Mississippi Valley Division,
Regional Planning and Environment Division South

Memphis Metropolitan Stormwater – North DeSoto County Feasibility Study, DeSoto County, Mississippi

Appendix H – Climate Change Assessment for DeSoto County, Mississippi

December 2022

CONTENTS

LIST OF TABLES

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

Section 1

Climate Change Assessment for DeSoto County, Mississippi

1.1 INTRODUCTION

Engineering and Construction Bulletin (ECB) 2018-14, rev. 1 (September 10, 2020) provides guidance for incorporating climate change information in hydrologic analyses in accordance with the USACE overarching climate preparedness and resilience policy and ER 1105-2-101.The ECB guides a qualitative analysis of potential climate change threats and impacts that may be relevant to USACE hydrologic analyses taking into consideration shifting natural climate variability.

The formal analyses outlined in the guidance result in better-informed planning and engineering decisions. Further implementation guidance may arise following the issuance of EO 14008, Tackling the Climate Crisis at Home and Abroad was issued on January 27, 2021, which emphasizes climate change considerations be incorporated in planning and programmatic documents.

The overall purpose of this assessment was to better understand possible future without project conditions and assess if resilience is likely needed to be built into the project.

Measures that were investigated for the original Tentatively Selected Plan (TSP)/Locally Preferred Plan (LPP) were related to functions under the Flood Risk Reduction and Ecosystem Restoration business line items.

Flood Risk Management Original NED/TSP. This plan included the channel enlargement, a single detention basin on Lateral D (a tributary of Horn Lake Creek), combined with nonstructural aggregation to address residual flooding. The original Locally Preferred Plan, which is also the original TSP included the channel enlargement, floodwall/levee, three detention basins (one on each of three tributaries of Horn Lake Creek), combined with nonstructural aggregation to address residual flooding.

Flood Risk Management Recommended NED/TSP. The original plan was scaled down to the recommended plan which includes a levee and floodwall along with voluntary dry floodproofing for identified residential and commercial structures.

National Ecosystem Restoration (NER) TSP. The National Ecosystem Restoration (NER) plan maximizes ecosystem restoration benefits compared to costs. The NER plan includes a bank stabilizing system of grade control structures coupled with riparian restoration on eleven streams (Camp, Cane, Horn Lake, Hurricane, Johnson, Lick, Mussacuna, Nolehoe, Nonconnah, Red Banks, and Short Fork Creeks). Figures H:1-1 and H:1-2 below shows the project features for each business line item.

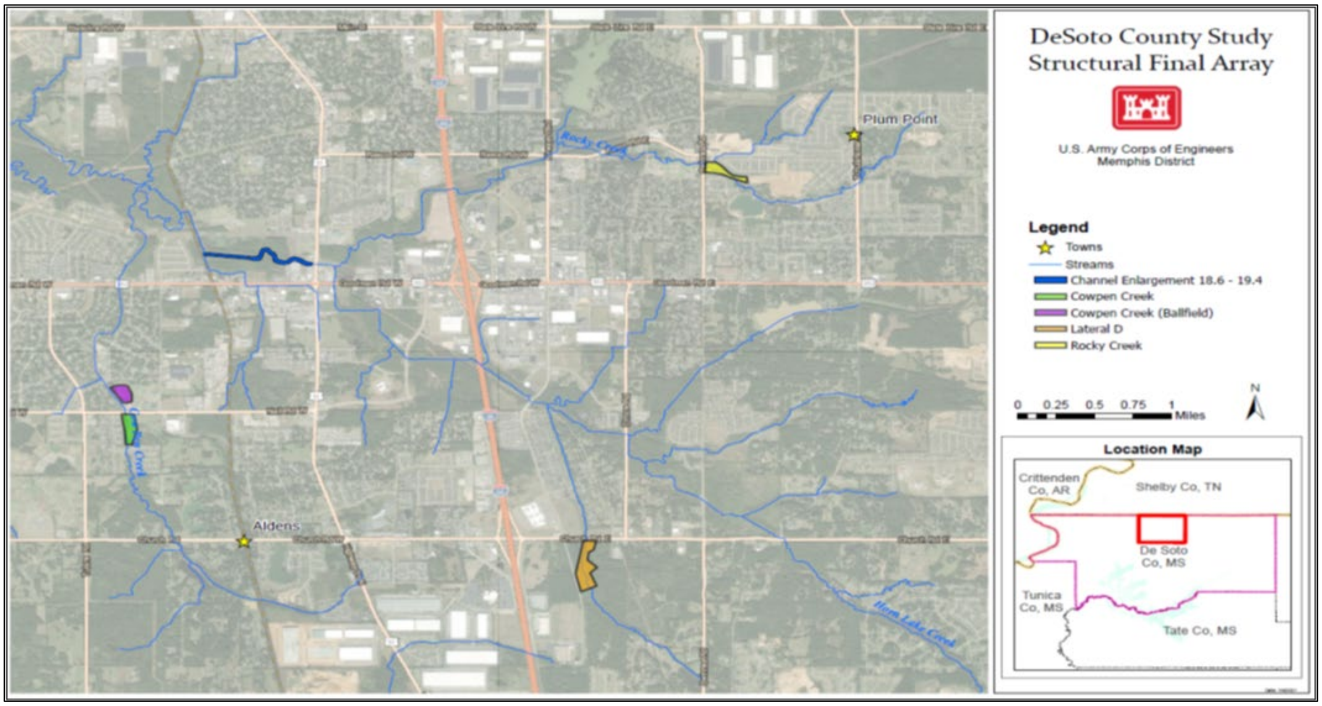


Figure H:1-1 FRM Structural Final Array

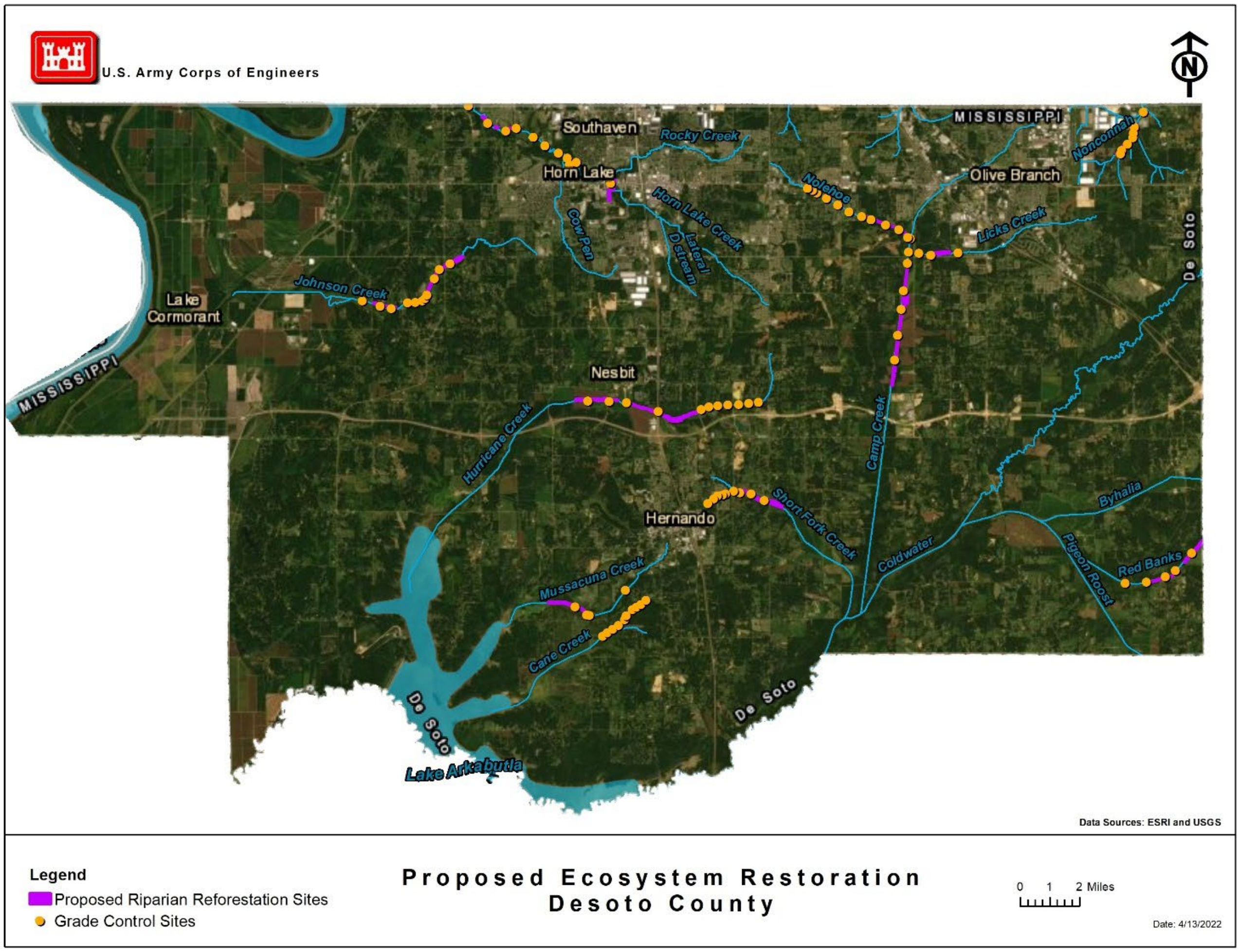


Figure H:1-2 FRM Structural Final Array

1.2 LITERATURE REVIEW

A literature review was performed to summarize climate change relevant to the study area and highlight both observed and projected assessments of relevant climate change variables. As this is a flood risk management study, the primary relevant variable is streamflow. This variable is also affected by precipitation and air temperature. Therefore, this review focuses on observed and projected changes in air temperature, precipitation and hydrology.

1.2.1 Temperature

1.2.1.1 Observed Temperature

The Fourth National Climate Assessment (USGCRP, 2017) states that observed temperatures in the United States have increased as much as 1.9 degrees Fahrenheit since

1895, with the increase in temperatures accelerating since the 1970s. The National Climate Assessment goes on to say that warming is projected for all parts of the United States. The 2015 review conducted by the USACE Institute for Water Resources (IWR) summarizes the available literature on climate change for the Lower Mississippi River Region, which includes the Horn Lake Creek Basin. In general, studies have found varying trends in observed air temperature. A study by Westby et al. (2013) identified a cooling trend in the region. Another study by Liu et al (2012), noted that the cooling trend ends in the 1970s and transitions to a warming trend from 1976 onwards. Overall, this region differs from the national results observed in the Fourth National Climate Assessment, as there is not a consistent overall warming trend since the early 1900s in the Lower Mississippi (USGCRP, 2017).

In addition, the IWR's Climate Change Literature Review notes that there is a statistically significant increasing trend in the number of one day extreme minimum temperatures in the Lower Mississippi Region. Note there is not a statistically significant trend for the number of one day extreme maximum temperatures. The consensus from the Climate Change Literature Review indicates only mild increases in annual temperature in the region over the past century with significant variability. However, there is consensus that the extreme minimum daily air temperatures are increasing.

Similar warming trends have been noted in the project area. The longest running gage in the area, located at the Memphis International Airport (MEM) has continuous records going back to the 1940s and is located seven miles north of the headwaters of the study area, as shown in Figure H:1-3. From 1930 to the 1970, the average annual temperature at the gage followed no noticeable trend but transitioned to a consistent increase starting in the 1970s.

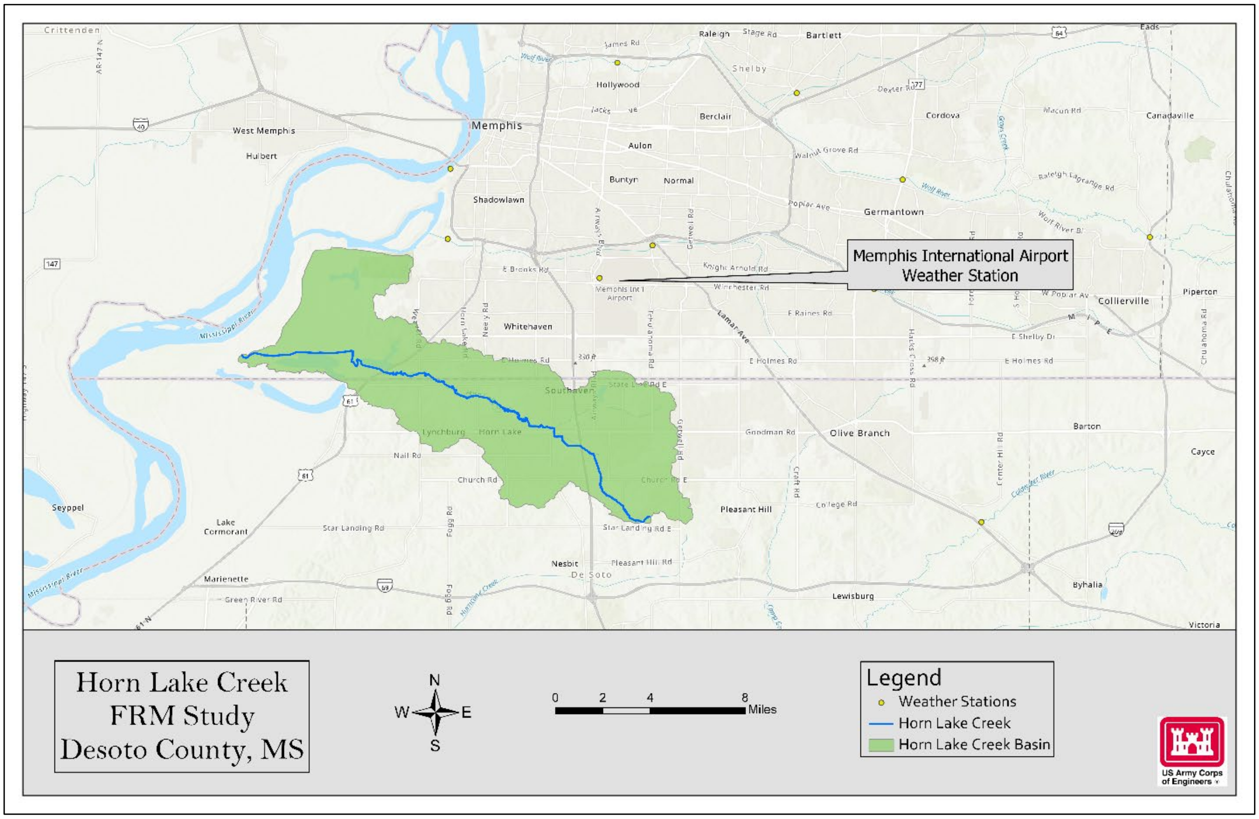


Figure H:1-3. Study Area and Location of the Memphis International Airport (MEM) Weather Station used in the Statistical Temperature Analysis for the Horn Lake Creek Basin

Statistical hypothesis testing was performed on the annual average temperature from the MEM airport gage. The alternative hypothesis of an apparent trend is accepted to be true at the 0.05 significance level – meaning that p-values less than 0.05 are indicative of statistical significance and p-values less than 0.001 as statistically highly significant. These thresholds are commonly adopted within statistical references. In this case, the entire period of record data produces a p-value of 0.0000007465, as seen in Figure H:1-4, which is very indicative of a statistically upward trend in temperatures.

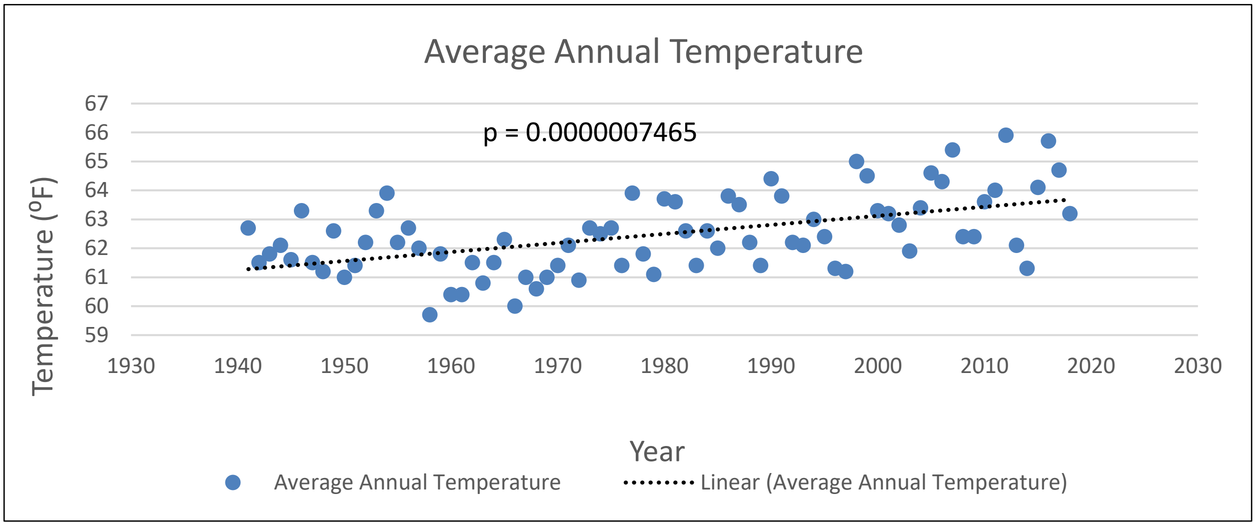


Figure H:1-4. Annual Average Temperature and P-Value from 1940 – 2018 (MEM)

Performing the same test of average annual temperatures from 1940 – 1970 produces a p-value of 0.01519, which is statistically significant as $P<0.05$ (Figure H:1-4). Visually there appears to be a decreasing trend in temperature from 1940 to 1970, much like the cooling period identified in the literature review in the Observed Temperature Section (Section 1.2.1.1). However, the statistical test on the dataset does show a statistically significant downward trend.

Performing the same statistical test from 1970 – 2018, as shown in Figure H:1-5, produces a p-value of 0.000856. This is below the reference threshold and is very indicative of a statistically significant upward trend in temperatures.

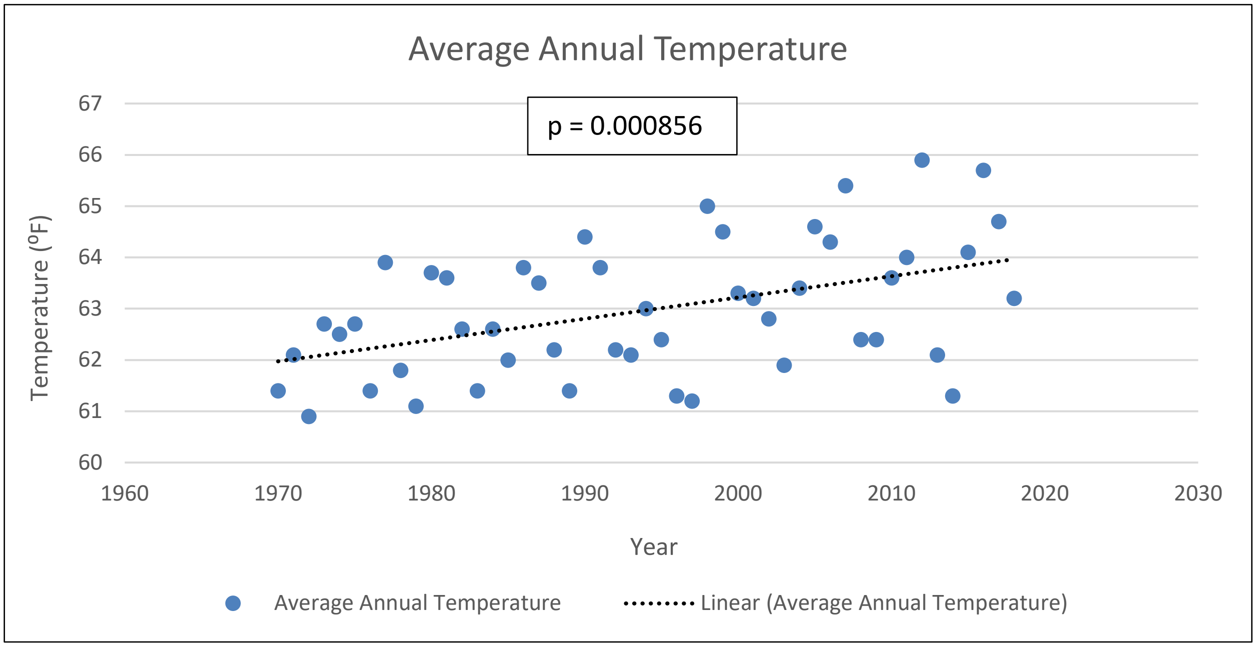


Figure H:1-5. Annual Average Temperature and P-Value from 1970 – 2018 (MEM)

1.2.1.2 Projected Temperature

Global Climate Models (GCMs) have been used to project future climate conditions in the U.S. including the Lower Mississippi River Region. Results show a significant warming trend at a national and regional scale. Figure H:1-6 shows the projected changes in seasonal maximum air temperatures based a report by Liu et al. (2013) assuming a "worst case" greenhouse gas emissions scenario. This shows that overall there is a projected warming trend of 2 to almost 4 degrees Celsius by 2055.

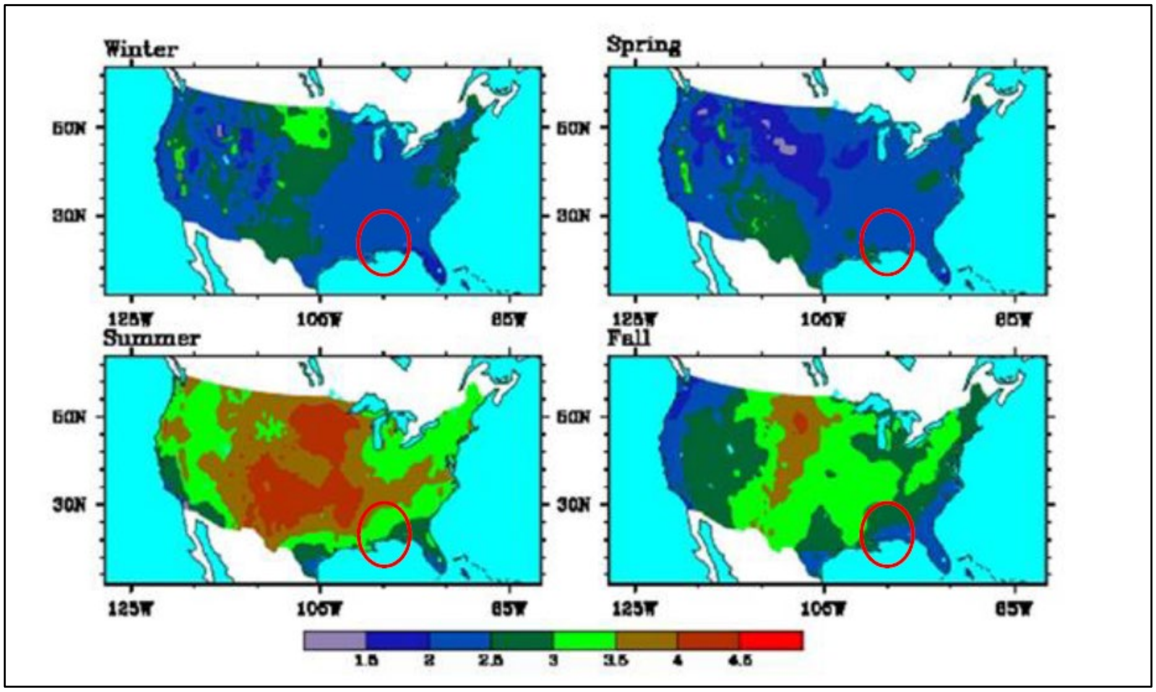


Figure H:1-6: Projected Changes in Seasonal Maximum Air Temperature, ºC, 2041 – 2070 vs. 1971 – 2000. The Lower Mississippi River Region is within the Red Oval. (Liu et al., 2013; reprinted from USACE, 2015).

1.2.2 Precipitation

1.2.2.1 Observed Precipitation

Annual Precipitation since the beginning of the last century has increased across most of the northern and eastern U.S, whereas decreases have been observed across much of the southern and western U.S. There is much more regional variation in observed precipitation change as compared with observed temperature change, as the influence of temperature on precipitation varies greatly based upon terrain, elevation, and proximity to moisture sources. Looking closely at the Lower Mississippi River Valley, the basin has seen a significant trend in increased precipitation (Simon et al. 2020). The IWR report (USACE, 2015) shows that there is a general increase in precipitation for the Lower Mississippi River region; however, it is highly variable. Analysis of gridded data from years 1950 -2000 identified an increasing trend in fall precipitation in the northern Lower Mississippi River Region, where the study area is located (Wang et al., 2009). The MRG&P Report No. 34 (Simon, et al, 2020) also identifies a peak seasonal trend for the fall months. This report notes that runoff events are getting more severe and more frequent and may be influenced by increasing hurricane activity moving through the Lower Mississippi Basin. An increase of 25 to 50% change in fall max 7-Day totals is reported over the past century (Figure H:1-7). Hurricanes affect subregions of the Lower Mississippi Basin generally between 01 June and 30 November. Precipitation data indicates that anomalies, likely from hurricanes occur most often in fall particularly in September. Other seasons; however, have shown increases in precipitation in some areas, decreases in some areas, and some areas with little change in precipitation.

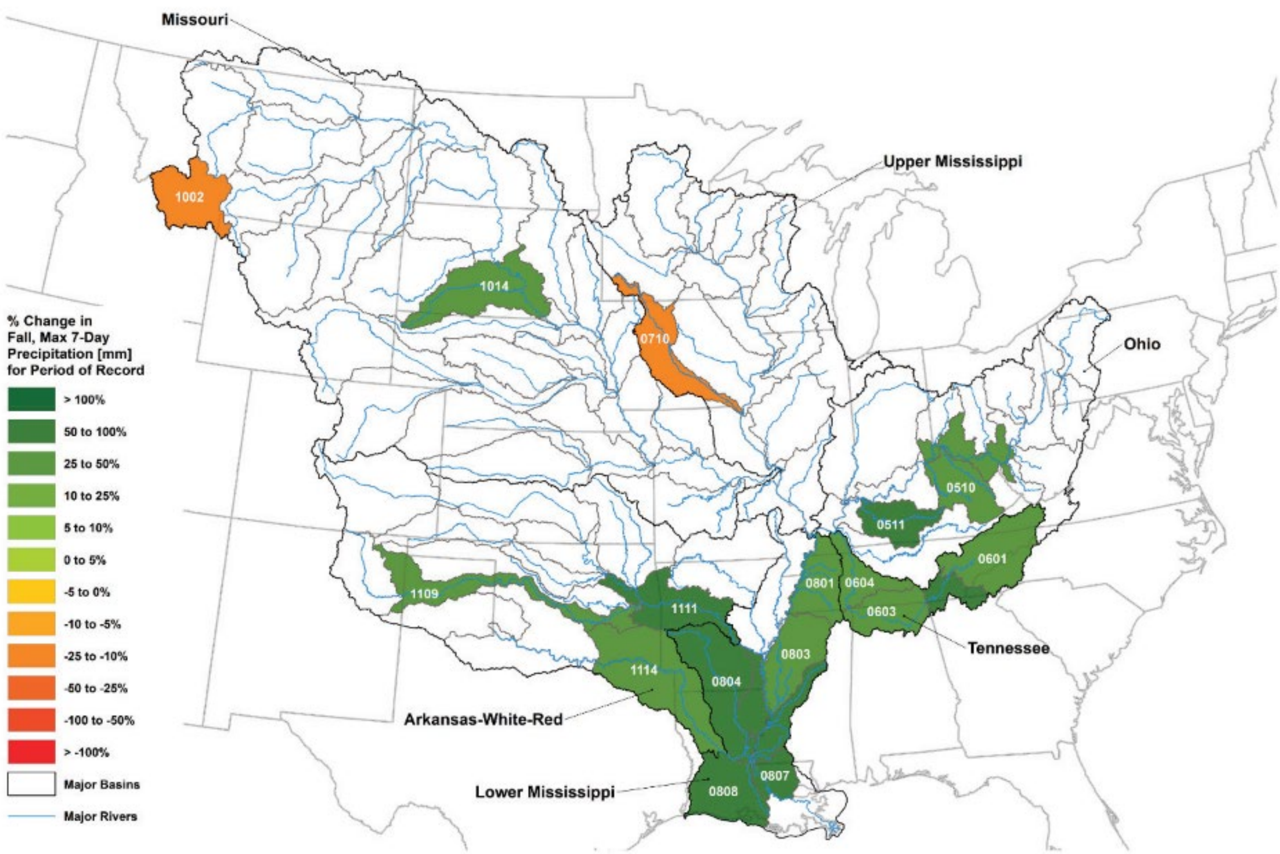


Figure H:1-7. Percent change in maximum 7-day fall rainfall for HUC-4s with statistically significant trends. (Simon et al., 2020)

An analysis of an extended data period (1895 – 2009) identified linear positive trends in the Lower Mississippi River Region, and particularly in the study area. Figure H:1-8 shows the observed linear trends in annual precipitation.

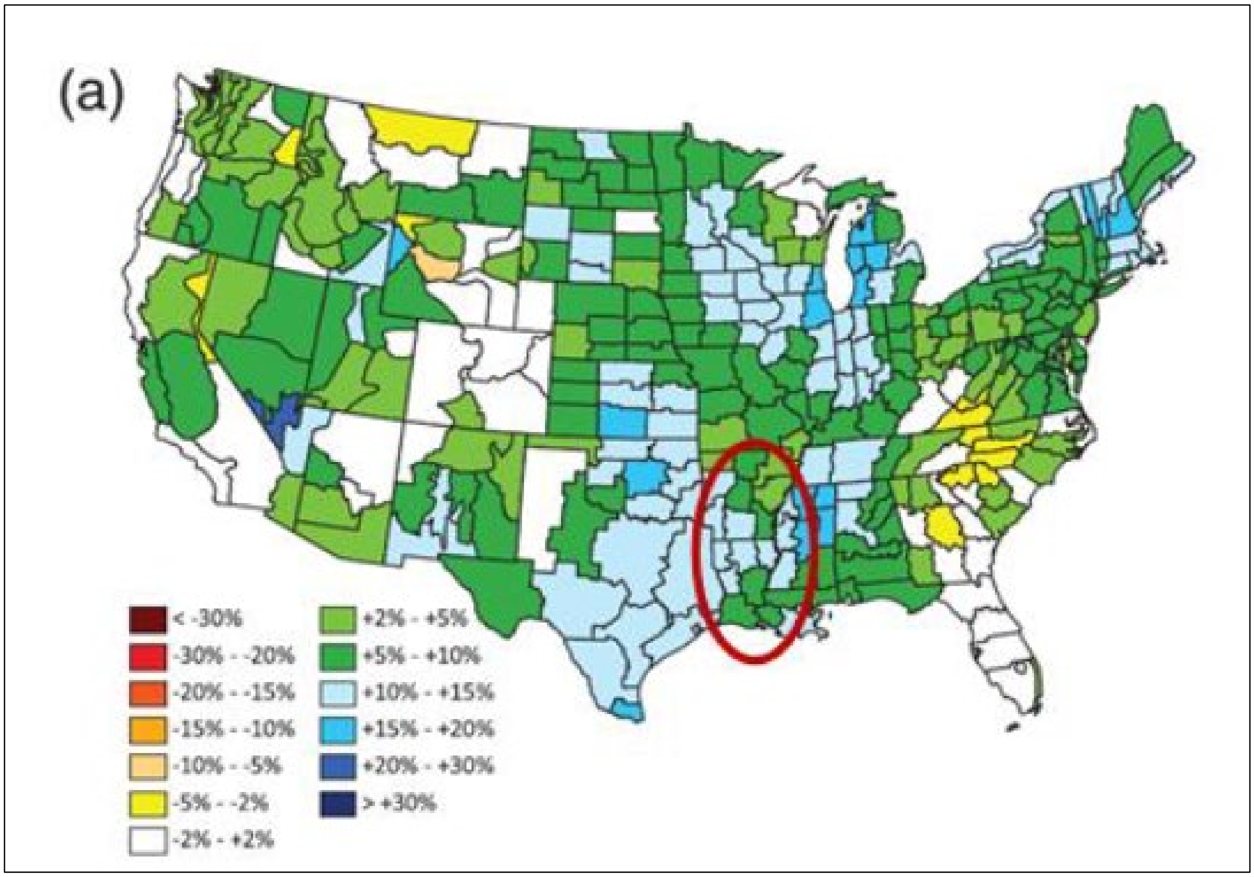


Figure H:1-8. Linear Trends in Annual Precipitation, 1895 - 2009, Percent Change per Century. The Lower Mississippi River Region is within the Red Oval (McRoberts and Nielsen-Gammon, 2011). DeSoto County, where the Horn Lake Creek is located, has Experienced a 10 - 15% Increase in Precipitation over the Century

The MEM Airport weather station shows fairly variable annual average precipitation since 1940 with no statistically significant upward trend based on a high p-value is 0.2928 (Figure H:1-9). Visually, it appears that extremes at either end are becoming more severe since the 1970s (Figure H:1-9).

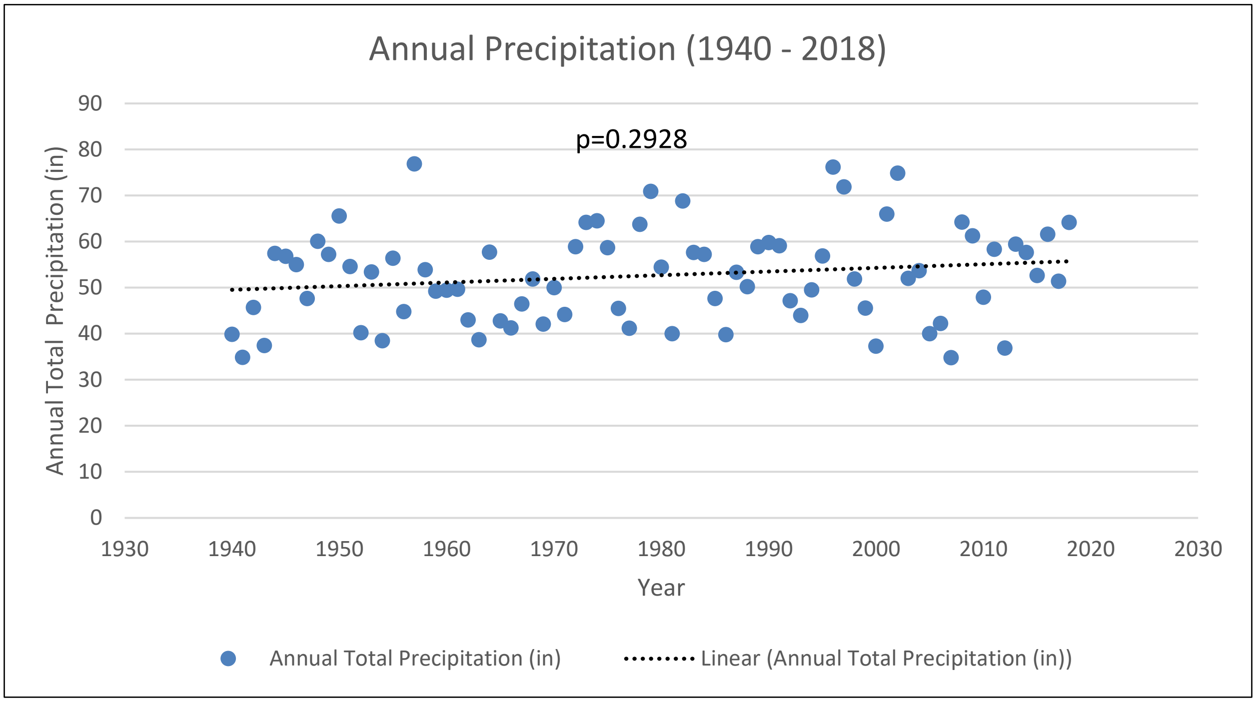


Figure H:1-9. Annual Total Precipitation and P-Value from 1940 – 2018 (MEM)

A study by Pryor et al. (2009) identified a statistically significant increasing trend in total annual precipitation and the number of precipitation days per year in the Lower Mississippi River region. The authors noted that the trend is not strictly linear, as the rate of change is increasing as well. The authors also identified no trend, or a possibly decreasing trend in the 90th percentile (high precipitation).

Most studies analyzed by the IWR (USACE, 2015) suggest that significance in increasing precipitation (the severity and frequency) trends in observed storm are not definitive; however, some analyzed literature shows mild increasing trends in these parameters. For instance, Li et al. (2011) investigated anomalous precipitation (based on deviation from the mean) in summer months in the southeastern U.S. and found that a greater number of climate stations within the region did not exhibit increasing trends in frequency of occurrence of heavy rainfall than those that did. Wang and Killick (2013) also investigated anomalous precipitation, but only detected a statistically significant positive trend for the 10th percentile (low precipitation) and none in the 90th percentile (high precipitation). Though there is not a strong consensus regarding trends in extreme precipitation observed events, it is important to remain mindful of the identified increasing trends in intensity and frequency of rainfall within the region.

1.2.2.2 Projected Precipitation

Projected future changes in precipitation for the Lower Mississippi River region are variable and lack consensus. The Liu et al. study (2013) quantified significant increases in spring precipitation associated with a 2055 future condition for the Lower Mississippi River Region.

Other seasons showed almost no increase or a slight decrease in precipitation. The Liu et al. study also projected increases in the severity of future droughts, as projected temperature and evapotranspiration impacts outweigh the increases in precipitation. Figure H:1-10 illustrates the projected change in seasonal precipitation.

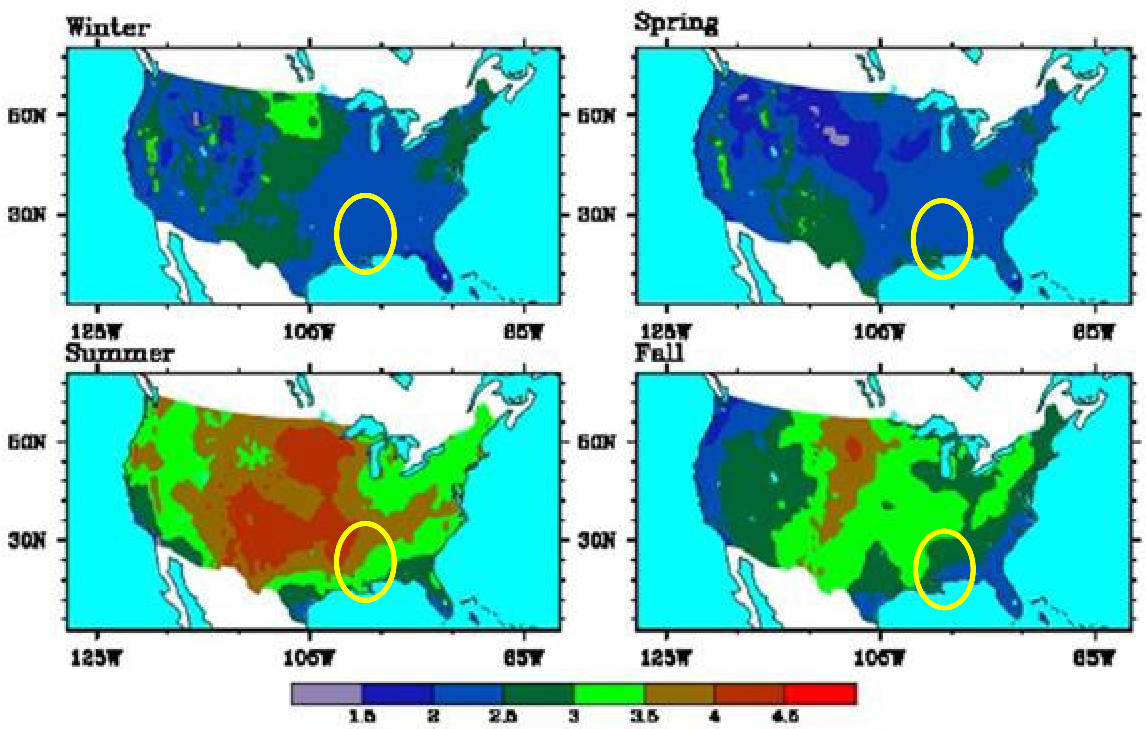


Figure H:1-10: Projected Changes in Seasonal Precipitation, 2055 vs. 1985, mm. The Lower Mississippi River Region is within the Yellow Oval (Liu et al., 2013; reprinted from USACE, 2015)

In contrast, the Simon et al. (2020) study identifies increasing trends in most seasons for the Lower Mississippi Basin with the largest increases over the past 100 years exceeding 150 mm (6 in.). Based on these findings it is reasonable to conclude that the project area will continue to see increases in annual precipitation from more frequent intense storms producing more intense runoff events.

1.2.3 Hydrology

1.2.3.1 Observed Streamflow

Generalized observations of streamflow trends in the Lower Mississippi River Region lack a clear consensus, with some models showing positive trends in some areas and others showing negative trends for areas in the southeast. Generally, most studies in the Lower Mississippi River Region indicated an increasing trend in streamflow. Most notably, studies have shown the positive trend in streamflow being more consistent for the region since the 1940s (Mauget, 2004; and Quian et al., 2007).

1.2.3.2 Projected Streamflow

No regional studies of future hydrology projections, specific to the Lower Mississippi River Region, were discussed in the IWR report (USACE, 2015). A national study by Thomson et al. (2005) indicated low consensus in projected hydrologic changes. This is due to the additional uncertainties that are added when coupling climate models to hydrologic models, both of which carry their own uncertainties. The IWR report did note that the National Climate Assessment (Carter et al., 2014) projects mild decreases in water availability for the Lower Mississippi region, in agreement with a Doll and Zhang (2010) study. Overall, the IWR literature review lacks consensus for projected streamflow, but did note that some studies suggest that streamflow may be decreasing over the next century in the Lower Mississippi River Region (USACE, 2015).

1.2.4 Summary

Figure H:1-11shows the discussed variables and their overall consensus in trends for both observed and projected scenarios based on the findings of the 2015 USACE IWR literature synthesis. Overall, the observed data indicates an increasing precipitation trend. There is less evidence in observed data pointing to trends in temperature or temperature maximums in the region. There is some evidence that hydrology and streamflow are increasing in the region, but unclear evidence whether temperature is increasing or decreasing.

Projections indicate a strong consensus of an increase in projected temperature of approximately 2 to 4 degrees Celsius by the late 21st century. There is some consensus that precipitation extremes may increase in the future both in terms of intensity and frequency. However, in general, projections of precipitation have been shown to be highly variable across the region. There is some consensus that streamflow is projected to decrease in the region. However, very few conclusions can be drawn regarding future hydrology in the region largely due to the substantial amount of uncertainly in these projections when coupling climate models with hydrology models.

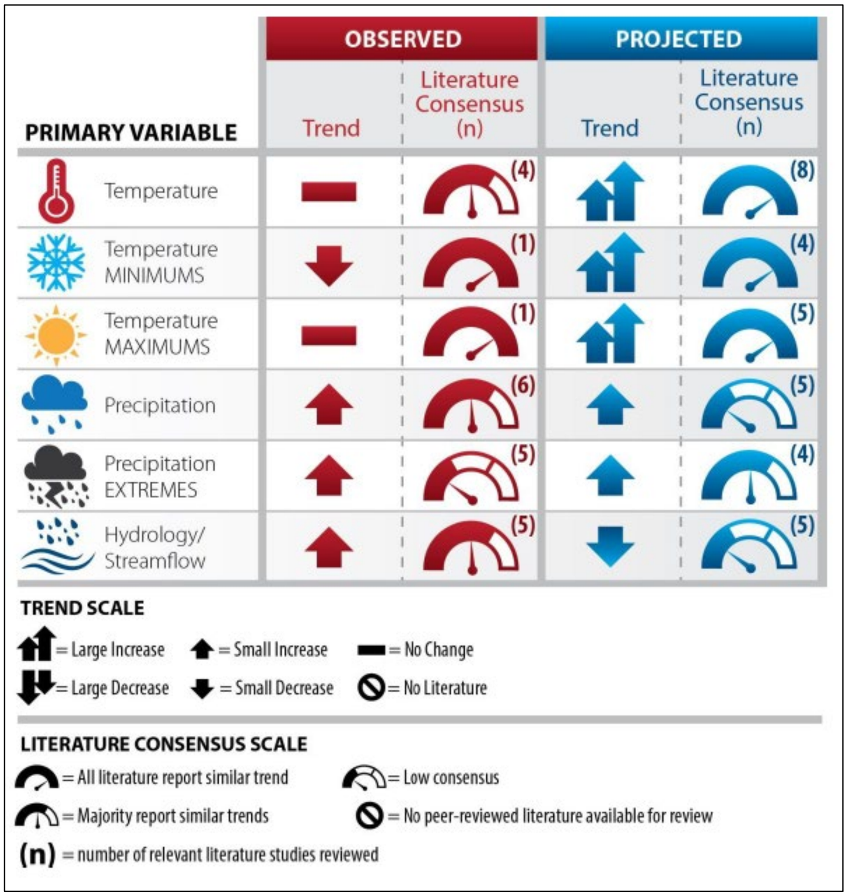


Figure H:1-11. Summary Matrix of Observed and Projected Climate Trends and Literary Consensus

1.3 NON-STATIONARITY ASSESSMENT

In accordance with ECB 2018-14, a stationarity analysis was performed to determine if there are long-term changes in peak streamflow statistics within the Horn Lake Creek basin and its vicinity. Assessing trends in peak streamflow is considered appropriate as one of the primary purposes of this feasibility study is to assess and reduce flooding in the Horn Lake Creek Basin. The current flood risk management measures being considered include channel enlargement, inline storage, and off-channel storage and are significantly affected by changes in peak streamflow. An environmental restoration feature is a part of the project. This feature will address channel instability and aquatic habitat degradation.

1.3.1 USACE Non-Stationarity Tool

The USACE Non-stationarity Tool was used to assess possible trends and change points in peak streamflow in the region. Since the Horn Lake basin does not possess a stream gage, the USGS 07032200 located in the Nonconnah Creek basin was used for the analysis (Figure H:1-12). The green area encompasses the study area within the larger Horn Lake Creek Basin. The gage in this analysis, located on Nonconnah Creek, is approximately 8.6

miles northeast of the Horn Lake Creek Watershed boundary. The Nonconnah Creek gage was chosen as its topography and basin size are comparable to Horn Lake Creek. Additionally, this gage is the only site with similar basin characteristics in the area and at least 30 continuous years of record which is the minimum recommended years for this tool to detect non-stationarities.

The lower reaches of Horn Lake Creek are affected by Mississippi River backwater. The Mississippi River 2011 event (second highest of record) backwater was estimated to extend 14 miles upstream from Horn Lake Creek's mouth; two miles from the Mississippi-Tennessee State-line. Since the backwater only extends two miles into Mississippi, it does impact the current assessments and is not expected to impact project conditions nor future flooding. As stated previously, the IWR literature review lacks consensus for projected streamflow, but did note that some studies suggest that streamflow may be decreasing over the next century in the Lower Mississippi River Region.

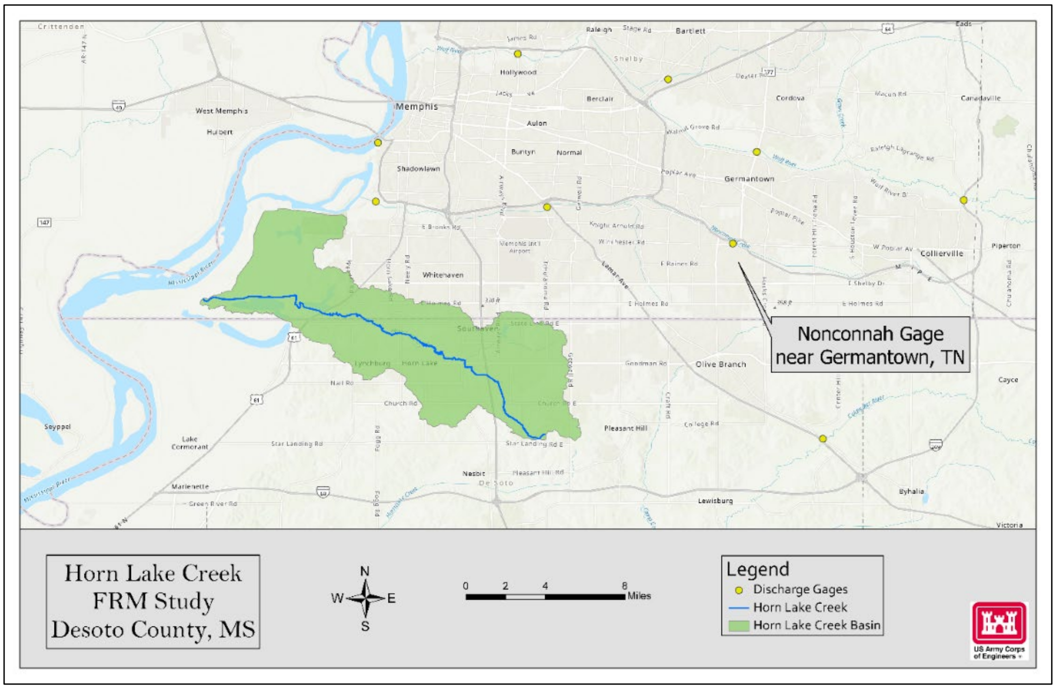


Figure H:1-12: The Horn Lake Creek Basin in relation to the Nonconnah Gage near Germantown, TN

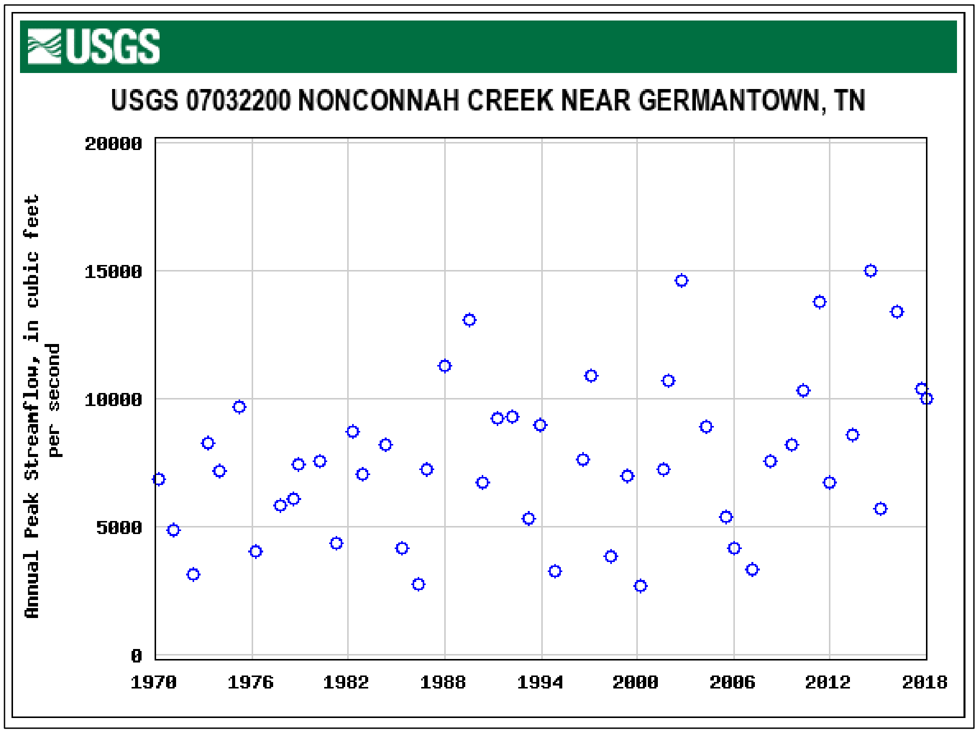


Figure H:1-13. APF at USGS 07032200 Nonconnah Creek near Germantown, TN

The following 16 statistical tests were conducted on the APF time series shown in Figure H:1-13 using the Non-Stationarity Tool:

1. Cramer-von-Mises distribution
2. Kolmogorov-Smirnov distribution
3. LePage distribution
4. Energy Divisive distribution
5. Lombard (Wilcoxon) abrupt mean
6. Pettitt mean
7. Mann-Whitney mean
8. Bayesian mean
9. Lombard (Mood) abrupt variance
10. Mood variance
11. Lombard (Wilcoxon) smooth mean
12. Lombard (Mood) smooth variance
13. Mann-Kendall trend
14. Spearman rank trend
15. Parametric trend
16. Sen's slope trend

Tests 1-12 are used to detect change points in the distribution, mean, and/or variance of the time series. These non-stationarity tests can be useful in detecting changes in annual instantaneous streamflow peaks driven by natural and human driven changes in the climate, addition/removal of water control structures, changes in land cover, as well as any other drivers of non-stationarity. Meanwhile, tests 13-16 are used to analyze monotonic trends. The variety of tests is essential for increasing confidence in the overall stationarity analysis. Significant findings in one or two tests are generally not enough to declare non-stationarity.

For this analysis the continuous period of water years 1970 – 2014 was analyzed. All sensitivity parameters were left in their default positions. Figure H:1-14 shows the results of tests 1-12. One abrupt non-stationarity was detected within the annual instantaneous peak stream flow record for Nonconnah Creek. The Lombard Wilcoxon test detected a change in the segment mean of the flow record. The detected non-stationarity is neither considered strong nor robust.

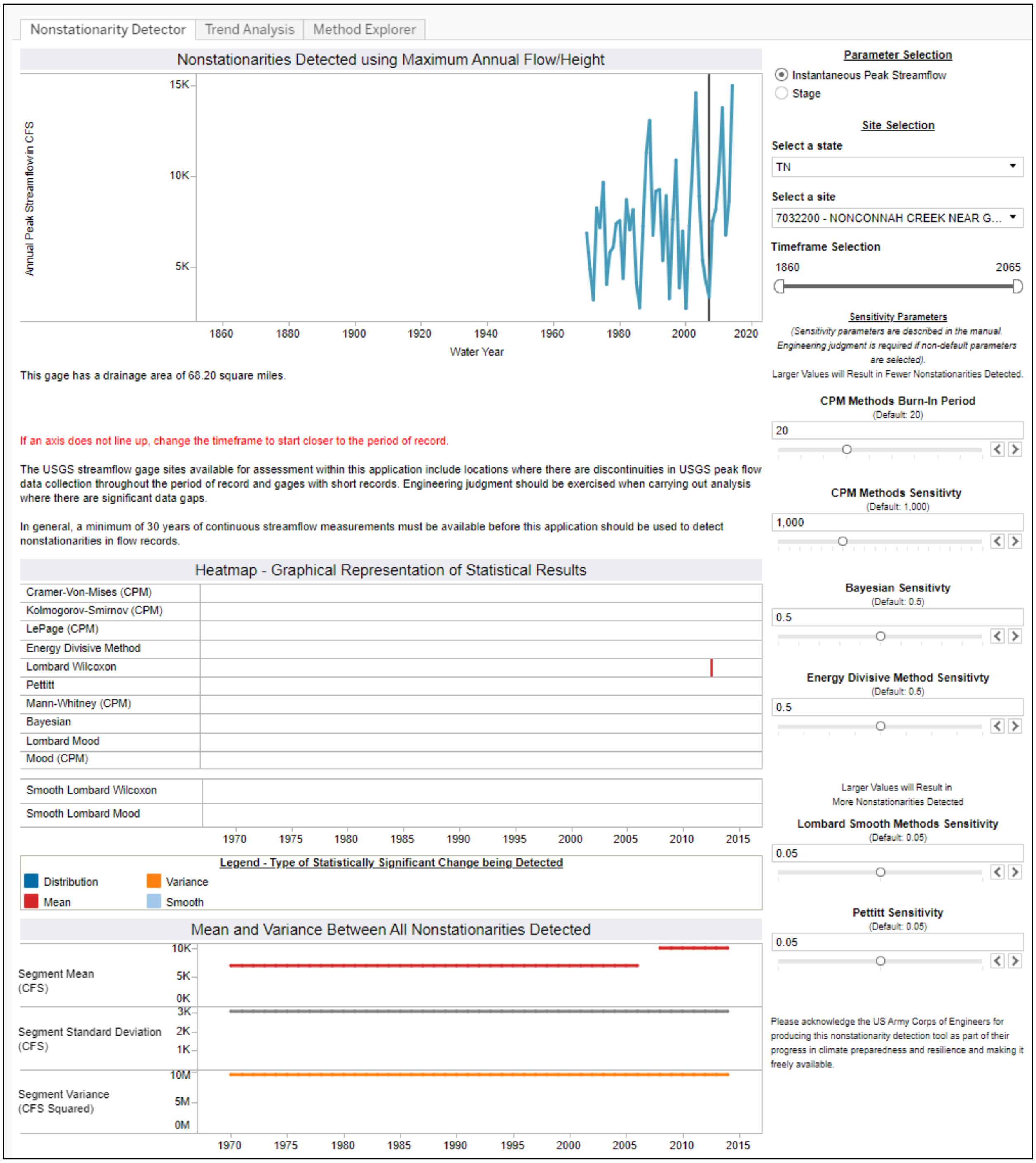
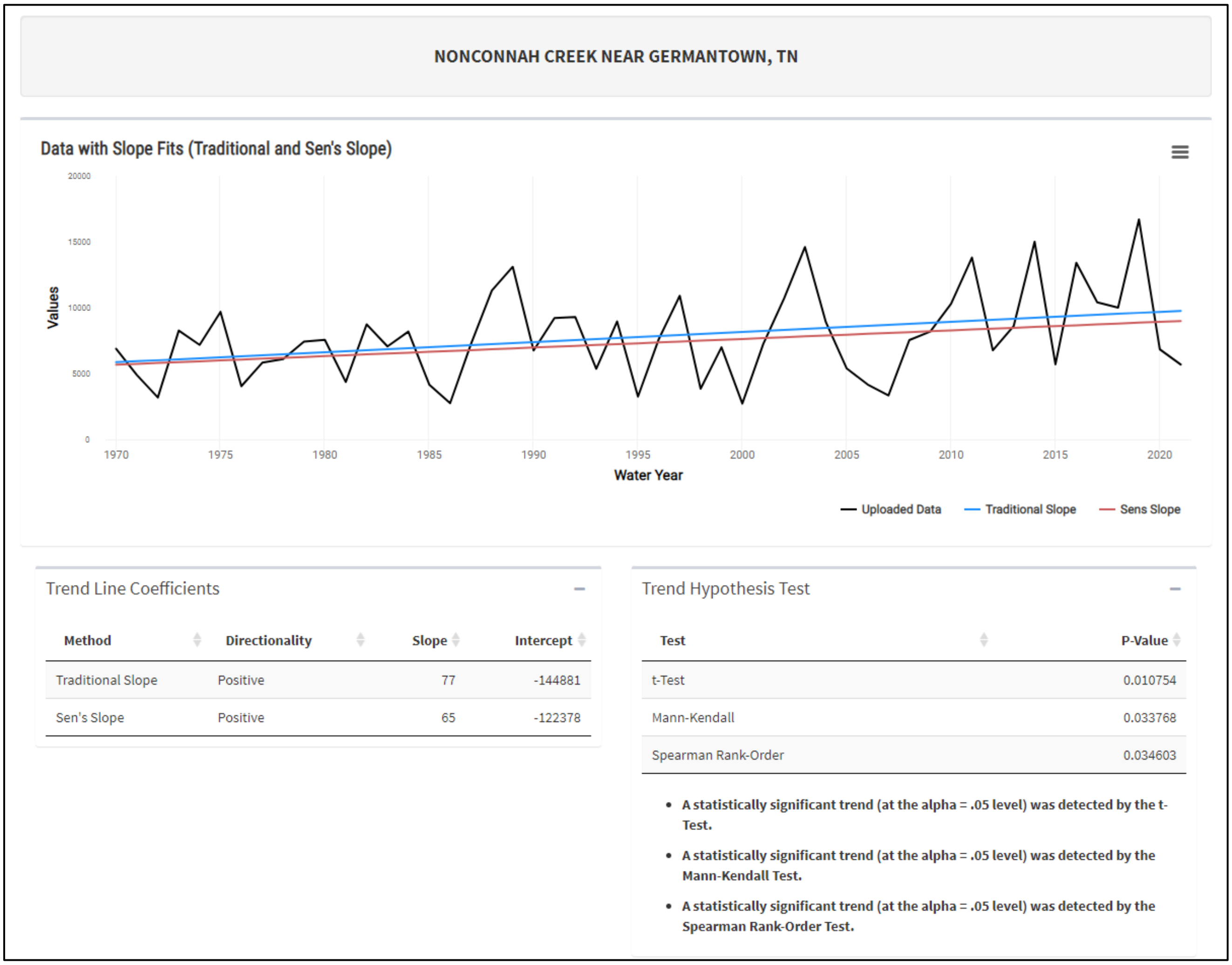


Figure H:1-14. Results of the Non-stationarity Assessment for USGS 07032200 Nonconnah Creek near Germantown, TN

Tests 13-16 (shown in Figure H:1-15 and Figure H:1-16) showed a statistically significant trend for the period of record at the gage (1970-2020). The period after the non-stationarity in 2007 is too short to detect a monotonic trend.



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	77	-144881
Sen's Slope	Positive	65	-122378

Trend Hypothesis Test

Test	P-Value
t-Test	0.010754
Mann-Kendall	0.033768
Spearman Rank-Order	0.034603

- **A statistically significant trend (at the alpha = .05 level) was detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Spearman Rank-Order Test.**

Figure H:1-15. Monotonic Trend Analysis for the full POR (1970-2014), taken from the US Army Corps of Engineers Non-stationarity Detection Tool. Trend statistically significant.

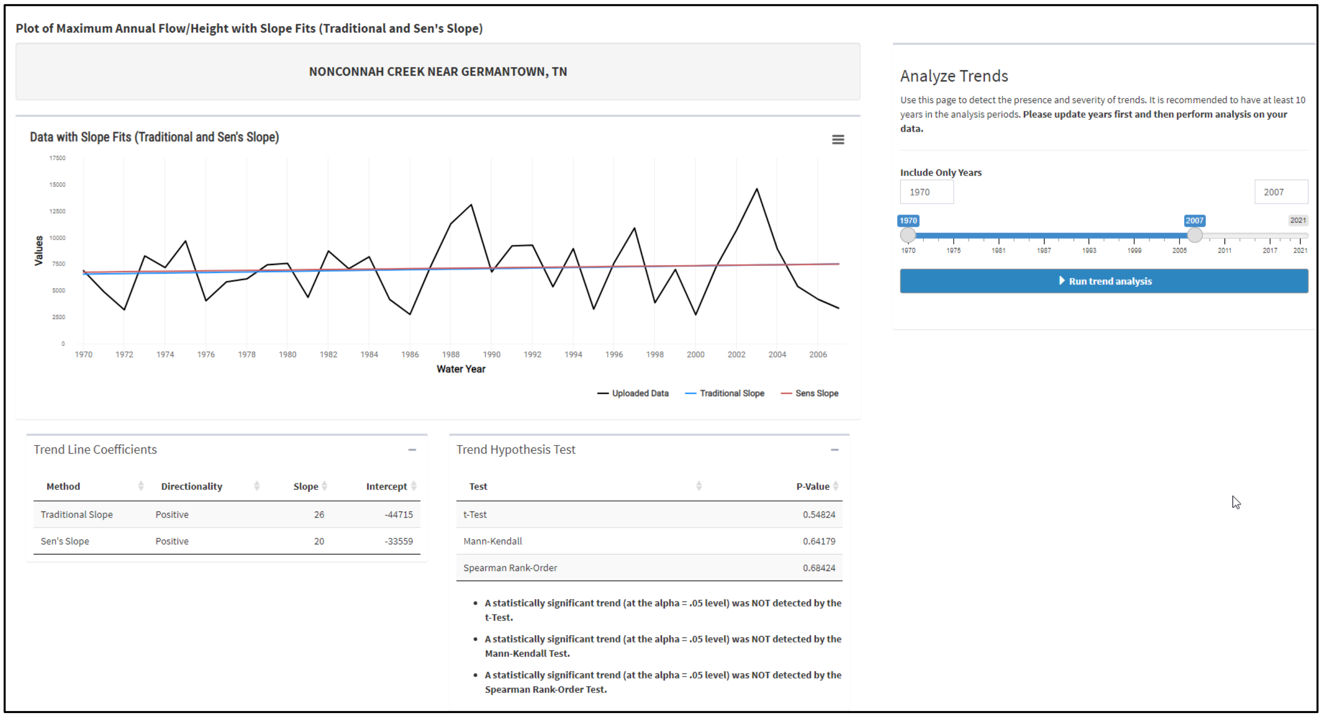


Figure H:1-16. Monotonic Trend Analysis for the POR before the Non-Stationarity (1970-2007), taken from the US Army Corps of Engineers Non-stationarity Detection Tool. No Statistically Significant Trend Found.

1.3.2 Analysis of Non-stationarity Tool Results

A non-stationarity is considered strong if two or more of the detection methods of the same type detect a non-stationarity in the data. For the gage at Nonconnah Creek, the 2007 non-stationarity is not considered strong. The Lombard Wilcoxon test detected a non-stationarity in the segment mean distribution in 2007 (Figure H:1-16). This Nonstationarity also triggered the smooth Lombard Wilcoxon test. A non-stationarity is considered robust if tests targeting changes in two or more different statistical properties indicate a non-stationarity. As only the mean distribution test detected a changepoint in 2007, the non-stationarity is not considered robust (Figure H:1-16).

In terms of magnitude, the changes in mean peak annual streamflow do not appear to be statistically significant but rather the result of a series of significant hydrologic events in the basin. The Nonconnah Creek drainage area above the Germantown gage is relatively small (the drainage area is 68.20 square miles), so the basin is more sensitive to hydrologic events impacting its statistical changepoints. Historical rainfall data at USGS 07032200 was not available prior to 2012, so it is not certain if hydrologic events contributed to the non-stationarity in 2007. However, as both clusters were neither strong nor robust changepoints, it is likely that significant hydrologic events contributed to the non-stationarity.

Using the USACE non-stationarity tool to compare segment mean, there is an increase of 2,998 cfs in mean peak annual streamflow after the 2007 changepoint compared to the period of record prior to the 2007 changepoint (10,027 cfs vs 7,029 cfs). For a small, urbanized basin like Nonconnah Creek an increase of only 2,998 cfs does not appear to be statistically significant.

Additional gages around the project site were tested using the non-stationarity tool in order to provide additional insight into the impacts of urbanization on the positive trending peak stream flows. Gages inside a 40-mile radius of the site having more rural and undeveloped drainage areas as well as basins similar to the project site were tested. The period of record for these gages fell into two categories with gages either having records from the early 1900s to 1970 or from 1970 onward. The gages with earlier records showed a decreasing trend in streamflow and the inverse was true for gages with a current record. The trend analysis produced results that were not statistically significant at all sites. No strong or robust changepoints were identified.

It is inconclusive that the non-stationarity identified is a result of increased urbanization or a result of climate change and increased occurrence of heavier more intense rainfall events.

1.3.3 Climate Hydrology Assessment

In addition to the stationarity assessment, the USACE Climate Hydrology Assessment Tool (CHAT) was used to assist in the determination of future streamflow conditions. For this assessment, the continuous period of record of 1970 – 2014 for USGS 07032200 was used. Figure H:1-17 shows the Climate Hydrology Assessment Tool output for this gage.

The CHAT analysis indicates that there might be statistically significant increasing trend in annual peak instantaneous streamflow for Nonconnah Creek (Figure H:1-17). There is no recommended threshold for statistical significance, but typically 0.05 is used as it is associated with a 5% risk of a false positive. The p-value in Nonconnah is 0.0033 which indicates that there is a statistically significant increasing trend. This is statistically significant upward trend is consistent with the results of the monotonic trend tab in the Non-stationarity Assessment Tool when applied to the entire period of record.

The Nonconnah Creek basin continues to experience development and is projected to continue this growth for the near future. Future land use estimates produced in the Memphis Metro Stormwater Study (1997) predicted the basin would be 100% developed by 2050. It should be emphasized that this growth is primarily located in the headwaters of Nonconnah Creek, above the Germantown gage. The contributing drainage area includes the suburbs of the surrounding communities of Olive Branch, Mississippi and southeastern Shelby County municipalities of Germantown and Collierville, Tennessee. The results are inconclusive, but it should be noted that there is likely a statistically significant increase in annual peak instantaneous streamflow at USGS 07032200.

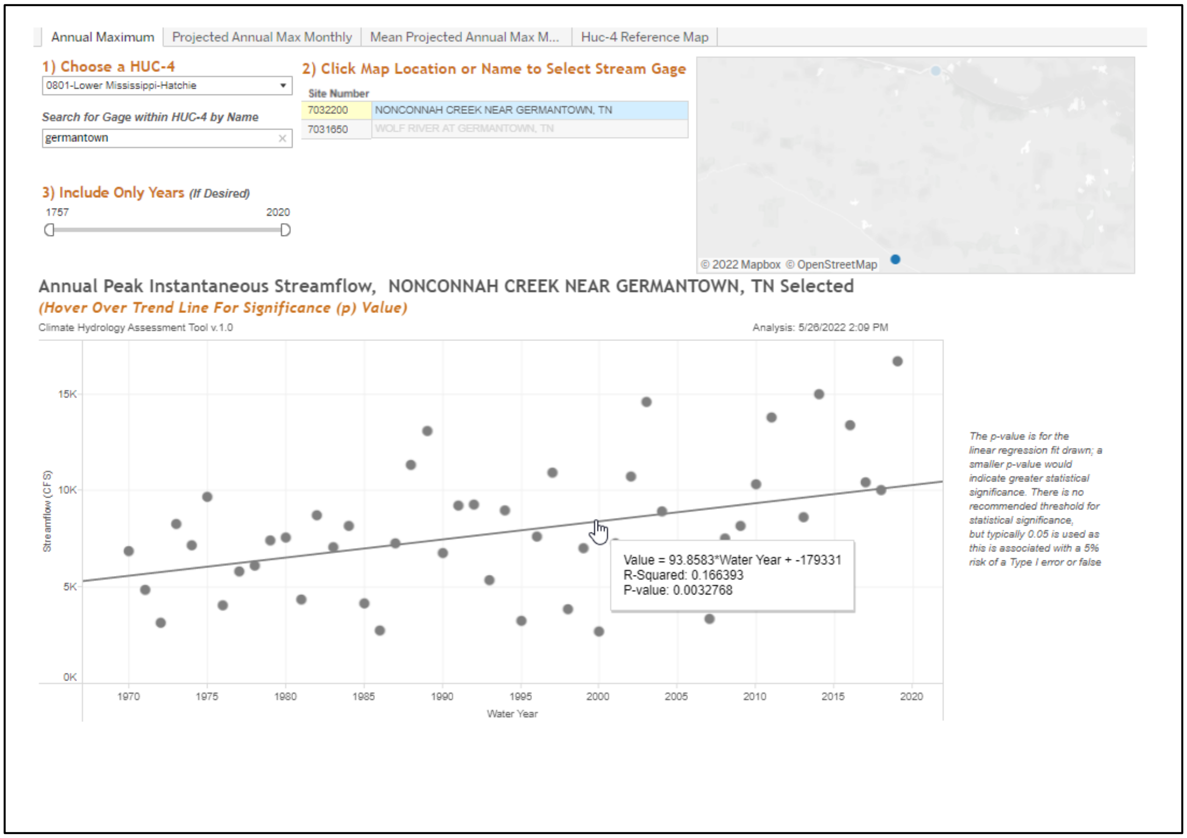


Figure H:1-17. CHAT Output for USGS 07032200 for Nonconnah Creek near Germantown, TN, P-Value=0.0033

A Hydrologic Unit Code 4 (HUC-4) level analysis of mean projected annual maximum monthly streamflow was also performed on the Mississippi River lower basin. The trends in mean projected annual maximum monthly streamflow presented in this analysis represent outputs from the Global Climate Models (GCMs) using different representative concentration pathways (RCPs) of greenhouse gasses that are then translated into a hydrologic response using the United States Bureau of Reclamation (USBR) Variable Infiltration Capacity (VIC) model. The VIC model, forced with GCM meteorological outputs is used to produce a streamflow response for both the hindcast period (1950-1999) and the future period (2000-2099). This dataset is unregulated and does not account for the many flood control structures located on the mainstem rivers within this HUC-4 basin.

The analysis indicates an upward trend in mean projected annual maximum monthly streamflow for the Lower Mississippi-Hatchie Basin, as shown in Figure H:1-17. This data represents flow near the downstream end of the Mississippi River basin, of which Nonconnah Creek is a tributary. The forecast visually indicates an upward trend in projected streamflow from years 2000 to 2099 within the basin, but the trend is not statistically significant (p-value of 0.19). The hindcast data shows no statistically significant trend from 1950 to 1999 (p-value: 0.973033).

Figure H:1-18 provides the mean value of the 93 projections of future, streamflow projections considered through water year 2099, as well as the range of projected streamflow values produced for the watershed. Looking at Figure H:1-18, the variability of the spread is fairly consistent for the projected portion of the record: 2000 to 2099.

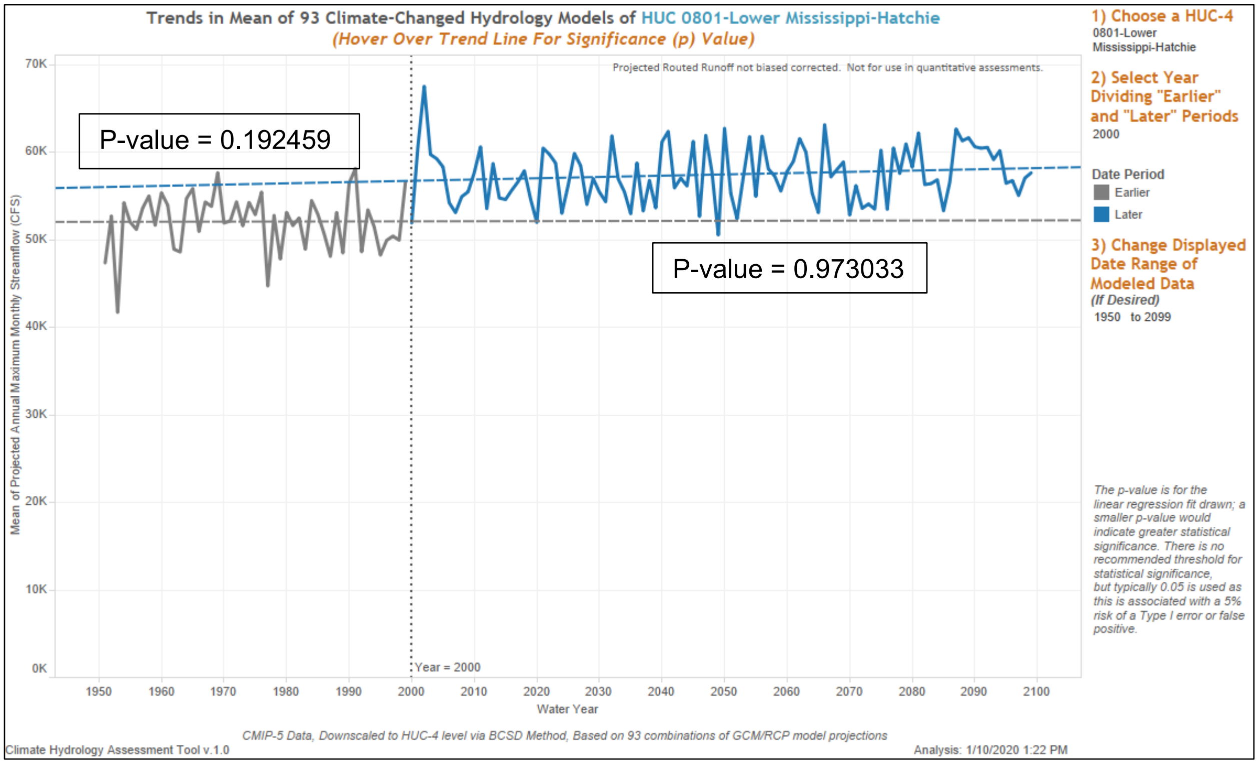


Figure H:1-18. Mean Projected Annual Maximum Monthly Streamflow for the Lower Mississippi-Hatchie HUC-4

It can be seen in Figure H:1-19 that there is significant uncertainty in projections of future streamflow (in Figure H:1-19 the yellow, shaded area is indicative of the spread in the data produced). It is important to understand that this uncertainty comes from each of the model sources that are used to develop the projected streamflow datasets. GCMs have uncertainty in the bounds of their atmospheric input such as the RCPs. Downscaling the output of these models to a smaller region may not account for some regional effects. Changes in future conditions that drive the hydrologic model are also a major uncertainty. Land use changes such as increased impervious areas can have a major effect on peak streamflow. There are many different land use projections for this region from many sources. Other uncertainties such as changes in temperature extremes and the seasonality of the extreme precipitation could also have a significant effect on the rainfall/runoff transformation. For these reasons, this quantitative analysis should be used with caution, with an understanding that this data should only be considered within the large uncertainly bounds of the analysis.

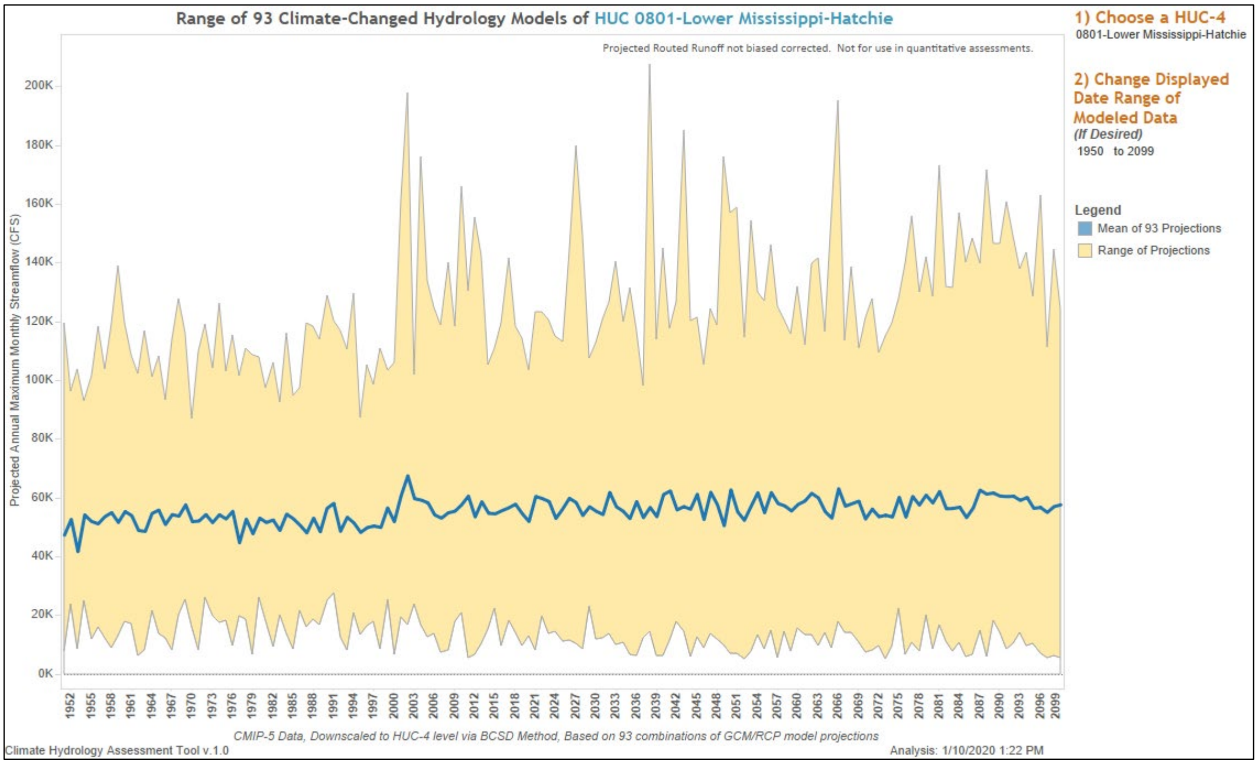


Figure H:1-19. Projected Hydrology for the Lower Mississippi-Hatchie HUC-4 Base on the Output from 93 Projections of Climate Changed Hydrology

1.4 VULNERABILITY ASSESSMENT

To understand potential climate change effects and to increase resilience/decrease vulnerability of flood risk management alternatives to climate change, the relative vulnerability of the basin to such factors was analyzed. In accordance with ECB 2018-14, the USACE Watershed Climate Vulnerability Assessment tool (National Standard) was used to identify vulnerabilities to climate change on a HUC-4 watershed scale relative to other HUC-4 basins across the nation. As this study is a screening-level assessment of flood risk management and environmental restoration alternatives, vulnerability with respect to the Flood Risk Reduction and the Environmental Restoration business lines is presented in this analysis.

To address vulnerabilities due to climate change, the Vulnerability Assessment tool utilizes two 30-year epochs centered on 2050 (2035-2064) and 2085 (2070-2099) as well as a base epoch. These epochs line up well with other national climate change assessments. For each epoch, the tool utilizes the results of 100 combinations of Global Circulation/Climate Models (GCM) run using different Representative Concentration Pathways of greenhouse gas emission to produce 100 traces per epoch for a given watershed. The results of the GCMs are translated into flow and are then sorted by cumulative runoff projections. Traces of the highest 50% of cumulative runoff are categorized as wet and traces with the lowest 50% of cumulative runoff are categorized as dry. This provides two scenarios (wet and dry) for each of the two epochs, excluding the base epoch. Consideration of both wet and dry scenarios reveals some of the uncertainties associated with the results produced using the climate changed hydrology and meteorology used as inputs to the vulnerability tool.

Flood Risk Management. The tool uses specific indicators of vulnerability relative to the business line being considered. A total of 27 indicators are available in the tool, 5 of which are used to derive the vulnerability score in the Lower Mississippi-Hatchie HUC 4 with respect to the Flood Damage Reduction business line. Table H:1-1lists the indicators and corresponding descriptions. Flood magnification had the largest impact on vulnerability for this site. However, Figure H:1-20 shows that the Lower Mississippi-Hatchie HUC 4 is not considered vulnerable by USACE criteria.

Table H:1-1. Dominate Indicators of the Flood Risk Management Business Line for Project HUC

Indicator Short Name	Indicator Full Name	Description
175C_ANNUAL_COV	Annual CV of unregulated runoff (cumulative)	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).
277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.
568L_FLOOD_MAGNIFICATION	Flood magnification factor (local)	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.
568C_FLOOD_MAGNIFICATION	Flood magnification factor (cumulative)	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.
590_URBAN_500YRFLOODPLAIN	Acres of urban area within 500-year floodplain	Acres of urban area within the 500-year floodplain.

*The coefficient of variation (CV) is the ratio of the standard deviation to the mean.

When a HUC is designated as vulnerable by the USACE tool, it means that the HUC ranks within the top 20% most vulnerable HUCs of those considered in the portfolio. Just because a HUC is not identified as vulnerable in the tool does not mean that it is not vulnerable. It simply means that it is not among the most vulnerable of those identified by USACE.

It is important to note that the vulnerability assessment only indicates vulnerability relative to the rest of the nation. It does not state that the basin itself is invulnerable to impacts of climate change on the Flood Risk Reduction business line. Therefore, it is beneficial to understand the composition of the relevant HUC04's (Lower Mississippi-Hatchie) vulnerability score in terms of how much each flood risk reduction indicator variable contributes to the vulnerability score for each subset of traces and for both epochs of time. Figure H:1-20 shows the dominant indicators relative to Flood Risk Reduction. Cumulative flood magnification is the prevailing indicator variable driving the Flood Damage Reduction vulnerability score, followed by the percent change in runoff, divided by the percent change in precipitation for the dry scenario and local flood magnification for the wet scenario.

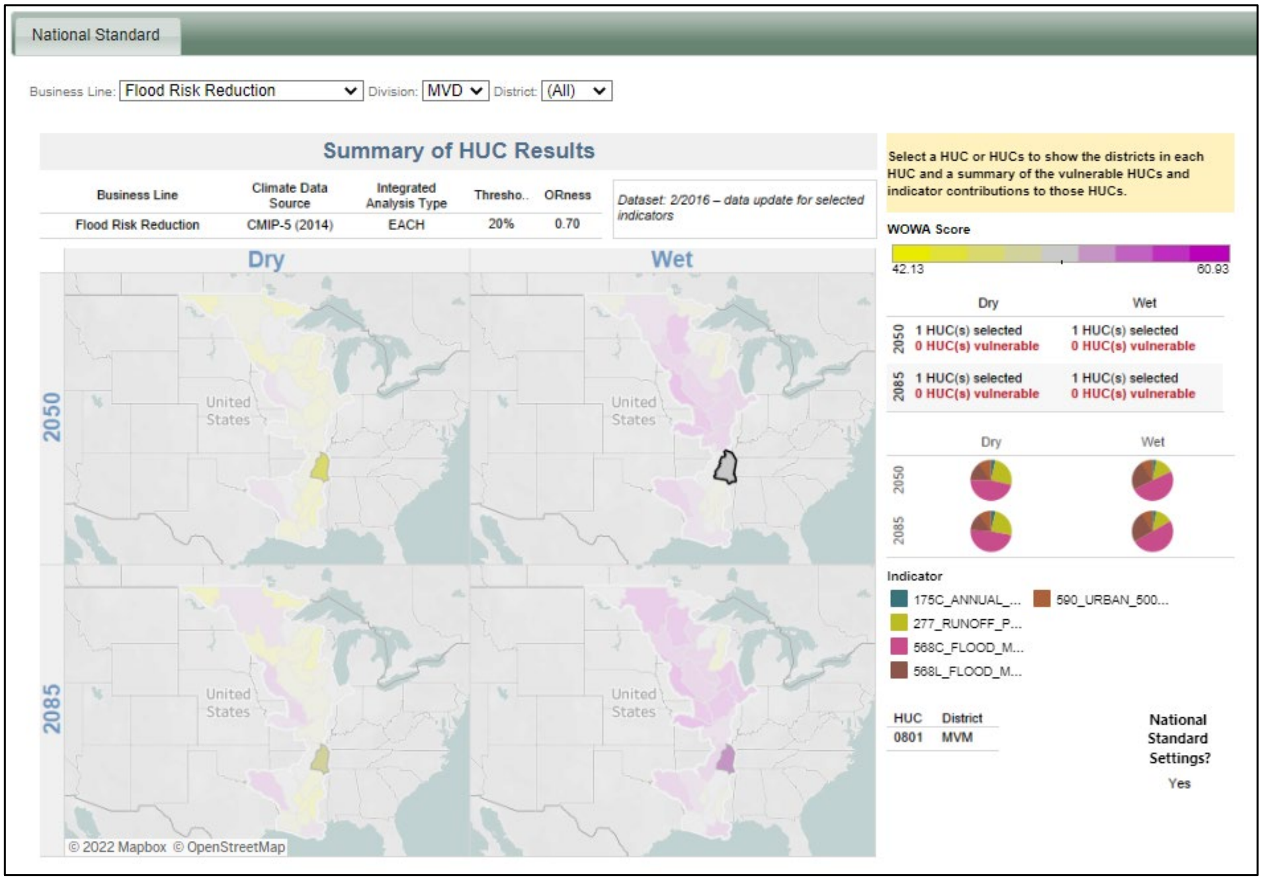


Figure H:1-20. Vulnerability of Project HUC for Flood Risk Reduction Business Line

Environmental Restoration The tool uses specific indicators of vulnerability relative to the business line being considered. A total of 27 indicators are available in the tool, 9 of which are used to derive the vulnerability score in the Lower Mississippi-Hatchie HUC 4 with respect to the Environmental Restoration business line. Table H:1-2 lists the indicators and corresponding descriptions.

Table H: 1-2 Indicators of Vulnerability

Indicator Short Name	Indicator Full Name	Description
175C_ANNUAL_COV	Annual CV of unregulated runoff (cumulative)	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).
277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.
568L_FLOOD_MAGNIFICATION	Flood magnification factor (local)	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.
568C_FLOOD_MAGNIFICATION	Flood magnification factor (cumulative)	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.
590_URBAN_500YRFLOODPLAIN	Acres of urban area within 500-year floodplain	Acres of urban area within the 500-year floodplain.

Figure H:1-21 shows the dominant indicators for the Environmental Restoration business line. The figure shows that At Risk Freshwater Plants is the prevailing indicator variable driving the Environmental Restoration vulnerability score, followed by the percent change in runoff, divided by the percent change in precipitation for the dry scenario and local flood magnification for the wet scenario.

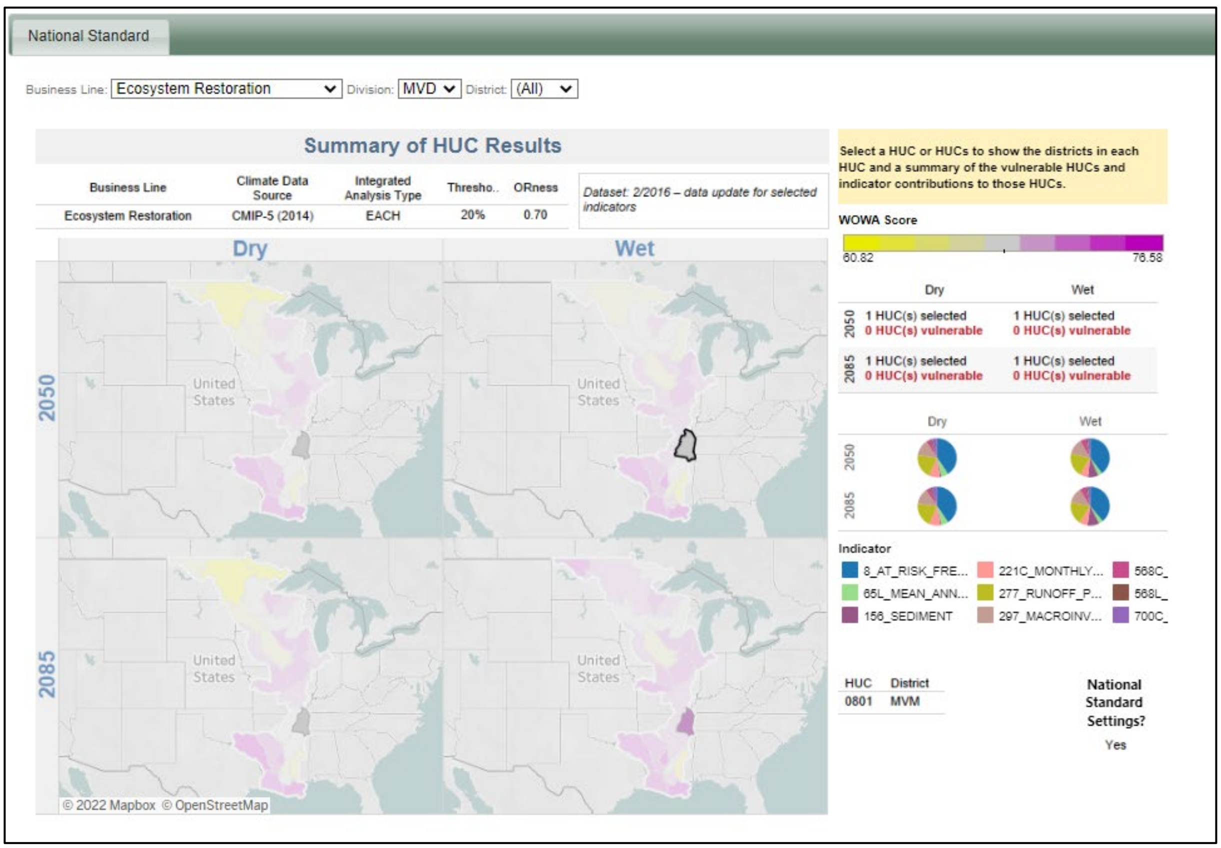


Figure H:1-21. Vulnerability of Project HUC for Environmental Restoration Business Line

1.5 CLIMATE CHANGE AND IMPACTS ON TSP AND RP

Table H:1-3 identifies climate change impacts on structural features of the Flood Risk Management and Ecosystem Restoration Tentatively Selected Plan and Recommended Plan. It should be noted that the Flood Risk Management plan process incorporated future condition flows which reflect highly developed land use in the Horn Lake Creek and Coldwater River basins.

Table H:1-3. Impacts of Climate Change on Structural Features of the Flood Risk Management and Ecosystem Restoration original TSP and Recommended Plan (Base and Future Conditions)

Feature or Measure (Alt ID)	Trigger	Hazard	Harm	Qualitative Likelihood
Channel Enlargement (5A, 5B, 6A, 6B-NED, 7A-LPP)	Increased precipitation from larger, slower moving storms.	Future flood volumes may be larger than present. Large flood volumes may occur more frequently.	Flood water will exceed the channel capacity and inundate structures causing damages.	Possible but not Likely
Multiple Detention (6A, 6B-NED, 7A-LPP)	Increased precipitation from larger, slower moving storms.	Future flood volumes may be larger than present. Large flood volumes may occur more frequently.	Floodwater will exceed the detention capacity and overtop the impoundment structure.	Possible but not Likely
Levee/ Floodwall (8A, 8B)	Increased precipitation from larger, slower moving storms.	Future flood volumes may be larger than present. Large flood volumes may occur more frequently.	Floodwater will exceed the detention capacity and overtop the impoundment structure.	Possible but not Likely
NER (Numerous)	Increased precipitation from larger, slower moving storms.	Future flood volumes may be larger than present. Large flood volumes may occur more frequently.	Floodwater will exceed the structure height. Erosion could occur and threaten a failure. Loss of property is possible.	Possible but not Likely

Section 2
Conclusions

Future without project site will possibly but not likely be affected by climate change in the future. A statistically significant increasing trend in peak streamflow was detected at a gage near the site, however, modeled streamflow for the historic and future HUC-level model simulations show no statistically significant trends. The additional gages tested in both rural and urban basins throughout West Tennessee lacked a significant period of record to support firm conclusions for the increasing peak streamflow. It is noted that gages with records pre-1970 showed decreasing trends while gages with records post-1970 showed increasing trends. Unfortunately, no gaged site in the area covers the full timeline. All the trends proved to be not statistically significant. Increasing trends can account for urbanization and coincide with urban growth in the area. In addition, results from the USACE vulnerability assessment do not show the project site as vulnerable for flood risk or ecosystem restoration business lines. Resilience should continue to be assessed for flood risk and ecosystem restoration products moving forward. It is recommended that resiliency be a considered for every construction project inside the limits of this study.

A trend analysis at a precipitation gage at the site shows no statistically significant trend. In addition, there is not a strong consensus regarding trends in extreme precipitation observed events. However, it is important to remain mindful of the identified increasing trends in intensity and frequency of rainfall within the region.

Annual average temperature did have a statistically significant upward trend. Based on the literature review, there are statistically significant trends in average annual temperature but trends in annual precipitation and the 90th percentile precipitation did not have supportable trends. The literature review lacks consensus in for projected streamflow trends.

Without a major increased in discharges, levee and combination floodwall should function as designed. Based on the lack of clear evidence showing an increase in streamflow, the effects of climate change can be considered within the standard uncertainty bounds associated with the hydrologic/hydraulic analysis being conducted as part of this study.

References and Resources

Project References:

Carter, L.M., J W. Jones, L. Berry, V. Burkett, J. F. Murley, J. Obeysekera, P. J. Schramm, and D. Wear, 2014: Ch. 17: Southeast and the Caribbean. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 396-417. doi:10.7930/J0NP22CB.

ETL 1100-2-3. Engineering Technical Letter: Guidance for Detection of Nonstationarities in Annual Maximum Discharges. *U.S. Army Corps of Engineers.* 28 April 2017.

ECB 2016-25. Engineering and Construction Bulletin: Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects. *U.S. Army Corps of Engineers.* 16 September.

ECB 2018-14. Engineering and Construction Bulletin: Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects. *U.S. Army Corps of Engineers.* 10 September.

Laseter, S.H., Ford, C.R., Vose, J.M., Swift, L.W. (2012) Long-term temperature and precipitation trends at the Coweeta Hydrologic Laboratory, Otto, North Carolina, USA. Hydrology Research 43, 890-901.

Li , W., Li, L., Fu, R., Deng, Y., Wang, H .(2011) Changes to the North Atlantic subtropical high and its role in the intensification of summer rainfall variability in the southeastern United States. Journal of Climate 24:1499-1506.

Liu L, Hong Y, Hocker JE, Shafer MA, Carter LM, Gourley JJ, Bednarczyk CN, Yong B,

Adhikari P (2012) Analyzing projected changes and trends of temperature and precipitation in the southern USA from 16 downscaled global climate models. Theoretical and Applied Climatology 109:345-360.

Liu Y, Goodrick SL, Stanturf JA (2013) Future U.S. wildfire potential trends projected using a dynamically downscaled climate change scenario. Forest Ecology and Management 294:120-135.

Mauget, S.A. (2004) Low frequency streamflow regimes over the central United States: 1939-1998. Climatic Change 63, 121-144.

National Centers for Environmental Information, 2020. Global Summary of the Year – Memphis International Airport, TN US USW00013893 (1970 – 2018). https://www.ncdc.noaa.gov/cdo-web/datasets/GSOY/stations/GHCND:USW00013893/detail

Patterson, L.A., Lutz, B., Doyle, M.W. (2012) Streamflow Changes in the South Atlantic, United States During the Mid- and Late 20th Century. Journal of the American Water Resources Association 48, 1126-1138.

Pryor SC, Howe JA, Kunkel KE (2009) How spatially coherent and statistically robust are temporal changes in extreme precipitation in the contiguous USA? International Journal of Climatology 29:31-45.

Qian T, Dai A, Trenberth KE (2007) Hydroclimatic trends in the Mississippi River basin from 1948 to 2004. Journal of Climate 20:4599-4614.

Simon A., Artita K., Simon G., Darby S.E., Leyland, J. (2020) Changes in Hydrology and Suspended-Sediment Transport in the Mississippi River Basin over the Past Century. United States. Army. Corps of Engineers. Mississippi Valley Division,, https://hdl.handle.net/11681/37073

USACE, 2015. Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Lower Mississippi River Region 08. Civil Works Technical Report, CWTS 2015-08, USACE, Washington, DC

USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp., doi: 10.7930/J0J964J6.

USGS, 2020. National Water Information System: Web Interface USGS 07032200 Nonconnah Creek Near Germantown, TN. https://waterdata.usgs.gov/tn/nwis/dv?referred_module=sw&site_no=07032200

Wang H, Killick R, Fu X (2013) Distributional change of monthly precipitation due to climate change: Comprehensive examination of dataset in southeastern United States. Hydrological Processes, in press.

Wang H, Schubert S, Suarez M, Chen J, Hoerling M, Kumar A, Pegion P (2009) Attribution of the seasonality and regionality in climate trends over the United States during 1950-2000. Journal of Climate 22:2571-2590.

Westby, R.M., Lee, Y.-Y., Black, R.X. (2013) Anomalous temperature regimes during the cool season: Long-term trends, low-frequency mode modulation, and representation in CMIP5 simulations. Journal of Climate 26, 9061-9076.