COMPREHENSIVE EVERGLADES RESTORATION PLAN

# LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT

## REVISED DRAFT INTEGRATED PROJECT IMPLEMENTATION REPORT AND ENVIRONMENTAL IMPACT STATEMENT

July 2019

Annex H

# ANNEX H
# CLIMATE CHANGE ASSESSMENT FOR
# LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT

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# H CLIMATE CHANGE ASSESSMENT ON LAKE OKEECHOBEE WATERSHED RESTORATION PROJECT

This annex discusses the climate change assessment performed for the Lake Okeechobee Watershed Restoration Project (LOWRP). Climate change assessments are required for all phases of the project life cycle including feasibility and pre-construction engineering and design (PED), for both existing and proposed projects. Because climate science is continuing to evolve, additional climate assessments may be performed during future project phases, which may include quantitative climate assessments on sea-level change (SLC) and/or updated hydrology. SLC and hydrologic changes in air temperature, precipitation, and streamflow patterns associated with climate change could have a dramatic impact on hydrologic conditions and water resources infrastructure in the state of Florida.

In this annex, 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. Therefore, the USACE has the need to understand and adapt to climate change and variability, while continuing to provide authorized performance under changing conditions. The objective of the USACE Climate Preparedness and Resilience (CPR) Community of Practice (CoP) is to mainstream climate change adaptation in all activities to enhance the resilience of the USACE water resource infrastructure and to reduce their potential vulnerabilities to the effects of climate change (USACE, 2018c).

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 effects and uncertainties associated with climate change and SLC relative to the USACE infrastructure.

For the LOWRP, there are two main climate assessments:

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

Because of the sea-level influence on project features located inland from the coastline, it will be necessary to assess climate change for both SLC and inland hydrology for most studies in Florida.

## H.2 Key Findings

1) LOWRP is vulnerable to climate change and at risk over the project life cycle (2028-2128) due to the following climate factors: increasing air temperatures, increases in extreme storm frequency and intensity, increasing streamflow, and rising sea level.
2) The Lake Okeechobee S-79 and S-80 outlet structures are vulnerable to sea-level rise (SLR) when looking at the high SLC projection. By 2067 and 2061, respectively, discharge capacity for S-79 may be reduced with existing headwater conditions and the S-80 downstream areas will be more susceptible to flooding properties along the river before emptying into the estuary. SLR does not affect the hydrologic boundaries governing the performance and operation of the LOWRP project features; however, benefits will change in the estuaries due to SLC.
3) Based on the vulnerability assessment, it is recommended that the project account for risk in climate change by including resiliency and adaptation measures in the project design for the duration of the project life cycle to account for the risk associated with the impact of climate change. This includes the design and operations 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 vulnerability assessment tool identified the USACE Flood Risk Management Business line as the most vulnerable.
4) Currently, climate change has been incorporated into the project risks, design, and cost contingency. Resiliency and adaptive management, however, should be revisited during PED. Because of the complex interaction between the LOWRP project and the Central & Southern Florida (C&SF) Project system, adaptations will need to be assessed for the C&SF system to address questions about the performance and operation of the LOWRP. The project team acknowledges that an assessment of the C&SF system is outside of the LOWRP scope and that resiliency and adaptive management in the LOWRP cannot be fully answered without a comprehensive assessment of the larger C&SF system.
5) Although impacts to the project net benefits due to SLR have not been fully analyzed, preliminary qualitative analysis seems to indicate that the average annual net project benefits would likely be reduced in comparison to the projected average annual net project benefits estimated assuming no SLR.

## H.3 Project Overview

To better understand how climate change impacts the LOWRP, it is important to understand how the project fits in with the surrounding projects in the region. For most studies in central and south Florida, projects are part of the C&SF Project, a larger system of interconnected projects (**Figure H-1**). The C&SF system is designed to capture, store, clean, and redistribute water to the south Florida ecosystem. This interaction between the LOWRP and surrounding C&SF projects is complex so, ultimately, in order to

assess future adaptations in the project needed for climate change, these will need to be comprehensively assessed for the larger C&SF system, as well.

### H.3.1 Central & Southern Florida System Description

The C&SF Project was authorized by the U.S. Congress in 1948 in response to significant flooding in south Florida. With its complex, regional water management infrastructure, significant portions of the natural system in central and south Florida were altered.

In response to the unintended impacts of the C&SF Project, the Water Resources Development Act (WRDA) 2000 approved the Comprehensive Everglades Restoration Plan (CERP), which is the framework for modification and operational changes to the Central and Southern Florida Project needed to restore, preserve, and protect the south Florida ecosystem while providing for other water-related needs of the region, including water supply and flood protection.

The CERP is the largest environmental restoration program in history with the restoration of the 18,000 square mile south Florida ecosystem. CERP focuses on “getting the water right” in the south Florida ecosystem. The plan is composed of a series of projects designed to address four major characteristics of water flow: quantity, quality, timing, and distribution. In total, 68 individual components comprise more than 50 projects in the plan. Together, these projects aim to get the right amount of water, of the right quality, delivered to the right places, at the right times. Implementing projects that capture, store, clean, and redistribute water will restore natural water flow, enhance and protect habitats, and improve the ability to retain and utilize freshwater within the ecosystem (USACE, 2015b).

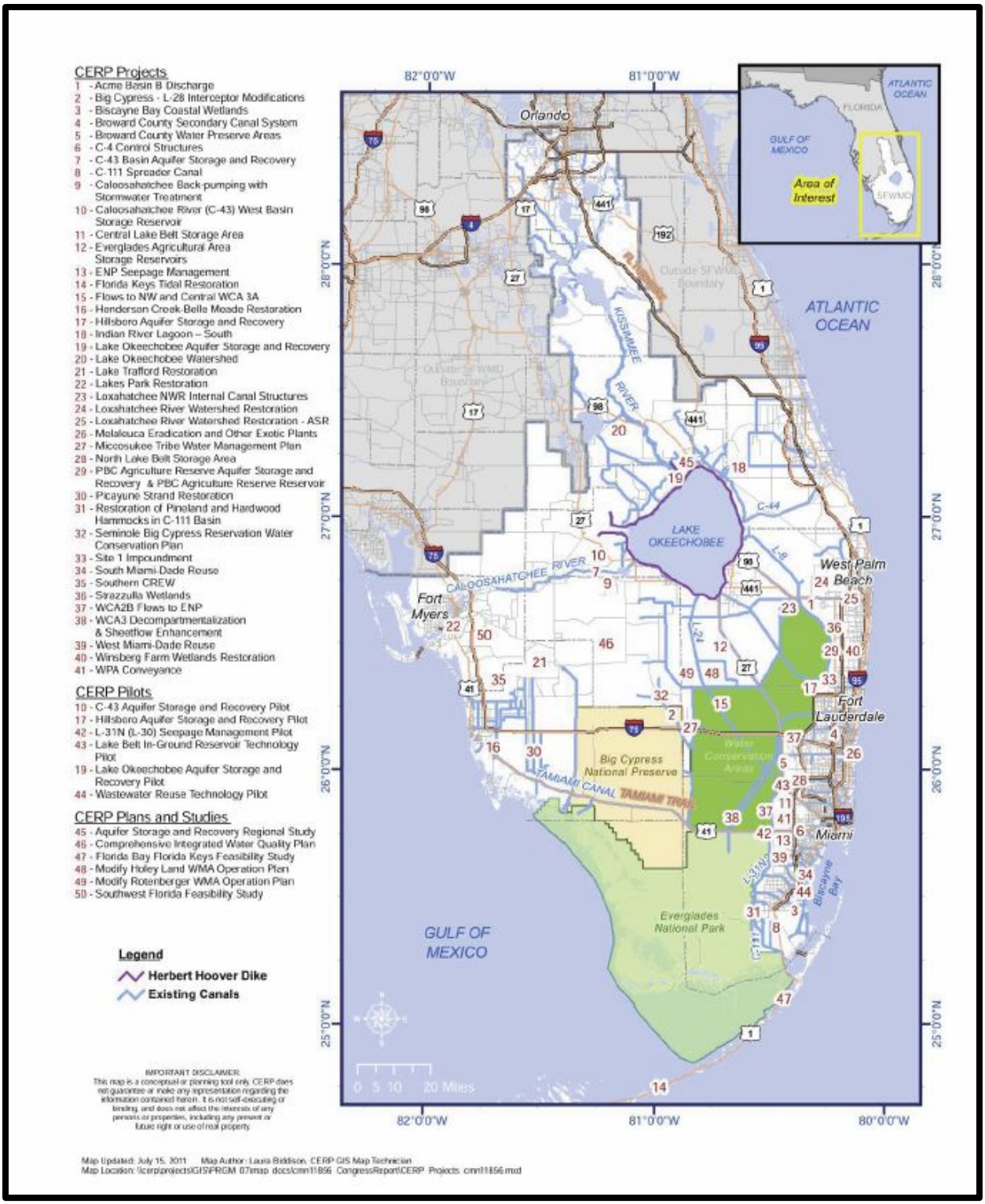


**Figure H-1. Map of Comprehensive Everglades Restoration Plan within the Central and Southern Florida Project (USACE, 2015b).**

### H.3.2 Lake Okeechobee Watershed Restoration Project Description

The LOWRP contains 3 of the 68 CERP components that are needed to collectively achieve the restoration goals of CERP within the C&SF system. These are the LOWRP's objectives:

1. Improve quantity, timing, and distribution of flows into Lake Okeechobee to maintain ecologically desired lake stage ranges more often.
2. Improve estuary discharges from Lake Okeechobee to improve the salinity regime and the quality of oyster, submerged aquatic vegetation (SAV), and other estuarine community habitats in the Northern Estuaries.
3. Increase the spatial extent and functionality of aquatic and wildlife habitat within Lake Okeechobee and the surrounding watershed.
4. Increase availability of the water supply to the existing legal water users of Lake Okeechobee commensurate with improving Lake Okeechobee ecology.

The LOWRP focuses on Lake Okeechobee and its northern watershed because they set the pulse of hydrologic flows and timing throughout the Everglades. Lake Okeechobee is often referred to as the "heart" of the Everglades because of its crucial role of driving the hydrology throughout this internationally recognized ecosystem and the associated estuaries. The LOWRP will restore historic conditions that allow Lake Okeechobee and its northern watershed to pulse water through the Everglades as they did historically, before the C&SF Project, within the constraints of the modern landscape. The LOWRP team's Optimized Plan includes a wetland attenuation feature (WAF) with 46,000 acre-feet of storage, 4,700 acres of wetland restoration, and 448,000 acre-feet of storage per year through 80 aquifer storage and recovery (ASR) wells (see **Figure H-2)**. The WAF will be designed to receive high peak flows from the Kissimmee River, while reducing freshwater discharges from Lake Okeechobee into the sensitive Northern Estuaries (Caloosahatchee to the west and St. Lucie to the east). The Optimized Plan will benefit the Caloosahatchee and St. Lucie estuaries by decreasing the number and severity of -high-volume regulatory flood control releases sent from Lake Okeechobee. Restored wetlands will provide ecological benefits. The ASR wells will store and recharge the lake to keep lake stages within the ecological band. There will also be benefits to water supply, as the number of cutbacks will be reduced. Water supply from the lake to existing users is currently reduced during extreme low stages in Lake Okeechobee.

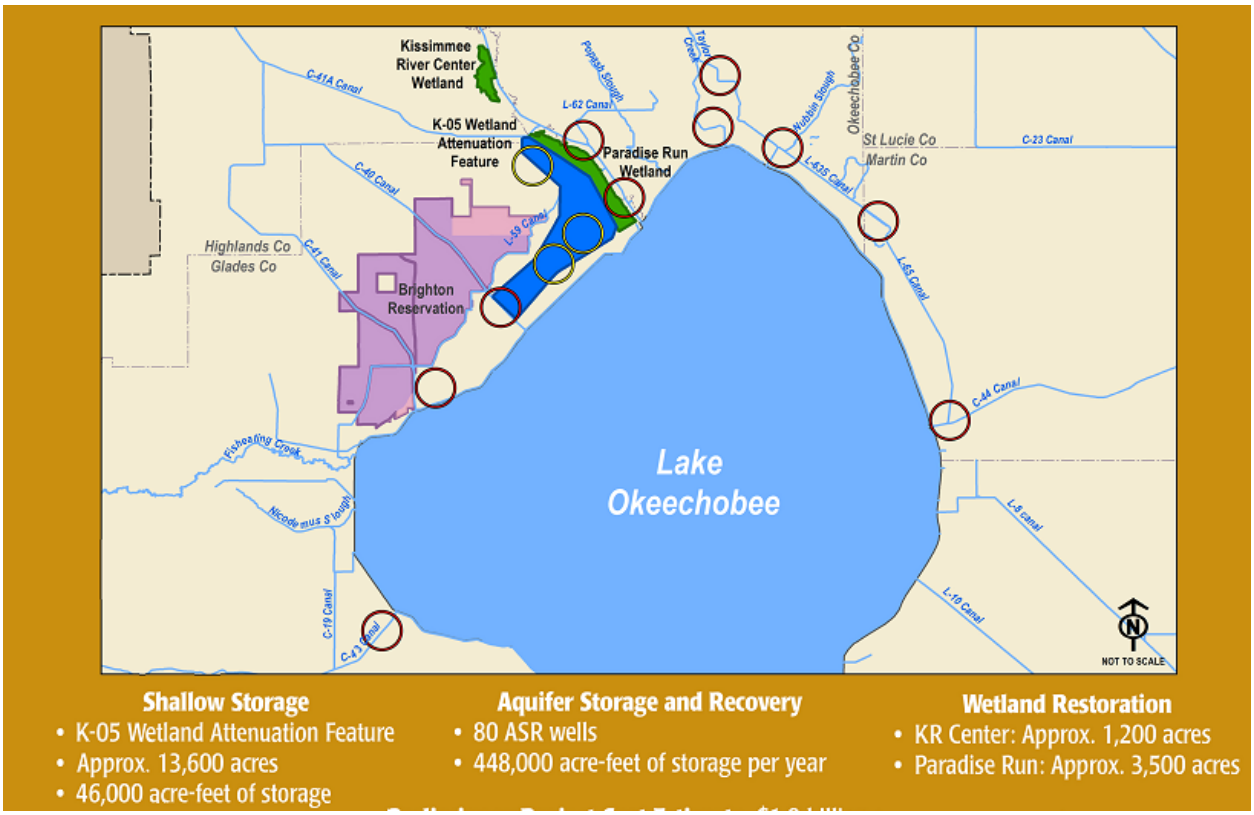


**Figure H-2. Map of the LOWRP Optimized Plan component locations.**

## 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 guidance from Engineering and Construction Bulletin (ECB) 2018-14, "Guidance for Incorporating Climate Change Impacts to inland Hydrology in Civil Works Studies, Designs, and Projects," for project areas at elevations less than or equal to 50 feet, 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 policy and procedures 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 guidance in ER 1100-2-8162 will apply.

SLC has been a persistent trend for decades in the United States and elsewhere in the world. Observed and reasonably foreseeable global SLR means that local sea levels will continue beyond the end of this

century. In most locations, global SLR results in local relative SLR, which has already caused impacts such as flooding and coastal shoreline erosion to the nation's assets located at or near the ocean. These impacts will continue to change in severity. Along the U.S. Atlantic Coast alone, almost 60 percent of the land that is within a meter of sea level is planned for further development. Wise decision-making requires adequate information on the potential rates and amount of SLC. Accordingly, the risks posed by SLC motivate decision-makers to ask: "What is the current rate of SLC, and how will that impact the future conditions that affect the performance and reliability of my infrastructure, or the current and future residential, commercial, and industrial development?" 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).

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

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

The calculator accepts user input—including project start date, selection of an appropriate NOAA long-term tide gauge, and project life span—to calculate projected 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 calculator 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

Although all the management measures proposed for the LOWRP are located inland, about 40 miles from the Florida's east coast and 60 miles from the west coast, there could be indirect effects to the project relative to the tidally influenced Lake Okeechobee outlet structures, S-79 in the west (Caloosahatchee River) and S-80 in the east (St. Lucie River). SLR does not directly affect the hydrologic boundaries governing the performance and operation of the LOWRP project features but benefits will change in the St. Lucie and Caloosahatchee estuaries due to SLC. **Figure H-3** shows a map that indicates location of the Lake Okeechobee outlet structures S-79 and S-80.

**Figure H-3. Location map illustrating Lake Okeechobee outlet structures in Caloosahatchee and St. Lucie Rivers.**

The discharge capacity of the S-79 and S-80 structures with existing headwater conditions are limited when the tidally influenced tailwater stage exceeds a threshold elevation. In order to assess what tailwater stages limit the discharge capacity at the Lake Okeechobee outlet structures, historic tailwater stage exceedance curves for S-79 and S-80 were plotted over the period of record (POR) 1 September 1995 – 1 March 2016 and 1 April 1995 – 15 April 2015 using recorded instantaneous 15-minute interval data (non-daily average). Daily averaged data is not representative nor indicative of potential impacts in the future due to tidal fluctuations that skew results.

#### H.4.1.1 Caloosahatchee River – Lake Okeechobee S-79 Outlet Structure

The Caloosahatchee River's (C-43 canal) downstream tidal structure is the S-79 lock and dam to the west of Lake Okeechobee. Currently, the S-79 structure is constrained to discharge when the tailwater stage is at or exceeds 2.3 feet (3.5 feet NGVD29) due to flood impacts of the Orange River area. **Figure H-4** shows the tailwater stage exceedance curve for S-79 indicating the percentage over the POR (1 September 1995 – 1 March 2016) for which specific elevations were exceeded. This POR data set consists of "breakpoint" data (over 717,000 data points) retrieved at 15-minute intervals. Using the S-79 data in **Figure H-4**, the tailwater elevation is at or exceeds 2.3 feet for 0.12% of the POR, which will limit the discharge capacity due to headwater and tailwater flow calculation restriction. It is important to mention that currently, the gates located at this location are sometimes overtopped by the tidal surge during storm surges at high tide (USACE, 2008). The top of gate for this structure is 3.3 feet. With sea level rise, overtopping will become more frequent.

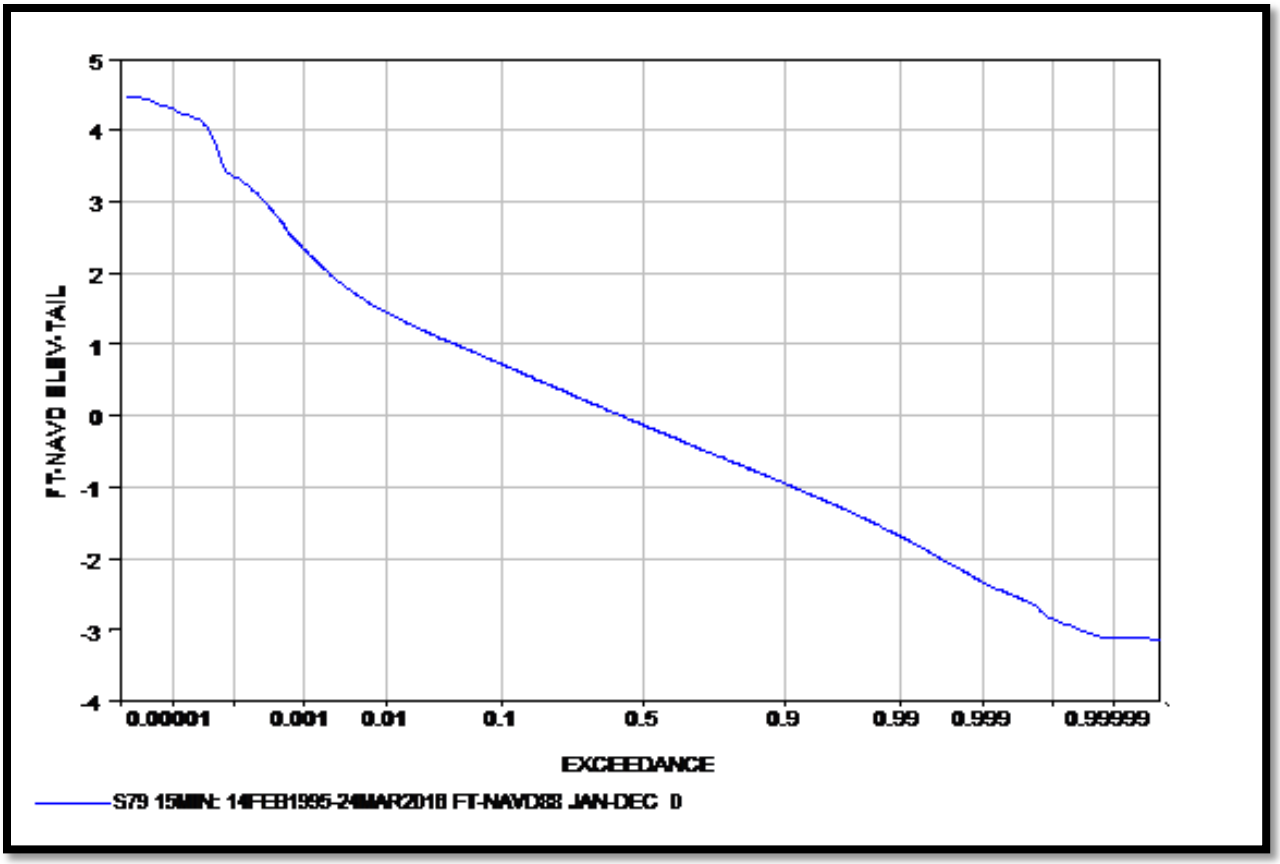


**Figure H-4. S-79 tailwater, elevation exceedance curve.**

### H.4.1.2 St. Lucie River – Lake Okeechobee S-80 Outlet Structure and Daytona Beach Shores Gauge

The St. Lucie Canal's (C-44 canal) downstream tidal structure is the S-80 lock and dam to the east of Lake Okeechobee. Currently, the S-80 structure discharge is constrained when the tailwater stage is at or exceeds 1.5 feet (3.0 feet NGVD29) (USACE, 2008) due to flood damage impacts of the South Fork area and mooring issues experienced at the Stuart Marina. **Figure H-5** shows the tailwater stage exceedance curve for S-80 indicating the percentage over the POR (1 April 1995-15 April 2015) for which specific elevations were exceeded. This POR data set consists of "breakpoint" data (over 693,000 data points) retrieved at 15-minute intervals. For S-80, the tailwater elevation is at or exceeds 1.5 feet for 0.36% of the POR, which will result in downstream flooding of properties along the river before emptying into the estuary.

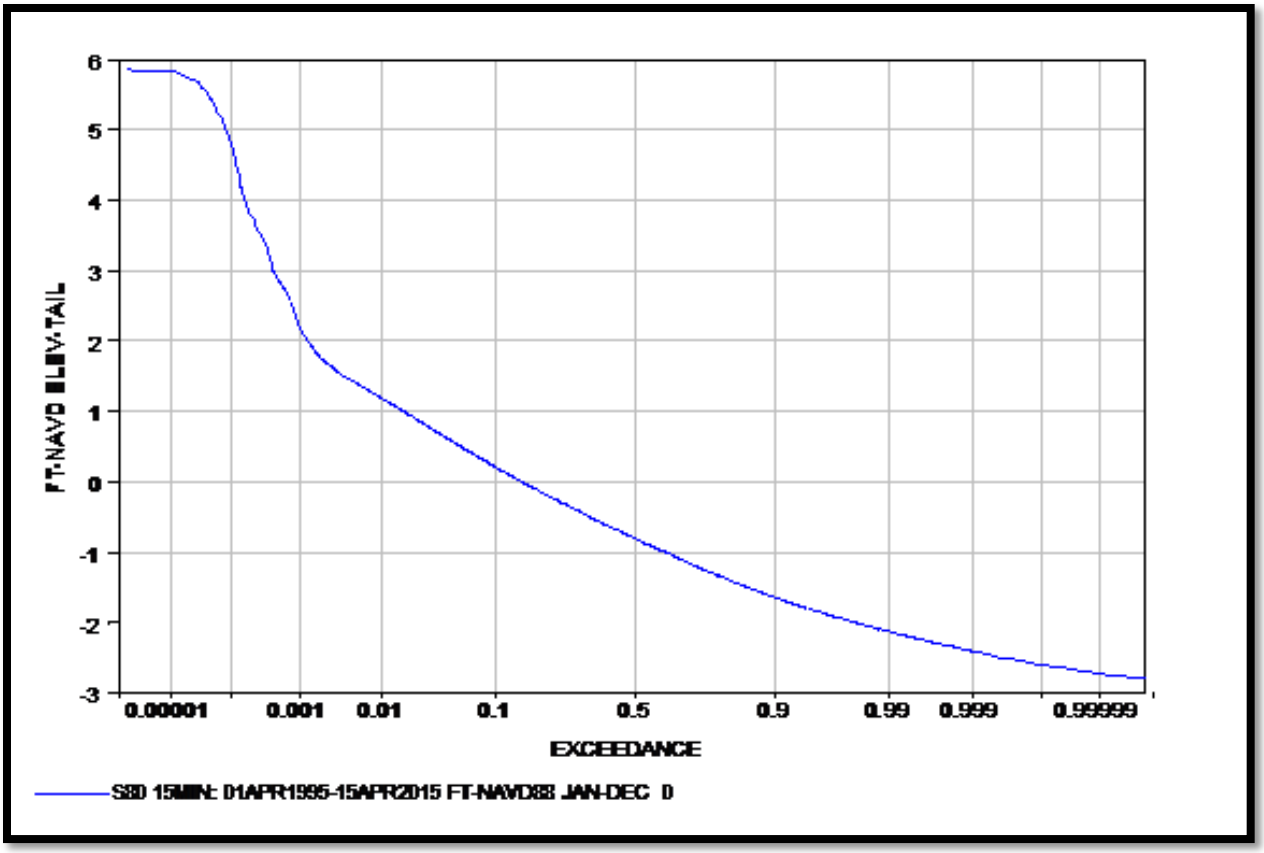


**Figure H-5. S-80 tailwater, elevation exceedance curve.**

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

The following analysis evaluates potential effects on operation of the primary Lake Okeechobee outlet structures at S-79 and S-80. For the purpose of this analysis, the following years are evaluated:

- 2028 (beginning of the LOWRP planning horizon at the start of construction)
- 2078 (50 years into the future, representing the LOWRP future without project (FWO) condition)
- 2128 (100 years into the future, representing the end of the LOWRP 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 some cases, however, the project life cycle starts before construction completion, typically because these projects start getting benefits during construction. For the LOWRP, the project life cycle begins in 2028, when construction is planned to be complete. The 2078 and 2128 conditions could ultimately affect releases made from Lake Okeechobee due to SLC and local storm water runoff from the C-43 and C-44 local drainage basins. Hence, SLC considerations may result in an increase in hydraulic loading impacts on Lake Okeechobee under future conditions. The magnitude of those impacts will depend on how soon the sea rises to a level that impacts

project performance. These impacts would be due to additional constraints on releases from the lake during high-water levels as prescribed in the Lake Okeechobee Regulation Schedule (LORS).

Sea levels relative to Lake Okeechobee outlet structures are expected to rise, depending on the projected rates of rise for low, intermediate, and high scenarios. **Figure H-6** shows the estimated relative SLC from 1992 to 2128, calculated with the USACE Sea Level Change Curve Calculator, at the Ft. Myers and Daytona Beach Shores NOAA gauges, which are in close proximity to the S-79 and S-80 outlet structures, respectively.

Lake Okeechobee Watershed Restoration Project (LOWRP)
8725520, Fort Myers, FL
NOAA's 2006 Published Rate: 0.00787 feet/yr
All values are expressed in feet relative to NAVD88

| Year | USACE Low | USACE Int | USACE High |
|---|---|---|---|
| 1992 | -0.41 | -0.41 | -0.41 |
| 1995 | -0.39 | -0.39 | -0.38 |
| 2000 | -0.35 | -0.34 | -0.32 |
| 2005 | -0.31 | -0.29 | -0.25 |
| 2010 | -0.27 | -0.24 | -0.15 |
| 2015 | -0.23 | -0.18 | -0.03 |
| 2020 | -0.19 | -0.12 | 0.10 |
| 2025 | -0.15 | -0.05 | 0.25 |
| 2030 | -0.11 | 0.02 | 0.43 |
| 2035 | -0.07 | 0.09 | 0.61 |
| 2040 | -0.03 | 0.17 | 0.82 |
| 2045 | 0.01 | 0.26 | 1.05 |
| 2050 | 0.05 | 0.35 | 1.29 |
| 2055 | 0.09 | 0.44 | 1.56 |
| 2060 | 0.13 | 0.54 | 1.84 |
| 2065 | 0.17 | 0.64 | 2.14 |
| 2070 | 0.20 | 0.75 | 2.46 |
| 2075 | 0.24 | 0.86 | 2.80 |
| 2080 | 0.28 | 0.97 | 3.15 |
| 2085 | 0.32 | 1.09 | 3.53 |
| 2090 | 0.36 | 1.22 | 3.92 |
| 2095 | 0.40 | 1.34 | 4.33 |
| 2100 | 0.44 | 1.48 | 4.76 |
| 2105 | 0.48 | 1.62 | 5.21 |
| 2110 | 0.52 | 1.76 | 5.68 |
| 2115 | 0.56 | 1.90 | 6.17 |
| 2120 | 0.60 | 2.06 | 6.67 |
| 2125 | 0.64 | 2.21 | 7.20 |
| 2128 | 0.66 | 2.31 | 7.52 |

Lake Okeechobee Watershed Restoration Project (LOWRP)
8721120, Daytona Beach Shores, FL
NOAA's 2006 Published Rate: 0.00761 feet/yr
All values are expressed in feet relative to NAVD88

| Year | USACE Low | USACE Int | USACE High |
|---|---|---|---|
| 1992 | -0.79 | -0.79 | -0.79 |
| 1995 | -0.77 | -0.77 | -0.76 |
| 2000 | -0.73 | -0.72 | -0.71 |
| 2005 | -0.69 | -0.68 | -0.63 |
| 2010 | -0.65 | -0.62 | -0.53 |
| 2015 | -0.62 | -0.57 | -0.42 |
| 2020 | -0.58 | -0.51 | -0.29 |
| 2025 | -0.54 | -0.44 | -0.14 |
| 2030 | -0.50 | -0.37 | 0.04 |
| 2035 | -0.46 | -0.30 | 0.22 |
| 2040 | -0.43 | -0.22 | 0.43 |
| 2045 | -0.39 | -0.14 | 0.66 |
| 2050 | -0.35 | -0.05 | 0.90 |
| 2055 | -0.31 | 0.04 | 1.16 |
| 2060 | -0.27 | 0.14 | 1.44 |
| 2065 | -0.23 | 0.24 | 1.74 |
| 2070 | -0.20 | 0.35 | 2.06 |
| 2075 | -0.16 | 0.45 | 2.40 |
| 2080 | -0.12 | 0.57 | 2.75 |
| 2085 | -0.08 | 0.69 | 3.12 |
| 2090 | -0.04 | 0.81 | 3.52 |
| 2095 | -0.01 | 0.94 | 3.93 |
| 2100 | 0.03 | 1.07 | 4.36 |
| 2105 | 0.07 | 1.21 | 4.80 |
| 2110 | 0.11 | 1.35 | 5.27 |
| 2115 | 0.15 | 1.49 | 5.76 |
| 2120 | 0.18 | 1.64 | 6.26 |
| 2125 | 0.22 | 1.80 | 6.78 |
| 2128 | 0.25 | 1.89 | 7.10 |

**Figure H-6. Estimated the USACE Low, Intermediate, and High SLC projections at Ft. Myers and Daytona Beach Shores, in feet relative to NAVD88, from years 1992 to 2128. (http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html).**

### H.4.2.1 Caloosahatchee River – Lake Okeechobee S-79 Outlet Structure

The closest tidal gauge to the S-79 outlet structure is NOAA tidal gauge 8725520 in Ft. Myers (tailwater of S-79). Using the USACE Sea Level Change Curve Calculator, the three projected SLC elevation trends range between -0.13 to 0.35 feet by 2028, 0.27 to 3.01 feet by 2078 (50 years), and 0.66 to 7.52 feet by 2128 (100 years). The 2006 NOAA published SLC rate is 0.00787 feet/year for the Ft. Myers gauge. See **Figure H-7** for details on the three USACE-adopted projected trends.

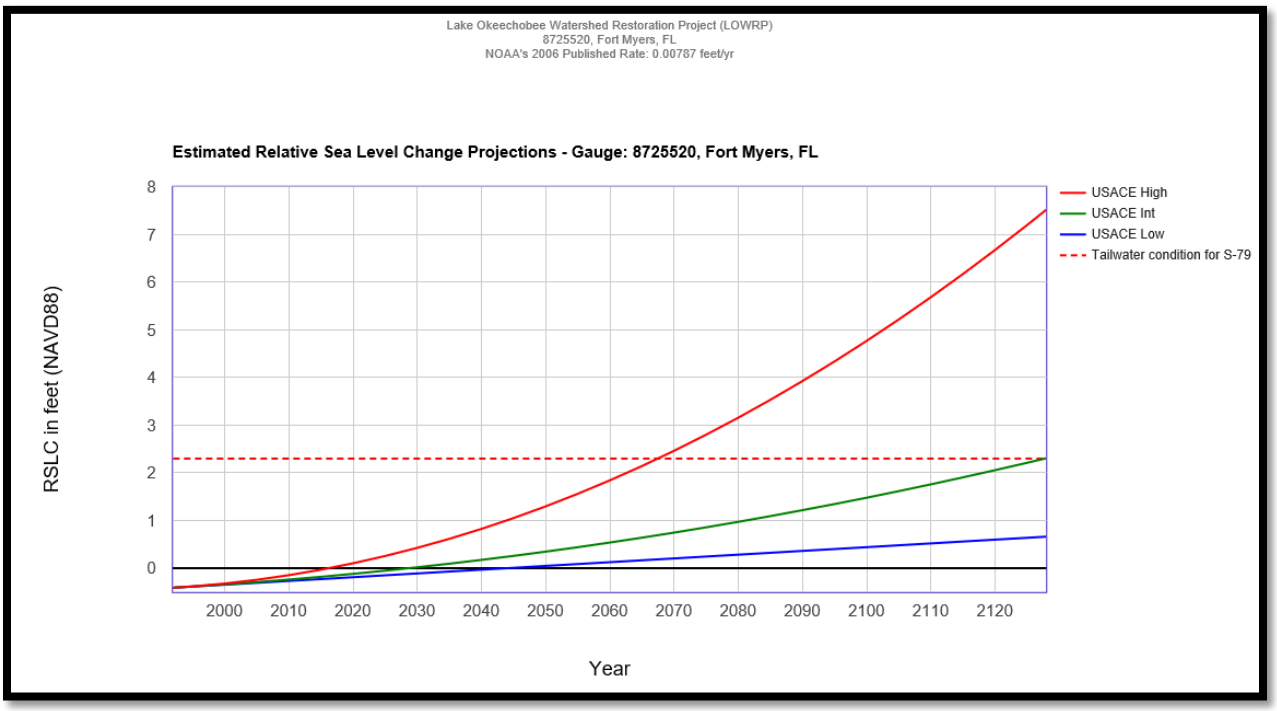


**Figure H-7. Relative SLC projections related to C-43 – Gulf of Mexico (Fort Myers, FL)**
**(**http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html**)**

Following the SLC projections from **Figure H-7** and the identified S-79 critical elevation of 2.3 feet, it can be assumed that the SLC low projected curve will intersect the discharge threshold of 2.3 feet by 2336 (beyond 2128), the SLC intermediate projected curve will intersect the threshold by 2127 and the SLC high projected curve will intersect the threshold by 2067.

### H.4.2.2 St. Lucie River – Lake Okeechobee S-80 Outlet Structure and Daytona Beach Shores Gauge

The closest tidal gauge to the S-80 outlet structure is NOAA tidal gauge 8721120 in Daytona Beach Shores, FL (tailwater of S-80). Using the USACE Sea Level Change Curve Calculator, the three projected SLC trends range between -0.52 to -0.04 feet by 2028, -0.14 to 2.61 feet by 2078 (50 years) and 0.25 feet to 7.1 ft by 2128 (100 years). The 2006 NOAA published SLC rate is 0.00761 feet/year for the Daytona Beach Shores gauge. See **Figure H-8** for details on the three USACE-adopted projected trends.

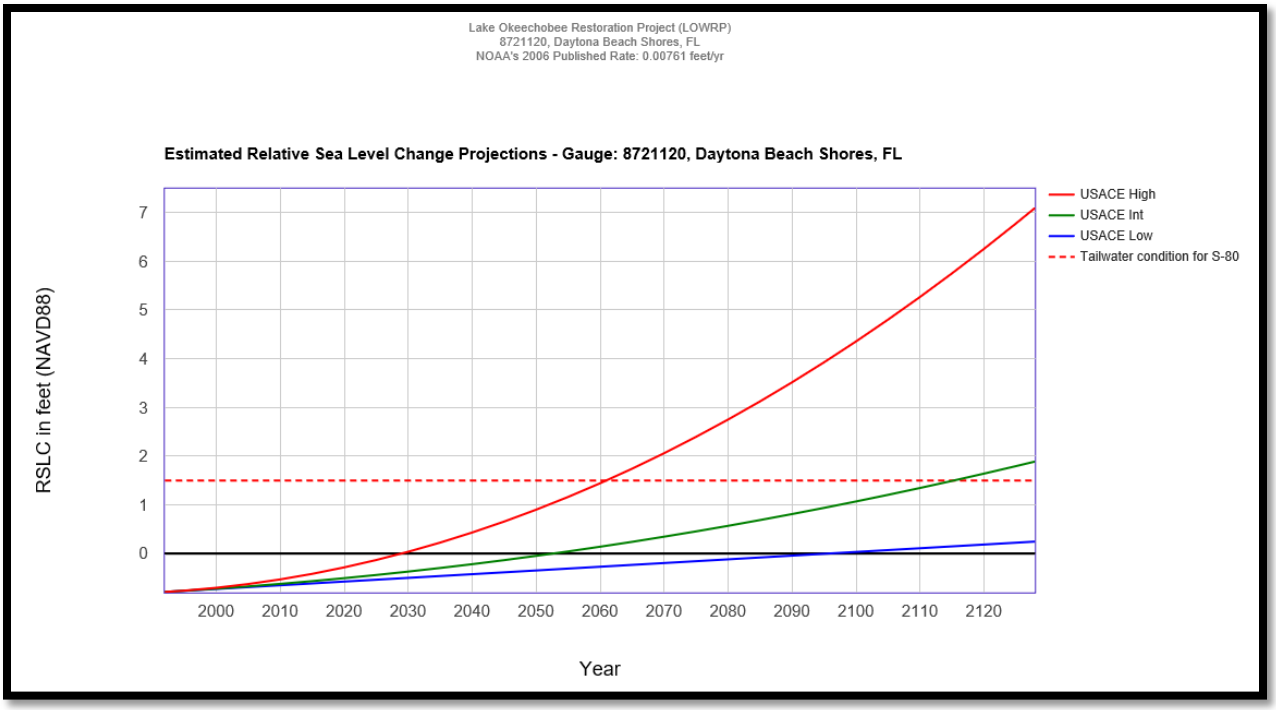


**Figure H-8. Estimated relative SLC projections related to C-44 – Port St. Lucie (Daytona Beach Shores, NOAA Gauge) (http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html)**

Following the SLC projections from **Figure H-8** and the identified S-80 critical elevation of 1.5 feet, it can be assumed that the SLC low projected curve will intersect the discharge threshold of 1.5 feet by 2293 (beyond 2128), the SLC intermediate projected curve will intersect the threshold by 2115, and the SLC high projected curve will intersect the threshold by 2061.

### H.4.3 Impacts on the LOWRP Benefits due to Sea-level Change

The effect of SLC on estuarine habitat will vary depending upon the location and elevation of the affected lands. In the Northern Estuaries, habitat coverage is represented by the area encompassing the preferred water depths (0.8-2.8 meter) for the desired restoration of submerged aquatic vegetation (SAV) species *Halodule wrightii* (Kenworthy and Fonseca, 1996; Steward et al., 2005). **Figure H-9** and **Figure H-10** show oyster and seagrass habitat within selected portions of the St. Lucie and Caloosahatchee Estuaries.

Based on the topography and the existing infrastructure, inland impacts from SLR to the Northern Estuaries will be restricted primarily to increased water depths and saline conditions in the estuaries and canal systems, as the majority of the coastline is built out and protected by seawalls and other hardened structures. Light limitation is commonly the principal factor controlling the distribution of seagrass in the Northern Estuaries. Thus, seagrass beds typically terminate at a deep-water edge where light is not sufficient to support photosynthesis. This deep-water boundary or maximum depth limit can be quantified based on monitoring (Steward et al., 2005). As the Northern Estuaries deepen in response to SLR, the deep-water edge of seagrass habitat throughout the basin will migrate upslope, but the relative depth of the deep-water edge in each sub-basin or segment will not change. With the existing infrastructure in place, suitable SAV habitat in the Northern Estuaries is expected to contract with SLR as the hardened

shoreline restricts inward movement of the coastline and the creation of new suitable estuarine habitat. The result is increased water depths beyond the preferred range for the desired restored submerged aquatic vegetation species, *Halodule wrightii*. Habitat loss may be even higher in areas of the basin impaired by persistent pollutant loading and poor water quality.

SLR during the next century will increase the exchange and circulation of Atlantic Ocean water with waters in the Caloosahatchee Estuary, Indian River Lagoon, and the St. Lucie Estuary. The effect of this would be a more saline condition overall and a shift in salinity ranges and their location within the estuary. This shift could affect the location and health of most of the flora and fauna in the estuary, including freshwater SAV, oysters, benthic communities, and shoreline vegetation. Salinities and canal stages are expected to increase in the St. Lucie and Caloosahatchee waterways (C-44 and C-43 canals), increasing the probability of urban flooding and saltwater intrusion. On the other hand, the adverse effects of large freshwater releases from Lake Okeechobee to the Northern Estuaries that reduce salinities below the targets will be dampened to some extent by SLR if the existing headwater conditions are retained.

Since no increase in surface water stages within the Caloosahatchee and St. Lucie Inlet is expected with the implementation of LOWRP, habitat loss for FWO is assumed to be similar to the with-project conditions. This means that the proportional habitat loss due to SLR affects both the LOWRP and FWO conditions fairly equally.

To reduce the risk associated with implementing the project, flexibility in the design and operation of features can be incorporated into the project during the planning phases. Features planned and operated for one purpose can be repurposed as SLR begins to affect water management needs in the future. LOWRP facilities would add additional flexibility to the operation of the system. For instance, during dry times, ASR wells proposed for LOWRP could be discharged into Lake Okeechobee and the water consequently be released to the Northern Estuaries to maintain salinity levels optimum for estuary health. Any operational modifications to address SLR would be considered in a future LORS update, as LOWRP is not the mechanism to propose these modifications.

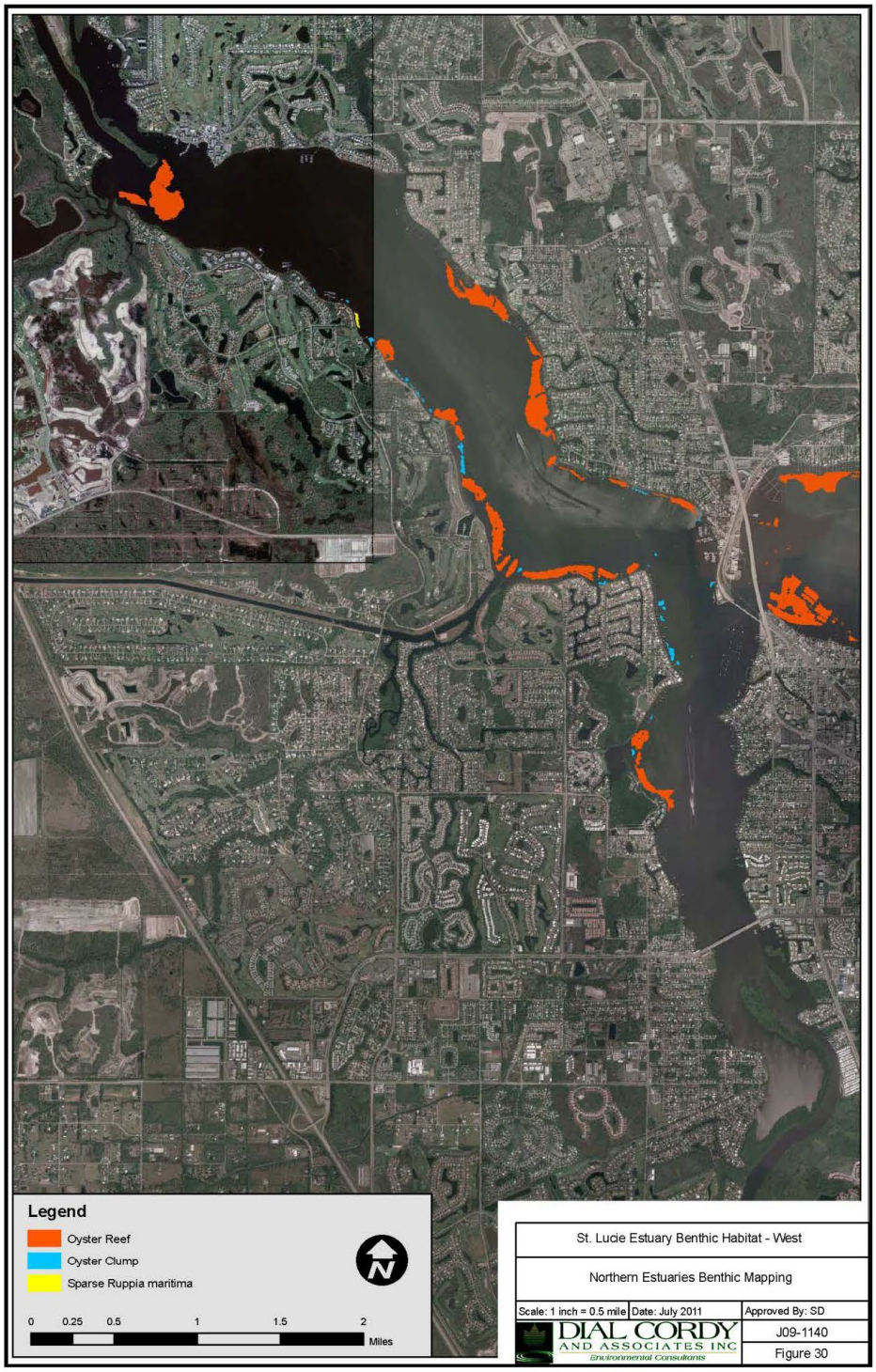


**Figure H-9. 2011 oyster and seagrass habitat within the western portion of the St. Lucie Estuary.**

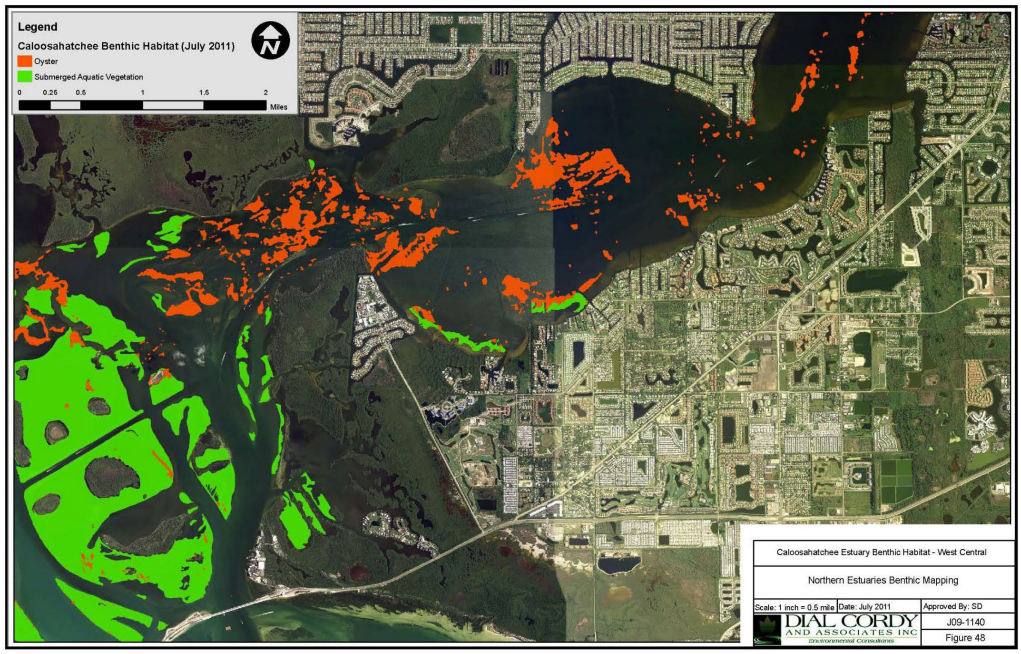


**Figure H-10. 2011 oyster and seagrass habitat with the lower portion of the Caloosahatchee River Estuary.**

### H.4.4 Sea Change-level Change Summary

The effects of SLC have been analyzed per ER 1100-2-8162 and ETL 1100-2-1. Because the project is located inland, SLC does not affect the hydrologic boundaries governing the performance and operation of the LOWRP project features. However, it is likely that the operations of the two Lake Okeechobee tidal structures, S-79 and S-80, would be affected due to SLC. This could lead to operational limitations at these structures, depending on the land use, social and environmental changes at the year of analysis.

The preceding analysis shows that the S-79 critical discharge elevation of 2.3 ft will be intersected by the low, intermediate and high SLC projected curves in the following years:

- Low curve: 2336 (after the 100-year project life cycle)
- Intermediate Curve: 2127 (99 years after the start of the project life cycle)
- High Curve: 2067 (39 years after the start of the project life cycle)

The S-80 critical discharge elevation of 1.5 ft, will be intersected by the low, intermediate and high SLC projected curves in the following years:

- Low curve: 2293 (after the 100-year project life cycle)
- Intermediate Curve: 2115 (87 years after the start of the project life cycle)
- High Curve: 2061 (33 years after the start of the project life cycle)

Flow from the controlling structures (S-80, S-79) to the estuaries are very unlikely to change based on the USACE low or intermediate SLC projections by the FWO project condition year of 2078 (also the end of

the 50-year economic planning cycle). However, it is likely that tailwater condition due to increased future sea levels will limit the ability of discharge with existing headwater stage at the S-79 structure in the USACE high SLC projection by the year 2067. For S-79, the high SLC scenario could increase sea level to the 2.3 feet discharge threshold by year 2067 (11 years before the FWO year of 2078) or increase sea levels to 7.93 feet by year 2128. In the case of S-80, downstream flooding of properties along the river represented by the threshold of 1.5 feet could be reached by 2061 in the USACE high SLC projections. For S-80, the high SLC scenario shows that sea level could reach the 1.5 feet discharge threshold by year 2061 (17 years before the FWO year of 2078) or increase sea levels to 7.1 feet by year 2128.

The LOWRP project is vulnerable to SLR by 2061 and 2067 at the S-80 and S-79 water control structures near the Northern Estuaries. While SLR does not affect the hydrologic boundaries governing the performance and operation of the LOWRP project features, benefits will change in the estuaries due to SLC. Since no increase in surface water stages within the Caloosahatchee and St. Lucie Inlet are expected with the implementation of LOWRP, habitat loss for FWO condition is assumed to be similar to the with-project conditions. This means that the proportional habitat loss due to SLR affects both the future with and FWO conditions fairly equally. Although impacts to the project net benefits due to SLR have not been fully analyzed, preliminary qualitative analysis seems to indicate that the average annual net project benefits would likely be reduced in comparison to the projected average annual net project benefits estimated assuming no SLR. However, if S-79 becomes non-functional and it is decommissioned due to SLR, this could result in an increase in ecological benefits for the area.

Resiliency and adaptive management measures should be considered with flows potentially limited at S-80 and S-79 by 2061 and 2067. Changes to S-80 and S-79 structure design and operations, or C-44 and C-43 canal capacity, could be studied; however the project team acknowledges this is outside of the LOWRP scope and that climate change in LOWRP cannot be fully answered without a comprehensive assessment of the larger C&SF system. Potential challenges with Lake Okeechobee operations will likely be studied by the Lake Okeechobee System Operating Manual (LOSOM) project.

## H.5 Inland Hydrology Overview

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-11**:

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 LOWRP project team determined that a qualitative hydrology assessment was sufficient to assess the vulnerabilities and risk of the project to future climate change.

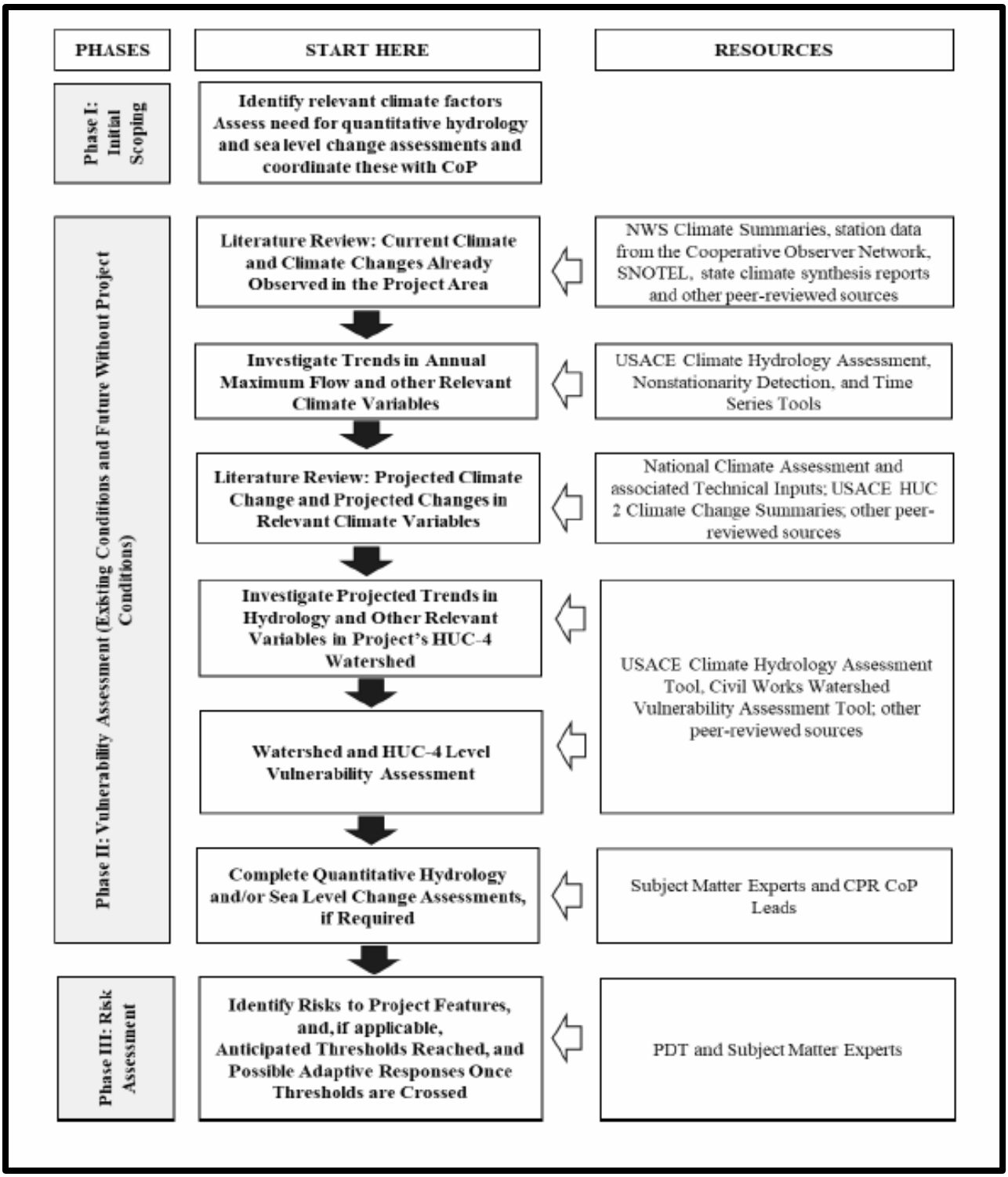


**Figure H-11. ECB 2018-14 flow chart for performing hydrologic climate change assessment (USACE, 2018a).**

#### H.5.1.2.2 Sea-level Change

As discussed in **Section H.4**, per guidance 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 policy and procedures 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. While SLR does not affect the hydrologic boundaries governing the performance and operation of the LOWRP project features, benefits will change in the estuaries due to SLC. Benefits, however, were not assessed in the estuaries using a quantitative hydrodynamic model due to schedule and budget constraints.

### 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-12**.

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.

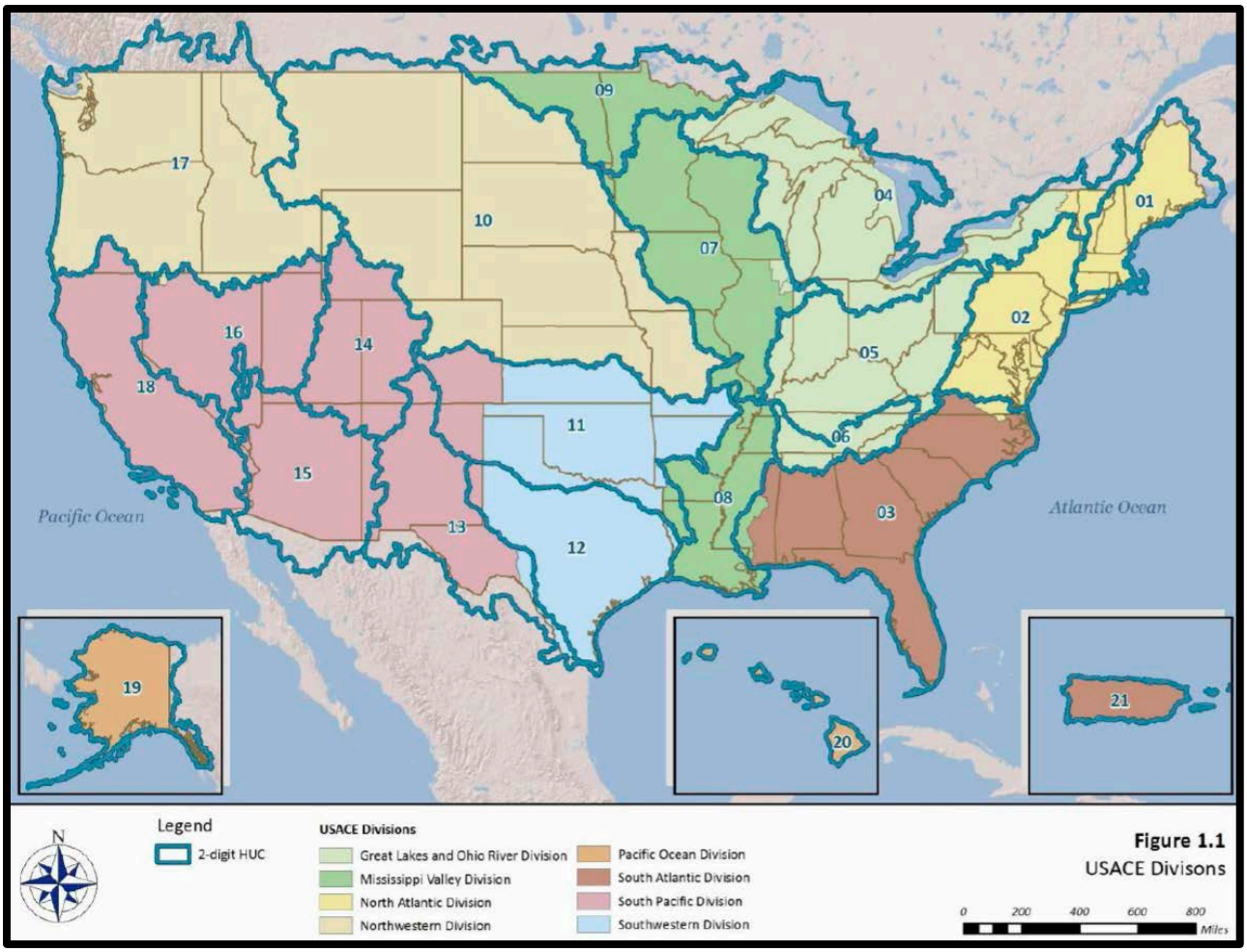


**Figure H-12. Map of 2-digit hydrologic unit code boundaries for the Continental United States, Alaska, Hawaii, and Puerto Rico (USACE, 2015a).**

### H.5.2.2 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.5.2.2.1 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. 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: an increase in frequency of approximately 25% – 50%. A 2011 study by Obeysekera et al. ( 2011) focused on identifying climate (temperature and 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 for their study region. 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-13**. Nine of the top 10 years for extreme one-day precipitation events have occurred since 1990 (EPA, 2016).

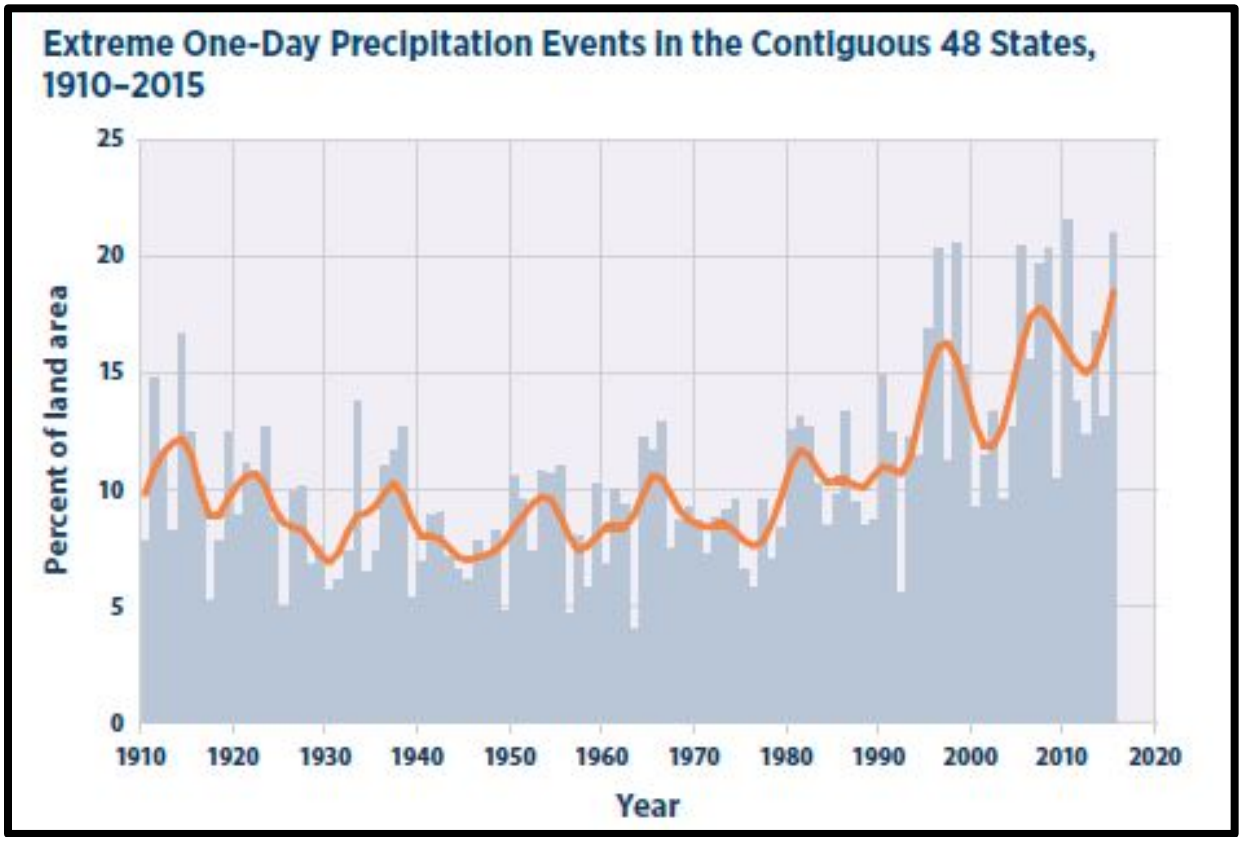


**Figure H-13. EPA extreme precipitation events (EPA, 2016).**

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. A national average increase of 4% in annual precipitation since 1901 is mostly a result of large increases in the fall season. Heavy precipitation events in most parts of the United States have increased in both intensity and frequency since 1901. 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-14** and **Figure H-15** show observed changes in annual/seasonal precipitation and extreme precipitation in the United States.

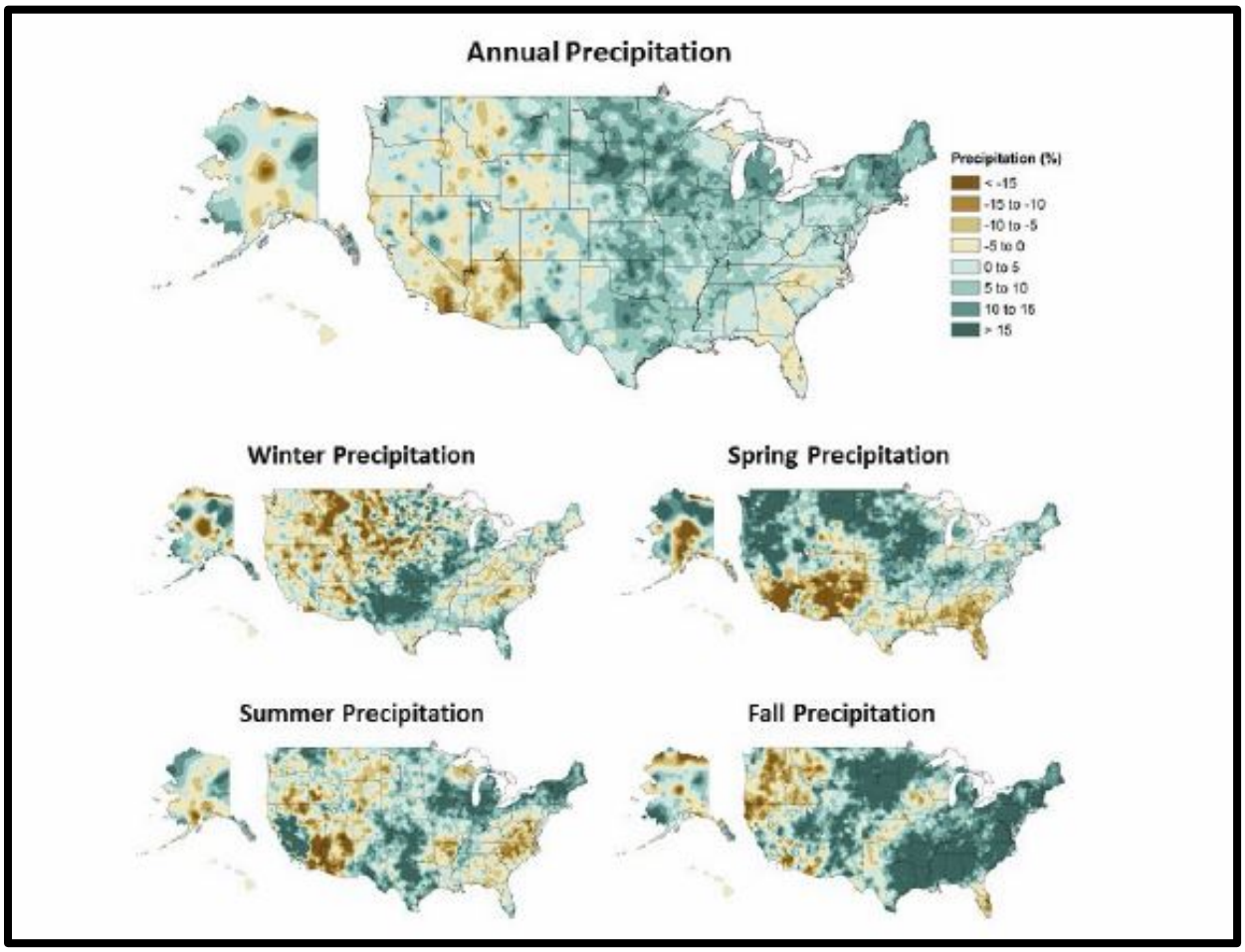


**Figure H-14. Fourth National Climate Assessment observed changes in precipitation over the United States (USGCRP, 2017).**

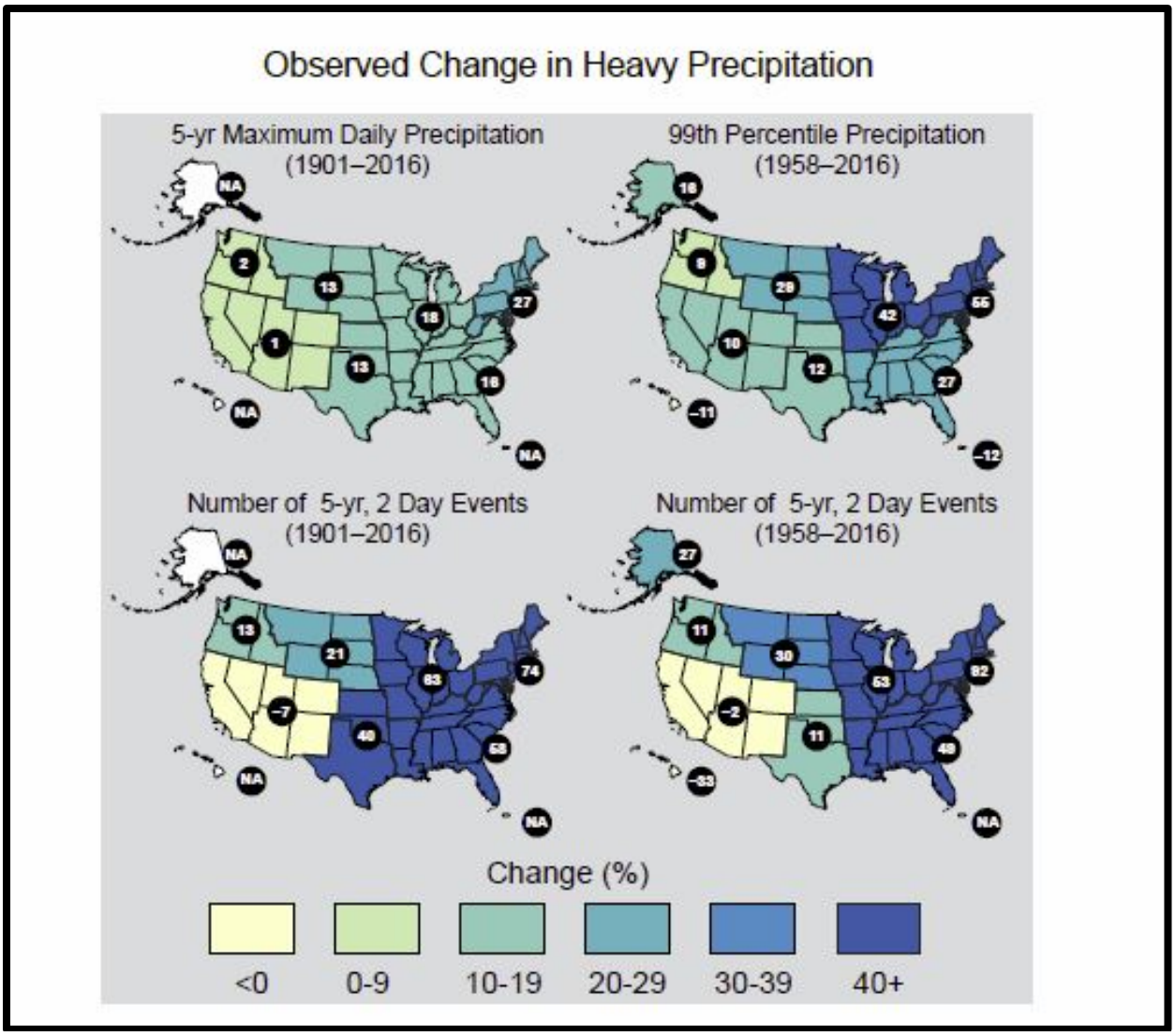


**Figure H-15. 4th National Climate Assessment observed changes in extreme precipitation over the United States (USGCRP, 2017).**

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 studies report* on current climate and climate changes already observed in the project 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.

Global climate change and variability, particularly at regional levels, are not completely understood. 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.

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).

#### H.5.2.2.2 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 in 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. Studies project that the observed increase in heavy precipitation events will continue in the future. Research shows that there is strong evidence that increased water vapor resulting from higher temperatures is the primary cause of the increases. The frequency of seasonal hourly precipitation extremes is expected to increase in all regions of the United States by up to five times in the same areas that show the highest increases in extreme precipitation rates. Regional model projections of precipitation from landfalling tropical cyclones over the United States suggest that the occurrence 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 the Atlantic basin (USGCRP, 2017). **Figure H-16** and **Figure H-17** show changes in projected seasonal precipitation and extreme precipitation in the United States.

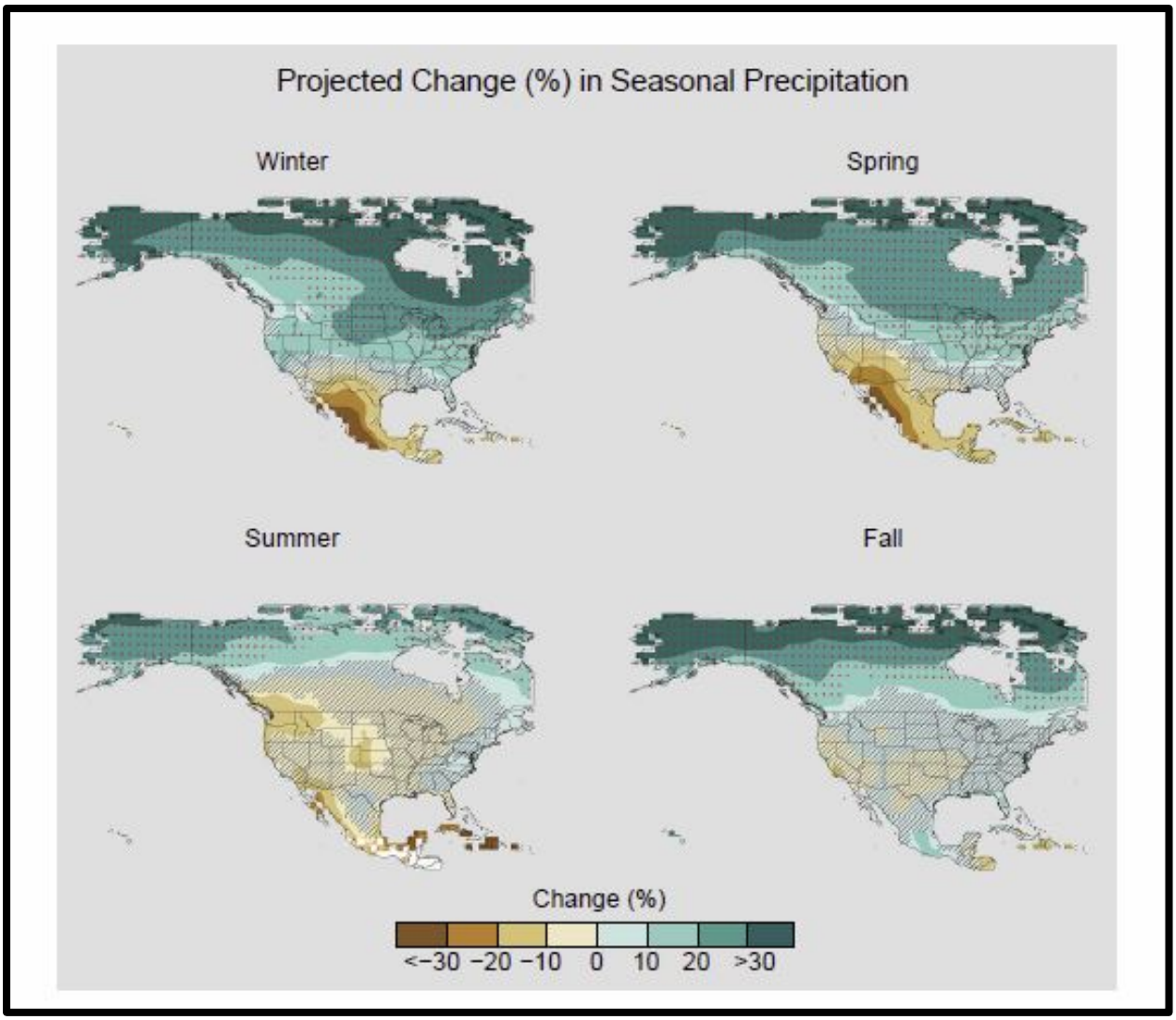


**Figure H-16. 4th National Climate Assessment projected percent change in total seasonal precipitation (USGCRP, 2017).**

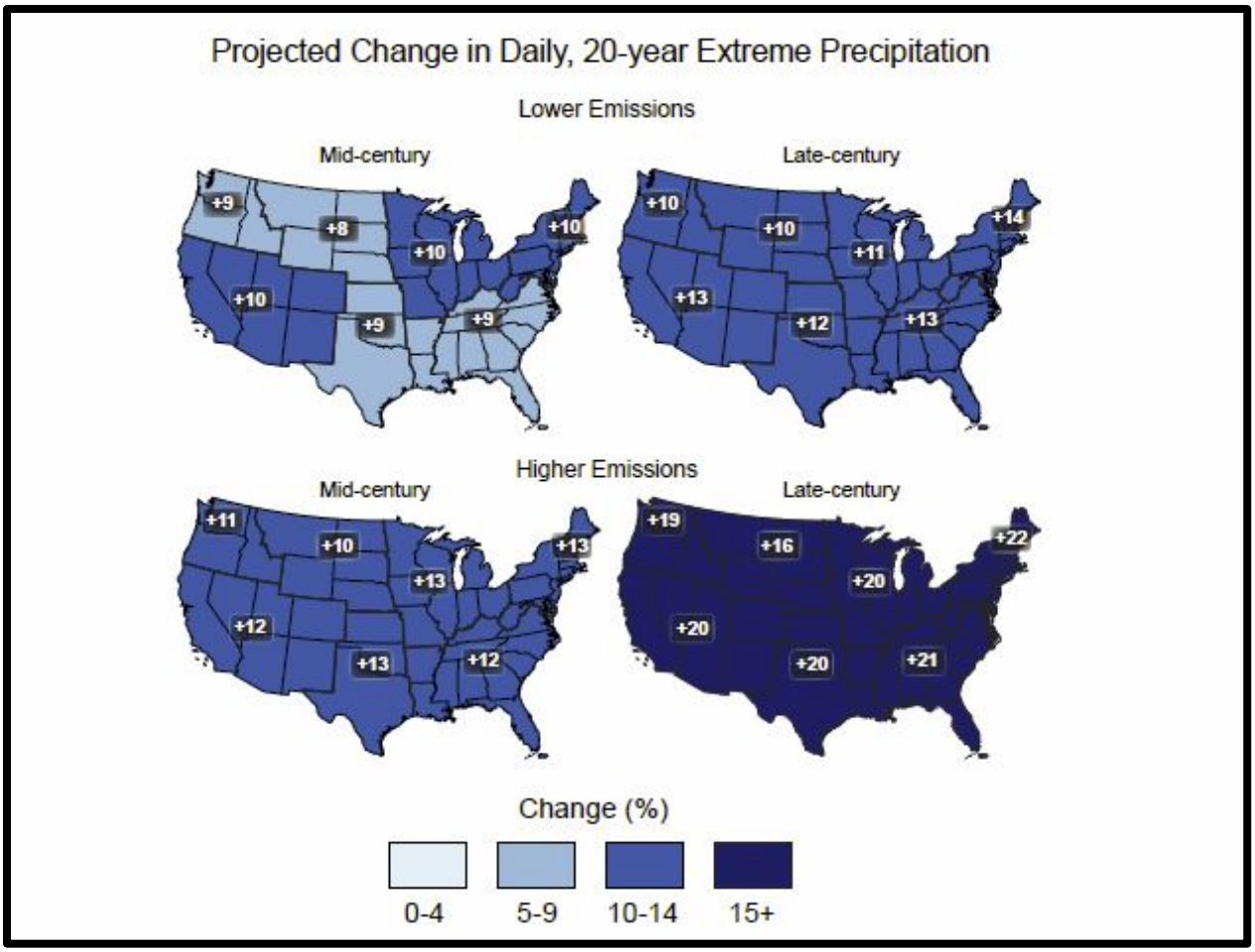


**Figure H-17. 4th National Climate Assessment projected change in the 20-year return period amount for daily precipitation for mid- and late-21st century (USGCRP, 2017)**

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 studies* report that the Florida Oceans Council (2009) predicts more frequent intense rainfall events will occur, coupled with longer dry periods in between. 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.

Current research indicates overall storm frequency may decrease, while the number of strong hurricanes (due to warmer temperatures) is expected to increase. 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 would complete this 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 this extreme.

#### H.5.2.3 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.5.2.3.1 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 2011 study by Obeysekera at al. (Obeysekera 2011) found no discernible trends in average and maximum daily temperatures, and extreme temperature events. However, the authors present evidence of increasing trends in the number of extreme heat days and in daily minimum temperature (USACE, 2015a).

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-18** (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-19** experienced an overall warming for the period 1986-2016 relative to 1901-1960 (**Figure H-20**). 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 20$^{th}$ century, followed by decades of cooling, and is not showing indications of warming. 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).

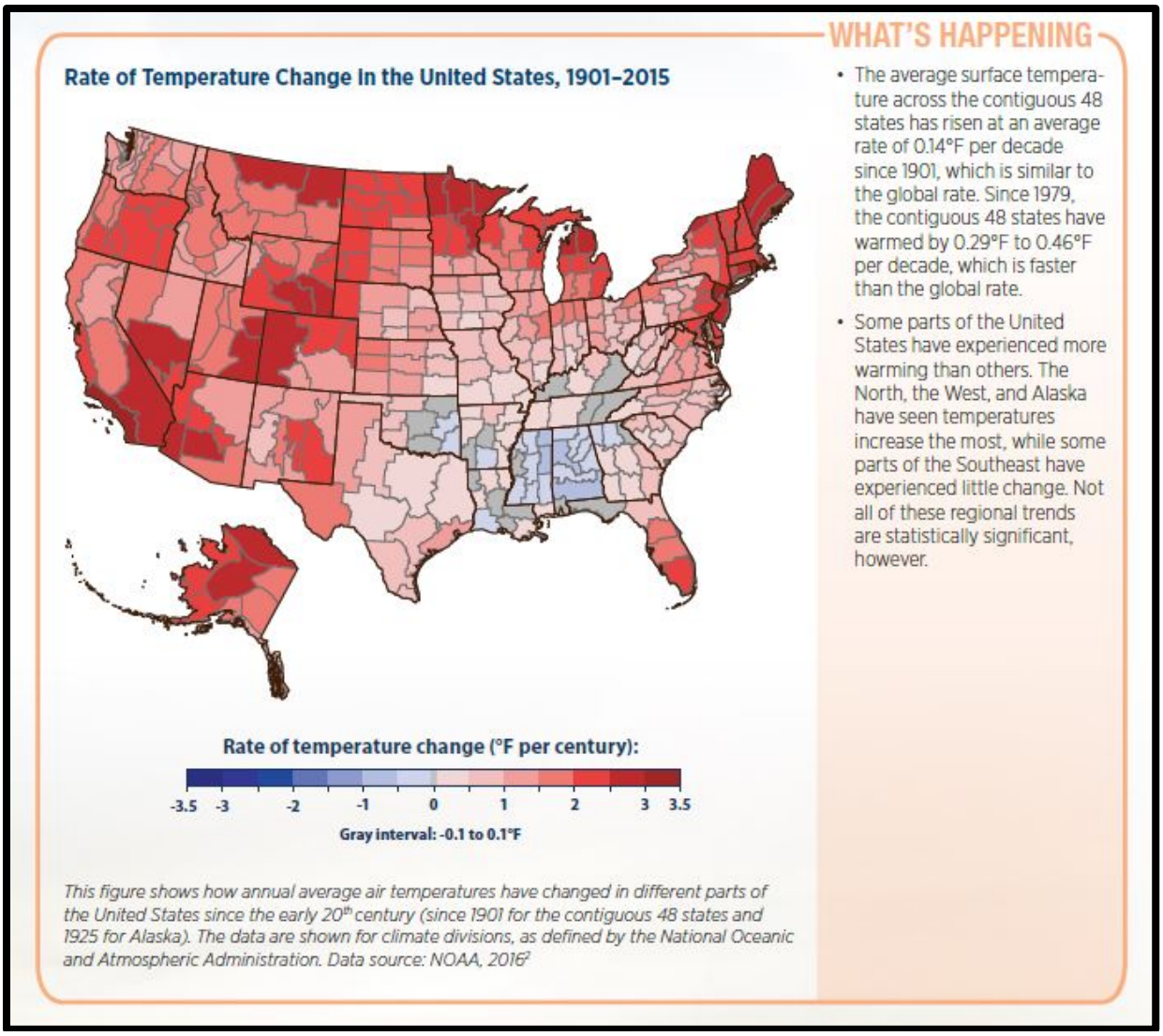


**Figure H-18. EPA rate of temperature change in the United States, 1901-2015 (EPA, 2016).**

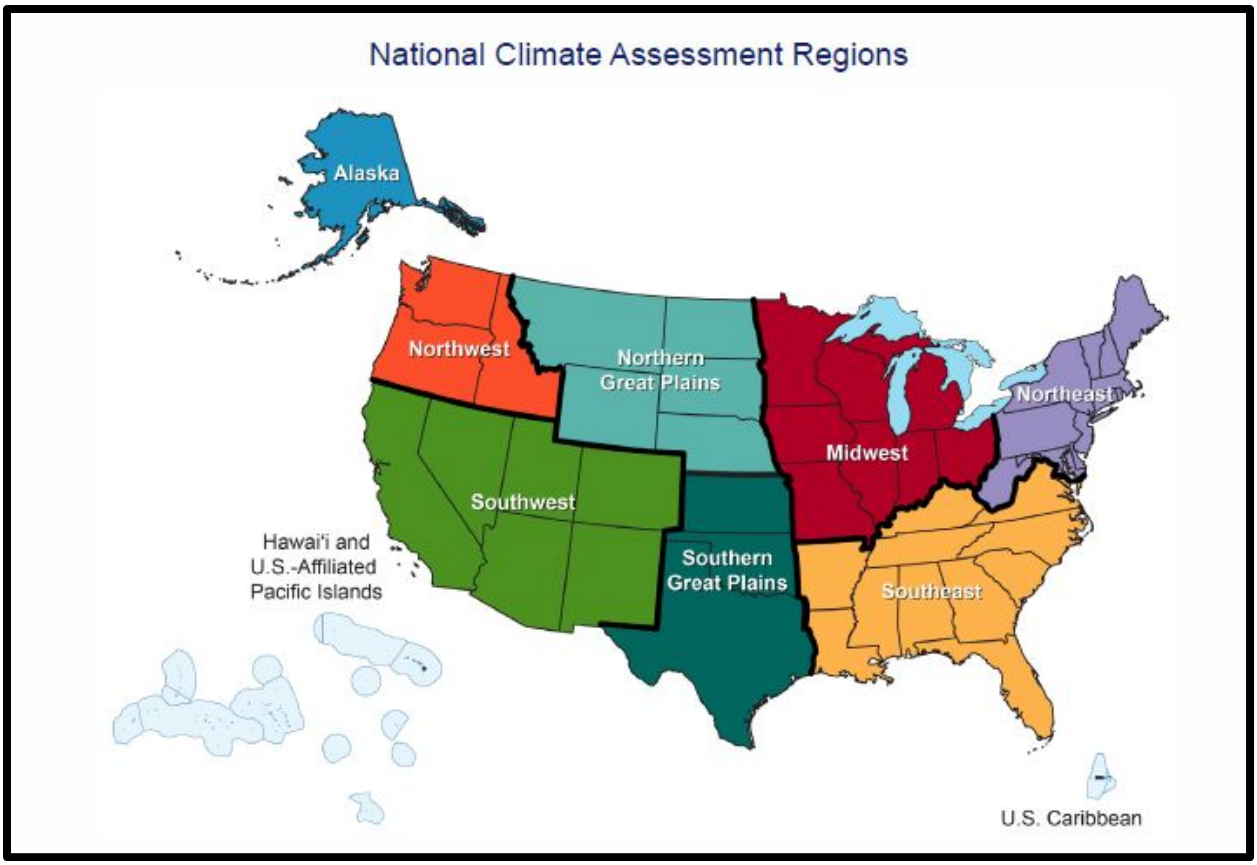


**Figure H-19. Fourth National Climate Assessment regional boundaries in CONUS (USGCRP, 2018).**

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. 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), as shown in **Figure H-21** (Runkle et al.,2017).

The *USACE Jacksonville District studies* report 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).

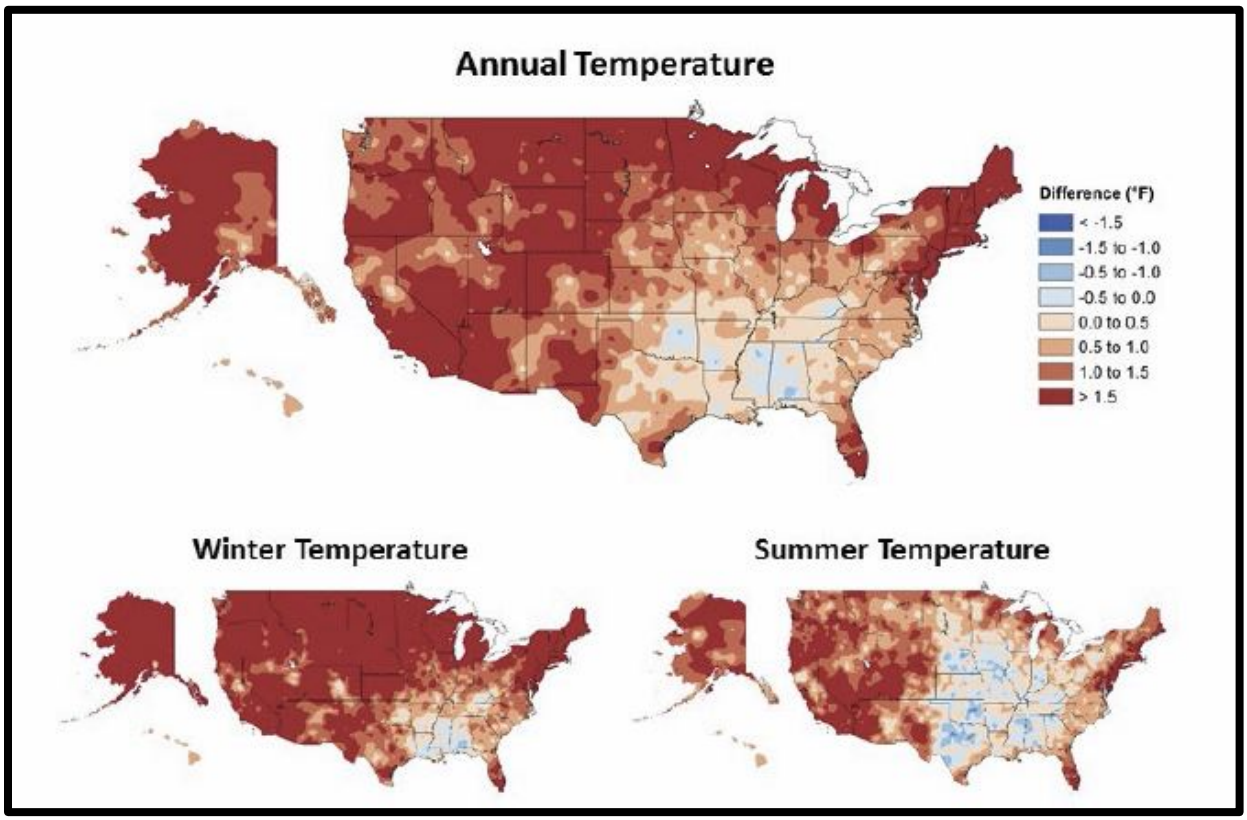


**Figure H-20. 4th National Climate Assessment observed changes in annual average temperature (USGCRP, 2017).**

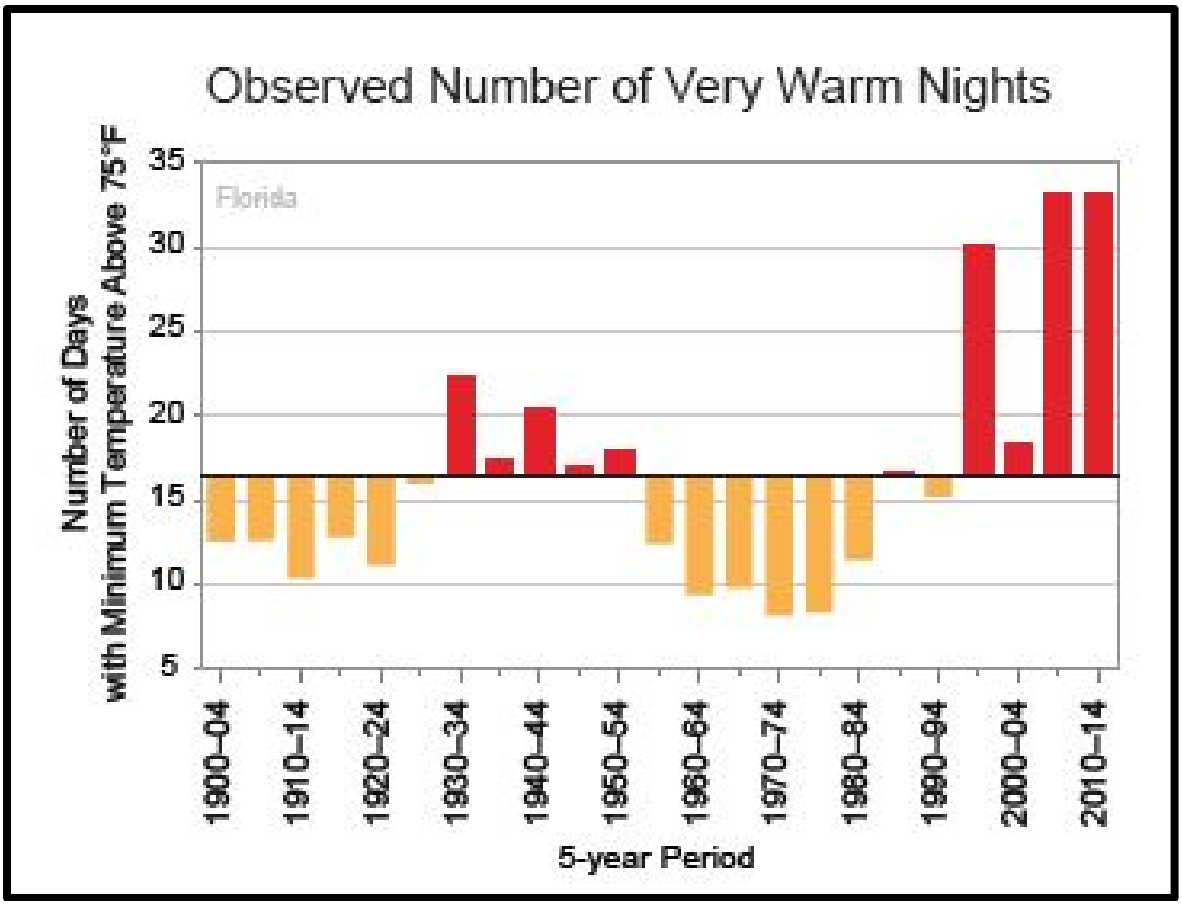


**Figure H-21. NOAA state climate summary for Florida: Observed number of very warm nights for 1900-2014 (Runkle et al., 2017).**

#### H.5.2.3.2 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 a 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-22** (USACE, 2015a).

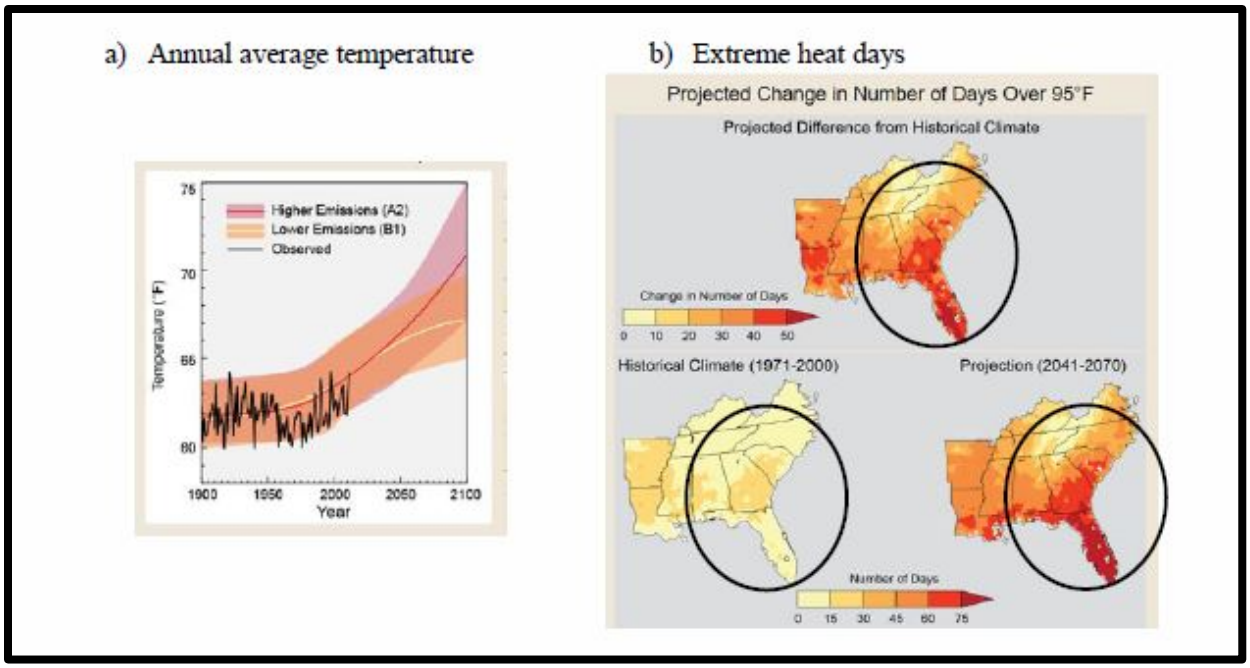


**Figure H-22. GCM projections of temperature change in the southeast United States (South Atlantic-Gulf Region circled in black) (USACE, 2015a).**

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 release 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. Future changes in "very rare" extreme temperatures are increasing (USGCRP, 2017). Rising air and water temperatures and 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-23** and **Figure H-24** show project changes in annual average temperatures and extreme temperatures in the United States.

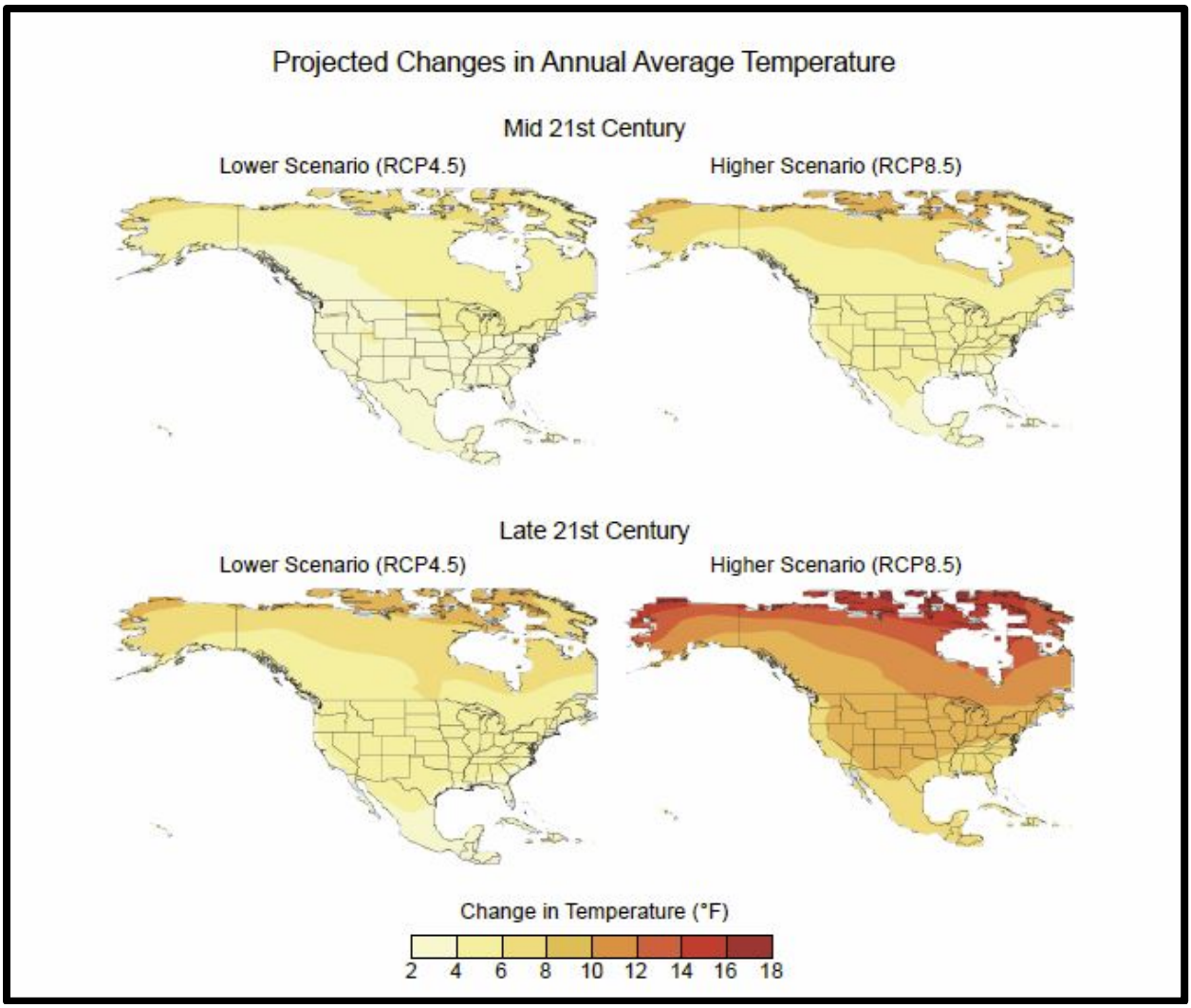


**Figure H-23. 4th National Climate Assessment projected changes in annual average temperatures (°F) (USGCRP, 2017).**

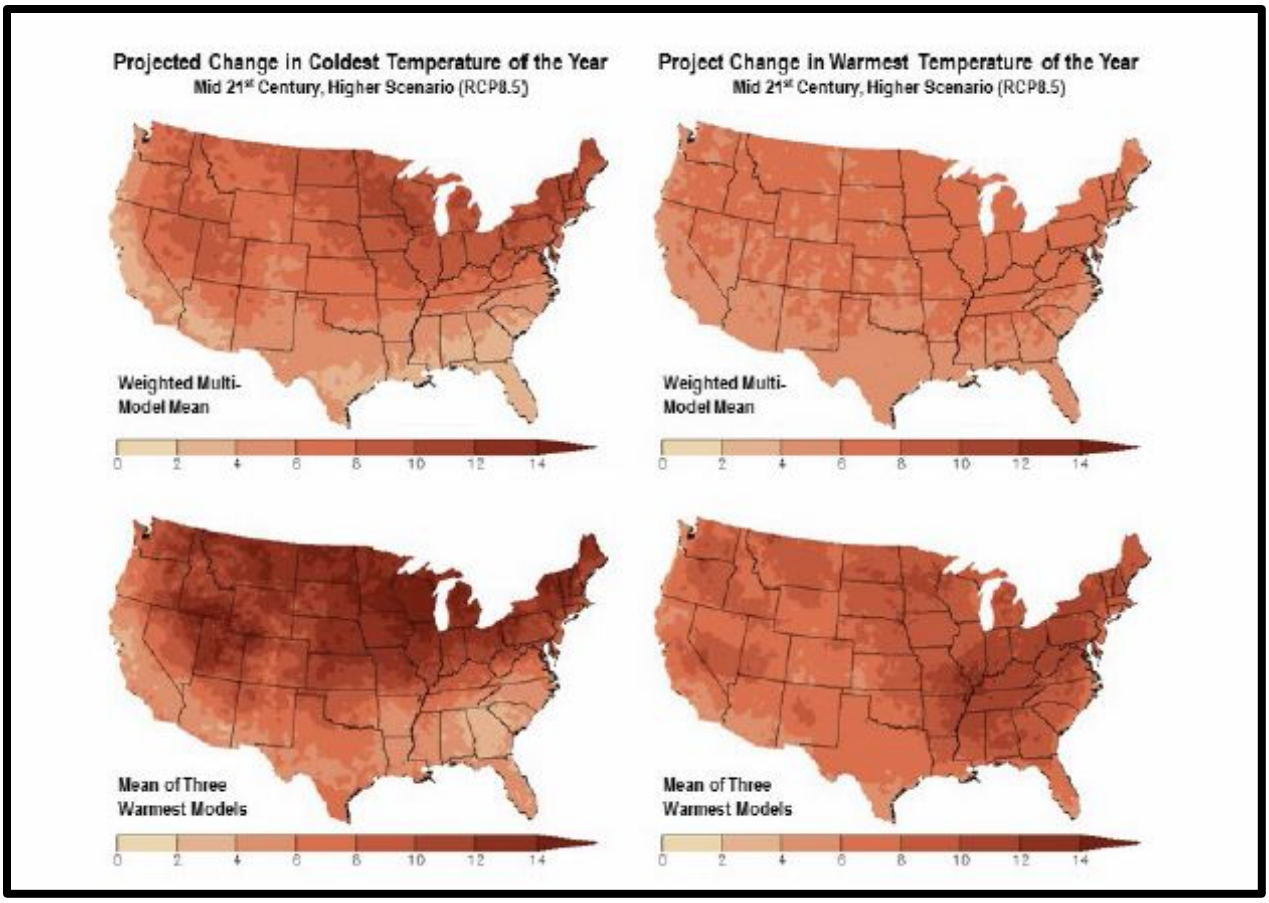


**Figure H-24. 4th National Climate Assessment Projected changes in coldest and warmest daily temperatures (°F) of the year in the contiguous United States (USGCRP, 2017).**

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-25** shows observed and projected air temperature changes for Florida.

The *USACE Jacksonville District studies* report 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).

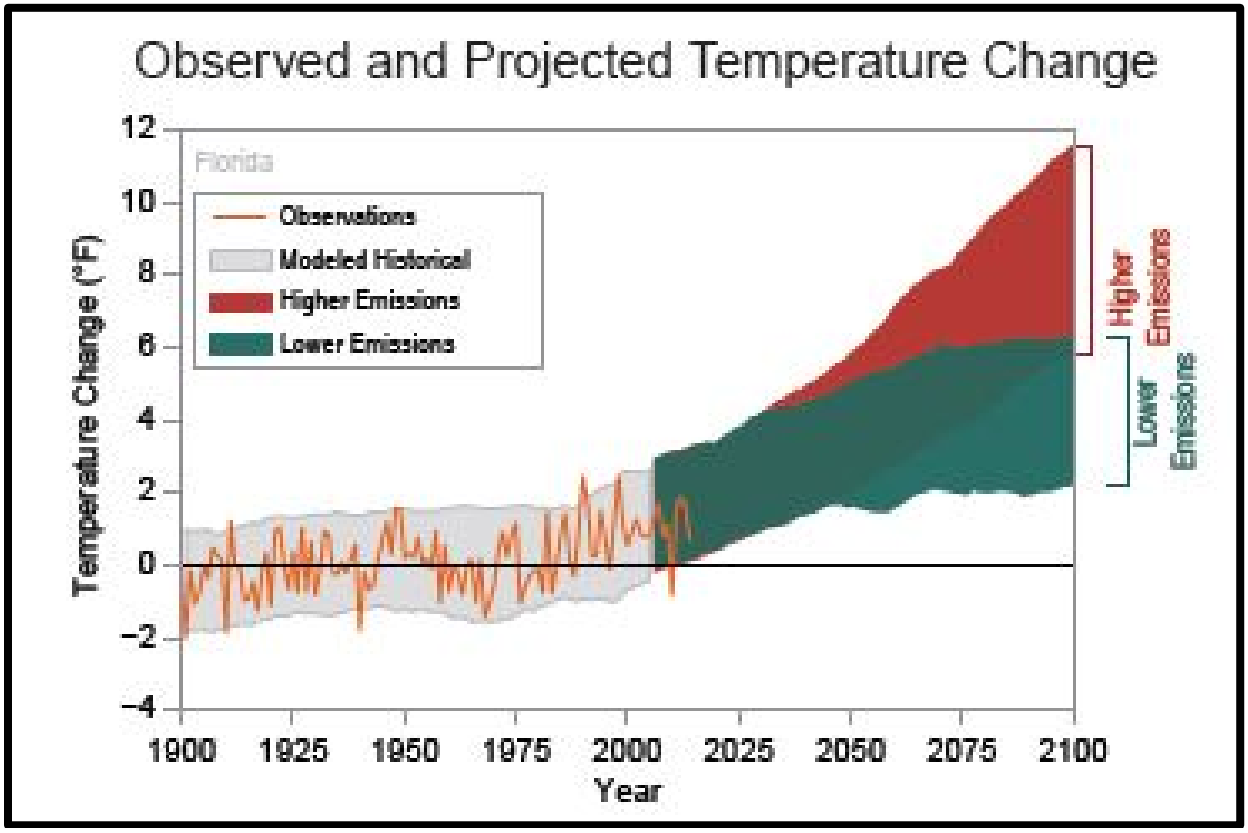


**Figure H-25. NOAA State Climate Summary for Florida: Observed and projected changes (compared to the 1901-1960 average) in air temperature for Florida (Runkle et al., 2017).**

### H.5.2.4 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.5.2.4.1 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 trends and non-stationarity 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-26** shows change in frequency of river flooding for sites in the United States.

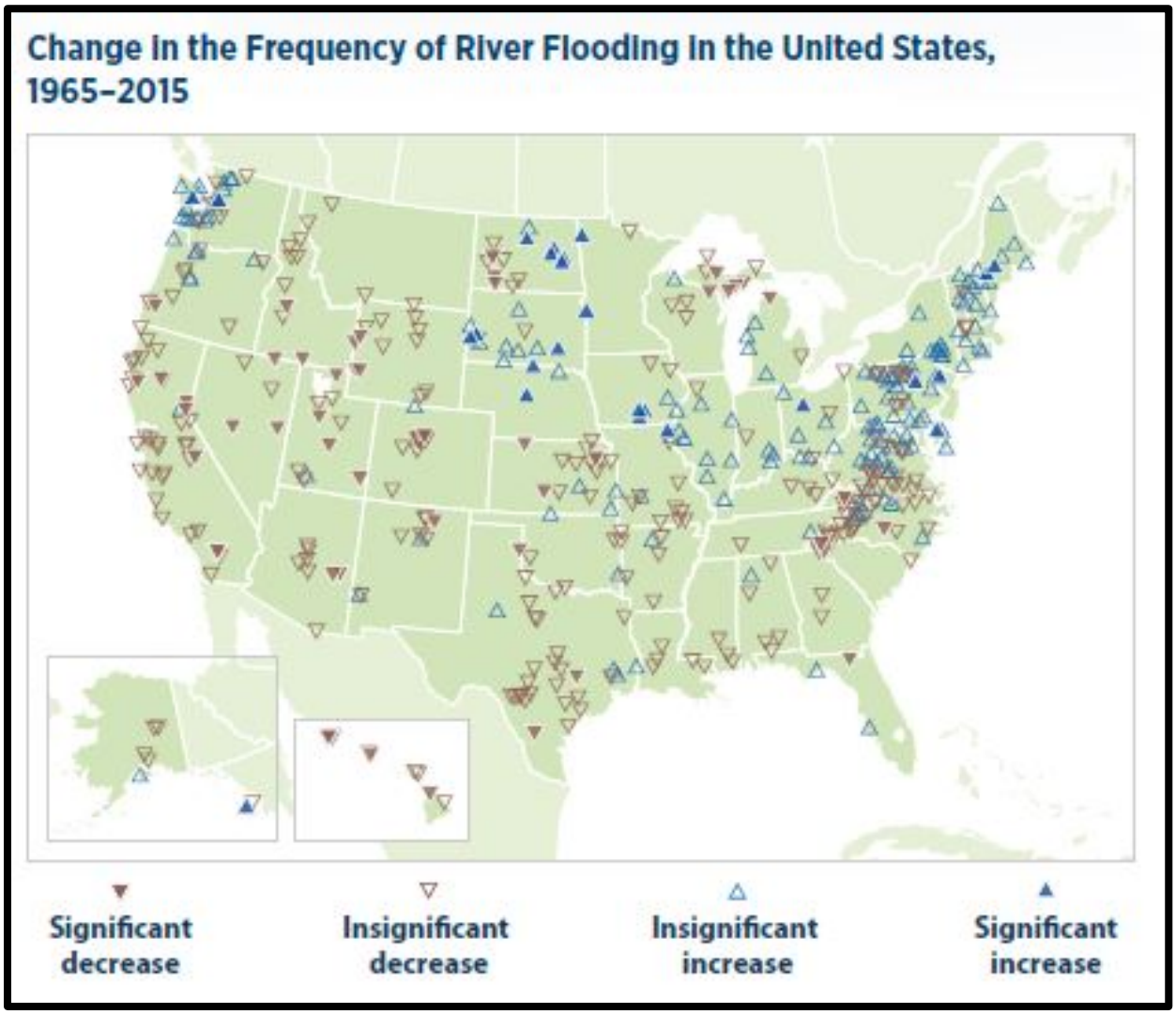


**Figure H-26. EPA change in the frequency of river flooding in the United States, 1965-2015 (EPA, 2016).**

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). A summary of the observed trends can be found in **Table H-1.**

#### H.5.2.4.2 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 here, results are almost evenly split between the two (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 and a mix of increases and decreases. Extreme precipitation is projected to continue to do so 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.5.2.5 Literature Summary

Observed and projected climate trends in the project area were sought in the literature review of the above sources. The intent of the review is to identify observed and projected climate trends in the project area, but it does not identify the causes of climate change, whether natural or unnatural. 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.

Observed air temperature trends among the five peer-reviewed literature sources show an increase in temperature, with a general consensus of an increase in minimum and maximum temperatures. Observed precipitation shows no discernible trends in annual/seasonal precipitation but shows an increase in the frequency and intensity of extreme precipitation events. Heavy precipitation events in most parts of the United States have increased in both intensity and frequency since 1901. Extreme precipitation events are generally observed to increase in intensity by about 6% to 7% for each degree Celsius of temperature increase (USGCRP, 2017). The annual frequency of hurricanes has remained relatively stable throughout the 20$^{th}$ and early 21$^{st}$ centuries; however, hurricane rainfall is expected to increase for Florida as the climate continues to warm. No trend in observed streamflow was found.

Projected air temperature trends among the five peer-reviewed literature sources show an increase in annual/seasonal precipitation and an increase 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 21$^{st}$ 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 is the primary cause of the increases. The frequency of seasonal hourly precipitation extremes is expected to increase in all regions of the United States by up to five times in the same areas that show the highest increases in extreme precipitation rates. While no consensus on an increase or decrease in projected streamflow is found, the hydrologic statistics support an increase in streamflow which may occur due to an increase in extreme storm frequency. A summary of the projected trends can be found in **Table H-2.**

**Table H-1. 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) | No trend | Increase | Increase | No Trend | Increase | No Trend |
| 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) | Increase | Increase | Increase | No Trend | Increase | No Trend |
| NOAA State Climate Summaries (Runkle et al., 2017) | Increase | Increase | No Trend | No Trend | No Trend | No literature |
| USACE Jacksonville District studies | No trend | No trend | Increase | No trend | Increase | No literature |

**Table H-2. 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) | No literature | No literature | No literature | No literature | No literature | No literature |
| 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 | No literature | Increase | No Trend | Increase | No literature |
| USACE Jacksonville District studies | No trend | No trend | Increase | No trend | Increase | No literature |

#### H.5.2.6 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 tools that provide qualitative information on projected climate conditions at the watershed scale (Hydrologic Unit 4 (HUC04)), a spatial scale consistent with the spatial and temporal precision of downscaled GCM climate-hydrology datasets.

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.5.2.6.1 Climate Hydrology Assessment Tool

The CHAT allows users to assess trends in both observed and projected hydrometeorological data to support consistent analyses and to develop reliable, qualitative projections of climate changes for the USACE projects.

The CHAT projects future changes in streamflow using GCMs at the watershed scale (HUC04), a spatial scale consistent with the spatial and temporal precision of downscaled modeling climate-hydrology datasets. **Figure H-27** shows the HUC04 basins for the South Atlantic-Gulf Region. The LOWRP project is located within the southernmost basin in Florida.

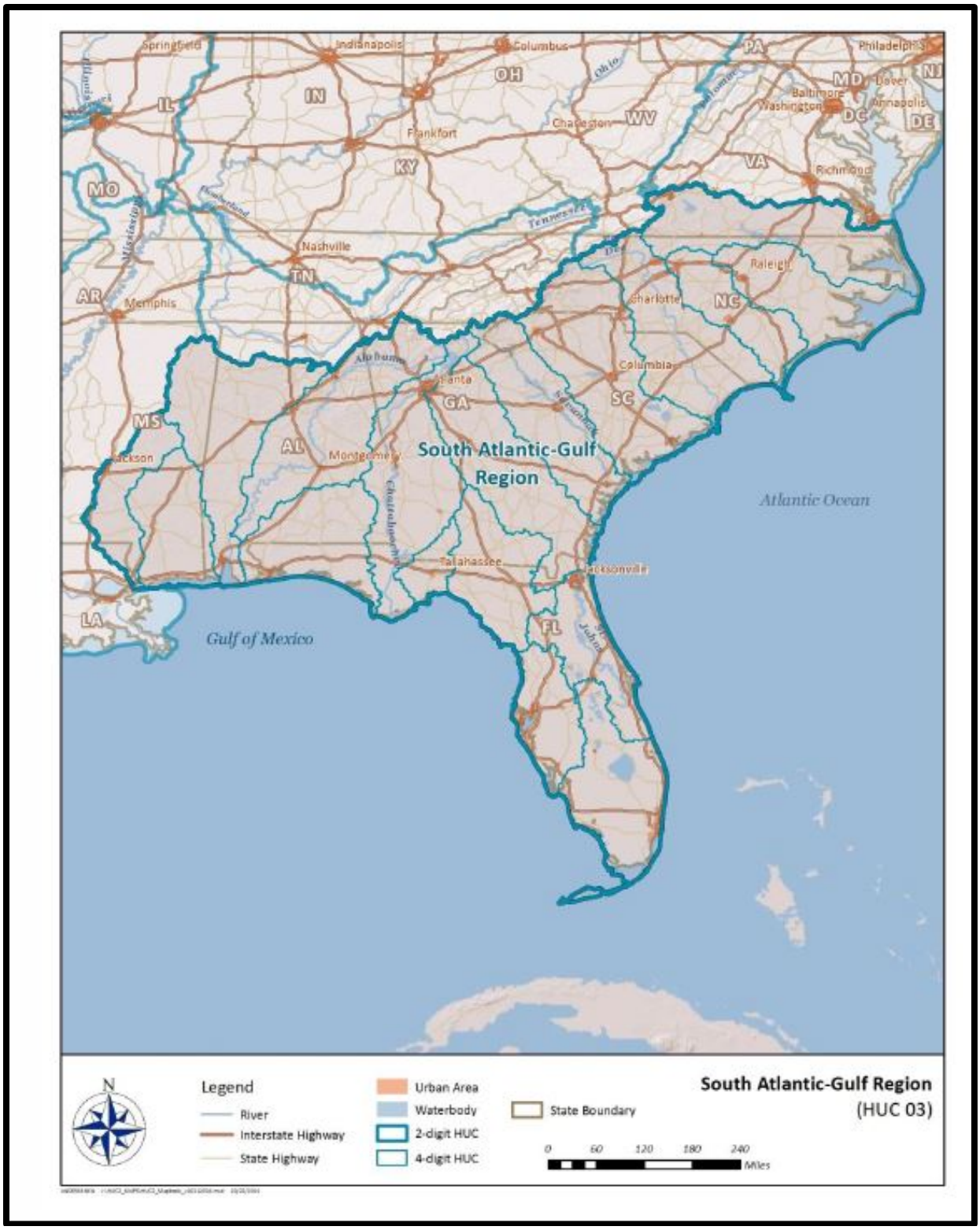


**Figure H-27. Water Resources Region 03: South Atlantic-Gulf Region boundary (USACE, 2015).**

#### H.5.2.6.1.1 Observed Trends

Using the CHAT, a first-order statistical analysis of trends in observed, peak streamflow data was conducted using data from Fisheating Creek U.S. Geological Survey (USGS) gauge 2256500 at Palmdale, Florida (see **Figure H-28**). Because the Fisheating Creek gauge has the longest unregulated period of record (see **Figure H-29**) of any streamflow gauge within the Lake Okeechobee watershed, it is used in the climate hydrology assessment to identify trends and potential nonstationarities within the period of record. There are other long-term gauges in the Lake Okeechobee watershed, but these gauges were not selected because they are 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 drainage area for Fisheating Creek has largely remained a natural basin and unchanged over time with little change to land use, drainage, and flood control infrastructure.

##### H.5.2.6.1.1.1 Peak Streamflow

Trends in peak streamflow may provide supporting evidence of climate change. The analysis focuses on high flows because the purpose of the LOWRP project is to improve the quantity, timing, and distribution of water flows to Lake Okeechobee and the estuaries by capturing high flows into Lake Okeechobee and releasing the flows in a manner that will provide optimal benefits to the downstream system. Because Lake Okeechobee stages and inflows, the lake are highly regulated, other variables relevant to the study purpose, such as reservoir elevations and flow durations, are highly influenced by water management decisions for Lake Okeechobee and the contributing watershed.

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

The CHAT applied a linear regression of the annual peak instantaneous discharges at Fisheating Creek USGS gauge 2256500 at Palmdale, FL. The p-value associated with trendline is 0.053 in **Figure H-30**, which is approximately the accepted threshold for significance of 0.05. The 0.05 threshold indicates that the trendline has a statistically significant trend. This result shows evidence that there might be a decreasing trend in the historically observed peak flow data over the period of record 1932-2014.

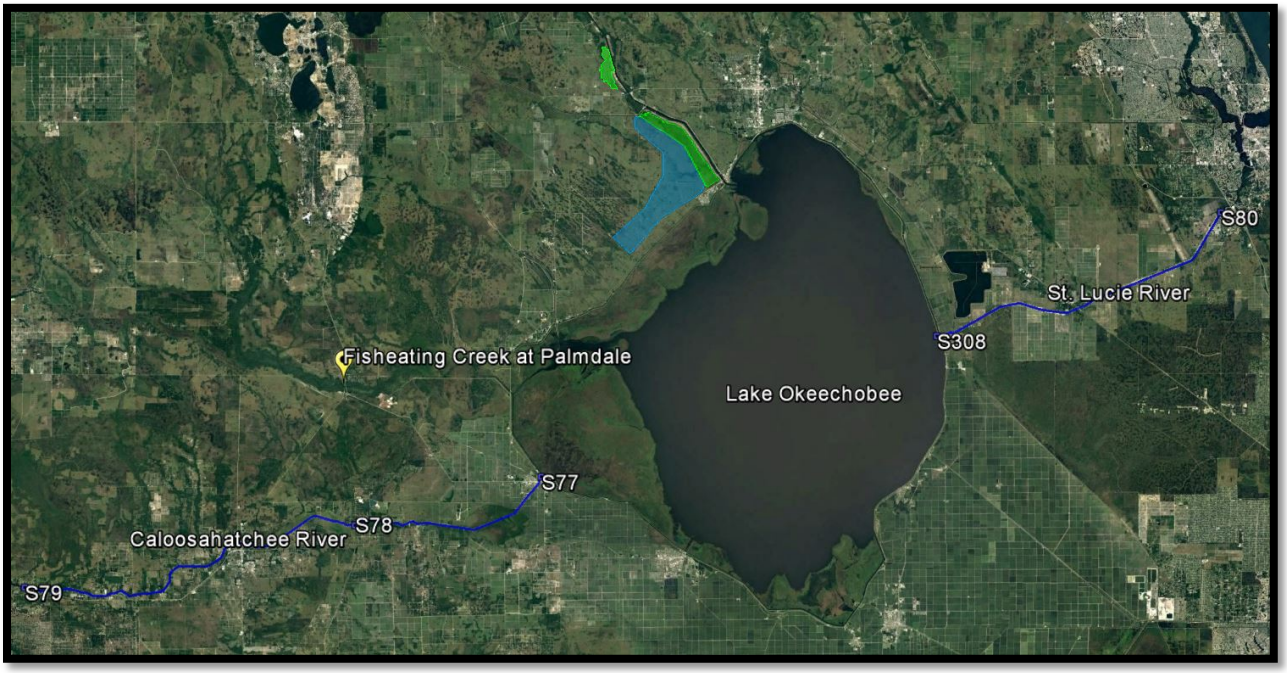


**Figure H-28. Location of the Fisheating Creek at Palmdale gauge.**

**02256500 FISHEATING CREEK AT PALMDALE, FL**

LOCATION - Lat 26°55'56", long 81°18'54" referenced to North American Datum of 1927, in SW 1/4 sec.03, T.41 S., R.30 E., Glades County, FL, Hydrologic Unit 03090103, near right bank on downstream side of southbound bridge on U.S. Highway 27, 1.0 mi south of Palmdale, and 16 mi upstream from Lake Okeechobee.

DRAINAGE AREA - 311 mi².

**SURFACE-WATER RECORDS**

PERIOD OF RECORD - April 1931 to current year.

REVISED RECORDS - WRD FL-66-2: Drainage area.

GAGE - Water-stage recorder and data-collection platform. Datum of gage is 27.19 ft above NGVD of 1929 and 25.91 ft below NAVD of 1988. Prior to Mar. 16, 1949, nonrecording gage and Mar. 16, 1949, to Jan. 23, 1956, water-stage recorder, at site 450 ft upstream at same datum.

COOPERATION - This gage is monitored in cooperation with the US Army Corps of Engineers Jacksonville District and the Florida Department of Agriculture and Consumer Services.

**Figure H-29. Pertinent data from USGS for Fisheating Creek at Palmdale gauge 02256500.**

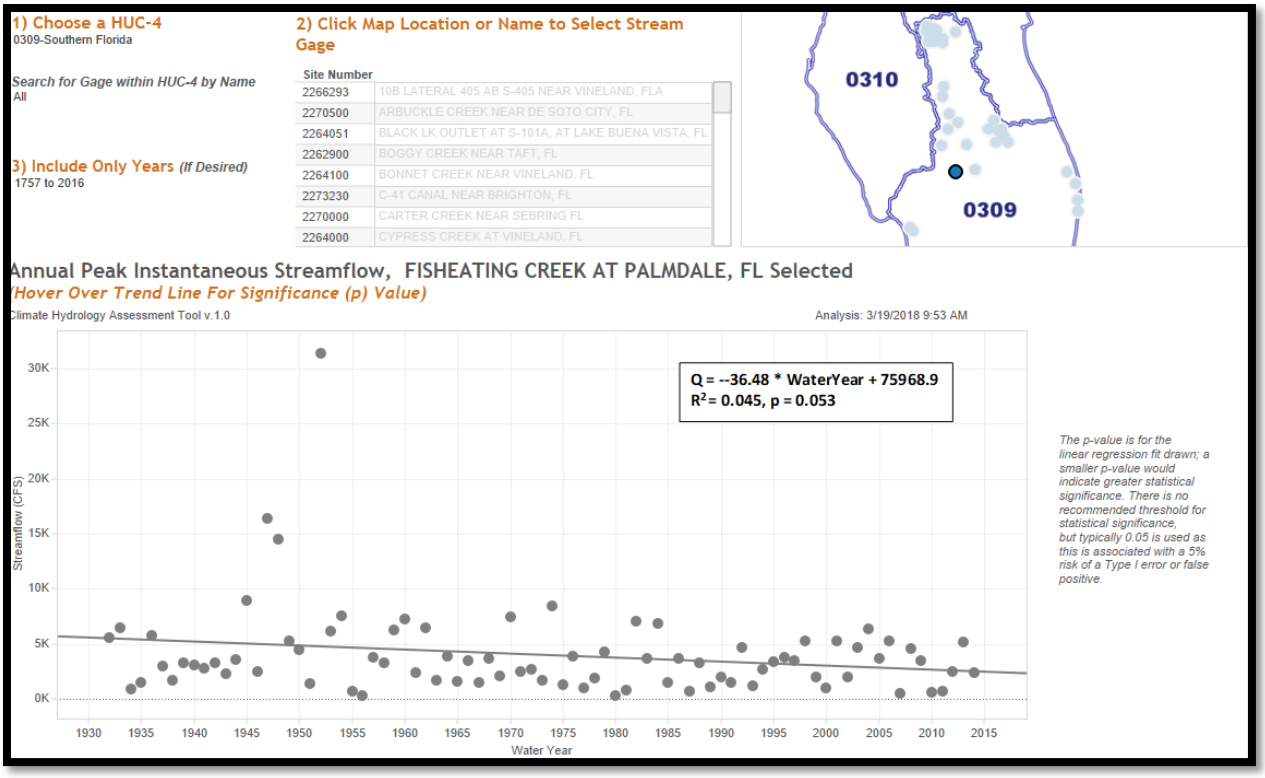


**Figure H-30. Climate Hydrology Assessment Tool output using annual instantaneous peak discharge at Fisheating Creek gauge; HUC04 Southern Florida Basin (HUC 0309).**

#### H.5.2.6.1.2 Projected Trends

Projected, future streamflow datasets are identified at a HUC04 watershed scale. The LOWRP project is located within the HUC04 southern Florida Basin 0309 (HUC 0309).

**Figure H-31** 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-31**. This range is representative of the uncertainty, such as future rainfall, evapotranspiration, and groundwater levels associated with climate-changed hydrology. Because of Florida's unique hydrology, with streamflow highly influenced by surface water and groundwater interactions, the uncertainty in projected streamflow is high.

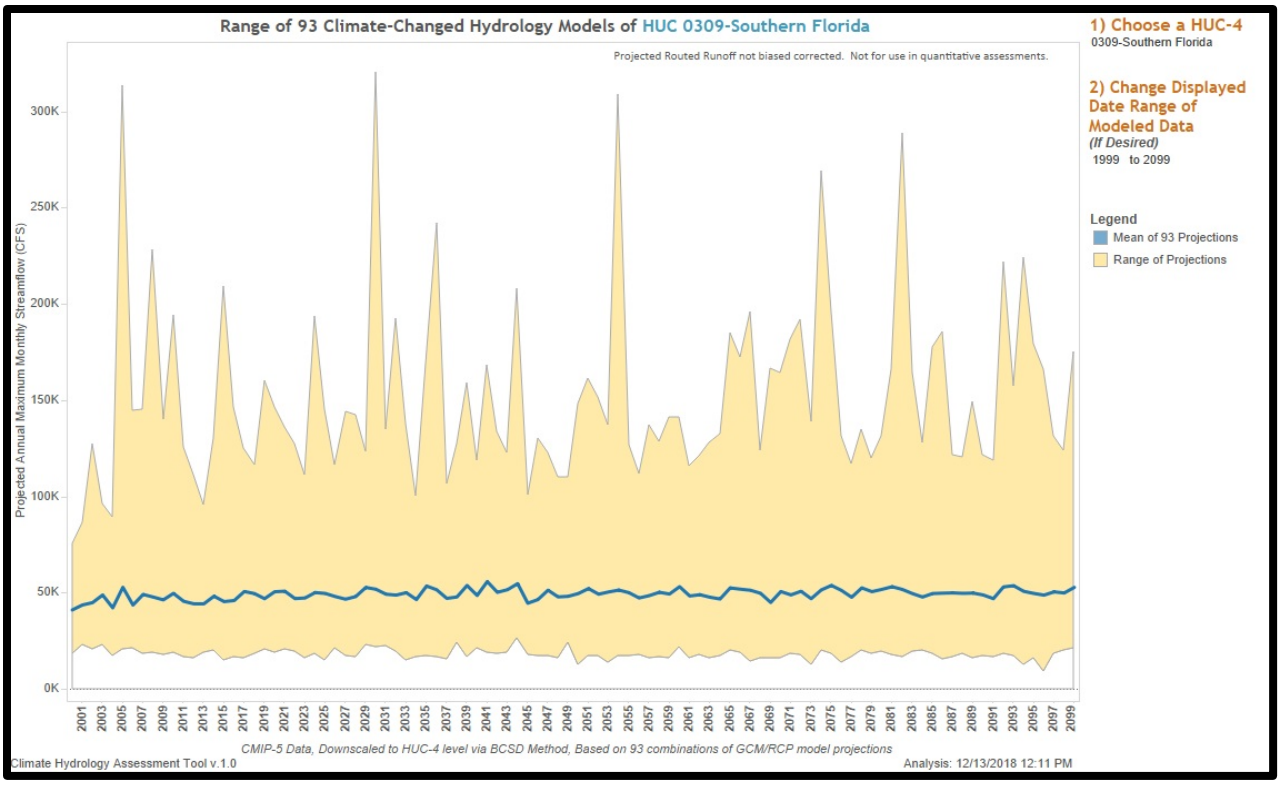


**Figure H-31. Range of projected annual maximum monthly streamflow in HUC04 Southern Florida Basin HUC 0309.**

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-32**). This increase is statistically significant (p-value < 0.05) and suggests the potential for future increases in streamflow relative to current conditions. This trend is not consistent with the literature as the literature projects no change in streamflow.

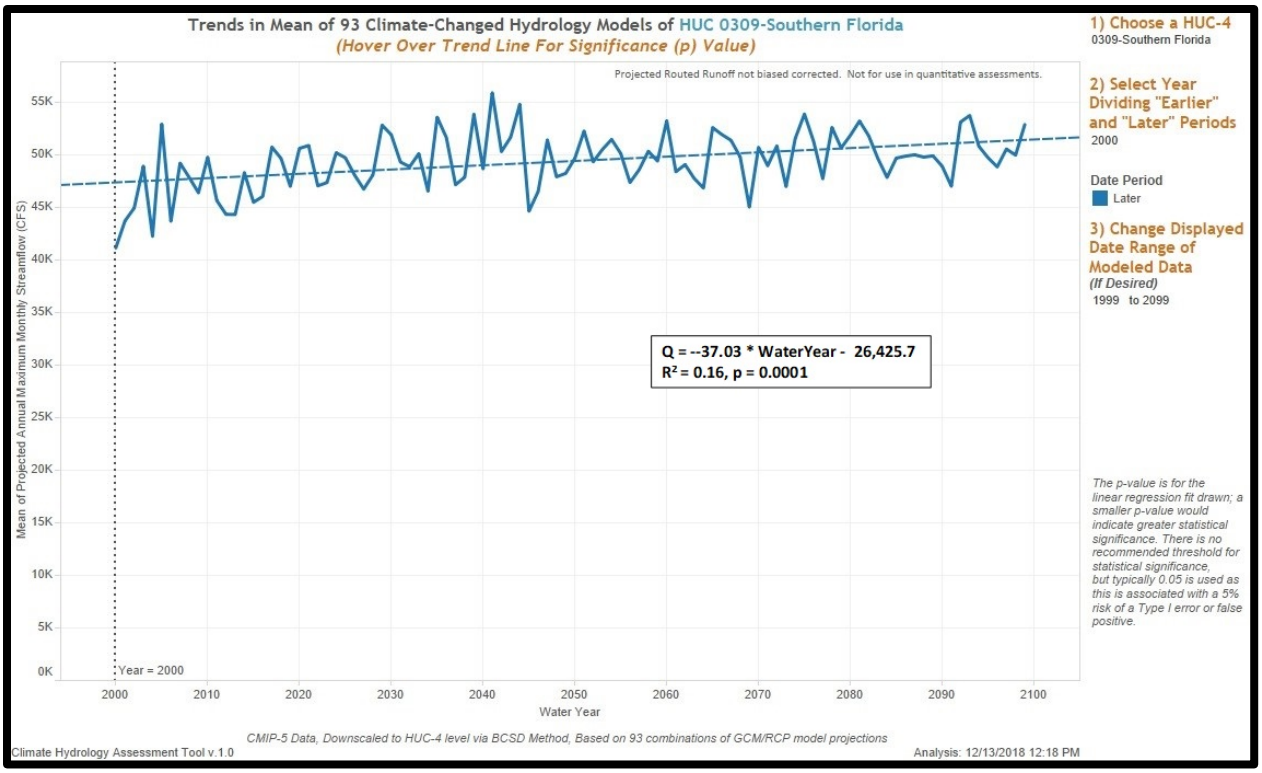


**Figure H-32. Trends in projected mean annual maximum monthly streamflow in HUC04 Southern Florida Basin (HUC04 0309.**

### H.5.2.6.2 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 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.

The relative strength of each nonstationarity is determined by considering the level of consensus between different statistical tests targeted at detecting the same type of nonstationarity (variance/standard deviation, mean, distribution) in the flow data sets (USACE, 2016d).

#### H.5.2.6.2.1 Detection of Nonstationarities in Observed Discharge Data

The NSD was utilized for the Fisheating Creek USGS gage 2256500 at Palmdale, FL 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. Similar to the CHAT analysis, the Fisheating Creek gage was selected because it has the longest unregulated period of record of any streamflow gage within the Lake Okeechobee watershed. 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-33** shows the results from the tool's period of record 1932-2014. The statistical methods collectively identified nonstationarities in two different years: 1953 and 1963, for the period of record 1932-2014. The nonstationarities were identified using the Energy Divisive Method for 1963 and the Lombard Wilcoxon Method for 1953. The Energy Divisive Method detected a change in the underlying distribution of the data. The Lombard Wilcoxon Method detected a change in the average value, or mean, of the data. None of the statistical methods detected abrupt or smooth changes in 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, neither the 1953 nor 1963 event is considered a strong change point. They do not meet the criteria for consensus, robustness, and magnitude, and are not considered statistically significant.

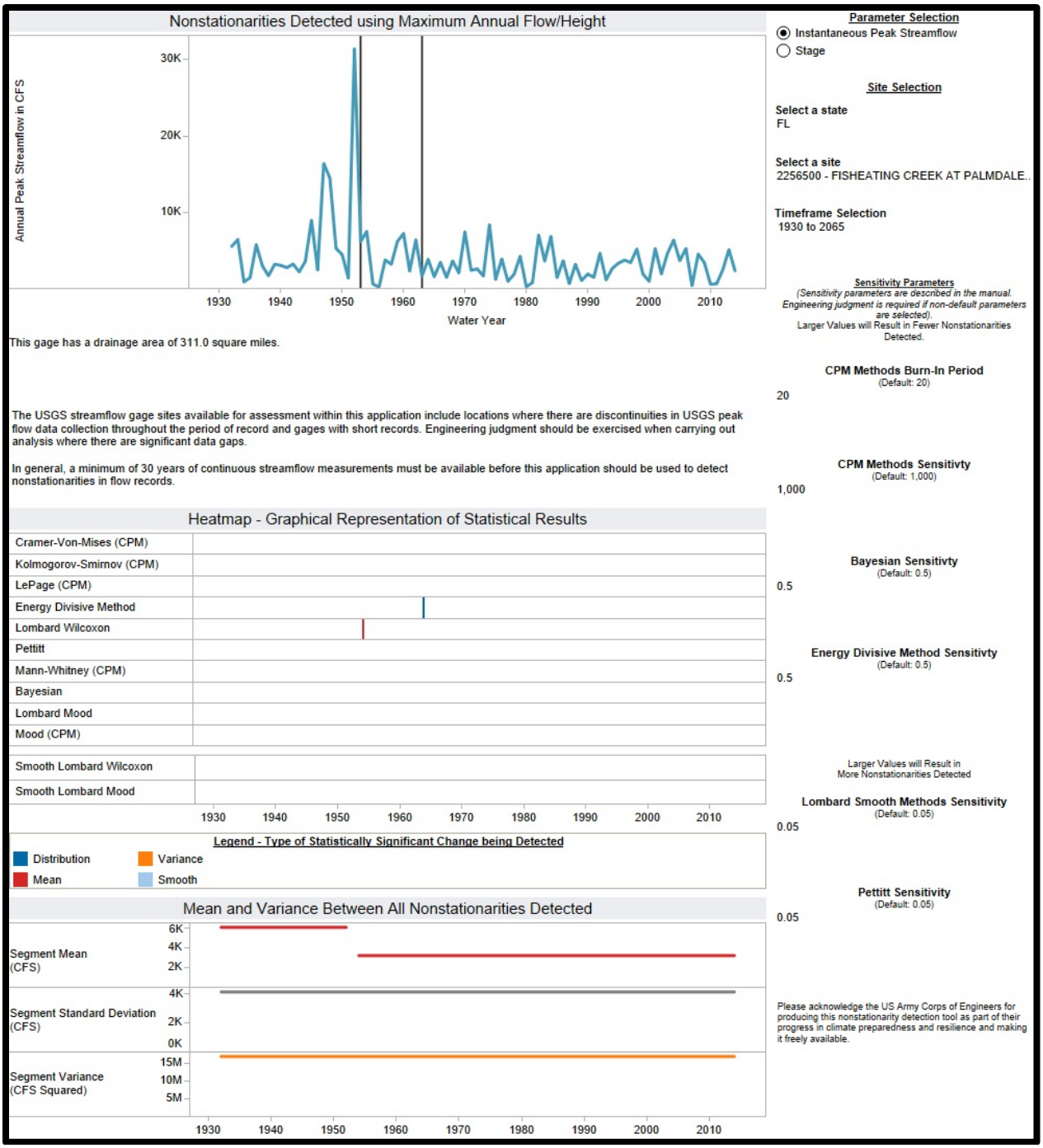


**Figure H-33. Output from Nonstationarity Detection tool – Fisheating Creek at Palmdale.**

### H.5.2.6.2.2 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 statistically significant 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 1932-2014 was assessed.

**Figure H-34** shows a monotonic trend analysis using the Mann-Kendall Test and Spearman Rank Order test for time period 1932-2014. No statistically significant trend in annual peak streamflow was detected for the period of record.

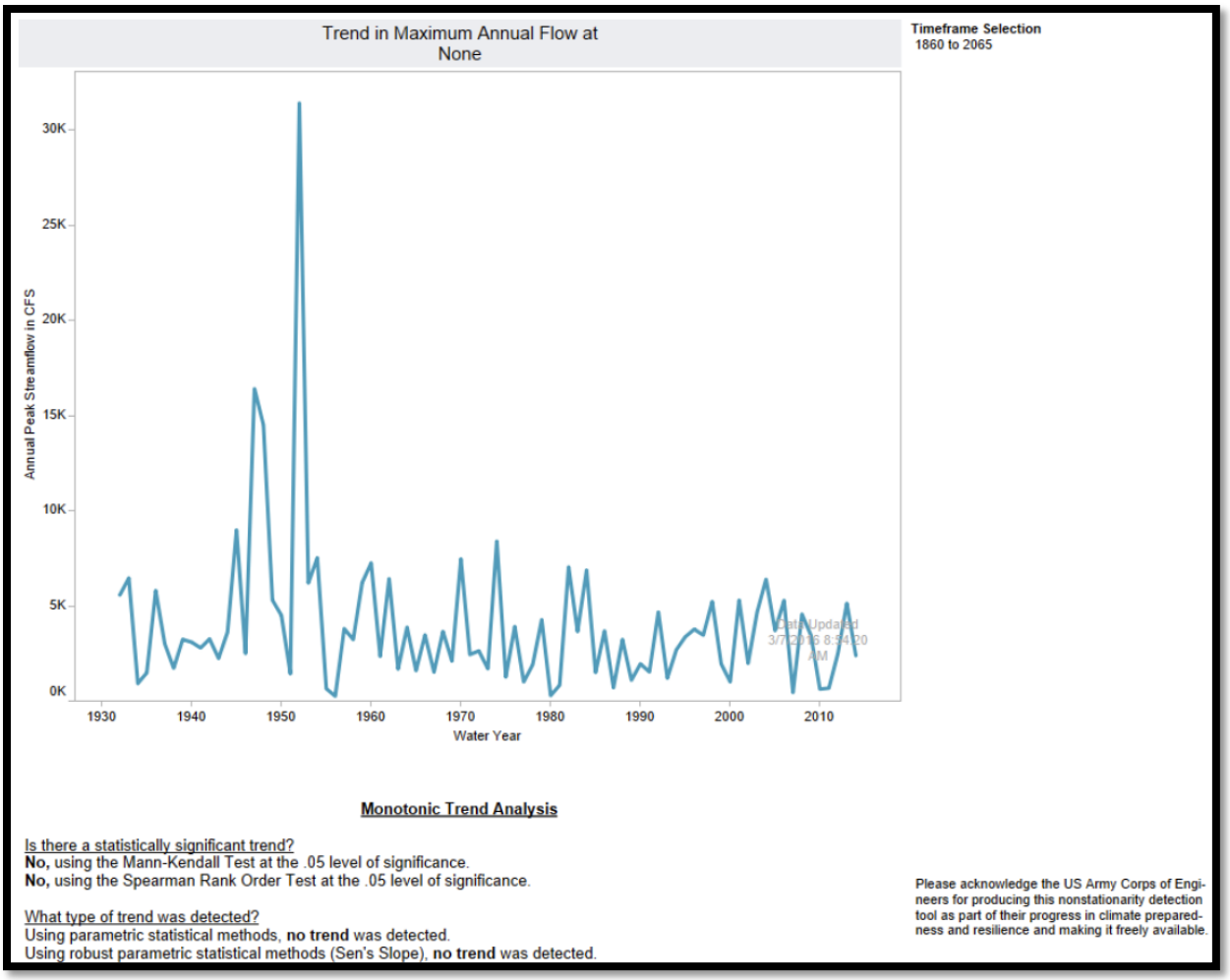


**Figure H-34. Monotonic trend analysis results.**

### H.5.2.6.3 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) where some datasets are often very large. 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 flow (e.g.

precipitation) or if the NSD does not have a gauge in close proximity to the project area. The time-series toolbox was not used for this project as a flow gauge was identified and evaluated in the NSD.

#### H.5.2.6.4 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 200 watersheds within the contiguous United States and to each of the USACE business lines. The Weighted Order Weighted Average (WOWA) method is used to aggregate individual vulnerability indicators and their associated datasets into the watershed-scale vulnerability scores. The WOWA score combines indicators using a weighting technique to control how much an indicator with a small value can average out an indicator with a large value, thereby affecting perceived vulnerability. 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).

The VA Tool examines the vulnerability of projects within all the USACE business lines using data for two scenarios and three epochs. The epochs include the current time period as the base period and two future 30-year periods centered on the years 2050 (2035-2065) and 2085 (2070-2099). Within each future epoch, GCMs are sorted by cumulative runoff projections and divided into two equal-sized groups that represent a Dry scenario and a Wet scenario. All results are thus given for each combination of scenario and future epoch: Dry-2050, Dry-2085, Wet-2050, and Wet-2085. The VA Tool allows the user to explore dominant indicators and summarize vulnerability in several different ways for each scenario/epoch combination. The current study will use the VA Tool to perform such an analysis on southern Florida (HUC 0309), which includes the LOWRP project, with emphasis on the indicators of vulnerability for the primary business line, Flood Risk Reduction. Additional analysis was also performed relative to the project's secondary business line, Emergency Management. It is recognized that other of the USACE business lines such as Ecosystem Restoration are important to the project, however, Flood Risk Reduction and Emergency Management are the only business lines with indicators that drive vulnerability within the VA Tool (USACE, 2016e).

**Table H-3** provides the number and name of selected indicators for the Flood Risk Reduction business line within the Vulnerability Assessment Tool within a National Standard View, along with a brief description of each.

**Table H-3. Number, name, and description of selected indicators for the Flood Risk Reduction Business Line within the Vulnerability Assessment Tool.**

| Number | Name | Description |
|---|---|---|
| 175C | ANNUAL_COV | Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative). |
| 277 | RUNOFF_PRECIP | Percent change in runoff divided by percent change in precipitation. |
| 568C | FLOOD_MAGNIFICATION | Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period. |

| Number | Name | Description |
|---|---|---|
| 568L | FLOOD_MAGNIFICATION | Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period. |
| 590 | 90PERC_EXCEEDANCE | Acres of urban area within 500-year floodplain. |

To set the context of this watershed nationally, within the USACE South Atlantic Division (SAD), and within the Jacksonville District (SAJ), **Table H-4** 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. Vulnerability of the Flood Risk Reduction business line within HUC 0309 for the Dry scenarios appears to be ranked near the top in all cases; in fact, HUC 0309 is ranked highest within its district and division. 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-35** 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%). These results suggest that climate change impacts must be considered in the planning and design of flood risk reduction within HUC 0309, including the LOWRP.

**Table H-4. 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 |

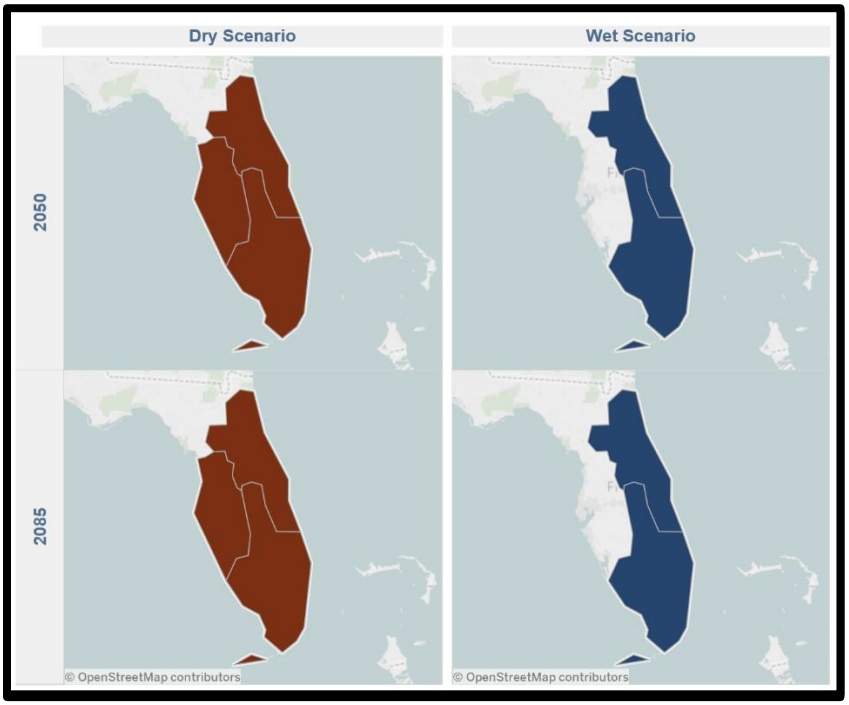


**Figure H-35. SAD watersheds identified as vulnerable for the Flood Risk Reduction business line for all scenario-epoch combinations (Dry-2050, Dry-2085, Wet-2050, and Wet-2085).**

The next step of the vulnerability assessment is to understand which indicators drive the vulnerability of the LOWRP in HUC 0309 in terms of the Flood Risk Reduction business line and how their individual values are projected to change between epochs. **Table H-5** provides the absolute values of each indicator for both scenarios and epochs, along with their percent contribution to the overall vulnerability score of each scenario-epoch combination. The indicator that dominates vulnerability in both scenarios is Indicator #590 (area of the 500-year floodplain), which contributes near 61% for both epochs in the Dry scenario and near 57% for both epochs in the Wet scenario. See **Table H-3** for more detailed indicator definitions. Note that, in all cases, Indicators #568C and #568L have values greater than 1 (1.03 and 1.02 in the Dry scenario and 1.28 and 1.27 in the Wet scenario for the 2050 and 2085 epochs, respectively), which indicates positive increases in future flood flows for both the dry and wet scenarios.

**Table H-5. The values/percent contribution to vulnerability of each indicator associated with the Flood Risk Reduction business line for all scenario-epoch combinations along with the percent change between epochs for each scenario.**

| Number | Dry-2050 | Dry-2085 | Percent Change | Wet-2050 | Wet-2085 | Percent Change |
|---|---|---|---|---|---|---|
| 175C | 0.34/2.97 | 0.33/2.86 | -2.21 | 0.31/2.58 | 0.32/2.63 | 4.47 |
| 277 | 2.00/10.65 | 1.99/10.44 | -0.62 | 2.04/6.57 | 2.12/6.60 | 3.99 |
| 568C | 1.03/19.45 | 1.02/19.98 | -0.78 | 1.28/22.63 | 1.27/22.07 | -0.66 |

| Number | Dry-2050 | Dry-2085 | Percent Change | Wet-2050 | Wet-2085 | Percent Change |
|---|---|---|---|---|---|---|
| 568L | 1.03/6.38 | 1.02/6.23 | -0.78 | 1.28/11.44 | 1.27/11.15 | -0.66 |
| 590 | 687.6/60.55 | 849.4/61.48 | 23.54 | 687.6/56.78 | 849.4/57.54 | 23.54 |

Indicator #590 suggests that consideration should be given to devising the steps in the planning and design phases of the LOWRP project that will reduce the vulnerability of the project to a growing urban 500-year floodplain.

The 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. Flood Risk Reduction and Emergency Management are the only business lines with indicators that drive vulnerability within the VA Tool (USACE, 2016e).There are, however, other business lines that may be impacted by changes in climate variables in central and south Florida: Ecosystem Restoration, Navigation, Water Supply, and Recreation. **Figure H-36** summarizes the projected climate trends and impacts on each of the USACE business lines (USACE, 2015a).

| CLIMATE VARIABLE | VULNERABILITY |
|---|---|
| Increased Ambient Temperatures | Increased ambient air temperatures throughout the century, and over the next century are expected to create the following vulnerabilities on the business lines in the region:<br>• Loss of vegetation from increased periods of drought and reduced streamflows may have impacts on vegetation within the region, which is important for sediment stabilization in the watershed. Loss of non-drought resistant vegetation may result in an increase in sediment loading, potentially causing geomorphic changes in the tributaries to the river system.<br>• Decrease in flows may result from periods of drought and reduced streamflow has implications for maintain water levels in the rivers.<br>• Risk of wildfires during hot and dry conditions may cause an increased risk of wildfires, especially in heavily forested and dry areas. Flora and fauna that are not drought resistant can also be impacted by longer drought conditions, which may reduce opportunities for recreational wildlife viewing.<br>**BUSINESS LINES IMPACTED:** |
| Increased Maximum Temperatures | Air temperatures are expected to increase 2-4°C in the latter half of the 21st century, especially in the summer months. This is expected to create the following vulnerabilities on business lines in the region:<br>• Increased water temperatures leading to water quality concerns, particularly for the dissolved oxygen (DO) levels, growth of nuisance algal blooms and influence wildlife and supporting food supplies.<br>• Increased evapotranspiration.<br>• Human health risk increases from extended heat waves, impacting recreational visitors and increasing the need for emergency management.<br>**BUSINESS LINES IMPACTED:** |
| Increased Storm Intensity and Frequency | Extreme storm events may become more intense and frequent over the coming century which are expected to influence the following vulnerabilities on business lines in the region:<br>• Increased flows and runoff, which may carry pollutants to receiving water bodies, decreasing water quality.<br>• Increased erosion with subsequent changes in sediment accumulation rates and creating water quality concerns.<br>• Increased groundwater recharge rates, as residence times are shortened within areas where evapotranspiration takes place during high intensity events.<br>• Increased flooding, which may have negative consequences for all infrastructure, habitats, and people in the area.<br>**BUSINESS LINES IMPACTED:** |
| Sea Level Rise | Sea level rise may exacerbate saltwater intrusion into fresh water supplies.<br>**BUSINESS LINES IMPACTED:** |

*NOTE: The Regulatory and Military Program business lines may be impacted by all climate variables*

= Navigation = Flood Risk Management = Ecosystem Restoration = Hydropower = Recreation = Water Supply = Emergency Management

**Figure H-36. Summary of projected climate trends and impacts on the USACE business lines (USACE, 2015a).**

### H.5.3 Phase III: Risk Assessment

The Phase II vulnerability assessment results indicate that the project is located in a relatively vulnerable watershed. There are some observed and projected climate trends evident based on the literature review and the statistical analysis conducted using the hydrologic tools. The watershed is most vulnerable to increases in extreme storm frequency and intensity, and increases in air temperature. There is statistical evidence that suggests the potential for future increases in streamflow relative to current conditions; however, no significant nonstationarities were detected for observed flow records.

The vulnerability assessment tool identified the USACE Flood Risk Management Business line as the most vulnerable. There are however other business lines that may be impacted by changes in climate variables. These changes could have an impact on Ecosystem Restoration, Navigation, Water Supply, Recreation, and Emergency Management business lines in central and south Florida.

Per guidance in ECB 2018-14, **Table H-6** identifies risk resulting from changed climate conditions in the future. The table shows the major project feature, 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 qualitative assessment of the likelihood and uncertainty of this harm. Note that not all impacts of climate change will result in increased risk, as there may be project benefits.

Increases in extreme storm frequency and intensity and increases in temperatures present risks to the project features. Increased precipitation may lead to increased flows and larger flood volumes and potential risk to the project's levees and higher likelihood of increased freshwater discharges to the estuaries. Increased temperatures may lead to decreased flows, drought, reduced benefits to Lake Okeechobee and restored wetlands, and cutbacks in Lake Okeechobee water supply.

Based on the vulnerability assessment, it is recommended that the project account for risk in climate change by including resiliency and adaptation measures in the project design to account for the risk associated with the impact of climate change for the duration of the project life cycle. This includes the design and operations 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. However, for the planning phase, climate change and resilience are incorporated in the risk register of the project and conservative assumptions have been considered during planning level design.

**Table H-6. Risk assessment.**

| Feature or Measure | Trigger | Hazard | Harm | Qualitative Likelihood |
|---|---|---|---|---|
| Wetland Attenuation Feature (WAF) | 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 | Likely |
| Wetland Restoration | Increased extreme precipitation – may occur from increased tropical storm activity. | Future flood volumes may be larger than present. | Water may 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 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 and stages in Lake Okeechobee | Likely |

| Feature or Measure | Trigger | Hazard | Harm | Qualitative Likelihood |
|---|---|---|---|---|
| Wetland Attenuation Feature (WAF) | 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 vegetation and reducing project benefits; increased water temperatures lead to water quality concerns. | Likely |
| Wetland Restoration | 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; increased water temperatures lead to water quality concerns. | 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 Lake Okeechobee | Likely |
| Water Supply | Increased temperatures | Increased evapotranspiration or drought | Decrease in flows may increase water supply cutbacks from Lake Okeechobee due to low lake levels | Likely |
| Water Control Structures | 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 requires that all existing and planned studies evaluate climate change for inland hydrology and sea level if the project's elevation is less than 50 feet NAVD88.
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 1110-2-8162 using a USACE statistical tool that projects future SLR.
4) LOWRP is vulnerable to climate change and at risk over the project life cycle (2028-2128) due to the following factors: increasing air temperatures, increases in extreme storm frequency and intensity, increasing streamflow, and rising sea-level elevations.
5) The Lake Okeechobee S-79 and S-80 outlet structures are vulnerable to SLR when looking at the high SLC projection. Limitations to discharge for S-79 may be reduced with existing headwater conditions and the S-80 downstream area will be more susceptible to flooding of properties along the river before emptying into the estuary by 2067 and 2061, respectively. SLR does not affect the hydrologic boundaries governing the performance and operation of the LOWRP project features; however, benefits will change in the estuaries due to SLR.
6) Based on the vulnerability assessment, it is recommended that the project account for risk in climate change by including resiliency and adaptation measures in the project design to account for the risk associated with the impact of climate change for the duration of the project life cycle. This includes the design and operations to handle extreme wet and dry conditions, including floods and droughts. This will ensure that the selected plan is robust enough to accommodate changing climatic conditions. The VA Tool identified the USACE Flood Risk Management business line as the most vulnerable.
7) Currently, climate change has been incorporated into the project risks, design, and cost contingency. Resiliency and adaptive management, however, should be revisited during PED. Because of the complex interaction between the LOWRP project and the C&SF system, adaptations will need to be assessed for the C&SF system to address questions about the performance and operation of the LOWRP. The project team acknowledges an assessment of the C&SF system is outside of the LOWRP scope and that resiliency and adaptive management in LOWRP cannot be fully addressed without a comprehensive assessment of the larger C&SF system.
8) Although impacts to the project net benefits due to SLR have not been fully analyzed, preliminary qualitative analysis seems to indicate that the average annual net project benefits would be likely to be reduced in comparison to the projected average annual net project benefits estimated assuming no SLR.

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