US Army Corps of Engineers®
Wilmington District

General Re-evaluation Report and Environmental Assessment Surf City, Onslow and Pender Counties, North Carolina Coastal Storm Risk Management Project

Appendix P: Changing Conditions Assessment

Final

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1.0 INTRODUCTION

To effectively incorporate change conditions adaptation and to increase resilience and decrease vulnerability of the Surf City nourishment, the first step was to identify where vulnerability exists. The current USACE Screening-Level Climate Change Vulnerability Assessment (VA) Tool and other tools described in Engineering & Construction Bulletin (ECB) 2018-14 were used in this analysis. This discussion will start with a literature review of climate observations and predictions before moving onto an analysis starting at the broad regional scale and finishing at the project level with the analysis. The project elevation is below 50 feet NAVD88, so a sea level change assessment will also be conducted in accordance with ECB 2018-14 guidance following Engineering Regulation (ER) 1100-2-8162 and Engineering Technical Letter (ETL) 1100-2-1.

2.0 LITERATURE REVIEW

The Surf City is in Water Resource Region number 03, the South Atlantic-Gulf Region. A January 2015 report conducted by the USACE Institute for Water Resources summarizes the available climate literature for this region. The report covers both observed and predicted changes using data published through 2014. **Figure 1** shows a summary matrix of the observed and projected trends used in the report.

Multiple studies focused on observed mean temperature, mean seasonal temperature and extreme temperatures. Generally, the studies concurred on increased average annual temperature (Carter et al, 2014, Patterson et al, 2012, Laseter et al, 2012). However, there are conflicting results on observed seasonal changes with some results showing warmer summers and colder winters (Wang et al, 2009) and others showing no observed seasonal changes (Westby et al, 2013). Analysis of global climate model (GCM) projections generally agree that over the next century mean annual temperatures will change with the largest increases in summer months (Carter et al, 2014; Elguindi and Grundstein, 2013; Qi et al, 2009; Tebaldi, 2006). The 2018 Fourth National Climate Assessment found increasing temperatures and increasing extreme heat events along the Southeast and projects increasing temperatures to continue in the future. The 2022 NOAA State Climate Summary for North Carolina show temperatures rising more than 1^{o}F since the beginning of the 20th century and projects the increase in temperatures to continue in the future.

Precipitation trend analysis for the South Atlantic-Gulf region showed mixed results with low consensus for increasing trends in annual precipitation totals and precipitation intensity, and moderate consensus for increasing extreme high precipitation events (Wang and Zhang, 2008; McRoberts and Nielsen-Gammon, 2011; Pryor et al., 2009). Wang and Zhang (2008) found an increase in extreme precipitation event frequency and Pryor et al. (2009) found a statistically significant increase in the number of precipitation days per year. Wang, Killick, and Fu (2013) investigated high and low extreme precipitation in the South-Atlantic Gulf region and supported the findings of Wang and Zhang (2008) with an increase in high extreme precipitation events but found no statistically significant change in the low extreme precipitation events. Analysis of GCM projections are split on future precipitation with some models showing more annual precipitation and others showing less (Bastola et al, 2007; Jayakody et al, 2013; Qi et al, 2009). There is general consensus on more intense and frequent storm events (Gao et al 2012; Tebaldi 2006; Wang and Zhang 2008). The 2018 Fourth National Climate

Assessment found increasing extreme rainfall events and projects this trend to continue in the future. The 2022 NOAA State Climate Summary for North Carolina found a small upward trend in total annual precipitation and an upward trend in the annual number of extreme precipitation events. The annual precipitation in North Carolina is projected to increase. The report also found the hurricane-associate storm intensity and landfall rates are project to increase with increasing temperatures.

Studies of stream gages in the regions have shown mixed results but have a moderate consensus on decreasing streamflow. Xu et al (2013) showed no statistically significant trend in stream flows. Kalra et al (2008) found a negative statistically significant trend in annual and seasonal stream flows. Small et al (2006) found a statistically significant negative trend for annual low flows at several gages across the region. GCM projections coupled with macro-scale hydrologic models show no clear consensus on future stream flow trends (Bastola et al, 2007; Carter et al, 2014; Hagemann et al, 2013; Irizarry-Ortiz et al, 2013; Qi et al, 2009; Wang et al 2013a; Wang et al 2013b). The 2018 Fourth National Climate Assessment projects increases in the frequency and severity of droughts in the Southeast US. The 2022 NOAA State Climate Summary for North Carolina also projects more intense droughts due to higher projected temperatures and increased rate of loss of soil moisture during dry spells.

Global (eustatic) sea level change is often caused by the global change in the volume of water in the world's oceans. Global sea level, referred to as global mean sea level, is the overage height of all the world's oceans. Relative sea level (RSL) change is the local change in the sea level relative to the elevation of the land at a specific point on the coast. RSLC is a combination of global SLC, changes in local estuarine and shelf hydrodynamics, regional oceanographic circulation patterns, river flow, and local vertical land motion (subsidence or uplift).

The NOAA 2022 Global and Regional Sea Level Rise Technical Report shows global sea level changing by 17 cm over the last 100 years (1920-2020) with noted acceleration since 1970. RSL change along the contiguous United States (CONUS) over the last 100 years averaged about 29 cm with the same noted acceleration as global sea level change. RSL along the CONUS is expected to change as much over the next 30 years as it has in the past 100 years. This expected change will cause tide and storm surge heights to increase leading to a change in US costal flood regimes, with major and moderate high tide flood events occurring as frequently in 2050 and minor and moderate high tide flood events occur today. Longer term future RSL prediction depend on future emissions pathways and for the CONUS coastline are about 0.6-2.2 m in 2100 and 0.8-3.9 m in 2150.

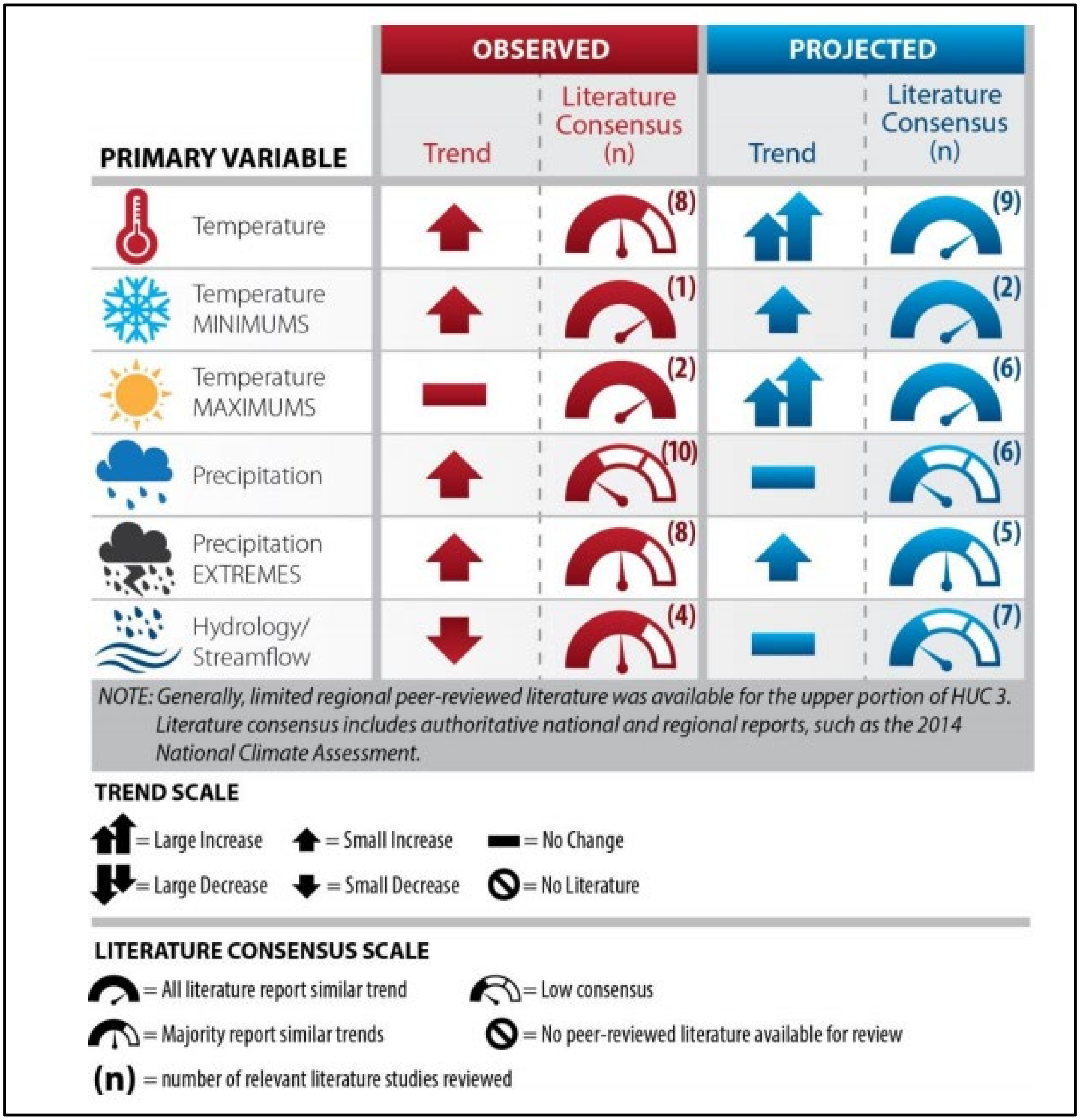

Figure 1. Summary matrix of observed and projected climate trends.

3.0 VULNERABILITY ASSESSMENT

With the knowledge that climate information and understanding is constantly evolving, USACE has developed the USACE Screening-Level Climate Vulnerability Assessment at the Watershed-Scale. The preliminary, screening-level nationwide analysis is built on existing, national-level tools and data that include indicators or processes to identify vulnerabilities in watersheds with respect to changing conditions. The USACE Watershed Climate Vulnerability Assessment (VA) Tool facilitates screening-level analysis of vulnerabilities of a given business line and HUC-4 watershed to the impacts of changing conditions, relative to the other continental United States HUC-4 watersheds. It uses the Coupled Model Intercomparison Project (CMIP5) GCM-BCSD-VIC dataset (2014) to define projected hydrometeorological inputs, combined with other data types, to define a series of indicator variables to define a vulnerability score. Vulnerabilities are represented by a weighted order weighted average (WOWA) score generated for two subsets of simulations (Wet - top 50% of cumulative runoff projections; and Dry - bottom 50% of cumulative runoff projections). Data are available for three epochs, the current epoch (Base), and two future 30-year epochs (centered on 2050 and 2085).

The VA Tool was used to examine the future flood risk reduction, emergency management, and recreation-related vulnerabilities of the project area in the Neuse-Pamlico watershed which are the three business lines impacted by this project. For the Neuse-Pamlico watershed (HUC 0302), this tool also shows that the area is projected to be relatively less vulnerable compared to the entirety of the USACE portfolio with respect to navigation and flood risk reduction business lines. While there is an increase in the WOWA scores between year 2050 and year 2085 for both the Dry and Wet scenarios (60.040 to 62.856 for Dry and 58.514 to 58.561 for Wet, respectively), the future increases still do not exceed the threshold for inclusion among the 20% most vulnerable HUC-4 watersheds represented by the recreation business line. For the flood risk reduction business line, which also does not exceed the threshold for inclusion among the 20% most vulnerable HUC-4 watersheds, there is also an increase in the WOWA scores between year 2050 and 2085 for both the Dry and Wet scenarios (45.129 to 47.590 for Dry and 48.158 to 51.991 for Wet, respectively). The emergency management business line also which also does not exceed the threshold for inclusion among the 20% most vulnerable HUC-4 watersheds. There is an increase in the WOWA score for the Dry scenario between the year 2050 and 2085 (66.254 and 68.850, respectively), but a slight decrease in the WOWA score for the Wet scenario (64.277 and 24.276)

The three largest indicators of vulnerability for the Emergency Management business line in the Neuse-Pamlico watershed (**Figure 3**) are low flow reduction, floodplain population, and disabled, except for the Wet scenarios for the Neuse-Pamlico where poverty population contributes more than low flow reduction. Low flow reduction is classified as the change in low flow, or the ratio of the runoff exceeded 90% of the time in the scenario to the base period. Low flow reduction contributes 17.67% of the vulnerability for the 2050 Dry scenario, 19.029% of the vulnerability for the 2085 Dry scenario, 8.00% of the vulnerability for the 2050 Wet scenario, and 7.581% of the vulnerability for the 2085 Wet Scenario. Floodplain population is the population withing the 500-year floodplain. Floodplain population contributes 14.18% of the vulnerability for the 2050 Dry scenario, 14.24% of the vulnerability for the 2085 Dry scenario, 17.65% of the vulnerability for the 2050 Wet scenario, and 17.70% of the vulnerability for the 2085 Wet scenario. Disabled population is percent of people disabled. Disabled population contributes 10.57% of the vulnerability for the 2050 Dry scenario, 10.58% of the vulnerability for the 2085 Dry scenario, 13.16% of the vulnerability for the 2050 Wet scenario, and 13.16% of the vulnerability for the 2085 Wet scenario. Poverty population is the number of people living below the poverty line. It contributes 10.11% of the vulnerability for the 2050 Wet scenario and 10.15% of the vulnerability for the 2085 Wet scenario.

The largest indicators of vulnerability for the Recreation business line in the Neuse-Pamlico watershed (**Figure 4**) are split and varied among low flow reduction, sediment, drought severity, 90% exceedance, 10% exceedance, and cumulative flood magnification.

Low flow reduction is classified as the change in low flow, or the ratio of the runoff exceeded 90% of the time in the scenario to the base period. Cumulative flood magnification is the change in flood runoff, or the ratio of the monthly runoff flow exceeded 10% of the time for the sicario compared to the base period including upstream freshwater flows. Sediment is the rate of change in the sediment load between the future and present sediment load. 90% exceedance is the monthly runoff that is exceeded 90% of the time. 10% exceedance is the monthly runoff that is exceeded 10% of the time. Drought severity is the most negative value calculated by subtracting potential evapotranspiration from precipitation over any 1-, 3-, 6- or 12-month period. The largest contributors for the 2050 Dry scenario are low flow reduction (21.75%), 90% exceedance (13.09%), and 10% exceedance (8.45%). The largest contributors for the 2085 Dry scenario are low flow reduction (21.24%), drought severity (14.94%), and sediment (14.94%). The largest contributors for the 2050 et scenario are low flow reduction (19.50%), 90% exceedance (12.77%), and 10% exceedance (8.63%). The largest contributors for the 2085 Wet scenario are low flow reduction (18.404%), 90% exceedance (12.47%), and cumulative flood magnification (9.08%) (**Figure 2**).

Floodplain population is the population withing the 500-year floodplain. Floodplain population contributes 14.18% of the vulnerability for the 2050 Dry scenario, 14.24% of the vulnerability for the 2085 Dry scenario, 17.65% of the vulnerability for the 2050 Wet scenario, and 17.70% of the vulnerability for the 2085 Wet scenario. Disabled population is percent of people disabled. Disabled population contributes 10.57% of the vulnerability for the 2050 Dry scenario, 10.58% of the vulnerability for the 2085 Dry scenario, 13.16% of the vulnerability for the 2050 Wet scenario, and 13.16% of the vulnerability for the 2085 Wet scenario. Poverty population is the number of people living below the poverty line. It contributes 10.11% of the vulnerability for the 2050 Wet scenario and 10.15% of the vulnerability for the 2085 Wet scenario.

The three largest indicators of vulnerability for the flood risk reduction business line for the Neuse-Pamlico watersheds are the cumulative flood magnification, the urban 500-year floodplain, and the local flood magnification. Cumulative flood magnification is the change in flood runoff, or the ratio of the monthly runoff flow exceeded 10% of the time for the sicario compared to the base period including upstream freshwater flows. Cumulative flood magnification contributes 20.37% of the vulnerability for the 2050 Dry scenario, 13.36% of the vulnerability for the 2085 Dry scenario, 22.60 % of the vulnerability for the 2050 Wet scenario, and 24.53% of the vulnerability for the 2085 Wet scenario. The urban 500-year floodplain is the acreage of urban landcover within the 500-year floodplain. Urban 500-year floodplain contributes 12.64% of the vulnerability for the 2050 Dry scenario, 21.67% of the vulnerability for the 2085 Dry scenario, 12.64% of the vulnerability for the 2050 Wet scenario, and 14.02% of the vulnerability for the 2085 Wet Scenario. Local flood magnification is the change in flood runoff, or the ratio of the monthly runoff flow exceeded 10% of the time for the sicario compared to the base period without upstream freshwater flows. Local flood magnification contributes 6.69% of the vulnerability for the 2050 Dry scenario, 6.75% of the vulnerability for the 2085 Dry scenario, 7.42% of the vulnerability for the 2050 Wet scenario, and 8.05% of the vulnerability for the 2085 Wet scenario.

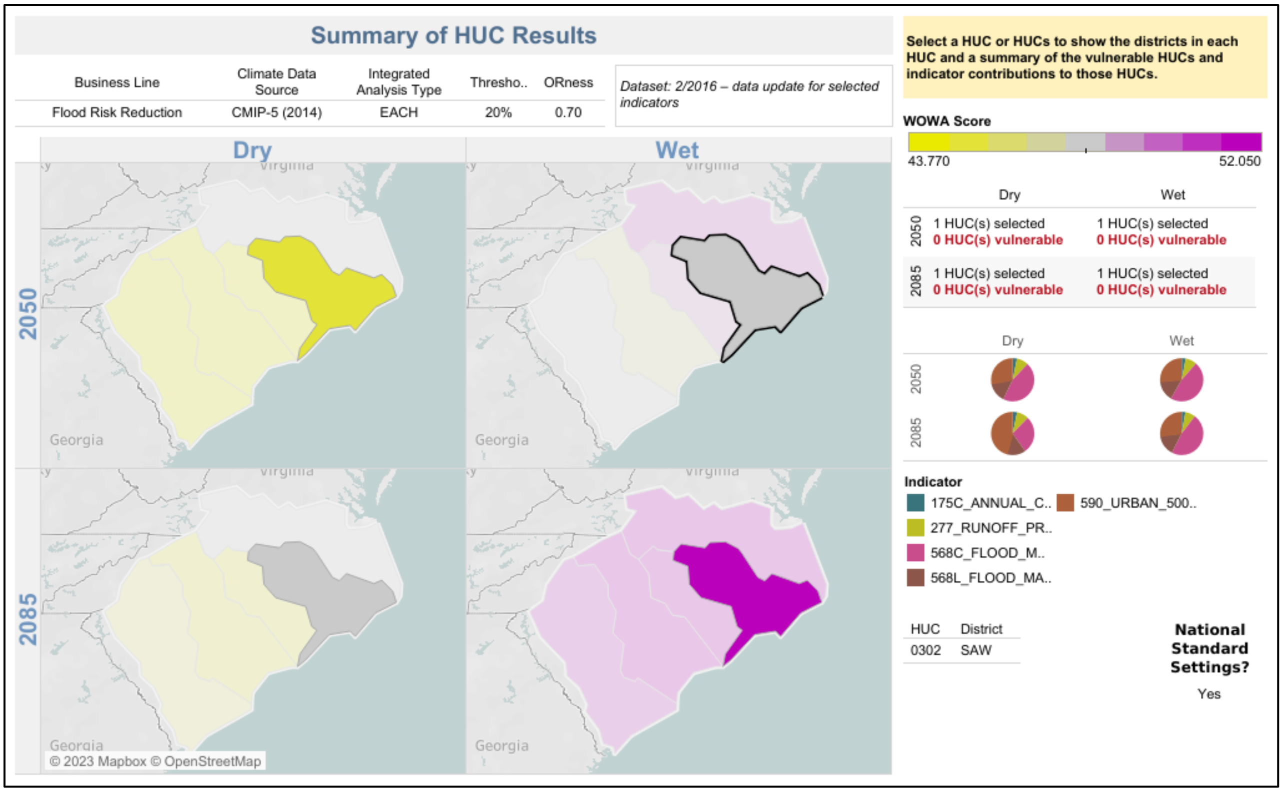

Figure 2. Projected Vulnerability for Chowan-Roanoke and Neuse-Pamlico Watersheds with respect to Flood Risk Reduction.

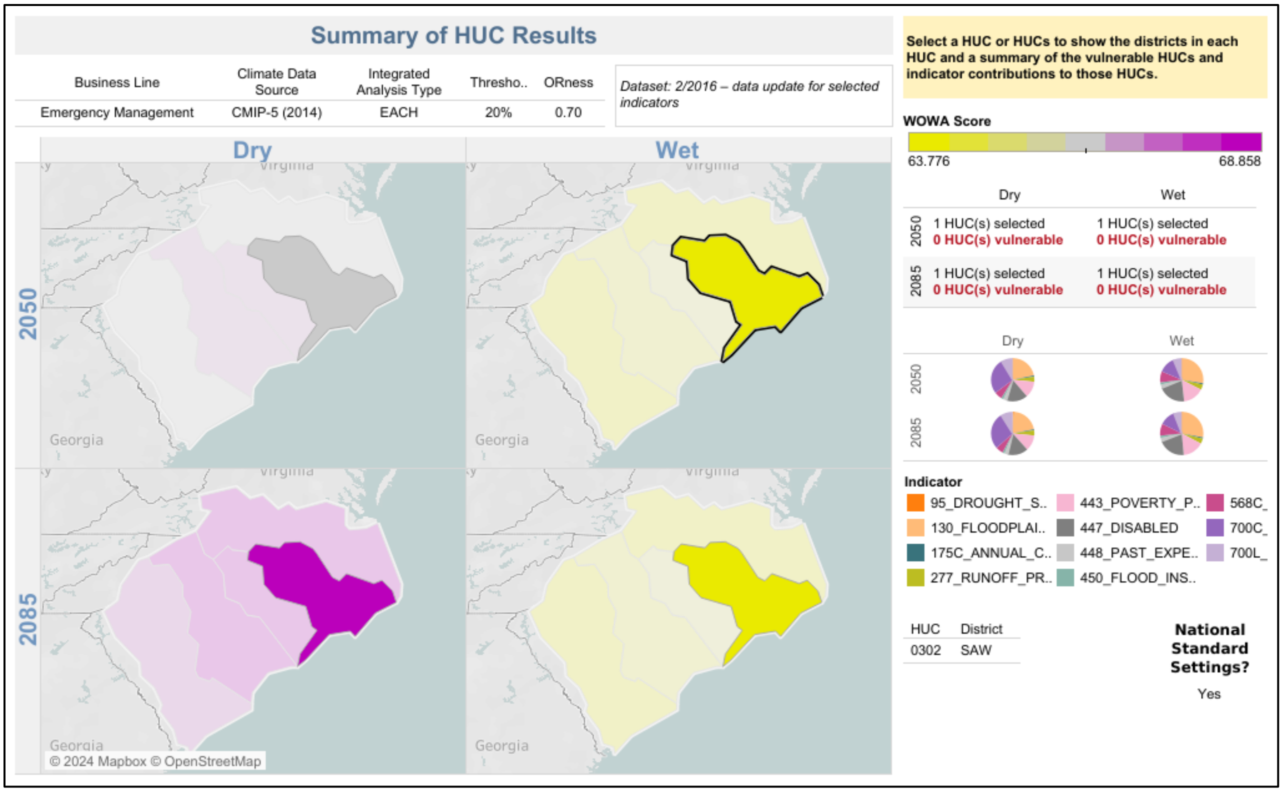

Figure 3. Projected Vulnerability for Chowan-Roanoke and Neuse-Pamlico Watersheds with respect to Emergency Management.

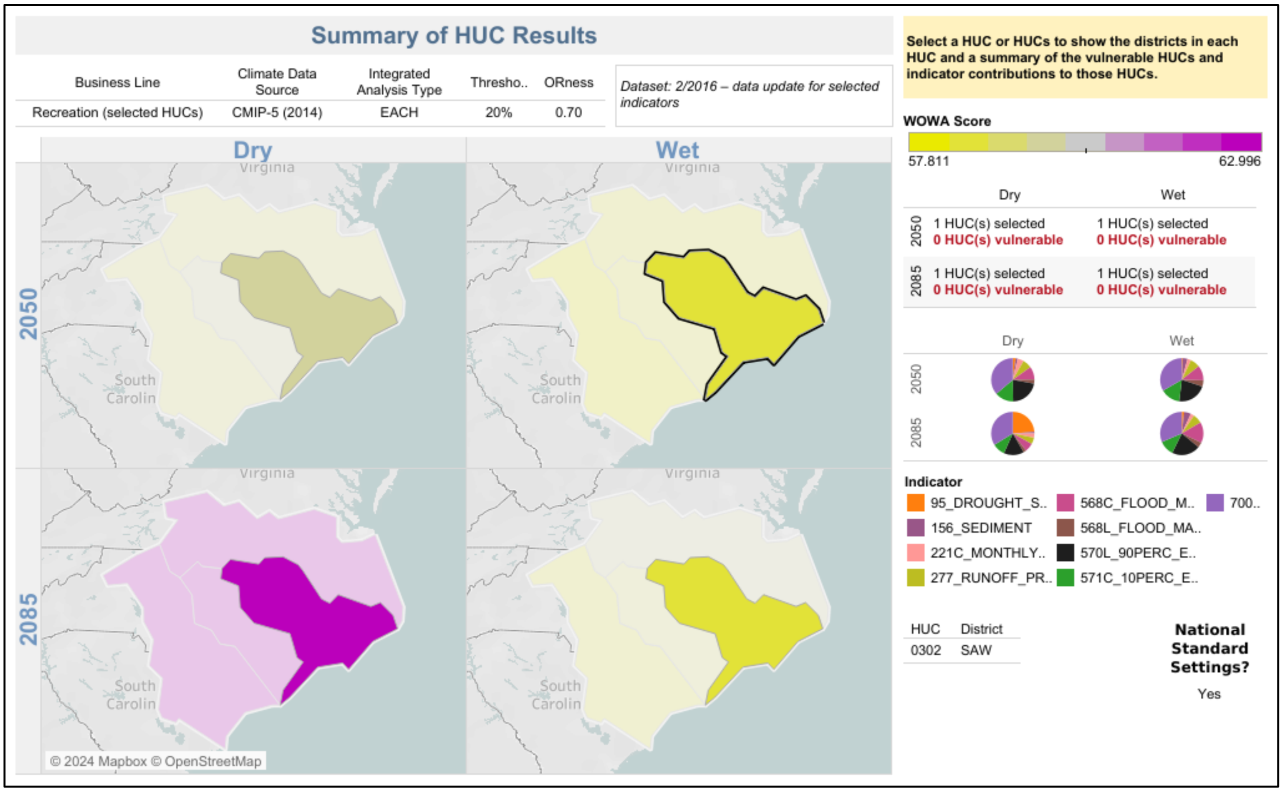

Figure 4. Projected Vulnerability for Chowan-Roanoke and Neuse-Pamlico Watersheds with respect to Recreation.

While the VA tool identifies watersheds that may or may not be relatively vulnerable, it may not be appropriate to cascade those results to the project by default, because projects exist at finer spatial scales than the HUC-4 watersheds. To give a fuller picture of the potential vulnerabilities at this project, additional tools were employed to assess conditions by investigating other data and projections.

4.0 CLIMATE HYDROLOGY ASSESSMENT TOOL

The USACE Climate Hydrology Assessment Tool (CHAT) was used to examine modeled, hindcast and projected trends in watershed hydrology to support the assessment, based on analysis of 32 general circulation model and 2 future emissions scenarios (representative concentration pathway) through the year 2099. The CHAT uses CMIP5-based simulations of hydrology and climatology, incorporating future projections of greenhouse gas emissions statistically downscaled using the Localized Constructed Analogs (LOCA) method. The CHAT compares a simulated hindcast period (1951-2005) to a simulated future period (2006-2099) of an unregulated basin condition using two different future emission scenarios (RCP 4.5 and RCP 8.5). The hindcast period simulation (1951-2005) assume greenhouse gas emissions to be equivalent to a reconstruction of historically observed greenhouse gas emission levels. The RCP 4.5 scenario represents a rising radiative forcing pathway stabilizing at 4.5 W/m^2 before 2100 and the RCP 8.5 scenario represents a rising radiative forcing pathway leading to 8.5 W/m^2 before 2100. Radiative forcing expresses the change in energy in the atmosphere due to greenhouse gas emissions. F Simulation data is available at the HUC-8 scale. The project area is within HUC 03030001. With the project location on the barrier islands, there is no streamflow, however the project area is still vulnerable to other changing climate variables, such as temperature and precipitation.

Simulated annual accumulated precipitation (**Figure 5**) has a not statistically significant increasing trend of 0.0198 in/year for the simulated hindcast period for the project watershed. Under the simulated future period with the RCP 4.5 scenario there is a statistically significant increasing trend of 0.0238 in/year. Under the simulated future period with the RCP 8.5 scenario there is a statically significant increasing trend of 0.0256 in/year.

Simulated historical annual mean temperatures (**Figure 6**) have a statistically significant trend of 0.0288 degF/year. For the simulated future period under the RCP 4.5 scenario there is a statistically significant increasing trend of 0.0407 degF/year. For the simulated future period under the RCP 8.5 scenario there is a statistically significant increasing trend of 0.0869 degF/year.

Simulated annual maximum temperatures (**Figure 7**) have a statistically significant trend of 0.0279 degF/year. For the simulated future period under the RCP 4.5 scenario there is a statistically significant trend of 0.0426 degF/year. For the simulated future period under the RCP 8.5 scenario there is a statistically significant increasing trend of 0.0984 degF/year.

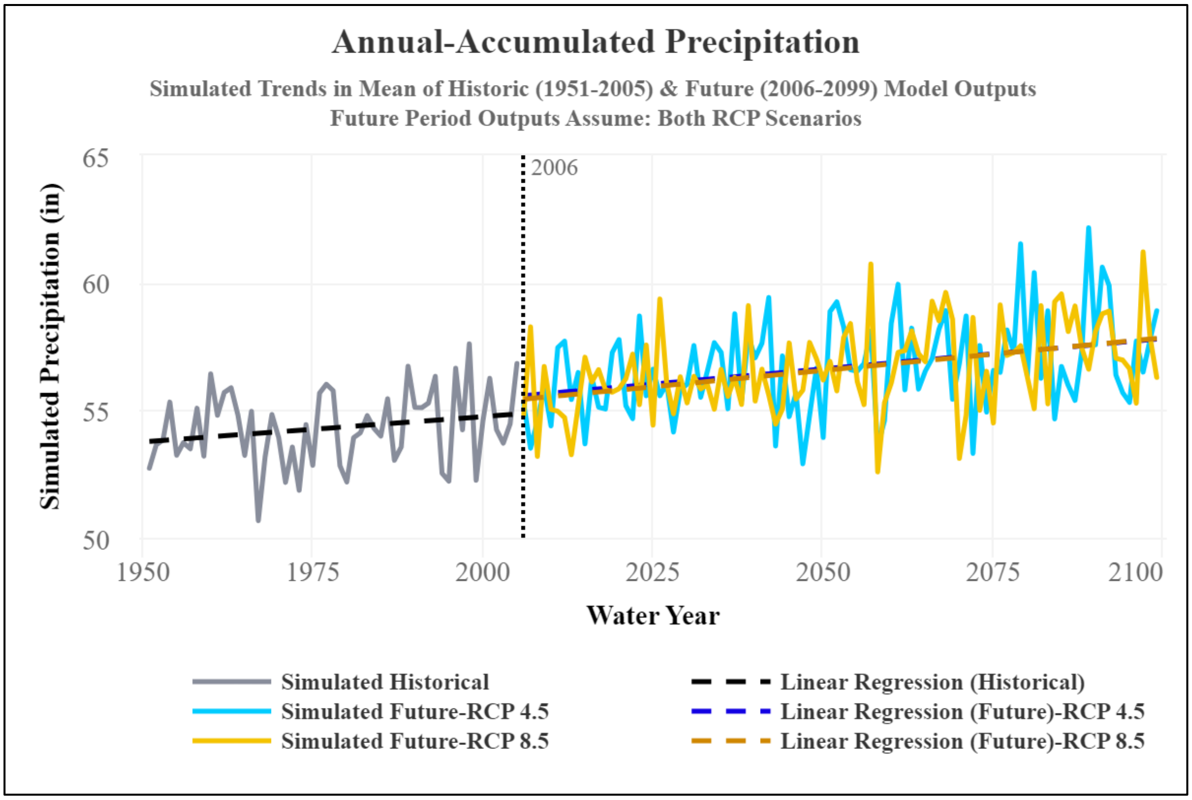

Figure 5. Trends in Projected Annual Accumulated Precipitation for the project area.

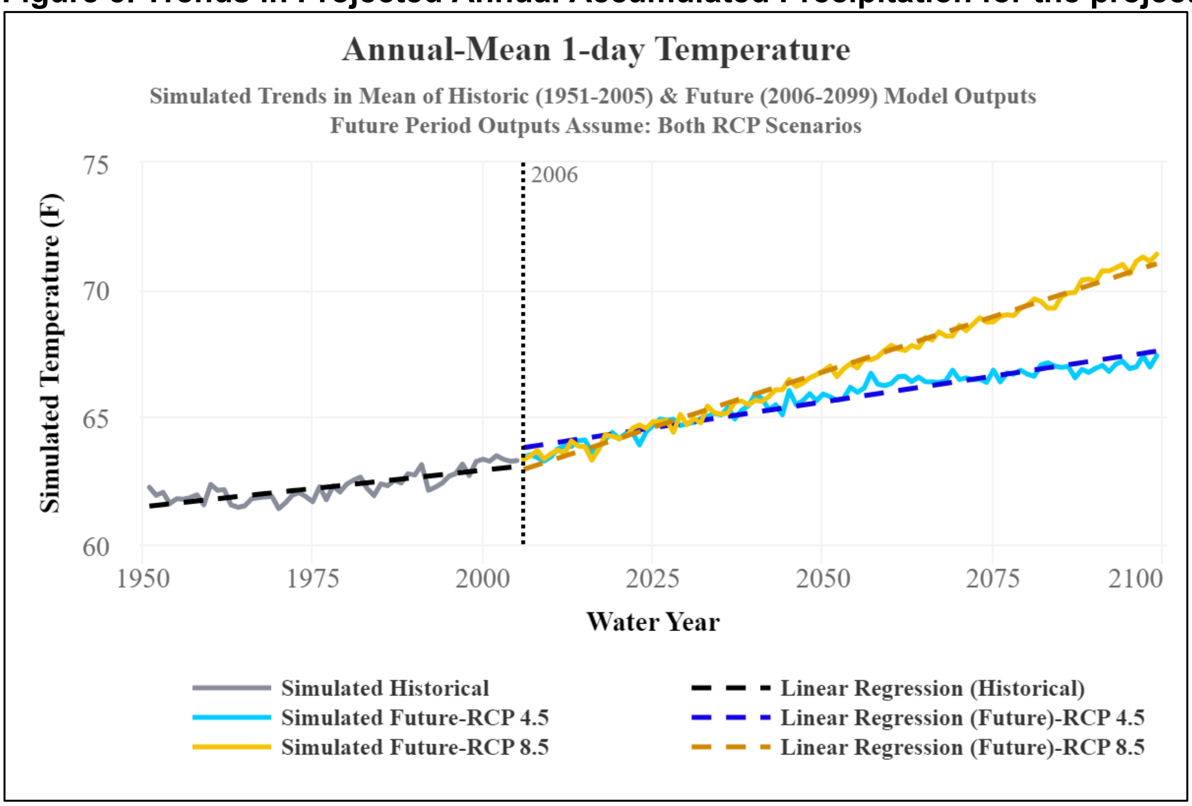

Figure 6. Trends in Projected Annual Mean Temperature for the Pamlico Sound Watershed.

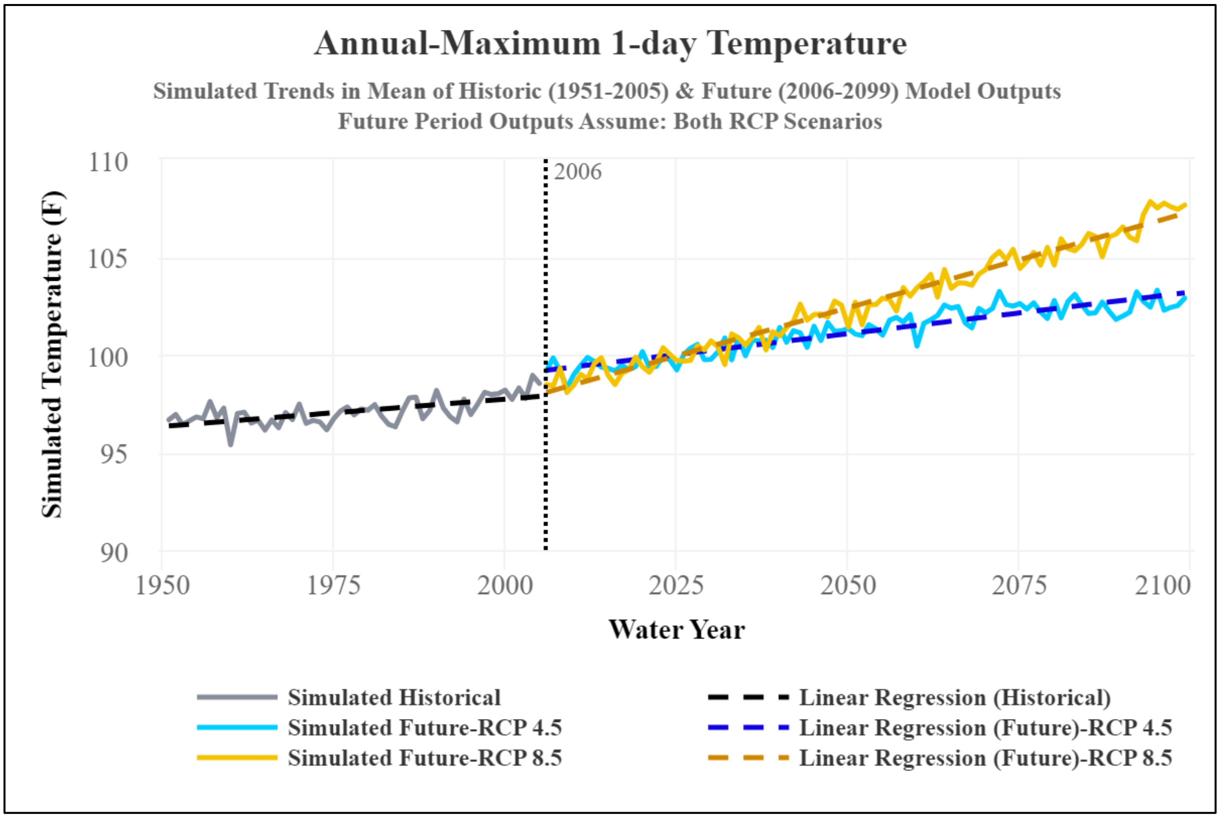

Figure 7. Trends in Projected Annual Maximum Temperature for the Pamlico Sound Watershed.

5.0 SEA LEVEL CHANGE

The historical SLC trends and future RSLC projection rates for the project were re-evaluated using guidance in Engineer Pamphlet (EP) 1100-2-1 "Procedures to Evaluate Sea Level Change: Impacts, Responses and Adaptation" (30Jun2019) and Engineer Regulation (ER) 1100-2-8162 (Dec 2013).

The Sea Level Tracker tool provides an estimate of observed sea level trends and projected RSLC curves (USACE 2023). The future RSLC projections are presented as "Low", "Intermediate", and "High" SLC scenarios based on global and local change effects. The historic MSL is represented as either 19-year or 5-year midpoint moving averages. Guidance in using the Sea Level Tracker and technical background is provided in the "Sea Level Tracker User Guide", Version 1.0, December 2018.

Table 1 summarizes the results of this analysis. The base year is shown (i.e., 2024) with a 100-year RSLC evaluation window. All estimates are presented in feet per mean sea level (ft/msl).

The updated RSLC projections informed the future risk associated with expected SLC. Trends provided by the Sea Level Tracker, since the original estimates for the 2010 Feasibility/EIS, indicate that RSLC at the project has decreased in acceleration.

Historical sea level trends were also re-evaluated for the project. For consistency with the 2010 Feasibility/EIS this analysis was based on the NOAA tide gauge located in Wilmington, North Carolina (Station #8658120), within the Cape Fear River and project area. The gauge is compliant and active with a historic record ranging from 1935 to present.

Figure 8 summarizes NOAA Gauge number 8658120's predicted SLC trends from 1992 to 2124. Trend lines represent SLC over the 19-Year (Metonic) epoch period and the 5-Year moving average. The light blue line represents the 5-year moving average and the heavy dark blue line represents the 19-year moving average. The 19-year average is useful in that this represents the moon's Metonic cycle and the tidal datum epoch. These estimates are referenced to the midpoint of the latest National Tidal Datum epoch, 1992. The red line in **Figure 9** is the High SLC prediction, the green is the Intermediate and the blue is the Low-rate prediction. The rates of observed sea level change can fluctuate over time, but generally the 19-year moving average is increasing to a rate between the High and Intermediate rates. The 5-year moving average significantly increased after 2013 and trends above the High rate.

Table 1. Wilmington, NC (Station #8658120) Relative Sea Level Change.

Project		USACE			NOAA			
Year	Year	Low	Int	High	Low	Int-Low	Int-High	High
Epoch	1992	-0.162	-0.162	-0.162	-0.162	-0.162	-0.162	-0.162
Original Authorization	2014	-0.008	0.036	0.178	-0.008	0.036	0.014	0.249
Start	2024	0.062	0.155	0.451	0.062	0.155	0.362	0.600
	2034	0.132	0.291	0.799	0.132	0.291	0.646	1.052
	2044	0.201	0.446	1.220	0.201	0.446	0.987	1.608
	2054	0.271	0.618	1.716	0.271	0.618	1.385	2.265
	2064	0.341	0.808	2.286	0.341	0.808	1.840	3.025
End	2074	0.411	1.015	2.929	0.411	1.015	2.352	3.888
	2084	0.481	1.240	3.648	0.481	1.240	2.922	4.853
	2094	0.551	1.484	4.440	0.551	1.484	3.548	5.919
	2104	0.621	1.744	5.306	0.621	1.744	4.232	7.089
	2114	0.691	2.023	6.246	0.691	2.023	4.973	8.360
	2124	0.761	2.320	7.261	0.761	2.320	5.771	9.735
2014 to 2024 Increase=		0.07	0.12	0.27	0.07	0.12	0.23	0.35
50 Year Increase=		0.35	0.86	2.48	0.35	0.86	1.99	3.29
100 Year Increase=		0.70	2.17	6.81	0.70	2.17	5.41	9.14

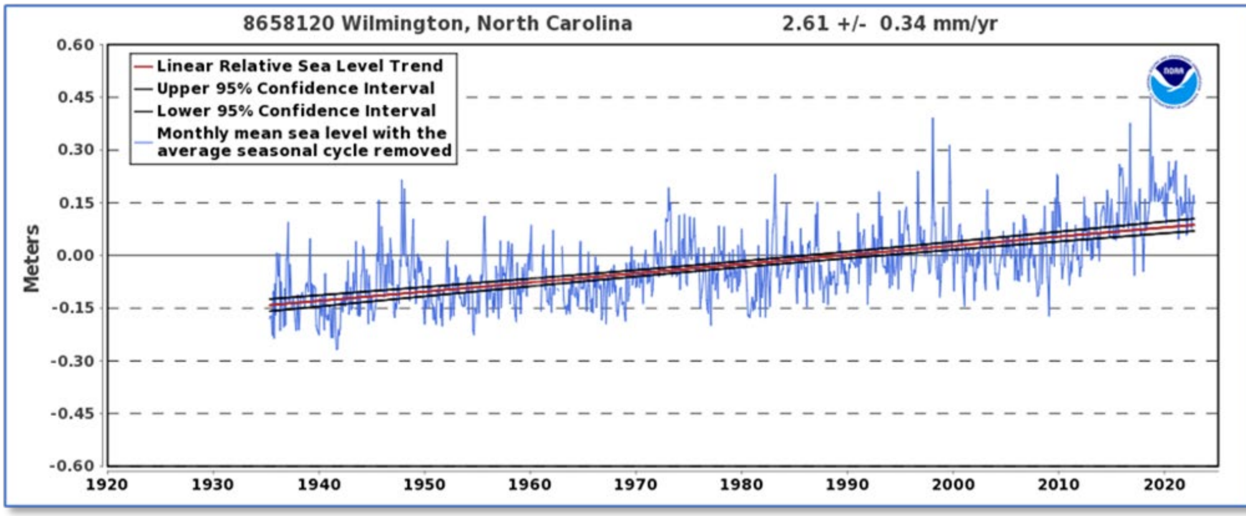

Figure 8. Relative Sea Level Trend, NOAA Gauge 8658120.

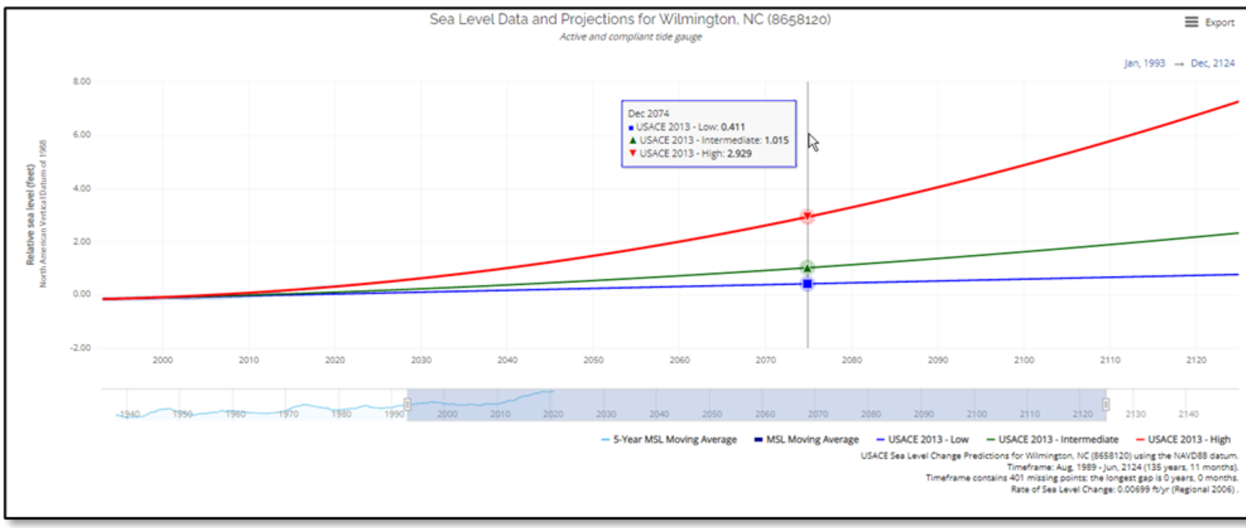

Figure 9. Wilmington gauge 8658120- USACE Sea Level Change Predictions, 1992 to 2124.

6.0 CONCLUSION

The Surf City Coastal Storm Risk Management (CSRM) project is a federally authorized beach nourishment project, undergoing a limited feasibility re-evaluation. Coastal protection is needed to reduce property damage, economic losses, and life-safety risks, as well as increase community resilience.

In the literature reviewed, temperatures are forecasted to increase in the future with more extreme rain events; however, there is less consensus on future annual precipitation totals. The changing conditionsis projected to lead to more extreme drought events. There is also potential for larger, more powerful tropical storms in the project area. These larger storms could lead to the need for a larger placement template or more frequent placement to provide the expected level of protection.

Within the project watershed, the CHAT tool predicts increasing annual maximum temperatures, annual mean temperatures, and annual precipitation in the simulated future period for both emissions scenarios (RCP 4.5 and 8.5).

An analysis of watershed climate vulnerability using the USACE VA Tool shows the area to be relatively less vulnerable for the emergency management, recreation, and flood reduction business lines compared to the entire USACE portfolio.

The potential for an increase in extreme drought events coupled with increased extreme rain events could lead to increased erosion in the project area. Increased erosion in the area could lead to more frequent nourishment intervals to provide the expected level of protection.

Increasing sea level trends have been observed at the Wilmington NC gauge. Over the next 50 years the sea level is expected to change up to 2.929 feet in this area. Increasing sea levels have the potential to require a larger placement template on the beach to provide the expected level of protection.

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