US Army Corps
of Engineers
Baltimore District

BALTIMORE HARBOR ANCHORAGES AND CHANNELS (BHAC) MODIFICATION OF SEAGIRT LOOP CHANNEL

FEASIBILITY STUDY

FINAL INTEGRATED FEASIBILITY REPORT & ENVIRONMENTAL ASSESSMENT

APPENDIX E:

CLIMATE CHANGE ASSESSMENT

FEBRUARY 2023

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CLIMATE CHANGE ASSESSMENT ON BALTIMORE HARBOR ANCHORAGES AND CHANNELS MODIFICATION OF SEAGIRT LOOP CHANNEL, MARYLAND

This appendix discusses the climate change assessment performed for the Baltimore Harbor Anchorages and Channels (BHAC) Modification of Seagirt Loop Channel, Maryland (“Seagirt Study”). Climate change assessments are required for all phases of the project life cycle including feasibility and pre-construction engineering and design (PED), for both existing and proposed projects. Because climate science is continuing to evolve, additional climate assessments may be performed during future project phases, which may include quantitative climate assessments on sea-level change and/or updated hydrology. Sea level change and hydrologic changes in air temperature, precipitation, and stream flow patterns associated with climate change could have a dramatic impact on hydrologic conditions and water resources infrastructure in the state of Maryland.

In this appendix, all elevations use North American Vertical Datum of 1988 (NAVD88) unless otherwise indicated.

E.1. INTRODUCTION

The USACE Civil Works Program and its water resources infrastructure represent a tremendous federal investment that supports public health and safety, regional and national economic development, and national ecosystem restoration goals.

Climate change is one of many global changes the USACE faces in carrying out its missions to help manage the nation's water resources infrastructure. The hydrologic and coastal processes underlying water resources infrastructure have the potential to be sensitive to changes in climate. Therefore, the USACE has the need to understand and adapt to climate change and variability, while continuing to provide the authorized level of performance under changing conditions. The objective of the USACE Climate Preparedness and Resilience (CPR) Community of Practice (CoP) is to mainstream climate change adaptation in all activities to enhance the resilience of the USACE water resources infrastructure and to reduce their potential vulnerabilities to the effects of climate change (USACE, 2019).

Recognizing that, over time, uncertainty may decrease as we increase our knowledge of climate change, its impacts, and the effects of adaptation and mitigation options (including unintended consequences), water resource engineers must establish decision processes that incorporate new information. The use of rigorous management in an adaptive fashion, where decisions are made sequentially over time, allows adjustments to be made as more information is known. The use of longer planning horizons, combined with updated economic analyses, will support sustainable solutions in the face of changing climate that meet the needs of the present without compromising the ability of future generations to meet their own needs (USACE, 2018d).

As part of its water resources management missions and operations, the USACE has been working together with other federal agencies, academic experts, nongovernmental organizations, and the private sector to translate climate science into actionable science for decision-making. The USACE Civil Works Program has developed tools to analyze the potential effects and uncertainties associated with climate change and relative sea level rise (RSLR) in relation to the USACE portfolio.

Engineering Construction Bulletin (ECB) no. 2018-14 (USACE ECB 2018) provides guidance for incorporating climate change information in hydrologic analysis in accordance with the USACE overarching climate change adaptation policy. It calls for a qualitative analysis. The goal of a qualitative analysis of potential climate threats and impacts to USACE hydrology-related projects and operations is to describe the observed present and possible future climate threats, vulnerabilities, and impacts of climate change specific to the study. This includes consideration of both past (observed) changes as well as potential future (projected) changes to relevant meteorological and hydrologic variables.

E.1.1. Climate Change Assessment Limitations and Areas of Future Study

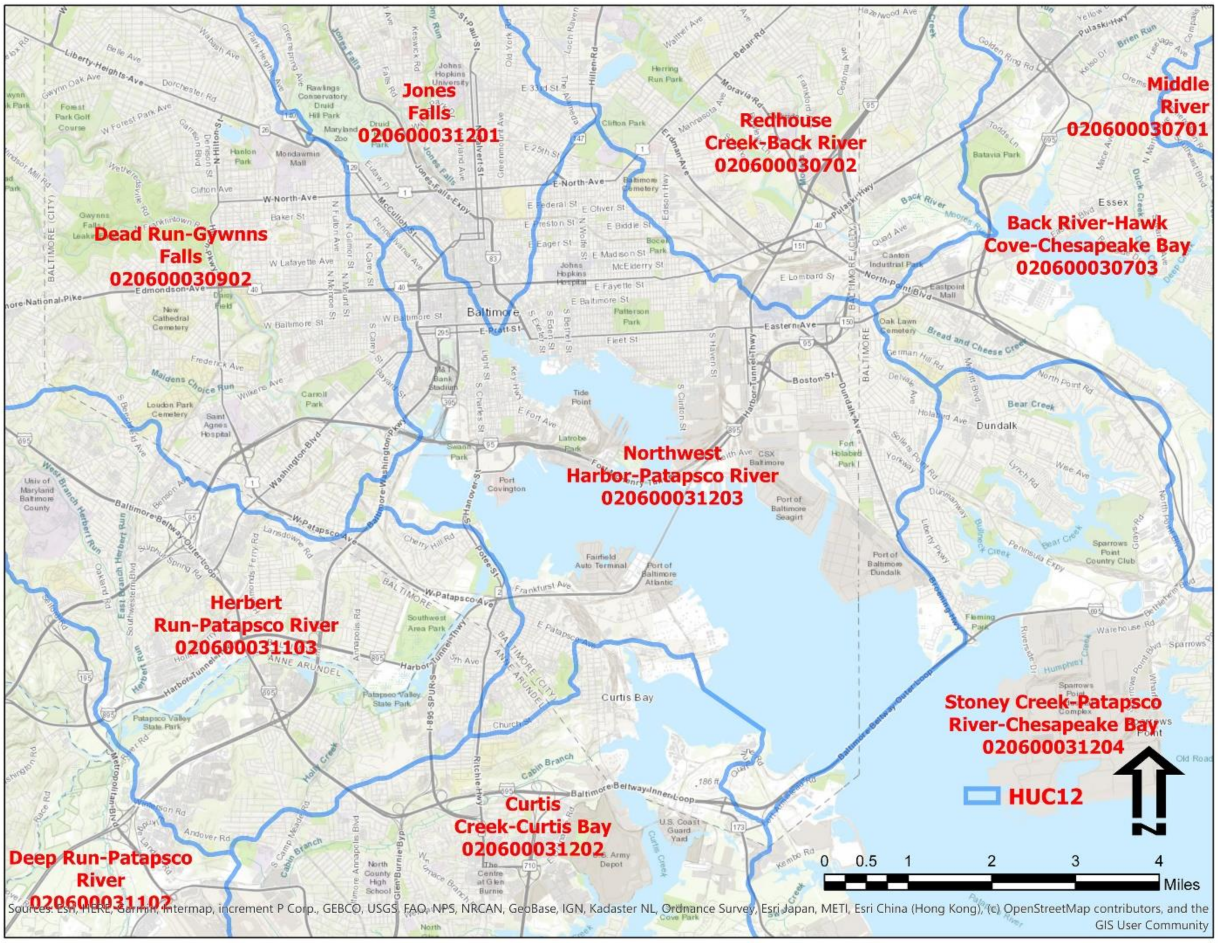
At this feasibility stage in the BHAC, many factors were analyzed with regard to climate change. There are additional factors that can affect Baltimore Harbor. The following changes are assumed to affect the Harbor with or without project. Shoaling rates, shoreline changes, velocities and salinity were not evaluated in this Climate Change Assessment. Shoaling rates, velocities, and salinity would take additional modeling, including the addition of sedimentation transport modeling.

E.2. KEY FINDINGS

1) The main climate change assessment is the potential of impacts from future sea level change .
2) The sea level change in the Baltimore Harbor is only forecasted to be RSLR.
3) Impacts from RSLR are unchanged from the No Action Alternative versus all Action Alternatives.
4) Inland hydrology is not expected to affect Baltimore Harbor, because it is the outlet of the drainage area.
5) Shoaling rates, shoreline changes, velocities and salinity were not evaluated with regard to climate change at this feasibility stage of the project.
6) There is a strong agreement in the literature that temperature for the mid-Atlantic region, and the entire country, will increase over the next century.
7) Projections for precipitation events and hydrology are less certain than temperature projections for the mid-Atlantic Region.

E.3. PROJECT OVERVIEW

To better understand how climate change impacts the BHAC, it is important to understand how the project fits in with the surrounding region. For most studies in waterways, projects are part of a larger watershed and interconnected ecosystem (Figure 1). The interaction between the Baltimore Harbor modifications and the larger watershed and interconnected ecosystem is complex. The project area is located in HUC 12 watershed number 020600031203 (Northwest Harbor-Patapsco River). In order to assess future adaptations in the project, climate change assessment is needed for the Watershed.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 1. Baltimore Harbor Northwest Patapsco River HUC 12 Watershed

E.3.1 BHAC Project Description

The feasibility study will analyze alternatives for navigation improvements to Baltimore Harbor including widening and deepening of the Seagirt Loop Channel (up to -50 feet Mean Lower Low Water [MLLW]), re-design of an anchorage to allow up to 47.5-foot draft vessels to standby within Baltimore Harbor, examining deepening of the South Locust Point Branch Channel and Turning Basin (up to -38 feet MLLW), and considering and evaluating other structural and nonstructural measures that will result in improved transportation efficiencies in Baltimore Harbor. The Seagirt Study will identify and evaluate a full range of reasonable alternatives including the No-Action alternative. The non-federal sponsor of the project is Maryland Port Administration (MPA). The study is conducted pursuant to the authority resulted in a Chief's Report dated June 8, 1998, and in project authority in §101(a)(22) of Water Resources Development Act (WRDA) of 1999 (Pub. L. No. 106-53).

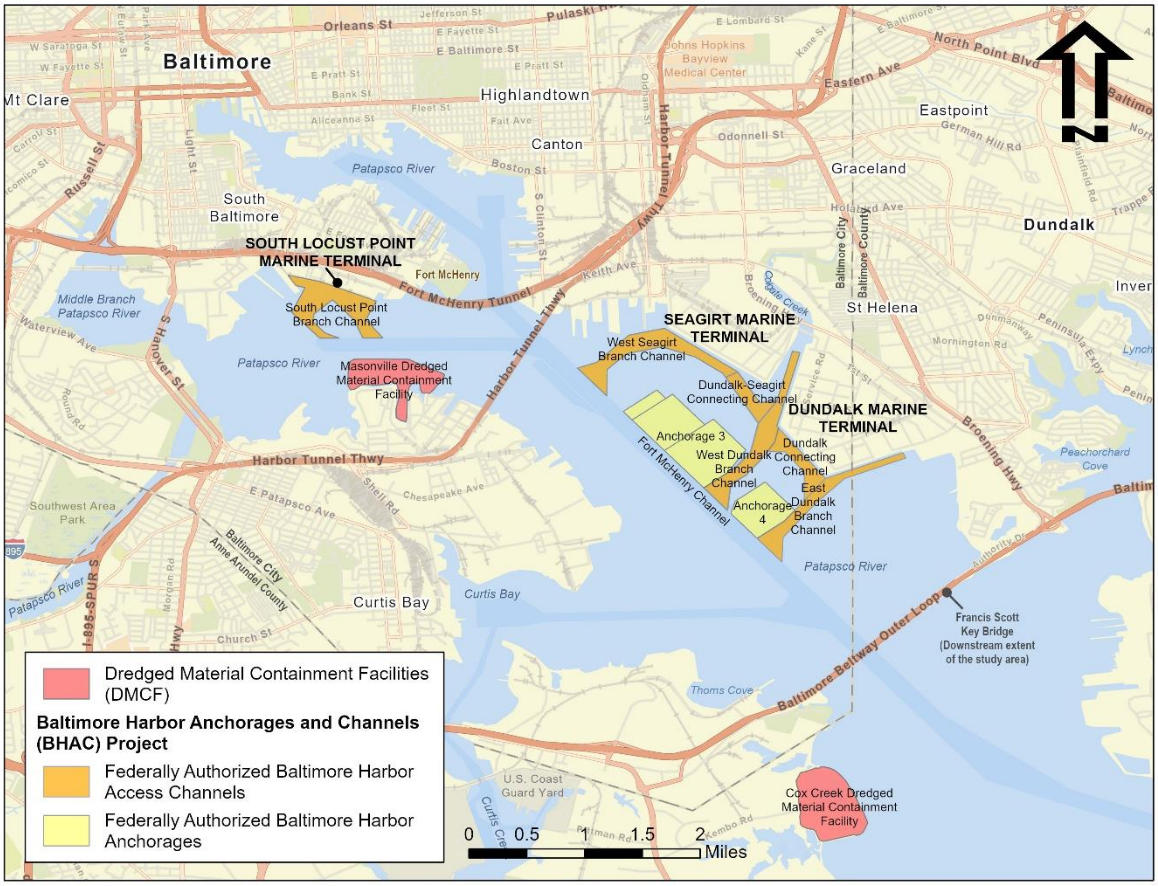


Figure 2. Baltimore Harbor Channels and Anchorages

E.3.2 Proposed Baltimore Harbor Channel Modifications

The Seagirt Study seeks to modify the existing federal navigation project in Baltimore Harbor, Baltimore County, Maryland. Details on plan formulation and screening is available in the main report. The study includes eight alternatives, with combinations of different proposed modifications, see Table 1.

Table 1. Seagirt Study Initial Array of Alternatives

Alternatives	***Management Measures***			
	Assume federal responsibility for BHAC Improvements	*Deepening and widening of Seagirt Loop Channels*	*Deepening and widening of South Locust Point Branch Channel*	*Re-design part of an existing Anchorage to 50' depths to accommodate larger vessels*
Alternative 1	*No Action*	*No Action*	*No Action*	*No Action*
Alternative 2	*Included*			
Alternative 3	*Included*	*Included*		
Alternative 4-1	*Included*	*Included*	*Included*	
Alternative 4-2	*Included*		*Included*	
Alternative 5-1	*Included*	*Included*	*Included*	*Included*
Alternative 5-2	*Included*	*Included*		*Included*
Alternative 5-3	*Included*			*Included*

E.4. LITERATURE REVIEW

As required by ECB 2018-14, a hydrologic literature review was conducted to summarize peer reviewed literature on current climate and observed climate trends and projected climate trends in the project area. The literature review includes sources specific to Maryland, and the surrounding northeast United States:

1) *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions: Mid-Atlantic Region 02 (USACE, May 201*5)
2) *Climate Change Indicators in the United States (U.S. Environmental Protection Agency, 2019)*
3) *Climate Science Special Report: Fourth National Climate Assessment, Volume I (Carter, et al., 2014)*
4) *NOAA State Climate Summaries for Maryland (Jennifer Runkle And Kenneth E. Kunkel, 2017)*

The literature focuses on the following climate variables, which are consistent with those identified for the project: precipitation, temperature, and streamflow.

A summary of the USACE peer-reviewed climate literature is available for the Mid-Atlantic Region 02 and is referenced as one of the primary sources of information in this literature review. This USACE report summarizes observed and projected climate and hydrological patterns cited in reputable peer-reviewed literature and authoritative national and regional reports and characterizes climate threats to the USACE business line (USACE, 2015). The project watershed falls within the Mid-Atlantic region, which is also referred to as Water Resources Region 02 (2-digit hydrologic unit code).

E.5. TEMPERATURE TRENDS

According to the Fourth National Climate Assessment, climate change is expected to intensify current, observed trends in temperature and precipitation in the U.S., including the northeast region (Carter, et al., 2014). The BHAC is located at the Baltimore Harbor, approximately 40 miles northeast of Washington DC.

Maryland’s climate is generally moist with a rather large seasonal range of temperatures. Due to Maryland’s mid-latitude location, the jet stream is often in the vicinity, particularly in the late fall, winter, and spring. In addition, Maryland’s location on the East Coast of the North American continent exposes it both to the cold winter and warm summer air masses of the continental interior and the moderate and moist air masses of the western Atlantic Ocean. In winter, the contrast between frigid air masses of the continental interior and the relatively warm Atlantic Ocean provides the energy for occasional intense storms commonly known as nor’easters. As a result of these varying influences, Maryland’s climate is characterized by moderately cold and occasionally snowy winters and warm, humid summer.

Average annual temperature has risen by more than 1.5 degrees Fahrenheit (°F) in Maryland since the beginning of the 20th century. Historically unprecedented warming is projected by the end of the 21st century under a higher emissions pathway. Heat waves are projected to be more intense while cold waves are projected to be less intense (Runkle & Kunkel, 2017).

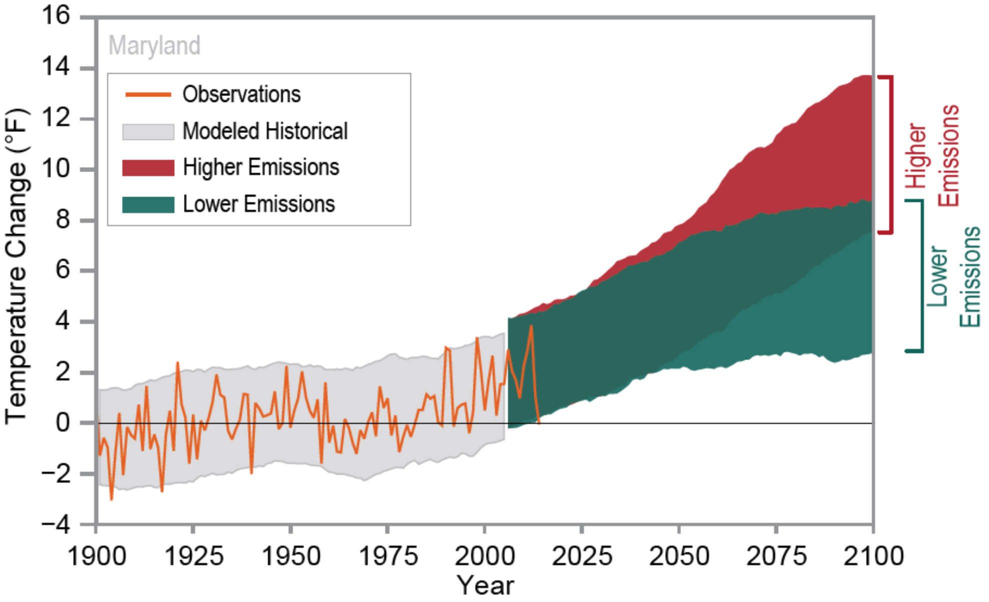


Figure 3. Observed and Projected Temperature Change for Maryland (Source: NOAA)

E.6. PRECIPITATION TRENDS

According to NOAA’s Maryland State Summaries, average annual precipitation varies from around 50 inches in the extreme west to around 40 inches just to the east of the Appalachian Mountains. The wettest period was the 1970s, with the wettest 5-year period being 1971–1975, while the driest period was the 1960s, with the driest five-year period being 1962–1966. Annual mean precipitation has been above average for the last two decades. The annual number of extreme precipitation events (days with more than 2 inches) averaged 2.5 days per year during 2005–2014 compared to 1.8 days per year during 1950–2004.

Maryland is susceptible to several extreme weather types including tropical storms and hurricanes, severe thunderstorms, tornadoes, nor’easters, blizzards and ice storms, flooding, drought, and heat and cold waves. Hurricane Irene in 2011 caused considerable wind damage along the coast. Hurricane Sandy in 2012 caused damage from wind and a storm surge of 4–5 feet, which destroyed a large portion of Ocean City’s fishing pier and caused widespread flooding in Crisfield and other low-lying areas of the lower Eastern Shore. On June 29, 2012, a derecho (a widespread, long-lived line of thunderstorms with very strong winds) moved through the Ohio Valley and the Mid-Atlantic states; Maryland and Washington, D.C. were two of the hardest hit areas. One-third of Maryland residents and one-quarter of D.C. residents were left without power after the storm, with some outages lasting longer than a week. Mountainous terrain in the narrow, western portion of the state, and the dense urbanized areas of the state are each highly vulnerable to flash flooding. During August 12–13, 2014, torrential rains of up to 6–10 inches occurred resulting in flooding along the coastal plain from Baltimore into New Jersey. This event resulted in the second highest calendar day precipitation total (6.3 inches on August 13) since 1933. Most recently, an extreme precipitation event occurred on July 30, 2016, impacting Ellicott City with 6 inches of rain in several hours and causing two fatalities.

Average annual precipitation is projected to increase in Maryland over the 21st century, particularly during winter and spring (Figure 4). This is part of a large-scale pattern of projected increases in precipitation over northern and central portions of North America. More frequent intense rainfall events are projected, potentially increasing flooding events in urban areas. The 100-year rain-storm event, as defined by historical data, is expected to occur every 20 to 50 years by the end of the century. Increasing and more intense extreme precipitation events will likely expand the flood hazard areas (areas that will be inundated by a flood event).

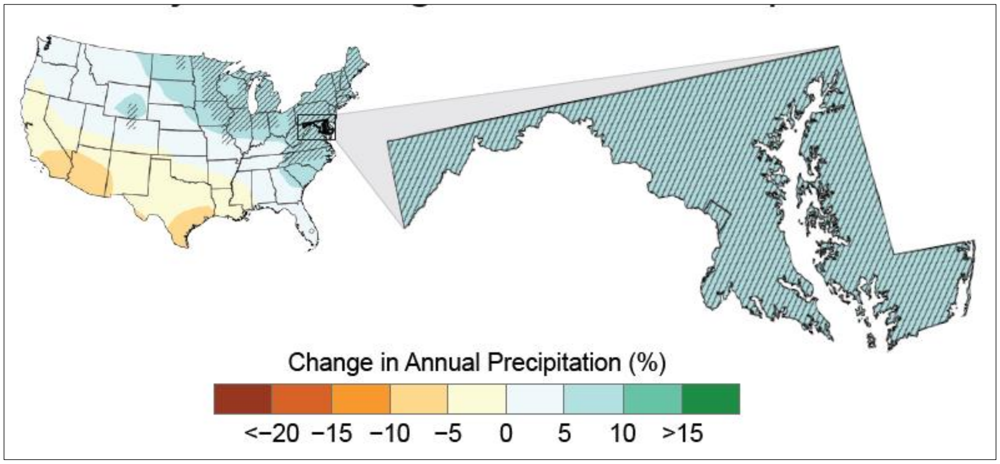


Figure 4. Projected Change in Annual Precipitation (Source: NOAA)

E.7. STREAMFLOW TRENDS

Studies of trends and non-stationarity in streamflow data collected over the past century have been performed throughout the continental U.S., some of which include the Mid-Atlantic Region. Xu et al. (2013) investigated trends for multiple stream gages in the Mid-Atlantic Region. No statistically significant ($p < 0.05$) trends in either annual streamflow or baseflow were identified for any of the stations in the Mid-Atlantic Region. These results are supported by Kalra et al. (2008) who analyzed historical streamflow (1952 – 2001) for over 600 flow stations throughout the U.S., including a large number in the Mid-Atlantic Region. None of the stations in the region exhibited statistically significant ($p < 0.05$) trends, in either direction, for annual or seasonal streamflow. (USACE, 2015).

E.8. WATERSHED VULNERABILITY ASSESSMENT

The USACE Watershed Vulnerability Assessment (VA) Tool provides a nationwide, screening-level assessment of climate change vulnerability relating to the USACE mission, operations, programs, and projects. Indicators are used to develop vulnerability scores specific to each of the 200 watersheds within the contiguous United States and to each of the USACE business lines. The Weighted Order Weighted Average (WOWA) method is used to aggregate individual vulnerability indicators and their associated datasets into the watershed scale vulnerability scores. The WOWA score combines indicators using a weighting technique to control how much an indicator with a small value can average out an indicator with a large value, thereby affecting perceived vulnerability. An increasing WOWA score is increasing in vulnerability. The VA Tool is based on downscaled climate information and hydrology aggregated at the watershed level for selected indicator variables. The tool supports a qualitative identification of potential vulnerabilities for more detailed study (USACE, 2020).

The VA Tool examines the vulnerability of projects within all the USACE business lines using data for two scenarios and three epochs. The epochs include the current time period as the base period and two future 30-year periods centered on the years 2050 (2035-2065) and 2085 (2070-2099). Within each future epoch, GCMs are sorted by cumulative runoff projections and divided into two equal-sized groups that represent a Dry scenario and a Wet scenario. All results are thus given for each combination of scenario and future epoch: Dry-2050, Dry-2085, Wet-2050 and Wet-2085. The VA Tool allows the user to explore dominant indicators and summarize vulnerability in several different ways for each scenario/epoch combination. The current study will use the VA Tool to perform such an analysis on Coastal Maryland (HUC 0206), which includes the BHAC area, with emphasis on the indicators of vulnerability for the primary business line, Navigation.

Table 2 provides the name of selected indicators for the Navigation business line and the importance weight within the VA Tool within a National Standard View, along with a brief description of each.

Table 2. Number, name, and description of selected indicators for the Navigation Business Line within the VA Tool

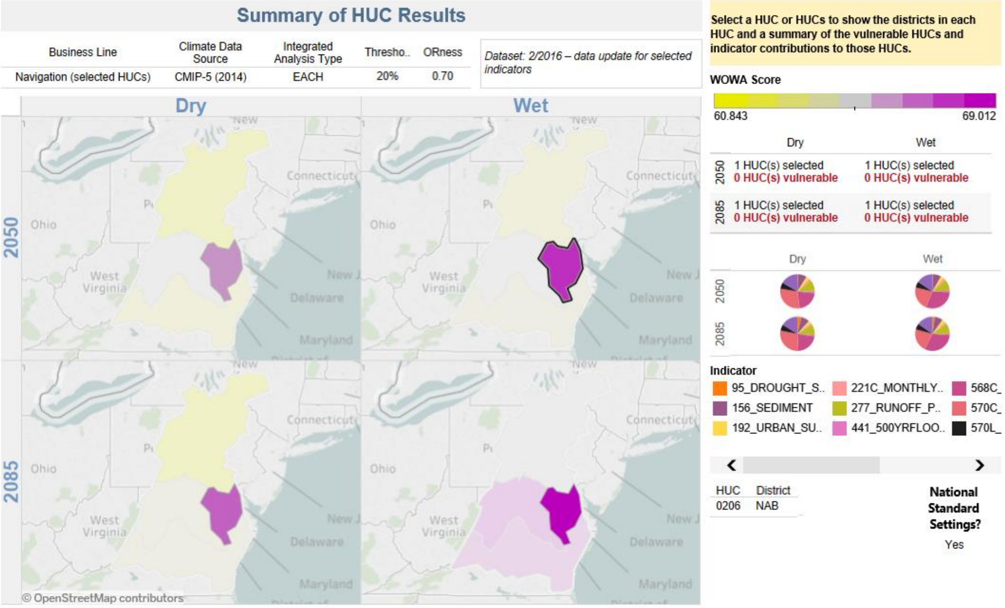
IMPORTANCE WEIGHT	NAME	DESCRIPTION
2.0	FLOOD MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.
2.0	DROUGHT SEVERITY	Greatest precipitation deficit: The most negative value calculated by subtracting potential evapotranspiration from precipitation over any 1-, 3-, 6-, or 12-month period.
1.75	90% EXCEEDANCE	Low runoff: monthly runoff that is exceeded 90% of the time,including upstream freshwater inputs (cumulative).
1.50	SEDIMENT	The ratio of the change in the sediment load in the future to the present load.
1.50	RUNOFF PRECIPITATION	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.
1.50	LOW FLOW REDUCTION	Change in low runoff: ratio of indicator 570C (monthly runoffexceeded 90% of the time, including upstream freshwater inputs) to 570C in base period.
1.25	90% EXCEEDANCE	Low runoff: monthly runoff that is exceeded 90% of the time,excluding upstream freshwater inputs (local).
1.0	URBAN SUBURBAN	Land area that is urban or suburban as a percentage of the total U.S. land area.
1.0	MONTHLY COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes upstream freshwater inputs (cumulative).
1.0	0.2 AEP FLOODPLAIN AREA	Area in the 0.2% Annual Exceedance Probability floodplain

To set the context of this watershed nationally, within the USACE North Atlantic Division (NAD), and within the Baltimore District (NAB), Table 3 lists the vulnerability scores for the Navigation business line for HUC 0206 as well as the range of scores nationally and for NAD and NAB for all scenario-epoch combinations. Vulnerability of the Navigation business line within HUC 0206 for the 2085 epoch for both wet and dry scenarios appear to be ranked near the top in the Baltimore District. For all dry scenarios and epochs HUC 0206 appears to rank closer to average nationally and rank slightly below in the North Atlantic Division average. For all wet scenarios and epochs HUC 0206 appears to rank slightly below national average and rank slightly above the North Atlantic Division average. For HUC 0206, no scenarios or epochs classify as vulnerable for the Navigation business line when compared to the rest of the nation (top 20%). These results suggest that climate impacts may be considered low in the planning and design of navigation within HUC 0206, including the Seagirt Study.

Table 3. Vulnerability Scores for HUC 0206 (WOWA Score) for the Navigation business line for each scenario-epoch combination nationally, NAD and NAB

Business Line	Epoch	WOWA Score	Range Nationally	Range in NAD	Range in NAB
Navigation	Dry -2050	65.858	54.86 - 77.47	60.84–66.82	60.84 –66.30
	Dry -2085	66.301			
	Wet -2050	67.494	56.39 - 84.43	61.79 –70.14	62.90 –69.01
	Wet - 2085	69.012			

Figure 5 shows the HUC 206 highlighted from yellow to pink based on the WOWA score. To the right of the figure shows a pie chart for each scenario, showing the weighted contributing indicators to vulnerability.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Thresho..	ORness
Navigation (selected HUCs)	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

	Dry	Wet
2050	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable
2085	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable

HUC	District
0206	NAB

National Standard Settings?
Yes

Figure 5. The Navigation WOWA Score

E.9. SEA-LEVEL CHANGE OVERVIEW

The climate assessment for RSLR follows the USACE guidance of Engineer Regulation (ER) 1100-2-8162, “Incorporating Sea Level Change in Civil Works Programs,” and Engineer Pamphlet (EP) 1100-2-1, “Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation.” ER 1100-2-8162 and EP 1100-2-1 provide guidance for incorporating the direct and indirect physical effects of projected future RSLR across the project life cycle in managing, planning, engineering, designing, constructing, operating, and maintaining the USACE project. Planning studies and engineering designs over the project life cycle, for both existing and proposed projects, will consider alternatives that are formulated and evaluated for the entire range of possible future rates of RSLR.

Per guidance from Engineering and Construction Bulletin (ECB) 2018-14, “Guidance for Incorporating Climate Change Impacts to inland Hydrology in Civil Works Studies, Designs, and Projects,” for project areas at elevations less than or equal to 50 feet NAVD88, a determination should be made as to whether RSLR will affect the river stage or performance/operation of the project by increasing (or decreasing) the water surface elevation downstream of the project area. If the project area is at an elevation less than or equal to 50 feet, then policy and procedures outlined in ER 1100-2-8162 will apply. For this project which is located at elevations less than 50 feet NAVD88; therefore, sea level guidance in ER 1100-2-8162 will apply.

RSLR has been a persistent trend for decades in the United States and elsewhere in the world. Observed and reasonably foreseeable global RSLR means that local sea levels will continue to rise beyond the end of this century. In most locations, global sea level change results in local RSLR, which has already caused impacts such as flooding and coastal shoreline erosion to the nation's assets located at or near the ocean. These impacts will continue to change in severity. Along the U.S. Atlantic Coast alone, almost 60 percent of the land that is within a vertical meter of sea level is planned for further development. Wise decision-making requires adequate information on the potential rates and amount of RSLR. To better empower data-driven and risk-informed decision-making, the USACE has developed two web-based SLC tools: Sea Level Change Curve Calculator and the Sea Level Tracker. Both tools provide a consistent and repeatable method to visualize the dynamic nature and variability of coastal water levels at tide gauges, allow comparison to the USACE projected RSLR scenarios, and support simple exploration of how RSLR has or will intersect with local elevation thresholds related to infrastructure (e.g. roads, power generating facilities, dunes), and buildings. Taken together, decision-makers can align various RSLR scenarios with existing and planned engineering efforts, estimating when and how the sea level may impact critical infrastructure and planned development activities (USACE, 2018b).

Both the Sea Level Change Curve Calculator and the Sea Level Tracker are designed to help with the application of the guidance found in ER 1100-2-8162 and EP 1100-2-1. The tools use equations in the regulation to produce tables and graphs for the following three RSLR scenarios:

1. Baseline (or "low") estimate, which is based on historic RSLR and represents the minimum expected RSLR.
2. Intermediate estimate.
3. High estimate, representing the maximum expected RRSLR.

The calculator accepts user input—including project start date, selection of an appropriate NOAA long- term tide gauge, and project life span—to calculate projected RSLR for the respective project. The Sea Level Tracker has more functionality for quantifying and visualizing observed water levels and RSLR trends and projections against existing threshold elevations for critical infrastructure and other local elevations of interest (USACE, 2018b). The start date used by the calculator is 1992, which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001.

E.9.1. Historic and Existing Conditions Relative Sea Level Rise

Although all the management measures proposed for the BHAC are located within 5 miles of Maryland's coast, there will be not direct effects to the hydrologic boundaries governing the performance and operation of BHAC project features. Estuary boundaries may change due to RSLR, but the estuary changes are not anticipated to affect the BHAC project features.

E.9.2. NOAA Tidal Gauge 8574680 at Baltimore Harbor

The nearest NOAA tide gauge located approximately 2 miles northeast of Baltimore Harbor at Fort McHenry, see Figure 6. The relative sea level trend is 3.22 mm/year +/-

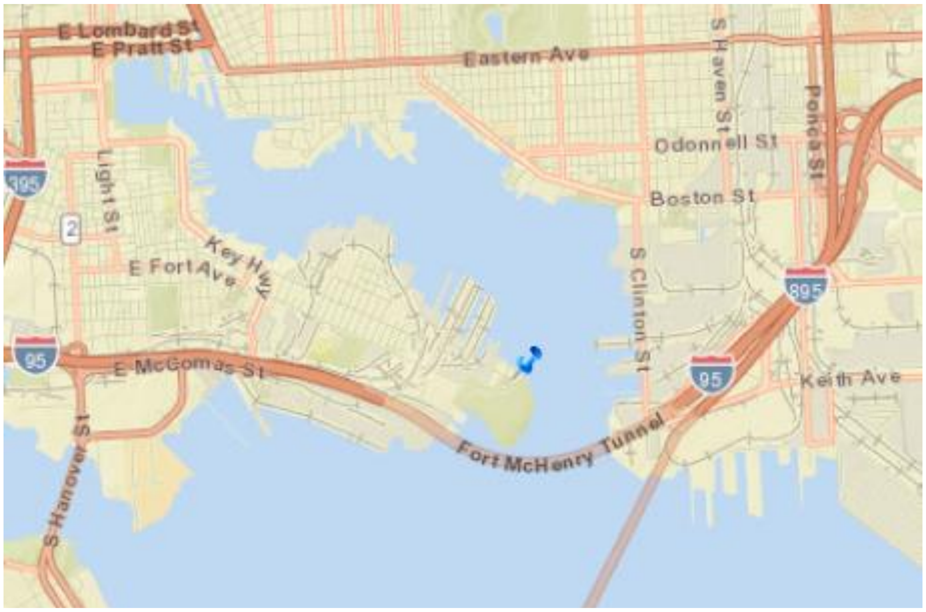


Figure 6. Location map of Fort McHenry tide gauges near the BHAC project

0.13 mm/year, equivalent to 0.127 inches/year +/- 0.005 inches/year, with a 95% confidence interval. This trend is based on monthly mean sea level data from 1897 to 2021 which is equivalent to a change of 1.2 feet in 100 years (NOAA, 2021). Figure 7 shows historical RSLR trend for NOAA tide gauge near Baltimore Harbor.

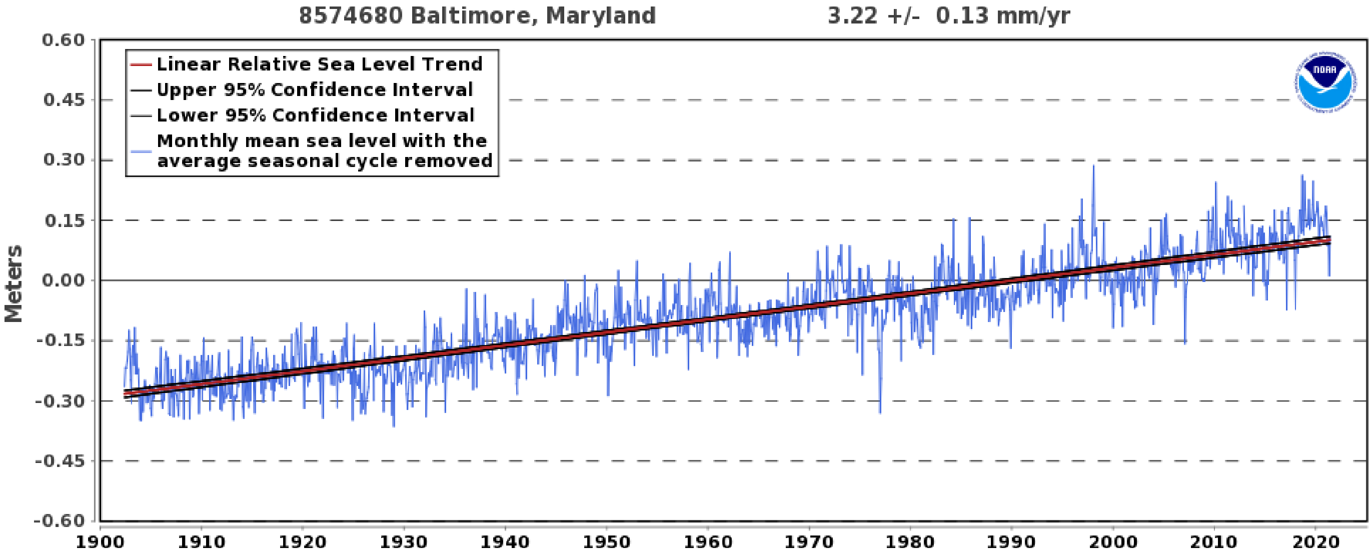


Figure 7. Historic relative sea level trend from Baltimore, MD

E.9.3. NOAA Tidal Gauge 8575512 at Annapolis, MD

The NOAA tide gauge 8575512 at Annapolis, MD is located approximately 20 miles southeast of Baltimore Harbor, see Figure 8. The relative sea level trend is 3.71 mm/year +/- 0.20 mm/year, equivalent to 0.146 inches/year +/- 0.008 inches/year, with a 95%

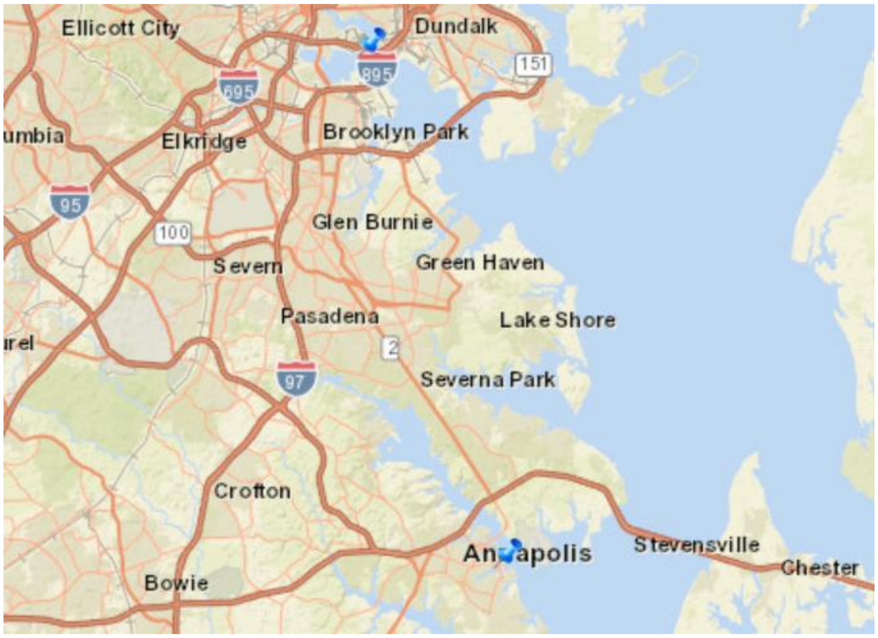


Figure 8. Location map of Fort McHenry tide gauges near the BHAC project

confidence interval. This trend is based on monthly mean sea level data from 1928 to 2020 which is equivalent to a change of 1.22 feet in 100 years (NOAA, 2021). Figure 9 shows historical RSLR trend for NOAA tide gauge near Annapolis, MD.

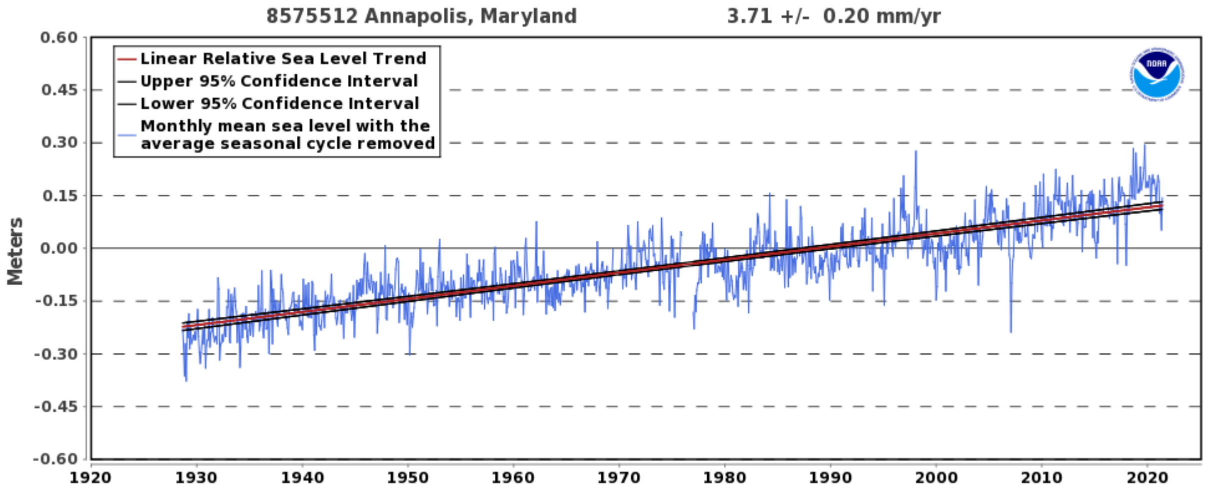


Figure 9. Historic relative sea level trend from Baltimore, MD

E.9.4. Potential Impacts to the Project from Future Sea-level Change

The following analysis evaluates potential effects on operation of Baltimore Harbor. The project start of construction date is 2025, the following years are evaluated:

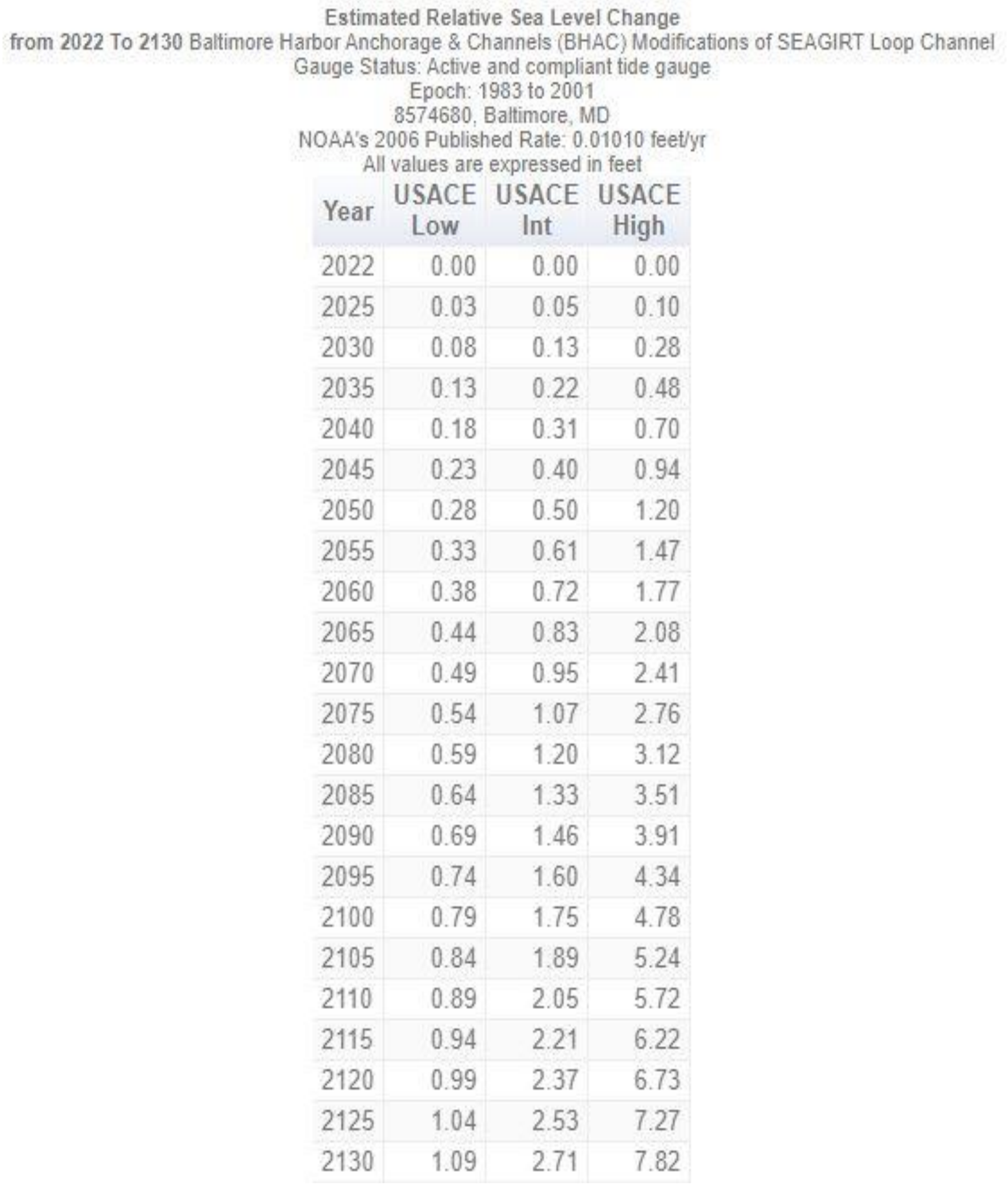
- 2030 (beginning of the BHAC planning horizon at the completion of construction)
- 2080 (50 years beyond completion of construction)
- 2130 (100 years beyond completion of construction)

Climate for which the project is designed can change over the planning life cycle of that project and may affect its performance, or impact operation and maintenance activities. Given these factors, the USACE guidance from ECB 2018-14, suggests that the project life cycle should be up to 100 years. For most projects, the project life cycle starts when construction is complete which typically corresponds to the time when the project starts accruing benefits. For the BHAC, the project life cycle begins in 2030, when construction is planned to be complete. The navigation benefits could ultimately be affected in the 2080 and 2130 conditions. The economic analysis is concluded for a 50-year planning horizon. Hence, RSLR considerations can show the magnitude of those impacts and will depend on how soon the sea rises to a level that impacts project performance.

Sea levels around Baltimore Harbor are expected to rise, depending on the projected rates of rise for low, intermediate, and high scenarios. Table 4 shows the estimated relative RSLR from 2022 to 2130, calculated with the USACE Sea Level Change Curve

Calculator, Version 2019.21, at Baltimore, Maryland NOAA gauge. The values shown for the Low, Intermediate and High USACE scenarios is rise in mean sea level .

Table 4. Estimated USACE low, intermediate and high RSLR projections at Baltimore Harbor, Maryland in feet relative to base year 2022, from years 2022 to 2130 (https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html).

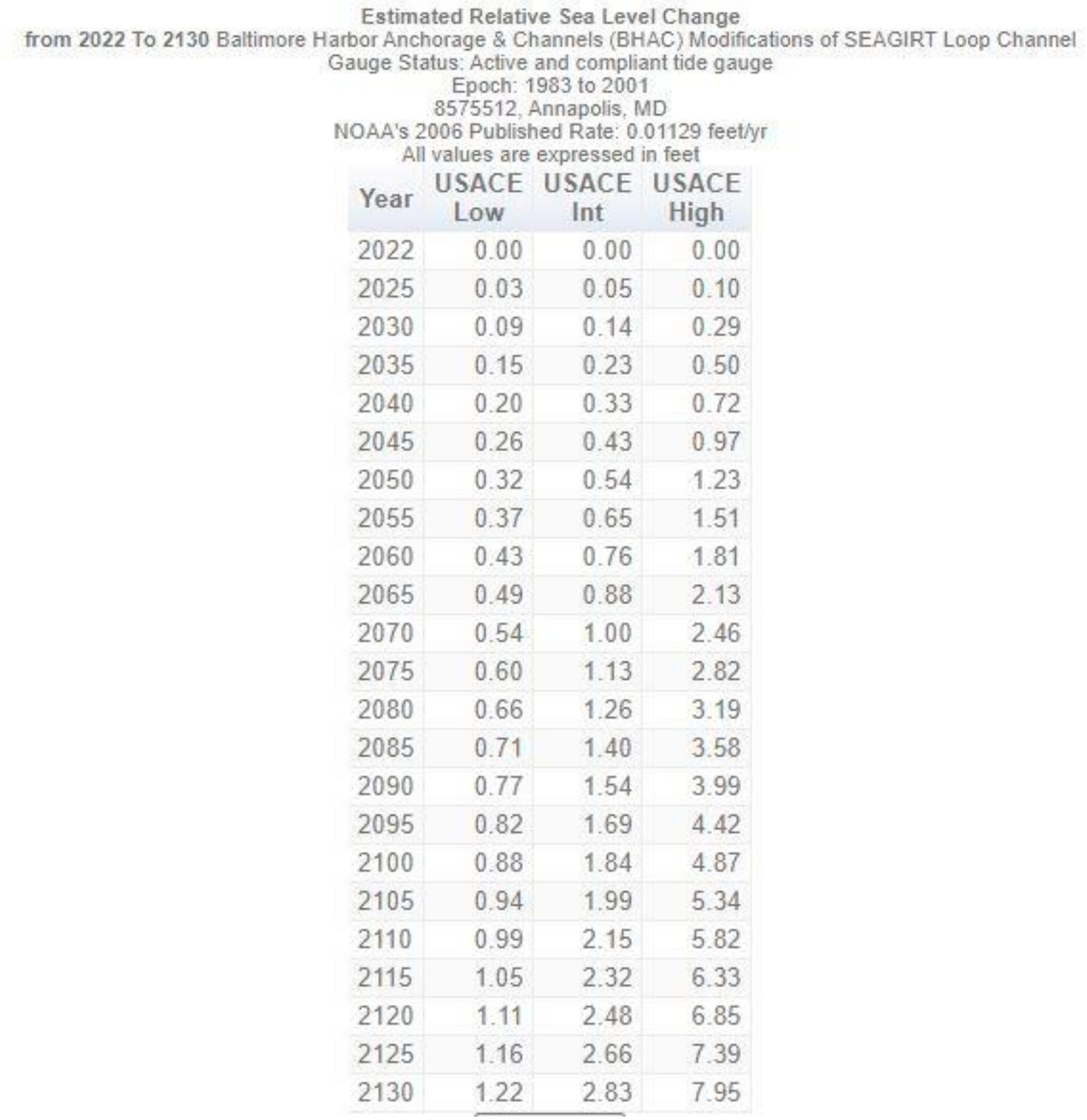


Estimated Relative Sea Level Change
from 2022 To 2130 Baltimore Harbor Anchorage & Channels (BHAC) Modifications of SEAGIRT Loop Channel
Gauge Status: Active and compliant tide gauge
Epoch: 1983 to 2001
8574680, Baltimore, MD
NOAA's 2006 Published Rate: 0.01010 feet/yr
All values are expressed in feet

Year	USACE Low	USACE Int	USACE High
2022	0.00	0.00	0.00
2025	0.03	0.05	0.10
2030	0.08	0.13	0.28
2035	0.13	0.22	0.48
2040	0.18	0.31	0.70
2045	0.23	0.40	0.94
2050	0.28	0.50	1.20
2055	0.33	0.61	1.47
2060	0.38	0.72	1.77
2065	0.44	0.83	2.08
2070	0.49	0.95	2.41
2075	0.54	1.07	2.76
2080	0.59	1.20	3.12
2085	0.64	1.33	3.51
2090	0.69	1.46	3.91
2095	0.74	1.60	4.34
2100	0.79	1.75	4.78
2105	0.84	1.89	5.24
2110	0.89	2.05	5.72
2115	0.94	2.21	6.22
2120	0.99	2.37	6.73
2125	1.04	2.53	7.27
2130	1.09	2.71	7.82

Table 5 shows the estimated relative RSLR from 2022 to 2130, calculated with the USACE Sea Level Change Curve Calculator, Version 2019.21, at Annapolis, Maryland NOAA gauge. The values shown for the Low, Intermediate and High USACE scenarios is the mean sea level expressed using NAVD88 elevation datum.

Table 5. Estimated USACE low, intermediate and high RSLR projections at Annapolis, Maryland in feet relative to 2022, from years 2022 to 2130 (https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html).



Estimated Relative Sea Level Change
from 2022 To 2130 Baltimore Harbor Anchorage & Channels (BHAC) Modifications of SEAGIRT Loop Channel
Gauge Status: Active and compliant tide gauge
Epoch: 1983 to 2001
8575512, Annapolis, MD
NOAA's 2006 Published Rate: 0.01129 feet/yr
All values are expressed in feet

Year	USACE Low	USACE Int	USACE High
2022	0.00	0.00	0.00
2025	0.03	0.05	0.10
2030	0.09	0.14	0.29
2035	0.15	0.23	0.50
2040	0.20	0.33	0.72
2045	0.26	0.43	0.97
2050	0.32	0.54	1.23
2055	0.37	0.65	1.51
2060	0.43	0.76	1.81
2065	0.49	0.88	2.13
2070	0.54	1.00	2.46
2075	0.60	1.13	2.82
2080	0.66	1.26	3.19
2085	0.71	1.40	3.58
2090	0.77	1.54	3.99
2095	0.82	1.69	4.42
2100	0.88	1.84	4.87
2105	0.94	1.99	5.34
2110	0.99	2.15	5.82
2115	1.05	2.32	6.33
2120	1.11	2.48	6.85
2125	1.16	2.66	7.39
2130	1.22	2.83	7.95

E.9.5. NOAA Tidal Gauge

E.9.6. NOAA Tidal Gauge 8574680 at Baltimore Harbor

The closest tidal gauge to Baltimore Harbor is NOAA tidal gauge 8574680 in Baltimore, Maryland. Using the USACE Sea Level Change Curve Calculator, the three projected RSLR levels relative to 2030 range between 0.51 feet to 2.84 feet by 2080 (50 years) and 1.01 to 7.54 feet by 2130 (100 years). The current RSLR rate is 0.01010 feet/year, from Table 4 for the Baltimore gauge. See Figure 10 for details on the three USACE-adopted projected trends.

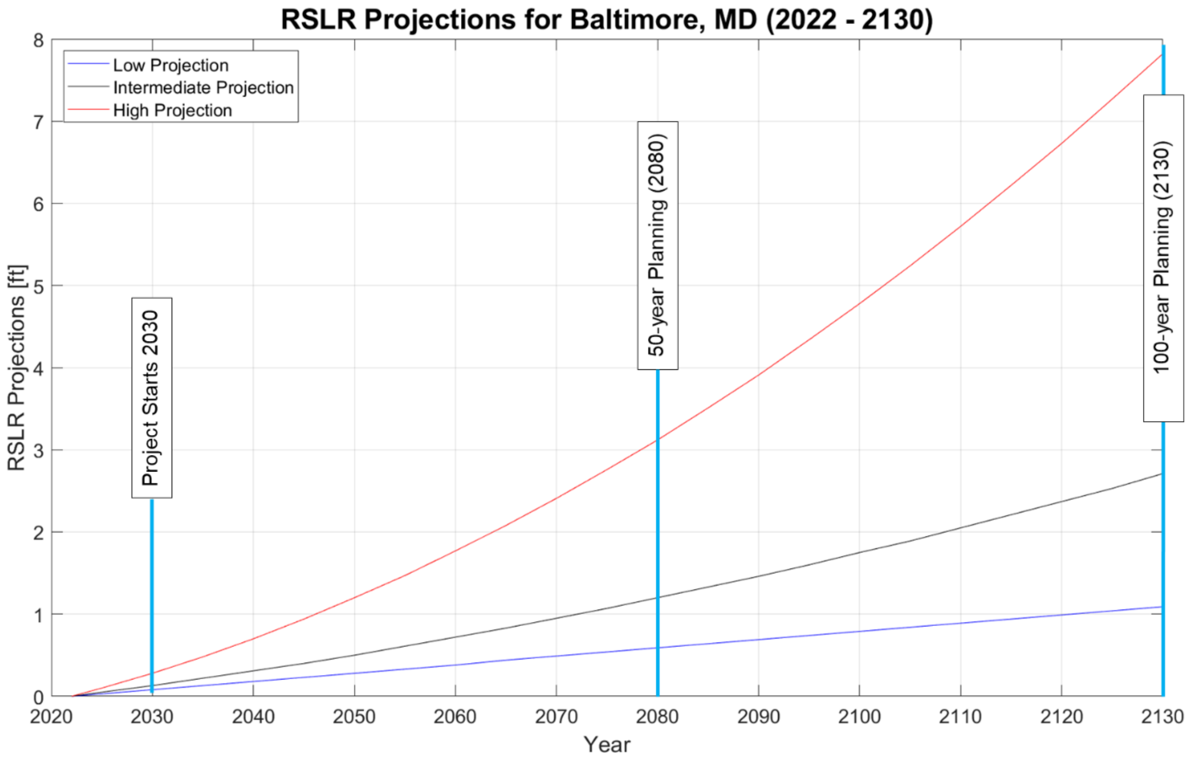


Figure 10. RSLR projections for Baltimore, Maryland NOAA Gauge (http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html).

Following the RSLR projections from Figure 10, the RSLR for the 50-year economic planning horizon is approximately 0.51 feet for the low projected curve, 1.07 feet for the intermediate projected curve and 2.84 feet for the high projected curve, relative to 2030. For the 100-year planning horizon the RSLR is estimated at approximately 1.01 feet for the low projected curve, 2.58 feet for the intermediate projected curve and 7.54 feet for the high projected curve.

E.9.7. NOAA Tidal Gauge 8575512 at Annapolis, MD

The NOAA Tide Gauge 8575512 at Annapolis, Maryland located 20 miles southeast of Baltimore Harbor. Using the USACE Sea Level Change Curve Calculator, the three projected RSLR levels relative to 2030 range from 0.57 to 2.90 feet by 2080 (50 years) and from 1.13 to 7.66 feet by 2130 (100 years). The current RSLR rate is 0.01129 feet/year, from Table 5 for the Annapolis gauge. See Figure 11 for details on the three USACE-adopted projected trends.

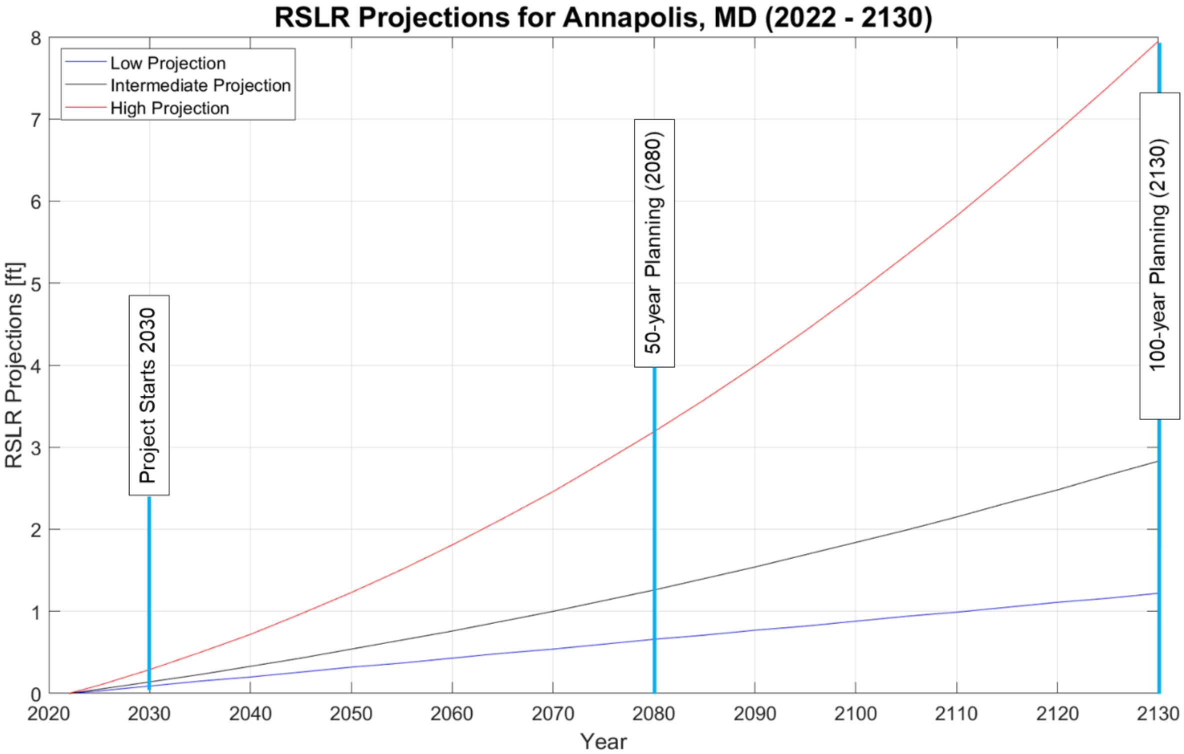


Figure 11. RSLR projections for Annapolis, Maryland NOAA Gauge (http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html).

Following the RSLR projections from Figure 11, the RSLR for the 50-year economic planning horizon is approximately 0.57 feet for the low projected curve, 1.12 feet for the intermediate projected curve and 2.90 feet for the high projected curve, relative to 2030. For the 100-year planning horizon the RSLR is estimated at approximately 1.13 feet for the low projected curve, 2.69 feet for the intermediate projected curve and 7.66 feet for the high projected curve.

E.10. IMPACTS ON THE BHAC BENEFITS DUE TO SEA-LEVEL CHANGE

The proposed channel modifications are an isolated section of widening and deepening, which will not affect the amount of tidal exchange entering the harbor, nor the tidal prism of the harbor. Therefore, it is assumed that the channel modifications will not change water levels from the existing water level and therefore RSLR, will have the same effect on any structural alternatives or, the No Action alternative.

Below in Figures 12 and 13, the NOAA Sea Level Rise Viewer was used to preliminarily understand what the effects of RSLR would look like at the port and the disposal area. Figures 12 and 13 shows inundated areas in blue, with dark blue being the deepest and lighter blue being shallower. Areas in green are low-lying areas. The NOAA RSLR viewer is a preliminary analysis and can be used for feasibility studies. The disposal area remains unflooded at the low, intermediate, and high RSLR projections. The Port of Baltimore’s Seagirt Marine Terminal appears to see inundation at a at 6 feet of RSLR along Colgate Creek with more significant flooding apparent at 7 feet of RSLR, see Figure 14. Please note that the inundation map by NOAA RSLR viewer is based on MHHW datum of 1992 base water elevation. However, the viewer does not provide maps at intermediate and/or fractional water elevation. Therefore, NAVD88 RSLR values, when converted to MHHW (1992) were used for generating the inundation maps. The maximum observed water level for the port was at 6.49-feet MHHW during Hurricane Isabel on September 19, 2003.

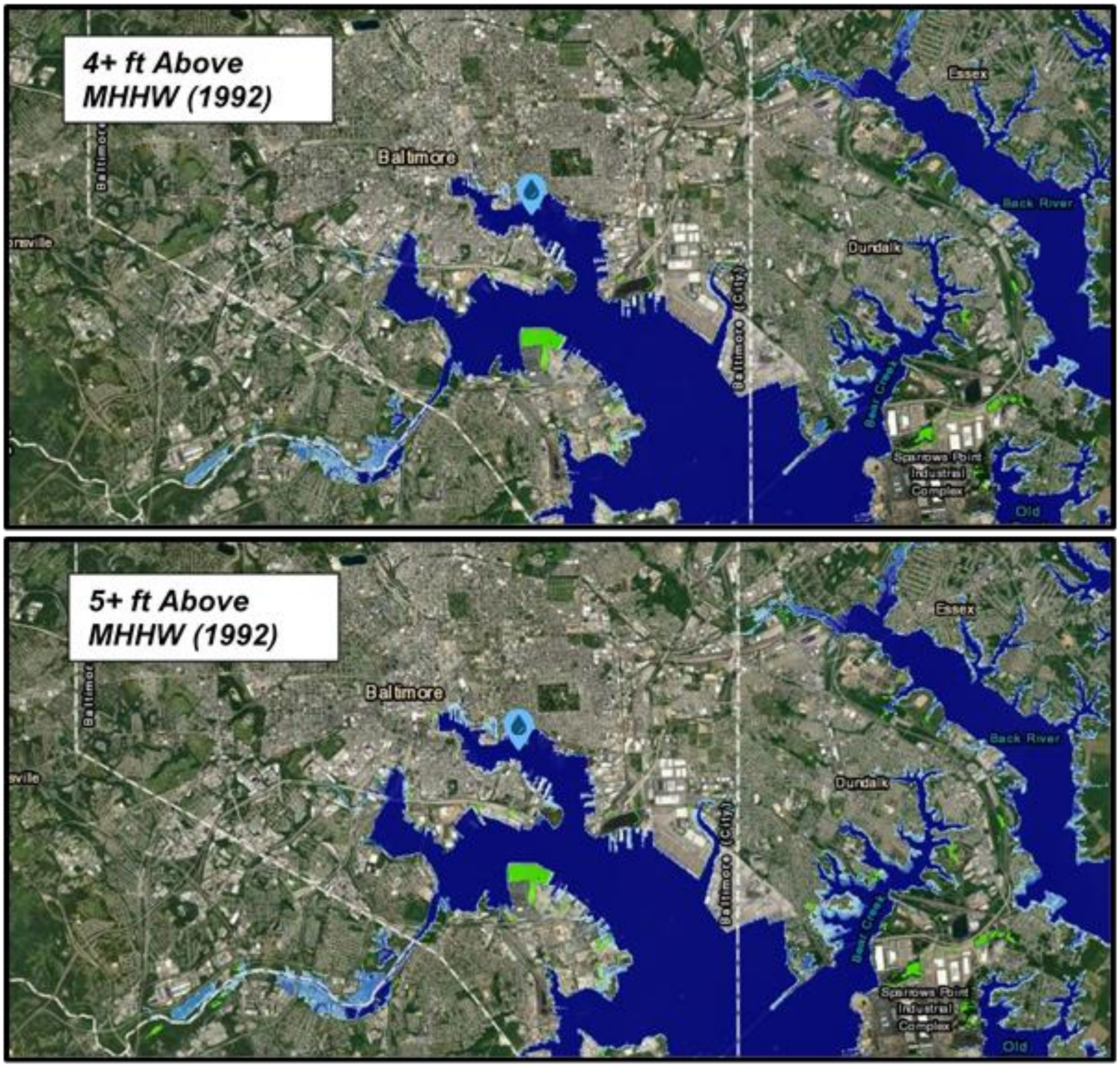


Figure 12. Sea Level Rise Viewer of Port of Baltimore Area. The top figure shows the Port Area at MHHW (1992) +4 feet of Sea Level Rise. The bottom figure shows the existing water level at Mean High Higher Water (1992) +5 feet (epoch: 1983-2001) (NOAA, 2020).

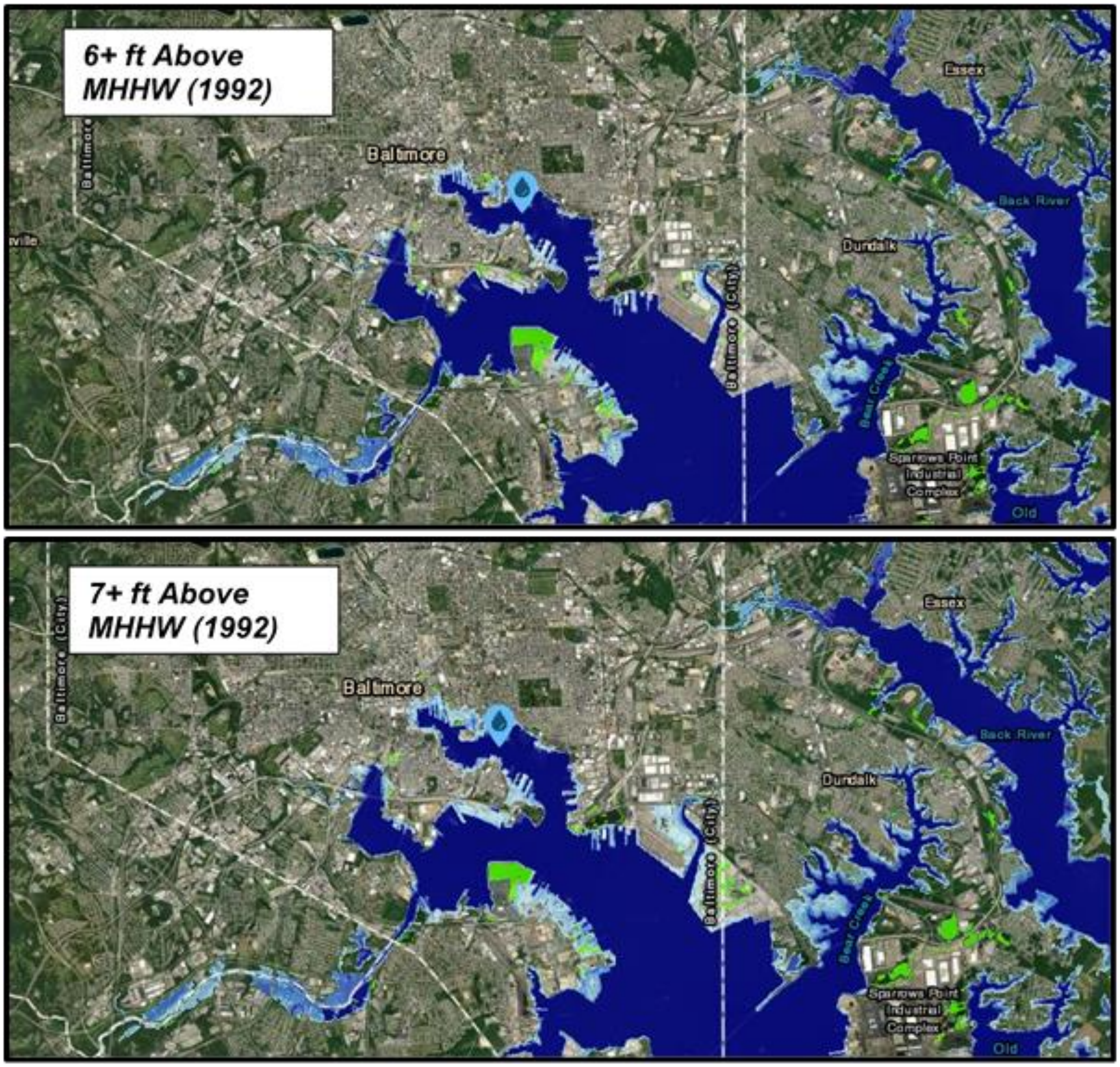


Figure 13. Sea Level Rise Viewer of Port of Baltimore Area. The top figure shows the Port Area at MHHW (1992) +6 feet of RSLR. The bottom figure shows the existing water level at Mean High Higher Water (1992) +7 feet (epoch: 1983-2001) (NOAA, 2020).

The tidal range of Baltimore Harbor is approximately 1.14 feet (Source: NOAA website: https://tidesandcurrents.noaa.gov/stationhome.html?id=8574680&units=standard). The estimated RSLR for the 50-year period of economic analysis ranges between 0.51 feet to 2.84 feet between the years of 2030 and 2080. Observed RRSLR from 1992 epoch through 2022 is 0.30 feet (using linear trend of 0.01010 feet/year). Up to an additional 0.28 feet of RRSLR could occur between 2022 and 2030 when construction is complete (for the USACE high projection), for a total of 0.58 feet in 2030. The maximum total increase in MHHW water surface elevation (WSEL) in 2080 under the USACE high projection is +3.42 feet MHHW 1992 (2.84 feet + 0.58 feet). It is unlikely that RSLR will affect the dock operations within the 50-year economic period of analysis. Further analysis, with higher resolution elevation data and RSLR models would be needed to develop further conclusions on flooding due to RSLR.

USACE will assess the need for modification as part of normal operations and maintenance actions. As part of normal maintenance of disposal areas, erosion and toe protection would be evaluated as needed. Low-lying and marsh areas will be impacted, and waterfront property owners will need to assess their own risk and adapt. The increase does not change any of the impacts over the without project condition alternative. It is expected that more tidal alerts would occur with higher RSLR.

The effect of RSLR on estuarine habitat will vary depending upon the location and elevation of the affected lands. Based on the topography and the existing infrastructure, inland impacts from RSLR on estuaries will be restricted primarily to increased water depths and saline conditions in the estuaries and canal systems, as the majority of the coastline is built out and protected by seawalls and other hardened structures. RSLR has the potential to effect harbor hydrodynamics including tides, currents, wave growth and fetch, and possibly sedimentation and shoaling. Wave growth and fetch could potentially increase with deeper waters that are inundating more area horizontally. Deeper water could potentially reduce velocities deeper in the water column and allow more sediment to settle our or change existing shoaling patterns. It does not appear that RSLR will change any of the impacts over the without project condition alternative. In order to reach further conclusions of changes in harbor hydrodynamics, additional modeling would need to be completed.

RSLR during the next century will increase the exchange and circulation of Atlantic Ocean water with waters in the Baltimore River, Patapsco River and Bear Creek. The effect of this would be a more saline condition overall and a shift in salinity ranges and their location within the estuary.

To reduce the risk associated with implementing the project, flexibility in the design and operation of features can be incorporated into the project during the planning phases. Features planned and operated for one purpose can be repurposed as RSLR begins to affect water management needs in the future.

E.11. SUMMARY FINDINGS

These are the summary findings of the climate change assessment:

1. The effects of RSLR have been analyzed per ER 1100-2-8162 and EP 1100-2-1.
2. The USACE requires that all existing and planned studies evaluate climate change for inland hydrology and sea level if the project's elevation is less than 50 feet NAVD88.
3. A qualitative climate change assessment of inland hydrology was conducted per ECB 2018-14 using the USACE statistical tools that evaluate observed and future climate trends.
4. A quantitative climate assessment of RSLR was conducted per ER 1110-2-8162 using a USACE statistical tool that projects future RSLR.
5. The sea level change in the Baltimore Harbor is only forecasted to be Relative Sea Level Rise (RRSLR).
6. Impacts from RSLR are unchanged from the No Action Alternative versus all Action Alternatives.
7. Inland hydrology is not expected to affect Baltimore Harbor, because it is the outlet of the drainage area.
8. Shoaling rates, shoreline changes, velocities and salinity were not evaluated with regard to climate change at this preliminary stage of the project.
9. The disposal area remains unflooded at the low, intermediate, and high RSLR projections.
10. The Port of Baltimore's Seagirt Marine Terminal appears to see inundation at a at 6 feet of RSLR along Colgate Creek with more significant flooding apparent at 7 feet of RSLR, see Figure 14 in this Appendix.
11. As outlined in Appendix B2 the effects of RSLR on the air draft clearance (ADC) of the PPX III Max class vessels showed to be dependent on both the assumed projection scenario (low, intermediate, high) and the tide stage when the vessel would pass beneath the Chesapeake Bay Bridge. The low, intermediate, and high RSLR projection showed that ADC at MHW will be approximately 0.5 feet by 2095, 2060, and 2045, respectively. Under the High RSLR scenario, ADC may limit the PPX Class III Max vessels starting in 2045.

E.12. REFERENCE LIST

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