APPENDIX H

CLIMATE CHANGE ASSESSMENT
LOXAHATCHEE RIVER WATERSHED RESTORATION PROJECT

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H CLIMATE CHANGE ASSESSMENT ON THE LOXAHATCHEE RIVER WATERSHED RESTORATION PROJECT

This appendix discusses the climate change assessment performed for the Loxahatchee River Watershed Restoration Project (LRWRP). 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.

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

H.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 management infrastructure have the potential to be sensitive to changes in climate and weather. Therefore, USACE has a compelling need to understand and adapt to climate change and variability while continuing to provide authorized performance despite changing conditions. The objective of USACE Climate Preparedness and Resilience (CPR) Community of Practice (CoP) is to mainstream climate change adaptation in all activities to help enhance the resilience of USACE-built and natural water resource infrastructure, reducing its potential vulnerabilities to the effects of climate change.

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 managers 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 uncertainties of climate change and sea level change relative to USACE infrastructure. For the LRWRP analysis, there are two main assessments that are applied:

1) Sea-level Change — an assessment of the potential impacts from future sea level change.
2) Inland Hydrology — an assessment of trends and vulnerabilities associated with current and projected inland hydrology.

Sea level change and changes in storm and rainfall patterns associated with climate change could have a potentially dramatic impact on water resources infrastructure in the state of Florida, including the Loxahatchee River Watershed.

H.2 Key Findings

The list below includes the key findings discussed in this Appendix.

1) LRWRP is most vulnerable to climate change and at risk over the project life cycle (2020-2120) due to the following factors: increasing air temperatures, increases in extreme storm frequency and intensity, and rising sea-level elevations.
2) A quantitative climate assessment of SLR was conducted per ER 1100-2-8162 using a USACE statistical tool that projects future SLR. Results show that the S-46, S-117 and Masten Dam may be vulnerable to SLR when looking at the high SLC projection. Limitation to discharges for S-46 may be reduced with existing headwater conditions beginning in 2049. The Lainhart and Masten Dams are not being impacted by any future sea level rise scenario during the 100-year planning horizon. SLR does affect the hydrologic boundaries governing the performance and operation of the LRWRP project features; however, the with-project condition provides better ecological conditions and resiliency for the river then the future without project condition under all SLR scenarios.
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) Based on the vulnerability assessment, it would be beneficial for the project to account for risk due to climate change by developing a strategy for adaptive management of the project during PED. Adaptive management could be used as a means of ensuring that the project is resilient to the impact of climate change for the duration of the project life cycle. This includes ensuring that the design of the project and prescribed operations can easily be adapted to handle extreme wet and dry conditions, including floods and droughts. This will ensure that the plan selected is robust enough to accommodate changing climatic conditions. The impacts of climate change are appropriately captured within the uncertainty bounds already incorporated into the project design. Resiliency and adaptive management, however, should be revisited during PED.

H.3 Project Description

The purpose of the Loxahatchee River Watershed Restoration Project is to improve the timing and distribution of wet and dry season flows to the Northwest Fork of the Loxahatchee River floodplain to help restore native plant and animal species abundance and diversity in Loxahatchee River watershed natural areas, river, and estuary. The features proposed in the Tentatively Selected Plan (TSP) include an above ground 9,500 ac-ft reservoir, 4 Aquifer Storage & Recovery (ASR) wells, an approximately 1500 ac-ft shallow flow-through marsh, and multiple pump stations and water control structures that will assist in achieving the project objectives of Ecosystem Restoration, as seen in **Figure H-1**.

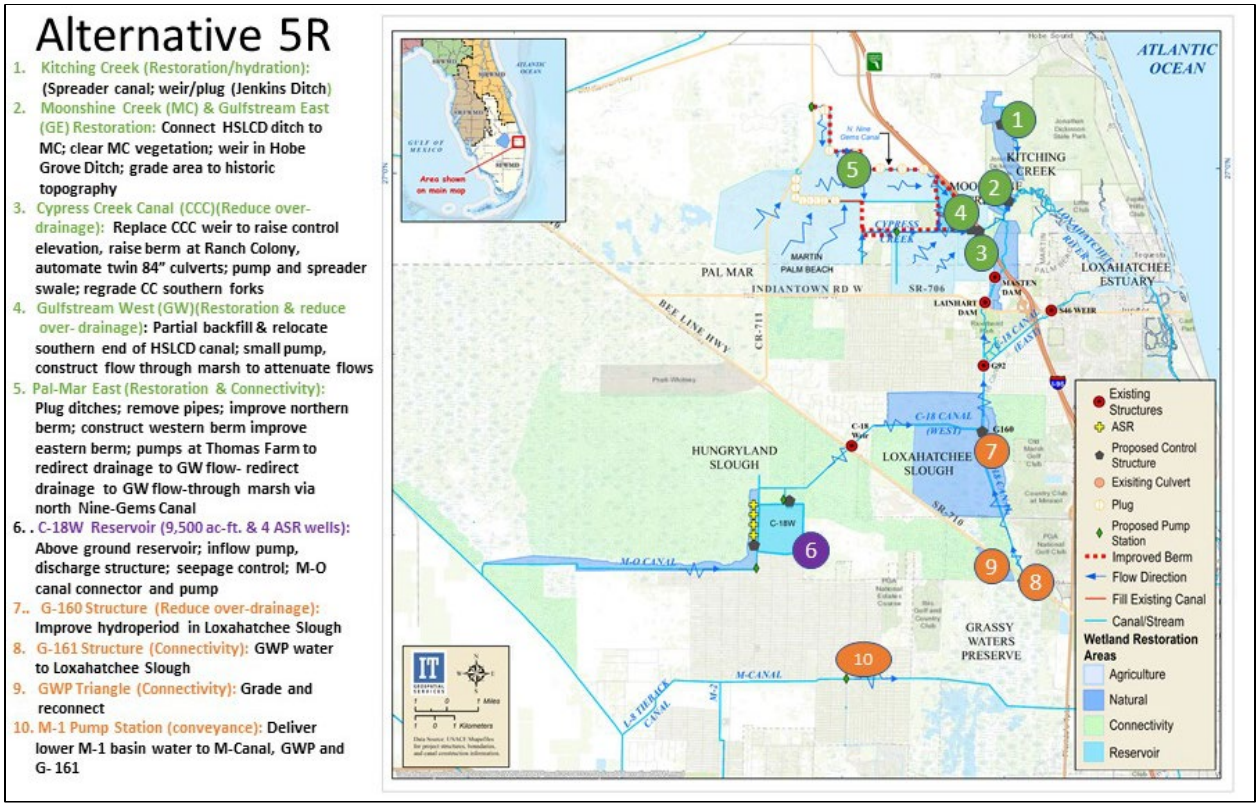

Figure H-1. Project Features Proposed in the TSP for the LRWRP.

H.4 Sea-Level Change Overview

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

Per guidelines 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, a determination should be made as to whether sea level rise (SLR) 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 guidelines outlined in ER 1100-2-8162 will apply. For this project and all projects in central and south Florida, projects are located at elevations less than 50 feet; therefore sea level guidelines in ER 1100-2-8162 will apply.

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 SLC scenarios, and support simple exploration of

how SLC 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 SLR scenarios with existing and planned engineering efforts, estimating when and how the sea level may impact critical infrastructure and planned development activities (USACE, 2018b).

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

H.4.1 Historic and Existing Condition Sea-Level Change

Portions of the Loxahatchee River and Loxahatchee River Estuary are subject to tidal influences through the direct connection to the Atlantic Ocean from the Jupiter Inlet. The historic rise of sea level has likely increased the range of tidal influence in the estuary of the project area. SLR directly affects the hydrologic boundaries governing the performance and operation of the LRWRP features. If sea level rise occurs as predicted, it is foreseeable that the tidal influence will move further upstream along the Loxahatchee Estuary, causing potential impacts to the proposed project benefits. The planning objectives, as described in the main body of the PIR, include the long term restoration of ecological communities in the Loxahatchee River Estuary. The goal is to increase base flow to limit saltwater intrusion in the tidal floodplain while maintaining the appropriate environmental conditions in the riverine floodplain for aquatic dependent species, communities and wildlife. Salinity target zones were developed as restoration targets for various portions of the river and estuary. Sea level rise may impact the salinity within these zones, decreasing the ecological performance of Recommended Plan. Sea level rise and its impacts on the future with-out project condition benefits were analyzed in the following sections.

H.4.2 Potential Impacts to the Project from Future Sea-Level Change

The following analysis evaluates potential effects on the Loxahatchee Estuary. For the purpose of this analysis, the following years are evaluated:

- 2020 (beginning of the LRWRP Preconstruction Engineering Design (PED) phase)
- 2070 (50 years into the future, corresponds to the LRWRP future without project (FWO) condition as modeled in the hydrologic assessment)
- 2120 (100 years into the future, representing the end of the LRWRP project life cycle).

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 LRWRP, the FWO condition of 2070 was identified at the beginning of the project study effort and corresponds to the hydrologic model output FWO condition used in assessing project performance and benefits. Since the planning horizon is normally 50 years, the beginning of the project life cycle was identified as 2020, which is representative of the beginning of planned PED phase. The 2070 and 2120 SLC considerations may result in an increase in salinity within the Loxahatchee Estuary under future conditions, impacting particular ecological

communities. The magnitude of those impacts will depend on how soon the sea rises to a level that impacts project performance from both an ecological standpoint as well as hydraulically. The potential impacts are described in subsequent sections.

The planning life cycle presented herein is different than identified in Section 2 of the PIR, which has the start of the period of analysis (base year) for the LRWRP as 2025 and the period of analysis ending in the year 2075. Since the SLR analysis is largely based on hydrologic modeling, the variations in the period of analysis beginning and ending years was determined to be appropriate. It is not anticipated that the SLR analysis results would differ significantly between 2070 and 2075.

H.4.3 Sea Level Rise Curves

To better understand the effects of projected future sea level change on design, construction, operation, and maintenance of Federal water resources projects, the USACE has provided guidance via ER 1100-2-8162 and ETL 1100-2-1. The web-based SLC tools described in Section H.4 use equations in the regulation to produce tables and graphs for the following three SLC scenarios:

- Baseline (or “low”) estimate, which is based on historic sea level rise and represents the minimum expected sea level change.
- Intermediate estimate.
- High estimate, representing the maximum expected sea level change.

Sea levels relative to Loxahatchee Estuary and proposed project structures are expected to rise, depending on the projected rates of rise for low, intermediate, and high scenario. The closest compliant tidal gauge, Miami Beach, FL, was selected as the basis for the sea level rise analysis. The USACE Sea Level Change Curve Calculator, based on the guidance found in ER 1100-2-8162, was used to compute the potential high, intermediate, and low curves for sea level rise, as shown in **Figure H-2**. The baseline Mean Sea Level condition for the Miami Beach, FL gauge in 1992 is -0.96 ft NAVD88, as illustrated in **Figure H-3.** The baseline of 1992 corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001.

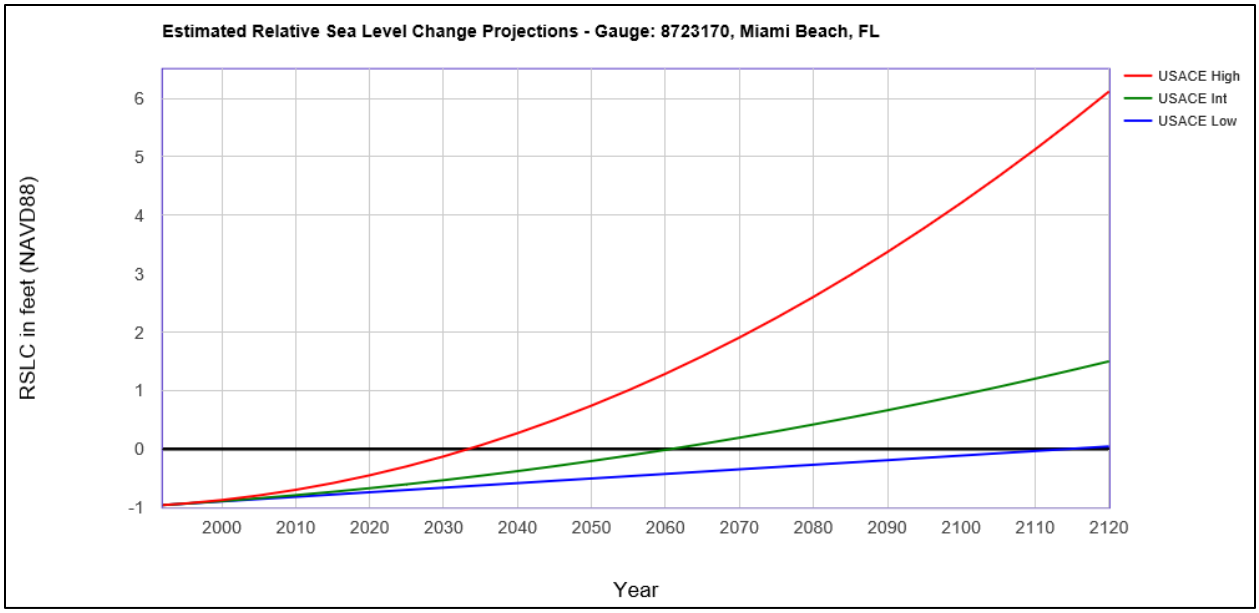

Figure H-2. Estimated Relative Sea Level Change Projections – Miami Beach FL Gauge.

Version of Data :	05/17/2017
ID:	8723170
Reference Datum:	NAVD88
Name:	Miami Beach, FL
HAT:	1.53 (ft)
MHHW:	0.33 (ft)
MHW:	0.25 (ft)
MSL:	-0.96 (ft)
MLW:	-2.20 (ft)
MLLW:	-2.37 (ft)
NAVD88:	0.00 (ft)
EWL Type:	NOAA GEV (NAVD88)
*100 Yr:	3.83 (ft)
50 Yr:	3.40 (ft)
20 Yr:	2.88 (ft)
10 Yr:	2.52 (ft)
5 Yr:	2.19 (ft)
2 Yr:	1.74 (ft)
Yearly:	1.14 (ft)
Monthly:	NaN (ft)
From:	1931
To:	1982
Years of Record:	51

Figure H-3. Tidal Datums – Miami Beach FL Gauge.

The USACE Sea Level Tracker (Sant-Miller et al., 2018) tool was used to analyze historic sea level behavior and the measured trends at a two selected gauges close to the project site that contain a recent period of record (POR), as seen in **Figure H-4** and **Figure H-5**. These figures show the historical data at the gauge along with the USACE High, Intermediate and Low Sea Level Change Prediction Curves available on the web-based USACE Sea Level Calculator and Sea Level Tracker tools. The Monthly Mean Sea Level Average curve at this time is either slightly above (Vaca Key, FL) or below (Key West, FL) the intermediate curve

estimate. The relative rate of sea level change is the regional (2006) estimate of 0.00951 ± 0.002 feet/year and 0.00722 ± 0.0005 feet/year for Vaca Key and Key West, FL Gauges, respectively. From these gauges, the team elected to formulate using the intermediate scenario. Following the intermediate curve, a new MSL baseline for the 2020 starting condition was defined as -0.671 ft NAVD88, as shown in **Figure H-6**. The reestablishment of the 2020 baseline was used as this it is assumed to be the starting point for when Preconstruction Engineering and Design (PED) efforts can occur if the project is approved in the 2020 Water Resource Development Act. Since almost 30 years has passed from 1992 it was determined that updating the baseline condition to 2020 was important for two reasons 1) Historical observed data could be utilized to understand what the current MSL in order to reassess the future curvatures for possible improved predictions 2) provide a singular start point that was representative of existing MSL for which to compare the future conditions for the 50-year planning horizon (2070) for numerical modeling purposes. This is described in greater detail in Section H.4.4.

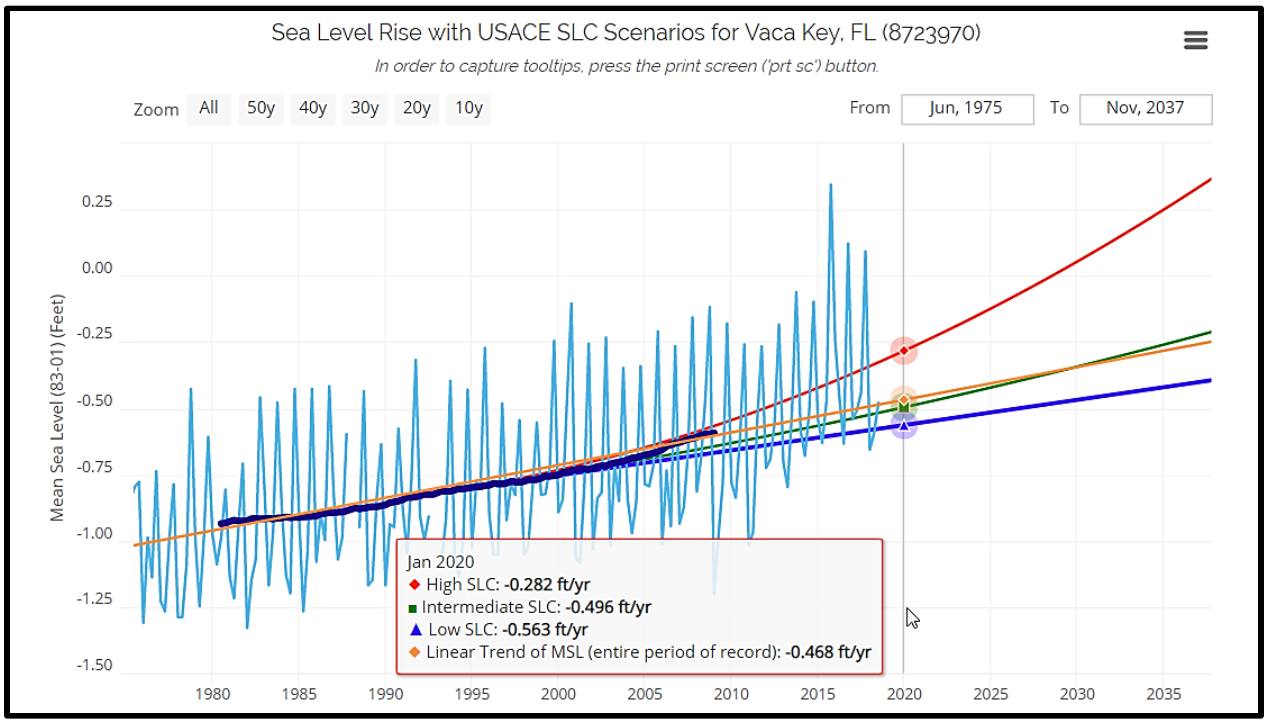

Figure H-4. SLR Estimate for Vaca Key, FL.

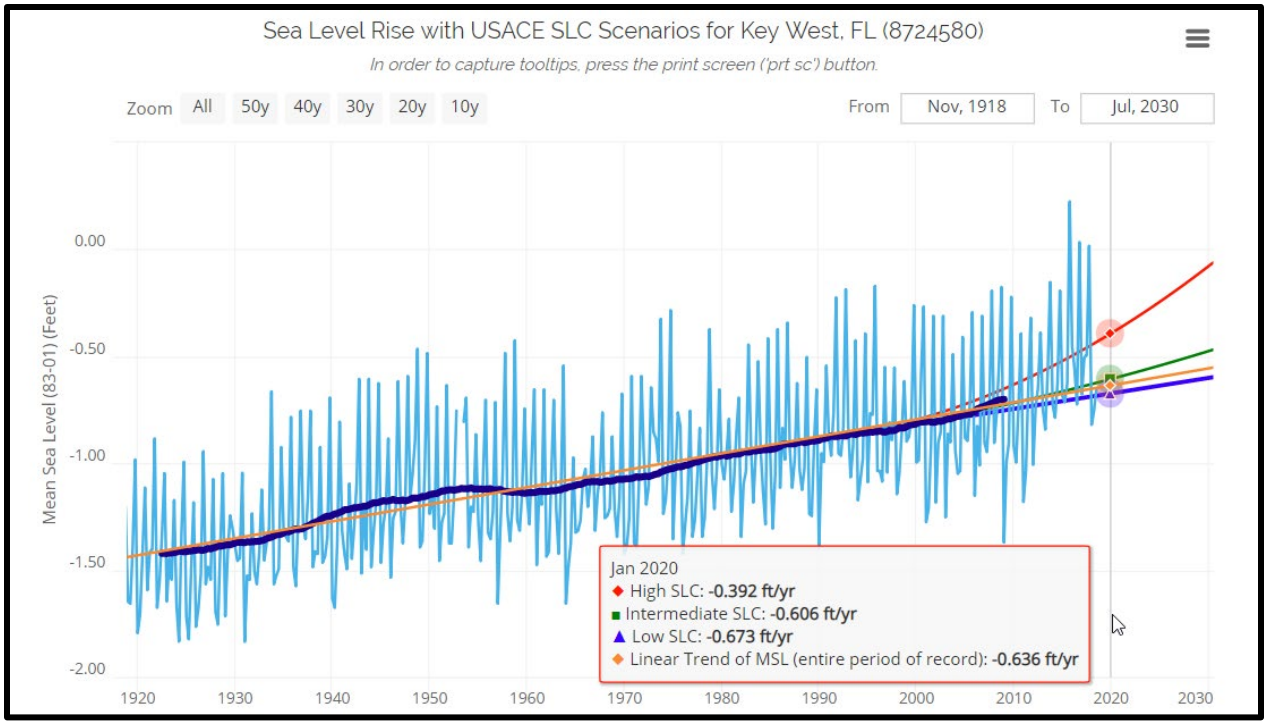

Figure H-5. SLR Estimate for Key West, FL.

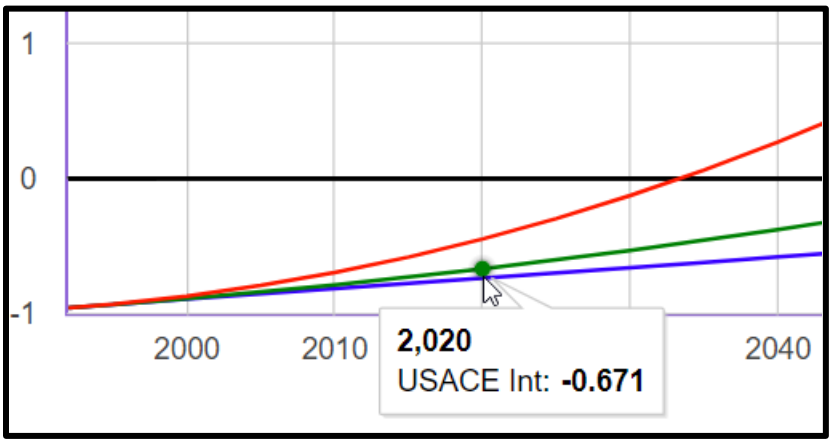

Figure H-6. Estimated Sea Level Change for Intermediate Curve at 2020.

The relative sea level change curves were updated using the USACE Sea Level Curve Calculator for the project start year of 2020. The high, intermediate, and low relative sea level change curves based on the 2020 baseline year is shown in **Figure H-7**, below.

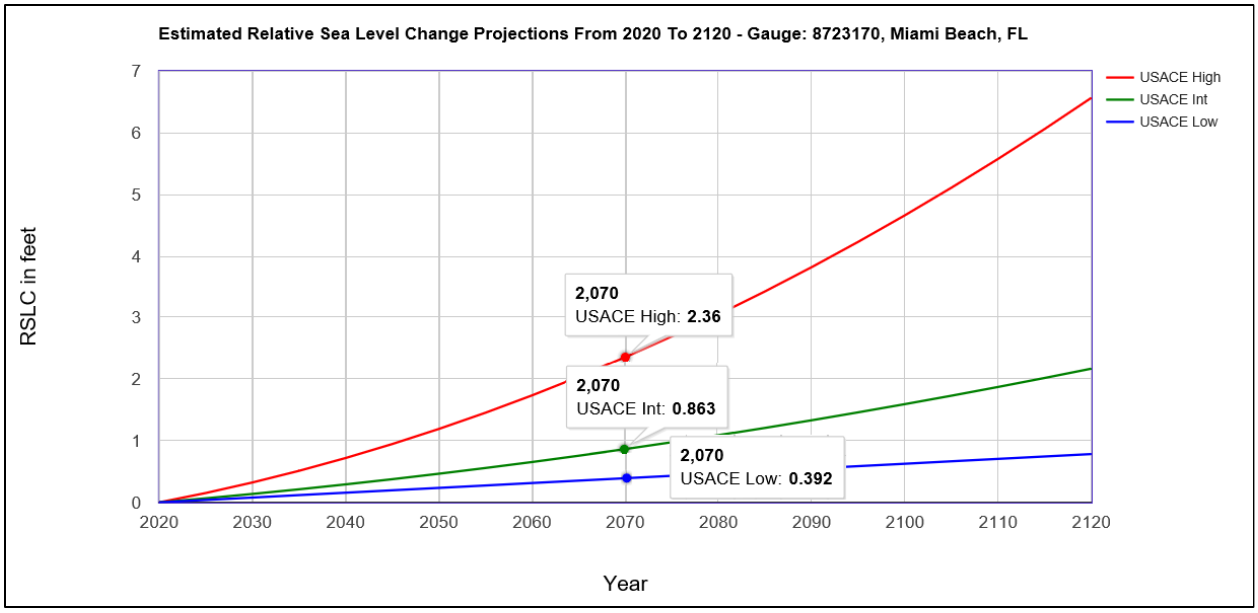

Figure H-7. 2070 SLR values for the low, intermediate, and high curves based on the 1992 start year

The values portrayed on the relative sea level projections curve are not referenced to NAVD88 and therefore the elevations were converted to represent the correct datum. From the above assumption, the baseline water level at 2020, and the representative starting point for the three curves, is -0.671 ft NAVD88. The high and low curves were re-projected with the starting point at the previously identified 2020 project baseline (-0.671). The shape of the curve between 2020 and 2070 was maintained but was translated along the Y-axis as necessary for the re-established 2020 baseline elevation. The entire graphic in Figure H-7 was therefore translated -0.671 ft along the Y-Axis to reflect elevations in NAVD88.

The low curve maintained the previously identified linear trend line but has a point of departure in 2020 of -0.671 ft. NAVD88, resulting in a 2070 elevation of -0.279 ft NAVD88 (0.392 ft – 0.67 ft). The intermediate curve was maintained, therefore the project 2070 condition will have a MSL at 0.193 ft NAVD88 (0.863 ft – 0.67 ft). The high curve maintained the trend from 2020 to 2070 but the starting point is the new 2020 baseline, resulting in a 2070 high elevation of 1.686 ft NAVD88 (2.36 ft – 0.67 ft). **Table H-1** includes the low, intermediate, and high curves adjusted for the 2020 baseline condition.

Table H-1. Sea level change for the year 2070, Re-established using the 2020 baseline.

Baseline	2070 High Curve	2070 Intermediate Curve	2070 Low Curve
1992	1.907	0.193	-0.348
2020	1.686	0.193	-0.279
Note: All measurements are in ft., NAVD88.			

Since the time of the original analysis (initial analysis July 2018, with subsequent benefit analysis modeling performed) the CPR CoP has provided additional clarification regarding the sea level change guidance. Their recommendation was that the SLC analysis should not re-baseline the SLC curves to a different project start year than the 1992 tidal epoch. It is understood that the re-baseline approach presented herein is acceptable by the CPR CoP, but in general, not an approach used for SLC assessments as it introduces a narrower range for the SLC future condition envelope by reducing the high curve values and

increasing the low curve values. The Project Delivery Team has assessed the risk associated with the re-base lining methodology and feels that the minor difference in the high curve scenario (0.2 feet) would not cause a discernable change in the SLC modeling and benefit analysis. The CPR CoP also determined that the PDT can proceed with the proposed method.

H.4.4 Evaluation of Sea Level Rise and Project Benefits

In order to evaluate the sea level rise impact on the restoration project for the 50-year planning horizon, a curvilinear three-dimensional hydrodynamic model CH3D (Sheng, 1986), was applied to the Northwest Fork of the Loxahatchee River and the Loxahatchee River Estuary. To incorporate projected SLR, the tidal boundary condition offshore of the Jupiter Inlet was developed by combining tidal components and projected mean sea level, including SLR, at Miami Beach. The SLR scenarios evaluated with CH3D were defined using the analysis described in H.4.3.

The CH3D model was initially calibrated/verified for a two-year period from 2003 to 2004 and applied in the Loxahatchee River to study the feasibility and effectiveness of saltwater barriers for the prevention of saltwater intrusion (Sun, 2004). The model was further validated for this restoration project for the period of 2005-2009. The CH3D model was run with a baseline condition starting at year 2020, using the estimated MSL of -0.67 ft NAVD88. This baseline starting elevation, representing a 2020 MSL condition, was used to simplify the model set-up for all simulations. If a singular baseline condition was not used, three varying baseline elevations would have needed to be incorporated into the model, making the relative difference between the FWO and the varying baseline conditions difficult to compute. The low, intermediate**,** and high projections for future SLR were incorporated into the boundary condition to provide a comparative framework between the three SLR scenarios. The tidal boundary conditions were computed by a tidal prediction program using known tidal harmonics at Jupiter Inlet.

Freshwater inflows (surface and groundwater) were prescribed at upstream boundaries including structures and major tributaries. The flows are output from the Lower East Coast Sub-regional Model – North Palm (LECSR-NP) hydrological model. Two alternatives were evaluated, the 2070 future without project (2070 FWO) and the Recommended Plan (future with-project). The existing condition baseline (ECB) was established starting at the year 2020, as it is the earliest year that the LRWRP can be incorporated into a Water Resource Development Act (WRDA). The future with-project condition baseline was selected at year 2070 as it both aligns with the hydrologic output from the LECSR-NP and provides sea level rise approximations for a 50-year planning horizon that can be compared to the FWO condition.

The two flow alternatives and three projected SLR conditions yield a combination of six scenarios or six model simulations. For each simulation, salinity and stage from the model results are to be evaluated based on the Valued Ecosystem Components (VECs) approach. For each VEC zone, a ranking score and the habitat volume was calculated based on the criteria laid out in the performance measure (PM1, see main report for PIR). Six desired habitat zones and their associated VECs would be established in the following areas of the river (presented as river miles (RM)) and have the associated salinity target ranges:

- Floodplain swamp and hydric hammock in the freshwater riverine floodplain – 0 practical salinity units (psu), 4 to 8 months inundation per year during the months of June–November (RM 16 to RM 9.5)
- Floodplain swamp in the tidal floodplain – < 2 psu (RM 9.5 to RM 8.1)
- Vallisneria americana – < 5 psu (RM 10.5 to RM 6.5)
- Fish larvae in the oligohaline zone – preferred salinity range of 2 to 8 psu (RM 10 to RM 5.5)
- Oysters in the mesohaline zone – preferred salinity range of 10 to 20 psu (RM 6.0 to RM 3.5)

- Seagrasses in the polyhaline zone – preferred salinity range of > 20 psu (RM 4.0 to RM 0.0)

Please note that the habitat units calculated for the river and estuarine benefits was modified, because the LECSR-NP model output of tributary flows was not sensitive enough to detect changes between alternatives and base conditions due to small geographic scale of tributaries and narrowness of Northwest fork (see Figure G-5 in **Appendix G**). The approach for integrating salinity changes for multiple overlapping zones as one index based on multiple salinity targets by an area also masked some of the improvements overall. For example, the existing conditions appeared to be meeting targets for downstream for the Tidal and Vallisneria zones (see Table G-18 and Table G-19 in **Appendix G**). However, actual monitoring data indicates this is not the case for existing flows. In addition, the habitat units are not directly comparable back to what was utilized for benefits evaluations (see **Appendix G**), but are useful for understanding relative change in salinity giving SLR projections with (TSP) and without the project (FWO).

For each VEC zone, a ranking score (see E.8.4 and E.8.5 in **Appendix G** for score maps) and the habitat units (**Table H-2** and **Table H-3**) were calculated based on the criteria laid out in the performance measure (PM1).

Table H-2. Habitat units (in acres) computed for five VEC zones during the wet seasons

SLR	Flow	Polyhaline	Mesohaline	Oligohaline	Vallisneria	Tidal
SLR0	FWO	619.3	137.3	36	74.8	17.7
	TSP	615.8	146.6	35.8	74.8	17.7
SLR1	FWO	669.9	132.2	40.0	74.8	17.7
	TSP	666.4	151.5	40.9	74.8	17.7
SLR2	FWO	670.2	130.5	40.0	74.8	17.7
	TSP	666.8	151.9	40.3	74.8	17.7
SLR3	FWO	654.7	140.7	40.4	74.8	17.7
	TSP	650.0	150.3	40.1	74.8	17.7
Available		731.0	302.6	161.0	74.8	17.7

Table H-3. Habitat units (in acres) computed for five VEC zones during the dry seasons

SLR	Flow	Polyhaline	Mesohaline	Oligohaline	Vallisneria	Tidal
SLR0	FWO	726.5	101	31.7	69.1	17.7
	TSP	721	128.3	38.6	74.2	17.7

SLR1	FWO	730.2	89.8	30.5	63.7	17.7
	TSP	728.9	111.2	38.2	71.5	17.7
SLR2	FWO	730.5	85.9	29.8	62.9	17.7
	TSP	729.6	110.8	37.8	70.7	17.7
SLR3	FWO	730.2	83.4	29.9	61.6	17.7
	TSP	729.2	110.2	39.8	70.7	17.7
Available		731.0	302.6	161.0	74.8	17.7

Note: SLR0= no sea level rise
SLR1= low projection
SLR2= intermediate projection
SLR3= high projection

Results (**Table H-2** and **Table H-3**) suggest the Tidal Flood Plain (RM9.5 to RM8.1) can meet the salinity target 100% for all three SLR projections with and without projects. However, existing conditions from real time data suggest otherwise. The salinity output results need to be viewed differently for the more freshwater tidal zones (0-2 psu) and not constrained by river mile. The results are provided as a separate check because they are most sensitive to sea-level change in **Table H-4.**

Table H-4. Average area in the Loxahatchee River with salinity less than 2 psu

SLR	Flow	Dry season	Wet season
SLR0	FWO	NA	NA
	TSP	97	148
SLR1	FWO	84	130
	TSP	96	133
SLR2	FWO	83	128
	TSP	93.8	130.2
SLR3	FWO	81.6	128
	TSP	93.1	129.8

Results show that habitat area highest decrease is by 4% for the TSP output under SLR scenario 3. This is a modest change and still provides a consistent lift over the FWO between 10 to 12 acres of sensitive tidal flood plain habitat.

Salinity target (less than 5) was met 100% for the Vallisneria zone for the wet season regardless SLR. However, SLR increases salt intrusion during the dry season resulting in decreased habitat units. The benefits of projects are clearly demonstrated for the SLR scenarios as HU different between TSP and FWO is the higher for the three projected SLR conditions than for no sea level rise. This would suggest the TSP flows are especially important for the Vallisneria zone regardless of the SLR conditions.

Similarly, for the Oligohaline zone which has a salinity target of between 2 and 8, the benefits are also demonstrated in the dry season. Sea level rise seems to help increase the habitat units to meet the lower end of the salinity target.

The Mesohaline Zone with a salinity target of 10 to 20 would be impacted by SLR during both the wet (2.5% increase) and dry seasons (up to 14% reduction from existing sea-level). Model results suggest clear benefits for both seasons as more freshwater from the projects benefit dry season habitat units and also benefit wet season habitat units under sea level rise conditions.

For the Polyhaline zone which has a salinity target of greater than 20, SLR would increase habitat units during the wet season as it get more salty but there would be no clear project benefits for either wet and dry season because of increased freshwater from future projects with all changes amounting to 1% or less over the FWO.

H.4.5 Evaluation of Sea Level Rise and Project Impacts

In addition to ecosystem impacts, existing and proposed infrastructure within the LRWRP footprint are susceptible to sea level rise. Existing structures include the Lainhart Dam, Masten Dam, and S-46 within the Loxahatchee River project area. Lainhart and Masten Dams are passive weir structures, located approximately 0.1 mile and 1.2 miles north of SR-706, respectively, along a 7.5-mile section of the Northwest Fork of the Loxahatchee River. Currently, the Lainhart and Masten Dams control and regulate upstream flow stages throughout the Northwest Fork and are used to prevent the migration of brackish water upstream, thereby alleviating the potential for adverse impacts upon the adjacent ecosystem (AMEC, 2015). The discharge capacity of the S-46 and Masten and Lainhart Dams structures, with existing headwater conditions may be limited when the tidally influenced tailwater stage exceeds a threshold elevation. It is important to note that S-46, Lainhart Dam, and Masten Dam, are not official project structures and will not be modified as part of the LRWRP, however they have a direct influence on project performance and therefore shall be analyzed as part of the sea level rise evaluation.

The sea levels relative to these outlet structures are expected to rise, depending on the projected rates of rise for low, intermediate, and high scenarios and may result in an impact to the hydraulic conditions for these structures. The re-baselined sea level curves were not used in the analysis of the critical thresholds, instead the 1992 baseline sea level curves, as presented in the USACE Sea Level Curve Calculator were used.

The Masten Dam was constructed with two inset weirs, each approximately 12 feet wide and 1.5 feet deep below the upper weir crest at an elevation of 5.9 ft NAVD88. As the Masten Dam was originally designed in the 1930's, the original design headwater and tailwater conditions are unknown. The critical threshold elevation is identified as the invert elevation, as elevations above this would cause potential backflow over the weir causing brackish water to reach upstream of the dam. Additionally, for tailwater conditions below the invert elevation, the weir is flowing under a free flow condition, therefore the discharge through the weir is independent of the tailwater elevation and the depth at the weir is usually taken as critical depth. Since the tailwater condition is tidally influenced, the downstream stage is directly

impacted by tidal and surge fluctuations above existing MSL and, depending on combined headwater and tailwater scenario and weir submergence, slight reductions in discharge capability may begin to occur at the identified threshold of 5.9 ft NAVD88. The structure performance will likely not be greatly influenced by the tailwater stage until elevations are close to or at the invert elevation. These scenarios, although important to understand due to the reduced discharge capacity, would not be critical as the structures purpose of preventing the migration of brackish water upstream would still be maintained until the tailwater elevation of 5.9 ft NAVD88 within the estuary occurred. The USACE Sea Level Change Curve Calculator was used to plot the critical threshold versus the relative sea level change curves, as shown in **Figure H-8**.

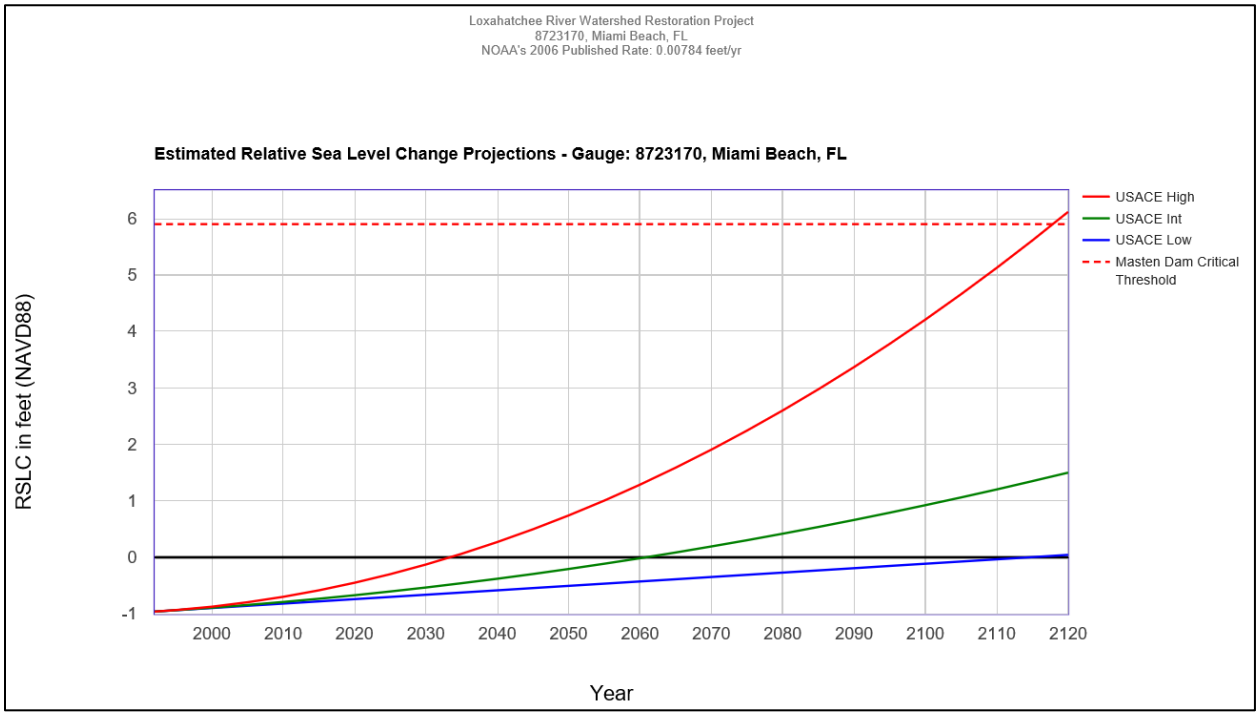

Figure H-8. Relative SLC projections related to the Masten Dam Critical Elevation

Following the SLC projections and the identified Masten Dam critical elevation of 5.9 ft NAVD88, it can be assumed that the SLC high projected curve will intersect the discharge threshold by 2117, which is just within the 100-year planning horizon. The SLC low and intermediate projected curve will intersect the threshold by 2229 and 2866, respectively, as show in **Table H-5**.

Table H-5. Sea Level Rise Curve Intersection with Masten Dam Critical Threshold

Curve Intersections	Masten Dam Critical Threshold (yr)
USACE High	2117
USACE Int	2229
USACE Low	2866

The Lainhart Dam structure is located upstream of the Masten Dam and has an invert elevation of 9.0 ft NAVD88. An increase in the headwater elevations of the Lainhart Dam may have a potential impact on

the discharge capabilities for communities upstream of the dam. Therefore, although the Lainhart Dam's purpose of reducing salinity issues is similar to the Masten Dam, the critical threshold from a flood control perspective may be lower than the invert elevation. The exact tipping point of reduced discharge capabilities due to a raised tailwater is unknown but it is anticipated to be much greater than 5.9 ft NAVD88, thereby not being impacted by any future sea level rise scenario during the 100-year planning horizon.

Similar to the Masten Dam, the critical threshold elevation is identified as the invert elevation, as elevations above this would cause potential backflow over the weir causing brackish water to reach upstream of the dam.

The S-46 structure, a gated spillway with discharge controlled by three stem operated, vertical lift gates, discharges directly to the Loxahatchee Estuary. The crest of the spillway is at 5.2 ft. NAVD88 and is designed for a headwater elevation of 11.3 ft. NAVD88 and tailwater of 0.7 ft NAVD88. The S-46 structure purpose is to provide discharges from the C-18 for flood control purposes. Therefore, although the invert elevation (5.2 ft NAVD88) would be a critical threshold elevation for structure performance, reduced discharge capabilities would exist above the design tailwater elevation of 0.7 ft NAVD88. The tailwater and invert elevation thresholds were plotted against the SLR curves as shown in **Figure H-9**. The critical threshold will vary depending on the structure operation criteria (flood versus normal operation) and hydraulic loading conditions, therefore both elevations are shown in the figure to provide range of possible scenarios.

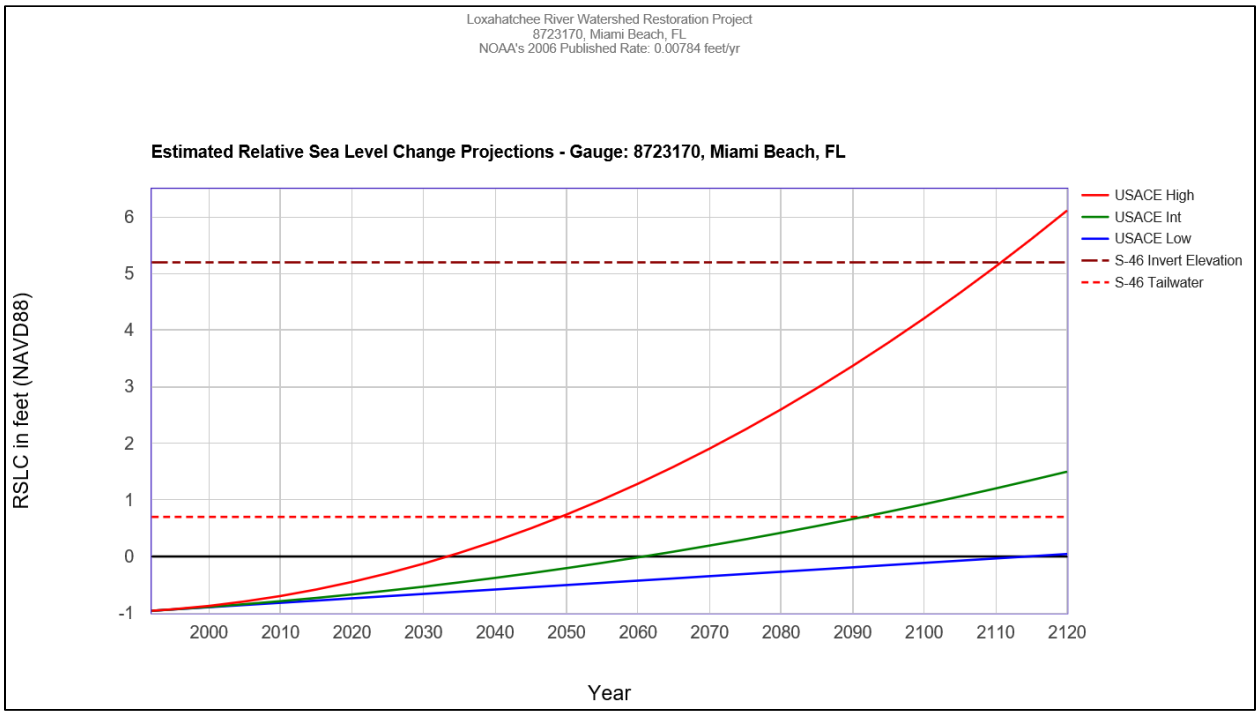

Figure H-9. Relative SLC projections related to the S-46 Critical Elevations

Table H-6. Sea Level Rise Curve Intersection with S-46 Critical Threshold Elevations

Curve Intersections	S-46 Tailwater (yr)	S-46 Invert Elevation (yr)
USACE High	2049	2110
USACE Int	2091	2214
USACE Low	2203	2777

Following the SLC projections from **Table H-6** and the identified S-46 critical elevation of 0.7 feet, it can be assumed that the SLC low projected curve will intersect the discharge threshold by 2206 (beyond 2120), the SLC intermediate projected curve will intersect the threshold by 2091 and the SLC high projected curve will intersect the threshold by 2049. The S-46 critical elevation for the structure invert will intersect the high curve in 2110 and well beyond the planning horizon of 2120 for the intermediate and low curves.

Within the Recommended Plan, there are three proposed structures that could be tidally influenced. These structures are located on the Cypress Creek Canal, Hobe Grove Ditch, and Kitching Creek which are three tributaries of the Northwest Fork of the Loxahatchee River. Based on preliminary design, the Cypress Creek Canal Structure, S-112, has an invert elevation of 6.5 ft NAVD88. The Hobe Grove Ditch water control structure, S-117, and Kitching Creek water control structure, S-116, have an invert elevation of 6.0 and 6.3 ft NAVD88, respectively.

The S-112 structure is dual bay ogee spillway with vertical slide gates. The design tailwater condition is 10.8 ft NAVD88, therefore both the invert elevation and design tailwater elevation are greater than the high curve SLR value at 2120. The S-116 structure is a gated culvert with the design tailwater condition of 11.3 ft NAVD88, which will intersect either at, or well beyond, 2120 for all SLR scenarios. It is anticipated that the S-112 and S-116 structures will not be impacted by SLR during the 100-year life cycle for this project.

The S-117 is an un-gated weir structure with an invert elevation that will intersect either at (2118 for high curve) or well beyond 2120 for the SLC projected curve scenarios. However, the design tailwater condition, 2.5 ft NAVD88, is lower than the design invert and may be susceptible to SLR. Therefore, although the invert elevation (6.0 ft NAVD88) would be a critical threshold elevation for structure performance due to potential backflow over the structure, the design tailwater elevation of 2.5 ft NAVD88 would likely be impacted due to SLR. To determine the potential impact on the S-117 structure, model simulations using a completed Hydrologic Engineering Center's River Analysis System (HEC-RAS) model (See **Annex A-3 HEC-RAS Model Documentation**) with varying tailwater surface elevations was analyzed. The model simulations showed that the design discharge capacity would only be impacted for tailwater elevations at or close to the invert elevation. A graphic of the HEC-RAS model output is included below, **Figure H-10**, and illustrates that the headwater elevation (and subsequent discharge) are not impacted by the varying tailwater conditions or 2.5 ft NAVD88 or 6.25 ft NAVD88. Therefore, SLR below 6 ft NAVD88 elevation would likely not impact the S-117 structures performance and the true governing critical threshold elevation for the S-117 structure becomes the invert elevation of 6.0 ft NAVD88. However, similar to S-46, the tailwater and invert elevation thresholds were plotted against the SLR curves as shown in **Figure H-11** to provide an understanding of how the design conditions compare to potential SLR.

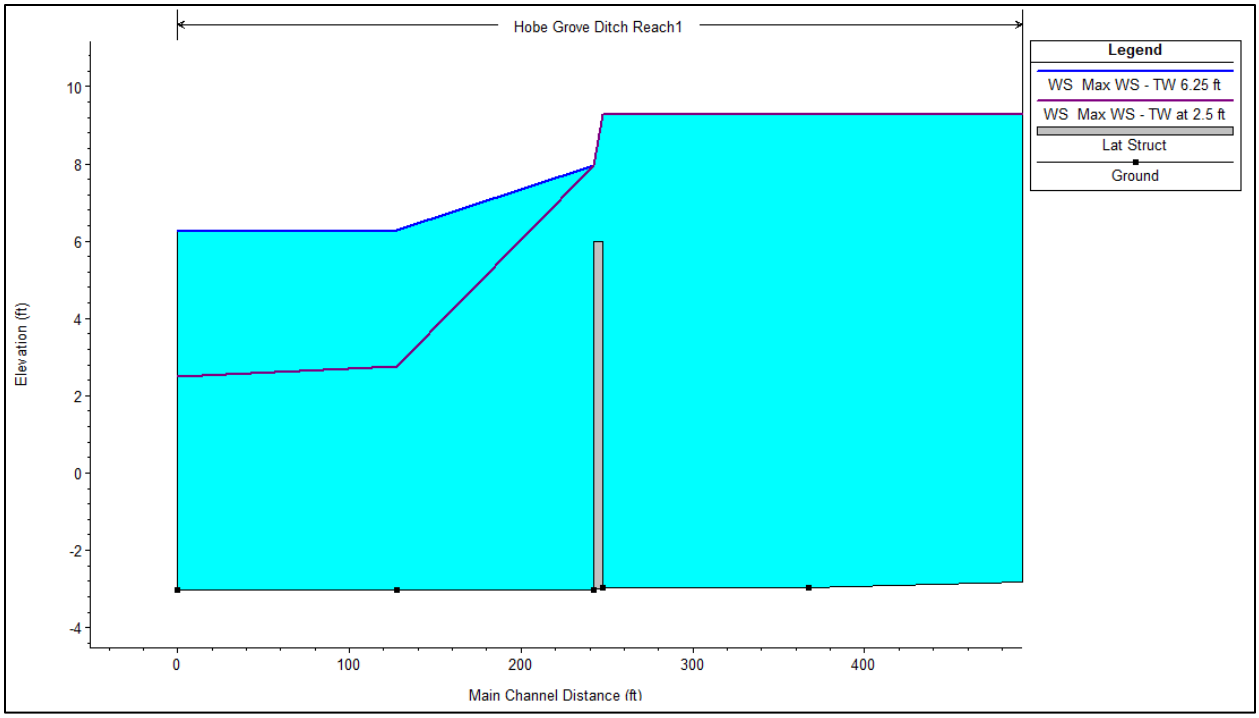

Figure H-10. HEC-RAS Water Surface Profiles Results for S-117 With Varying Tailwater Elevations

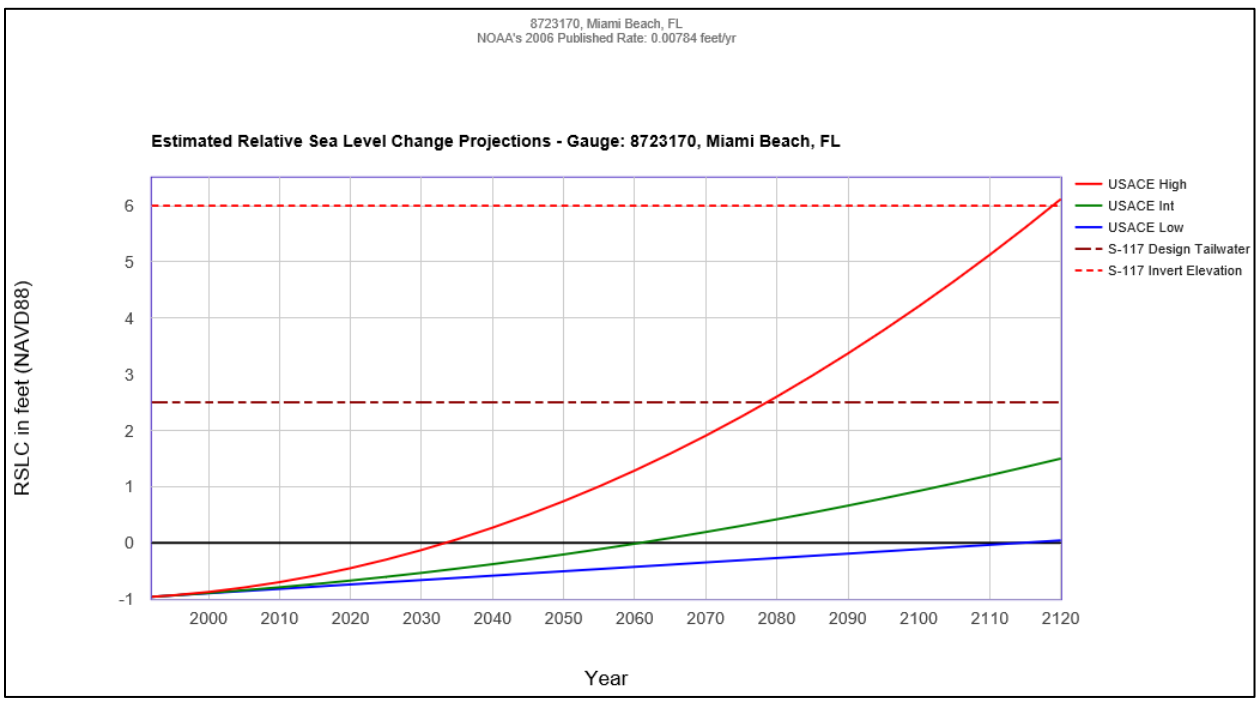

Figure H-11. Relative SLC projections related to the S-117 Critical Elevations

Table H-7. Sea Level Rise Curve Intersection with S-117 Critical Threshold Elevations

Curve Intersections	S-117 Invert Elevation (yr)	S-117 Design Tailwater (yr)
USACE High	2118	2078
USACE Int	2231	2150
USACE Low	2879	2433

Following the SLC projections from **Table H-7** and the identified S-117 critical elevation of 2.5 feet, it can be assumed that the SLC low and intermediate projected curve will intersect the discharge threshold well beyond 2120. The SLC high projected curve will intersect the invert elevation and design tailwater thresholds by 2118 and 2078, respectively.

Although the existing and proposed project features have invert elevations close to or greater than the "high" curve project life cycle of 2120, the conditions within the estuary and river are highly dependent upon tidal conditions, storm severity, and timing and duration of runoff. Therefore, it is important to analyze the potential extreme water levels (EWL) to further understand the potential exceedance probability for water levels within the estuary. EWL are statistically derived probability of future storm events developed from recorded high water events. The NOAA EWLs are derived using the Generalized Extreme Value (GEV) probability distribution function and plotted with the SLR curves using the USACE Sea Level Tracker tool. It is important to note that extreme coastal water levels typically result from high tides, surge, and wave set-up (likely due to storm events) and therefore are may occur at intermittent intervals during the project life cycle but are not expected to remain constant in coincidence with sea level rise. The 10% exceedance probability calculations were applied to the intermediate and high sea level rise scenario to provide better understanding of potential performance issues in the tidal reach due to a coastal forcing scenario, as seen in **Figure H-12** and **Figure H-13**, respectively.

Figure H-12 illustrates that if SLR follows the intermediate (or low) curve, no project structure critical threshold elevation pertaining to the invert of the structure will be impacted when SLR is coupled with the 10% exceedance water surface elevation. The critical tailwater design threshold elevation for S-46 and S-117 are at an elevation below the 10% EWL under the 2020 beginning of project life cycle conditions within the Loxahatchee Estuary. As stated above, based on HEC-RAS modeling, an increase in the tailwater elevation above the design elevation will not cause an impact to the design discharge rate until tailwater elevations near the invert elevation (6 ft NAVD88), which remain unaffected by the intermediate curve with 10% EWL for the project life cycle.

Figure H-13 shows that project structure invert and tailwater critical threshold elevations would be impacted earlier during the project life cycle if sea level rise follows the high curve coupled with a 10% EWL event. For example, many of the abovementioned project structures with the critical threshold elevation at approximately 6.0 ft NAVD88 are not impacted over the project life cycle under the high sea level scenario (close to or beyond 2120), but coupled with a 10% EWL, impacts may be experienced at approximately 2080. Understanding the magnitude and potential timing of an increase in water surface elevations within the estuary become important for operational decisions and understanding potential changes to structure performance.

H.4.6 Sea Level Change Summary

The effects of SLC have been analyzed per ER 1100-2-8162 and ETL 1100-2-1. An analysis of sea level change on the future with (TSP was simulated) and without project condition for 2070 was performed using a hydrodynamic model. Three sea level change scenarios (low, medium, high) were incorporate

through the tidal boundary condition. The two flow alternatives and three projected SLR conditions yielded a combination of six scenarios for six model simulations. For each scenario, salinities from the model results were used to evaluate performance measures based on the Valued Ecosystem Components approach. Benefits of the with-project (TSP) are noted in the increased number of habitat units for all SLC scenarios over the future without project condition for the 50-year planning horizon. In summary, the with-project condition provides better ecological conditions and resiliency for the river then the future without project condition.

Due to the projects location close to the Loxahatchee Estuary, tidally influenced structures were analyzed due to potential affects from SLC. The analysis included the existing structure S-46, Masten and Lainhart Dam as well as proposed project structures S-112, S-116 and S-117. The Lainhart dam and S-112 were found to have critical threshold elevations greater than the high SLC projected curve for the 100 year project lifecycle (2120) and therefore impacts due to SLR will likely be limited. These structure will experience effects of SLR if it occurs at a rate greater than the high curve as well as when sea level rises in the future, the performance of these structures will be affected by storms that produce extreme water levels. The preceding analysis shows that the Masten Dam critical discharge elevation of 5.9 ft will be intersected by the low, intermediate and high SLC projected curves in the following years:

- Low curve: well after the 100-year project life cycle
- Intermediate Curve: well after the 100-year project life cycle
- High Curve: 2117 (97 years after the start of the project life cycle)

The S-46 critical discharge elevations of 5.2 ft and 0.7 ft for the invert and tailwater conditions, respectively, will be intersected by the low, intermediate and high SLC projected curves in the following years:

- Low curve: both are well after the 100-year project life cycle
- Intermediate Curve: 2214, 2091 (invert is after the 100-year project life cycle, tailwater is 71 years after the start of the project life cycle)
- High Curve: 2110, 2049 (90 and 29 years after the start of the project life cycle)

The S-117 critical discharge elevations of 6.0 ft and 2.5 ft for the invert and tailwater conditions, respectively, will be intersected by the low, intermediate and high SLC projected curves in the following years:

- Low curve: both are well after the 100-year project life cycle
- Intermediate Curve: both well after the 100-year project life cycle
- High Curve: 2118, 2078 (98 and 58 years after the start of the project life cycle)

From the above analysis, the effects of SLR may be felt along the hydrologic boundaries for which the aforementioned structures provide hydraulic connection, but these effects will likely not be experienced until closer toward the end of the project life cycle. Resiliency and adaptive management measures should be considered with flows potentially limited at S-46 by 2049. In order to ensure project performance is maintained for the project lifecycle, despite uncertain future conditions, potential adaptation steps should be analysis. These steps include potential changes to the S-46 structure design, including possible modifications to the structure geometry (including invert elevation, weir or gate configuration, etc.), number of spillway bays, and performance of an updated analysis of tailwater design and potential

limitations to discharge should be analyzed in the future. Additionally, operational changes to the structures, including modifying control water surface elevations, periods of discharge, and gate operations, should be considered. A period of record analysis should be conducted to inform the Project Operating Manual, to better understand the interconnected headwater and tailwater elevations and associated discharge rates. An example of an adaptive measure includes conducting releases from S-46 at a lower headwater elevation and for a longer duration, due to a higher tailwater condition, to ensure upstream water surface elevations are maintained at the appropriate flood control elevation. A comprehensive assessment of the upstream C&SF system, including the C-18 and C-18W Canals will need to occur to gain a better understanding of the appropriate headwater elevation of S-46 and associated reduced discharge capability due to SLR.

The S-117 structure tailwater critical condition was determined, through HEC-RAS model simulations, to cause minimal to no impact to design discharge up to the invert elevation. Therefore, the invert elevation is the critical elevation, with potential impacts occurring at the end of the project life cycle for the high curve scenario. Resiliency and adaptive management measures may also be considered for this project, including increasing the weir elevation concurrent with improving upstream conveyance capacity into the adjacent natural system. This would allow the current headwater design to be maintained while increasing the weir elevation, and corresponding critical threshold for S-117.

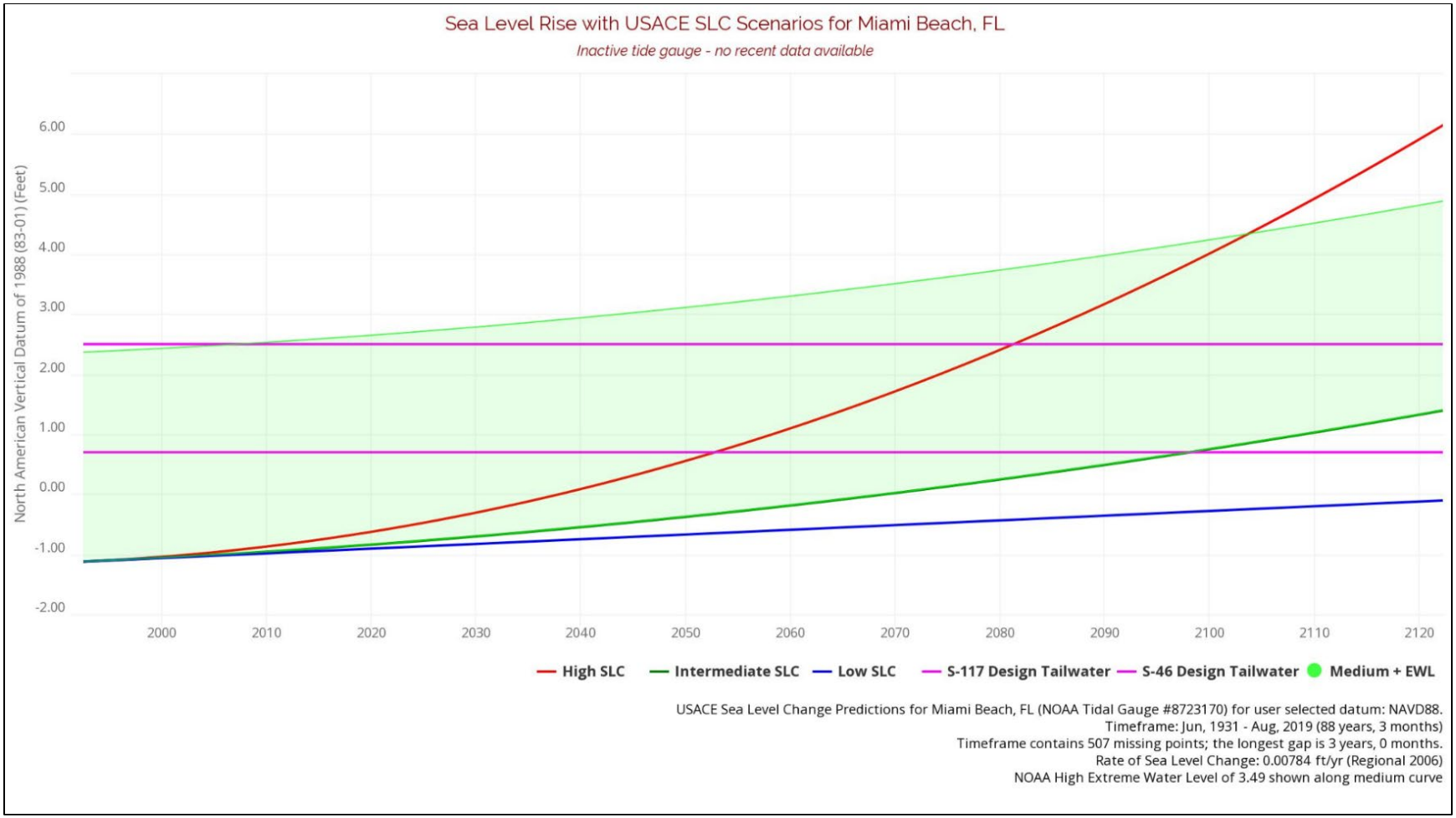

Figure H-12. SLR Graphic Illustrating a 10% Exceedance Probability for NOAA EWL for the Intermediate Curve

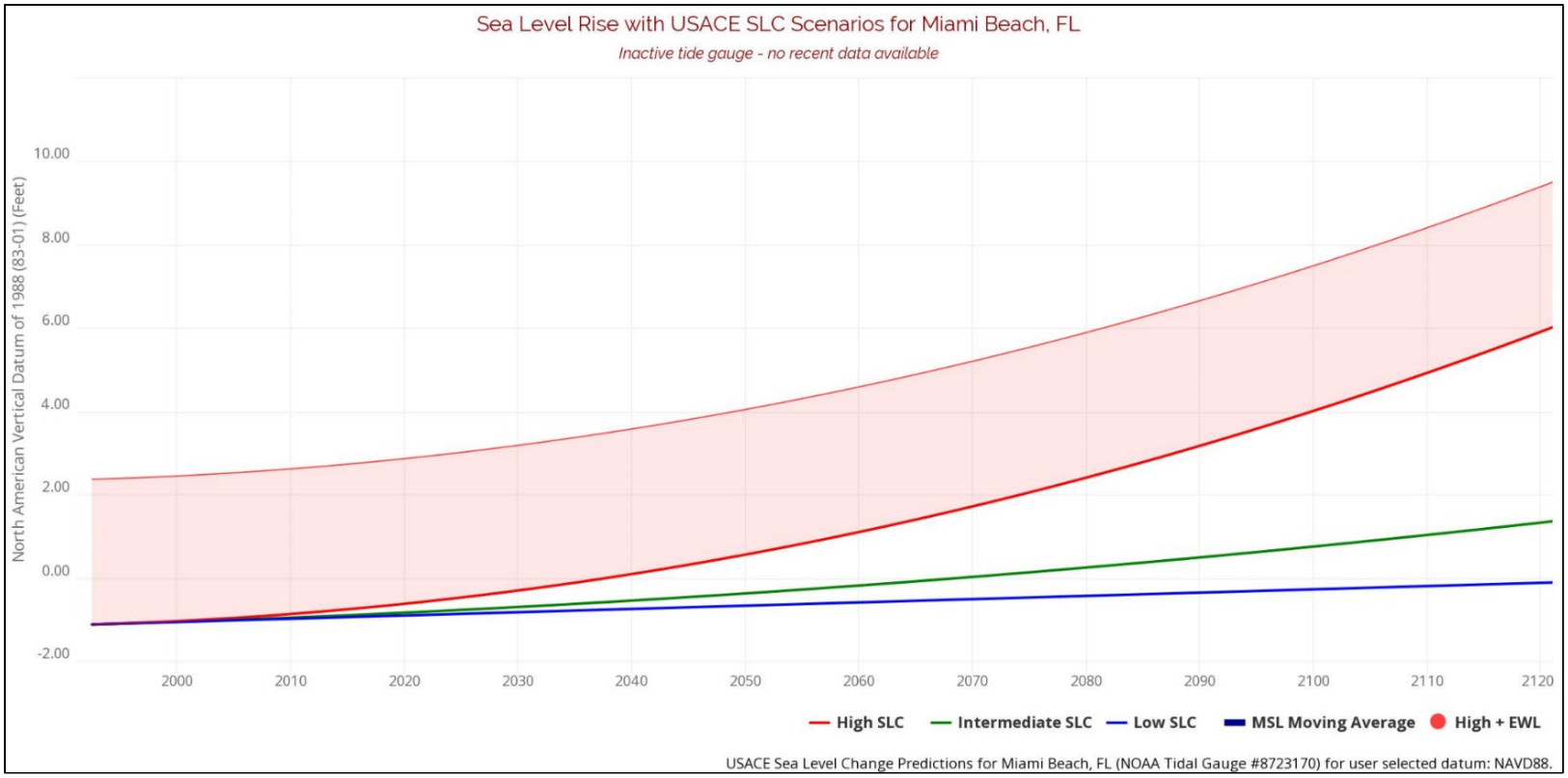

Figure H-13. SLR Graphic Illustrating a 10% Exceedance Probability for NOAA EWL for the High Curve

H.5 Hydrologic Analysis

The climate assessment for inland hydrology follows ECB 2018-14, which provides guidance for incorporating climate change information in the hydrologic analyses in accordance with the USACE climate preparedness and resilience policy and ER 1105-2-101, *Risk Assessment for Flood Risk Management Studies*. This policy requires consideration of climate change in all current and future studies to reduce vulnerabilities and enhance the resilience of communities. The objective of ECB 2018-14 is to enhance the USACE climate preparedness and resilience by incorporating relevant information about observed and expected climate change impacts in hydrologic analyses for planned, new, and existing USACE projects. This ECB helps support a qualitative assessment of potential climate change threats and impacts that may be relevant to the particular USACE hydrologic analysis being performed. The qualitative analysis required by ECB 2018-14 should focus on those aspects of climate and hydrology relevant to the project's problems, opportunities, and alternatives, and include consideration of both observed changes as well as projected future changes (USACE, 2018a).

The qualitative analysis for inland hydrology consists of three phases outlined in ECB 2018-14, as shown in **Figure H-14**:

1) Scoping
2) Vulnerability assessment
3) Risk assessment

H.5.1 Phase I: Initial Scoping

Initial scoping of climate change for the project is typically performed near the beginning of the project planning process. There are two purposes of this phase:

1) Understanding what climate variables are relevant to the analysis.
2) Determining whether quantitative hydrology and/or SLC assessments are needed.

H.5.1.1 Climate Variables

Not all aspects of climate are relevant to all the USACE projects, and professional judgment is necessary to identify which aspects affect changes in the future without project conditions. For this project, it was determined that the following climate variables were the most relevant: temperature, precipitation, streamflow, and SLR.

H.5.1.2 Quantitative Climate Change Assessments

For most of the USACE projects and studies, a qualitative analysis will provide the necessary information to support the assessment of climate change risk and uncertainties to the project design or constructed project. A quantitative assessment for hydrology will be described in future additions to ECB 2018-14 and can currently be considered on a case-by-case basis if changes to observed hydrology are detected (USACE, 2018a).

H.5.1.2.1 Inland Hydrology

Quantitative climate tools have not yet been developed for the hydrologic assessment, so the LRWRP project team determined that a qualitative hydrology assessment was sufficient to assess the vulnerabilities and risk of the project to future climate change.

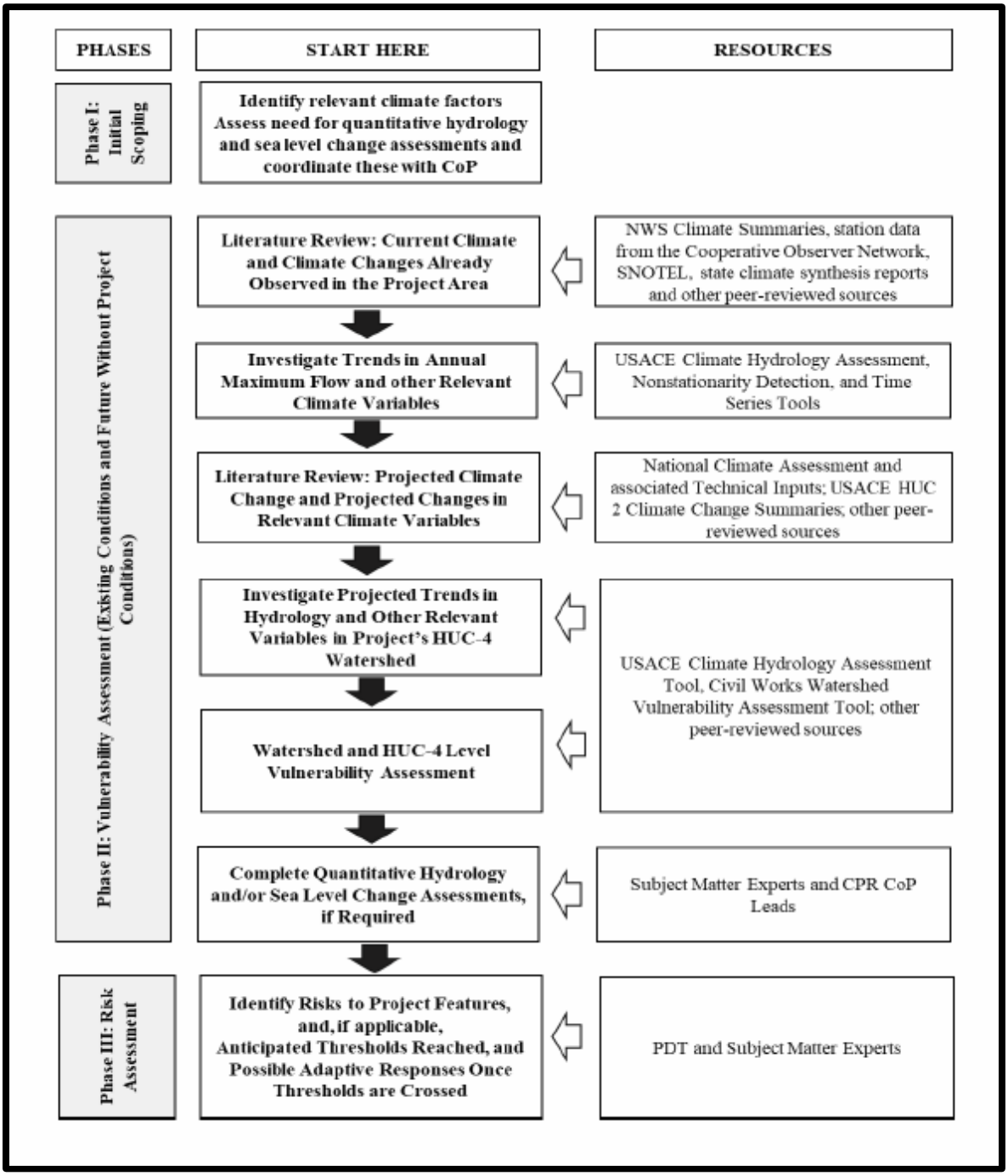

Figure H-14. ECB 2018-14 flow chart for performing hydrologic climate change assessment (USACE, 2018a).

H.5.1.2.2 Sea-level Change

As discussed Section H.4, per guidelines from ECB 2018-14, for project areas at elevations less than or equal to 50 feet, a determination should be made as to whether SLR 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 guidelines outlined in ER 1100-2-8162 will apply. For all projects in central and south Florida, elevations are less than 50 feet, therefore sea level guidance in ER 1100-2-8162 will apply.

H.5.2 Phase II: Vulnerability Assessment

In the vulnerability assessment phase, information is collected and analyzed to determine the Optimized Plan. The assessment addresses whether changes are presently occurring and whether expected changes in future hydrologic conditions will result in performance requirements significantly different from the present.

Climate change information for the hydrologic assessment includes direct changes to hydrology through changes in temperature, precipitation, and streamflow. While SLR is identified as a relevant climate variable to the project, it is not evaluated as part of the hydrology vulnerability assessment. The project's vulnerability to SLR is evaluated in **Section H.4**. The vulnerability assessment includes a literature review of current climate and observed and projected climate trends and application of climate tools used to provide information on observed and projected climate trends relevant to the project area.

H.5.2.1 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 Florida and also the surrounding region:

1) *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* (USACE, 2015a)
2) *Climate Change Indicators in the United States* (EPA, 2016)
3) *Climate Science Special Report: Fourth National Climate Assessment, Volume I* (USGCRP, 2017) *and II* (USGCRP, 2018)
4) *NOAA State Climate Summaries* (Runkle et al., 2017)
5) *USACE Jacksonville District Report on Climate Change*, *Comprehensive Everglades Restoration Plan Central Everglades Planning Project Final Integrated Project Implementation Report and Environmental Impact Statement* (USACE, 2014)

The literature focuses on the following climate variables, which are consistent with those identified for the project:

1) Precipitation
2) Temperature
3) Streamflow

A synthesis of the USACE peer-reviewed climate literature is available for the South Atlantic-Gulf Region 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 lines (USACE, 2015a). The project watershed falls within the South Atlantic-Gulf Region, which is also referred to as Water Resources Region 03 (2-digit hydrologic unit code, or HUC03); see **Figure H-15**.

Additional national and regional reports from the United States Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA)—including the United States Global Change Research Program (USGCRP) report *Climate Science Special Report: Fourth National Climate Assessment, Volume I and II*—are cited to further identify observed changes in climate variables and assess projected, future changes in climate variables for the study area.

Finally, in order to report on climate trends specific to central and south Florida, a USACE Jacksonville District report on climate is referenced. This report summarizes observed and projected climate patterns cited in various Florida reports and studies.

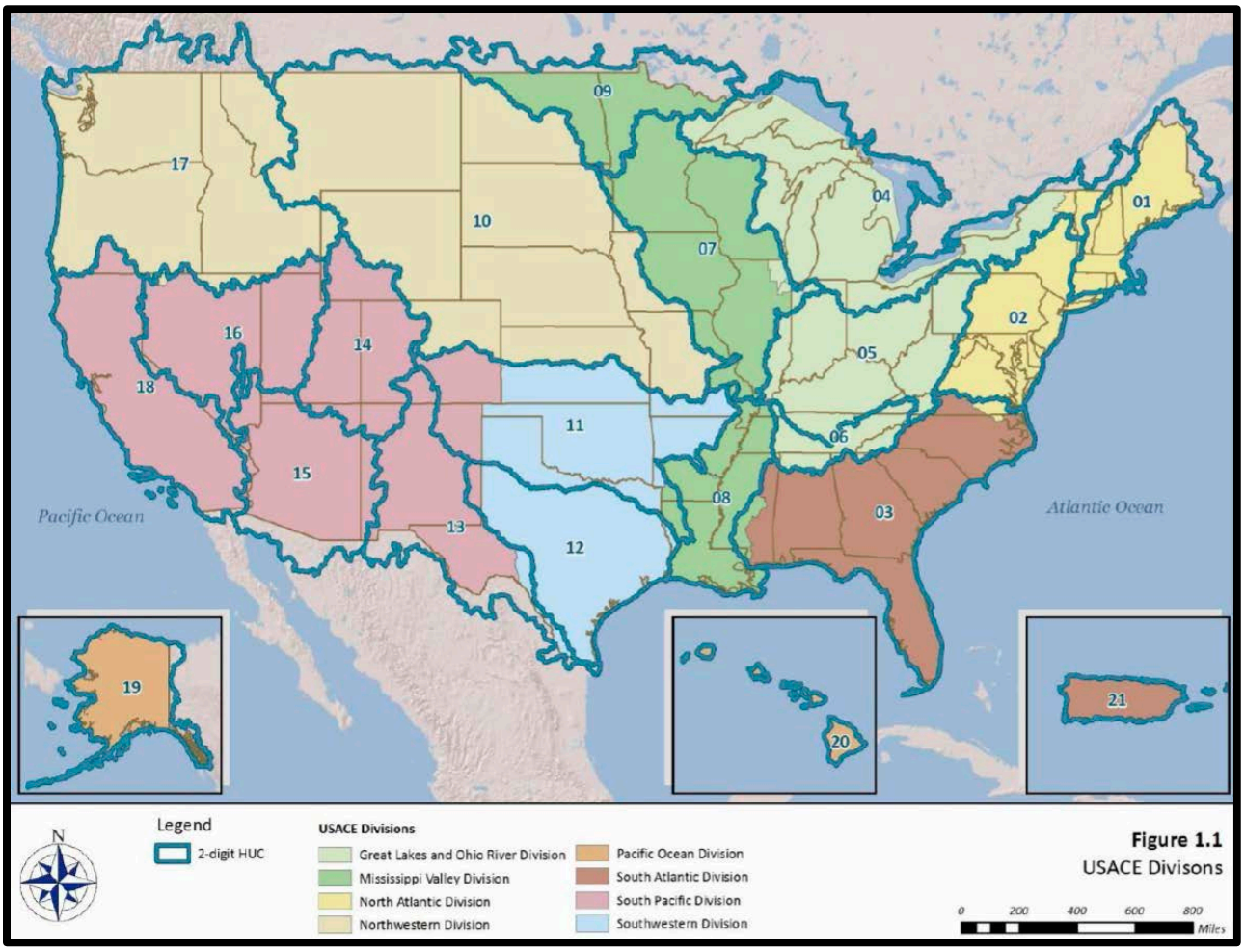

Figure H-15. Map of 2-digit hydrologic unit code boundaries for the Continental United States, Alaska, Hawaii, and Puerto Rico (USACE, 2015a).

H.5.2.2 Summary of Present Day Climatic Conditions in the Study Area

The Lake Okeechobee watershed is in the transition zone between a tropical (to the south) and humid subtropical (to the north) climate. Both climates are dominated by hot, humid summers and mild-to-warm winters. The subtropical climate of south Florida, with its distinct wet and dry seasons, high rate of evapotranspiration, and climatic extremes of floods, droughts, and hurricanes, represents a major physical driving force that sustains the Everglades while creating water supply and flood control issues in the agricultural and urban segments.

Seasonal rainfall patterns in south Florida resemble the wet and dry season patterns of the humid tropics more than the winter and summer patterns of temperate latitudes. Recorded annual rainfall averages 53 inches per year in south Florida. Recorded extremes range from 37 in. to 106 inches. Of that 53 inches of average annual rainfall, 75% falls during the wet season months of May through October. During the wet season, thunderstorms that result from easterly tradewinds and land-sea convection patterns occur almost daily. Wet season rainfall follows a bimodal pattern, with peaks during mid-May through June and September through mid-October. Tropical storms and hurricanes also provide major contributions to wet season rainfall with a high level of interannual variability and low level of predictability. During the dry season (November through April), rainfall is governed by large-scale winter weather fronts that pass through the region approximately weekly. However, due to the variability of climate patterns (AMO, La Niña and El Niño), dry periods may occur during the wet season and wet periods may occur during the dry season. Multi-year high and low rainfall periods often alternate on a time scale approximately on the order of decades. These interannual extremes in rainfall result in frequent years of flood and drought (USACE, 1999).

Mean annual temperature for the south Florida ecosystem ranges from 72° F (22° Celsius (C)) in the northern Everglades to 76° F (24° C) in the southern Everglades (Thomas, 1974). Mean monthly temperatures range from a low of 63° F (17° C) in January to a high of 85° F (29° C) in August (Thomas, 1974). High evapotranspiration rates in south Florida roughly equal annual precipitation. Evapotranspiration removes between 70% and 90% of the rainfall in undisturbed south Florida wetlands (Duever et al., 1994). Evaporation from open water surfaces peaks annually in the late spring when temperatures and wind speeds are high and relative humidity is low. Evaporation is lowest during the winter when the temperatures and wind speeds are low (Duever et al., 1994).

H.5.2.3 Naturally Occurring Long-Term Persistent Climate Trends Impacting the Study Area

Over the last two decades, South Florida Water Management District (SFWMD) scientists have researched how natural, global climatic patterns such as the El Niño/La Niña-Southern Oscillation and the Atlantic Multidecadal Oscillation (AMO) are linked to south Florida's weather and climate.

Since 1900, there have been two cool phases and two warm phases of the AMO cycle with each of these phases lasting approximately 20-40 years each. The exact year of the phase start and finish is an estimate as each phase goes through a "transition period" of a few years. South Florida was in a much drier regime from 1965 to the early 1990s, experiencing more droughts and dry weather, when the AMO transitioned from the cool phase to the warm phase. High-water events (some extreme) started to be more frequent during the current warm phase. South Florida has been in a "wetter" regime since the early 1990s mostly due to the AMO as well.

With AMO phases lasting typically 20-40 years, the current AMO warm phase has likely peaked. Thus, the generally wetter than normal conditions that Florida has experienced since the early 1990s should begin to slowly decline. After the peak, the warm phase wave will begin its gradual decline where we will see continually cooler anomalies over the next 10-20 years. As we approach the end of the cycle, Florida will experience an increase in dry years compared to wet years. Given the temporal stage of the current phase, conditions will continue to remain wetter than average for the next 10-20 years, but with a slow and gradual decline in intensity until this phase ends and a cool phase begins. However, low frequency dry years can still occur due to other events such as La Niña, which can occur on an average of every 2-7 years.

During the period between the present and 2072, south Florida should experience a full multi-decadal cycle of Atlantic hurricane activity. Currently the area is in an active phase of this cycle that started in 1995. This active phase followed a 25-year period of low hurricane activity. This suggests that, between the present and year 2078, the area will complete its current active phase, pass through another low-activity period, and begin another active phase. Tropical storms and hurricanes provide huge amounts of rain for the area. The loss of storm associated rainfall could have significant implications for the SFWMD regional water supplies. If the number of storms does decrease, there may be significant changes to the distribution of rainfall, which will affect the water supply and natural ecology of south Florida. Less rainfall may mean the region is under drought conditions more often. If tropical storms and hurricanes become more intense, the potential damage to levees, canals, and other water control structures may also increase, resulting in an increased likelihood of flooding on a local and regional scale. Water supply and water quality may also be adversely affected by extreme dry conditions.

It is unclear at this time what the interrelationship is between climate change and El Niño/La Niña-Southern Oscillation and AMO. There is no consensus on whether climate change will any influence on the AMO or occurrence, strength, or duration of El Niño/La Niña-Southern Oscillation.

H.5.2.4 Precipitation Trends

A literature review conducted on observed and projected precipitation trends in Florida and the South Atlantic-Gulf Region is presented in the following paragraphs.

H.5.2.4.1 Observed Precipitation Trends

A number of studies in the USACE *Recent U.S. Climate Change and Hydrology Literature Applicable to U.S. Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* literature synthesis focused on trends in historical precipitation. There is consensus amongst references reviewed as part of the USACE synopsis that there is an increasing trend in observed precipitation extremes. Although the majority of references reviewed indicate an overall increasing trend in precipitation, there is less consensus amongst sources. Palecki et al. (2005) examined historical precipitation data from across the continental United States. For the South Atlantic-Gulf Region, statistically significant increases in winter storm intensity (mm per hour) and fall storm totals were identified for the southernmost portion of the region. Wang et al. (2009) identified generally positive significant trends in annual precipitation for most of the U.S. For the South Atlantic-Gulf Region, the authors identified a mild increasing trend in winter precipitation for most of the area. Changes in extreme precipitation events observed in recent historical data have been the focus of a number of studies. Studies of extreme events have focused on intensity, frequency, and/or duration of such events. Wang and Zhang (2008) used recent historical data and downscaled Global Climate Models (GCMs) to investigate changes in extreme precipitation across North America. Statistically significant increases in the frequency of the 20-year storm event were quantified across the southern and central U.S., in both the recent historical data and the long-term future projections. For the South Atlantic-Gulf

Region, significant changes in the recurrence of this storm were identified for the period 1977-1999 compared to the period 1949 – 1976: the results indicate an increase in frequency of approximately 25% – 50%. Two years later, Irizarry-Ortiz et al. (2013) quantified an overall decreasing trend in wet season (most evident in the month of May) precipitation for the state of Florida using an extended data set (1892-2008). In contrast, they also found evidence of an increase in the number of dry season (November- January) precipitation days in Florida (USACE, 2015a).

The EPA's *Climate Change Indicators in the United States* report finds that, on average, the total annual precipitation has increased in some parts of the contiguous United States since 1901, but the state of Florida shows little change. Since approximately 1990, a larger percentage of precipitation has come in the form of intense single-day events, as shown in **Figure H-16**. Nine of the top 10 years for extreme one-day precipitation events have occurred since 1990 (EPA, 2016).

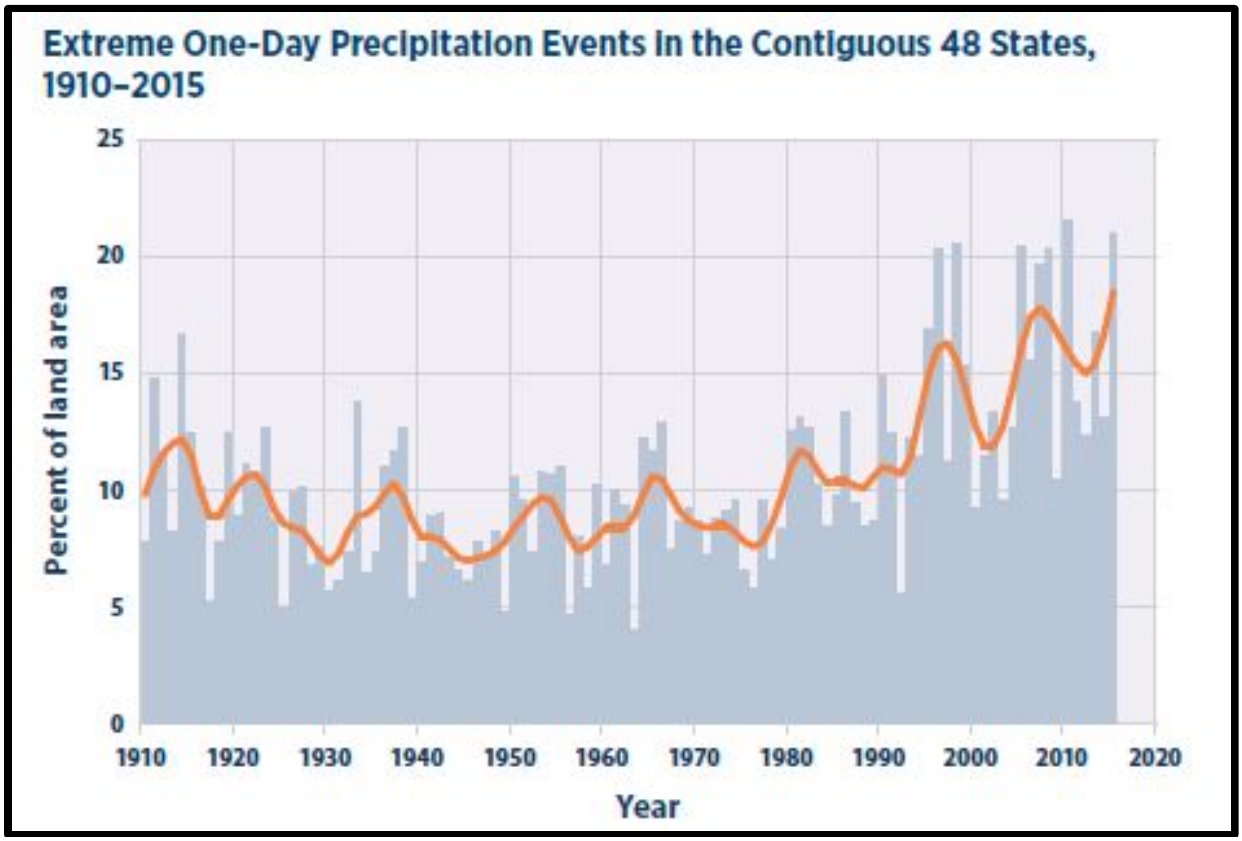

Figure H-16. EPA extreme precipitation events (EPA, 2016).

The USGCRP's *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, report finds that annual precipitation has decreased in much of the Southeast, including Florida. A national average increase of 4% in annual precipitation since 1901 is mostly a result of large increases in the fall season. However, the state of Florida has only seen increases in the winter months (**Figure H-17**). Heavy precipitation events in most parts of the United States have increased in both intensity and frequency since 1901. The state of Florida exhibits marked increases in extreme precipitation (see **Figure H-18**). Extreme precipitation events are generally observed to increase in intensity by about 6% to 7% for each degree Celsius of temperature increase (USGCRP, 2017). **Figure H-17** and **Figure H-18** show observed changes in annual/seasonal precipitation and extreme precipitation in the United States.

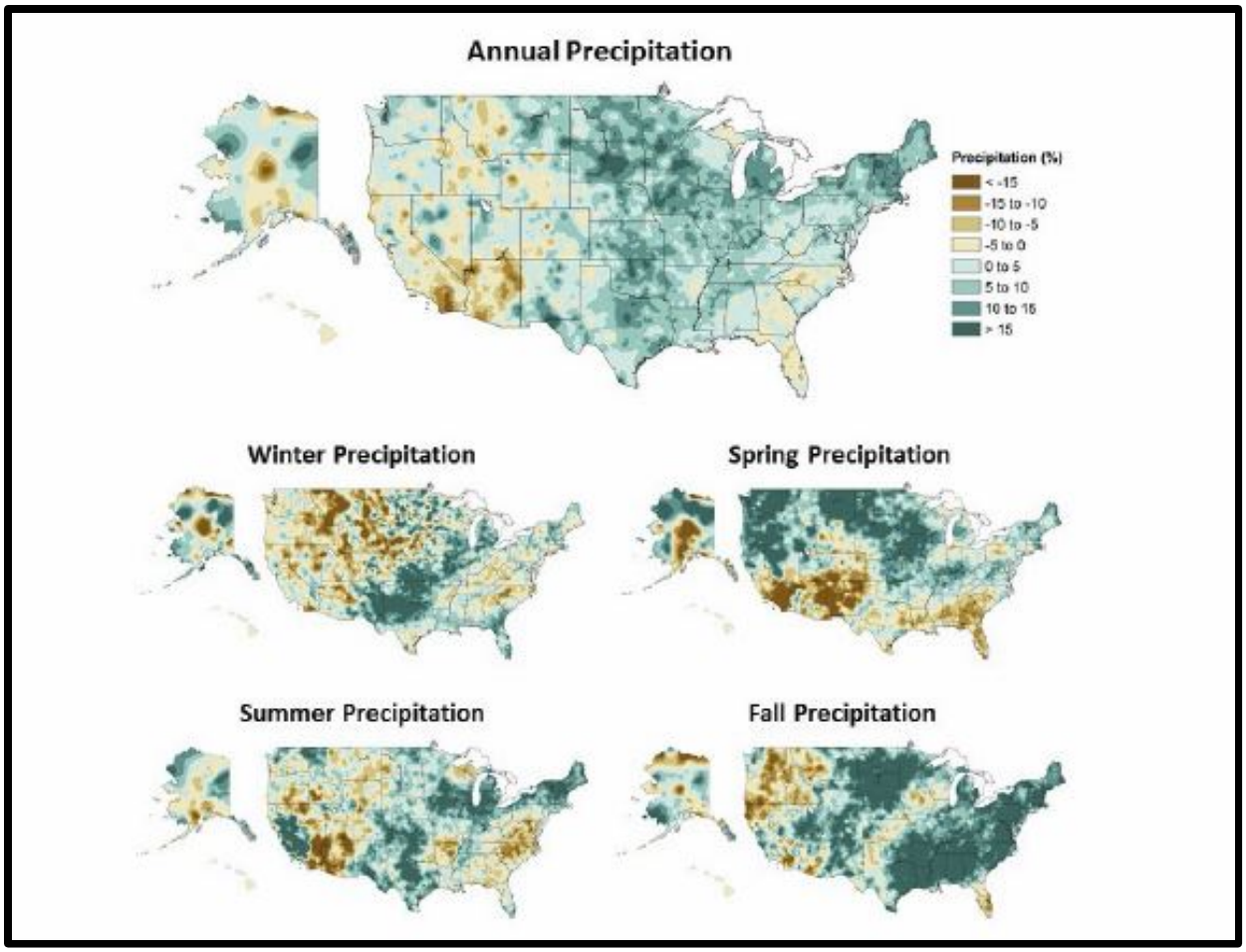

Figure H-17. Fourth National Climate Assessment observed changes in precipitation over the United States (USGCRP, 2017).

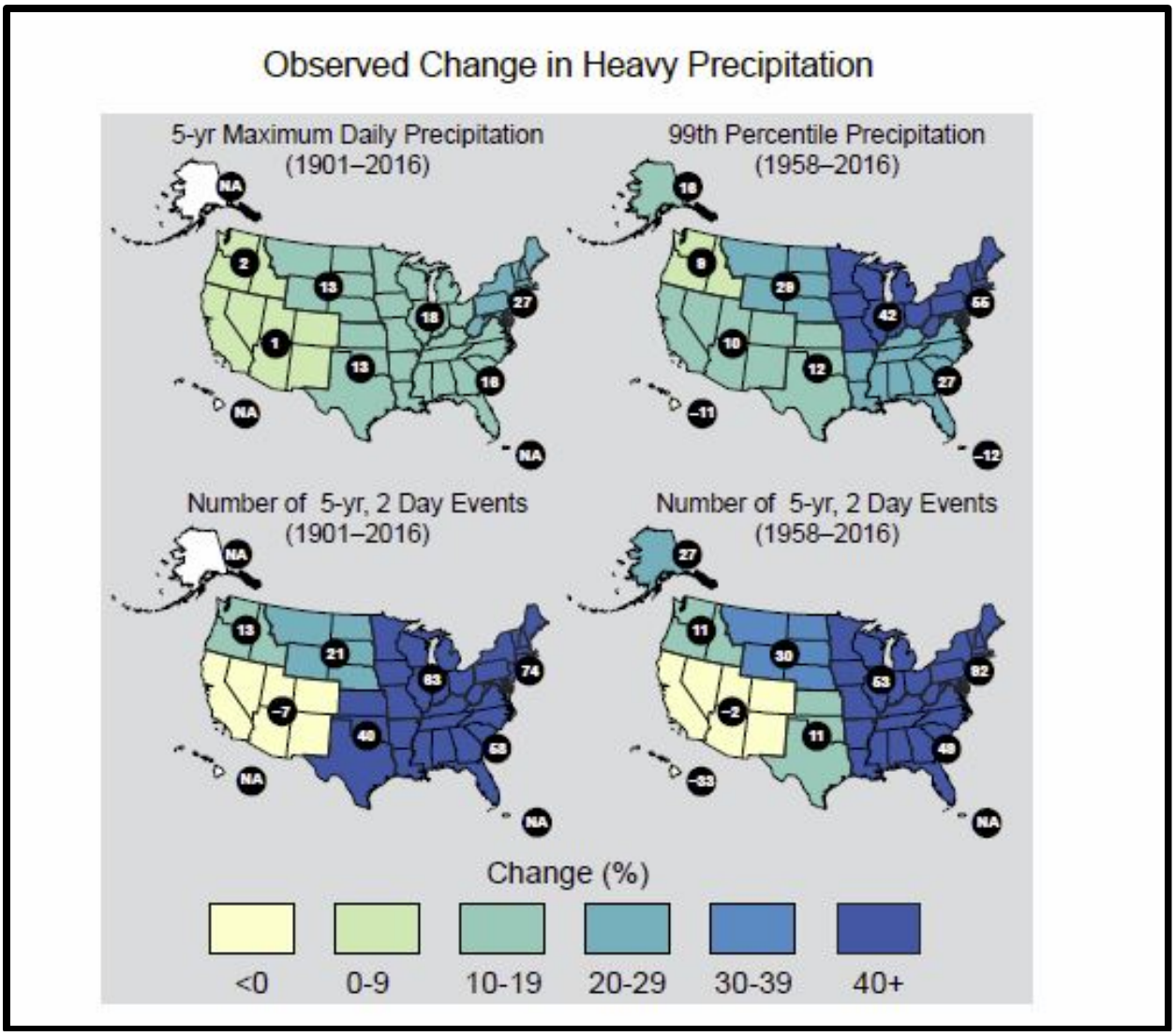

Figure H-18. 4th National Climate Assessment observed changes in extreme precipitation over the United States (USGCRP, 2017).

The *NOAA State Climate Summaries* for Florida finds that annual precipitation for the state varies widely between years, and that Florida has experienced below average annual precipitation in the last decade. Historically, the number of extreme precipitation events (precipitation greater than 4 inches) has been highly variable. Drought is a consistent climate threat for Florida resulting in reductions in water supplies, disruptions to agriculture, and increased risk of wildfires (Runkle et al., 2017).

The USACE Jacksonville District report, *Comprehensive Everglades Restoration Plan Central Everglades Planning Project Final Integrated Project Implementation Report and Environmental Impact Statement* (USACE, 2014) discussed the current climate observed in the project area. As part of the research collected by the Jacksonville District, a 2011 study by Obeysekera et al. (2011) focused on identifying climate (precipitation) trends for south Florida using historical data. This study examined a number of climate metrics with data extending back to the 1890s. For all of the metrics, including total annual precipitation and the occurrence of temperature extremes, no discernible trends were found within the study region.

H.5.2.4.2 Projected Precipitation Trends

For a better understanding of projected trends in hydrologic climate variables, it should be noted that projected, future changes in climate variables referenced in the literature are estimated using Global Circulation Models (GCMs) of the earth. Although significant uncertainties are inherent in these model projections, they represent the best available science to predict trends in climate (USACE, 2015a). Projected meteorological datasets derived using the GCMs are spatially downscaled so that the results can be used to estimate projected trends in climate variables at a watershed scale.

The USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* literature synthesis finds that, similar to the rest of the United States, projections of future changes in precipitation in the South Atlantic-Gulf Region are variable and generally lacking in consensus among studies or across models. The Liu et al. study (2013), quantified significant increases in winter and spring precipitation associated with a 2055 planning horizon, relative to a recent historical baseline (1971-2000, centered around 1985), for the South Atlantic Region. Smaller increases, or even slight decreases, are projected for the other seasons. However, the authors also project increases in the severity of future droughts for the region, as projected temperature and evapotranspiration (ET) impacts outweigh the increases in precipitation. Future projections of extreme events, including storm events and droughts, are the subject of studies by Tebaldi, Wang and Zhang, Gao et al., and Wang et al. (Tebaldi 2006, Wang & Zhang 2008, Gao et al. 2012, and Wang et al. 2013). They forecast small increases in the occurrence and intensity of storm events by the end of the 21st century for the general study region. Storm events in northern Florida are projected to be more intense and more frequent in the future (USACE, 2015a).

The USGCRP's *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, report projects that the frequency and intensity of heavy precipitation events will continue to increase over the 21st century. Florida is not projected to experience significant changes in average precipitation (see Figure H-16). Studies project that the observed increase in heavy precipitation events will continue in the future. As with the rest of the continental United States, Florida is expected to see increases in heavy precipitation in the future (see Figure H-17).Research shows that there is strong evidence that increased water vapor resulting from higher temperatures is the primary cause of the increases. **Figure H-19** and **Figure H-20** show changes in projected seasonal precipitation and extreme precipitation in the United States.

Regional model projections of precipitation from land falling tropical cyclones over the United States suggest that the frequency of post-landfall tropical cyclones over the United States during the rest of the 21st century will change little compared to present day. Several studies have projected increases of precipitation rates within hurricanes over ocean regions, particularly over the Atlantic basin (USGCRP, 2017).

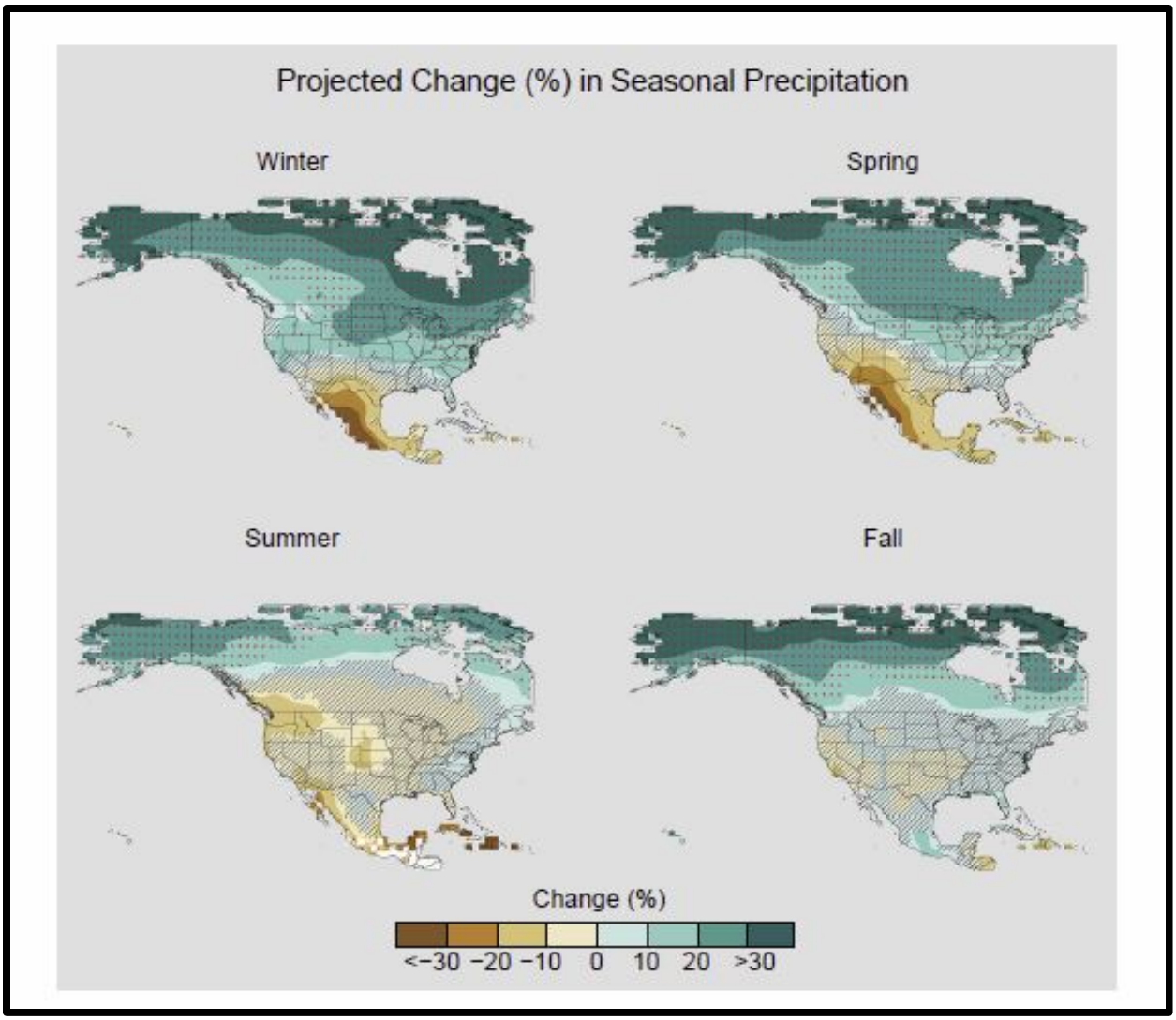

Figure H-19. 4th National Climate Assessment projected percent change in total seasonal precipitation (USGCRP, 2017).

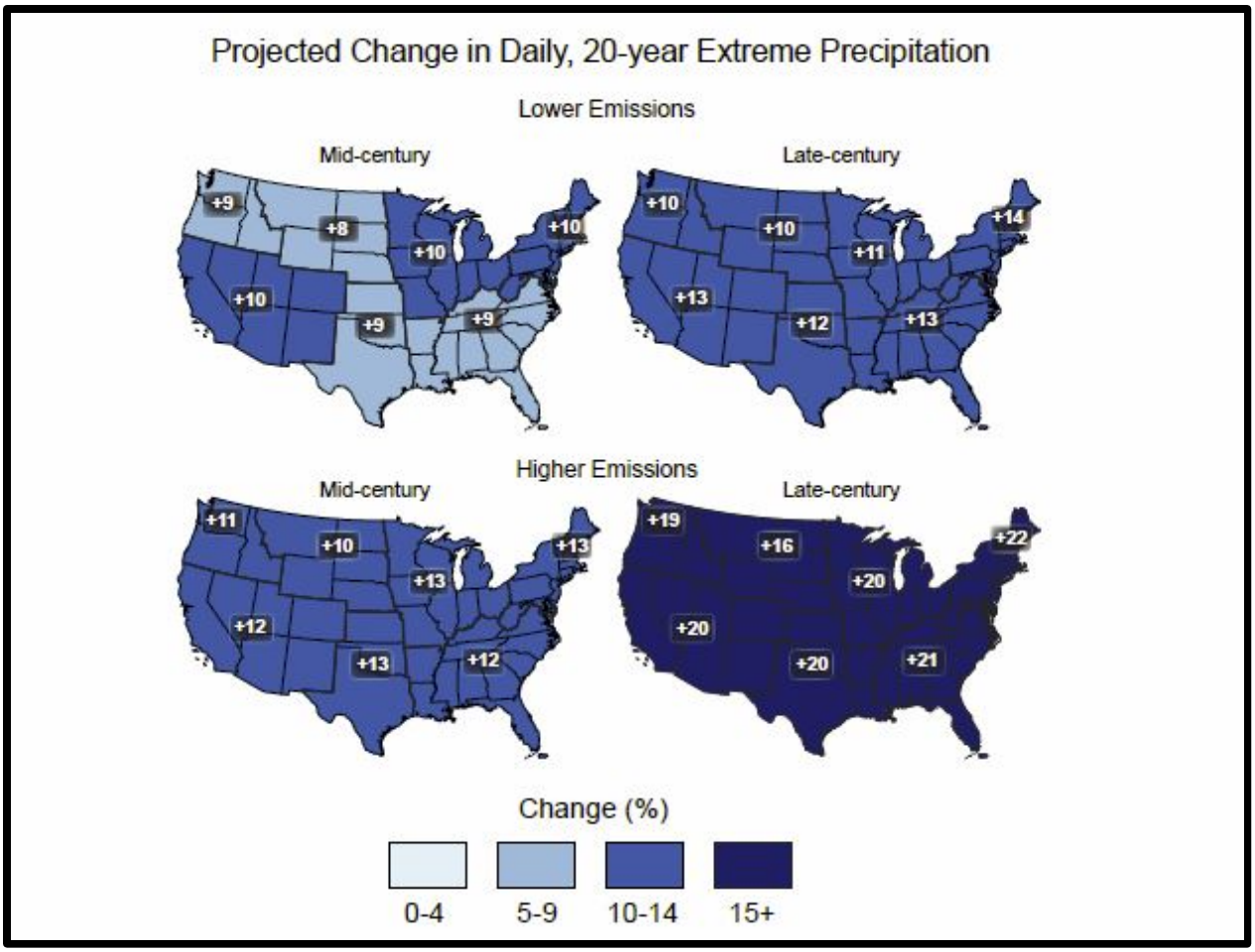

Figure H-20. 4th National Climate Assessment projected change in the 20-year return period amount for daily precipitation for mid- and late-21st century (USGCRP, 2017)

The NOAA's *State Climate Summaries* for Florida finds that future projections of average precipitation are uncertain, but an increase in intense rainfall is projected. Average summer precipitation may not change. Higher temperatures will increase the rate of loss of soil moisture and thereby droughts will be more intense. Decreased water availability will continue to increase competition for water and affect the region's economy and unique ecosystems. While annual frequency of hurricanes has remained relatively stable throughout the 20th and early 21st centuries, hurricane rainfall is expected to increase for Florida as the climate continues to warm (Runkle et al., 2017).

The USACE Jacksonville District report finds that the Florida Oceans Council (2009) predicts more frequent intense rainfall events will occur, coupled with longer dry periods in between. SFWMD data indicates that there has been an increase in heavy downpours in many parts of the region. Additionally, the percentage of the region experiencing moderate to severe drought has increased over the past three decades.

H.5.2.5 Air Temperature

A literature review conducted on observed and projected air temperature trends in Florida and the South Atlantic-Gulf Region is presented in the following paragraphs.

H.5.2.5.1 Observed Temperature Trends

A number of studies in the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* literature synthesis focused on observed trends in historical temperatures. A study by Wang et al. (2009) examined climate trends using gridded mean monthly climate data for 1950-2000. The study identified a positive warming trend for the state of Florida. Grundstein and Dowd (2011) investigated trends in one-day extreme maximum and minimum temperatures across the continental United States. The study finds statistically significant increasing trends in the number of one-day extreme minimum and maximum temperatures. This appears to agree with the findings of Wang et al. (2009).

The EPA's *Climate Change Indicators in the United States* report finds that average temperatures have risen across the contiguous United States since 1901. Nationwide, unusually hot summer days (highs) have become more common over the last few decades. Unusually hot summer nights (lows) have become more common at an even faster rate. This trend indicates less "cooling off" at night as shown in **Figure H-21** (EPA, 2016).

The USGCRP's *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, report finds that each National Climate Assessment (NCA) region shown in **Figure H-22** experienced an overall warming for the period 1986-2016 relative to 1901-1960 (**Figure H-23**). The southeast study region is larger than, but inclusive of, the South Atlantic-Gulf Region described in the 2015 USACE literature synthesis. For this area, historical data generally shows mild warming of average annual temperatures in the early part of the 20th century, followed by decades of cooling, and overall is not showing indications of consistent warming in average annual temperature. Florida, however, appears to be experiencing warming in average annual temperatures as shown in Figure H-20. There have been marked changes in temperature extremes across the contiguous United States. The number of high temperature records set in the past two decades far exceeds the number of low temperature records (USGCRP, 2017).

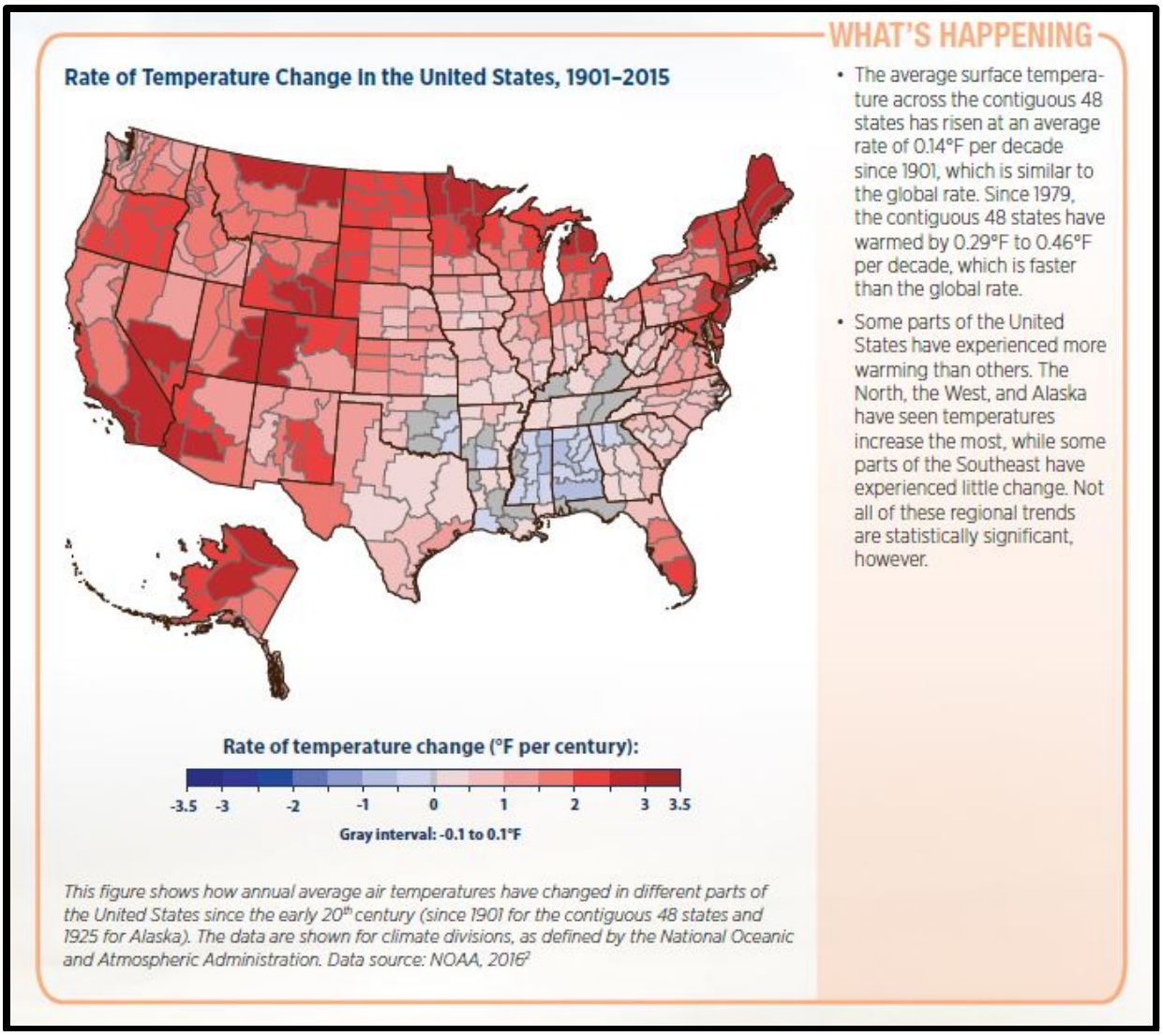

Figure H-21. EPA rate of temperature change in the United States, 1901-2015 (EPA, 2016).

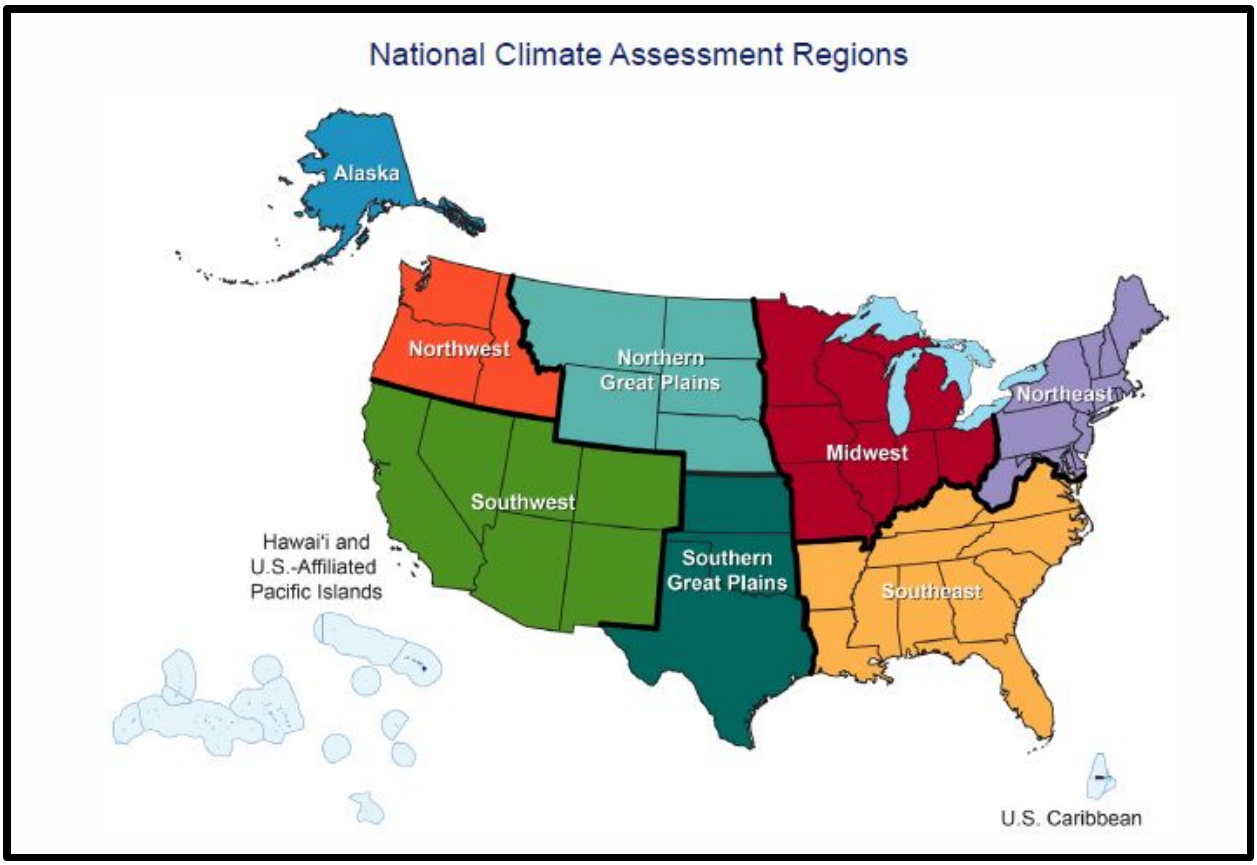

Figure H-22. Fourth National Climate Assessment regional boundaries in CONUS (USGCRP, 2018).

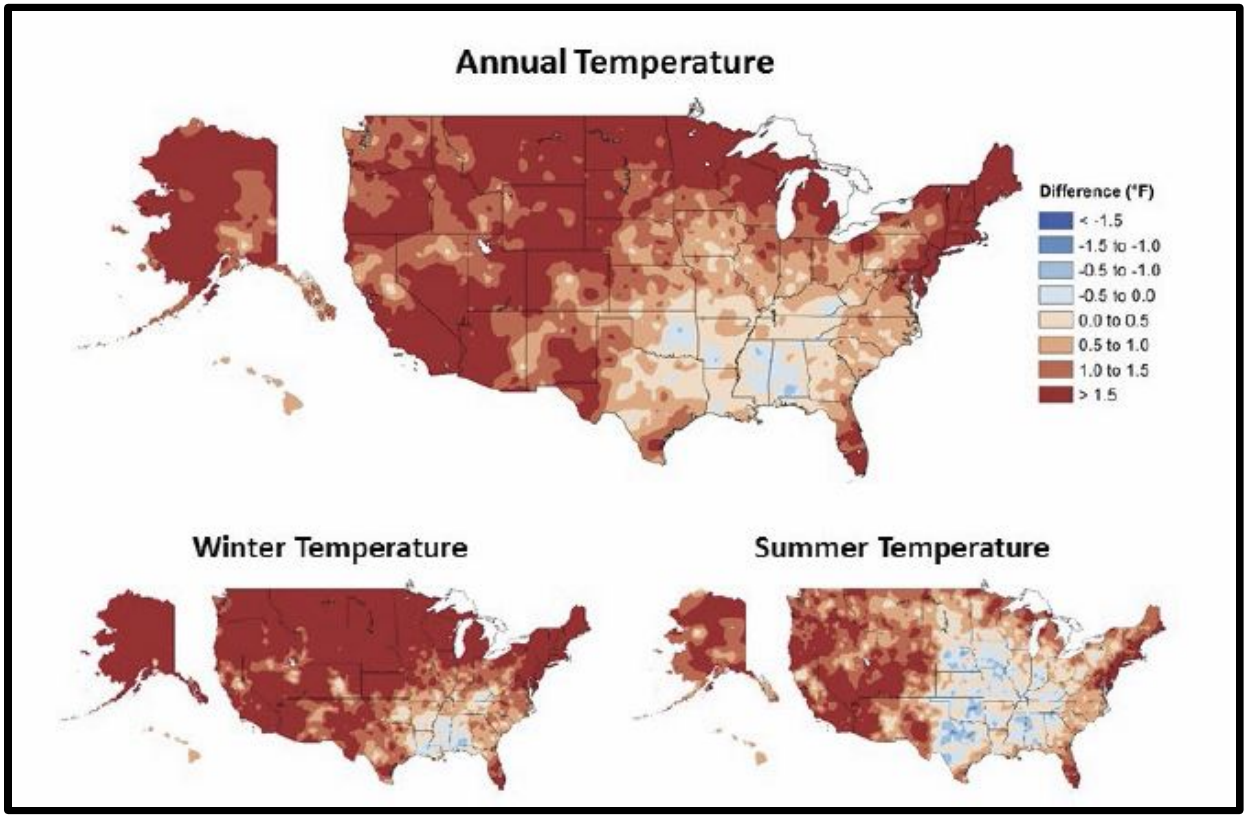

Figure H-23. 4th National Climate Assessment observed changes in annual average temperature (USGCRP, 2017).

The *NOAA State Climate Summaries* for Florida finds that temperatures in Florida have increased about 1° Fahrenheit (F) since the beginning of the 20th century. While there has been a lack of general daytime warming, the frequency of very warm nights (minimum temperature above 75° F) has risen dramatically in the last two decades. As shown in **Figure H-233** (Runkle et al.,2017), the number of very warm nights in the first part of the 21st century has nearly doubled when compared to the occurrence of very warm nights in the mid-20th century (1930-1954).

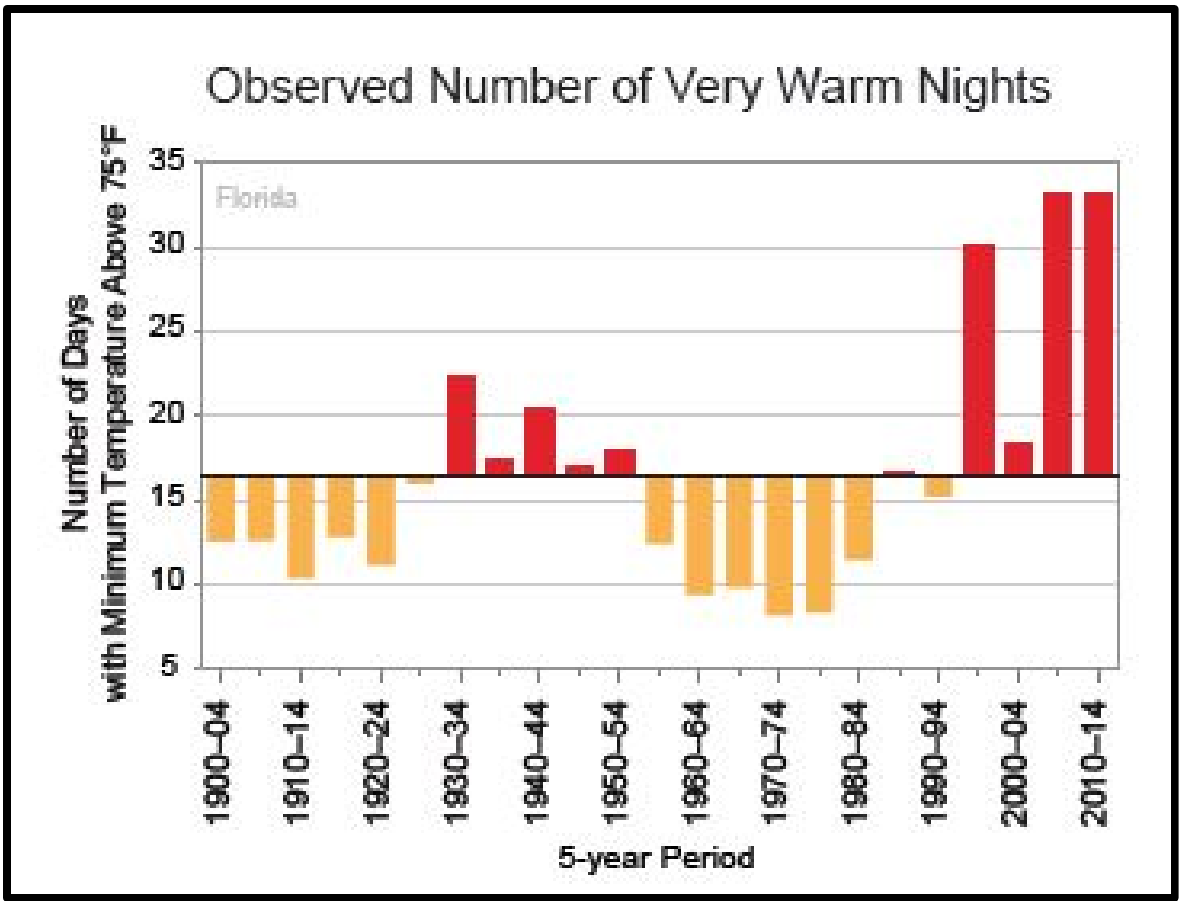

Figure H-24. NOAA state climate summary for Florida: Observed number of very warm nights for 1900-2014 (Runkle et al., 2017).

H.5.2.5.2 Projected Temperature Trends

Review of the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* literature synthesis indicates strong consensus that air temperatures will increase over the next century in the South Atlantic-Gulf Region. The studies reviewed generally agree on an increase in mean annual air temperature of approximately 2° to 4° C by the latter half of the 21st century for the region. The largest increases are projected for the summer months. Reasonable consensus is also seen in literature with respect to projected increases in extreme temperature events, including more frequent, longer, and more intense summer heat waves in the long-term future compared to recent past, as shown in **Figure H-25** (USACE, 2015a).

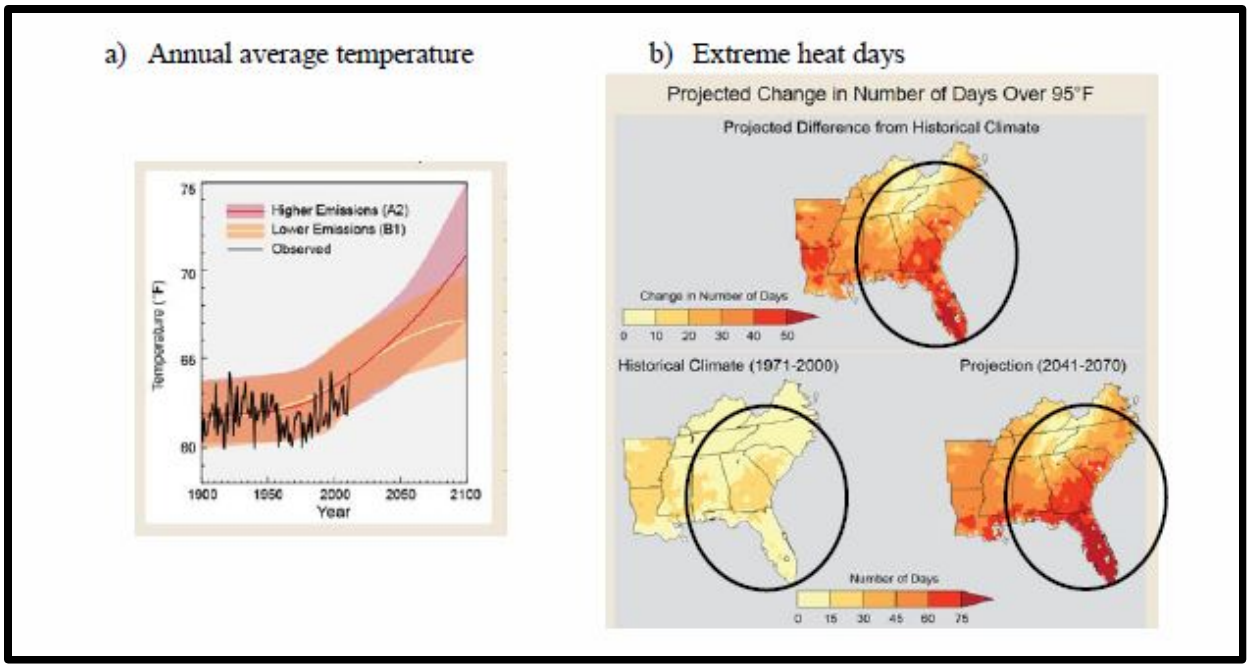

Figure H-25. GCM projections of temperature change in the southeast United States (South Atlantic-Gulf Region circled in black) (USACE, 2015a).

The USGCRP's *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, report finds that extreme temperatures are projected to increase even more than average temperatures. Statistically significant warming is projected for all parts of the United States throughout the 21st century. The Southeast has slightly less warming because of latent heat released from increases in evapotranspiration. From a sub-regional perspective, less warming is projected along the coasts of the contiguous United States, due to maritime influences, although increases are still substantial. Daily extreme temperatures are projected to increase substantially in the contiguous United States. On a regional basis, annual extremes are consistently projected to rise faster than annual averages. In the future, the number of "very rare" extreme temperatures are projected to increase (USGCRP, 2017). Rising air and water temperatures and increases in precipitation are intensifying droughts, increasing heavy downpours, reducing snowpack, and causing declines in surface water quality, with varying impacts across regions. Future warming will add to the stress on water supplies and adversely impact the availability of water in parts of the United States (USGCRP, 2018). **Figure H-26** and **Figure H-27** show project changes in annual average temperatures and extreme temperatures in the United States.

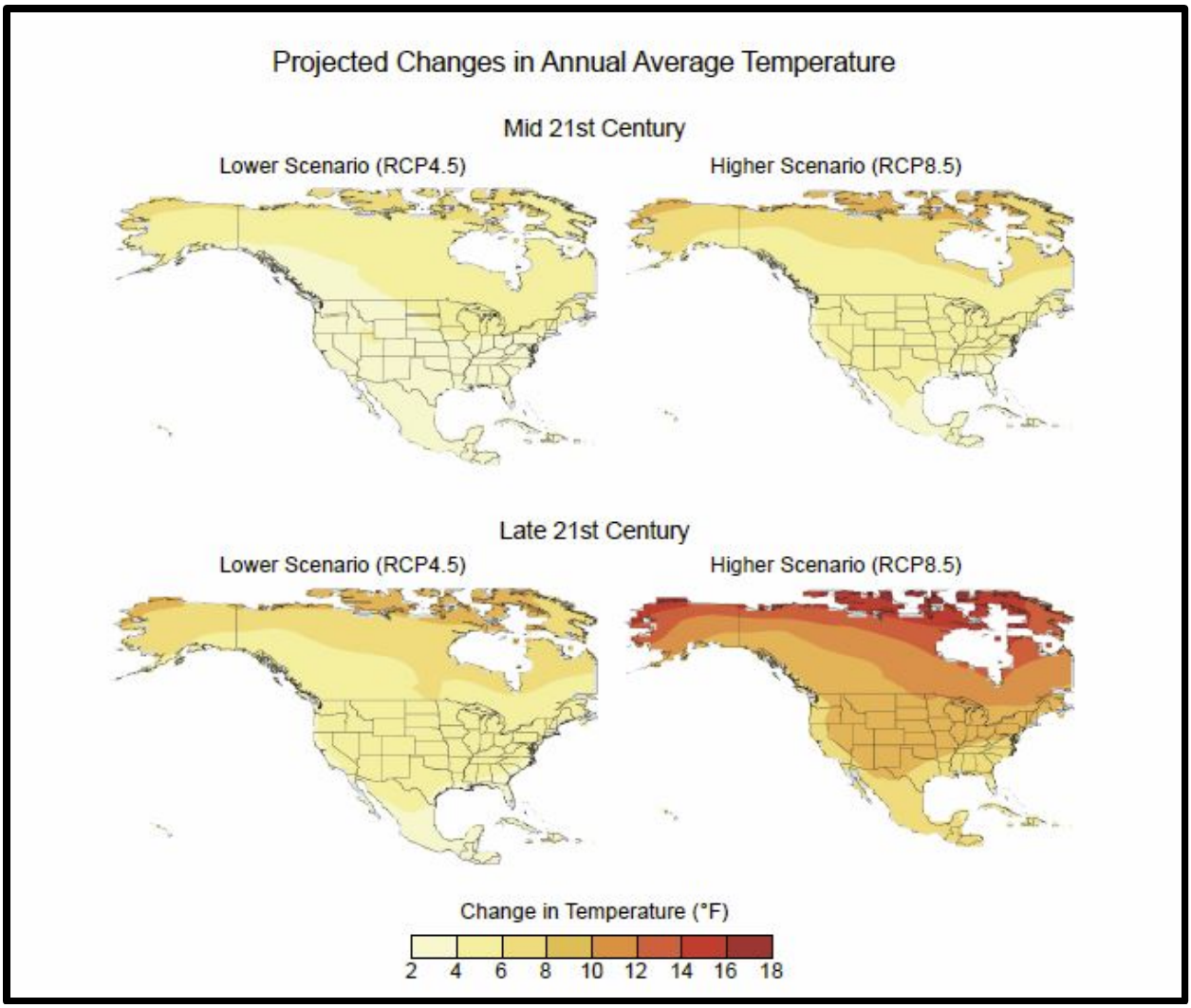

Figure H-26. 4th National Climate Assessment projected changes in annual average temperatures (°F) (USGCRP, 2017).

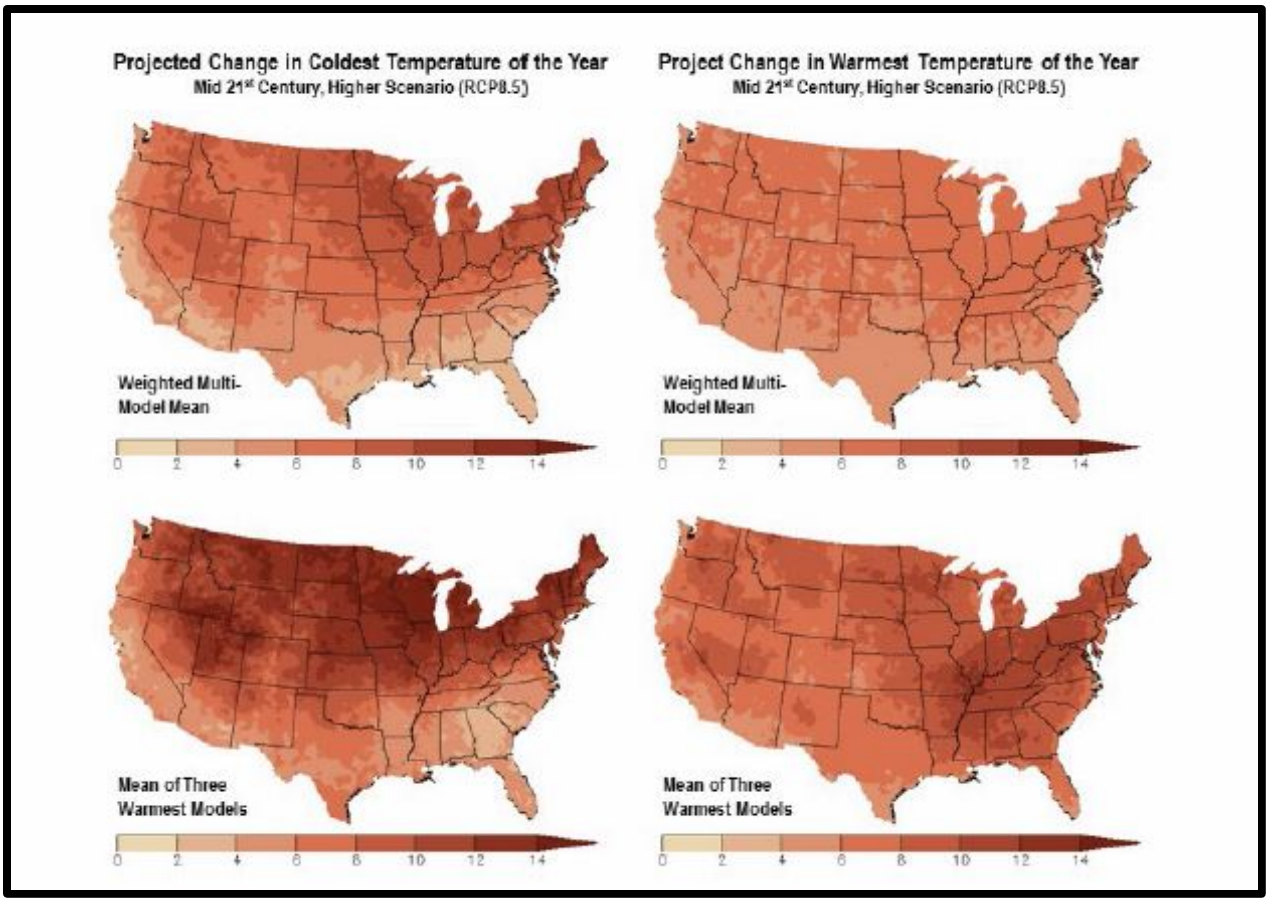

Figure H-27. 4th National Climate Assessment Projected changes in coldest and warmest daily temperatures (°F) of the year in the contiguous United States (USGCRP, 2017).

The *NOAA State Climate Summaries* for Florida projects that average annual temperatures will most likely exceed historical record levels by the middle of the 21st century. By 2055, projections show an increase over most of the state of Florida of more than 50 days with temperatures exceeding 95° F (Runkle et al., 2017). **Figure H-28** shows observed and projected air temperature changes for Florida.

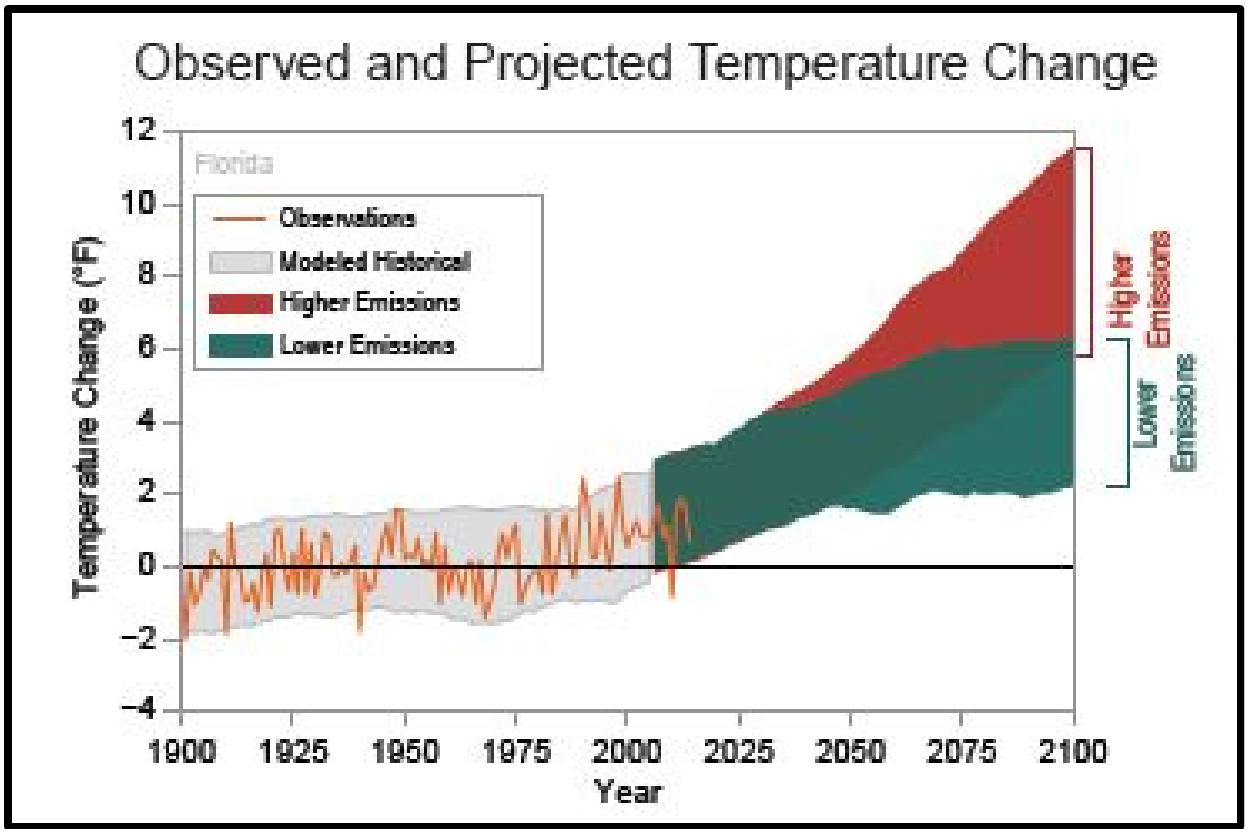

Figure H-28. NOAA State Climate Summary for Florida: Observed and projected changes (compared to the 1901-1960 average) in air temperature for Florida (Runkle et al., 2017).

The USACE Jacksonville District report finds that climatologists predict air temperatures will increase, with projections of summer temperatures being up to 3° to 7° F warmer by 2100 (Twilley et al., 2001; Union of Concerned Scientists, 2008). Increases in air temperature, solar radiation, and water vapor deficit due to climate change are expected to increase evapotranspiration. Models used by Calanca et al. (2006) predict a 20% increase in evapotranspiration if summer temperatures increase from 4° to 7° F. Other climate modeling used a 1.5° C increase of temperatures in the Everglades and +/-10% change in precipitation by 2060 (Obeysekera et al., 2011). The temperature change equates to a 7% increase in evapotranspiration. Unless precipitation increases similarly (+7% to +10%), then drought frequency is expected to increase in the Everglades. As a peat soil ecosystem, increasing drought would reduce available water to keep the soils wet, resulting in higher peat oxidation and loss of soil elevations in the freshwater wetlands (FAU, 2013). Hydrological modeling indicates that surface water duration may decrease by 10-50% in the Everglades by 2060 (FAU, 2013).

H.5.2.6 Streamflow

A literature review conducted on observed and projected streamflow trends in Florida and the South Atlantic-Gulf Region is presented in the following paragraphs.

H.5.2.6.1 Observed Streamflow Trends

Review of the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* literature synthesis finds that analysis on trends and nonstationarity in streamflow data collected over the past century have been performed throughout the continental United States, some of which include the South Atlantic-Gulf Region. Statistically significant negative trends in both annual streamflow and baseflow were identified for two stations in Florida. The vast majority of stations, distributed throughout the HUC, show no significant trend in streamflow in either direction (USACE, 2015a).

The EPA's *Climate Change Indicators in the United States* report finds that increases and decreases in frequency and magnitude of river flood events generally coincide with increases and decreases in the frequency of heavy rainfall events. In addition to climate change, several other types of human influence could affect the frequency and magnitude of floods — for example, dams, floodwater management activities, agricultural practices, and changes in land use. To minimize these influences, this analysis focused on a set of sites that are not heavily influenced by human activities (EPA, 2016). **Figure H-29** shows change in frequency of river flooding for sites in the United States. As can be seen from the figure, both decreasing and increasing trends are evident at streamflow gaging sites in Florida.

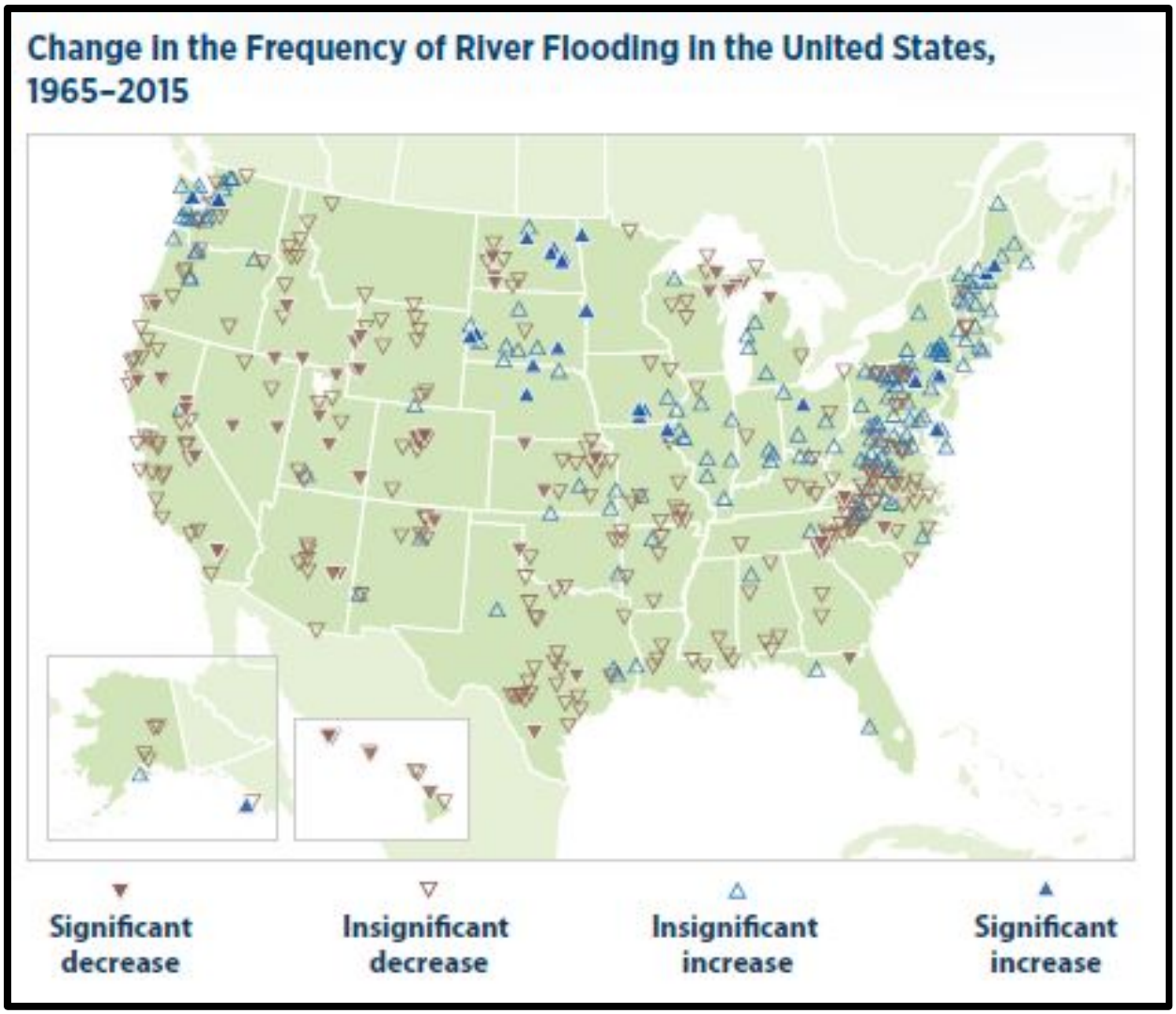

Figure H-29. EPA change in the frequency of river flooding in the United States, 1965-2015 (EPA, 2016).

The USGCRP's *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, report finds that detectable changes in some classes of flood frequency have occurred in parts of the United States, with a mix of increases and decreases. Extreme precipitation, one of the controlling factors in flood statistics, has generally increased. However, formal attribution approaches have not established a significant connection between increased riverine flooding and human-induced climate change (USGCRP, 2017).

H.5.2.6.2 Projected Streamflow Trends

A number of global and national scale studies have attempted to project future changes in hydrology, relying primarily on a combination of GCMs and macro-scale hydrologic models. Review of the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* literature syntheses includes projections of potential hydrologic changes in the South Atlantic-Gulf Region. Thomson et al. (2005) applied two GCMs, across a range of varying input assumptions, in combination with the macro-scale Hydrologic Unit Model to quantify potential changes in water yield across the United States. For the South Atlantic-Gulf Region, contradictory results are

generated by the two GCMs. For the same set of input assumptions, one model predicts significant decreases in water yield, the other model projects significant increases in water yield. Similarly, clear consensus is lacking in the hydrologic projection literature. Projections generated by coupling GCMs with macro-scale hydrologic models in some cases indicate a reduction in future streamflow but in other cases indicate a potential increase in streamflow in the study region. Of the limited number of studies reviewed as part of the USACE literature synopsis, results are almost evenly split between projected increasing and decreasing trends (USACE, 2015a).

The USGCRP's *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, report finds that detectable changes in some classes of flood frequency have occurred in parts of the United States with a mixture of increasing and decreasing streamflow trends. Extreme precipitation is projected to continue to increase across the United States in a warming atmosphere. However, formal attribution approaches have not established a significant connection of increased riverine flooding to human-induced climate change, and the timing of any emergence of a future detectable anthropogenic change in flooding in unclear (USGCRP, 2017).

H.5.2.7 Literature Summary

The literature review summarizes available resources discussing observed and projected hydroclimatic trends in the project area. There is evidence of changes to global climate patterns that will likely have an impact on central and south Florida in terms of rainfall and air temperature. A summary of the literature reviewed as part of the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* is displayed in **Figure H-30**.

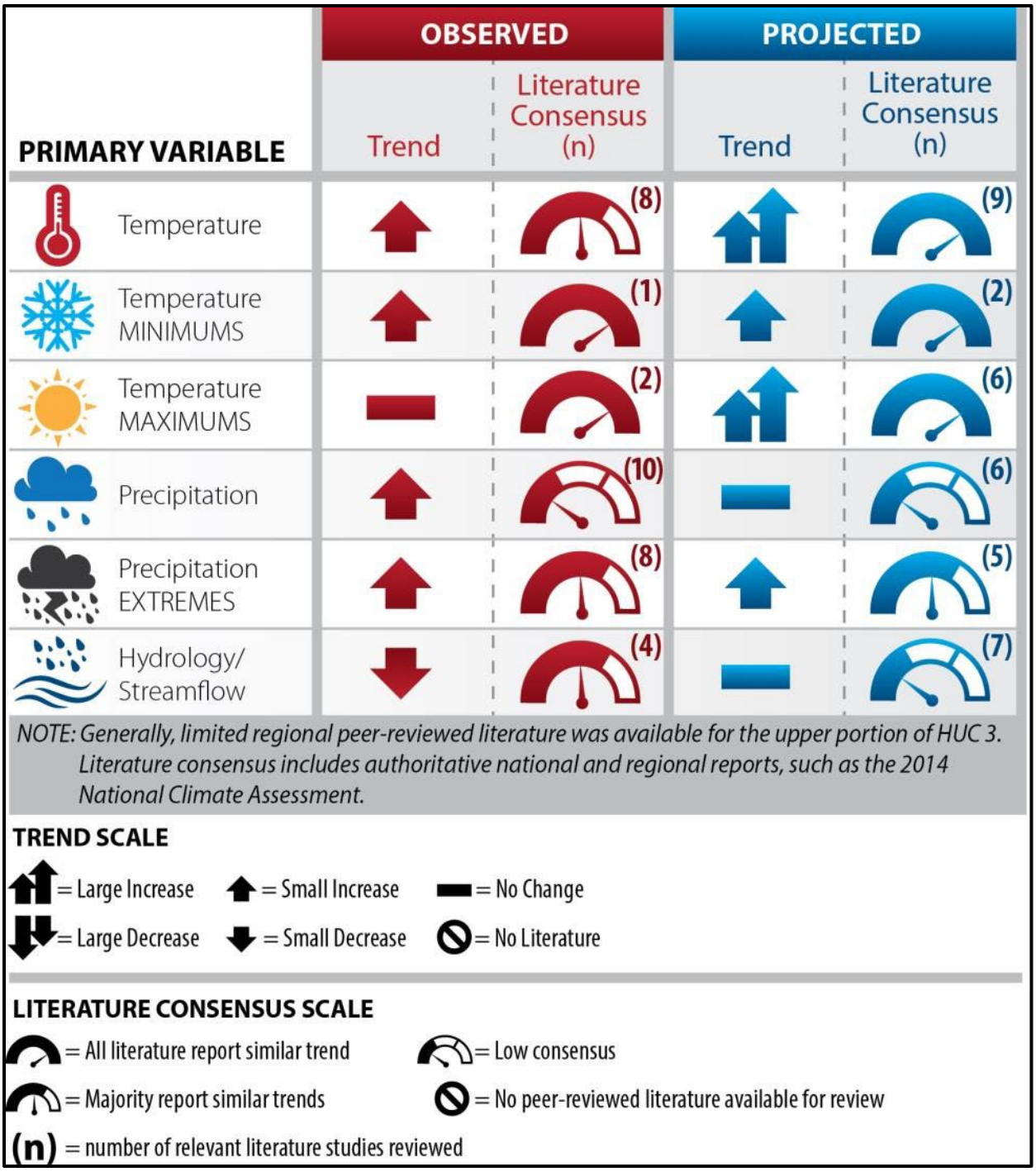

Figure H-30. Summary Figure from USACE Literature Synopsis of South Atlantic-Gulf Region- 03

Based on the references reviewed, there is an increasing trend in observed annual/seasonal air temperature trends among the five peer-reviewed literature sources show an increase in temperature, as well as temperature extremes. This literature review indicates that observed precipitation shows no discernible trends in annual/seasonal precipitation but shows an increase in the frequency and intensity

of extreme precipitation events. The annual frequency of hurricanes has remained relatively stable throughout the 20th and early 21st centuries; however, hurricane rainfall is expected to increase for Florida as the climate continues to warm. SFWMD data indicate that there has been an increase in heavy downpours in many parts of the region, while the percentage of the region experiencing moderate to severe drought increased over the past three decades. Rising air and water temperatures and in precipitation are intensifying droughts and increasing heavy downpours. No trend in observed streamflow was found. A summary of the observed trends can be found in **Table H-8.**

Projected air temperature trends among the five peer-reviewed literature sources show an increase in in air temperature minimums and maximums. The studies reviewed generally agree on an increase in mean annual air temperature for the South Atlantic-Gulf Region of approximately 2° to 4° C by the latter half of the 21st century. The largest increases are projected for the summer months, with extreme temperatures expected to increase even more than average temperatures. Projected precipitation shows no discernible trend in annual/seasonal precipitation, but does show an increase in the frequency and intensity of extreme precipitation events. Research shows that there is strong evidence that increased water vapor resulting from higher temperatures will likely be the primary cause of the projected increases. The frequency of seasonal hourly precipitation extremes is expected to increase in all regions of the United States. In addition, future projections of extreme events, including droughts, are the subject of the literature. Drought is a consistent climate threat for Florida resulting in reductions in water supplies, disruptions to agriculture, and increased risk of wildfires. The literature projects increases in the severity of future droughts for the region, as projected temperature and evapotranspiration (ET) increases outweigh the increases in precipitation. There is no consensus on an increase or decrease in projected streamflow. A summary of the projected trends can be found in **Table H-9.**

Table H-8. Observed trends of the climate variables reviewed in the literature.

Literature Source	Temperature (annual/seasonal)	Temperature Minimums	Temperature Maximums	Precipitation (annual/seasonal)	Precipitation Extremes	Streamflow
Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03 (USACE, 2015)	Increase	Increase	Increase	Increase, but low consensus	Increase	Decreasing Trend, but low consensus
Climate Change Indicators in the United States (EPA, 2016)	Increase	Increase	Increase	No Trend	Increase	No Trend
Climate Science Special Report: Fourth National Climate Assessment, Volume I and II (USGCRP, 2017; USGCRP, 2018)	No trend	Increase	Increase	Decreases in Spring Precipitation & Increases in Winter Precipitation; no trend in summer or fall precipitation	Increase	No Trend
NOAA State Climate Summaries (Runkle et al., 2017)	Increase	Increase	No Trend	No Trend	No Trend	Not Addressed
USACE Jacksonville District studies	No trend	No trend	No trend	No trend	Not Addressed	Not Addressed

Table H-9. Projected trends of the climate variables reviewed in the literature.

Literature Source	Temperature (annual/seasonal)	Temperature Minimums	Temperature Maximums	Precipitation (annual/seasonal)	Precipitation Extremes	Streamflow
Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03 (USACE, 2015)	Increase	Increase	Increase	No Trend	Increase	No Trend
Climate Change Indicators in the United States (EPA, 2016)	Not Addressed	Not Addressed	Not Addressed	Not Addressed	Not Addressed	Not Addressed
Climate Science Special Report: Fourth National Climate Assessment, Volume I and II (USGCRP, 2017; USGCRP, 2018)	Increase	Increase	Increase	No Trend	Increase	No Trend
NOAA State Climate Summaries (Runkle et al., 2017)	Increase	Not Addressed	Increase	No Trend	Increase	Not Addressed
USACE Jacksonville District studies	Increase	Not Addressed	Not Addressed	Not Addressed	Increase	Not Addressed

H.5.2.8 Climate Tools

In addition to a literature review, the vulnerability assessment includes the application of climate tools to provide information on observed and projected climate trends relevant to the project area.

These tools provide information on historic trends in observed data:

1. Climate Hydrology Assessment Tool (CHAT)
2. Nonstationarity Detection Tool (NSD)
3. Time Series Toolbox

The following tools provide qualitative information on projected climate conditions at the watershed scale (Hydrologic Unit 4 (HUC04)):

1. Climate Hydrology Assessment Tool (CHAT)
2. Vulnerability Assessment Tool (VA)

These tools are available on the USACE Climate Preparedness and Resilience CoP Applications Web portal (USACE, 2018c).

H.5.2.8.1 Climate Hydrology Assessment Tool

The CHAT allows users to assess trends in both observed and projected streamflows. The CHAT tool supports consistent analyses by producing reliable, qualitative projections of climate changed hydrology for USACE projects.

The CHAT projects future changes in annual maximum monthly streamflow using GCM outputs aggregated at the watershed scale (HUC04). This is consistent with the spatial and temporal precision of the downscaled GCM outputs converted into a climate changed hydrologic response. **Figure H-31** shows the HUC04 basins for the South Atlantic-Gulf Region. The LRWRP project is located within the southernmost basin in Florida.

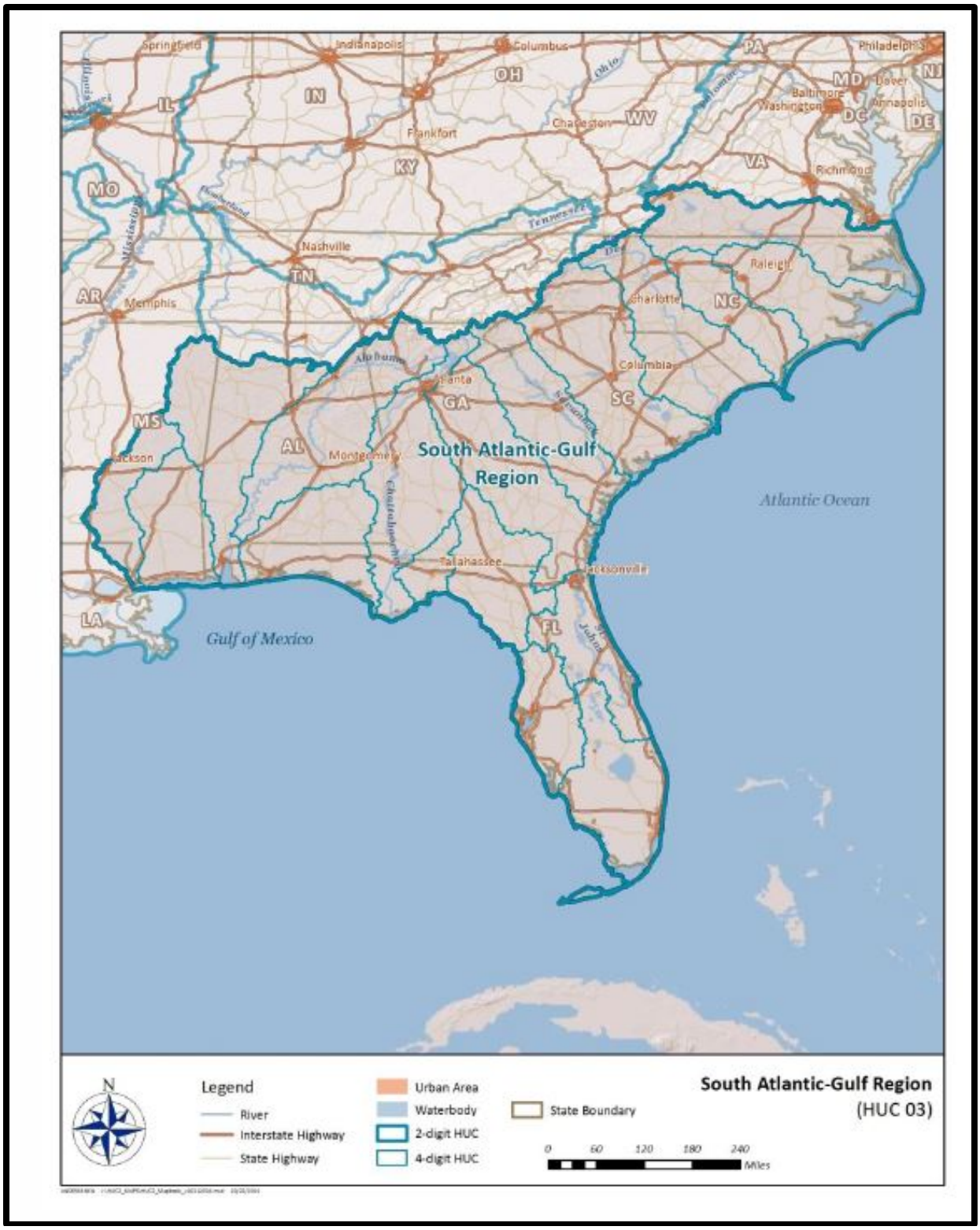

Figure H-31. Water Resources Region 03: South Atlantic-Gulf Region boundary (USACE, 2015).

H.5.2.8.1.1 Observed Trends

Using the CHAT, a first-order statistical analysis of trends in observed, peak streamflow data was conducted using data from the U.S. Geological Survey (USGS) gauge 2277600 'Loxahatchee River near Jupiter, Florida' (see **Figure H-32**). It should be noted that flow trends and potential nonstationarities for this gauge, like most in the region, are likely not influenced by climate change but by human activity that could affect the frequency and magnitude of flood flows – for example, water management activities, agricultural practices, changes in land use, and water control structure operations. The streamflow gauge with the longest unregulated period of record in the region is located along the northwest shore of Lake Okeechobee about 80 miles inland from the Loxahatchee streamflow gauge. The Loxahatchee gauge has an upstream control (G-92) structure that has had varying operations over the past decades.

H.5.2.8.1.1.1 Peak Streamflow

Trends in peak streamflow may provide supporting evidence of climate change. The analysis focuses on high flows because one of the purposes of the LRWRP is to improve the timing and distribution of wet season flows to the Northwest Fork of the Loxahatchee River floodplain.

Peak streamflow may also impact flood risk reduction and ecosystem restoration projects, making it important to the Ecosystem Restoration and Flood Risk Reduction USACE business lines.

The CHAT tool applies a linear regression analysis to the annual instantaneous peak discharges recorded at the USGS Loxahatchee River gauge (see pertinent data for gauge in **Figure H-33**). The p-value associated with the trend line is 0.32 in **Figure H-34**, which is greater than the accepted threshold for significance of 0.05. A p-value of 0.32 indicates that the trend is not significant at the 0.05 significance level.

Figure H-32. Location of the USGS Loxahatchee gauge

02277600 LOXAHATCHEE RIVER NEAR JUPITER, FL

LOCATION - Lat 26°56'20", long 80°10'31" referenced to North American Datum of 1927, in NE 1/4 SE 1/4 NE 1/4 sec.06, T.41 S., R.42 E., Palm Beach County, FL, Hydrologic Unit 03090202, near left bank, 0.2 mi downstream from State Road 706, 1.3 mi upstream from Florida's Turnpike and 5.2 mi west of Jupiter.

DRAINAGE AREA - Indeterminate.

REVISIONS HISTORY - WDR FL-04-2A: 2003.

SURFACE-WATER RECORDS

PERIOD OF RECORD - April 1971 to current year.

GAGE - Satellite data collection platform with water-stage recorder and a slave radio modem. Datum of gage is National Geodetic Vertical Datum of 1929 and 1.47 ft below North American Vertical Datum of 1988(NAVD 88).

COOPERATION - South Florida Water Management District.

REMARKS - Flow is augmented by diversion from C-18 canal 2.0 mi upstream from the gage. High-water flow can be diverted into C-18 canal by backflow through the structure.

Figure H-33. Pertinent data for USGS Loxahatchee gauge

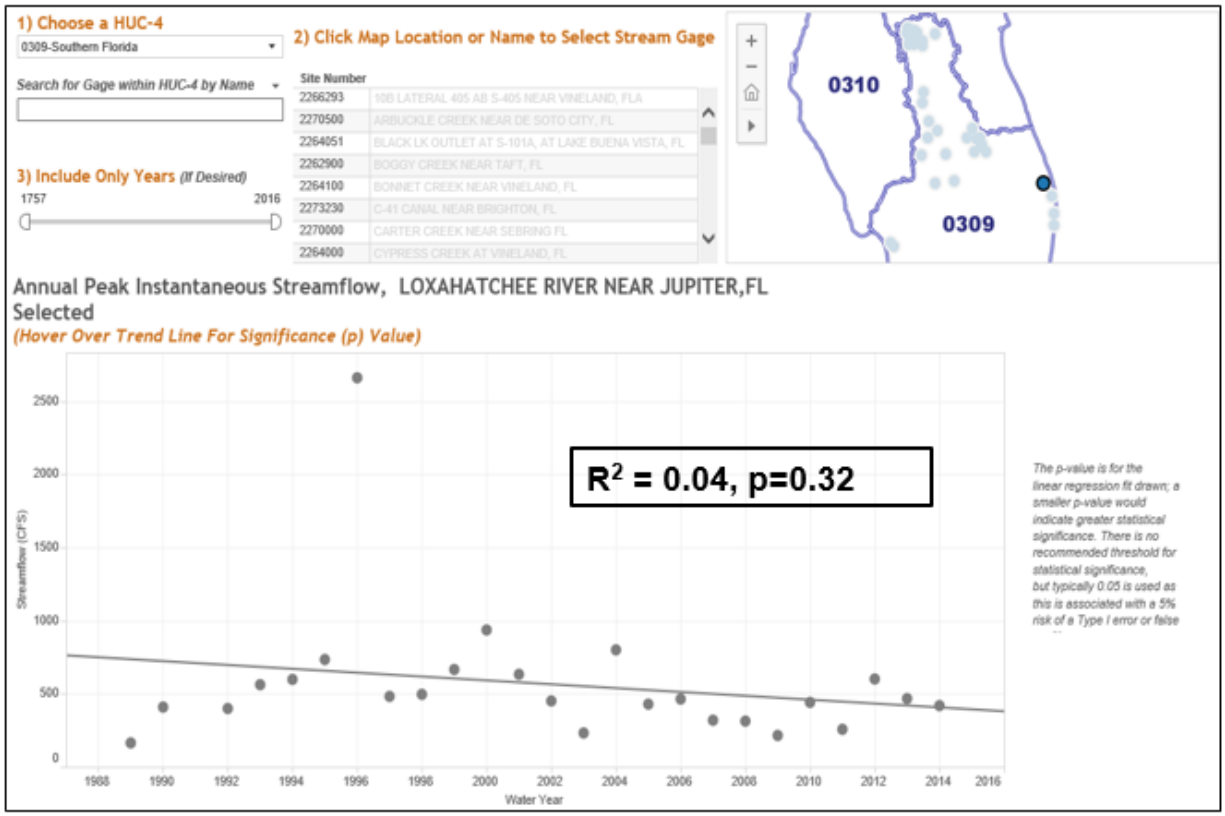

Figure H-34. Climate Hydrology Assessment Tool output using annual instantaneous peak discharge at USGS Loxahatchee gauge; HUC04 Southern Florida Basin (HUC 0309).

H.5.2.8.1.2 Projected Trends

The CHAT present analysis of projected, future streamflow datasets at a HUC04 watershed scale. The LRWRP project is located within the HUC04 southern Florida Basin 0309 (HUC 0309).

Figure H-35 displays the range of projected, unregulated, annual maximum monthly flows computed by 93 different combinations of GCM outputs generated using different concentration pathways of greenhouse gas emissions. Climate-changed hydrology is generated for a period of 2000-2099 for the HUC044 Basin 0309 (Southern Florida).

There is a consistent range in the projected annual maximum monthly flows in **Figure H-35**. This range is representative of the uncertainty of many variables including error in temporal downscaling, error in spatial downscaling, errors in the hydrologic modeling, errors associated with emissions scenarios, and errors associated with GCMs themselves.

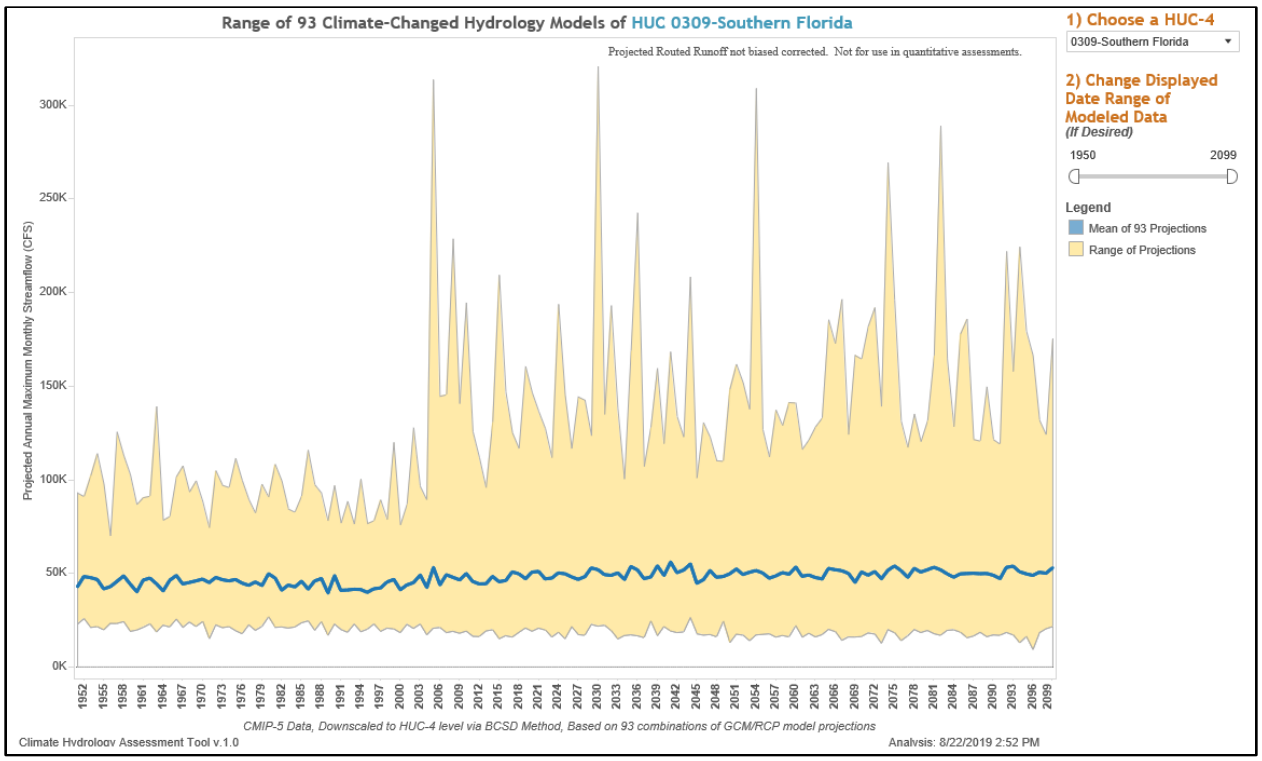

Figure H-35. Range of projected annual maximum monthly streamflow in HUC04 Southern Florida Basin HUC 0309.

A statistical analysis of the projected hydrology for 2000-2099 indicates a statistically significant linear trend of increasing average annual maximum monthly flows (**Figure H-36**). This increase suggests the potential for future increases in streamflow relative to current conditions. This trend is not consistent with an assessment of trends in observed annual peak streamflows or the literature. The literature points to no projected change in streamflow. Based on the analysis of observed, historic flows carried out as part of this study and the literature there isn't strong evidence of a trend in historic flows. There is only some evidence of a decreasing trend in streamflow, but there is not a great deal of consensus or statistical significance associated with this trend.

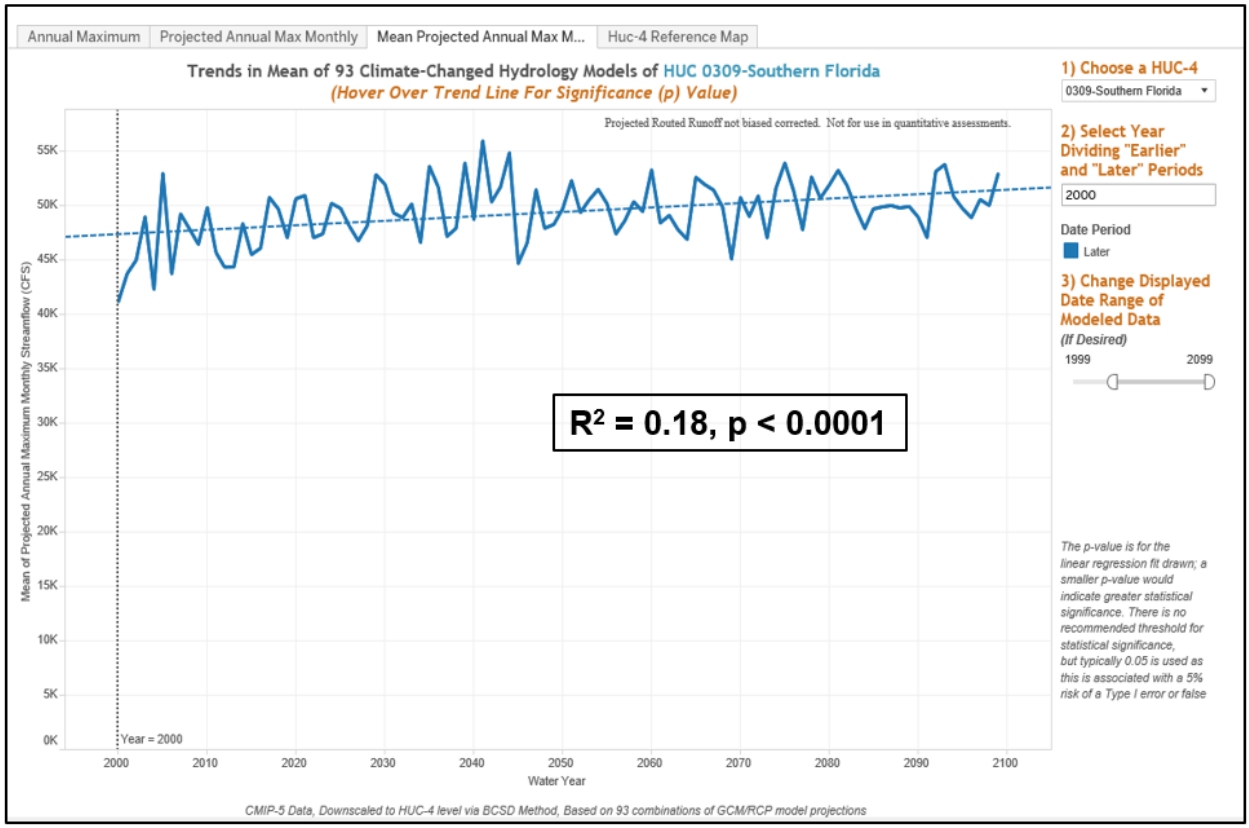

Figure H-36. Trends in projected mean annual maximum monthly streamflow in HUC04 Southern Florida Basin (HUC04 0309.

H.5.2.8.2 Nonstationarity Detection Tool

The current guidance for detecting nonstationarities is the USACE ETL 1100-2-3, "Guidance for Detection of Nonstationarities in Annual Maximum Discharges." The USACE projects, programs, missions, and operations have generally proven robust enough to accommodate the range of natural climate variability over their operational life. But in some places and for some impacts relevant to the USACE operations, climate change and modifications to watersheds are undermining the fundamental design assumption of stationarity (the statistical characteristics of hydrologic time series data are constant through time). This assumption has enabled the use of well-accepted statistical methods in water resources planning and design that rely primarily on the observed record. ETL 1100-2-3 provides technical guidance on detecting nonstationarities in the flow record which may continue to impact flow into the future and should be considered in the Future without (FWO) project conditions.

The Nonstationarity Detection Tool (NSD) was developed to support ETL 1100-2-3. The USACE Responses to Climate Change (RCC) Program developed the tool to enable users to detect abrupt and slowly varying changes (nonstationarities) in observed, annual instantaneous peak discharges at USGS streamflow gauges with over 30 years of record. The tool allows users to conduct monotonic trend analysis on the data and any resulting subsets of stationary flow records identified.

Nonstationarities are identified when the statistical characteristics of a hydrologic data series are not constant through time. The NSD, however, is not a substitute for engineering judgment. Engineers are advised to use their judgment to consider the resilience of the system when incorporating the range of results in the hydrologic study or design results (USACE, 2016d).

It is up to the tool's user to determine which, if any, of the statistically significant nonstationarities identified by the NSD may be used to segment the data for hydrologic analysis. The user assesses the relative "strength" of any nonstationarities detected to identify "strong" nonstationarities for use in further analyses. The tool applies several methods that assess nonstationarities in time series datasets driven by changes in the mean, variance/standard deviation, and in the distributional properties of the dataset.

H.5.2.8.2.1 Detection of Nonstationarities in Observed Discharge Data

The NSD was utilized for the USGS gauge 00006795 'S44 Howell Creek Near Altamonte Spring' in accordance with ECB 2018-14. The tool analyzes whether the assumption of stationarity, which is the assumption that statistical characteristics of time-series data are constant over the period of record, is valid for a given hydrologic time-series data set. The Howell Creek gage was selected for the NSD assessment, instead of the Loxahatchee gauge used in the CHAT, because the Loxahatchee gauge does not have the 30-year period of record required by the NSD. The Howell Creek gauge is the closest gauge to the LRWRP project available in the NSD tool. Similar to the observed CHAT assessment, an assessment of observed streamflow data is conducted to determine if there is supporting evidence of climate change at this gauge.

Figure H-37 shows the results from the tool applied to the period of record available at the Howell Creek gage: 1978-2017. The tool's default sensitivity parameters were applied to evaluate the stationarity of the streamflow record. The statistical methods collectively identified nonstationarities in one year: 1990, for the period of record 1978-2017. The nonstationarities were identified using the Cramer-Von-Mises, Pettitt, Mann-Whitney, and Bayesian for 1990. The Cramer-Von-Mises detected a change in the underlying distribution of the data. The Pettitt, Mann-Whitney, and Bayesian detected a change in the average value, or mean, of the data.

A "strong" nonstationarity is one for which there is a consensus among a minimum of three nonstationarity detection methods (more than one test flagging a nonstationarity targeted at the same statistical property), robustness in detection of changes in statistical properties (tests flagging nonstationarities targeted at different statistical properties), and relatively large change in the magnitude of a dataset's statistical properties (mean or standard deviation).

Based on these criteria, there is not enough strong evidence of statistical non-homogeneity in the 1990 event to warrant consideration within the decision making process. The detected nonstationarities meet the criteria of consensus and robustness, but are not considered strong, operationally significant nonstationarities because of the relatively small change in magnitude (approximately 500 cfs) of the dataset's statistical properties.

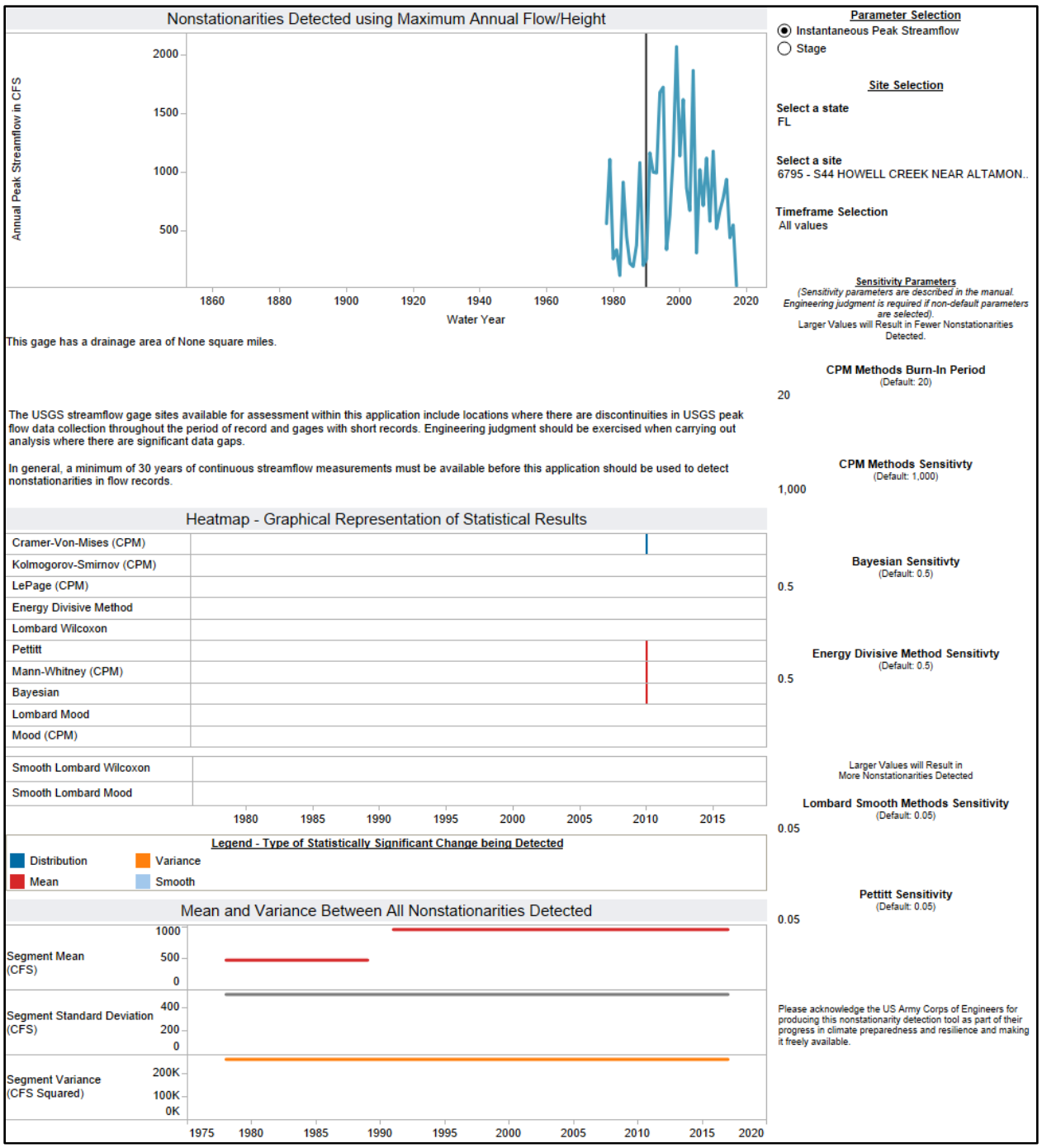

Figure H-37. Output from Nonstationarity Detection tool – USGS Howell Creek gauge

H.5.2.8.2.2 Monotonic Trend Analysis

A monotonic trend analysis is conducted to identify statistically significant trends in peak streamflow. Detected nonstationarities are used to subdivide the period of record into stationary subsets, each of which are tested for the presence of monotonic trends. If no strong nonstationarities are identified within an annual instantaneous peak streamflow dataset, then the entire period of record could be assessed for

monotonic trends. Because the nonstationarities identified are not considered statistically significant, the entire period of record of 1978-2017 was assessed.

Figure H-38 shows a monotonic trend analysis using the Mann-Kendall Test and Spearman Rank Order test for time period 1978-2017. No statistically significant trend in annual peak streamflow was detected for the period of record.

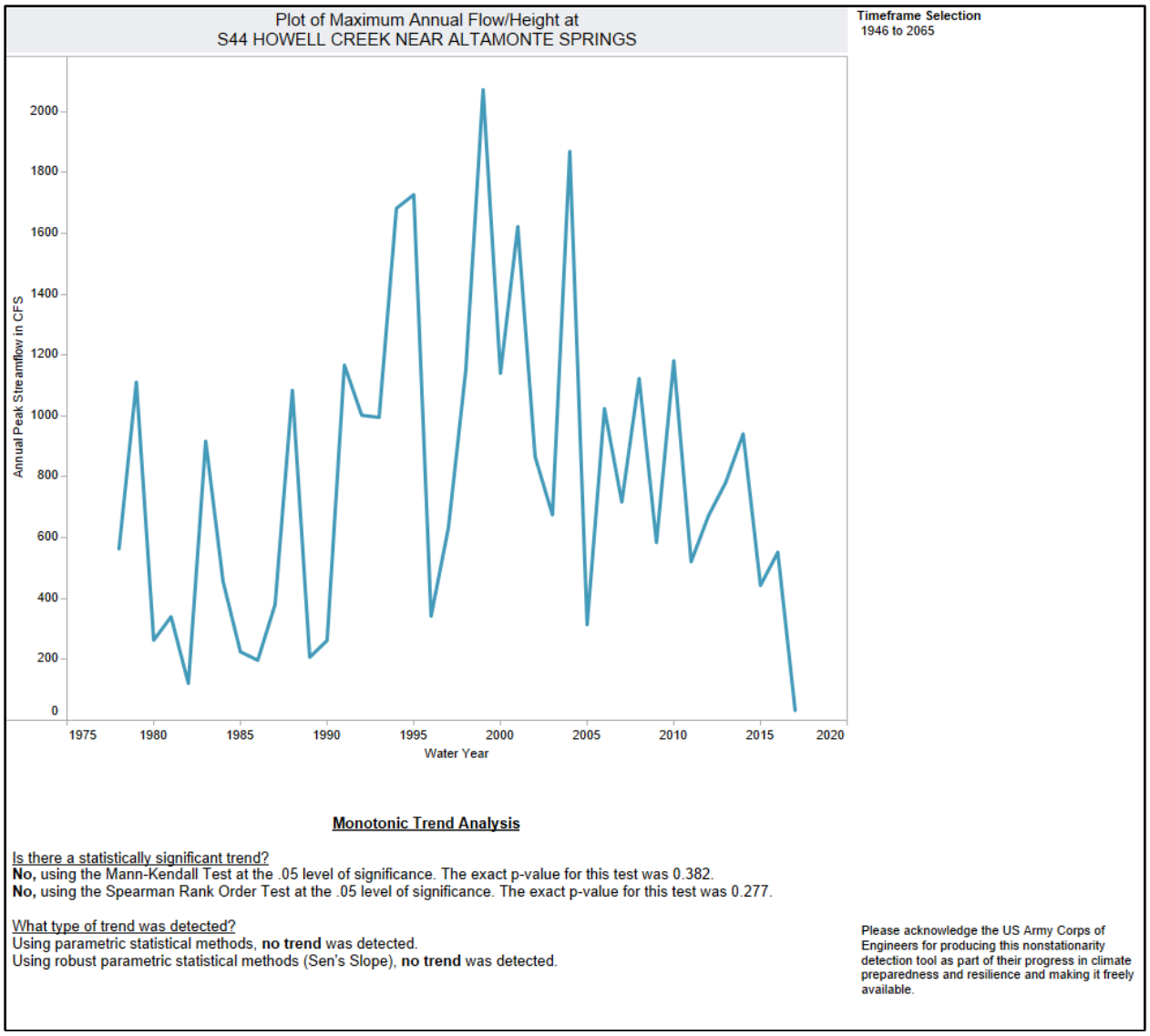

Figure H-38. Monotonic trend analysis results – USGS Howell Creek gauge

H.5.2.8.3 Time-Series Toolbox

The Time-Series Toolbox application was developed by the USACE to address the need for multiple types of analytical methods for time series data analysis. Climate-related data can come from a variety of sources (e.g. streamflow, water levels, tide gauge data, precipitation data). The Time-Series Toolbox provides the user with automated data pre-processing and works to standardize and streamline common

approaches to time series analysis by performing trend analysis and nonstationarity detection for user-supplied datasets. A common use for the Time-Series Toolbox is to use it in place of the NSD when a climate assessment is needed for a climate variable other than peak flow (e.g. precipitation) or if there is an interest in analyzing an unregulated dataset. The time-series toolbox was evaluated for a precipitation gauge located near the LRWRP project as an alternative option to assessing nonstationarity of streamflow. As discussed previously, streamflow in the region is typically impacted by highly regulated water control operations and therefore difficult to assess unregulated trends in the data.

A nonstationarity analysis was performed using daily precipitation data from the Pratt-Whitney precipitation gauge located in the project area. The Time Series Toolbox uses statistical testing to detect the presence of nonstationarities in the data. These tests examine the data for nonstationarities (or changes) in the data mean, variance, or distribution. **Figure H-39** shows the nonstationarity results using rainfall from the tool's period of record 1957-2019. Although the figure shows multiple data gaps, less than 2% of the precipitation dataset has missing data (417 of 22210 records). It is assumed that the tool is computing these results due to the precipitation dataset being at a daily timestep and there are many zero values within the period of record. The precipitation dataset utilized for this analysis contains the longest period of record of any rain gauge located within the project area and therefore is assumed to be the most representative dataset for this analysis.

The statistical methods collectively identified nonstationarities in three different years: 2008, 2009, and 2013 for the period of record 1957-2019. The nonstationarities were identified using the Lombard Mood for 2008, LePage and Mood for 2009, and Cramer-Von-Mises for 2013. The Cramer-Von-Mises and Lepage detected a change in the underlying distribution of the data. The Lombard Mood and Mood detected a change in the variance of the data.

There is not enough strong evidence of statistical non-homogeneity in any of the events to warrant consideration within the decision making process. They do not meet the criteria for consensus, robustness, and magnitude, and are not considered statistically significant.

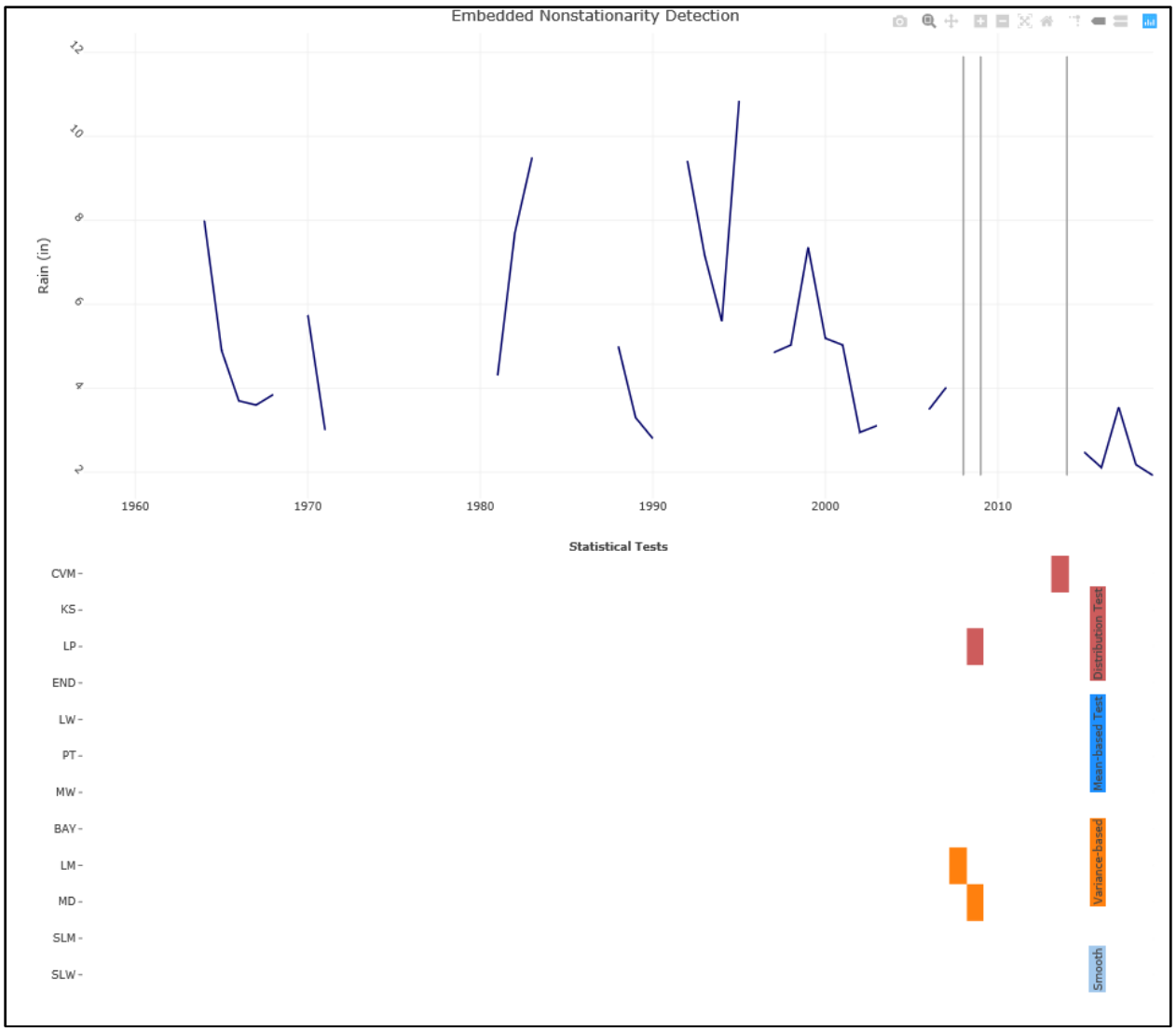

Figure H-39. NSD using Time-Series Toolbox with Annual Daily Maximum rainfall

H.5.2.8.4 The USACE Watershed Vulnerability Assessment Tool

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 202 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 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, 2016b).

There is a great deal of uncertainty with the climate changed hydrology and meteorology used by the vulnerability assessment tool. The uncertainty associated with projected hydrologic and meteorologic

data includes error in temporal downscaling, error in spatial downscaling, errors in the hydrologic modeling, errors associated with emissions scenarios, and errors associated with GCMs. Some of the uncertainty associated with the tool can be visualized because the tool separates results for each of the scenarios (wet versus dry) and epochs (2050 versus 2085) combinations rather than presenting a single, aggregate result (USACE, 2016b).

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 LRWRP project used the VA Tool to perform such an analysis on southern Florida (HUC 0309), with emphasis on the indicators of vulnerability for the Flood Risk Reduction and Ecosystem Restoration business lines.

Table H-10 and **Table H-11** provides the number and name of selected indicators for the Flood Risk Reduction and Ecosystem business lines within the Vulnerability Assessment Tool, along with a brief description of each.

Table H-10. Number, name, and description of selected indicators for the Flood Risk Reduction Business Line within the Vulnerability Assessment Tool.

Number	Name	Description
175L & 175C	ANNUAL CV of UNREGULATED RUNOFF	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean.
277	PERCENT CHANGE IN RUNOFF DIVIDED BY PERCENT CHANGE IN PRECIPITATION	Percent change in runoff divided by percent change in precipitation.
568C &568L	FLOOD_MAGNIFICATION FACTOR	Change in flood runoff: ratio of indicator 571C/L (monthly runoff exceeded 10% of the time) for projected period to 571C/L in base period.
590	ACRES OF URBAN AREA WITHIN 500-YEAR FLOODPLAIN	Acres of urban area within 500-year floodplain.

Table H-11. Number, name, and description of selected indicators for the Ecosystem Restoration Business Line within the Vulnerability Assessment Tool.

Number	Name	Description
8	PERCENT OF FRESHWATER PLANT COMMUNITIES AT RISK	Percentage of Wetland and Riparian plant communities that are at relative risk of extinction.
65L & 65C	MEAN ANNUAL RUNOFF	Water discharged in surface streams within a watershed.
156	CHANGE IN SEDIMENT LOAD DUE TO CHANGE IN FUTURE PRECIPITATION	Changes in the average sediment load in response to future changes in precipitation.
221L & 221C	MONTHLY CV OF RUNOFF	Short-term variability in a region's hydrology. It is the 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of the monthly runoff.
277	PERCENT CHANGE IN RUNOFF DIVIDED BY PERCENT CHANGE IN PRECIPITATION	Percent change in runoff divided by percent change in precipitation.
297	MACROINVERTEBRATE INDEX OF BIOTIC CONDITION	Overall biological condition of streams.
568C & 568L	FLOOD_MAGNIFICATION FACTOR	Change in flood runoff: ratio of indicator 571L/C (monthly runoff exceeded 10% of the time) to 571L/C in base period.
700L & 700C	LOW FLOW REDUCTION FACTOR	Change in low runoff: ratio of indicator 570L/C (monthly runoff exceeded 90% of the time) to 570L/C in base period.

For the Flood Risk Reduction business line, HUC309 is relatively vulnerable to the effects of climate change for both epochs and subsets of scenarios (WET and DRY). **Table H-12** lists the vulnerability scores for the Flood Risk Reduction business line for HUC 0309, as well the range of scores nationally and for SAD and SAJ for all scenario-epoch combinations.

Within the USACE South Atlantic Division (SAD), and within the Jacksonville District (SAJ), HUC309 has one of the highest flood risk management vulnerability scores for the DRY subsets of traces.

When looking at the WET scenario for the same business line, HUC 0309 is slightly above average for both epochs when compared to the rest of the nation. **Figure H-40** reveals that the VA tool classifies HUC 0309 as vulnerable for all scenario-epoch combinations for the Flood Risk Reduction business line when compared to the rest of the nation (top 20%). Indicators include 175C, 277, 568C, 568L, and 590 with descriptions shown in Table H-10.

Table H-12. Vulnerability Scores for HUC 0309 (Column 3) for the Flood Risk Reduction business line for each scenario-epoch combination nationally, SAD and SAJ.

Business Line	Scenario - Epoch	WOWA Score	Range Nationally	Range in SAD	Range in SAJ
Flood Risk Reduction	Dry – 2050	67.07	35.15 – 70.08	41.53 – 68.18	44.88 – 68.18
	Dry – 2085	68.18	35.15 – 70.08	41.53 – 68.18	44.88 – 68.18
	Wet – 2050	70.46	39.80 – 92.85	46.76 – 71.78	49.40 – 71.18
	Wet – 2085	71.78	39.80 – 92.85	46.76 – 71.78	49.40 – 71.18

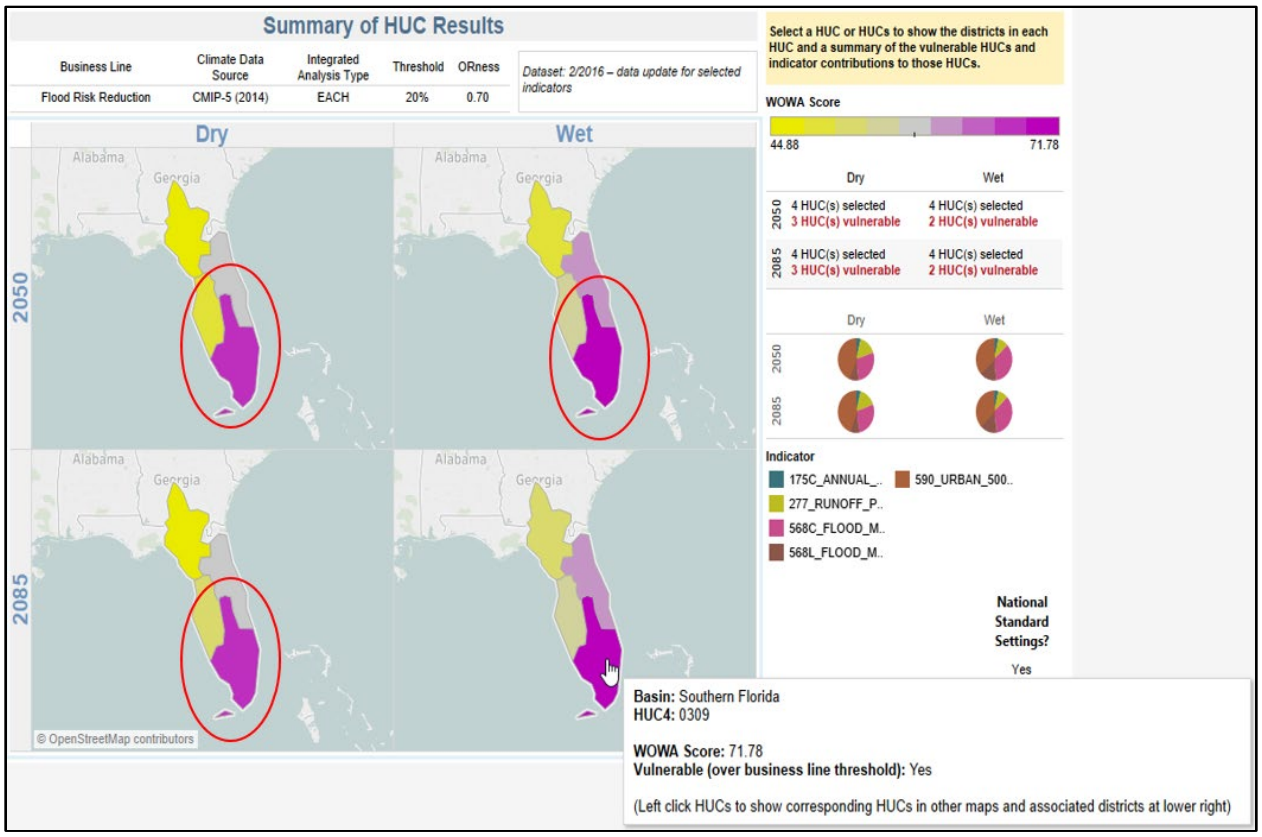

Figure H-40. HUC 0309 Watershed Vulnerability Evaluation for the Flood Risk Reduction business line for all scenario-epoch combinations (Dry-2050, Dry-2085, Wet-2050, and Wet-2085).

Relative to the other 201 HUC 04 watersheds in the CONUS (as shown in **Figure H-41**), HUC 0309 is not as vulnerable to climate change impacts for Ecosystem Restoration. The vulnerability score is increasing slightly in time. For all scenarios, HUC 309 does not have an ecosystem restoration vulnerability score within the 20% of scores when compared to the rest of the nation and is ranked last within its district.

Table H-13 lists the vulnerability scores for the Ecosystem Restoration business line for HUC 0309 for HUC 0309, as well the range of scores nationally and for SAD and SAJ for all scenario-epoch combinations.

Table H-13. Vulnerability Scores for HUC 0309 (Column 3) for the Ecosystem Restoration business line for each scenario-epoch combination nationally, SAD and SAJ.

Business Line	Scenario - Epoch	WOWA Score	Range Nationally	Range in SAD	Range in SAJ
Ecosystem Restoration	Dry – 2050	69.62	59.69 – 89.84	64.82 - 73.76	69.62 - 73.48
	Dry – 2085	70.21	54.69 - 89.84	64.82 - 73.76	69.62 - 73.48
	Wet – 2050	69.90	55.84 - 81.85	64.20 - 73.36	69.90 - 73.36
	Wet – 2085	70.30	55.84 - 81.85	64.20 - 73.36	69.90 - 73.36

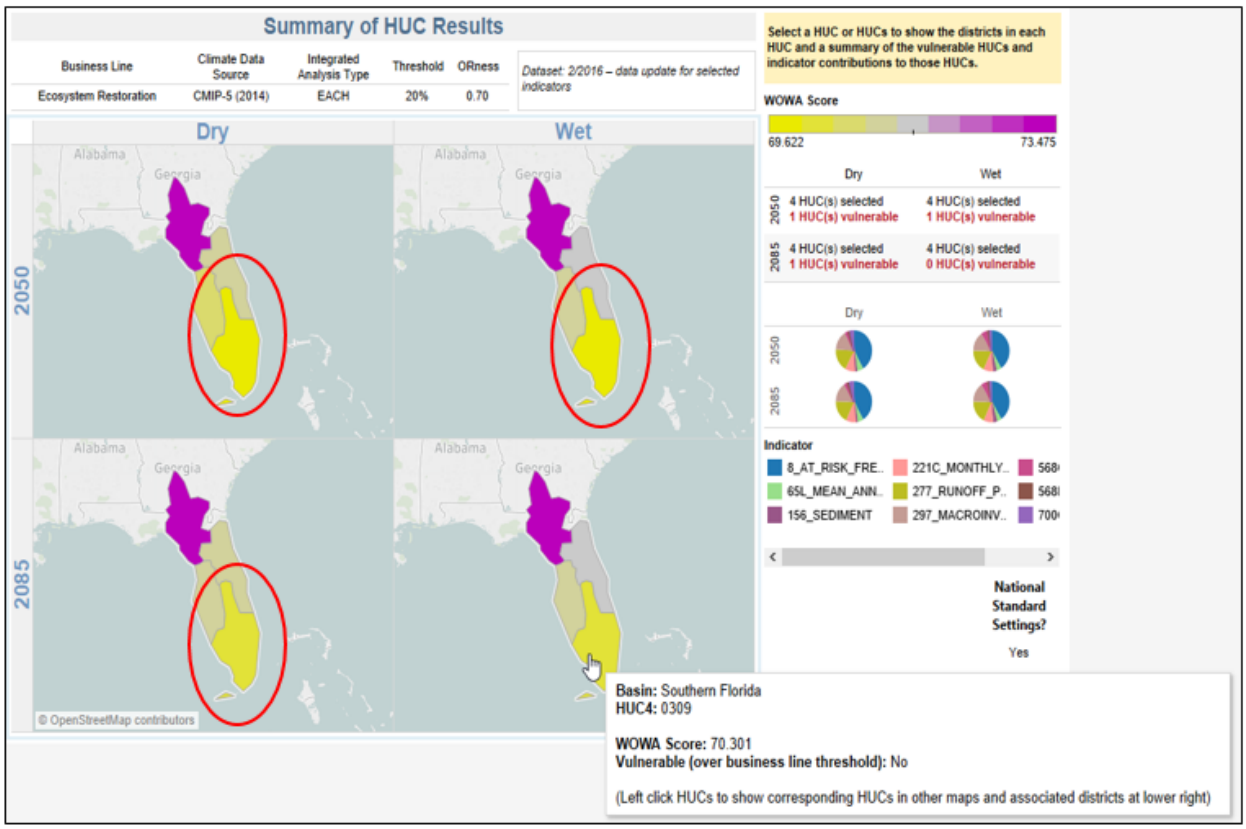

Figure H-41. HUC 0309 Watershed Vulnerability Evaluation for the Ecosystem business line for all scenario-epoch combinations (Dry-2050, Dry-2085, Wet-2050, and Wet-2085).

In addition to evaluating the overall vulnerability scores, it is also beneficial to understand which indicators variables drive the vulnerability scores computed for HUC 0309 in terms of the Flood Risk Reduction and

Ecosystem Restoration business lines and how the indicator variables are projected to change between epochs. The indicator that contributes most to the vulnerability score for the Flood Risk Reduction business line for all scenarios is Indicator #590 (area of the 500-year floodplain). The indicator that contributes the most significantly to the vulnerability score for the Ecosystem Restoration business line in all scenarios is Indicator #8 (percent of freshwater plant communities at risk). Both business lines show that the vulnerability score is increasing slightly over time.

USACE projects are varied, complex, and often encompass multiple business lines. The relationships among these business lines, with respect to impacts from climate change, are complicated, with cascading effects. Such interrelationships must be recognized as an essential component of future planning efforts when considering the best methods or strategies to adapt.

H.5.3 Phase III: Risk Assessment

The increases in extreme storm frequency and intensity and increases in temperatures indicated by the literature review present risks to the project features. The literature and statistical analysis show little evidence that indicates change in streamflow. Despite there being no consensus in the literature regarding trends in either observed or projected streamflow, it can reasonably be expected that increased extreme precipitation may lead to increased flows and larger flood volumes and potential risk to the project's levees and higher likelihood of increased flow to the estuary. Increased temperatures may lead to decreased flows and increases in drought severity and frequency. A reduction in flow could result in reduced projects benefits to the estuary and undermine the project purpose by disrupting the timing and distribution of flows to the Northwest Fork of the Loxahatchee River floodplain.

The Phase II vulnerability assessment tool results indicate that the project is not relatively vulnerable to the impacts of climate change for the ecosystem restoration business line, but the project is located in a relatively vulnerable watershed for the flood risk management business line. The watershed is most vulnerable to increases in extreme storm frequency and intensity, and increases in air temperature.

Per guidance in ECB 2018-14, **Table H-14** identifies residual future risk resulting from changed climate conditions. The table shows the major project features, the trigger event (climate variable that causes the risk), the hazard (resulting dangerous environmental condition), the harms (potential damage to the project or changed project output), and a qualitative assessment of the likelihood and uncertainty of this harm. Note that not all impacts of climate change will result in increased risk, as at times climate change might provide benefits to the project and its operating objectives.

In general all project features were designed for robustness and to adequately handle the design event of the 100-year, 72 hour precipitation frequency event. All proposed gated water control structures were designed with telemetry operated gates that provide additional operational flexibility to handle larger flood volumes and disperse to the Estuary appropriately. A majority of the pump stations designed for the project have pump mix capacities that allow for operational flexibly. Additionally, the C-18W Reservoir and Gulfstream West flow through marsh project feature were designed following the Design Criteria Memorandums (DCM), ER 1110-2-1156, and other applicable USACE design guidance, which follows a conservative risk informed design, capable of handling extreme precipitation events.

Because there is not substantial evidence within the observed streamflow record and the literature that inflows to the study area are presently increasing for the planning phase, climate change and resilience

should be accounted for by incorporation into the project's risk register. The impacts of climate change are appropriately captured within the uncertainty bounds already incorporated into the project design. Based on the vulnerability assessment, (literature review results indicate a high potential for increases in temperature and extreme precipitation and in the projections of annual maximum monthly streamflow), it would be beneficial for the project to account for risk due to climate change by developing a strategy for adaptive management of the project. Adaptive management could be used as a means of ensuring that the project is resilient to the impact of climate change for the duration of the project life cycle. This includes ensuring that the design of the project and prescribed operations can easily be adapted to handle extreme wet and dry conditions, including floods and droughts. This will ensure that the plan selected is robust enough to accommodate changing climatic conditions.

Specifically, additional modifications can be made to the following components:

a) Gulfstream West Flow through marsh levee height may be increased to allow for a greater storage volume; an ASR well may also be added to provide additional operational flexibility for discharge during the dry season;

b) Operations of project structures, including the C-18W Reservoir discharge, S-46 structure, and S-112 may be modified to optimize flows reaching the Loxahatchee Estuary, especially during the dry season.

c) Additional pump stations may be added to select project pump configurations to provide increased pump capacity. Additional pump stations may be required if it is determined that increased rainfall totals lead to an inability to capture a majority of the runoff and pump capacities need to be increased to capture the peak runoff values. Potential triggers that may identify the need for additional pumps include large freshwater pulses to the Loxahatchee Estuary (either over Lainhart or through the NW Fork) above the wet/dry season targets over multiple occurrences throughout the water year.

Operational changes are assumed to have no additional cost. The Adaptive Management and Monitoring Plans Annex contains cost estimates for a few structural measure to improve substrates for submerged aquatic plants and oysters that might move upstream or downstream depending on the balance of sea level change and increased flow to the Northwest Fork of the Loxahatchee River. Large scale construction such increasing the capacity of storage features will likely require a new study and USACE HQ approval or even Congressional Authorization. Costs will be developed and justified at that time.

Also, is should be noted that algae blooms are not anticipated in those project features that store water (C-18W reservoir and Gulfstream West flow through marsh). Source waters for the C-18W Reservoir flow from undeveloped lands (J.W. Corbett WMA), and are expected to show low total phosphorus and nitrate concentrations. These constituents serve as a primary trigger for algae blooms. In addition, surface water south of C-18W Reservoir in the M-1 upper and lower basins are conveyed to the south for discharge into the M-Canal, so would not contribute potentially nutrient-rich water into the C-18W Reservoir. Adjacent to the Gulfstream West flow-through marsh are developed areas and agricultural lands that may be sources of nutrient-rich surface water. Reducing algae bloom potential would be managed operationally, by maintaining wet-season flows through this feature.

Table H-14. Risk assessment.

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Storage Reservoir, C-18W	Increased extreme precipitation – may occur from increased tropical storm activity.	Future flood volumes may be larger than present.	Flood waters may remain on the levee for longer durations, and more frequently, potentially damaging levee. Larger flood volumes may not be adequately captured and have to bypass to the Estuary.	Somewhat Likely
Flow Through Marsh	Increased extreme precipitation – may occur from increased tropical storm activity.	Future flood volumes may be larger than present.	Flood waters may remain on the levee for longer durations, and more frequently, potentially damaging levee. Larger flood volumes may not be adequately captured and have to bypass to the Estuary.	Somewhat Likely
Aquifer Storage and Recovery (ASR)	Increased extreme precipitation – may occur from increased tropical storm activity.	Future flood volumes may be larger than present.	Increased inflow may exceed inflow rate and/or capacity of ASR resulting in increased flows bypassing the reservoir and ASR to the Loxahatchee estuary.	Somewhat Likely
Storage Reservoir, C-18W	Increased temperatures	Increased evapotranspiration or drought	Decrease in flows may result in lower reservoir stages, resulting in lower flows being sent to the Estuary, resulting in loss of habitat and vegetation and reducing project benefits.	Likely
Flow Through Marsh	Increased temperatures	Increased evapotranspiration or drought	Decrease in flows may no longer inundate restoration feature during all or part of year, resulting in loss of habitat and reducing project benefits.	Likely
Aquifer Storage and Recovery (ASR)	Increased temperatures	Increased evapotranspiration or drought	Decrease in flows may not supply the ASRs with necessary volume, resulting in loss of habitat and reducing project benefits in the Estuary	Likely

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Water Control Structures and Pump Stations	Increased extreme precipitation – may occur from increased tropical storm activity.	Future flood volumes may be larger than present.	Increase in flows resulting in structure under-performing during high flow events.	Somewhat Likely
Water Control Structures and Pump Stations	Increased Sea Level	Future sea-level elevation may be larger than present.	Increased SLR may limit discharge capacities of water control structures near the coast with current headwater conditions.	Likely

H.6 Summary Findings

These are the summary findings of the climate change assessment:

1) The USACE suggests 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.
2) 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.
3) A quantitative climate assessment of SLR was conducted per ER 1100-2-8162 using a USACE statistical tool that projects future SLR.
4) LRWRP is most vulnerable to climate change and at risk over the project life cycle (2020-2120) due to the following factors: increasing air temperatures, increases in extreme storm frequency and intensity, and rising sea-level elevations.
5) Evaluation of SLR and project benefits: Results show that the S-46, S-117 and Masten Dam may be vulnerable to SLR when looking at the high SLC projection. Limitation to discharges for S-46 may be reduced with existing headwater conditions beginning in 2049. SLR does affect the hydrologic boundaries governing the performance and operation of the LRWRP project features; however, the with-project condition provides better ecological conditions and resiliency for the river then the future without project condition under all SLR scenarios.
6) Evaluation of SLR and project impacts: In addition to ecosystem impacts, existing and proposed infrastructure within the LRWRP footprint are susceptible to sea level rise. Existing structures include the Lainhart Dam, Masten Dam, S-46 and Ranch Colony Canal and Hobe Grove Ditch water control structures within the Loxahatchee River project area. The Lainhart and Masten Dams are not being impacted by any future sea level rise scenario during the 100-year planning horizon. The existing and proposed water control structures were analyzed with the potential extreme water levels (EWL) to further understand the potential exceedance probability for water levels within the estuary.
7) Based on the vulnerability assessment, it would be beneficial for the project to account for risk due to climate change by developing a strategy for adaptive management of the project during PED. Adaptive management could be used as a means of ensuring that the project is resilient to the impact of climate change for the duration of the project life cycle. This includes ensuring that the design of the project and prescribed operations can easily be adapted to handle extreme wet and dry conditions, including floods and droughts. This will ensure that the plan selected is robust enough to accommodate changing climatic conditions. The impacts of climate change are appropriately captured within the uncertainty bounds already incorporated into the project design. Resiliency and adaptive management, however, should be revisited during PED.

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