point (days per year) for NWS minor, moderate, and major flooding before the impacts to roads and infrastructure are unacceptable. However, the analysis shows that major investments in bulkheads and storm water systems (i.e. pump stations) are likely to be required in the future for the portions of the study area to be inhabitable.

Year	Minor	Minor	Minor	Moderate	Moderate	Moderate	Major	Major	Major
	Low	Int.	High	Low	Int.	High	Low	Int.	High
1930	1.1			0			0		
1955	1.7			0.2			0.1		
1980	3.6			0.5			0.2		
2005	14.5			0.7			0		
2015	26.5			2.2			0.5		
2030	54.7	73.2	139.8	4.7	5.9	21.1	0.1	0.3	1
2055	98	164.5	325.8	9.5	25.5	191.6	0.5	2.1	37.7
2080	153.8	282.6	356.2	23.1	100.9	349.9	1.5	11.1	298.3
2105	218.6	342	356.3	50.1	243.2	356.3	4.4	69.6	356.3
2130	258.5	350.6	352.3	78.1	327.3	352.3	5.8	182.3	352.3

Note: 10-year running mean filter applied to determine annual flood occurrences

Table 4 High-Frequency Flood Occurrences (Per Year)

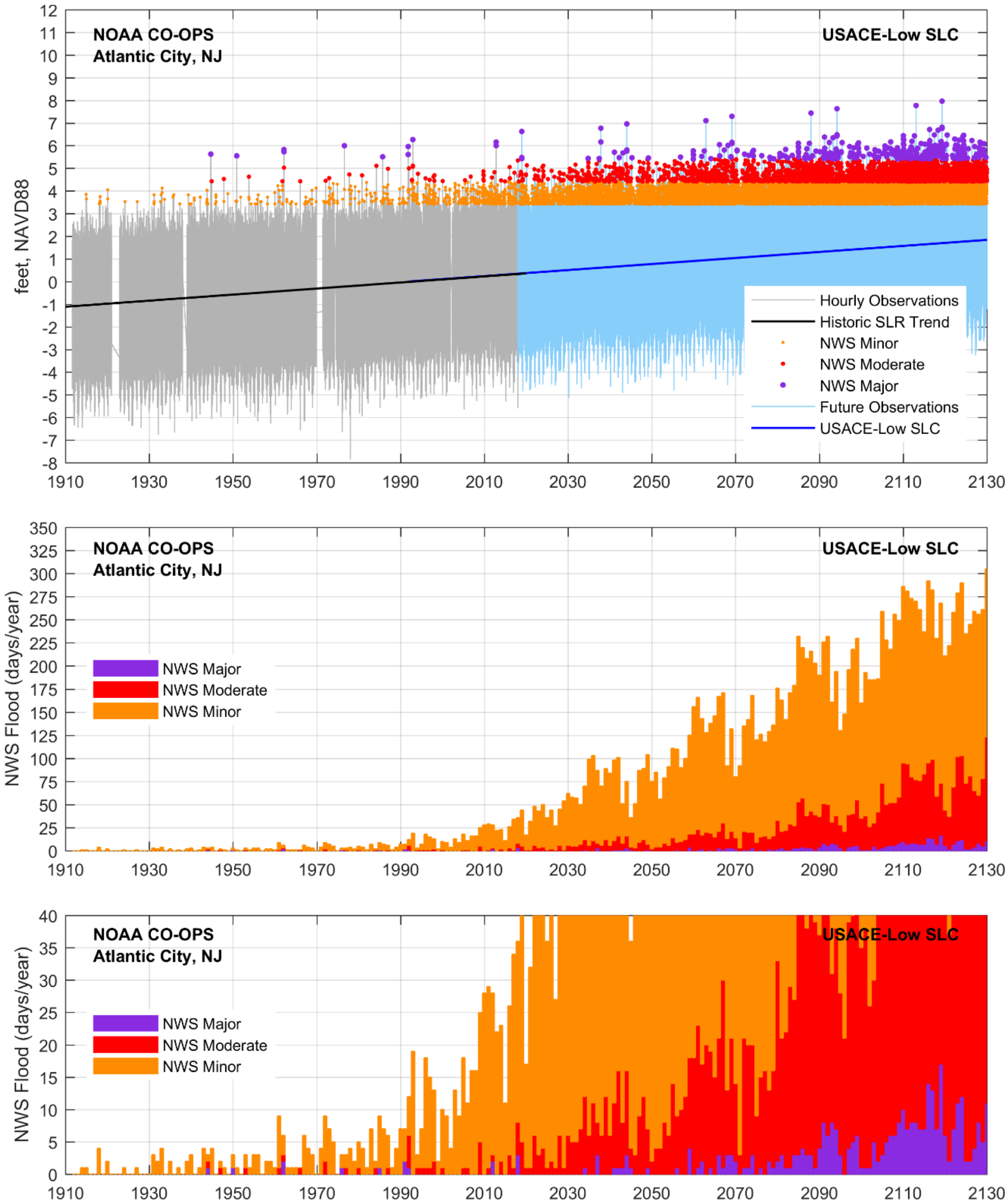


Figure 17: Future High-Frequency Flooding – USACE-Low SLC

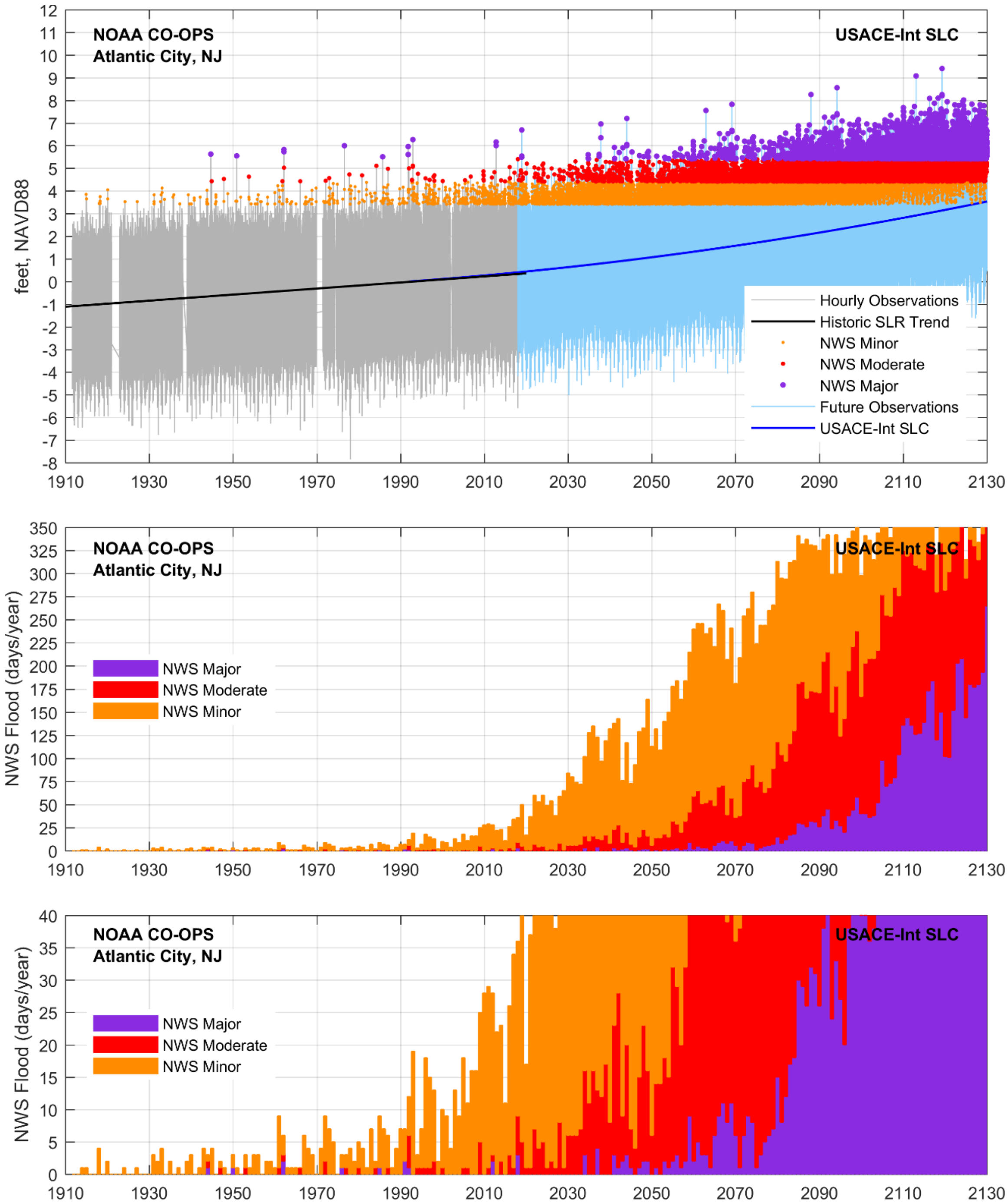


Figure 18: Future High-Frequency Flooding – USACE-Intermediate SLC

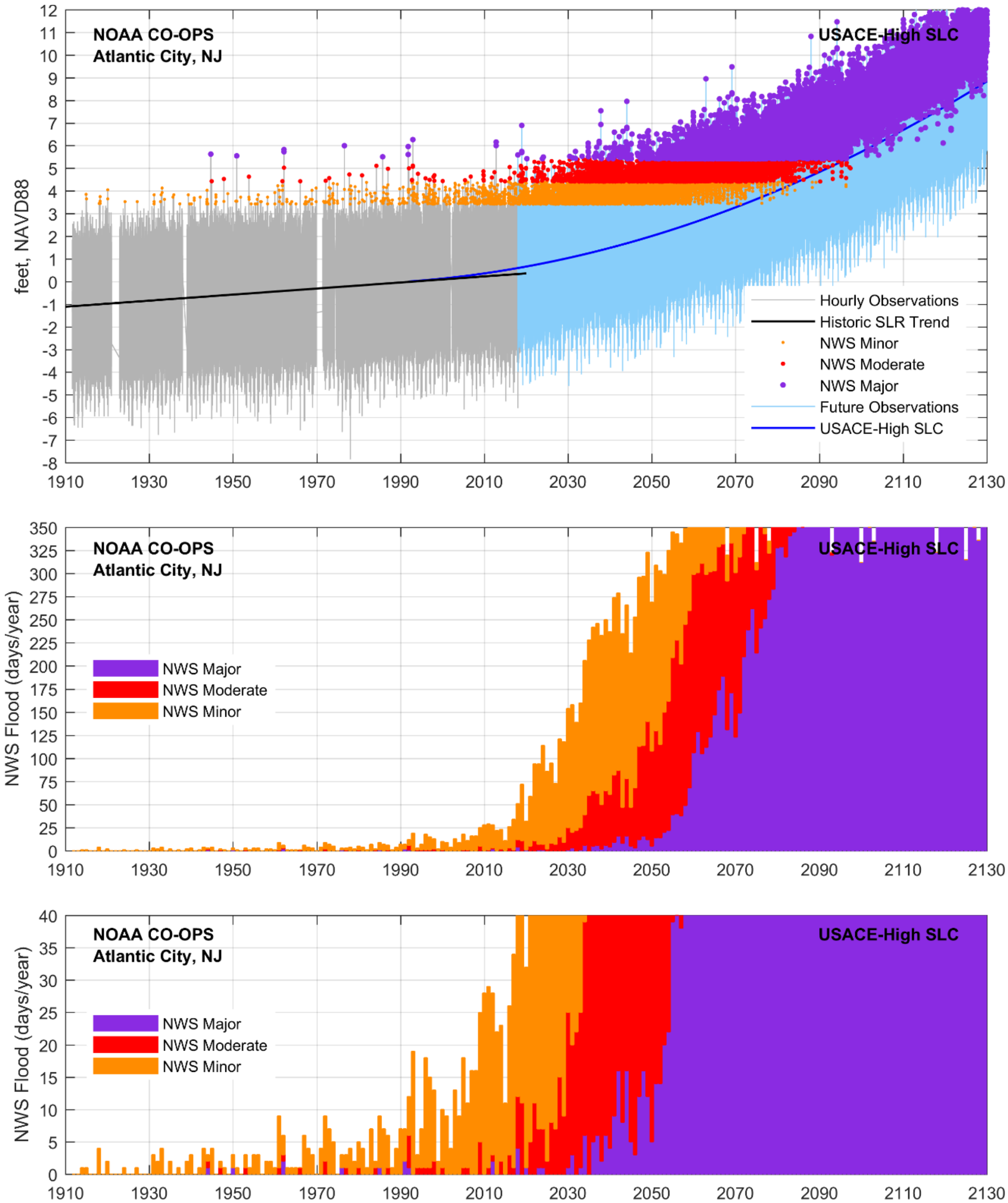


Figure 19: Future High-Frequency Flooding – USACE-High SLC

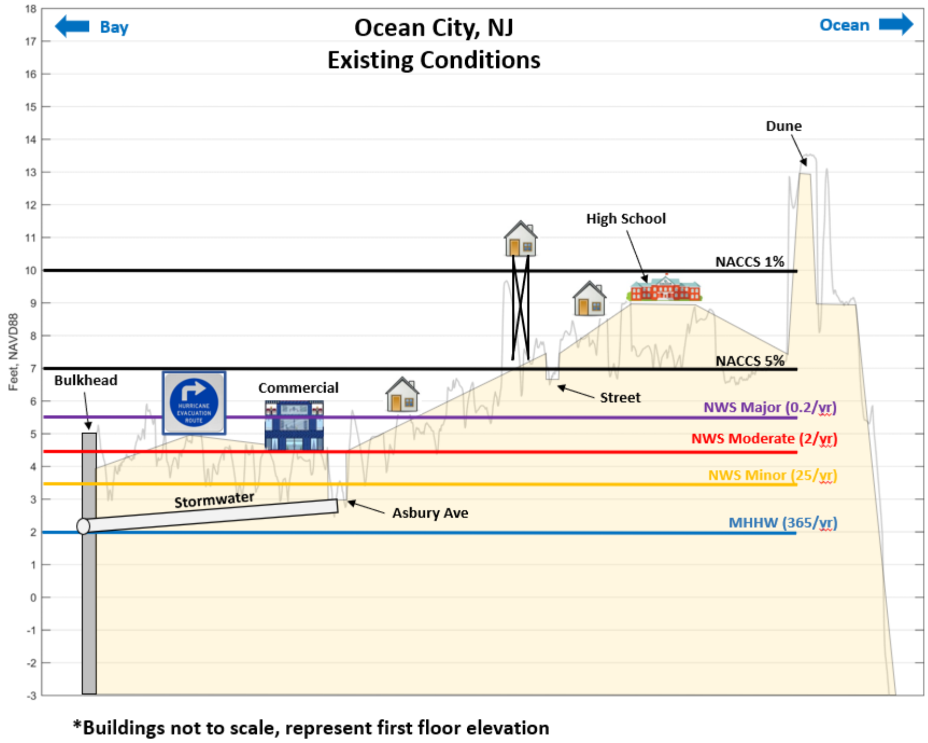


Figure 20 Existing Conditions in Ocean City New Jersey

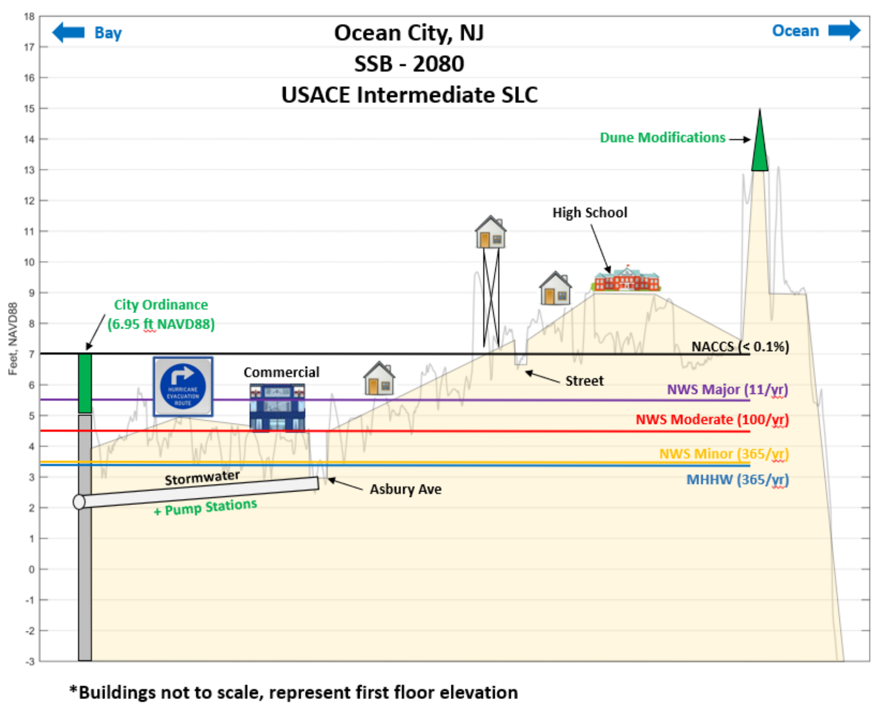


Figure 21 Sea Level in 2080 in Ocean City New Jersey

Figure 20 and Figure 21 show a schematic of Ocean City New Jersey with water elevations, topographic elevations and features identified like stormwater outfalls, bulkheads, road elevations identified for current conditions and the intermediate rates of Sea level change. Ocean City is typical of most coastal towns in that it has its highest elevations near the oceanfront, and it gently slopes downward to the bay. This location will likely be protected by a SSB, but HFF impacts will still impact the study area since the SSB's will not be closed during HFF events.

The study team chose 4 elevations to evaluate against sea level change to see how the area may be impacted for the future with project condition and the steps that would be necessary in the future with a project in place. These critical elevations were evaluated with the Sea Level Tracker with the intermediate rate of sea level change from the Atlantic City Tide gauge. As a result of intermediate sea level projections to 2080, the city will likely have to update its bulkhead ordinance, install pump systems with check valves to pump out stormwater, consider if roadways are vulnerable to sea level change and may need to augment its existing dune systems to account for additional water during storm events. This is due to the surplus of water on top of existing MHHW infiltrating stormwater systems and storm systems overtopping existing bulkhead and dune systems.

6.0 Section 113 (b) analysis for Sea level change

The September 17, 2021 Implementation Guidance for Section 113(b) of the Water Resources Development Act of 2020, Review of Resiliency Assessments, Assessment of Benefits from Addressing Sea Level Change and Inland Flooding Resiliency in Feasibility Reports states that Section 113(b) of the of the Water Resources Development Act (WRDA) of 2020 directs the Secretary, when conducting a study for flood risk management (FRM), coastal storm risk management (CSRM), or aquatic ecosystem restoration (AER) under Section 905 of WRDA 1986 (33 U.S.C. 2282), to consider, upon the request of the non-Federal interest for the study, whether the need for a project is predicated upon or exacerbated by conditions related to sea level change or inland flooding. The Non-Federal Sponsor made this request to the Corps. Additionally, for any study with such a request, the Secretary is directed, to the maximum extent practicable, to document the potential effects of sea level change or inland flooding on the project, and the expected benefits of the project relating to sea level change or inland flooding, during the 50-year period after the date of project completion.

Coastal Analysis

This analysis will document the extent of impacts of sea level change to the project area. For the NED account, the impact of sea level change (for each projected SLC curve) will be isolated in HEC-FDA to show the contribution of damages solely from SLC compared to storm events. Inundation mapping showing the extent of "repetitively flooded” land (inundated at sub 1-year events) across each SLC scenario will also show the long-term impacts from SLC alone. For RED and OSE accounts, two separate analyses to more effectively address the incorporation of SLC impacts, benefits, and residual damages would include: a) An OSE and RED analysis using the IMPLAN economic software to assess commercial business interruption, and b) A semi-quantitative real estate market value analysis to address the loss of taxable income from property destruction associated with different SLC scenarios.

Inland Hydrology Analysis

The NJBB recommended plan and associated interior drainage system improvements may help reduce flooding from precipitation in some areas near the NJBB structure features, but it will not address the broader challenges the study area faces from climate change and existing storm water systems. As sea levels change, many of the existing storm water systems in the study area will be stressed, especially those that rely on gravity sewers to drain water. Evaluating and addressing issues with municipal storm water systems is not the focus of the NJBB and is outside the USACE authority.

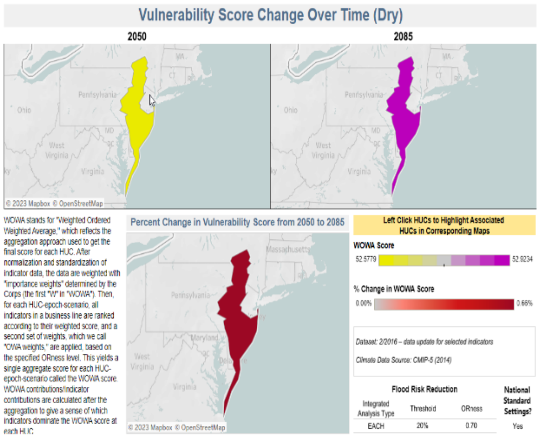
The results of this analysis have not been completed as of the writing of this appendix and will be included in the final report’s climate change appendix.

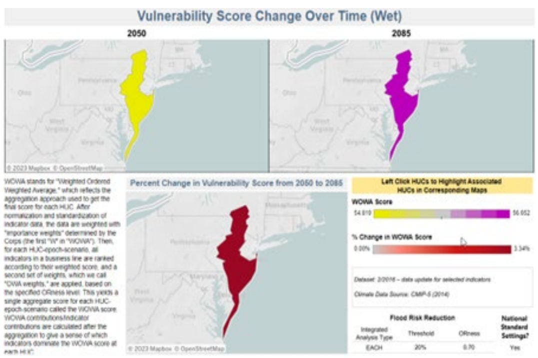
7.0 Vulnerability Assessment and Climate and Hydrology Assessment Tool (CHAT) Climate

Vulnerability Assessment (VA) tool

Climate vulnerability assessments are necessary to help guide adaptation planning and implementation so that USACE can successfully perform its missions, operations, programs, and projects in an increasingly dynamic physical, socioeconomic, and political environment. USACE has completed several high level assessments of vulnerability to climate change at the HUC 4 level, Figure 22.

The screening-level vulnerability assessment results are reported out in a simple, visual format that is intended to make the new and complex information more easily digestible. The assessments can be conducted by business line, at national, regional, and district levels, and for individual indicators. The Vulnerability assessment indicates that the Delaware River Watershed is forecast to see a magnification on flood risk from 2050-2085 Figure 22.





- For the FRM Business line the Increases to the WOWA score from 2050 to 2085 for the Watershed Vulnerability Assessment were mainly driven by Flood Magnification Factors.
- The Flood Magnification factor was responsible for the increase in WOWA score from 2050 to 2085 with a percent change in indicator contribution of 65%

Figure 22 Vulnerability Assessment Tool outputs at the HUC 4 level

Climate Hydrology and Assessment Tool (CHAT) analysis

The USACE Climate Hydrology Assessment Tool (CHAT) evaluates stream discharge, temperature and precipitation statistics at the HUC 8 level for watershed and to the stream segment level throughout the country. The projections are based on Global Climate models and the CIMP5 emissions scenarios to 2100. The emissions scenarios represent RCP 4.5 and RCP 8.5 (Representative Concentration Pathways) which bracket low and high concentration of greenhouse gasses in the atmosphere based on future emissions from the Intergovernmental Panel CHAT

CMIP-5 GCM model outputs included in the CHAT are analyzed annually for the period available for analysis (1951-2099). Model outputs included in the tool are also analyzed comparatively by describing monthly, simulated changes between different epochs (time periods).

CHAT allows users to visualize annual streamflow, precipitation, and temperature time series model outputs and to perform simulated trend analysis for these annual time series. Annual model output is assessed for both a historic period (water years 1951-2005) and a future period (water years 2006-2099).

The simulated trendlines in the Modeled Time Series Trend Analysis tab should not be used to predict exact changes in future hydrologic variables. Numerical results should not be directly applied in support of any USACE study/analysis.

Stream discharge, temperature and precipitation statistics are divided into historic and future projections. GCM based, simulated, annual temperature and precipitation outputs displayed in the CHAT are available for water years 1951–2005 representing the historical timeframe and for water years 2006–2099 representing the future timeframe. Projections start in 2006 because when CMIP5 was developed, 2006 was defined as the cutoff year where projections of emissions, rather than a historic reconstruction of greenhouse gas emissions begin to be used as boundary conditions in GCM simulations.

The tool also indicates the statistical significance of the data through three tests, the t-test, Spearman Rank Order tests and Mann-Kendal tests. The t-test is a parametric hypothesis test that relies on the assumption of normality. A p-value from a t-test is computed to determine whether two sets of data are significantly different from each other. The Spearman Rank-Order test is another non-parametric measure to determine whether there is a monotonic association between two ranked variables (e.g., time and the measurement of interest). Mann-Kendall is a non-parametric hypothesis test applied to determine the presence of a monotonic trend, defined as a consistently increasing or decreasing trend over time. To be consistent with published statistical standards, the CHAT uses a default significance level of 0.05 for the Student's t-test, Mann-Kendall test, and Spearman Rank-Order test (Fisher, 1934). This implies that trends with computed p-values less than or equal to 0.05 will be considered statistically significant, and values greater than .05 will be considered not statistically significant.

Multiple stream flow into and adjacent to the NJBB study area including; Manasquan River, Metedeconk River, Forked River, Toms River, Cedar Creek, The Mullica River, Great Egg River. Streams that were evaluated for this Climate Change Appendix and their potential impact on surge barriers, surge barrier pumps, nonstructural elevations were the Great Egg Harbor River, stream segment 02002085, and Toms River stream segment- 02002109, Figure 23. Toms River discharges into Barnegat Bay in the northern portion of the study area.

Figure 23 Watersheds and Stream Segment locations from CHAT

Stream Flow, Precipitation and Temperature Variables from CHAT

Simulated, annual streamflow outputs displayed in the CHAT are available for water years 1951–2005 representing the historical timeframe and for water years 2006–2099 representing the future timeframe.

Temperature and Precipitation Variables:
The temperature and precipitation variables are derived from statistically-downscaled LOCA, CMIP-5 GCM meteorological outputs that have been spatially aggregated to an 8-digit HUC resolution. They represent the temperature and precipitation modeled within a specific 8-digit HUC's boundaries.

Toms River Stream Segment
Annual Maximum of Mean monthly discharge, 1-day Precipitation and Annual Maximum 1-Day Temperature were all forecast to increase slightly at Toms River stream segment location for RCP 4.5 and RCP 8.5, with varying degrees of statistical significance, Figure 24, Figure 25, Figure 26.

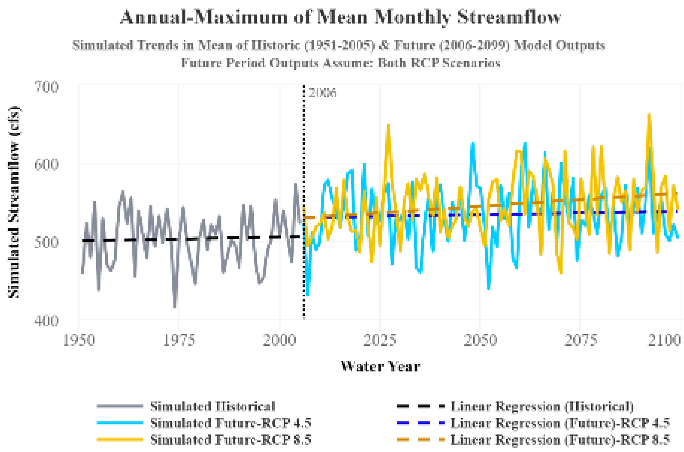


Figure 24 Toms River Maximum of Mean Monthly Stream Flow

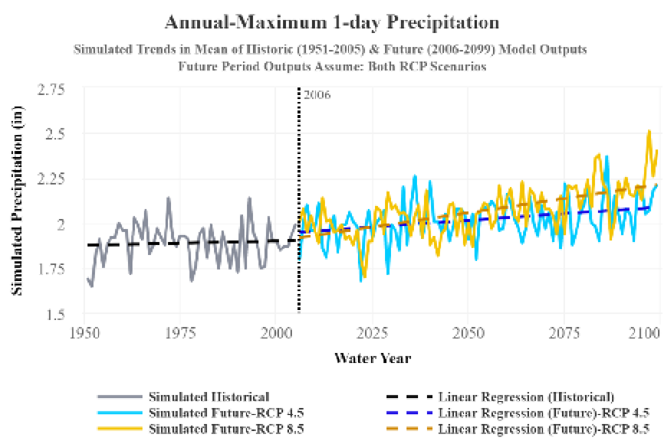


Figure 25 Toms River Annual Maximum of 1-Day Precipitation

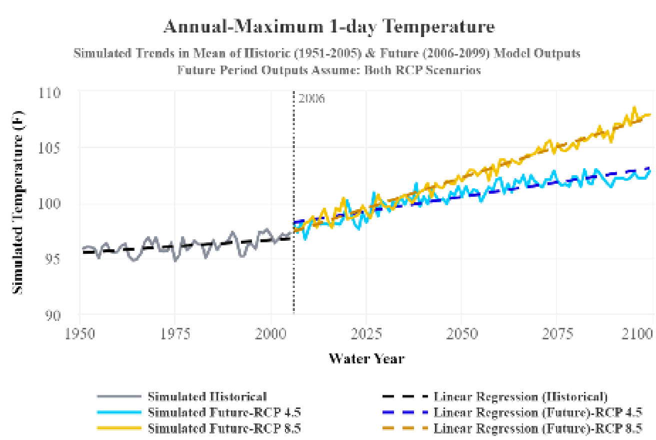


Figure 26 Toms River Annual Maximum 1-Day Temperature

The annual discharge forecasts showed increases at this stream segment, but at a p-values that were greater than .05, for RCP 4.5 indicating that it lacked statistical significance for the t-test, the Mann Kendal and the Spearman Rank order. The modeled historic data also had p values greater than .05. The CHAT did contain values less than .05 for each statistical test in the RCP 8.5 scenario, indicating their statistical significance for increases in annual discharge for that emissions scenario.

The 1-day precipitation forecast had p values less than .05 for each test, and for both RCP 4.5 and 8.5, indicating strong statistical significance for the modeled data for increased precipitation in the future, similar to other regional climate assessments in the National Climate Assessment Report and the State of NJ Climate Assessment from NOAA. The CHAT forecasted 2-3 inches of increased annual precipitation for this location for RCP 4.5 and 8.5 with p-values less than .05.

As expected, the CHAT tool predicted temperature increases for the region with strong statistical significance for the historic, RCP 4.5, and RCP 8.5, all showing p -values less than .05. The temperatures modeled by the tool indicated that Maximum 1 day temperatures could reach between 104-107 degrees Fahrenheit by 2100 for both RCP scenarios. The Annual Mean Temperature was projected to rise for Toms River to 59-63 degrees from the current mean of 55 degrees Fahrenheit for RCP 4.5 and RCP 8.5 with statistically significant p-values for all three tests. Increases in temperature are likely driving precipitation and river discharge projected increases since as warmer air holds more moisture, and regional shifts in precipitation are anticipated with future emissions and temperature scenarios.

Great Egg Harbor Stream Segment

Annual Maximum of Mean monthly discharge, 1-day Precipitation and Annual Maximum 1-Day Temperature were also forecast to increase slightly at the Great Egg Harbor River stream segment location for RCP 4.5 and RCP 8.5, with varying degrees of statistical significance, Figure 27, Figure 28, Figure 29.

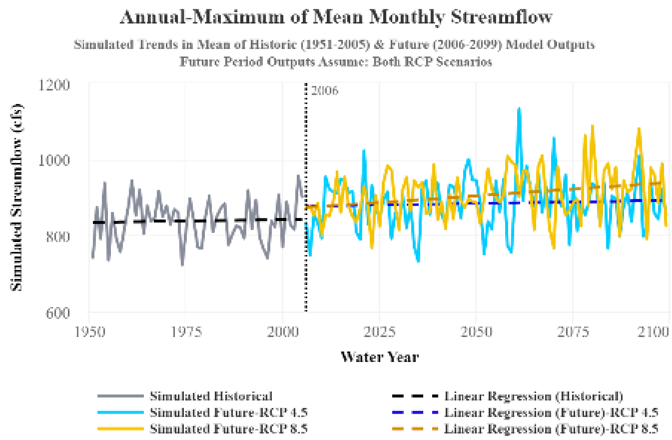


Figure 27 Great Egg Maximum of Mean Monthly Stream Flow

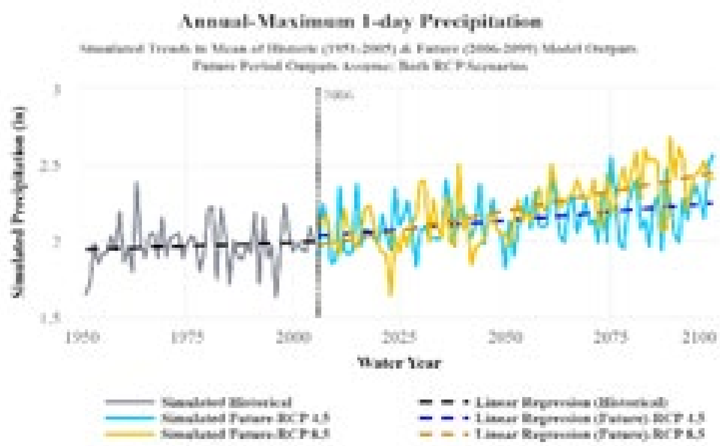


Figure 28 Great Egg Maximum 1-Day Precipitation

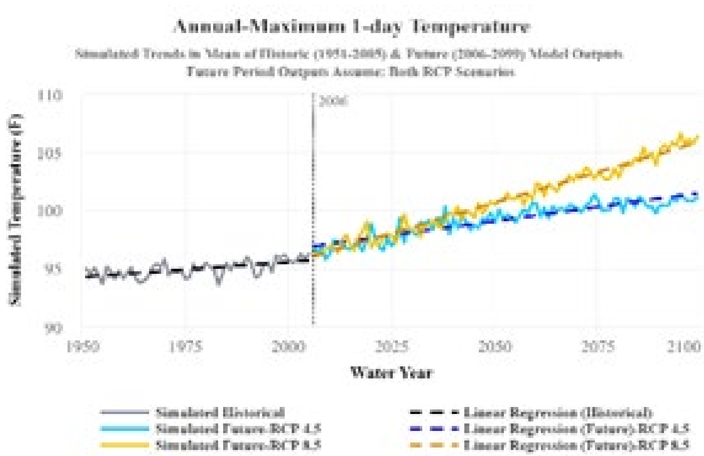


Figure 29 Great Egg Annual Maximum 1-Day Temperature

For stream discharge, only RCP 8.5 saw a slight increase with statistical significance, with RCP 4.5 and the simulated historic both showing p values greater than .05 for each test. Increases in 1 day precipitation were forecast for both RCP scenarios, with both projections having statistically significant p-values less than .05.

Increases in annual precipitation were also projected with this value increasing from 44 inches per year to 47 inches per year with p- values less than or at .05 for all scenarios, the historic simulations, and RCP 4.5 and RCP 8.5.

The Annual Mean Temperature projected for Great Egg was projected to increase to 60-63 degrees from the current annual mean of 56 degrees Fahrenheit for RCP 4.5 and RCP 8.5 with statistically significant p-values for all three tests.

8.0 Council on Environmental Quality (CEQ) Guidance on GHG

On January 9th 2023 the Council on Environmental Quality released draft guidance titled National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and Climate Change, and requested comments by March 10, 2023. The CEQ is issuing this interim guidance to assist agencies in analyzing greenhouse gas (GHG) and climate change effects of their proposed actions under the National Environmental Policy Act (NEPA). NEPA reviews should quantify proposed actions' GHG emissions, place GHG emissions in appropriate context and disclose relevant GHG emissions and relevant climate impacts, and identify alternatives and mitigation measures to avoid or reduce GHG emissions. CEQ encourages agencies to mitigate GHG emissions associated with their proposed actions to the greatest extent possible, consistent with national, science based GHG reduction policies established to avoid the worst impacts of climate change.

The guidance specified that the analysis should be included in NEPA reviews, agencies should consider the potential effects of a proposed action on climate change, including by assessing both GHG emissions and reductions from the proposed action; and the effects of climate change on a proposed action and its environmental impacts. As part of the Corps Clean Air Act Statement of conformity, we are required to quantify the constructed projects contribution to carbon and nitrous oxide emission, but that has not been accomplished for this Supplemental Environmental Impact Statement (SEIS). The Clean Air Act analysis will be completed as part of the final report in 2025 with the appropriate considerations of GHG emissions from of the construction of the project and the potential mitigation recommendations.

Worldwide and US Co2 and GHG emission emissions

The website Our World In Data (https://ourworldindata.org/) publishes global and country level carbon dioxide and other GHG historic emissions. The data was current for emissions to 2021. The source of the data is the Global Carbon Project. The data show that carbon dioxide emissions were about 36 billion metric tons (metric ton is equal to 2204.6 pounds) in 2021, up from a potentially pandemic low of approximately 35 billion metric tons in 2020 Figure 30. Since data was only current at the Our World in Data site, the International Energy Agency (IEA) report was considered for 2022 data on emissions. The IAE reported that global energy-related CO2 emissions grew by only 0.9%, or 321 Mt, in 2022, reaching 36.8 Gt (1 Gt is equal to 1 billion tons). The IEA reported that "following two years of exceptional oscillations in energy use and emissions, caused in part by the Covid-19 pandemic, last year's growth was much slower than 2021's rebound of more than 6%". The United State emitted 5 billion tons of carbon dioxide in 2021, an increase from 4.72 billion tons in 2020, Figure 31.

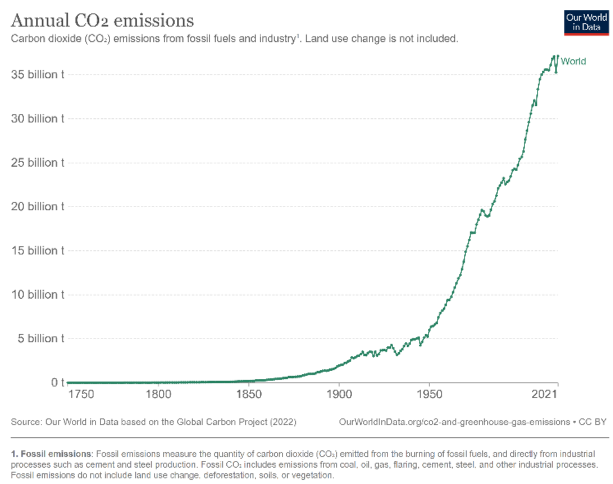


Figure 30 Annual Global CO2 emissions

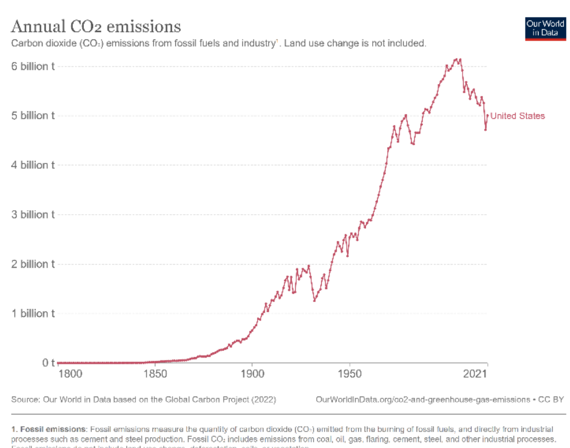


Figure 31 Annual US CO2 emissions

Carbon dioxide is only one of many Greenhouse Gases that can impact temperature and climate change. Green House Gas (GHG) emissions also include methane and nitrous oxide that also contribute to global warming. In 2019, according to the Global

Climate Project and Our World in Data site the world's GHG emissions in carbon dioxide equivalents were 49 billion tons, representing a steady increase in total GHG emissions since 1990, Figure 32. Our project construction would increase global GHG emissions during construction and as part of the clean Air Act Statement of Conformity, Carbon Dioxide, Nitrous Oxide and other GHG emissions have to be calculated. These emissions are the result of construction vehicles, transportation of materials and workers to sites, Scope 1,2,3 emissions for materials, and any permanent housing required for large scale features like SSB's.   -

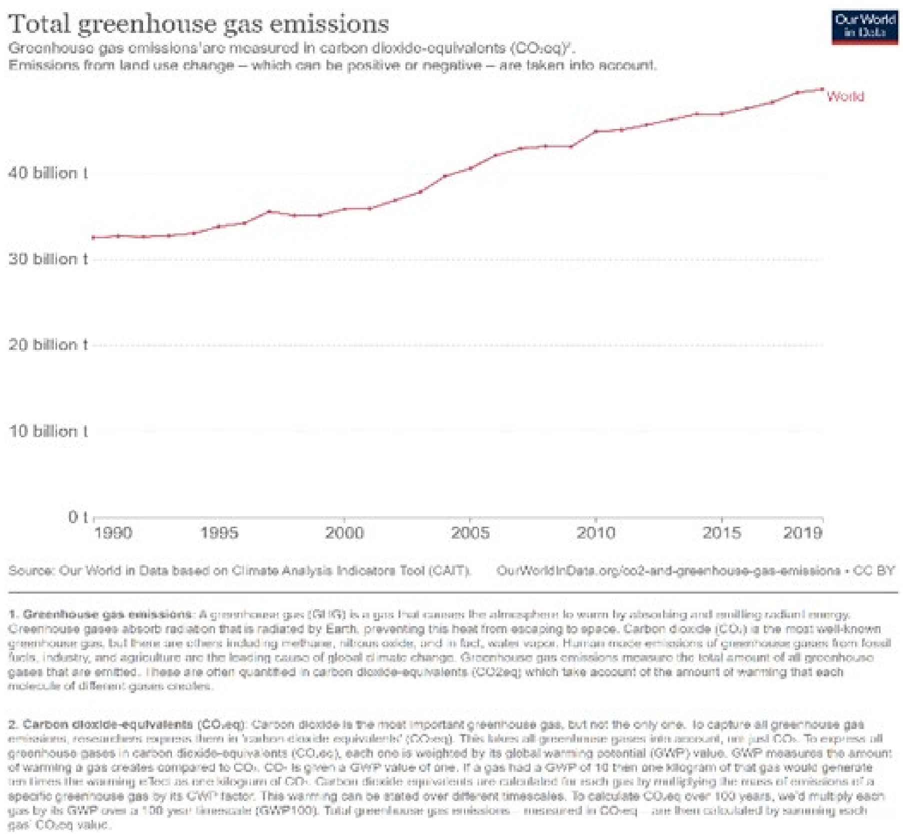


Figure 32 Total Global Greenhouse Gas Emissions

Increases in CO2 emission are likely causing increases in over CO2 concentration at the Mauna Lau observatory in Hawaii Figure 33 . Increase emissions are likely to have secondary impacts to world temperatures and asea level change with continued impacts to the study area.

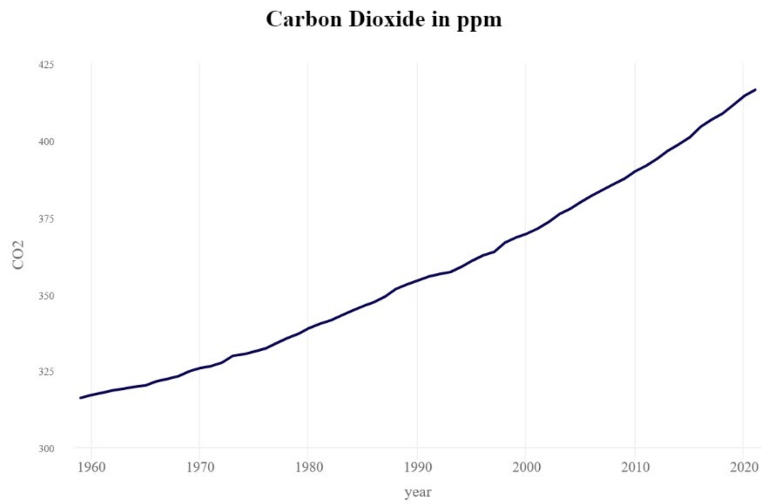


Figure 33 Co2 in ppm, Mauna Lau Observatory

As part of the feasibility process the Corps is required to conduct and emission inventory for the emissions released during construction of the project. These emissions are related to the release on nitrous oxide, volatile organic compounds, particulate matter, sulfur dioxide, carbon monoxide and carbon dioxide. It's likely that carbon dioxide and Nitrous Oxide will have the greatest impact on emissions related to climate/temperature, with sulfur dioxide , volatile organic compounds, and particulate matter having more of an impact on health and environmental quality, potentially being cidered and environmental justice issue. This information is contained in the main report in Section 4 and in the Environmental Appendix (F)

The construction of the New Jersey Back Bay selected plan of home raising floodproofing, and NBS will contribute to GHG emissions of carbon dioxide, methane and Nitrous Oxide during the construction timeframe with the use of heavy machinery and the potential for the release of GHG during the creation of building materials like concrete and the power devoted to energizing buildings, temporary during construction and permeant for Operations and Maintenance.

The contribution of GHG during construction will add these gases to the atmosphere and contribute to warming trends being seen nationally and globally, but minimally. These warming trends will have effects on sea level change, high frequency flooding, precipitation changes and riverine discharge changes, as well as potentially contributing to drought conditions expected with a warmer climate. The degree to which these emissions contribute that these climate change phenomenon is likely small compared to over global emissions.

TSP impact on Carbon and GHG emissions

The 20% non structural plan would produce approximately 1,823 tons of CO_2, 0.4 tons of CH_4, and 0.2 tons of N_2O in any construction year in both air regions combined.

The nonstructural floodproofing plan for critical infrastructure (CI) would likewise produce GHG emissions from construction equipment. A GHG emission estimate was also prepared and results in emissions of approximately 22 tons of CO_2, 0.01 tons of CH_4, and 0.11 tons of N_2O in any construction year in both air regions combined.

The NBS plan would result in greenhouse gas emissions. The plan would produce approximately 967 tons of CO_2, 0.12 tons of CH_4, and 0.03 tons of N_2O in any construction year (estimated to be 3 construction events over a 50 year period). The NBS plan involves the maintenance of saltmarsh habitat, which would provide long-term benefits ("blue carbon") by sequestering GHG carbon from the atmosphere. Coastal wetlands are known to annually sequester carbon at a rate ten times greater than mature tropical forests, and store three to five times more carbon per equivalent area than tropical forests. Most coastal blue carbon is stored in the soil of coastal marshes (retrieved from https://oceanservice.noaa.gov/ecosystems/coastal-blue-carbon/ on 6/1/2023). Carbon sequestration rates for saltmarshes vary widely worldwide 1.2 to 1,167 grams/m2/year, but average 167 grams/m2/year (Miller et al. 2022).

Combined, the construction of the TSP would emit approximately 2,812 tons of CO_2 as well as other greenhouse gas emissions while potentially sequestering an average of 167 grams/m2/year (CO_2) across 217 acres of NBS. This amount of CO@ was evaluated at the Environmental Protection Agency (EPA) Greenhouse Gas Equivalencies Calculator located at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results. This amount of CO_2 the equivalent of 595 gas powered cars being driven for one year and 287,000 gallons of gasoline being consumed.

Theoretically, the amount of CO_2 produced from the one time initial construction could be absorbed by the continuous sequestration of salt marsh system over multiple decades, but the NBS systems component requires multiple renourishments, negating the sequestration by adding more CO_2 to the atmosphere during construction. In addition, there is no guarantee of continued sequestration of NBS systems since erosion an inundation effects from continued sea level change could negate these benefits. The Final Report Climate Change appendix will consider calculations on sequestration rates and the social costs of carbon in the analysis.

9.0 Critical Elevation Analysis

A bar chart for the residential structures in the TSP (5-year) is shown in . A bulk of the home elevations would appear to be in the 5.0-6.5 NAVD 88 elevation range, with lower elevations of about 4.0 NAVD 88, and very little elevated to above 7.5 NAVD 88. No structures were identified as being less than 4.0 NAVD88. This is the existing FFE of the structures eligible to be in the NS Plan (TSP or 5-year plan).

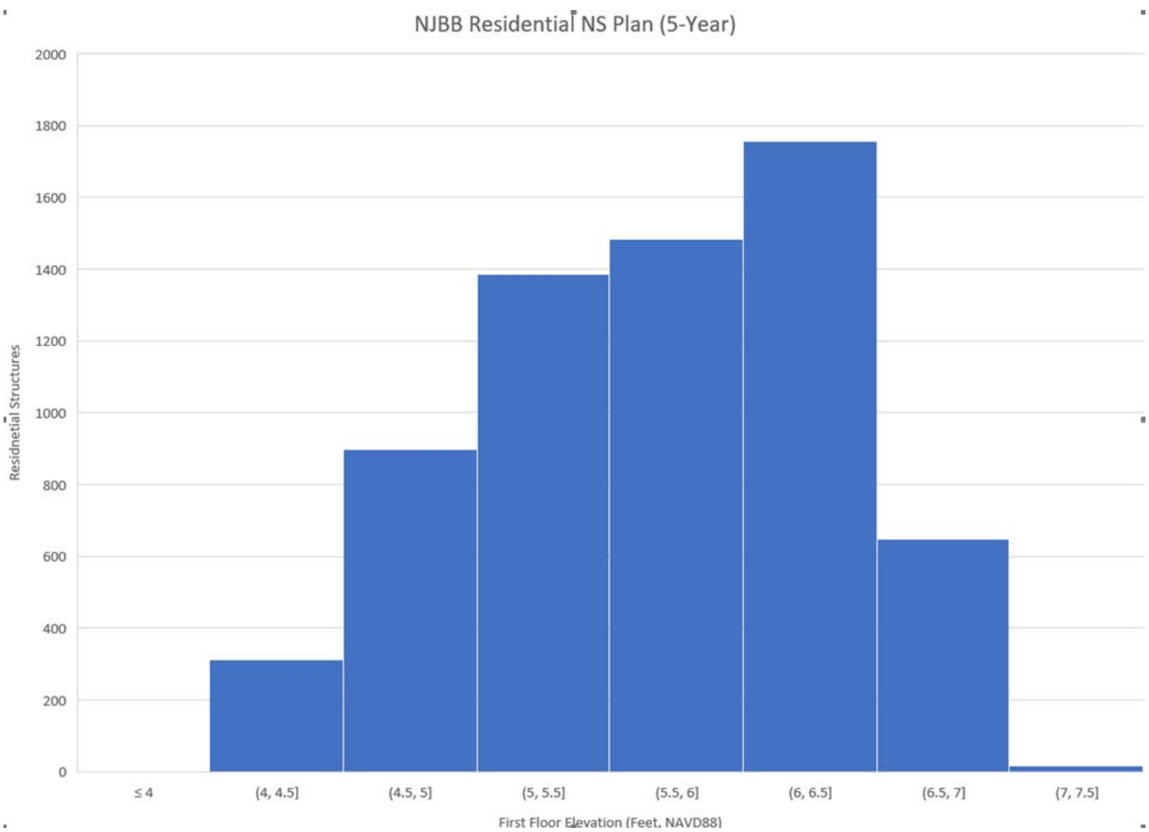


Figure 34 First Floor Elevation in Long Beach Island

Information on existing conditions and first floor elevations was used as an input into the Sea Level Analysis Tool to determine impacts from historic, intermediate and high rates of sea level change. The results are presented in Figure 34,and Table 5.

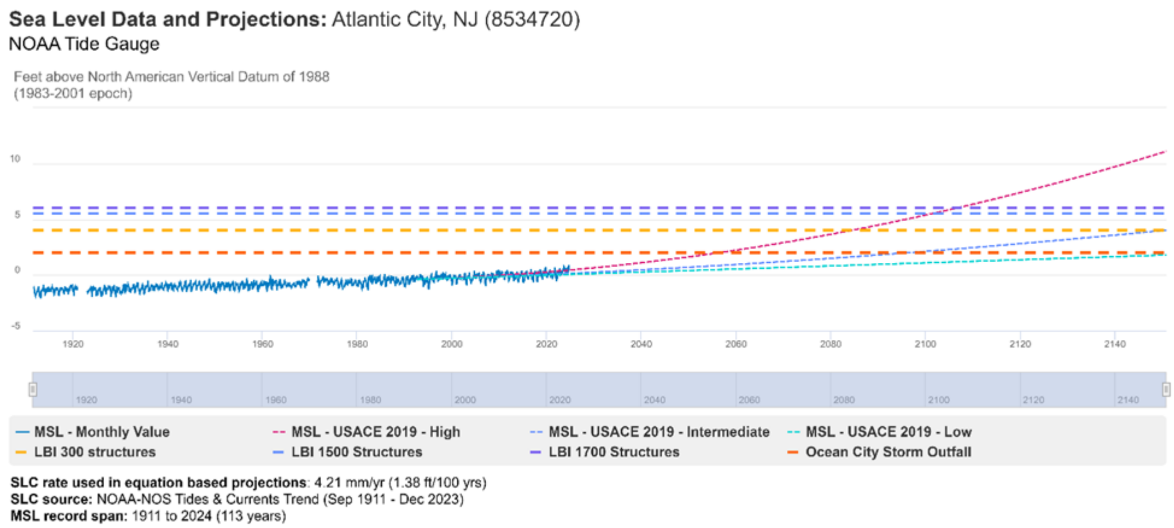


Figure 35 Sea Level Change against Critical Elevations

Curve	Intersections
Intersections with LBI 300 structures (4 feet NAVD88)	
MSL - USACE 2019 - High	2084
MSL - USACE 2019 - Intermediate	2150
MSL - USACE 2019 - Low	None
Intersections with LBI 1500 Structures (5.5 feet NAVD 88)	
MSL - USACE 2019 - High	2101
MSL - USACE 2019 - Intermediate	None
MSL - USACE 2019 - Low	None
Intersections with LBI 1700 Structures (6 feet NAVD88)	
MSL - USACE 2019 - High	2106
MSL - USACE 2019 - Intermediate	None
MSL - USACE 2019 - Low	None
Intersections with Ocean City Storm Outfall (2 feet NAVD88)	
MSL - USACE 2019 - High	2056
MSL - USACE 2019 - Intermediate	2096
MSL - USACE 2019 - Low	None

Table 5 Sea Level Change Against Critical Elevations Output

The existing conditions for home elevations were used to define critical elevations and thresholds in the SLAT (https://climate.sec.usace.army.mil/slat/). Most structures in the existing conditions example appear to be insulated well from sea level change. The most at risk structures in the sample at 4.0 NAVD 88 would be at risk from sea level change in 2084 in the existing conditions for the high rate of sea level change, and in 2150 for the intermediate rate of sea level change, with the other structure less at risk due to their increase in first floor elevation. This risk would likely decrease with the Future With Project Conditions when these homes are elevated. Other features, like storm water systems in project locations like Ocean City New Jersey, are likely impacted from high rates and intermediate of sea level change between 2056 and 2096, respectively.

10.0 Conclusion

Heat, precipitation, sea level, drought durations, and stream discharge are all likely to increase as a result of climate change based on the results of the Vulnerability Assessment, the CHAT and the sea lev tools. But the study area is most vulnerable to increases in water level from sea level change. Sea level change will continue to impact High Frequency Flooding (HFF) days in the study area, its storm drainage systems and low lying elevations according to our analysis and reports published by NOAA. Residual damages will increase in areas with nonstructural solutions as some properties are elevated above the BFE, but vehicles, low lying roads, and infrastructure will be flooded. Critical Infrastructure and floodproofing features will be impacted with future sea level change rates since floodproofing measures are fixed to 3'-4.5' above grade, and the feature will likely see damages above that height with future sea level change.

Climate change will have an impact to the project area as warming continues, sea level changes and High Frequency Flooding increases. Future Without Project Damages (FWOP) increase with climate change and the study area will be more exposed with future emission scenarios and climate change. Nonstructural solutions relating to floodproofing may be overwhelmed with sea level change since there is a fixed +3' to 4.5' above grade elevation that may be eclipsed by sea level change. Nature Based Solutions (wetlands) may not be able to withstand increase in sea level, and may be inundated over time.

Adaption planning and strategic decisions on future feasibility studies will have to be implemented at certain thresholds for this study area, mainly as a result of sea level change. The study team has already anticipated, and built in, certain rates of sea level change based on measurements at the Atlantic City tide gauge into first floor elevation heights of the home elevations, but this may not be enough. Measures to reduce residual risk are also identified in the main report, with spin-off feasibility studies considered as future investments to follow this study. Based on evaluating the critical elevations in the SLAT, its likely that additional efforts may be necessary for follow on studies, adaptation planning or revaluation of completed works in the 2056- 2084 timeframe. In addition, a Watershed 729 study is recommended in the main report to

continuously triage future studies, authorities and funding priorities in order to be able to conduct assessments of how to proceed in the face of climate change and residual risk.
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