APPENDIX E

CLIMATE CHANGE

1.0 CLIMATE CHANGE ASSESSMENT

The US Army Corps of Engineers (USACE) Civil Works Program and its water resources infrastructure – built and natural, structural and nonstructural – represent a tremendous Federal investment that supports regional and national economic development, public health and safety, and national ecosystem restoration goals.

The hydrologic and coastal processes underlying this water resources management infrastructure are very sensitive to changes in climate and weather. Therefore, USACE has a compelling need to understand and adapt to climate change and variability to continue providing authorized performance despite changing conditions.

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

For more information about climate change impacts to water resources, see the overview report, USGS Circular 1331 "Climate Change and Water Resources Management: A Federal Perspective," located at http://pubs.usgs.gov/circ/1331/, and also the USACE Responses to Climate Change website at https://corpsclimate.us/.

In 2019 a climate change assessment was performed for the New Savannah Bluff Lock and Dam (NSBLD). The project proposed removing the NSBLD and constructing a fixed crest weir with a rock ramp sloping upstream from the existing dam location with a floodplain bench for high stage flood conditions. By choosing to remove the Lock and Dam structure, the USACE is attempting to improve ecological conditions, thus counteracting any potential, future, negative impacts the Savannah watershed might experience in the face of a changing climate. The assessment determined that impacts associated with climate change will not likely affect either the primary objective of the NSBLD Fish Passage project, which is to allow fish to access their native breeding grounds, or some of the project constraints (sustain water sully, maintain recreation benefits, prevent an increase in flood risk) because there exists a significant water management structure upstream which is able to moderate for both low and high flow conditions. The training wall and pile dikes are minor features in comparison to the NSBLD. To understand the conditions of the project area, along the Savannah River, the USACE conducted extensive hydraulic modeling of the Disposition alternatives to determine the associated hydrodynamic impacts. Analysis results showed negligible change to hydrodynamics. The recommended plan to remove the training wall and associated pile dikes is not likely to have impacts associated with climate change due to the aforementioned reasons that applied to NSBLD Fish Passage project.

The important hydrologic variables affecting the project include water surface elevation (stage) and river discharge. A significant water management structure is located upstream of the study area: J. Strom Thurmond Dam. River stage and discharge is affected by releases from Thurmond Dam and inflow from tributaries between Thurmond Dam and NSBLD. The gates at New Savannah Bluff Lock and Dam are used to help maintain a pool elevation between 111.2 and 114.2 feet NAVD88 upstream of the NSBLD. Impacts to recreation and navigation appear to occur when inflows to NSBLD fall below 5,000 cfs. As a result of proposed project alternatives, variation in river flow will have a much larger impact on NSBLD pool elevations as compared to existing conditions.

Besides fluctuations in climate, stage and flow in the study area can be influenced by long-term geomorphic change, changes to J. Strom Thurmond Dam operating plans, and gage relocation. Discharge can be influenced by changes in upstream water storage due to dam construction, changes in land-use, and measurement techniques. These factors can make it difficult to determine the role of climate change in affecting the hydrologic signal at the project scale. The relevant question to answer at the project scale is whether there has been, or will be a change due to climate change that affects ecological conditions in the study area and how this change would impact the resilience of the proposed project in terms of its ability to meet operating objectives for recreation

More frequent or longer duration flood conditions can stress floodplain forest and aquatic communities in the Augusta Shoals area, which is the historic breeding grounds for Atlantic and Short-nose Sturgeon just downstream of Stephen's Creek Dam. Long periods of high water can kill trees and plant habitat in the Augusta Shoals area or weaken the root zone creating conditions more conducive to erosion. Excessive inflows to aquatic areas increases sediment and nutrient loading affecting plant and fish communities.

1.1 Literature Review

According to the *Third National Climate Assessment,* climate change is expected to intensify current, observed trends in temperature and precipitation in the U.S., including the Southeast region (Carter et al, 2014). The NSBLD Fish Passage Project is located on Savannah River, on the border of Georgia and South Carolina, approximately 187 river miles upstream of Savannah, GA. The project location relative to the Southeast region is highlighted in Figure 1.

Figure 1. Regions identified as part of the 3rd National Climate Assessment – Approximate project area circled in yellow – Southeast region is in light orange

Observed Temperature Trends

Georgia's latitude and close proximity to the warm waters of the Gulf of Mexico and the Atlantic Ocean characterize the climate as long, hot, humid summers and short, mild winters. Over the last 100 years, the Southeast's observed, average annual temperatures have cycled between warm and cool periods, but since 1970, temperatures have increased an average of 2°F. In that time, the number of days above 95°F and nights above 75°F have been increasing, while extremely cold days have been decreasing (Kunkel et al 2013).

Warmer temperatures have effected seasonal cycles. In the Southeast, the frost-free season has already expanded on average by 6 days. Projections based on global climate models suggest the trend toward a longer frost-free season is likely to continue. The southern freeze-free zone will continue to move northward, displacing species requiring freezing (Walsh et al, 2014).

A positive, but mild, warming trend is identified within observed temperature records for most of the area in the spring and summer. For the fall months, the southern portion of the area is shown to be warming.

Projected Temperature Trends

Temperatures across the Southeast are projected to increase during this century as depicted in Figures 2 and 3. Major consequences of warming include significant increases in the number of hot days, 95°F and above (Carter et al, 2014). This increases evaporation and decreases freezing events. Increased evaporation correlates to overall less flow in the river, possibly exposing more shoaling areas and diminishes the amount of spawning areas available for fish. The NSBLD Fish Passage Project is located in the part of the region with a projected increase in number of days above 95°F of approximately 45-60 days. Further, climate change is expected to increase harmful algal blooms and several disease causing agents in inland waters, not previously problems in the region (Carter et al, 2014). This could have detrimental effects on fish in the Savannah River, especially in the Augusta Shoals area.

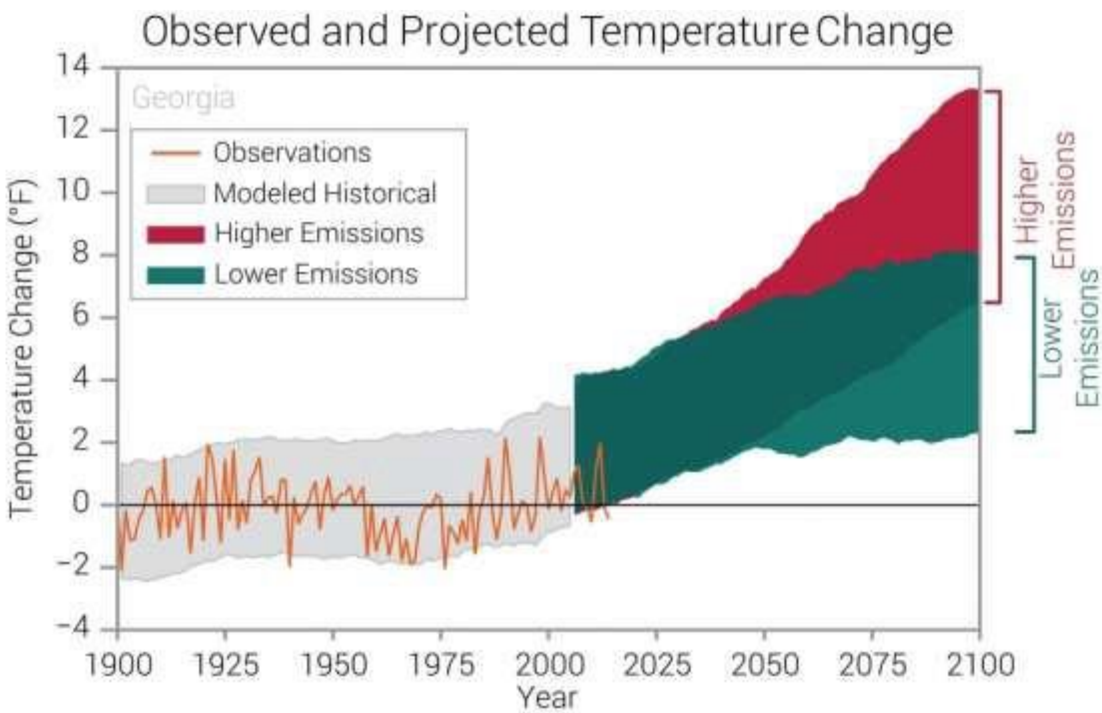


Figure 2: Georgia observed temperature change (orange line) and projected temperature change Source: CICS-NC/NOAA NCEI

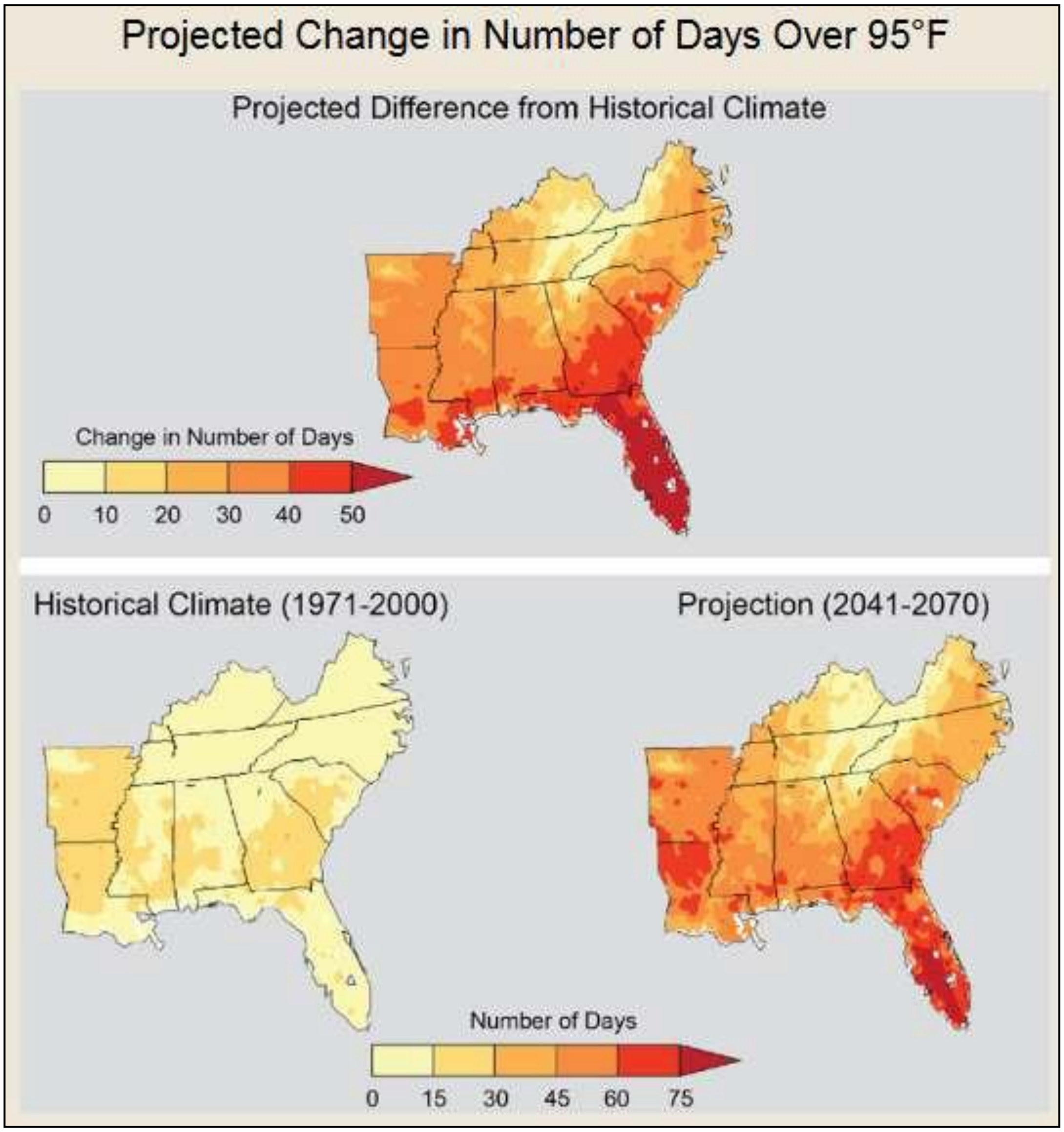


Figure 3: Projected Change in Number of Days over 95°F (Source: NOAA NCDC/CICS-NC)

Observed Precipitation Trends

Georgia receives frequent precipitation throughout the year, ranging from upwards of 80 inches in the mountainous northeastern corner of the state to around 45 inches in the eastern and central portions. Precipitation projections for Georgia are uncertain (Figure 4). Even if average annual precipitation remains constant, higher temperatures will increase evaporation rates and decrease soil moisture during dry spells, leading to greater drought intensity. This could increase competition for limited water resources, which currently support large population centers like the City of Augusta.

The Eastern portion of the Southeast has observed drier conditions whereas the rest of the region has experienced wetter conditions. Daily and five-day observed rainfall intensities have increased (Ingram et al 2013), but summers have been either increasingly dry or extremely wet, which is indicative of the variability of the climate in the Southeast (Kunkel et al 2013). Linear trends in observed annual precipitation indicate a -2 to -5% reduction in precipitation in the upper Savannah River Basin and a +2 to +5% increase in precipitation in the lower Savannah River Basin (McRoberts and Nielsen-Gammon, 2011). The Southeast has seen a

27% increase in heavy precipitation events (defined as the heaviest 1% of all daily events) since 1900 (Karl et al 2009) and is projected to see a varied increase in storm severity and in the frequency of severe storms in the future.

Projected Precipitation Trends

The frequency and intensity of precipitation is projected to increase more across the northern portion of the region and show less of an increase in the southern part of the Southeast region. As can be seen in Figure 4, precipitation is projected to increase throughout Georgia, however, these changes are small relative to the natural variability in this region. Seasonal differences in precipitation will have a significant effect on many hydrologic processes. Soil moisture, critical for vegetation and agriculture, is determined in part by precipitation and temperature, which drives evapotranspiration (ET). Soil moisture fluctuates seasonally and has been observed to be decreasing over time in the Southeast (Hay et al 2011, Zhang and Georgakakos 2011).

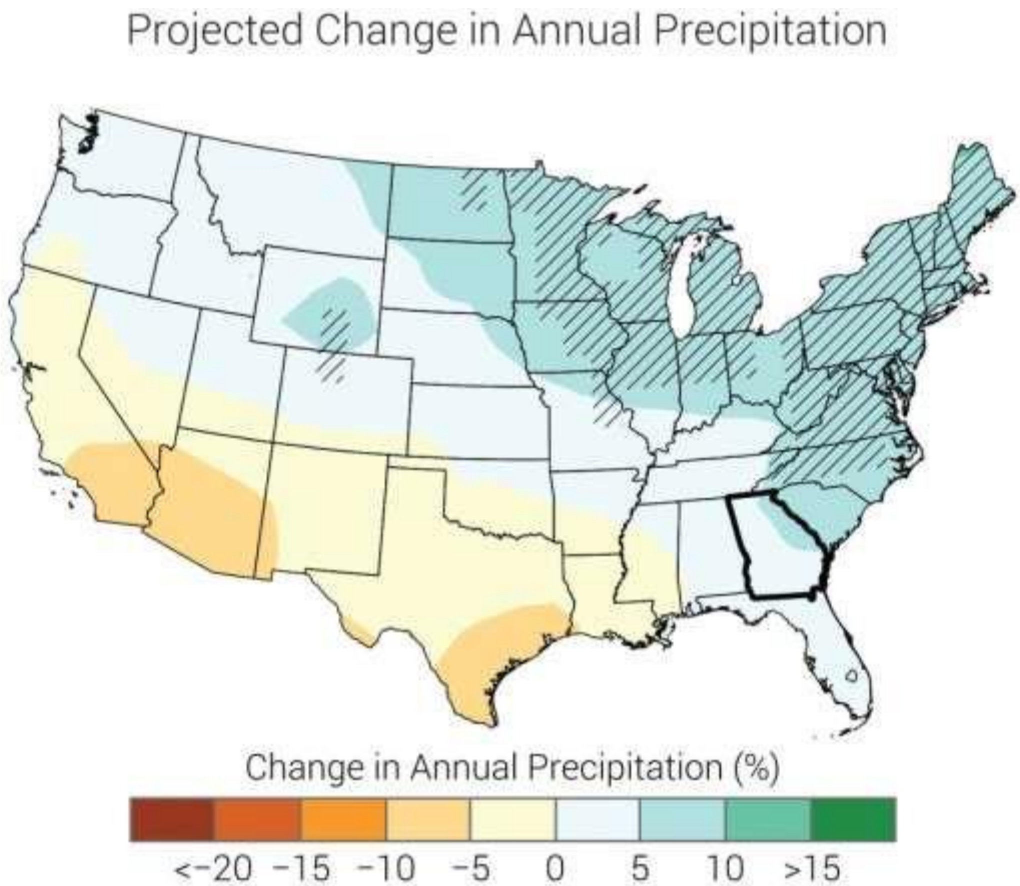


Figure 4: Climate model projections of changes (%) in annual precipitation for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Source: CICS-NC, NOAA NCEI, and NEMAC.

Observed Streamflow Trends

Studies of trends and non-stationarities in streamflow datasets collected over the past century have been performed throughout the continental U.S., some of which include the South Atlantic-Gulf Region. With the exception of two stations in Florida, the vast majority of stations distributed throughout the region showed no significant trend in streamflow in either direction (USACE, 2015).

In contrast to the findings described above, Kalra et al. (2008) found statistically significant negative trends in annual and seasonal streamflow for a large number of stream gages in the South Atlantic-Gulf Region, analyzed in aggregate, for the historical period 1952 – 2001 (USACE, 2015). A study by Patterson et al. (2012) also observed a “transition” period occurring around 1970, as well as identified significant decreasing trends in streamflow in the South Atlantic-Gulf Region for the period 1970 – 2005. Results were mixed for an earlier time period (1934 – 1969), with some decreasing and some increasing trends (USACE, 2015). While several studies contradict each other in terms of observed streamflow trends in the Southeast Region, overall a mild downward trend in mean streamflow in the Southeast Region, particularly since the 1970s, has been identified by multiple authors.

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. These studies include 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 projects significant increases in water yield (USACE, 2015). No clear consensus has been found in projected streamflow changes in the South Atlantic-Gulf Region. Some studies point toward mild increases in flow, while other studies point toward mild decreases in projected streamflow.

Summary

There is strong agreement in the literature that temperature for the Southeast region, and the entire country, will increase over the next century. The studies 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 South Atlantic-Gulf Region (USACE, 2015). Projections for precipitation events and hydrology are less certain than temperature projections for the Southeast Region. Figure 5 shows a summary matrix of observed and projected climate trends and projections for the HUC 03, which is the South Atlantic-Gulf Region, where the NSBLD Fish Passage Project is located.

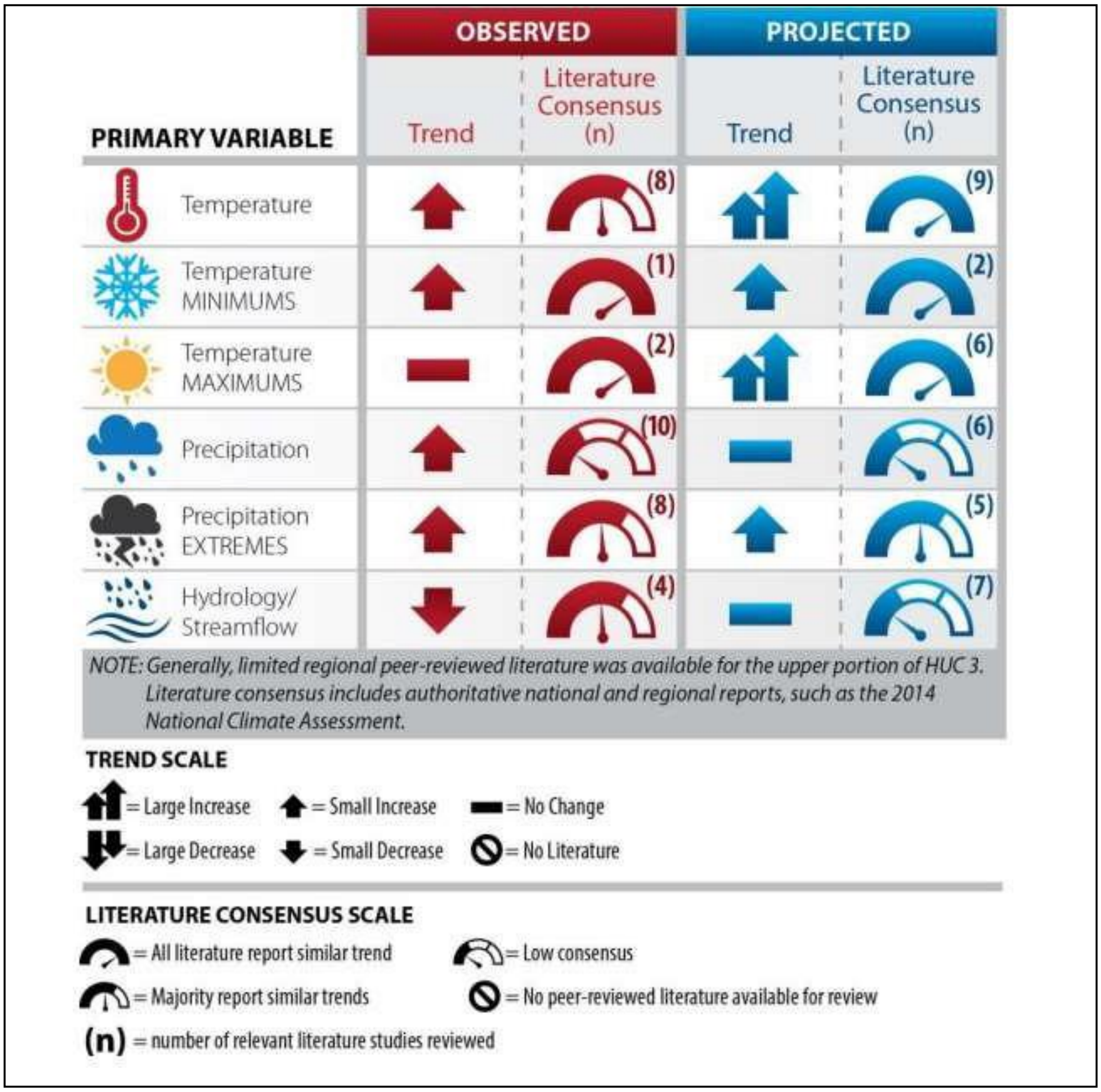


Figure 5: Summary Matrix of Observed and Projected Climate Trends and Literary Consensus (Source: USACE Climate Change Assessment for Water Resources Region 03).

The Southeast is also vulnerable to flooding caused by sea level rise. While sea-level rise is expected for the Southeast Region, the NSBLD Fish Passage Project is several hundred miles inland of the coast and therefore will not be impacted by the effects of sea level rise. The recommended plan consists of a weir with an average crest elevation of 108.2 feet NAVD88 (109.0 NGVD29). The pool elevation at the weir would fluctuate between elevation 110 and 111 feet (NAVD 88) during normal river flows. Thus, the elevations in the study area are considerably higher than the 50 foot NAVD88 threshold which necessitates considering sea level change as part of the analysis.

<u>Precipitation and Temperature Trend Assessment Specific to the State of Georgia</u>

A study conducted by Binita, Shepherd and Gaither in 2015 sought to quantify the state of Georgia’s vulnerability to climate change using an integrated approach which takes into account socioeconomic conditions, as well as changing biophysical conditions. The Binita, Shepherd and Gaither study found that temperature trends observed within the study area are consistent with trends observed throughout the Southeast Region. Temperatures have been increasing in recent decades. As can be seen in Figure, 6, between 1975 and 1984 there was a period of cooling in the region, but greater anomalies in temperature reflecting a warming trend have been observed in the decades since then.

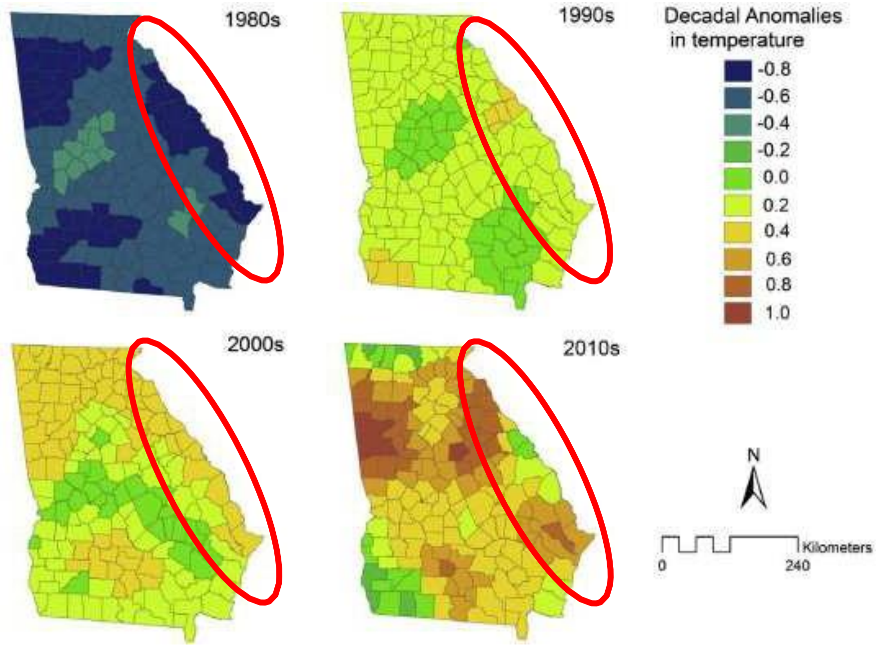


Figure 6. Historic Temperature Trends in the State of Georgia. Study area circled in red. "Anomalies in decadal temperature in 1980s (1975-1984), 1990s (1985-1994), 2000s (1995-2004), and 2010s (2005-2012) compared to the 30-year climate normal (1971-2000). Gradation of brown color code indicates positive temperature anomaly while blue gradation indicates negative temperature anomaly (Binita, Shepherd & Gaither 2015)."

As indicated within Figure 7, Georgia has been experiencing drier conditions. There has been an increase in the number of moderate to severe droughts between 2000 and present. The Binita, Shepherd and Gaither (2015) paper also indicates that the state of Georgia has been experiencing more flood events in recent decades.

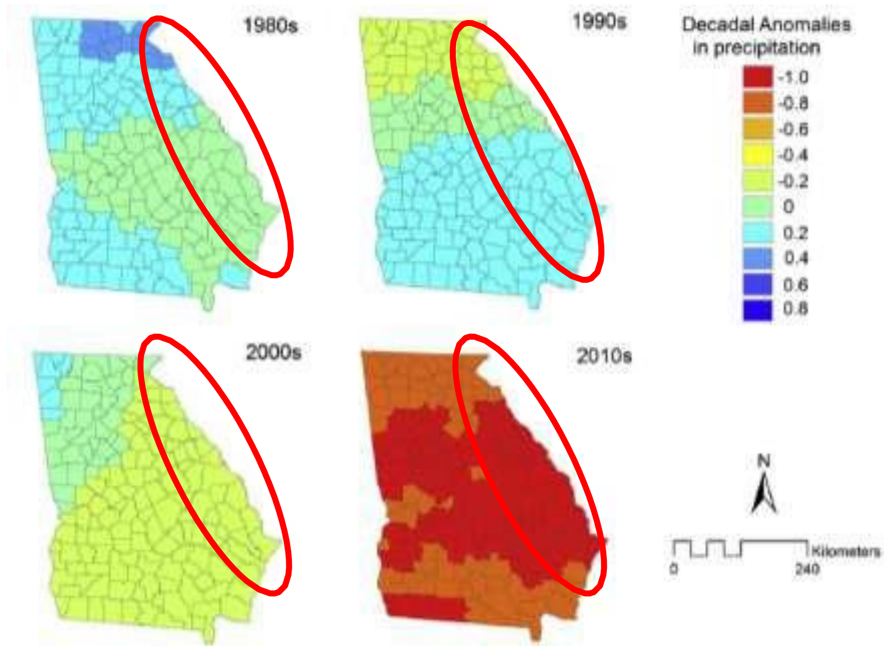


Figure 7. Historic Precipitation Trends in the State of Georgia. Study area circled in red. "Anomalies in decadal precipitation in 1980s (1975-1984), 1990s (1985-1994), 2000s (1995-2004), and 2010s (2005-2012) compared to the 30-year climate normal (1971-2000). Gradation of blue color code indicates positive precipitation anomaly, that is, increase in precipitation while red gradation indicates negative precipitation anomaly, that is, decrease in precipitation (Binita, Shepherd & Gaither 2015)."

In addition to evaluating hydroclimatic variables to assess climate change vulnerability, Binita, Shepherd & Gaither (2015) also evaluated changing social and land cover conditions in Georgia to identify which portions of the state are likely most vulnerable to climate change impacts. The results of their vulnerability assessment are displayed in Figure 8.

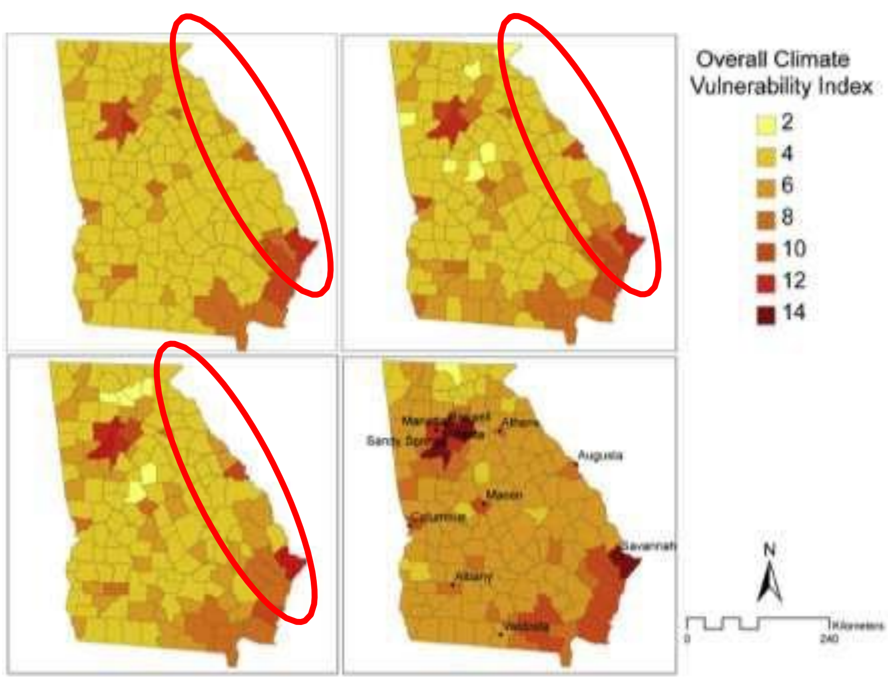


Figure 8. Overall climate vulnerability index derived by combing the climate change vulnerability index and geographic vulnerability. Gradation of red indicates high overall climate vulnerability (Binita, Shepherd & Gaither 2015)." Study area circled in red.

1.2 First Order Statistical Analysis: Trends in Streamflow & Climate Change at a Regional Scale

The USACE Climate Hydrology Assessment Tool was used to investigate potential future trends in streamflow for HUC 0306, the Ogeechee-Savannah watershed. Figure 9 below shows the location of the project area relative to the HUC04 watershed delineations.

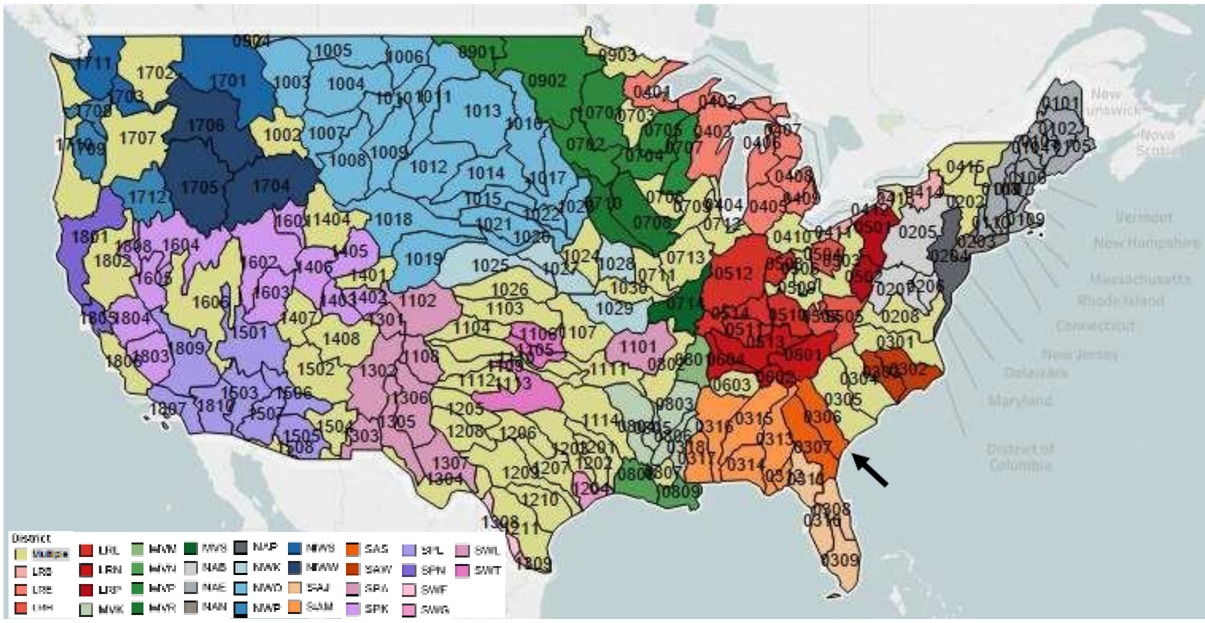


Figure 9: Reference Map of HUC 4 Watersheds by District. The Ogeechee-Savannah is highlighted by the black arrow.

Figure 10 displays the range of projected annual maximum monthly streamflows computed from 93 different climate changed hydrologic model runs for the period of 1951-2099. Climate Changed hydrology output is generated using various greenhouse gas emission scenarios (RCPs) and global circulation models (GCM) to project precipitation and temperature data into the future. These meteorological outputs are spatially downscaled using the BCSD statistical method and then inputted in the U.S. Bureau of Reclamation's Variable Infiltration Capacity (VIC) precipitation-runoff model to generate a streamflow response. The VIC model represents unregulated basin conditions. This is relevant because the Ogeechee-Savannah basin is impacted by regulation. As expected for this type of qualitative analysis, there is considerable, but consistent spread in the projected annual maximum monthly flows. The spread in the projected annual maximum monthly flows is indicative of the high degree of uncertainty associated with projected, climate changed hydrology.

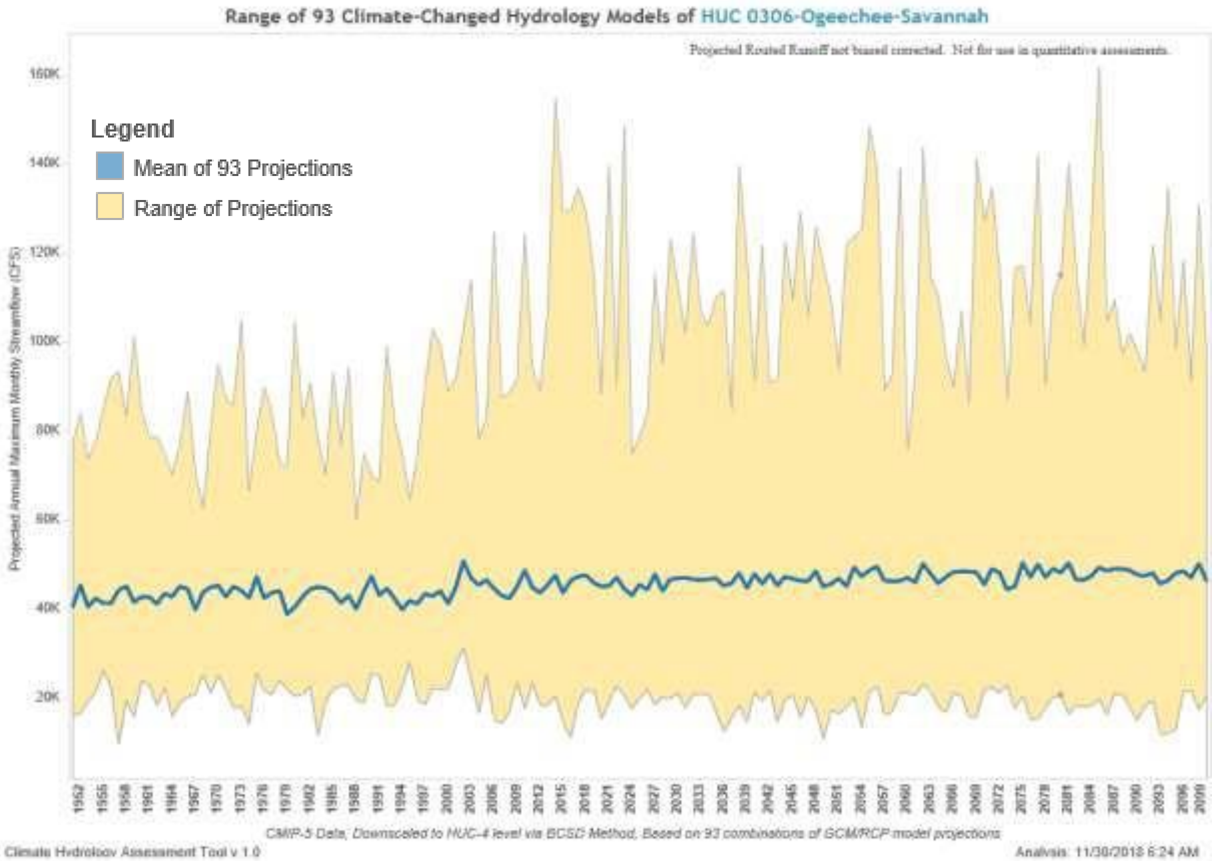


Figure 10: Range of Projected Annual Maximum Monthly Streamflow among Ensemble of 93 Climate-Changed Hydrology Models, HUC 306 Ogeechee-Savannah.

There is no statistically significant trend in the data modeled using GCM inputs for the hindcast period (1951-1999). There is a statistically significant (p-value <0.0001) increasing trend in the mean projected annual maximum monthly streamflow for 2000-2099(AMMS; Figure 11). The p-value is for the linear regression fit drawn; a smaller p-value indicates greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or a false positive. This finding suggests that there is potential for AMMS to increase in the future in the study area, relative to the current conditions.

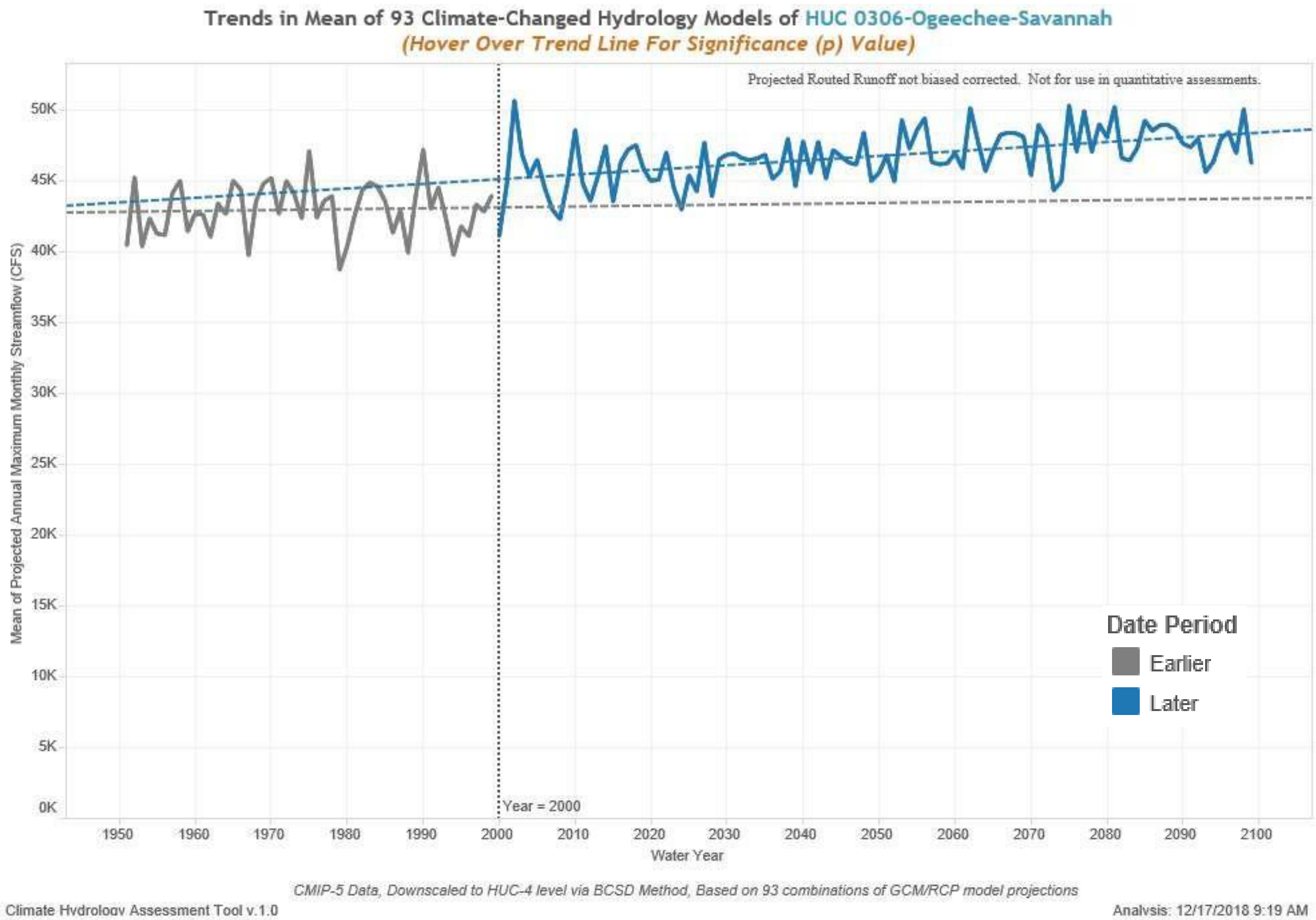


Figure 11: Mean Projected Annual Maximum Monthly Streamflow, HUC 306 Ogeechee-Savannah.

1.3 Screening Level Vulnerability Assessment to Climate Change Impacts

The USACE Watershed Climate Vulnerability Assessment Tool (VA Tool) was used to compare the relative vulnerability to climate change of the HUC 0306, Ogeechee-Savannah watershed, to all HUC 04 watersheds across the continental United States (CONUS). The tool facilitates a screening level, comparative assessment of how vulnerable a given HUC 04 watershed is to the impacts of climate change. The tool can be used to assess the vulnerability of a specific USACE business line such as “Ecosystem Restoration” to projected climate change impacts. Assessments using this tool help to identify and characterize specific climate threats and particular sensitivities or vulnerabilities, at least in a relative sense, across regions and business lines. The four (4) USACE business lines relevant to the SHEP Fish Passage project include: Ecosystem Restoration (Mitigation), Recreation, Water Supply, and Flood Risk Reduction. The tool uses the Weighted Order Weighted Average (WOWA) method to represent a composite index of how vulnerable a given HUC 04 watershed (Vulnerability Score) is to climate change specific to a given business line.

WOWA stands for “Weighted Ordered Weighted Average,” which reflects the aggregation approach used to get the final score for each HUC. After normalization and standardization of indicator data, the data are weighted with “importance weights” determined by the Corps (the first “W”). Then, for each HUC-epoch-scenario, all indicators in a business line are ranked according to their weighted score, and a second set of weights (which are the OWA weights),” are applied, based on the specified ORness level. This yields a single aggregate score for each HUC-epoch-scenario called the WOWA score. WOWA indicator contributions are calculated after the aggregation to give a sense of which indicators dominate the WOWA score at each HUC. Further information regarding indicators can be found in Table 1.

Indicators considered within the WOWA score for Ecosystem Restoration (Mitigation; Table 2) include: macroinvertebrate index (sum score of six metrics indicating biotic condition), percent of at risk freshwater plant communities, runoff elasticity (ratio of streamflow runoff to precipitation), short-term variability in hydrology, change in sediment load, mean annual runoff, two indicators of flood magnification (indicator of how much high flows are projected to change overtime), and change in low runoff.

Indicators considered within the WOWA score for Recreation (Table 3) include: two indicators of flood flow, runoff elasticity (ratio of streamflow runoff to precipitation), short-term variability in hydrology, change in sediment load, drought severity, two indicators of flood magnification (indicator of how much high flows are projected to change overtime), and change in low runoff.

Indicators considered within the WOWA score for Water Supply (Table 4) include: change in sediment load, long-term variability in hydrology, short-term variability in hydrology, runoff elasticity (ratio of streamflow runoff to precipitation), and drought severity.

Indicators considered within the WOWA score for Flood Risk Reduction (Table 5) include: long-term variability in hydrology, runoff elasticity (ratio of streamflow runoff to precipitation), two indicators of flood magnification (indicator of how much high flows are projected to change overtime), and the acres of urban area within the 500-year floodplain.

When assessing future risk projected as a result of climate change, the USACE VA Tool makes an assessment for two 30-year epochs of analysis centered at 2050 and 2085. These two periods were selected to be consistent with many of the other national and international analyses. The tool assesses how vulnerable a given HUC 04 watershed is to the impacts of climate change for a given business line using climate changed hydrology based on a combination of projected climate outputs from the general climate models (GCMs) and representative concentration pathway (RCPs) resulting in 100 traces per watershed per time period. The top 50% of the traces by flow magnitude is called the “wet” subset of traces and the bottom 50% of the traces is called the “dry” subset of traces. Meteorological data projected by the GCMs is translated into runoff using the VIC macroscale hydrologic model.

Because projected, climate changed meteorology and hydrology is used to compute indicator variables there is a significant amount of uncertainty in the data used to generate vulnerability scores. Many of the indicators included in the VA Tool rely on an ensemble of GCMs to capture some of the uncertainty inherent in climate projections. Some of this uncertainty is revealed by the tool by presenting separate results for each of the scenario-epoch combinations rather than presenting a single aggregate result.

For this assessment the default, National Standards Settings are used to carry out the vulnerability assessment.

Table 1: Descriptions for indicators used in the Fish Passage Vulnerability Tool analysis.

Indicator Short Name	Indicator Name	Large Values = High Vulnerability	Indicator Description	Data Sources	Last Updated
8 AT RISK FRESHWATER PLANT	% of freshwater plant communities at risk	Yes	% of wetlands & riparian plant communities that are at risk of extinction, based on remaining number & condition, remaining acreage, threat severity, etc.	NatureServe - Explorer (customized dataset). Data were obtained from Jason McNees at NatureServe, 1101 Wilson Blvd., 15th Floor Arlington, VA 22201 via email on July 31, 2009	Feb-2016
65L MEAN ANNUAL RUNOFF	Mean annual runoff (local)	No	Mean runoff: average annual runoff, excluding upstream freshwater inputs (local).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014
95 DROUGHT SEVERITY	Drought Severity Index	Yes	Greatest precipitation deficit: The most negative value calculated by subtracting potential evapotranspiration from precipitation over any 1-, 3-, 6-, or 12-month period.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Jul-2015
156 SEDIMENT	Change in sediment load due to change in future precipitation	Yes	The ratio of the change in the sediment load in the future to the present load.	CDM	Feb-2016
175L ANNUAL COV	Annual CV of unregulated runoff (local)	Yes	Long-term variability in hydrology: ratio of the SD of annual runoff to the annual runoff mean. Excludes upstream freshwater inputs (local).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014
221C MONTHLY COV	Monthly CV of runoff (cumulative)	Yes	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the SD of monthly runoff to the mean of monthly runoff. Includes upstream freshwater inputs (cumulative).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014
277 RUNOFF PRECIP	% change in runoff divided by % change in precipitation	Yes	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014) using method of Sankarasubramanian & Vogel 2001 WRR 37(6)1771-1781	Feb-2015
297 MACROINVERTEBRATE	Macroinvertebrate index of biotic condition	No	The sum (ranging from 0-100) of scores for six metrics that characterize macroinvertebrate assemblages: taxonomic richness, taxonomic composition, taxonomic diversity, feeding groups, habits, pollution tolerance.	USEPA - Wadeable Streams Assesment (WSA) (Stream Water Benthic Macroinvertebrate Metrics)	Feb-2016
568C FLOOD MAGNIFICATION	Flood magnification factor (cumulative)	Yes	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014
568L FLOOD MAGNIFICATION	Flood magnification factor (local)	Yes	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014
570L 90PERC EXCEEDANCE	Low flow (monthly flow exceeded 90% of time; local)	No	Low runoff: monthly runoff that is exceeded 90% of the time, excluding upstream freshwater inputs (local).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014
571C 10PERC EXCEEDANCE	Flood flow (monthly flow exceeded 10% of time; cumulative)	Yes	Flood runoff: monthly runoff that is exceeded 10% of the time, including upstream freshwater inputs (cumulative).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014
571L 10PERC EXCEEDANCE	Flood flow (monthly flow exceeded 10% of time; local)	Yes	Flood runoff: monthly runoff that is exceeded 10% of the time, excluding upstream freshwater inputs (local).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014
590 URBAN 500YRFLOODPLAIN AREA	Acres of urban area within 500-year floodplain	Yes	Acres of urban area within the 500-year floodplain.	(1) FEMA - 500 year Flood Zones (2) EPA - Integrated Climate & L& Use Scenarios (ICLUS)	Jan-2011
700C LOW FLOW REDUCTION	Low flow reduction factor (cumulative)	No	Change in low runoff: ratio of indicator 570C (monthly runoff exceeded 90% of the time, including upstream freshwater inputs) to 570C in base period.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Sep-2014

The results of the USACE VA Tool analysis of the four business lines in the HUC 306 Ogeechee-Savannah watershed are found in Table 2. Within Table 2, a comparison can be made between the Ogeechee-Savannah watershed's WOWA scores, the CONUS Range of WOWA scores, and the South Atlantic Division- USACE (SAD) range of WOWA scores. The SAD is compromised of the states of Florida, Alabama, Georgia, South Carolina, North Carolina, and Delaware, as well as a portion of Eastern Mississippi (see figures below). The Ogeechee-Savannah watershed is not considered vulnerable to the impacts of climate change for the ecosystem restoration, recreation, water supply and flood risk reduction business lines (does not falls within the top 20% of vulnerability scores) relative to the other 201 HUC 04 watersheds in the CONUS.

Table 2: Projected Vulnerability (WOWA Score) comparison chart.

Summary of Vulnerability				
Business Line	**Scenario - Epoch**	**WOWA Score**	**Range Nationally**	**Range SAD**
Ecosystem Restoration (Mitigation)	Dry 2050	70.93	55.95 - 81.73	64.82 -73.30
	Dry 2085	71.31	55.84 - 81.85	65.21 - 73.76
	Wet 2050	70.25	55.64 - 89.84	64.20 -73.16
	Wet 2085	70.83	54.69 - 89.43	64.65 - 73.36
Recreation	Dry 2050	59.17	57.05 - 74.39	58.65 - 61.20
	Dry 2085	68.19	57.42 - 82.23	62.53 - 76.96
	Wet 2050	57.67	57.67 - 85.65	57.67 - 60.40
	Wet 2085	57.23	56.67 - 83.62	56.67 - 66.63
Water Supply	Dry 2050	46.57	43.70 - 73.54	43.70 - 46.57
	Dry 2085	60.70	46.91 - 79.27	50.13 - 60.70
	Wet 2050	55.98	49.86 - 80.34	53.78 - 56.03
	Wet 2085	58.03	49.42 - 81.82	56.56 - 60.68
Flood Risk Reduction	Dry 2050	43.81	35.15 - 70.08	41.53 - 67.07
	Dry 2085	44.20	35.66 - 69.10	41.93 - 68.18
	Wet 2050	47.73	39.80 - 92.85	46.76 - 70.46
	Wet 2085	48.65	40.86 - 86.71	47.65 - 71.78

Relative to the other HUC 04 watersheds in SAD, the Ogeechee-Savannah watershed is relatively more vulnerable to the impacts of climate change on ecosystem restoration (mitigation) for both the wet and dry subsets of traces (Figure 12). For the Ogeechee-Savannah watershed, the major drivers of the computed ecosystem restoration vulnerability score are, “At Risk Freshwater Plants”, the “Macroinvertebrate Index”, and “Runoff Elasticity” (Table 3).

Table 3: Indicators associated with Ecosystem Restoration (Mitigation) and their contribution to the WOWA scores.

Ecosystem Restoration (Mitigation)					
Dry Scenario					
Indicator #	**2050 Value**	**2050 % Score**	**2085 Value**	**2085 % Score**	**% Change**
297 MACROINVERTEBRATE INDEX	16.55	23.34	16.55	23.21	0.00
8 AT RISK FRESHWATER PLANTS	28.50	40.19	28.50	39.97	0.00
277 RUNOFF PRECIPITATION (Elasticity)	9.23	13.01	9.47	13.28	2.61
221C MONTHLY COV (Flow Variability)	5.51	7.77	5.63	7.89	2.10
156 SEDIMENT LOAD	1.34	1.89	1.23	1.72	-8.41
65L MEAN ANNUAL RUNOFF	3.01	4.25	3.01	4.23	0.07
568C FLOOD MAGNIFICATION	2.02	2.84	2.04	2.86	1.17
568L FLOOD MAGNIFICATION	0.80	1.12	0.81	1.13	1.17
700C LOW FLOW REDUCTION	3.97	5.59	4.07	5.71	2.59
Wet Scenario					
Indicator #	**2050 Value**	**2050 % Score**	**2085 Value**	**2085 % Score**	**% Change**
297 MACROINVERTEBRATE INDEX	16.29	23.19	16.40	23.16	0.68
8 AT RISK FRESHWATER PLANT	28.06	39.94	28.25	39.88	0.68
277 RUNOFF PRECIPITATION (Elasticity)	9.32	13.27	9.14	12.90	-2.00
221C MONTHLY COV(Flow Variability)	5.17	7.36	3.06	4.31	-40.95
156 SEDIMENT LOAD	2.95	4.20	5.40	7.62	83.05
65L MEAN ANNUAL RUNOFF	2.24	3.18	2.24	3.16	0.16
568C FLOOD MAGNIFICATION	3.86	5.49	4.01	5.66	3.97
568L FLOOD MAGNIFICATION	0.90	1.29	0.94	1.33	3.97
700C LOW FLOW REDUCTION	1.46	2.08	1.40	1.98	-3.87

Ecosystem Restoration (Mitigation)

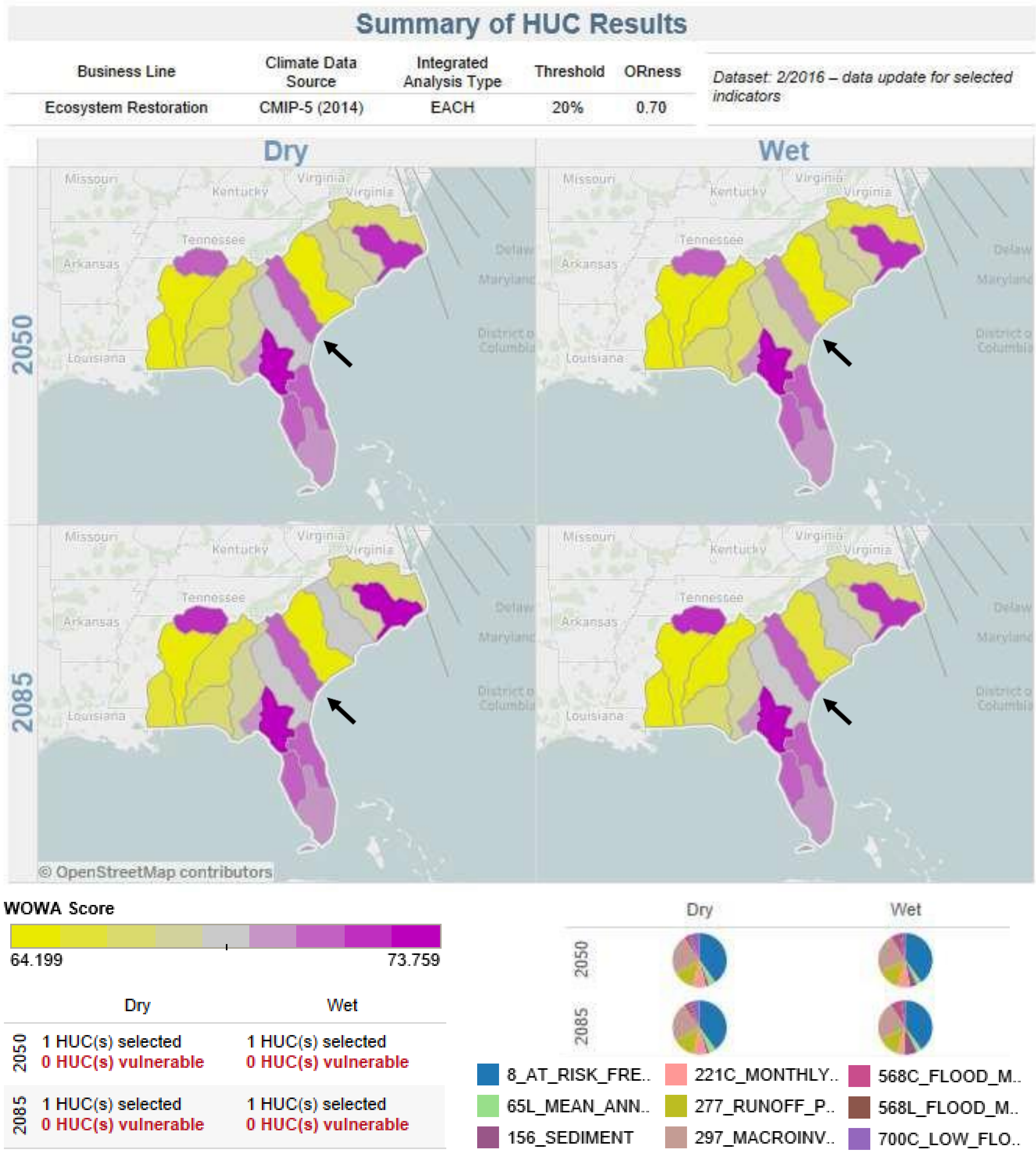


Figure 12: Results of the USACE climate vulnerability analysis for the Ecosystem Restoration WOWA score of the Ogeechee-Savannah watershed (highlighted by the black arrow) compared to SAD.

Relative to the other HUC 04 watersheds in SAD, the Ogeechee-Savannah watershed is relatively less vulnerable to the impacts of climate change on recreation for both the wet and dry subsets of traces (Figure 13). For the Ogeechee-Savannah watershed, the major drivers of the recreation vulnerability score are, “Low Flow Reduction”, the local and cumulative “90% Exceedance” (Table 4). “Drought Severity” is a major driver of the computed recreation vulnerability score in the 2085 dry subset of traces.

Table 4: Indicators associated with Recreation and their contribution to the WOWA scores.

Recreation					
Dry Scenario					
Indicator #	**2050 Value**	**2050 % Score**	**2085 Value**	**2085 % Score**	**% Change**
571C 90PERC EXCEEDANCE FLOW	8.47	14.31	6.01	8.81	-29.07
570L 90PERC EXCEEDANCE FLOW	12.25	20.70	8.75	12.83	-28.56
277 RUNOFF PRECIP (Elasticity)	3.13	5.29	2.96	4.33	-5.56
221C MONTHLY COV (Flow variability)	2.25	3.81	2.12	3.11	-6.03
156 SEDIMENT LOAD	0.89	1.51	0.75	1.11	-15.70
95 DROUGHT SEVERITY	4.07	6.88	27.00	39.59	563.25
568C FLOOD MAGNIFICATION	5.37	9.07	3.85	5.64	-28.32
568L FLOOD MAGNIFICATION	1.35	2.28	1.25	1.84	-6.89
700C LOW FLOW REDUCTION	21.39	36.15	15.51	22.74	-27.52
Wet Scenario					
Indicator #	**2050 Value**	**2050 % Score**	**2085 Value**	**2085 % Score**	**% Change**
571C 90PERC EXCEEDANCE	8.95	15.53	8.87	15.50	-0.95
570L 90PERC EXCEEDANCE	12.09	20.97	11.81	20.64	-2.29
277 RUNOFF PRECIP (Elasticity)	4.35	7.55	4.18	7.31	-3.88
221C MONTHLY COV (Flow variability)	2.91	5.05	1.69	2.95	-42.08
156 SEDIMENT LOAD	1.61	2.79	2.88	5.04	79.54
95 DROUGHT SEVERITY	0.49	0.85	2.20	3.84	349.86
568C FLOOD MAGNIFICATION	6.45	11.18	6.58	11.49	1.98
568L FLOOD MAGNIFICATION	2.10	3.64	1.27	2.22	-39.57
700C LOW FLOW REDUCTION	18.71	32.44	17.75	31.01	-5.14

Recreation

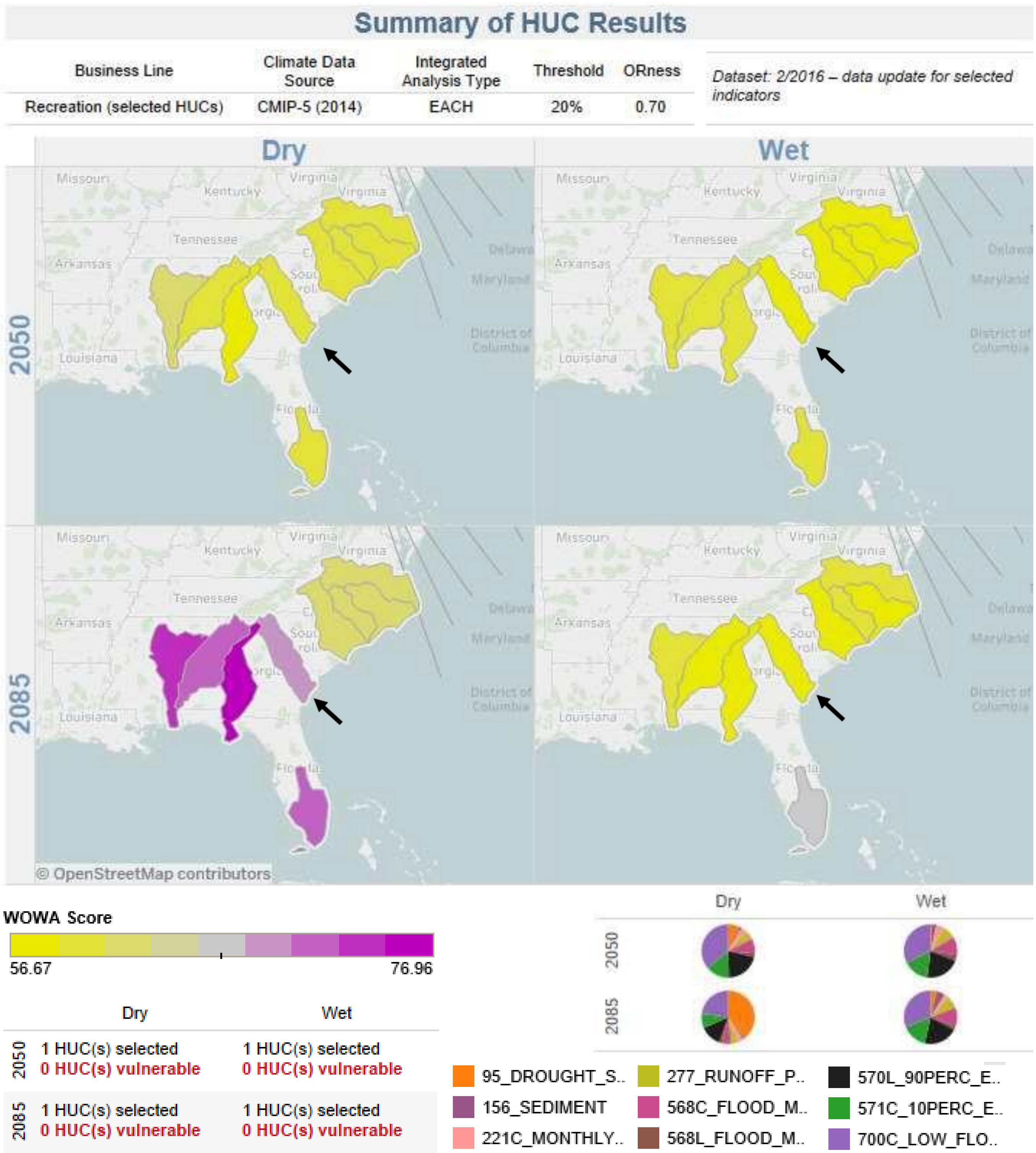


Figure 13: Results of the USACE climate vulnerability analysis for the Recreation WOWA score of the Ogeechee-Savannah watershed (highlighted by the black arrow) compared to SAD.

Relative to the other HUC 04 watersheds in SAD, the Ogeechee-Savannah watershed is relatively more vulnerable to the impacts of climate change on water supply for both the wet and dry subsets of traces (Figure 14). For the Ogeechee-Savannah watershed, the major drivers of the computed water supply vulnerability score are, “Sediment Load” and the “Runoff Elasticity.” For the 2085 dry subset of traces, “Drought Severity” also contributes significantly to the vulnerability score (Table 5).

Table 5: Indicators associated with Water Supply and their contribution to the WOWA scores.

Water Supply					
Dry Scenario					
Indicator #	**2050 Value**	**2050 % Score**	**2085 Value**	**2085 % Score**	**% Change**
156 SEDIMENT LOAD	23.55	50.57	13.21	21.76	-43.91
175C ANNUAL COV (Flow Variability)	1.89	4.07	1.78	2.93	-6.01
221C MONTHLY COV (Flow Variability	3.07	6.60	3.02	4.98	-1.61
277 RUNOFF PRECIPITATION (Elasticity)	12.00	25.77	7.71	12.70	-35.76
95 DROUGHT SEVERITY	6.05	13.00	34.97	57.62	477.80
Wet Scenario					
Indicator #	**2050 Value**	**2050 % Score**	**2085 Value**	**2085 % Score**	**% Change**
156 SEDIMENT LOAD	34.62	61.84	36.00	62.03	3.99
175C ANNUAL COV (Flow Variability)	2.84	5.08	1.79	3.09	-36.83
221C MONTHLY COV (Flow Variability	4.73	8.45	2.90	5.00	-38.68
277 RUNOFF PRECIPITATION (Elasticity)	12.91	23.07	11.99	20.66	-7.17
95 DROUGHT SEVERITY	0.88	1.57	5.35	9.22	509.96

Water Supply

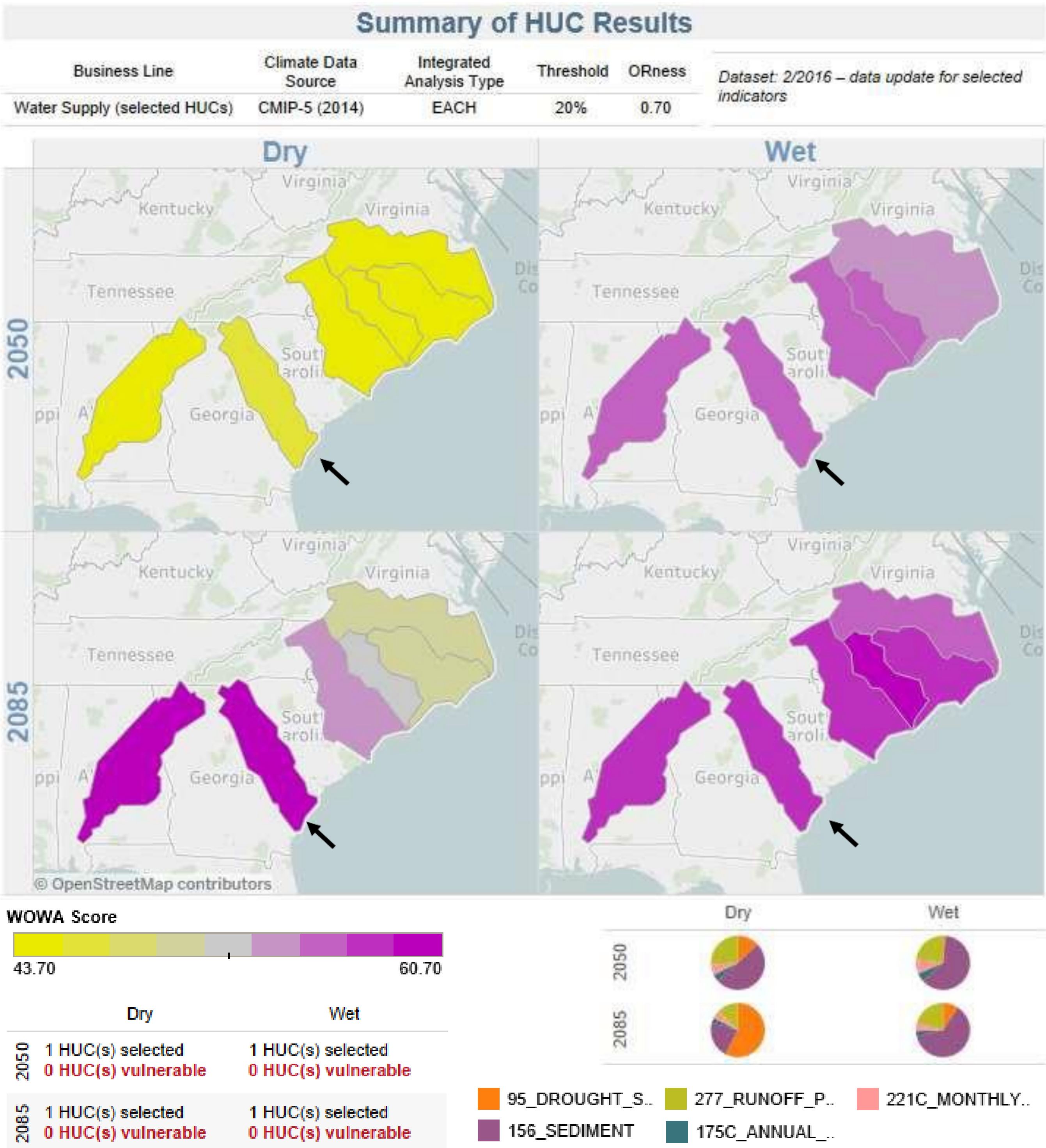


Figure 14: Results of the USACE climate vulnerability analysis for the Water Supply WOWA score of the Ogeechee-Savannah watershed (highlighted by the black arrow) compared to SAD.

Relative to the other HUC 04 watersheds in SAD, the Ogeechee-Savannah watershed is relatively less vulnerable to the impacts of climate change on Flood Reduction for both the wet and dry subsets of traces (Figure 15). For the Ogeechee-Savannah watershed, the major drivers of the computed flood risk reduction vulnerability score are, local and cumulative “Flood Magnification”, and the “Urban 500 YR Floodplain Area” (Table 6).

Table 6: Indicators associated with Flood Risk Reduction and their contribution to the WOWA scores.

Flood Risk Reduction					
Dry Scenario					
Indicator #	**2050 Value**	**2050 % Score**	**2085 Value**	**2085 % Score**	**% Change**
175C ANNUAL COV (Flow Variability)	1.66	3.79	1.62	3.66	-2.47
277 RUNOFF PRECIPITATION (Elasticity)	4.10	9.35	4.20	9.51	2.61
568C FLOOD MAGNIFICATION	19.51	44.55	19.74	44.66	1.17
568L FLOOD MAGNIFICATION	6.41	14.62	6.48	14.66	1.17
590 URBAN 500YR FLOODPLAIN AREA	12.13	27.69	12.16	27.51	0.23
Wet Scenario					
Indicator #	**2050 Value**	**2050 % Score**	**2085 Value**	**2085 % Score**	**% Change**
175C ANNUAL COV (Flow Variability)	1.54	3.23	1.57	3.23	1.96
277 RUNOFF PRECIPITATION (Elasticity)	4.20	8.80	4.09	8.41	-2.67
568C FLOOD MAGNIFICATION	22.48	47.09	23.21	47.71	3.26
568L FLOOD MAGNIFICATION	7.38	15.46	7.62	15.66	3.26
590 URBAN 500YR FLOODPLAIN AREA	12.13	25.42	12.16	24.99	0.23

Flood Risk Reduction

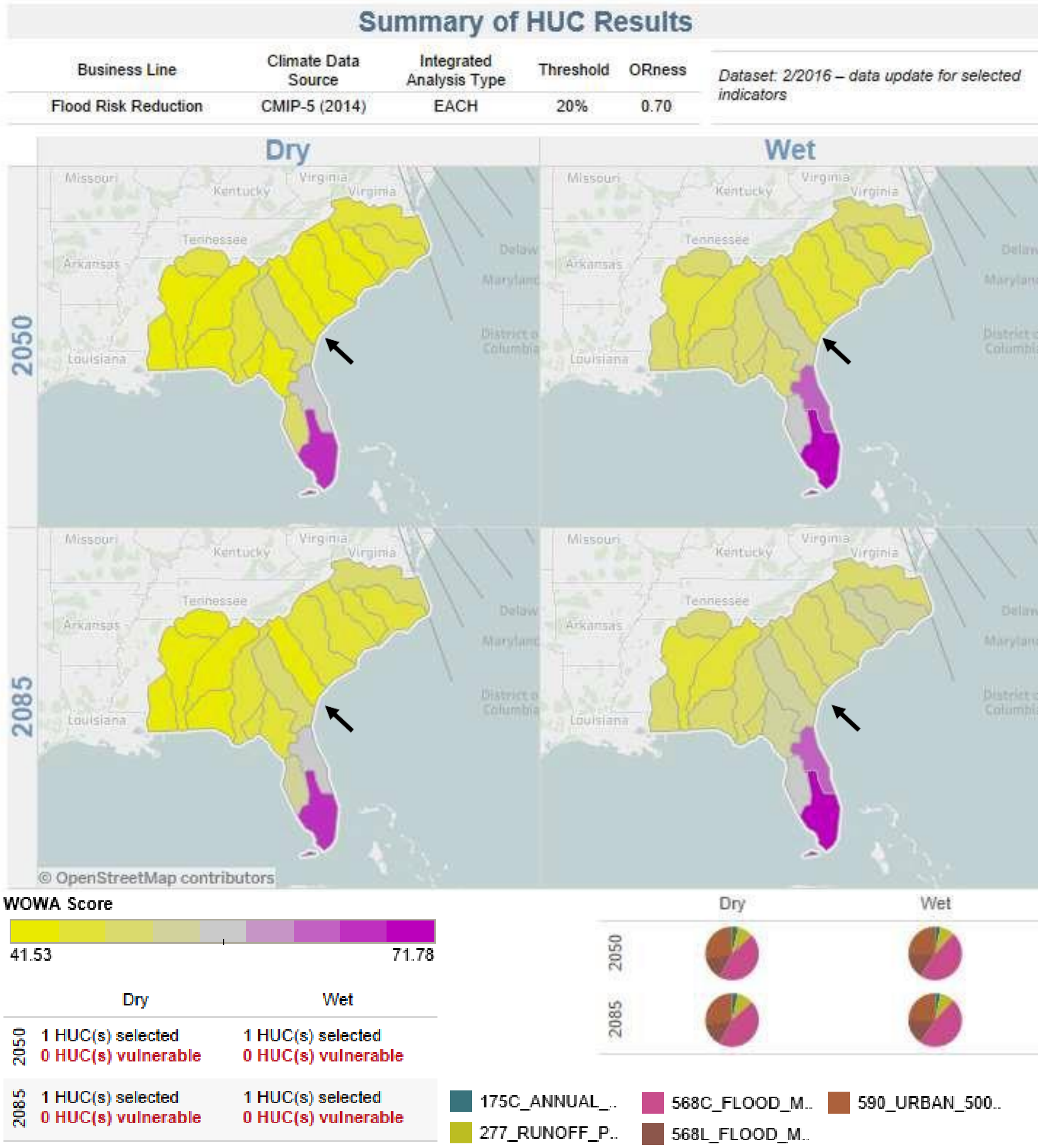


Figure 15: Results of the USACE climate vulnerability analysis for the Flood Risk Reduction WOWA score of the Ogeechee-Savannah watershed (highlighted by the black arrow) compared to SAD

1.4 First Order Statistical Analysis: Site Specific Trends and Nonstationarity Assessment
In accordance to Engineering Technical Letter (ETL) 1100-2-3, a series of twelve different nonstationarity detection tests were carried out on the peak annual discharge record collected at USGS gage 02197000 Savannah River at Augusta, GA using the USACE Nonstationarity Detection Tool. Maximum annual flow was chosen for this analysis. NSBLD Fish Passage is a mitigation project focused on creating a passageway for the Atlantic Sturgeon to reach spawning grounds. High flow is a strong signal for the fish to find their way upriver to the spawning grounds.

A “strong” nonstationarity is one for which there is a consensus among multiple nonstationarity detection methods, robustness in detection of changes in statistical properties, and relatively large change in the magnitude of a dataset’s statistical properties (USACE 2017). Output from the Nonstationarity Detection Tool offers insight into the following three key criteria related to each identified nonstationarity, which can be used to help the user select a homogenous dataset that can be further used for hydrologic analysis (Friedman et al 2018).

i. There is consensus surrounding a detected nonstationarity if the nonstationarity is detected by two or more detection methods of the same type (e.g. mean or variance/standard deviation or distribution). If consensus cannot be found for a given year or short period of time, then it is reasonable to discount it.

ii. A statistically significant nonstationarity can be considered robust when tests targeting changes in two or more different statistical properties (mean, variance/standard deviation and/or overall distribution) are indicating a statistically significant nonstationarity. While a robust nonstationarity is not necessarily stronger, it represents a multifaceted change in the record. This can be taken into consideration when deciding which portion of the period of record to use in order to perform hydrological analysis.

iii. An identified nonstationarity is also associated with a given magnitude of change in the mean or standard deviation/variance in the annual instantaneous peak streamflow datasets prior to and after the identified nonstationarity. Nonstationarities that are produced by greater changes in the statistical properties of the datasets before and after the identified nonstationarities may be important to take into consideration when performing subsequent hydrologic analysis.

Discharge data for the Savannah River at Augusta, GA (USGS gage 02197000), which includes an annual record of daily river flows from 1884 to present and a continuous annual instantaneous peak streamflow record from 1876 to present, is analyzed. The location of the Augusta gage is at the New Savannah Bluff Lock and Dam which is 0.2 miles upstream from Butler Creek, and 12 miles downstream from the city of Augusta, GA. The Savannah River at Augusta, GA gage is impacted by regulation.

The upper natural river system above the Savanah gage has been fragmented by a series of reservoirs, including three large federal reservoirs (from upstream to downstream: Hartwell Lake, Richard B. Russell Lake, and J. Strom Thurmond Lake). These reservoirs are operated for hydropower, water supply, recreation, and to a limited degree for flood control. River flows at Augusta and New Savannah Bluff Lock and Dam (NSBLD) are most significantly impacted by J. Strom Thurmond Dam (completed in 1954). During normal operating conditions, flows range from 3,600 cfs to around 8,000 cfs at NSBLD, though there is daily and even hourly variability in flow due in large part to hydropower generation at Thurmond.

In addition to the effects of the three, large upstream reservoirs, flows are impacted to a lesser extent by Stevens Creek Dam. Stevens Creek Dam, built in 1916 and located between Thurmond Dam and Augusta/NSBLD, impounds a minor run-of-the-river reservoir. Stevens Creek Dam and other dams upstream of Hartwell Lake have little impact on flood discharges at Augusta/NSBLD.

The Savannah River at Augusta, GA gage has a total upstream drainage area of 7,510 square miles and a local drainage area of 1,329 square miles between the NSBLD and J. Strom Thurmond Dam. J. Strom Thurmond Dam is located approximately 25 miles upstream of NSBLD. The NSBLD is a run-of-river project and provides no flood control benefits. The NSBLD was constructed in 1937 for the purpose of navigation. This project purpose has since been de-authorized.

Figure 16 shows the annual instantaneous peak streamflow time series obtained from the USGS website. A visual examination of this time series suggests that there have been changes in the annual instantaneous peak streamflow record over the past 150 years. In particular, the values prior to the 1950s are on average higher than later years. Examination of the metadata associated with this record indicates that the construction of the J. Strom Thurmond Dam was completed around 1954. Based on this information, a priori knowledge exists that an abrupt change occurred in the early nineteen fifties due to construction of the J. Strom Thurmond Dam. Therefore, the next step in the analysis is to formally test whether a nonstationarity exists in the annual instantaneous peak streamflow record observed at Savannah River at Augusta, GA in the early fifties.

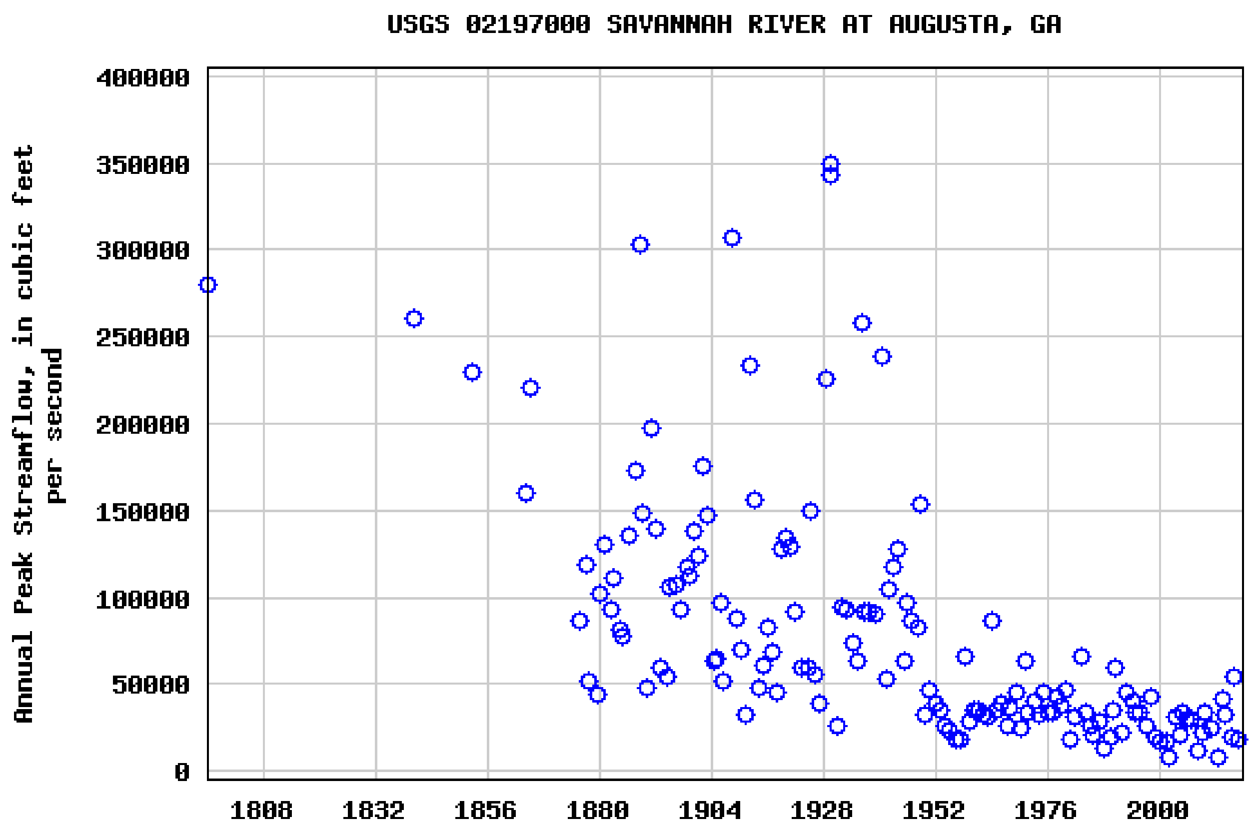


Figure 16: Annual peak streamflow time series for the Savannah River at Augusta, GA (USGS ID 02197000)

Figure 17 shows the results of the nonstationarity analysis. Statistically significant nonstationarities are shown as black lines in the top graph. The heatmap (middle graph) indicates which nonstationarity detection test identified a statistically significant nonstationarity. As shown in Figure 17 below, although a statistically significant, nonstationarity was detected by the Mood (CPM) test in 1926 and 1931 and by the Energy Divisive Method in 1985, there is no consensus between the statistical tests at these points in time so it can be concluded that there are no operationally significant nonstationarities in the flow record at those times (Friedman, et al. 2018). However, eight of the twelve statistical tests show statistically significant nonstationarities between 1948 and 1950 and three of the twelve statistical tests indicate a statistically significant nonstationarity in 1998 (Figure 17).

The detected nonstationarity circa 1950 can be considered strong because there is consensus between statistical tests targeting a change in mean (three tests) and overall distribution (four tests). The 1998 nonstationarity is robust because tests targeting changes in mean, overall distribution and variance (one test) are all indicating a nonstationarity. There is a significant decrease in the segment mean between the pre and post 1948-1950 portions of the period of record. Between 1948 and 1950, the mean annual instantaneous peak streamflow decreases from approximately 100,000 cfs to approximately 25,000 cfs. There is also a notable decrease in the variability associated with the peak streamflow record (reduced standard deviation/variance). Both a decrease in mean and variance is anticipated due to the construction of J. Strom Thurmond Dam.

The detected nonstationarity in 1998 can be considered strong because there is consensus between statistical tests targeting a change in overall distribution (two tests). The 1998 nonstationarity is robust because tests targeting changes in mean, overall distribution (one test) and variance (one test) are all indicating a nonstationarity. A smaller decrease in segment mean and variance is exhibited between the portions of the period of record prior to and after 1998. Even when the time series is limited to the portion of the period of record post the construction on the J. Strom Thurmond Dam, four statistical tests still indicate a change in the statistical properties (most notably a reduction in mean) of the flow record around 1998.

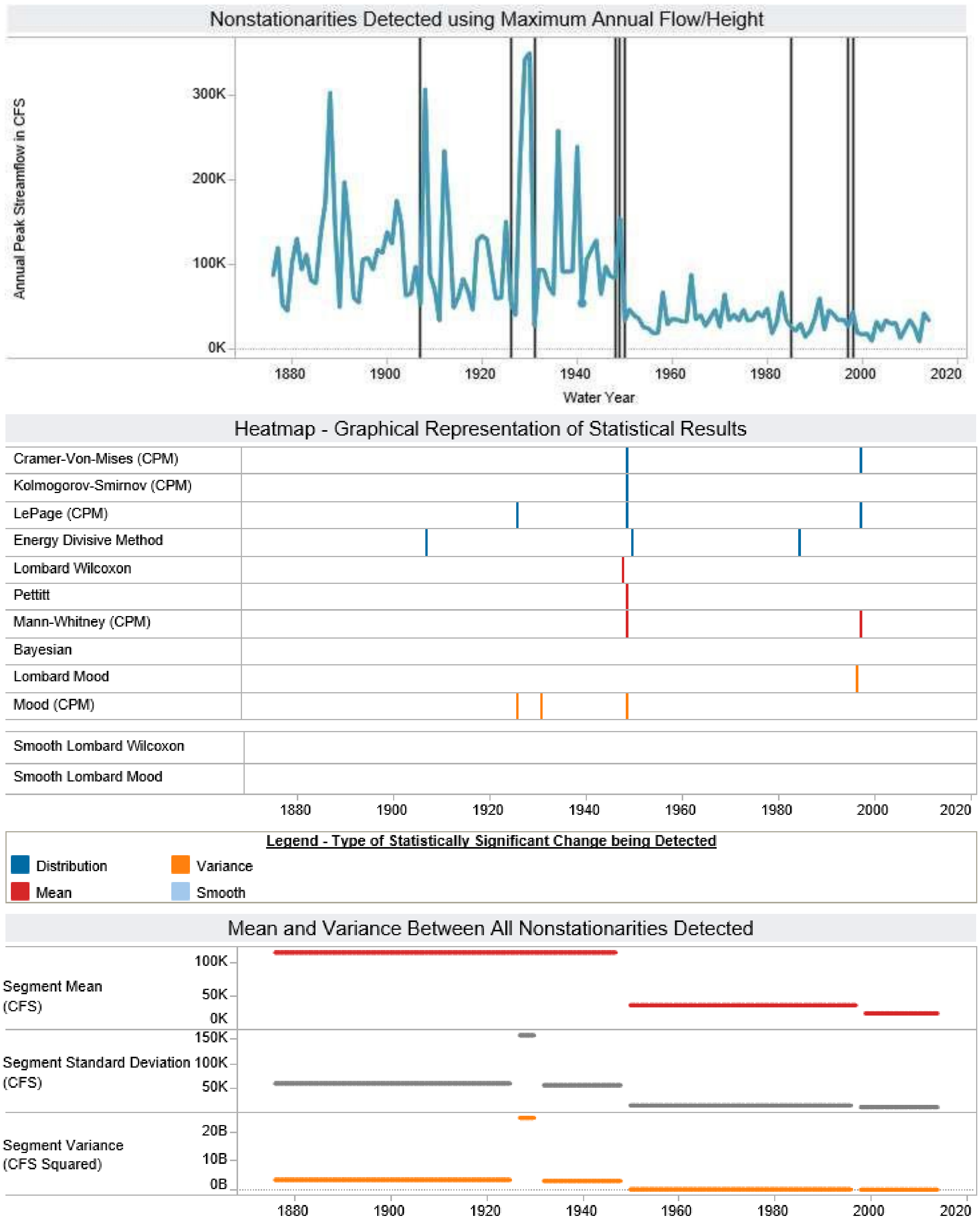


Figure 17: Nonstationary Analysis of Peak Annual Discharge for the Savanah River at the Augusta, GA USGS gage (Gage Number 02197000) from 1876 to 2014.

The next portion of the analysis consists of assessing the data for monotonic trends. The Entire continuous period of record was analyzed. Because two strong, statistically significant nonstationarities are detected circa 1950, and in 1998 the data was also divided into three segments or periods of record:

- Entire continuous, period of record: 1876-2014
- 1876-1949 (Before J. Strom Thurmond Dam)
- 1950-2014 (After J. Strom Thurmond Dam)
- 1998-2014 (After J. Strom Thurmond Dam and post – 1998 nonstationarity detection)

To assess monotonic trends within these subsets of the flow record, the trend analysis tab within the USACE Nonstationarity Detection Tool was used. This tool performs multiple statistical tests to detect the presences of monotonic trends in the annual instantiations peak streamflow record. Initially, the entire period of record from 1876 to 2014 was assessed for trends. A statistically significant decreasing trend is identified within the data (see Figure 18).

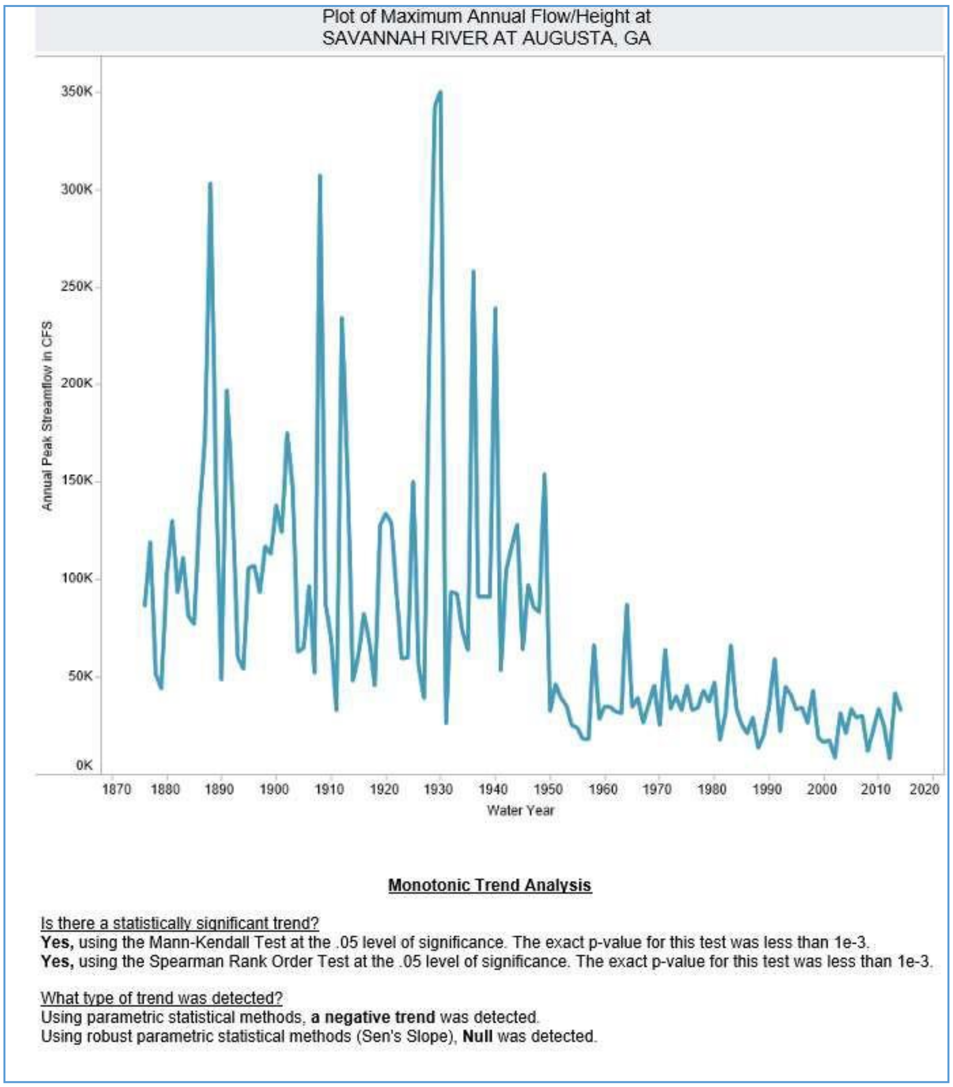


Figure 18. Monotonic Trend Analysis: Period of Record 1876-2014

If the dataset is separated into a statistically homogenous subset of flow data prior to the construction of the J. Strom Thurmond Dam (1876-1949), there is not an overall, statistically significant, monotonic trend in the annual instantaneous peak streamflow record for the Savannah River at Augusta (Figure 19).

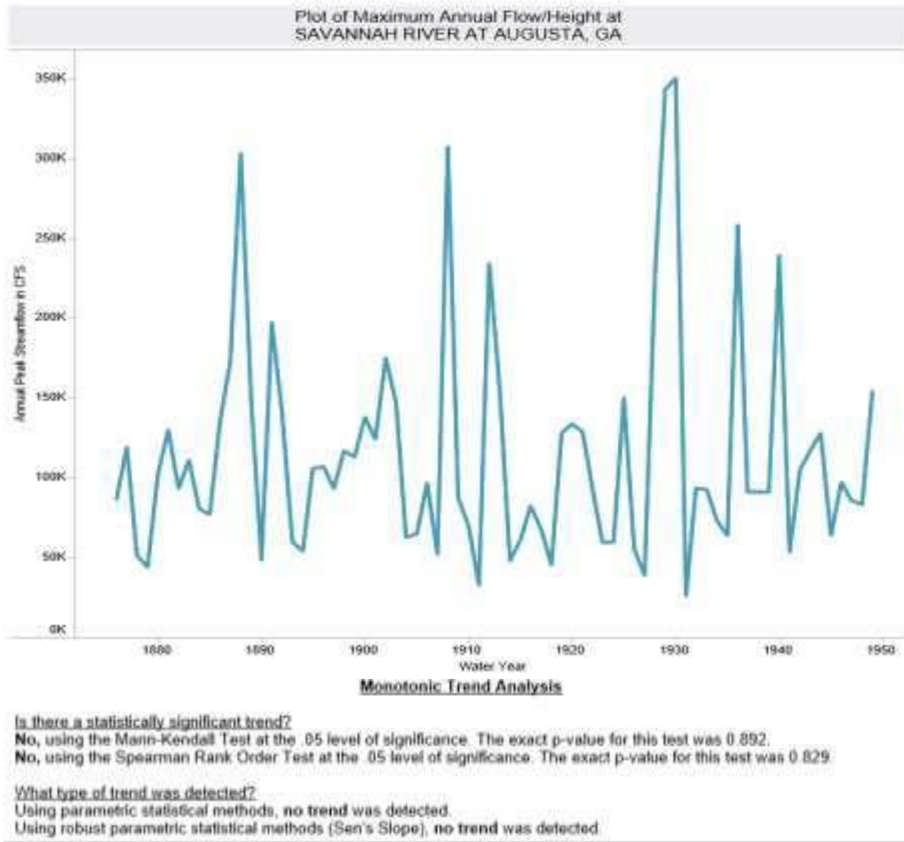
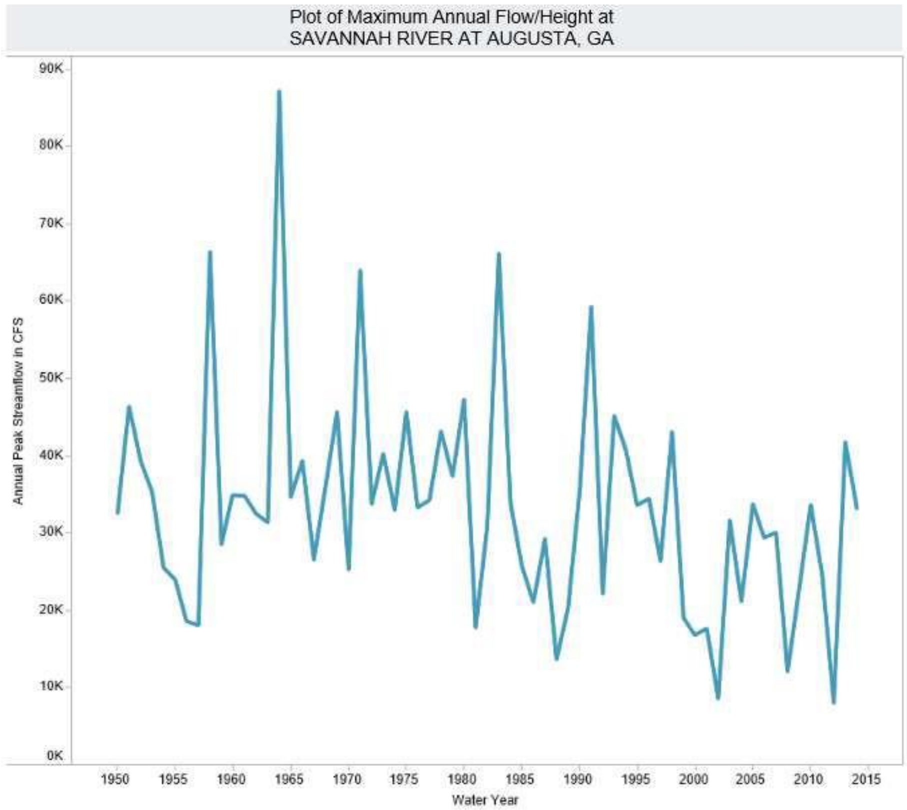


Figure 19: Trend Analysis for the Savannah River at Augusta gage before the J Strom Thurmond Dam was constructed (1876-1949; P-value > 0.05).

If the nonstationarity in 1998 is disregarded and a monotonic trend assessment is applied for the entire portion of the period of record post the construction of the J. Strom Thurmond Dam (1950-2014), a statistically significant, decreasing trend is still detected in the subset of data. This lends further credibility to the nonstationarity detected in 1998. (Figure 20)



Monotonic Trend Analysis

Is there a statistically significant trend?
Yes, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.020.
Yes, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.019.

What type of trend was detected?
Using parametric statistical methods, **a negative trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **Null** was detected.

Figure 20. Trend Analysis for the Savannah River at Augusta gage after the construction of J. Thurmond Dam (1950-2014; P-value <0.05).

Taking the nonstationarity identified in 1998 back into consideration, the monotonic trend assessment from 1998 – 2014 finds no statistically significant, monotonic trend in the annual instantaneous peak streamflow record for the Savannah River at Augusta. (Figure 21)

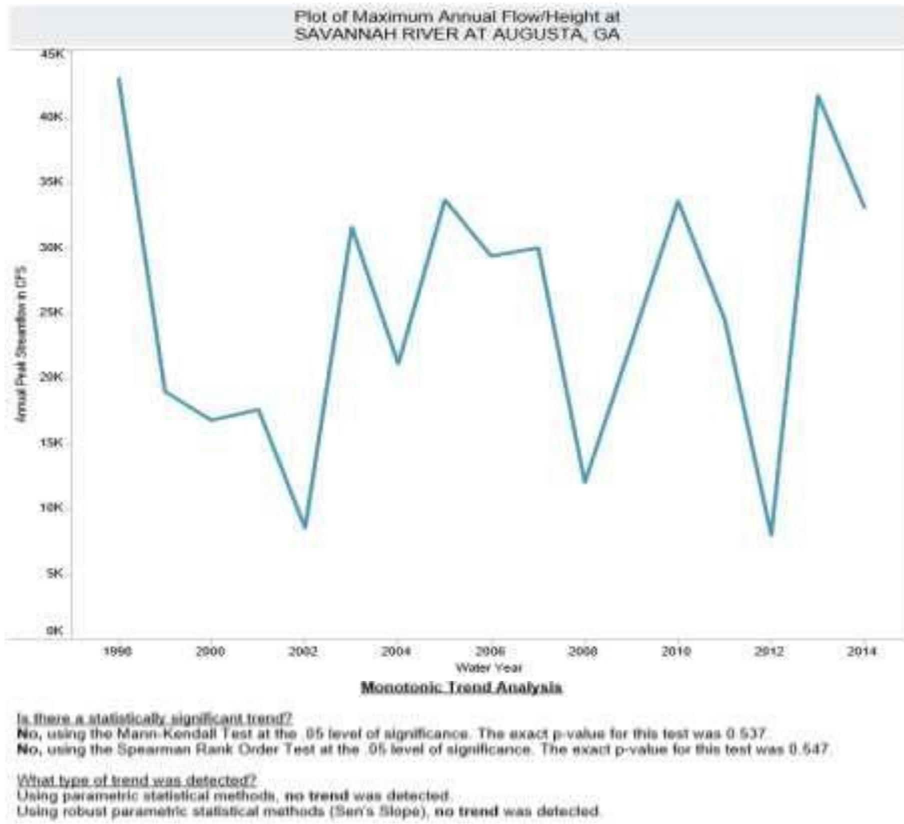


Figure 21: Trend Analysis for the Savannah River at Augusta gage after the significant drought of record in 1998 (1998-2014; P-value > 0.05).

The significant nonstationarity detected circa 1950 can be attributed to the construction of the J. Strom Thurmond Dam located 34 miles north of Augusta, GA. The dam was constructed between 1946 and 1954 and was officially completed July 1954. Post dam construction, the range in maximum annual flow height is greatly reduced as shown in Figures 17 and 18. It is also clear from the large change in the segment mean and notable decrease in variance/standard deviation pre and post dam construction that the J Strom Thurmond Dam construction is a significant driver of nonstationarity in the flow record collected at the Augusta, GA gauge (02197000).

It is difficult to attribute the nonstationarity detected in 1998 to a specific cause. However, a notable Drought of Record that lasted several years began in 1998. This notable drought led to the USACE updating the Drought Plan for the J Strom Thurmond Dam and Lake Project.

Due to the Savannah River at Augusta, GA gage being impacted by regulation, a second set of analyses were completed on the Broad River near Bell, GA (USGS gage 02192000), an unregulated stream within the Ogeechee-Savannah Watershed (Figure 22). The Broad River near Bell, GA gage is located 12 miles southeast of Elberton, GA and has a drainage of 1,420 square miles. The Broad River reaches its confluence with the Savannah River at Russell Lake, upstream of J. Strom Thurmond Reservoir. Figure 22

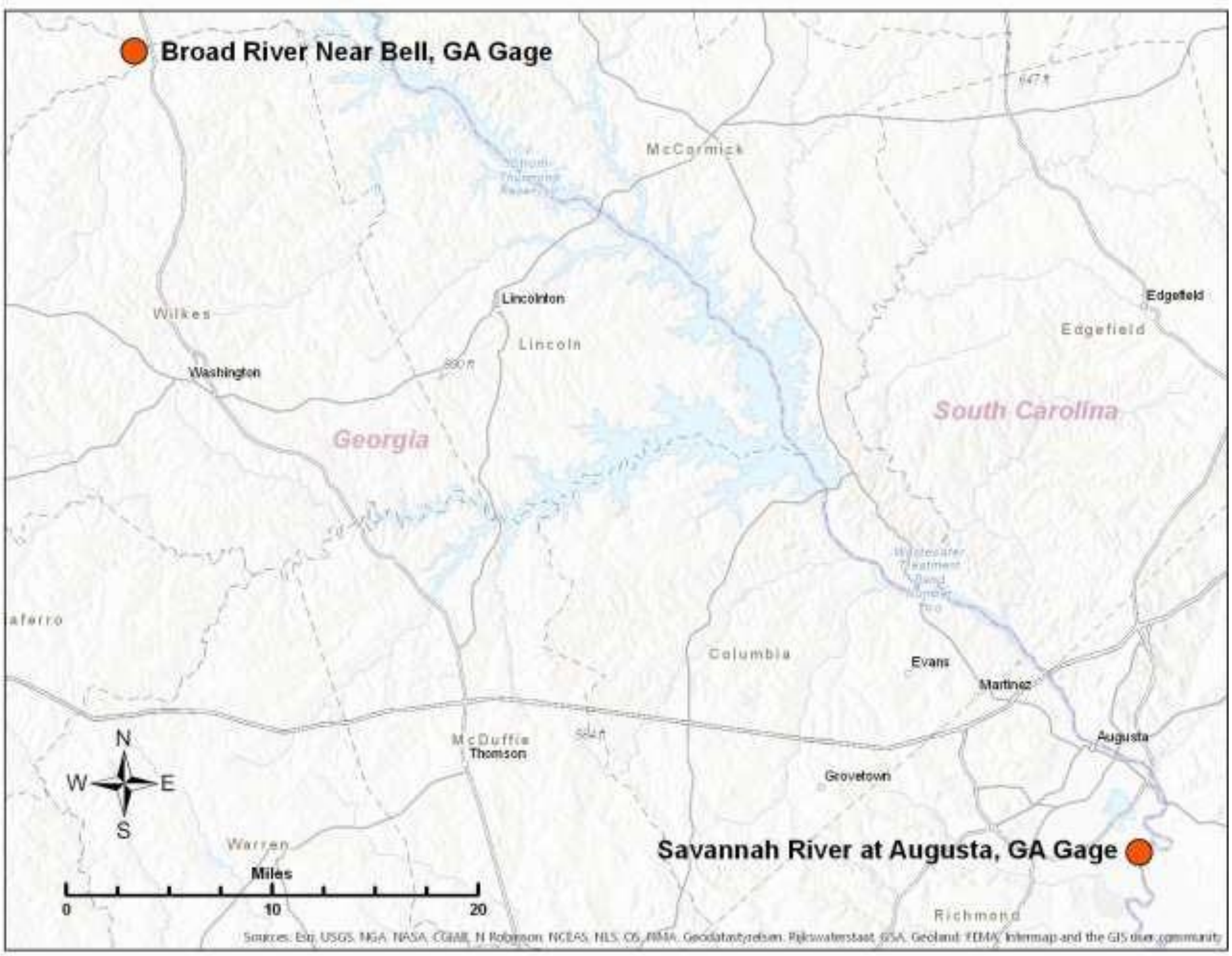


Figure 22: Map depicting the locations of the Broad River near Bell, GA gage and the Savannah River at Augusta, GA Gage.

The dates analyzed for the continuous portion of the period of record, from 1938 to 2014. Data is also available for water years 1908, and 1927-1932 (Figure 23). By completing this second analysis on an unregulated stream, more insight can be gained into whether or not the nonstationarities being detected at Augusta area solely caused by J. Strom Thurmond Dam or if the nonstationarities might be at least be in part driven by another source of change in the basin like anthropogenic climate change.

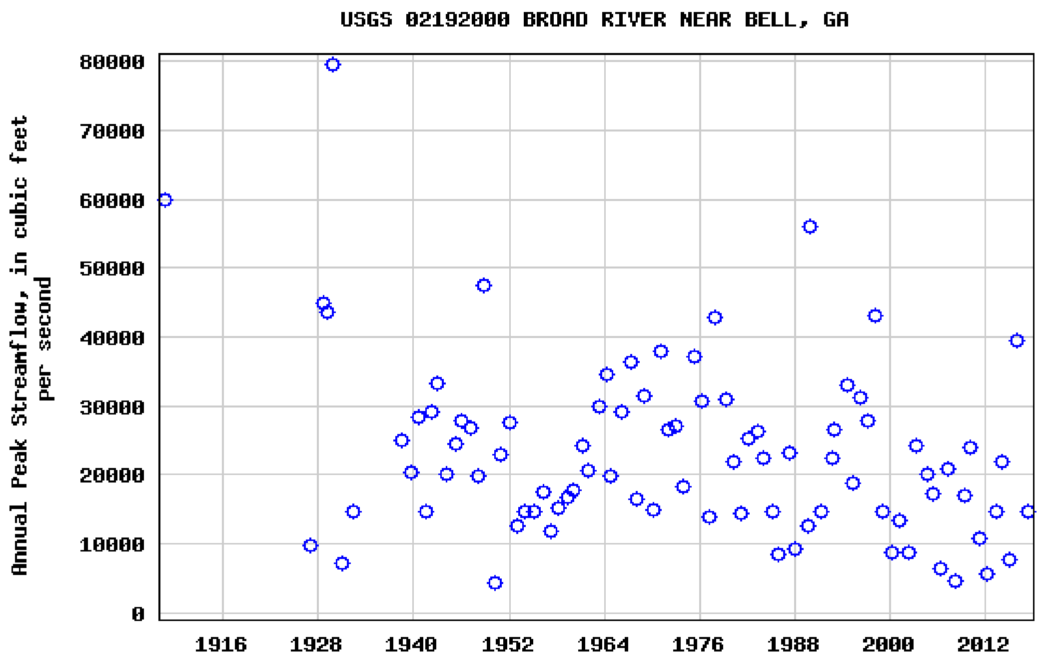


Figure 23: Annual peak streamflow time series for the Broad River near Bell, GA (USGS ID 02192000)

Figure 24 shows the results of the nonstationarity analysis for the Broad River near Bell, GA. Statistically significant nonstationarities are shown as black lines in the top graph. The heatmap (middle graphic) indicates which nonstationarity detection test identified a statistically significant nonstationarity. As shown in Figure 20 below, although statistically significant nonstationarities are detected by the Bayesian test in 1948, 1949, 1989 and 1990 and by the Lombard Wilcoxon test in 1985, there is no consensus between the statistical tests at these points in time so it can be concluded that there are no operationally significant nonstationarities in the flow record at those times (Friedman, et al. 2018). However, five of the twelve statistical tests show statistically significant nonstationarities around 1998. There is consensus between four statistical test targeting changes in the mean of the dataset. This nonstationarity can be considered robust because statistical tests which detect changes in the mean and the overall distribution (the Cramer Von Mises Test) are indicating a nonstationarity. There is a significant decrease in the segment mean in the pre and post 1998 portion of the period of record. Around 1998, the mean of the annual instantaneous peak streamflow record decreases from approximately 25,000 cfs to approximately 14,500 cfs.

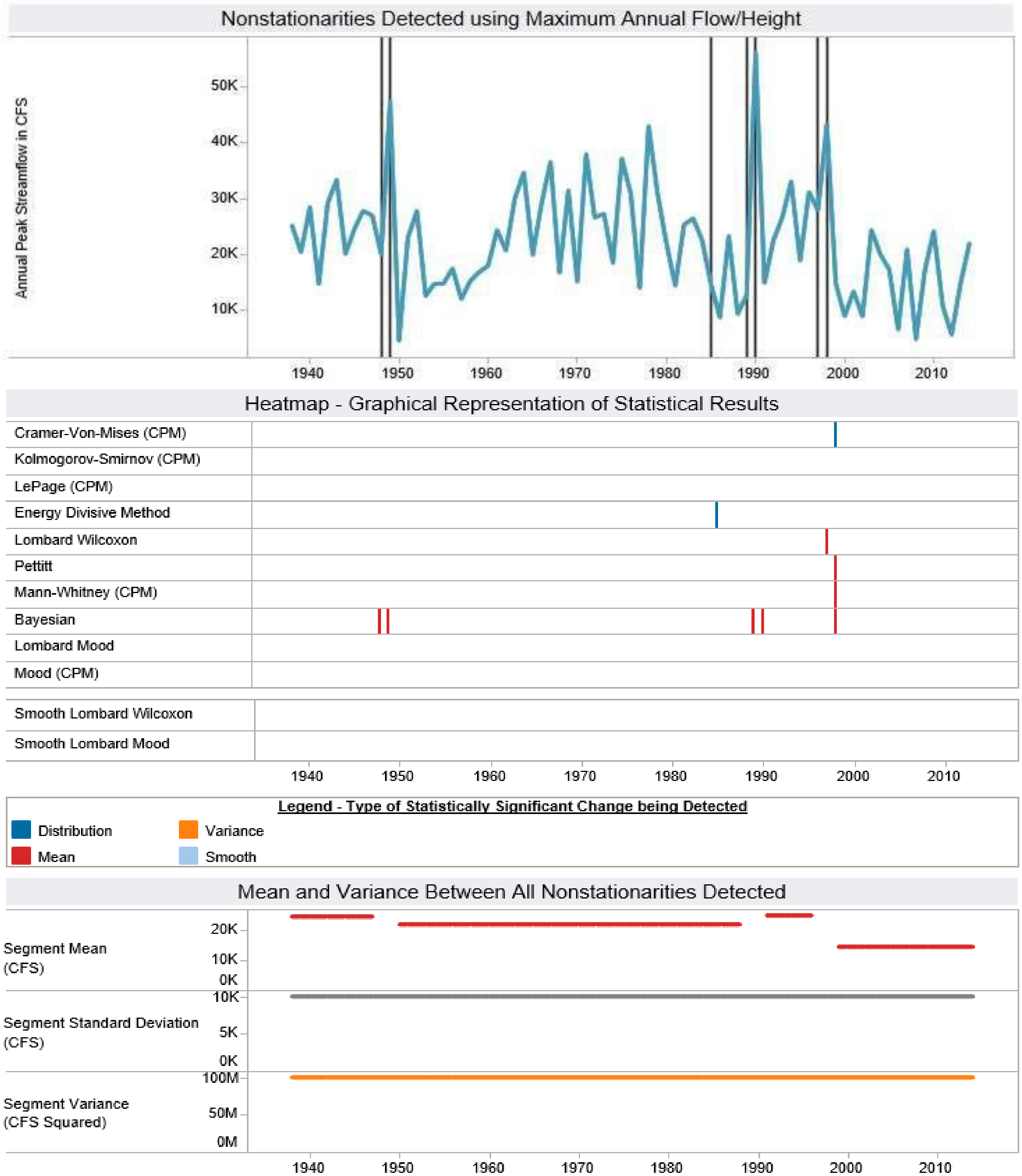
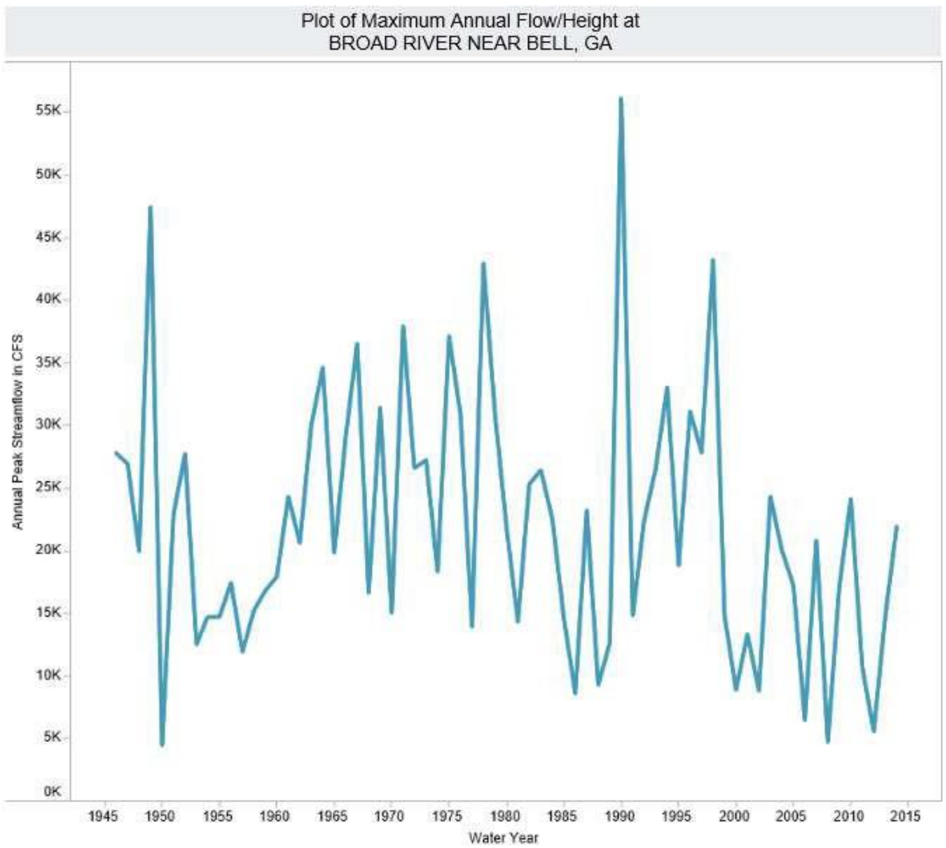


Figure 24: Nonstationary Analysis of Peak Annual Discharge for the Broad River near Bell, GA USGS gage (Gage Number 02192000) from 1938 to 2014.

The next portion of the analysis consists of assessing the data for monotonic trends. A monotonic trend test is conducted for the entire, continuous period of record and for two subsets of data thought to be representative of homogenous hydrologic conditions. Because a strong, statistically significant nonstationarity was detected around 1998, the data were divided into two statistically stationary (homogenous) segments or periods of record based on the nonstationarity period identified:

- 1938-2014 (Entire Period of Record)
- 1938-1997
- 1998-2014

As completed with the Savannah River at Augusta, GA gage, to assess monotonic trends within these subsets of the flow record, the trend analysis tab within the USACE Nonstationarity Detection Tool was used. Interestingly, there are no statistically significant trends the dataset when the entire period of record is analyzed (Figure 25).



Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.102.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.083.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Figure 25. Trend Analysis for the Broad River near Bell gage for the entire period of record (1938-2014, P-value>0.05)

If the dataset is separated into statistically homogenous subsets of flow data pre and post the 1998 nonstationarity detected, there are no, statistically significant, monotonic trends in the subsets of the annual instantaneous peak streamflow record for the Broad River near Bell, GA (Figures 26 and 27).

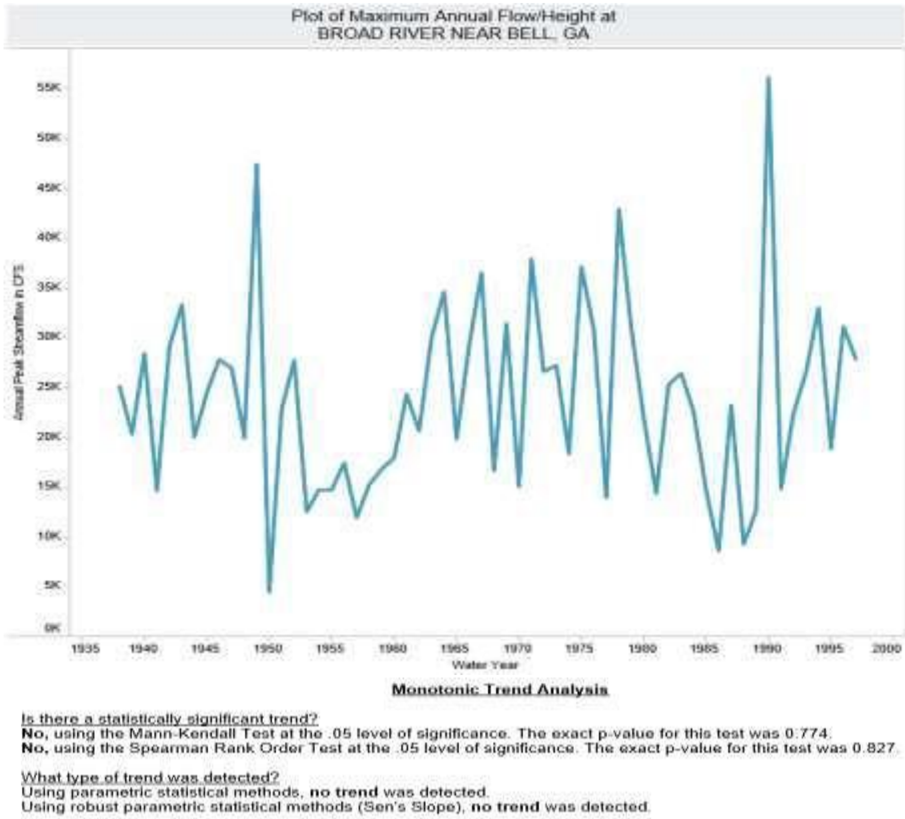


Figure 26: Trend Analysis for the Broad River near Bell gage before the significant drought of record in 1998 (1938-1997; P-value > 0.05).

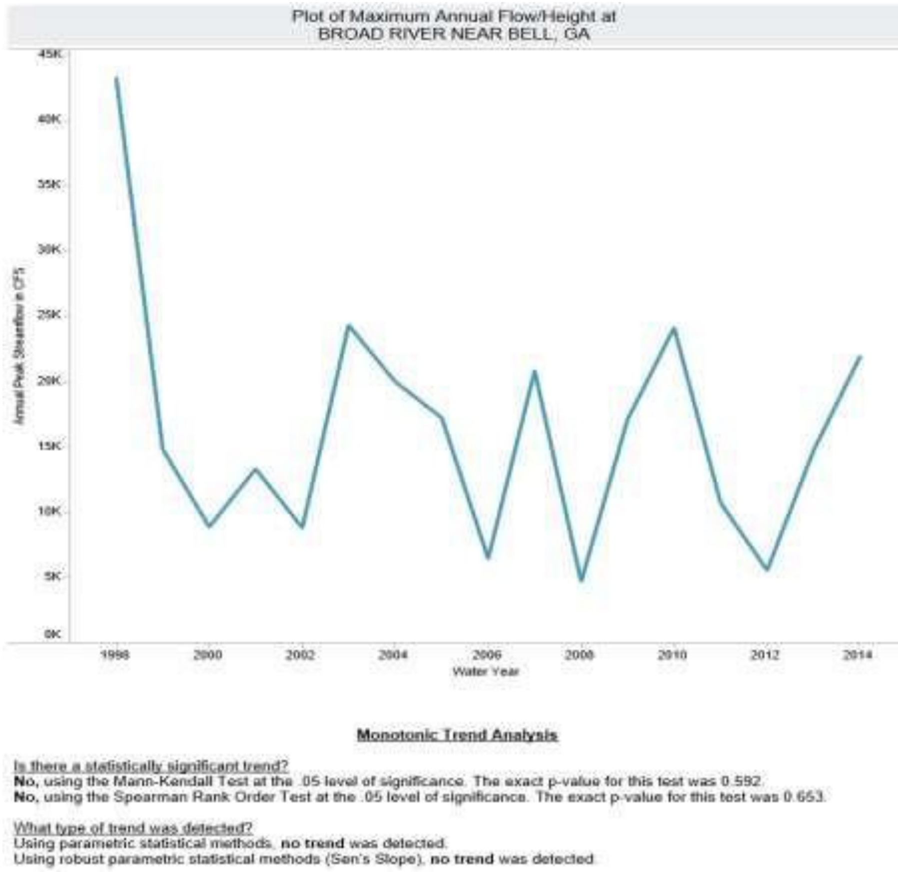


Figure 27: Trend Analysis for the Broad River near Bell, GA gage after the significant drought of record in 1998 (1998-2014; P-value > 0.05).

Based on the results of the second nonstationarity detection analysis carried out for an unregulated river in the vicinity of the study area, it can be more definitively concluded that the construction of the J Strom Thurmond Dam is the driver of the nonstationarity detected at the Savanah gage circa 1950. Additionally, it can be concluded that the period of record prior to 1998 can likely be considered representative of relatively homogenous hydro-climatic conditions.

The 1998 nonstationarity detected at the regulated Savanah gage, was also detected at the unregulated Broad River gage. However, no significant linear trend in the dataset is detected when the entire period of record is used at the Broad River gage. A significant drought occurred in the basin in 1998. As noted before, this drought led to the USACE updating the Drought Plan for the J Strom Thurmond Dam and Lake Project.

Besides high flow, another important trigger for migration of Atlantic sturgeon upriver is water temperature. Atlantic sturgeon are triggered to spawn during the fall when water temperatures fall below 25˚C (Ingram and Peterson, 2016). Fall was considered the months of September through December for this analysis. To analyze if there are any trends in fall water temperature at the project site, annual fall water temperature data was gathered from the Savannah River at Augusta, GA gage. The gage's temperature data was collected from 1973-1992 (missing 4 years). A Mann-Kendall test was performed using the Kendall Package in R to look for significant trends in the data (McLeod 2011; R Core Team 2018). Since the 1970's there are no significant trends being detected for fall water temperature in the project area (Figure 28, P-value > 0.05).

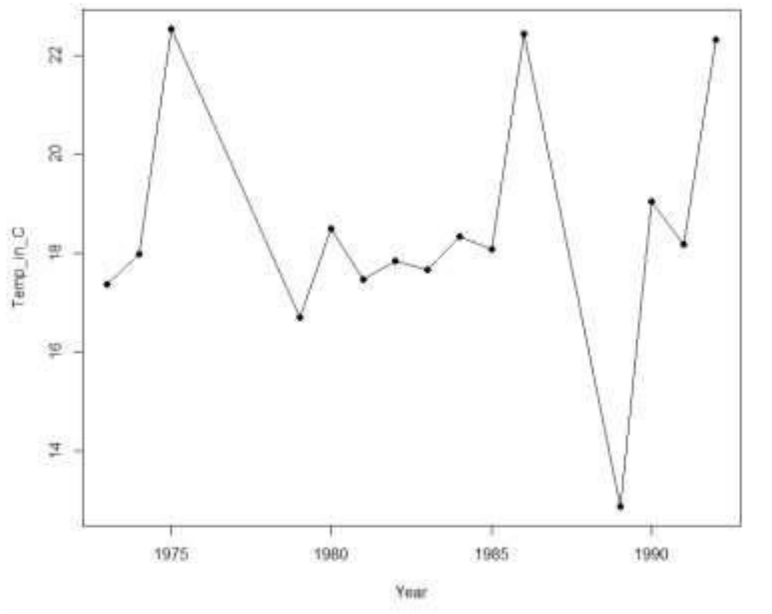


Figure 28: Average Fall temperatures for the Savannah River at Augusta, GA gage (1973-1992).

1.5 Summary and Conclusions

Based on the results of the USACE Vulnerability Assessment Tool, relative to the other 201 HUC04 watersheds in the continental United States, the Ogeechee-Savannah watershed isn't highly vulnerable (top 20% of CONUS watersheds) to the impacts of climate change on any of the four business lines evaluated (Ecosystem Restoration, Recreation, Water Supply, or Flood Risk Reduction). The results of the vulnerability assessment do not imply that the Ogeechee-Savannah watershed will not be impacted by climate change, but rather that climate change will have comparatively less of an impact in the Ogeechee-Savannah watershed relative to its impact on other HUC04 watersheds in the U.S. Climate change could affect the operating objectives of the recommended alternative both negatively and positively. How climate change will impact Sturgeon migration is complex. While occasional flooding can be beneficial to the ecosystem and floodplain, it could also negatively affect fish migration if flows in the river become prohibitive to the fish being able to swim upstream. Significant droughts in the basin could also negatively affect fish migration due to insufficient streamflow for adequate spawning pool depths in the sturgeon breeding grounds like Augusta Shoals. None of the evaluated project alternatives would be impacted positively or negatively more so, than another by climate change effects.

A review of climate change literature specific to the region suggests a strong trend towards warmer climate and a less pronounced trend towards more extreme precipitation in the future. Temperature trends within the state of Georgia are consistent with trends observed throughout the region. The state of Georgia is likely to experience more extremes in the future in terms of both increased precipitation and droughts.

Projected climate changed hydrology for the Savanah Basin indicates that streamflow could potentially increase in the future. Two annual instantaneous peak streamflow gages, representative of both regulated and unregulated watershed conditions, were evaluated for site specific trends and nonstationarities. The regulated gage showed two instances of nonstationarity: one in 1950 and one in 1998. The 1950 nonstationarity is attributed to the construction of J. Strom Thurmond Dam. Compared to the period of record prior to 1950, the flow record post-construction of the dam has a significantly lower mean and less variability. The nonstationarity detected in 1950 is only flagged within the regulated record.

Both the regulated and unregulated records contain a nonstationarity detected in 1998. The 1998 nonstationarity coincides with the onset of a severe, prolonged drought in the Savannah River Basin. The mean annual instantaneous peak streamflow decreased when the periods of record prior to and post 1998 are compared. If the dataset is separated into statistically homogenous subsets of flow data prior to the J. Strom Thurmond Dam, and post the 1998 nonstationarity, there is not an overall, statistically significant, monotonic trend in the annual instantaneous peak streamflow record for the Savannah River at Augusta. An assessment was carried out to see if trends are apparent within water temperature records in the study area, but no trend was found

It is unlikely that changes in flow rates and variability over time will be operationally significant due to the large impact the J. Strom Thurmond Dam has on flow rates in the project area (Figure 17). Since the construction of the J Strom Thurmond Dam, flow rates through the project area have not exceeded 100,000 cfs; an amount that was topped over 15 times prior to dam construction (1900 – 1948). During droughts, Thurmond Dam operates according to an approved Drought Management Plan (DMP). The DMP provides adequate in-stream flow for fish and wildlife and has been approved by all appropriate state and federal agencies.

The Tentatively Selected Plan (TSP) for the project is Alternative 2-6, Alternative 2-6 includes a fixed crest weir with a rock ramp sloping upstream from the existing dam location with a floodplain bench for high stage flood conditions. Table 7 identifies potential hazards that could be caused due to climate change effects to the tentatively selected project, the harms associated with those effects, and the qualitative likelihood of this harm being realized.

Table 7: Identified climate risks for recommended alternative, 2-6d.

Feature of Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Alternative 2-6d: Fixed crest weir with a flood plain bench	Increased precipitation from larger, slower-moving storms	Some hazard exists with greater than 30,000 cfs flows as to whether the weir may need repair following the event	If the weir is damaged to the point that the water elevation is reduced, municipal and industrial water supply intakes may be impacted	Not Likely
Alternative 2-6d: Fixed crest weir with a flood plain bench	Decreased precipitation or increased severity of drought	Because the water releases are controlled from the upstream reservoir based on the Drought Management Plan, flows below 3,600 cfs are not likely	Water supply intakes are not impacted at 3,600 cfs flows, however they would be impacted with in-stream flows less than 3,600 cfs	Not Likely

The New Savannah Bluff Lock and Dam Fish Passage project is a mitigation project and thus falls mostly under the Corps' Ecosystem Restoration business line. By choosing to remove the Lock and Dam structure, the USACE is attempting to improve ecological conditions, thus counteracting any potential, future, negative impacts the Savannah watershed might experience in the face of a changing climate. Further, impacts associated with climate change are not likely going to affect either the primary objective of the project, which is to allow fish to access their native breeding grounds, or some of the project constraints (sustain water supply, maintain recreation benefits, prevent an increase in flood risk) because there exists a significant water management structure upstream which is able to moderate for both low and high flow conditions. All alternatives considered would be impacted by climate change in a similar manner. In order for the project to adversely compound the impacts of climate change on the study area, significant increases or decreases in precipitation would have to occur-beyond what could be managed by the upstream projects. Based on the literature review, first order statistical analysis and the vulnerability assessment it is unlikely that changes of this magnitude will occur within the next 100 years. For this reason, resilience measures for climate change are not suggested to be included in the recommended alternative, 2-6d, during the design phase.

The training wall and pile dikes are minor features in comparison to the NSBLD. The recommended plan to remove the training wall and associated pile dikes is not likely to have impacts associated with climate change due to the aforementioned reasons that applied to NSBLD Fish Passage project.

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