APPENDIX H

COMBINED OPERATIONAL PLAN

HYDRAULICS & HYDROLOGY

ANNEX 9
CLIMATE CHANGE ASSESSMENT FOR THE COP

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H-9 Inland Hydrology Overview

The climate assessment for inland hydrology follows the USACE guidance of Engineering and Construction Bulletin (ECB) 2018-14, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects. ECB 2018-14 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*.

The vulnerability and risk to this project associated with inland hydrology climate change was assessed qualitatively as outlined in ECB 2018-14. In general, projects addressing climate change as part of an operational study are less comprehensive than projects evaluated at the Feasibility phase.

The vulnerability assessment includes a literature review and an application of climate tools to evaluate observed and projected climate trends.

H-9.1 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 1**.

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.

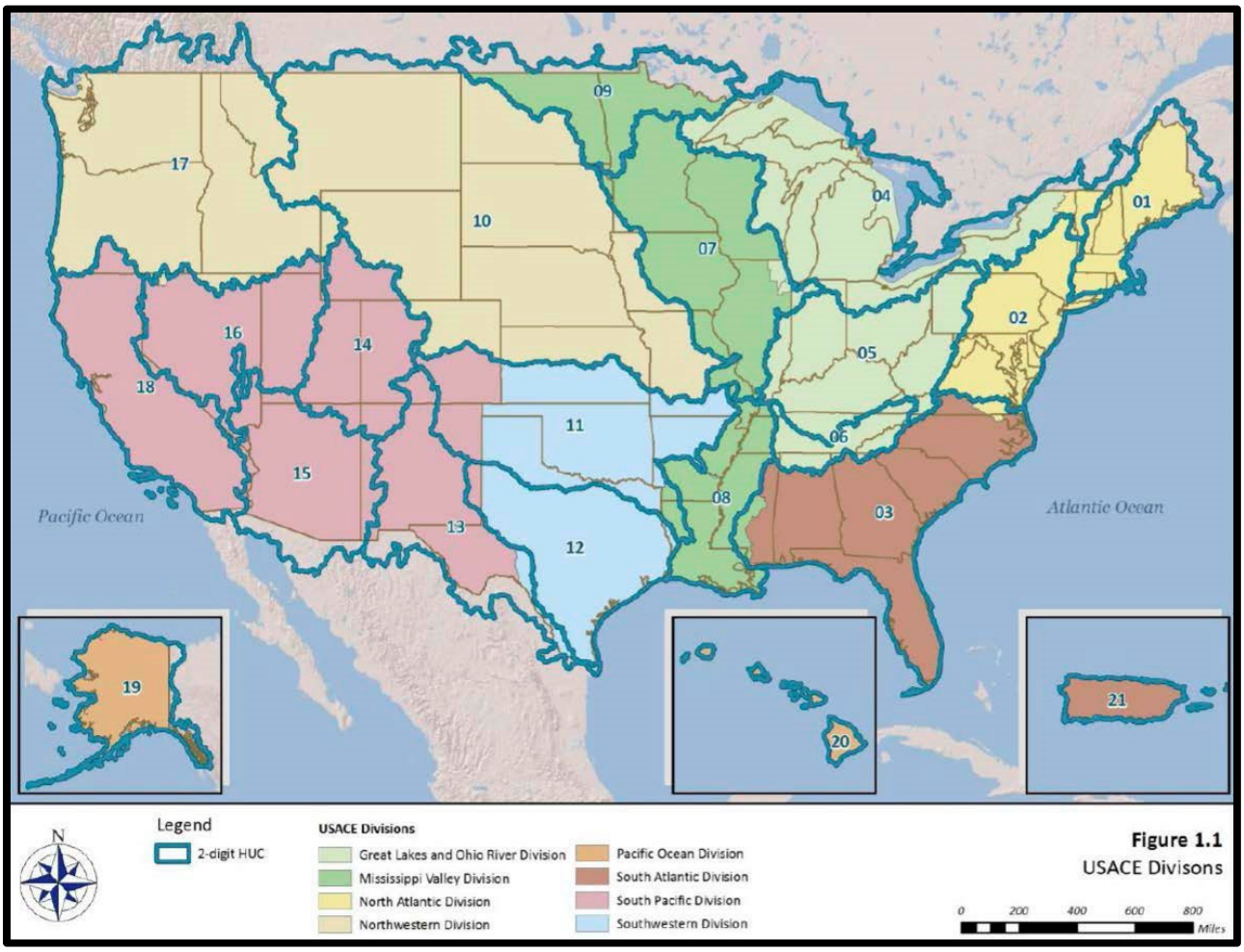

Figure 1. Map of 2-digit hydrologic unit code boundaries for the Continental United States, Alaska, Hawaii, and Puerto Rico (USACE, 2015a).

H-9.1.1 Literature Summary

The literature review summarizes available resources discussing observed and projected hydroclimatic trends in the project area. There is evidence of changes to global climate patterns that will likely have an impact on central and south Florida in terms of rainfall and air temperature. A summary of the literature reviewed as part of the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army*

Corps of Engineers Missions – South Atlantic-Gulf Region 03 is displayed in **Figure 2**. The figure represents observed and projected trends for climate variables in the South Atlantic-Gulf region which includes Florida. The literature however found an increasing number of one-day extreme maximum temperatures in Florida, whereas there was no overall observed maximum temperature trend for the South Atlantic-Gulf region.

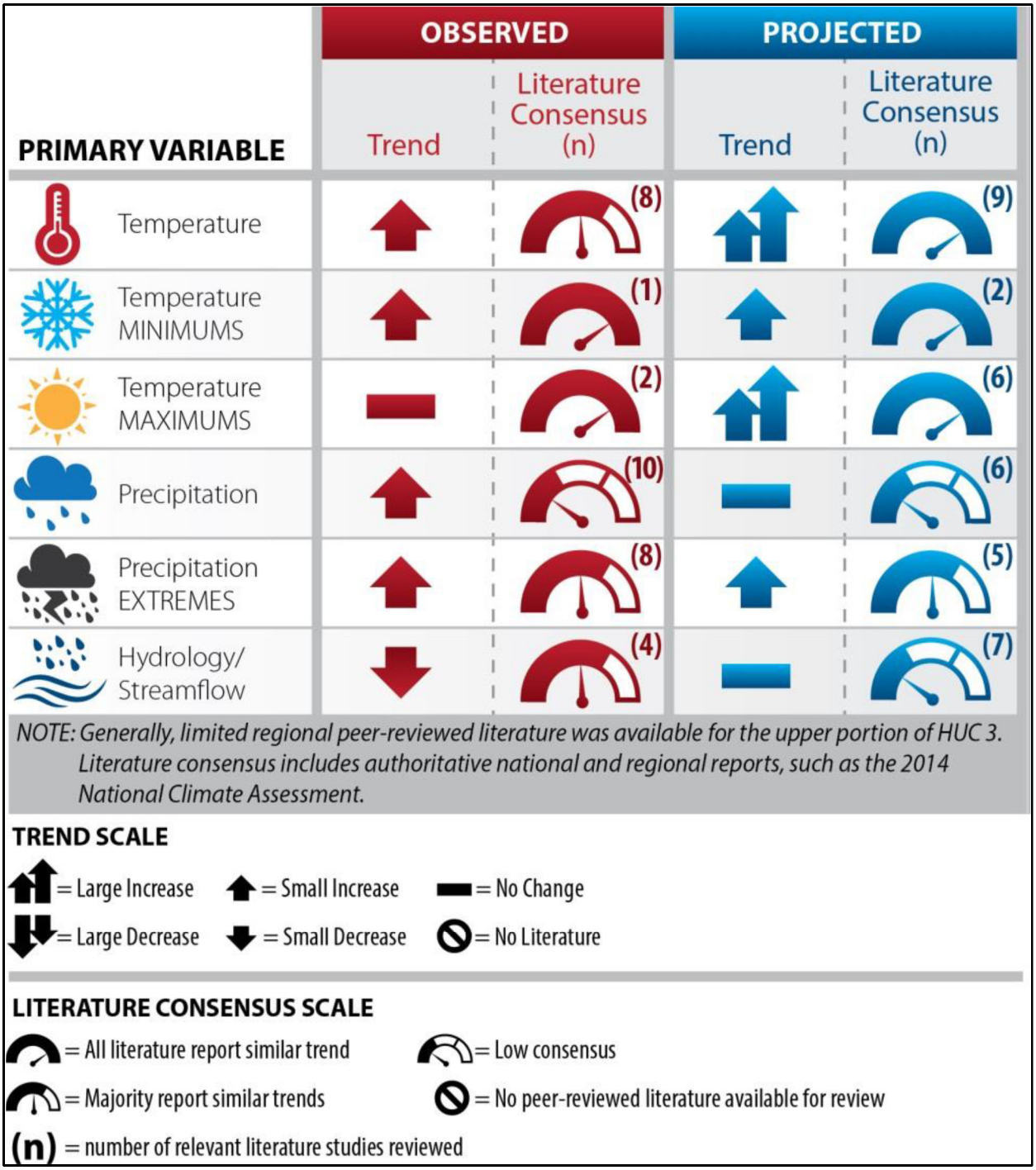

Figure 2. Summary Figure from USACE Literature Synopsis of South Atlantic-Gulf Region- 03

Based on the references reviewed, there is an overall increasing trend in observed, annual/seasonal air temperature, as well as temperature extremes. This literature review indicates that observed precipitation shows no discernible trends in annual/seasonal precipitation, but shows an increase in the frequency and intensity of extreme precipitation events. The annual frequency of hurricanes has remained relatively stable throughout the 20th and early 21st centuries; however, hurricane rainfall is expected to increase for Florida as the climate continues to warm. SFWMD data indicate that there has been an increase in heavy downpours in many parts of the region, while the percentage of the region experiencing moderate to severe drought increased over the past three decades. Rising air and water temperatures and in precipitation are intensifying droughts and increasing heavy downpours. No trend in observed streamflow was found. A summary of the observed trends can be found in **Table 1.**

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

Table 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)	Increase	Increase	Increase	Increase, but low consensus	Increase	Decreasing Trend, but low consensus
Climate Change Indicators in the United States (EPA, 2016)	Increase	Increase	Increase	No Trend	Increase	No Trend
Climate Science Special Report: Fourth National Climate Assessment, Volume I and II (USGCRP, 2017; USGCRP, 2018)	Increase	Increase	Increase	Decreases in Spring Precipitation & Increases in Winter Precipitation; no trend in summer or fall precipitation	Increase	No Trend
NOAA State Climate Summaries (Runkle et al., 2017)	Increase	Increase	No Trend	No Trend	No Trend	Not Addressed
USACE Jacksonville District studies	Not Addressed	Not Addressed	Not Addressed	No trend	Not Addressed	Not Addressed

Table 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)	Not Addressed	Not Addressed	Not Addressed	Not Addressed	Not Addressed	Not Addressed
Climate Science Special Report: Fourth National Climate Assessment, Volume I and II (USGCRP, 2017; USGCRP, 2018)	Increase	Increase	Increase	No Trend	Increase	No Trend
NOAA State Climate Summaries (Runkle et al., 2017)	Increase	Not Addressed	Increase	No Trend	Increase	Not Addressed
USACE Jacksonville District studies	Increase	Not Addressed	Not Addressed	Not Addressed	Increase	Not Addressed

H-9.1.2 Climate Tools

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

These tools provide information on historic trends in observed data:

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

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

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

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

H-9.1.2.1 Application of Climate Tools

The purpose of COP is to define the water management operations for the Water Conservation Area (WCA) 3A, WCA 3B, structures in the L-31N and the C-111 basins constructed as part of the C&SF project and the constructed components of the MWD and C-111 South Dade projects. The climate analysis focuses on peak flows because the purpose of the COP project is consistent with the original purposes of the C&SF project to provide flood control, water supply for agricultural irrigation, municipalities and industry. Because the C&SF system is highly regulated, other variables relevant to the study purpose, such as canal elevations and flow durations, are influenced by water management decisions. Peak streamflows also impact flood risk reduction and ecosystem restoration projects, making it important to the Flood Risk Reduction and Ecosystem Restoration USACE business lines.

Because the Fisheating Creek gauge (refer to map on **Figure 3**) has the longest unregulated period of record (see **Figure 4**) of any streamflow gauge within the central and south Florida region, 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 central and south Florida region, but these gauges were not selected because they are influenced by known man-made changes to basin hydrology that could affect the frequency and magnitude of flood flows and mask the impacts of climate change on the basin. Examples of readily identifiable factors that can induce trends in streamflow records include 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 with little change to land use, drainage, and flood control infrastructure.

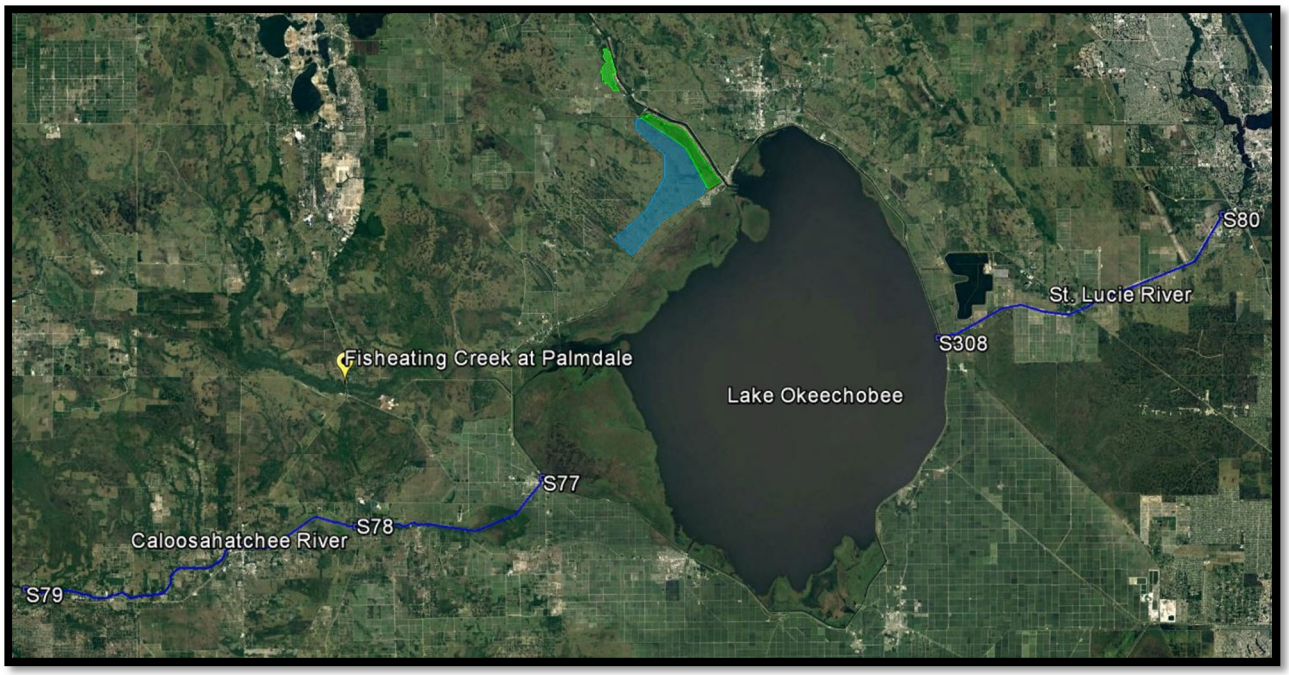

Figure 3. Location of the Fisheating Creek at Palmdale gauge.

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 4. Pertinent data from USGS for Fisheating Creek at Palmdale gauge 02256500.

H-9.1.2.2 Climate Hydrology Assessment Tool

The CHAT allows users to assess trends in both observed and projected streamflows. The CHAT tool supports consistent analyses by producing reliable, qualitative projections of climate changed hydrology for USACE projects. The CHAT projects future changes in annual maximum monthly streamflow using Global Circulation Model (GCM) outputs aggregated a watershed scale (HUC04). This is consistent with

the spatial and temporal precision of the downscaled GCM outputs converted into a climate changed hydrologic response. **Figure 5** shows the HUC04 basins for the South Atlantic-Gulf Region. The COP project is located within the southernmost basin in Florida.

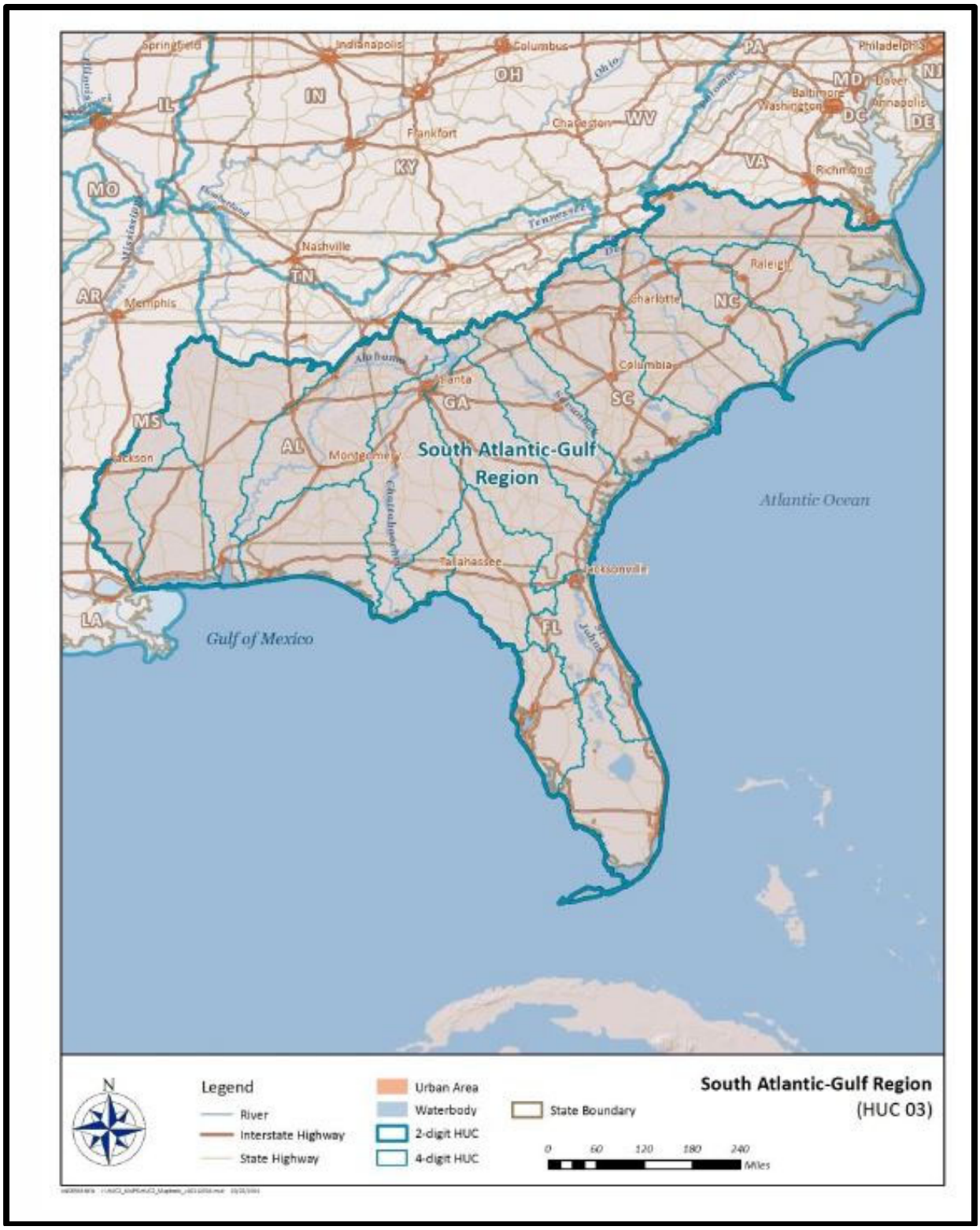

Figure 5. Water Resources Region 03: South Atlantic-Gulf Region boundary (USACE, 2015).

H-9.1.2.2.1 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.

The CHAT tool applies a linear regression analysis to the annual instantaneous peak discharges recorded at Fisheating Creek USGS gauge 2256500 at Palmdale, FL. The p-value associated with trendline is 0.053 in **Figure 6**, which is approximately the accepted threshold for significance of 0.05. This result shows evidence that there might be a decreasing trend in the historically observed peak flow data over the period of record from 1932-2014.

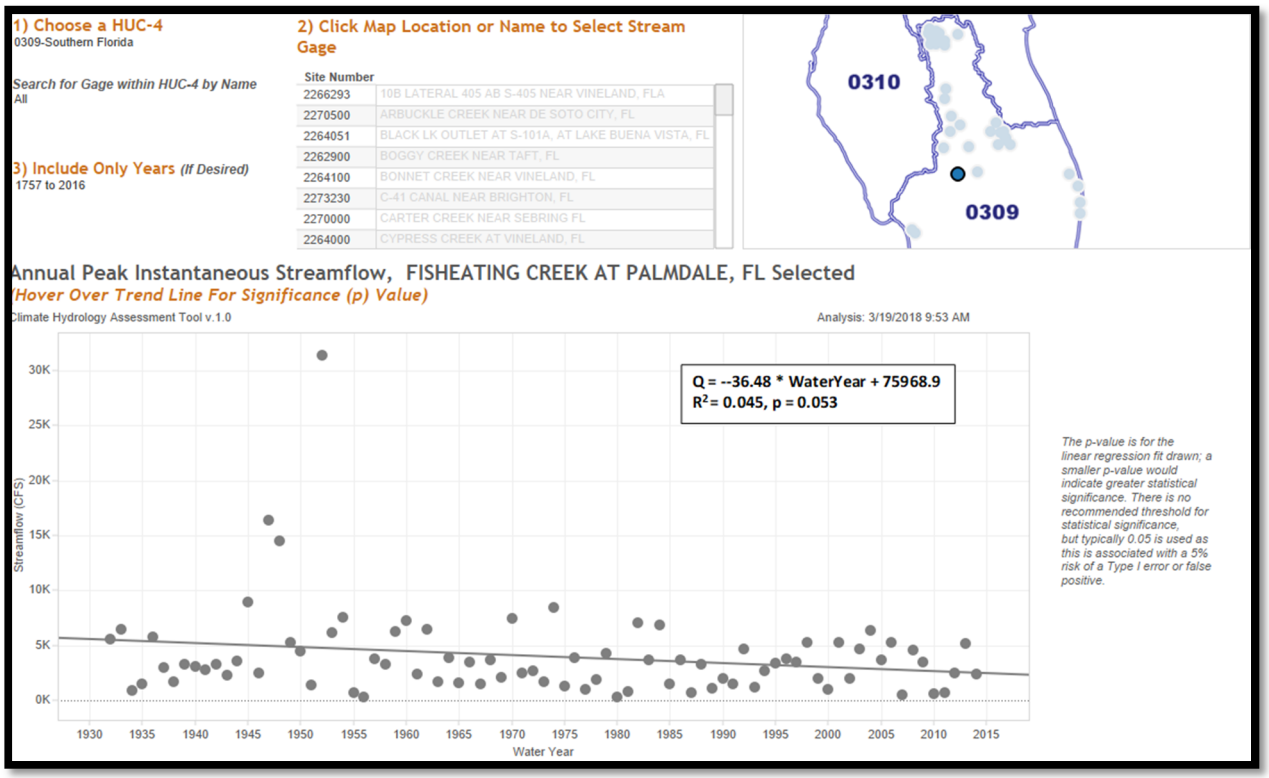

Figure 6. Climate Hydrology Assessment Tool output using annual instantaneous peak discharge at Fisheating Creek gauge; HUC04 Southern Florida Basin (HUC 0309).

H-9.1.2.2.2 Projected Trends

The CHAT present analysis of projected, future streamflow datasets at a HUC04 watershed scale. The COP project is located within the HUC04 southern Florida Basin 0309 (HUC 0309). **Figure 7** 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 7**. This range is representative of the uncertainty of many variables including error in temporal downscaling, error in spatial downscaling, errors in the hydrologic modeling, errors associated with emissions scenarios, and errors associated with GCMs themselves.

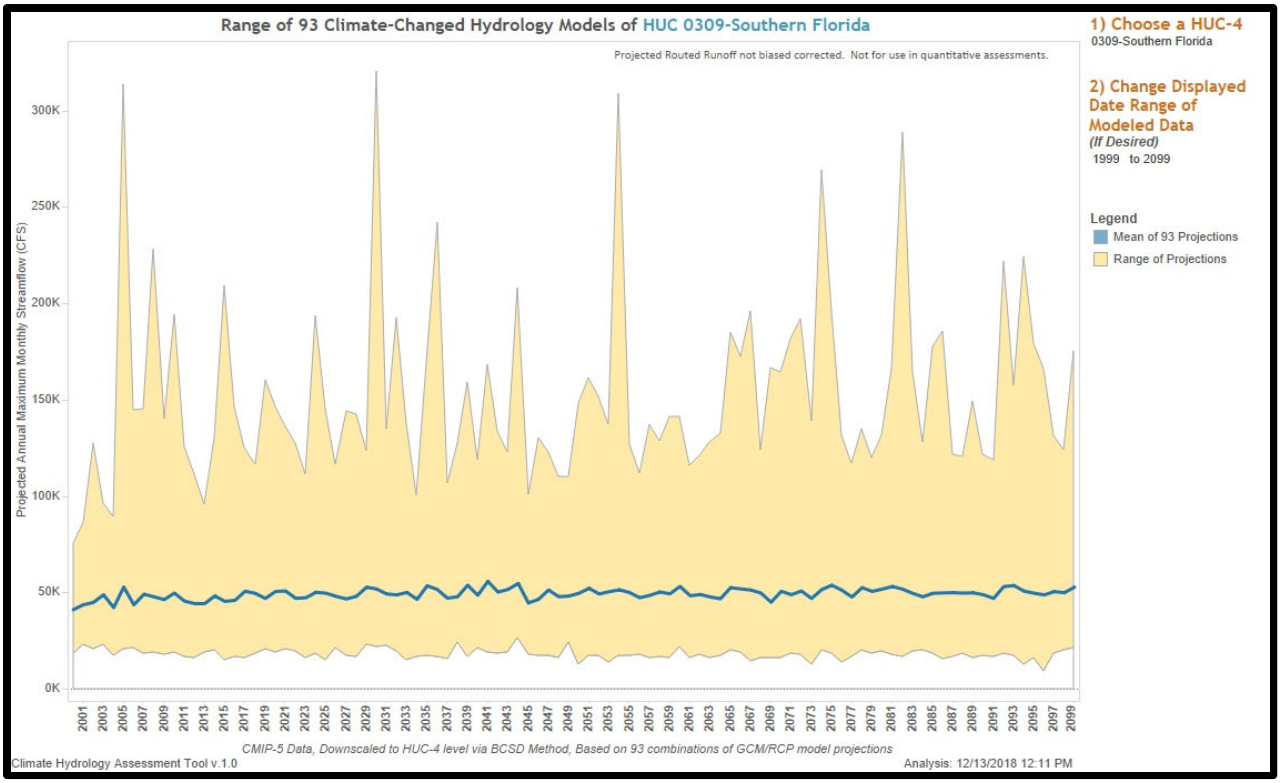

Figure 7. Range of projected annual maximum monthly streamflow in HUC04 Southern Florida Basin HUC 0309.

A statistical analysis of the projected hydrology for 2000-2099 indicates a statistically significant linear trend of increasing average annual maximum monthly flows (**Figure 8**). 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 an assessment of trends in observed annual peak streamflows or the literature. The literature points to no projected change in streamflow. Based on the analysis of observed, historic flows carried out as part of this study and the literature there isn't strong evidence of a trend in historic flows. There is only some evidence of a decreasing trend in streamflow, but there is not a great deal of consensus or statistical significance associated with this trend.

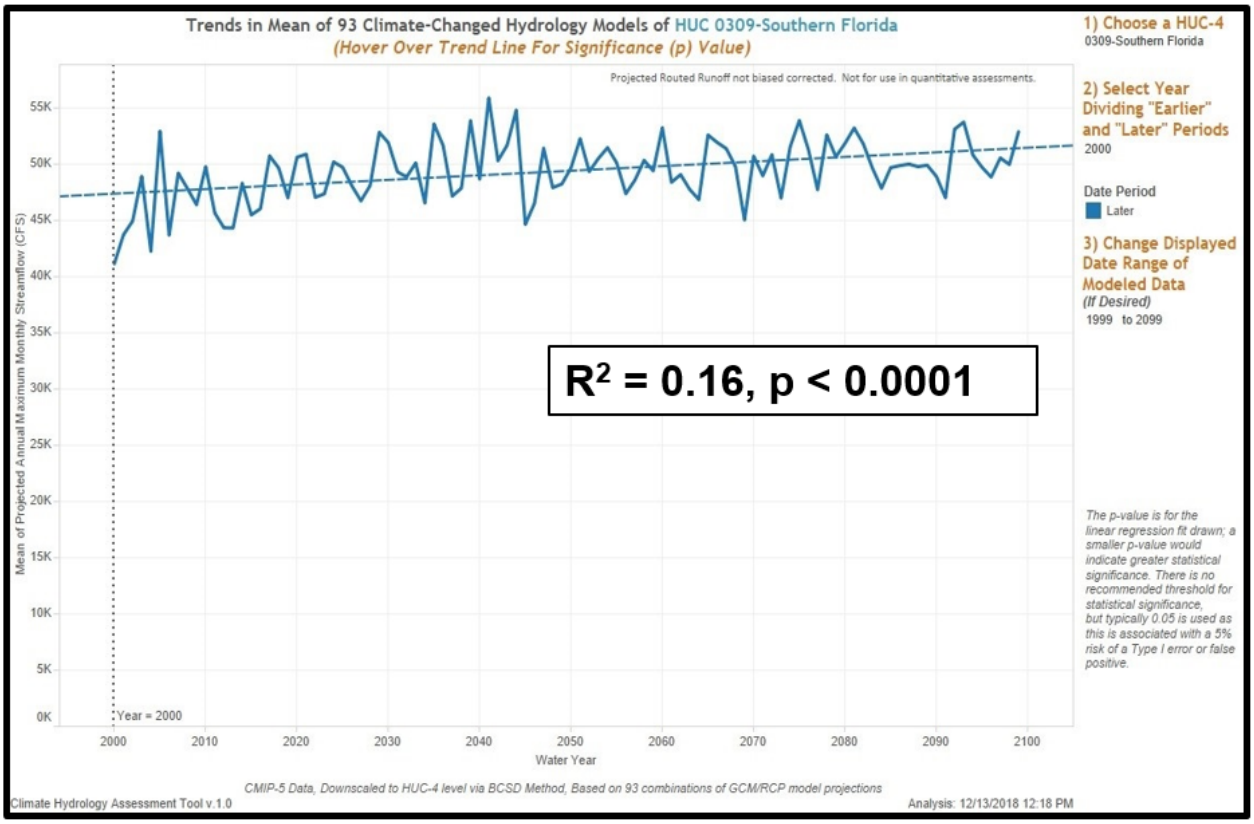

Figure 8. Trends in projected mean annual maximum monthly streamflow in HUC04 Southern Florida Basin (HUC04 0309).

H-9.1.2.3 Nonstationarity Detection Tool

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

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

Nonstationarities are identified when the statistical characteristics of a hydrologic data series are not constant through time. The NSD, however, is not a substitute for engineering judgment. Engineers are

advised to use their judgment to consider the resilience of the system when incorporating the range of results in the hydrologic study or design results (USACE, 2016d).

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

H-9.1.2.3.1 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.

Figure 9 shows the results from the tool applied to the period of record available at the Fisheating Creek gage: 1932-2014. The tool's default sensitivity parameters were applied to evaluate the stationarity of the streamflow record. The statistical methods collectively identified nonstationarities in two different years: 1953 and 1963. 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.

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

Based on these criteria, there is not enough strong evidence of statistical non-homogeneity in either the 1953 or 1963 event to warrant consideration within the decision making process. Because the detected nonstationarities are only indicated by a single test they do not meet the criteria of consensus, robustness, and magnitude, and are not considered strong, operationally significant nonstationarities.

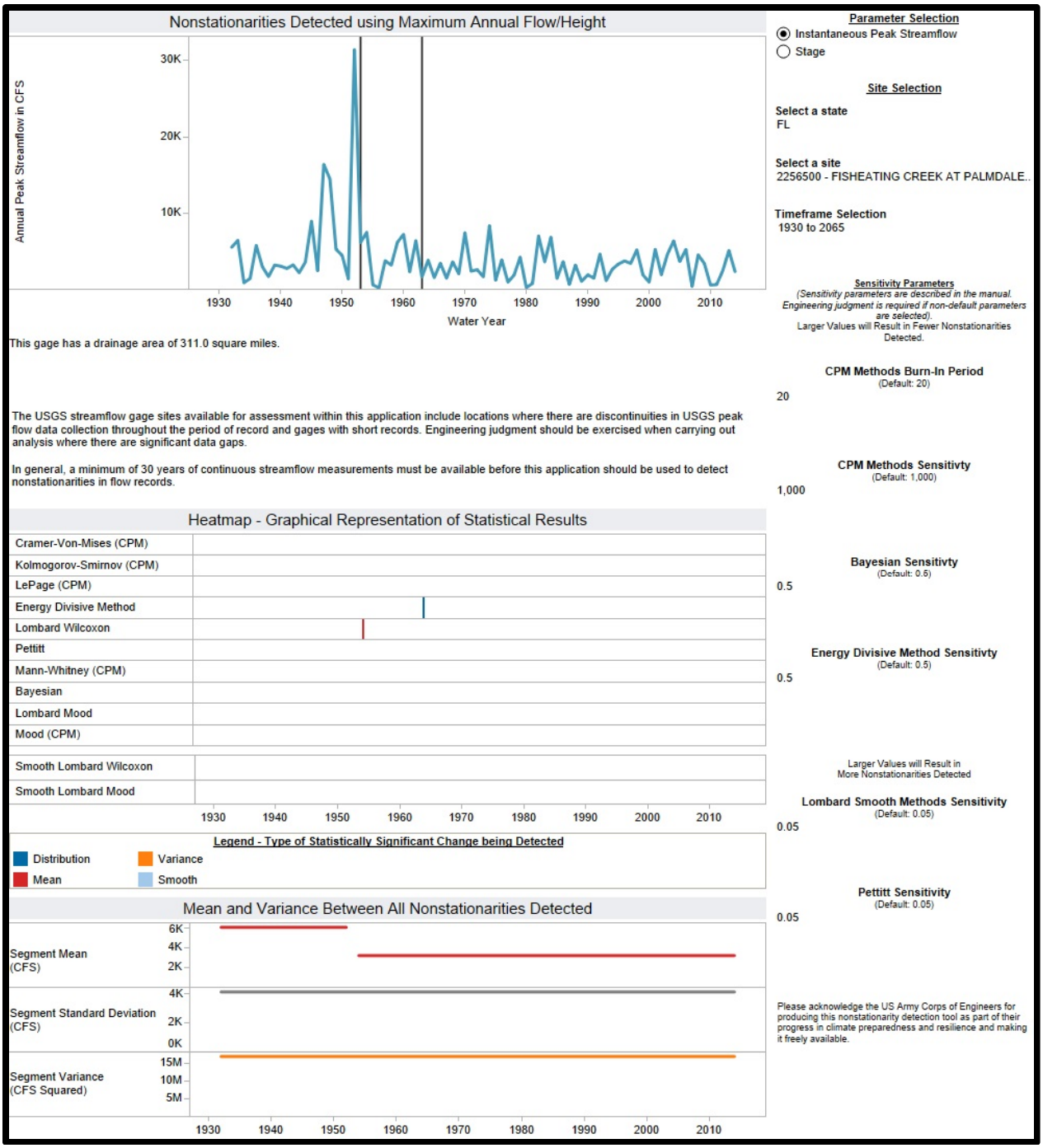

Figure 9. Output from Nonstationarity Detection tool – Fisheating Creek at Palmdale.

H-9.1.2.3.2 Monotonic Trend Analysis

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

monotonic trends. Because the nonstationarities identified are not considered operationally significant, the entire period of record of 1932-2014 was assessed.

Figure 10 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.

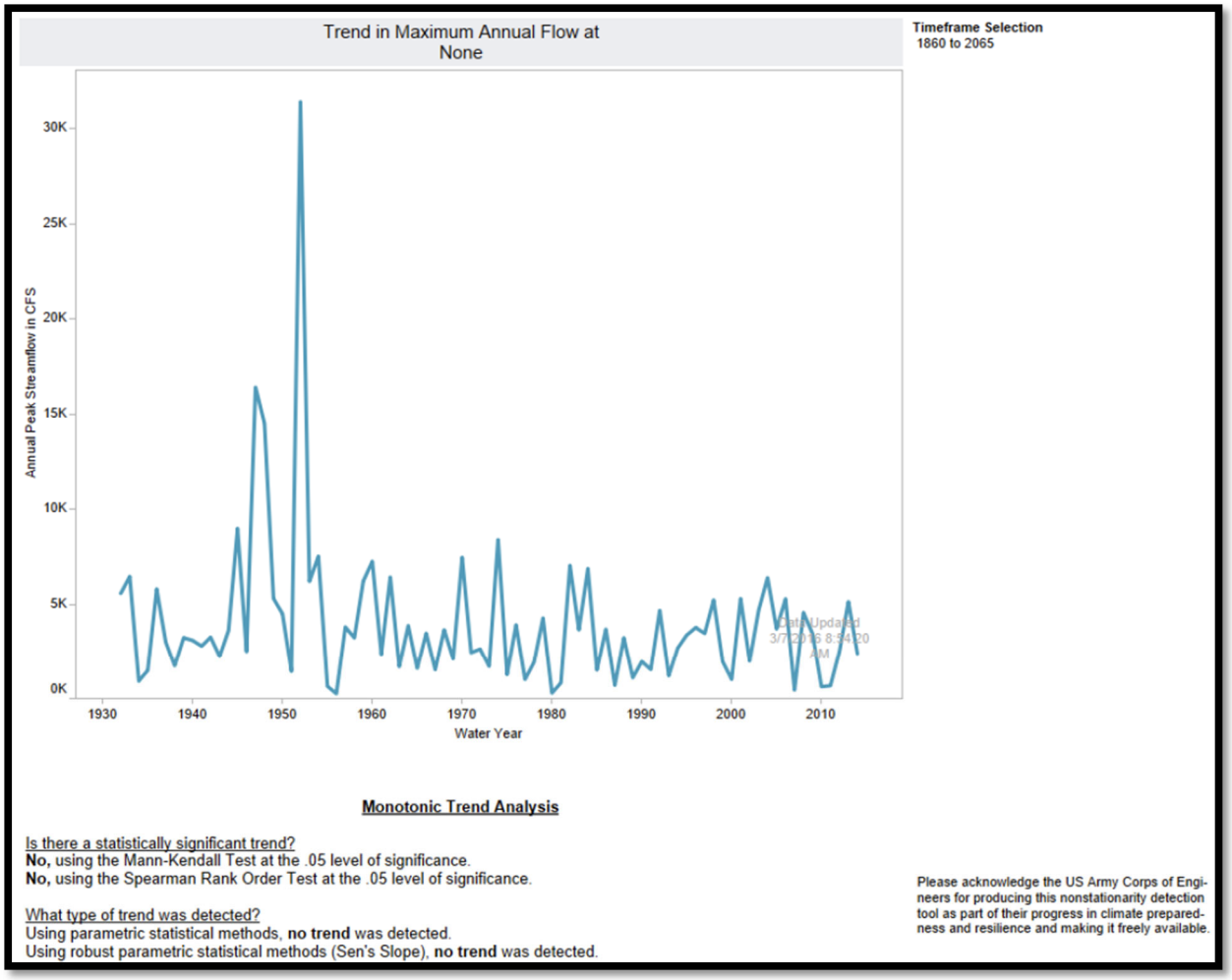

Figure 10. Monotonic trend analysis results.

H-9.1.2.4 Time-Series Toolbox

The Time-Series Toolbox application was developed by the USACE to address the need for multiple types of analytical methods for time series data analysis. Climate-related data can come from a variety of sources (e.g. streamflow, water levels, tide gauge data, precipitation data). The Time-Series Toolbox provides the user with automated data pre-processing and works to standardize and streamline common approaches to time series analysis by performing trend analysis and nonstationarity detection for user-supplied datasets. A common use for the Time-Series Toolbox is to use it in place of the NSD when a climate assessment is needed for a climate variable other than peak flow (e.g. precipitation) or if there is

an interest in analyzing an unregulated dataset. The time-series toolbox was evaluated for a precipitation gauge located near the project as an alternative option to assessing nonstationarity of streamflow. As discussed previously, streamflow in the region is typically impacted by highly regulated water control operations and therefore difficult to assess unregulated trends in the data.

A nonstationarity analysis was performed using daily precipitation data from the NP-206 precipitation gauge located in the project area. The Time Series Toolbox uses statistical testing to detect the presence of nonstationarities in the data. These tests examine the data for nonstationarities (or changes) in the data mean, variance, or distribution. **Figure 11** shows the nonstationarity results using rainfall from the period of record 1985-2016. The precipitation dataset utilized for this analysis contains the longest period of record of any rain gauge located within the project area and therefore is assumed to be the most representative dataset for this analysis.

The statistical methods collectively did not identify any nonstationarities within the period of record 1985-2016. Based on these results, there is not enough strong evidence of statistical non-homogeneity in the period of record to warrant consideration within the decision making process.

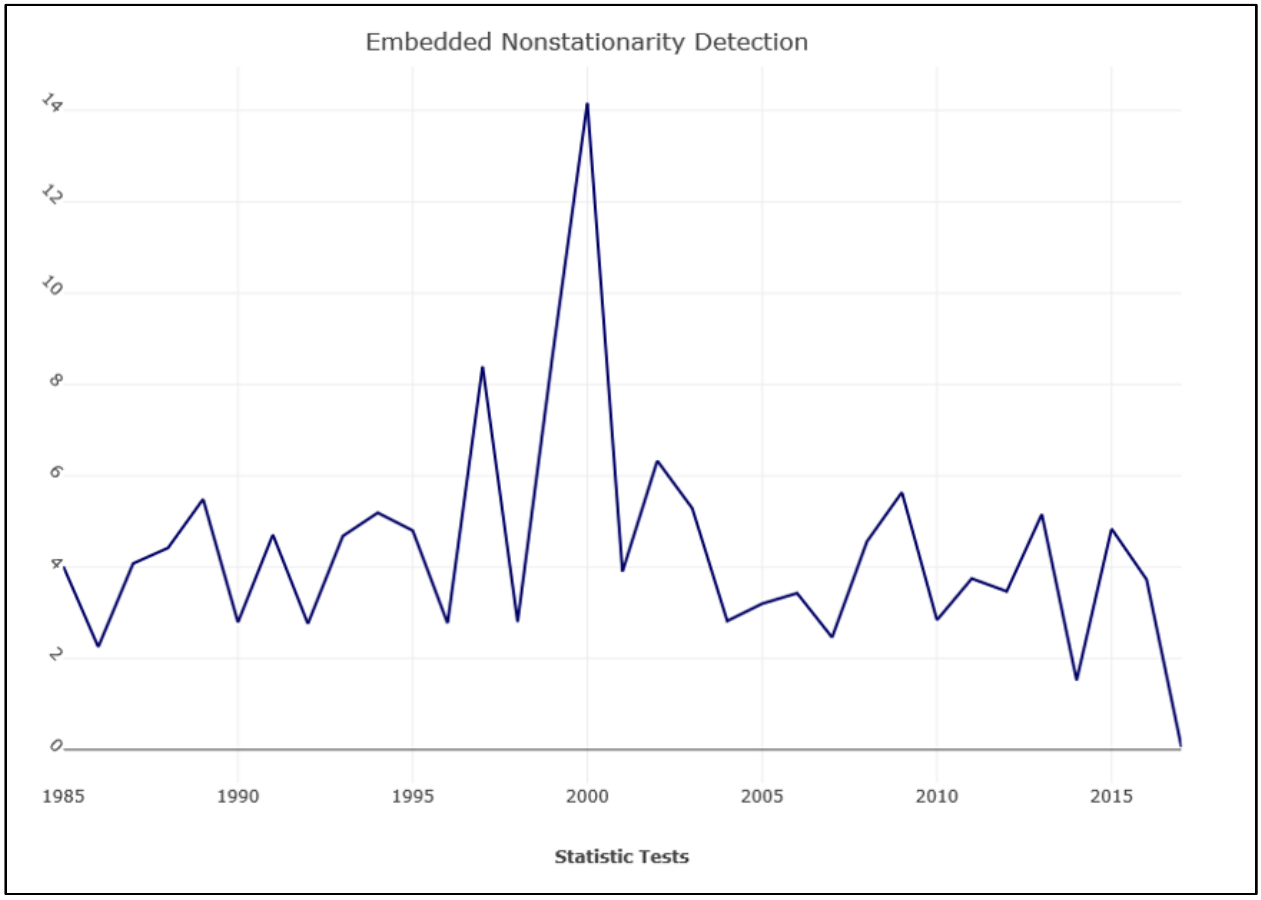

Figure 11. NSD using Time-Series Toolbox with Annual Daily Maximum rainfall

H-9.1.2.5 The USACE Watershed Vulnerability Assessment Tool

The USACE Watershed Vulnerability Assessment (VA) Tool provides a nationwide, screening-level assessment of climate change vulnerability relating to the USACE mission, operations, programs, and projects. Indicators are used to develop vulnerability scores specific to each of the 202 watersheds within the contiguous United States and to each of the USACE business lines. The Weighted Order Weighted Average (WOWA) method is used to aggregate individual vulnerability indicators and their associated datasets into the watershed-scale vulnerability scores. The VA Tool is based on downscaled climate information and hydrology aggregated at the watershed level for selected indicator variables. The tool supports a qualitative identification of potential vulnerabilities for more detailed study (USACE, 2016b).

There is a great deal of uncertainty with the climate changed hydrology and meteorology used by the vulnerability assessment tool. The uncertainty associated with projected hydrologic and meteorologic data includes error in temporal downscaling, error in spatial downscaling, errors in the hydrologic modeling, errors associated with emissions scenarios, and errors associated with GCMs. Some of the uncertainty associated with the tool can be visualized because the tool separates results for each of the scenarios (wet versus dry) and epochs (2050 versus 2085) combinations rather than presenting a single, aggregate result (USACE, 2016b).

The VA Tool examines the vulnerability of projects within all the USACE business lines using data for two scenarios and three epochs. The epochs include the current time period as the base period and two future 30-year periods centered on the years 2050 (2035-2065) and 2085 (2070-2099). Within each future epoch, GCMs are sorted by cumulative runoff projections and divided into two equal-sized groups that represent a Dry scenario and a Wet scenario. All results are thus given for each combination of scenario and future epoch: Dry-2050, Dry-2085, Wet-2050, and Wet-2085. The VA Tool allows the user to explore dominant indicators and summarize vulnerability in several different ways for each scenario/epoch combination. The COP project used the VA Tool to perform such an analysis on southern Florida (HUC 0309), with emphasis on the indicators of vulnerability for the Flood Risk Reduction and Ecosystem Restoration business lines.

Table 3 and **Table 4** provide the number and name of selected indicators for the Flood Risk Reduction and Ecosystem business lines within the Vulnerability Assessment Tool, along with a brief description of each.

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

Number	Name	Description
175L & 175C	ANNUAL CV of UNREGULATED RUNOFF	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean.
277	PERCENT CHANGE IN RUNOFF DIVIDED BY PERCENT CHANGE IN PRECIPITATION	Percent change in runoff divided by percent change in precipitation.

Number	Name	Description
568C &568L	FLOOD_MAGNIFICATION FACTOR	Change in flood runoff: ratio of indicator 571C/L (monthly runoff exceeded 10% of the time) for projected period to 571C/L in base period.
590	ACRES OF URBAN AREA WITHIN 500-YEAR FLOODPLAIN	Acres of urban area within 500-year floodplain.

Table 4. Number, name, and description of selected indicators for the Ecosystem Restoration Business Line within the Vulnerability Assessment Tool.

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

For the Flood Risk Reduction business line, HUC309 is relatively vulnerable to the effects of climate change for both epochs and subsets of scenarios (WET and DRY). **Table 5** lists the vulnerability scores for the Flood Risk Reduction business line for HUC 0309, as well the range of scores nationally and for SAD and SAJ for all scenario-epoch combinations.

Within the USACE South Atlantic Division (SAD), and within the Jacksonville District (SAJ), HUC309 has one of the highest flood risk management vulnerability scores for the DRY subsets of traces. When looking at the WET scenario for the same business line, HUC 0309 is slightly above average for both epochs when compared to the rest of the nation. **Figure 12** 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%).

Table 5. 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

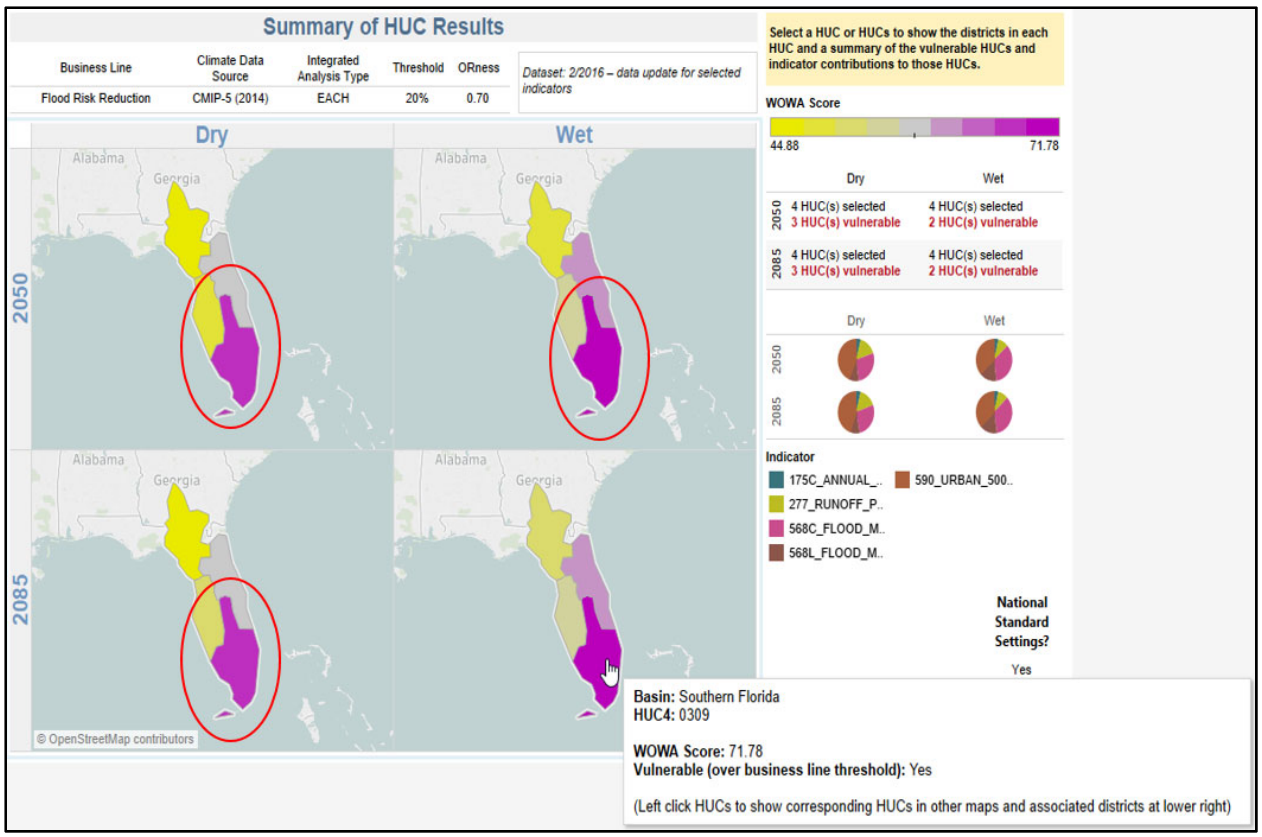

Figure 12. HUC 0309 Watershed Vulnerability Evaluation for the Flood Risk Reduction business line for all scenario-epoch combinations (Dry-2050, Dry-2085, Wet-2050, and Wet-2085).

Relative to the other 201 HUC 04 watersheds in the Continental United States (CONUS) (shown in **Figure 13**), HUC 0309 is not as vulnerable to climate change impacts for Ecosystem Restoration. The vulnerability score is increasing slightly in time. For all scenarios, HUC 309 does not have an ecosystem restoration vulnerability score within the 20% of scores when compared to the rest of the nation and is ranked last within its district. **Table 6** lists the vulnerability scores for the Ecosystem Restoration business line for HUC 0309, as well the range of scores nationally and for SAD and SAJ for all scenario-epoch combinations.

Table 6. Vulnerability Scores for HUC 0309 (Column 3) for the Ecosystem Restoration business line for each scenario-epoch combination nationally, SAD and SAJ.

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

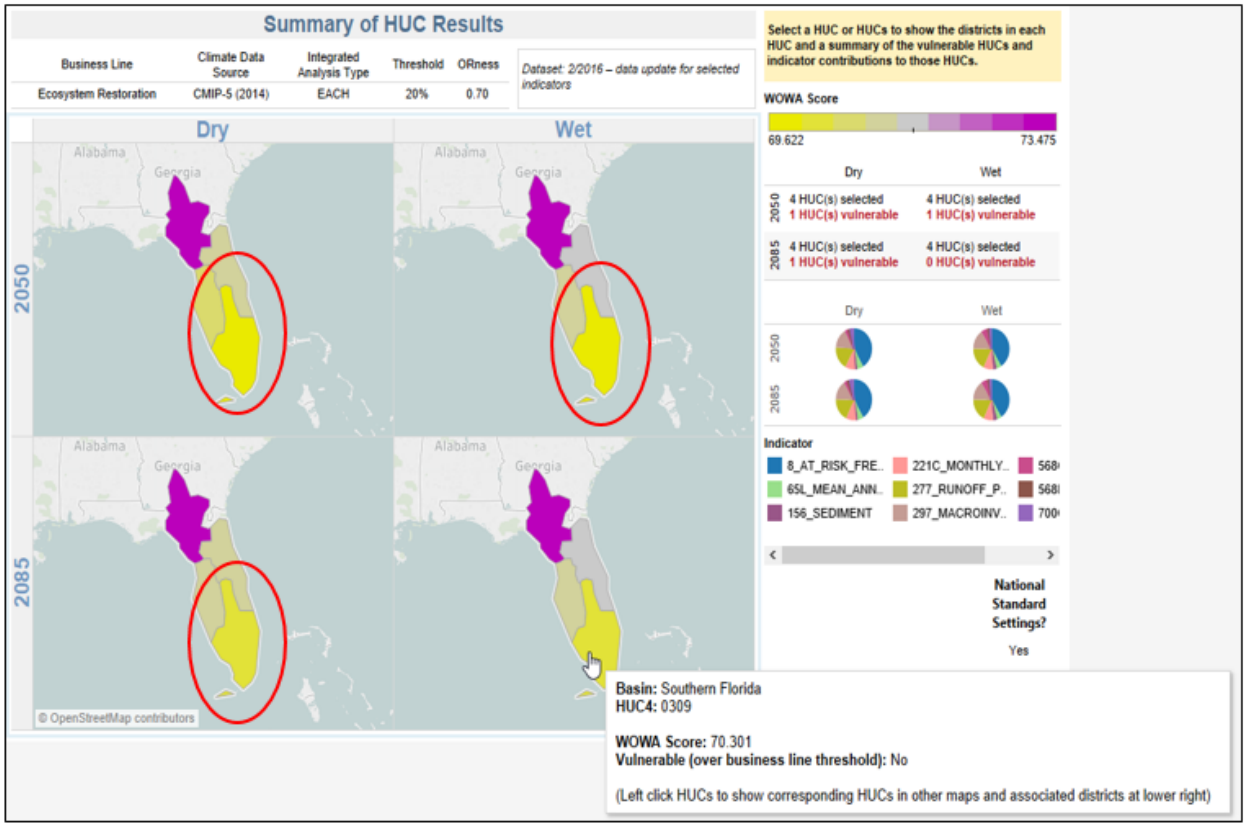

Figure 13. HUC 0309 Watershed Vulnerability Evaluation for the Ecosystem business line for all scenario-epoch combinations (Dry-2050, Dry-2085, Wet-2050, and Wet-2085).

In addition to evaluating the overall vulnerability scores, it is also beneficial to understand which indicator variables drive the vulnerability scores computed for HUC 0309 in terms of the Flood Risk Reduction and Ecosystem Restoration business lines and how the indicator variables are projected to change between epochs. The indicator that contributes most to the vulnerability score for the Flood Risk Reduction business line for all scenarios is Indicator #590 (area of the 500-year floodplain). The indicator that contributes the most significantly to the vulnerability score for the Ecosystem Restoration business line in all scenarios is Indicator #8 (percent of freshwater plant communities at risk). Both business lines show that the vulnerability score is increasing slightly over time.

USACE projects are varied, complex, and often encompass multiple business lines. The relationships among these business lines, with respect to impacts from climate change, are complicated, with cascading effects. Such interrelationships must be recognized as an essential component of future planning efforts when considering the best methods or strategies to adapt. To provide further context to the Vulnerability Assessment Tool Results, **Figure 14** summarizes the projected climate trends from the USACE Climate Literature Synthesis for HUC 02 the South Atlantic-Gulf Region 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: • 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. • Decrease in flows may result from periods of drought and reduced streamflow has implications for maintain water levels in the rivers. • 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. **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: • 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. • Increased evapotranspiration. • Human health risk increases from extended heat waves, impacting recreational visitors and increasing the need for emergency management. **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: • Increased flows and runoff, which may carry pollutants to receiving water bodies, decreasing water quality. • Increased erosion with subsequent changes in sediment accumulation rates and creating water quality concerns. • Increased groundwater recharge rates, as residence times are shortened within areas where evapotranspiration takes place during high intensity events. • Increased flooding, which may have negative consequences for all infrastructure, habitats, and people in the area. **BUSINESS LINES IMPACTED:**
Sea Level Rise	Sea level rise may exacerbate saltwater intrusion into fresh water supplies. **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 14. Summary of projected climate trends and impacts on the USACE business lines (USACE, 2015a).