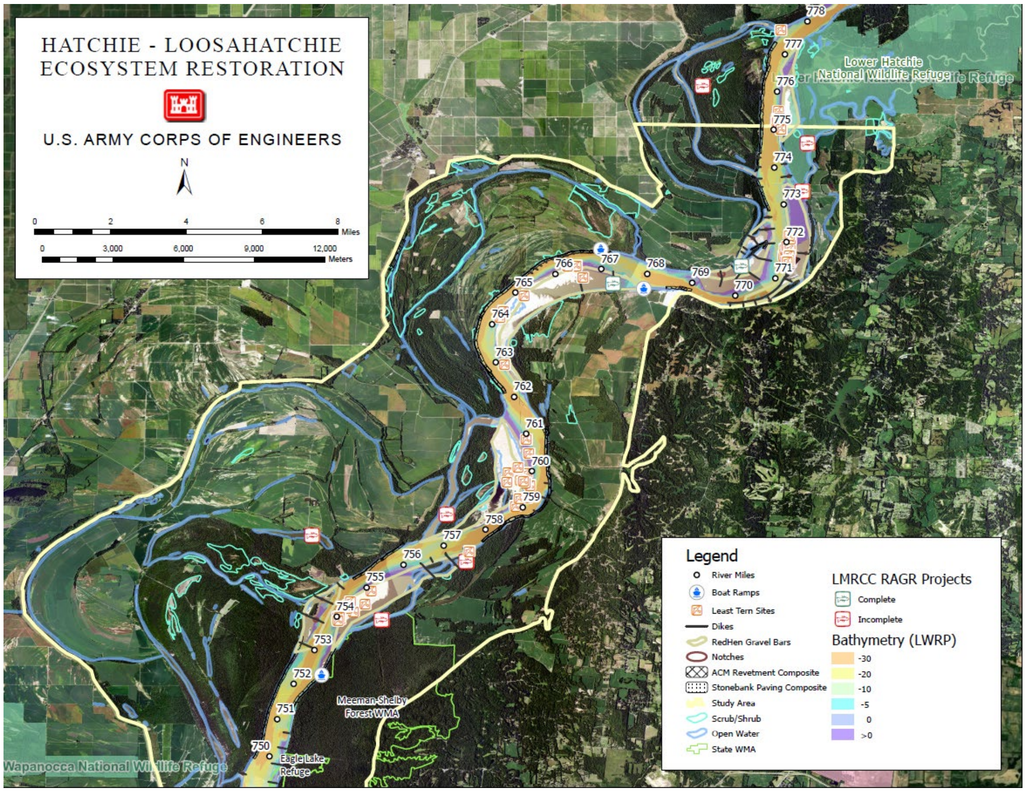
Mississippi Valley Division,
Regional Planning and Environment Division South

Mississippi River Hatchie/Loosahatchie Mississippi River Mile 775-736, Tennessee and Arkansas



Appendix 10 - Climate Change Appendix

February 2023

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Climate Change Assessment

1.1 INTRODUCTION

This climate change assessment is performed to highlight existing and future challenges facing the study area following the guidance in United States Army Corps of Engineers' (USACE) Engineering Construction Bulletin (ECB) 2018-14, Guidance For Incorporating Climate Change Impacts To Inland Hydrology In Civil Works Studies, Designs, and Projects, revised 19 August 2022. 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. This evaluation identifies potential climate change vulnerabilities for the Hatchie Loosahatchie Mississippi River Ecosystem Restoration Feasibility study. The study area includes a 39-mile reach of the Mississippi River from approximately river mile 775-736. A more detailed description of the study background information can be found in the main report. Measures included in the tentatively selected plan (TSP) were related to functions under the Ecosystem Restoration business line items.

The project area lies entirely within the four digit HUC 0801. No river gages exist within the project area, but the gage for Mississippi River at Memphis, TN is approximately one mile downstream of the project area. The USACE Memphis District has records at this gage since the late 1800s. The Mississippi River basin covers 41% of the continental US, but at Memphis, TN has a drainage area of over 930,000 square miles. The project area floods frequently, with the majority of the area inundated during the 50% Annual Exceedance Probability (AEP) event.

1.2 LITERATURE REVIEW

A literature review was conducted to summarize climate change literature relevant to the study area and to highlight both observed and projected assessments of relevant climate change variables. The primary climate variables impacting this ecosystem restoration study are temperature, precipitation, streamflow, and drought. A 2015 review conducted by the USACE Institute for Water Resources (IWR) summarizes the available literature on climate change for the Lower Mississippi River Region 08, which includes the Hatchie to Loosahatchie reach of the Mississippi River.

1.2.1 Temperature

1.2.1.1 Observed Temperature

In general, studies have found varying trends in observed air temperature for the Lower Mississippi River Water Resources Region. Liu et al. (2012), noted that the cooling trend ends in the 1970s and transitions to a warming trend from 1976 onwards. Another study Wang et al. (2009) showed a positive trend (increasing) for most of the US but a slightly cooling trend for the Lower Mississippi River basin, particularly for the fall and summer months. The IWR climate change literature review ultimately concluded there is not clear consensus on a significant change in observed mean air temperature for the Lower Mississippi River. However, Schwartz et. al (2013) identified a delay in spring warming by a few days for the 2001-2010 time period when compared to 1950s-1960s indicating a small shift in the seasons and potential ecological impact.

1.2.1.2 Projected Temperature

Future climate conditions in the U.S. have been projected using Global Climate Models (GCMs). USACE (2015) concluded there is a strong consensus in the literature of a projected temperature increase in the study area. A study by Liu et al. (2013) assumed a “worst case” greenhouse gas emissions scenario projected an overall warming trend of 2 to almost 4 degrees Celsius (ºC) by 2055 for the Lower Mississippi River Region (Figure 1).

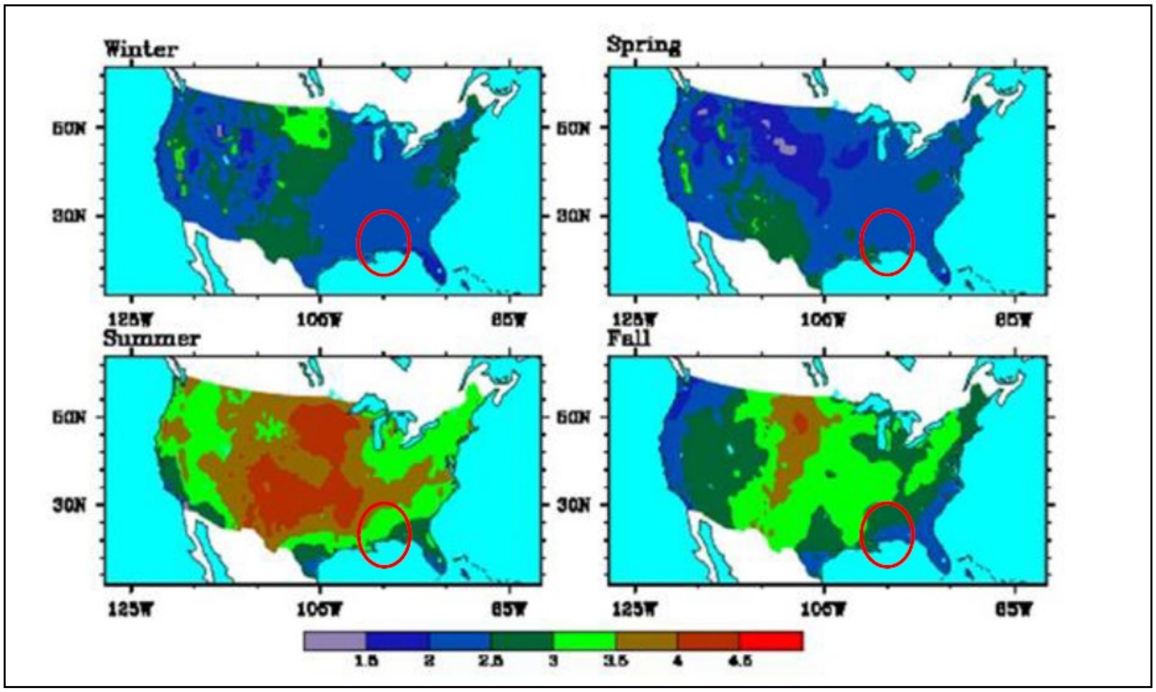


Figure 1: Projected Changes in Seasonal Maximum Air Temperature, ºC, 2041 – 2070 vs. 1971 – 2000. The Lower Mississippi River Region is within the Red Oval. (Liu et al., 2013; reprinted from USACE, 2015).

Similarly, Scherer and Diffenbaugh (2014) a less extreme global climate change scenario and projected an increase of 3.9 ºC in the summer and 3.2 ºC in the winter by 2090. Dale et al. (2010) applied the GCM projections to Tennessee and focused on the same moderate greenhouse emission scenario as Scherer and Diffenbaugh (2014) and projected seasonal changes in temperature. The largest increase was projected for summer and fall seasons with 1 to 2 ºC increase by 2030 and 2 to 6 ºC increase by 2080.

1.2.2 Precipitation

1.2.2.1 Observed Precipitation

Several relevant studies were identified in the IWR climate change review. A mild upward trend in precipitation was identified by multiple authors (Palecki et al. 2005; Grundstein 2009; Wang and Zhang 2008; McRoberts and Nielsen-Gammon 2011). Grundstein (2009) identified a positive linear trend in both annual precipitation and soil moisture index for the southeastern US. Soil moisture index reflects both precipitation and evapotranspiration. McRoberts and Nielsen-Gammon (2011) considered the time period from 1895-2009 and identified linear positive trends in annual precipitation totals and estimated an increase on the order of 2-15% per century for water resources region 8. This included a 10-15% for West TN and 2-5% for the Missouri bootheel and Eastern AR (Figure 2).

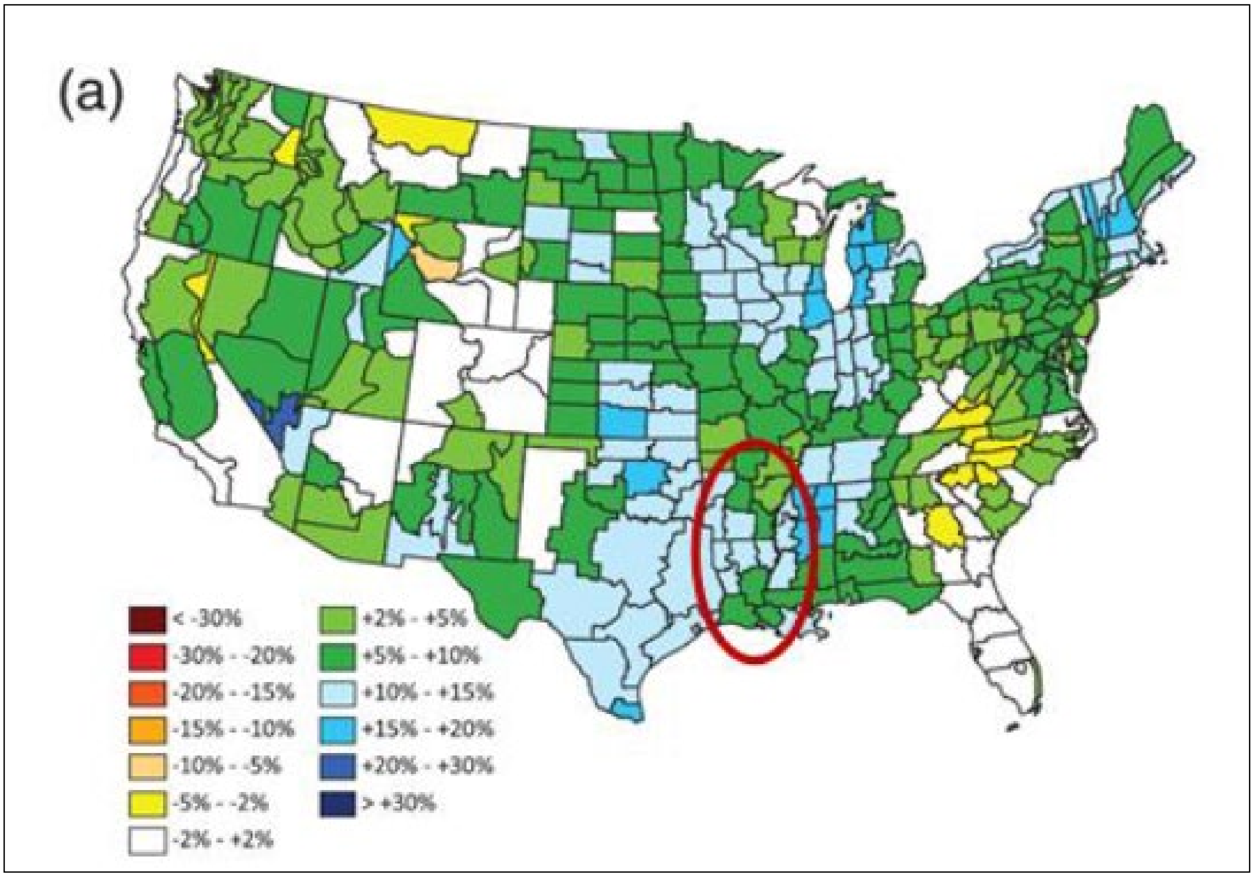


Figure 2. Linear Trends in Annual Precipitation, 1895 - 2009, Percent Change per Century.

The Lower Mississippi River Region is within the Red Oval (McRoberts and Nielsen-Gammon, 2011).

1.2.2.2 Projected Precipitation

There is a general lack of consensus and high variability in the literature regarding future annual precipitation projections (USACE 2015). Liu et al. (2013) projected significant increases in spring precipitation for 2055 when compared to 1971-2000. The authors also project future increases in severity of drought. Dale et al. 2010 ran GCM projections for Tennessee projected three possible futures that lack consensus: 1) increase in monthly precipitation of 1mm/month, 2) some months slightly wetter and some slightly dryer and 3) a decrease in monthly precipitation of approximately 1mm/month.

1.2.3 Streamflow

Most of the literature for climate change impacts on streamflow focuses on rivers and streams of all sizes within the region. However, since this project area lies on the mainstem of the Mississippi River, hydrology from the entire Mississippi River watershed impacts streamflow in the area. Mauget (2004) identified an increase in streamflow for the Mississippi watershed as a whole but did not necessarily focus on flow in the mainstem of the Mississippi River.

1.2.4 Summary

Figure 3 summarizes the overall consensus and trends for climate related variables based on the findings of the 2015 USACE IWR study. There is a strong consensus for projected increases in temperature in the Lower Mississippi River region. Precipitation trends are expected to increase. Although there is a low level of consensus regarding total precipitation, there is a general consensus that extreme precipitation is expected to increase in the future. Few conclusions can be made about future hydrology in the region due to a substantial amount of uncertainty and the large drainage area of the Mississippi River.

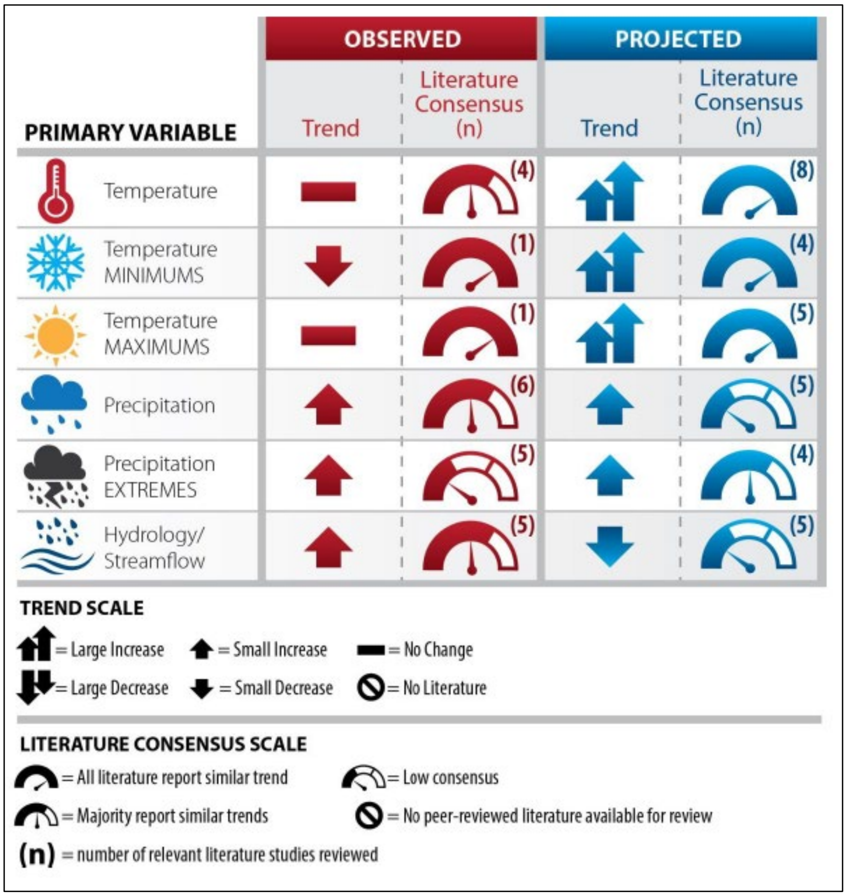


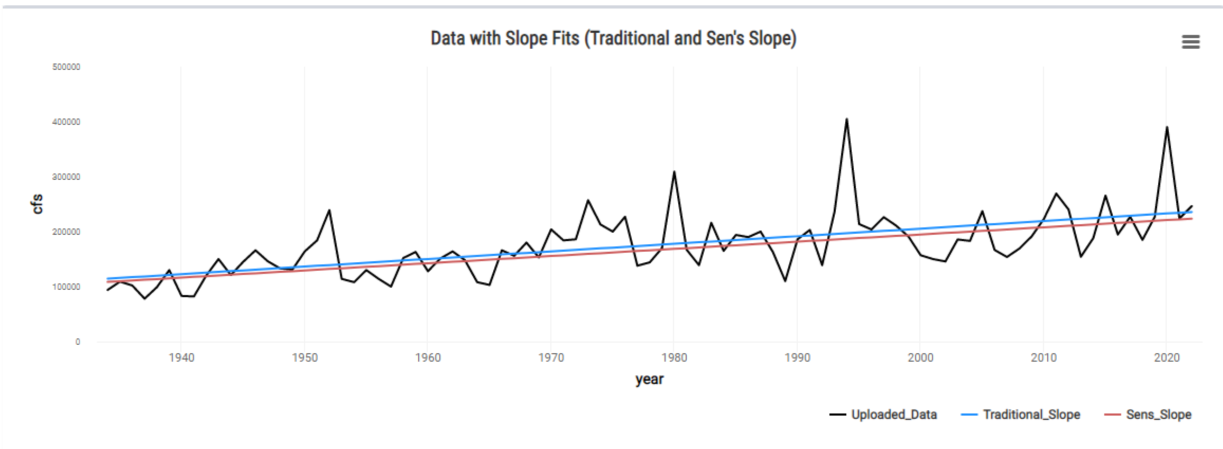
Figure 3. Summary Matrix of Observed and Projected Climate Trends and Literary Consensus reprinted from USACE (2015)

1.3 NONSTATIONARY ASSESSMENT

In accordance with ECB 2018-14, a stationarity analysis was performed to determine if there are long-term changes in streamflow statistics for the Mississippi River using the USACE Time Series Toolbox (TST). The TST performs statistical tests to test the assumption of stationarity (statistical characteristics are not changing with time) using guidance outlined in Engineering Technical Letter (ETL) 1100-2-3, Guidance for the Detection of Non-stationarities (2017). The USACE gage for the Mississippi River at Memphis, TN (MS126) is approximately 1 river mile downstream of the study area boundary and has a period of record for flow starting in 1932. Flows from 1932-2021 were used in this analysis. Typically, peak streamflow is used for this analysis, however the measures proposed for this study will be more sensitive to low flows. Therefore, minimum yearly flow was analyzed. The majority of the study area is inundated during low frequency flood events (50% and 20% Annual Exceedance Probability).

Minimum yearly flow for MS126 was calculated for the entire period of record A statistically significant, increasing trend was identified when examining all mean seasonal temperatures as well as the average annual temperatures. This means the p-value was less than 0.05

which exhibits a statistically significant trend at a 95% confidence level. The Regression add-in in excel was used to calculate the p-value. using HEC-DSSVue. Trend analysis for MS126 for 1933-2021 is shown in Figure 4. A statistically significant, increasing trend was identified when examining all mean seasonal temperatures as well as the average annual temperatures. This means the p-value was less than 0.05 which exhibits a statistically significant trend at a 95% confidence level. The Regression add-in in excel was used to calculate the p-value.



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	1379	-2552148
Sen's Slope	Positive	1308	-2419340

Trend Hypothesis Test

Test	P-Value
t-Test	1.9168e-10
Mann-Kendall	< 2.2e-16
Spearman Rank-Order	2.0689e-13

- **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 4. Time series toolbox output for yearly minimum flows for Mississippi River at Memphis, TN

The TST was also used to detect non- stationarities in the data (Figure 5). Non-stationarities were identified in the early 1940’s and the late 1960s. Both of these time periods correspond with major construction activities in the watershed (i.e. channel cutoff program (Biedenharn et al. 2017) and construction of major flood control reservoirs) that can account for this non-stationarity. The TST was then used to identify breakpoints in the data. One breakpoint was identified in 1968 (Figure 6). Data prior to 1968 was removed and the trend analysis re-ran (Figure 7). After 1968, a significant trend in yearly minimum flow was not identified.

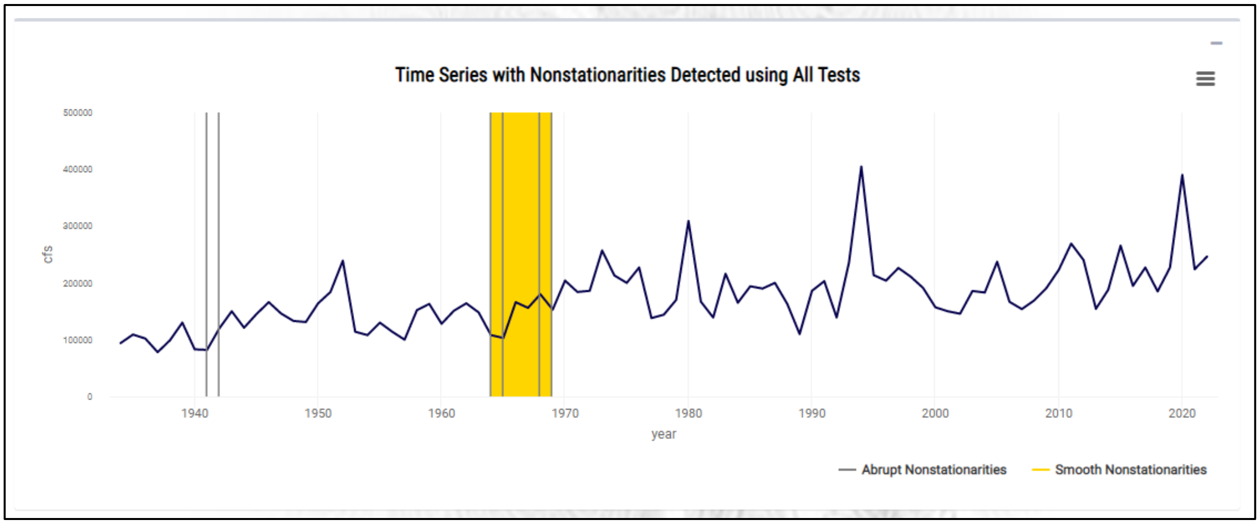
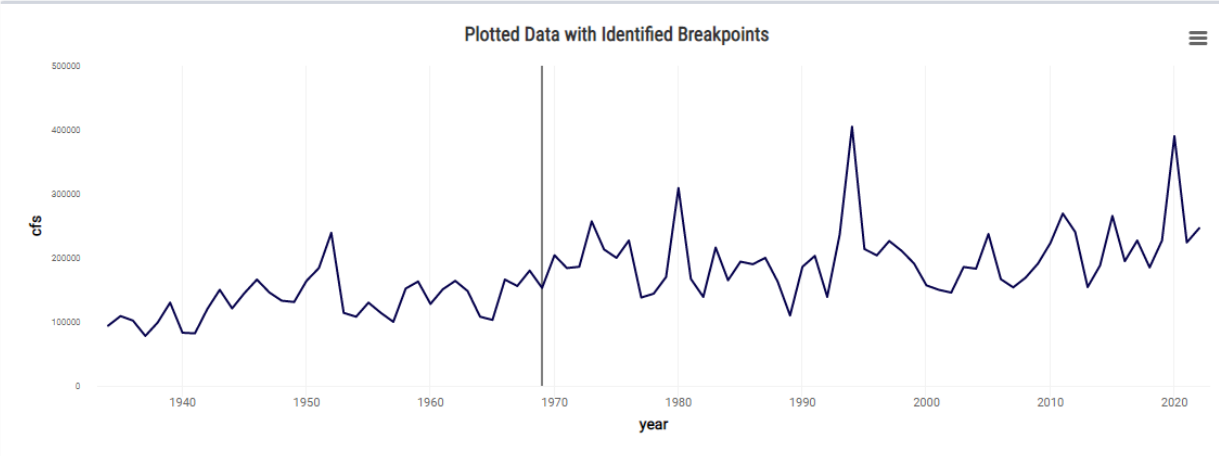


Figure 5. Nonstationarities identified with the time series toolbox output for yearly minimum flows for Mississippi River at Memphis, TN.



1 Number of Breakpoints

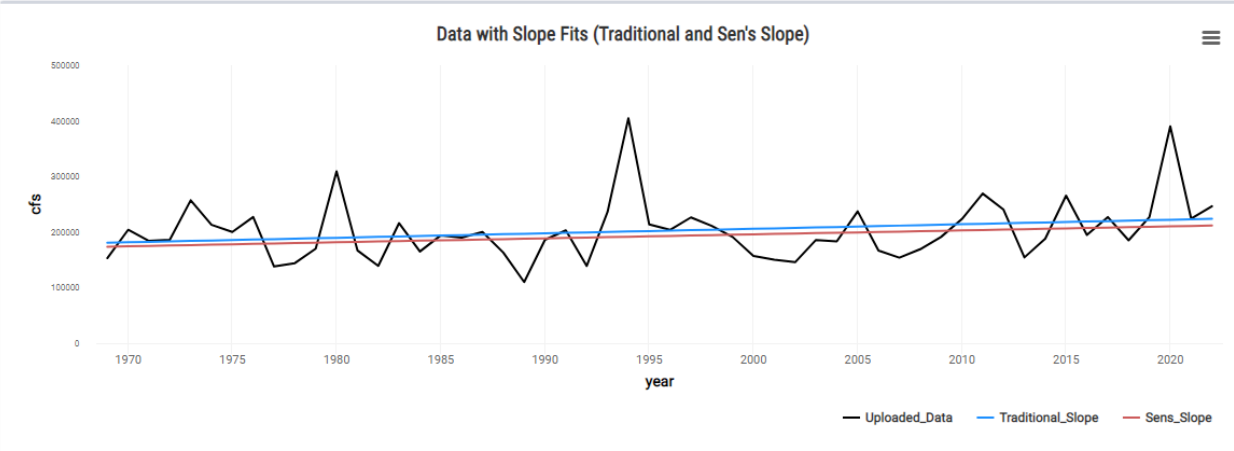
2185 Minimum BIC

46875 Total RMSE

Breakpoint Segment Details

Date Range	Slope		P-Value (Trend)	Intercept	Directionality	
1933-12-31 to 1968-12-31	1428.571429	**	0.0066071	107293.65079	Positive	–
1968-12-31 to 2021-12-31	809.957538		0.089325	179893.94549	Positive	–

Figure 6. Breakpoints identified with the time series toolbox output for yearly minimum flows for Mississippi River at Memphis, TN.



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	810	-1413293
Sen's Slope	Positive	714	-1232075

Trend Hypothesis Test

Test	P-Value
t-Test	0.089325
Mann-Kendall	0.062138
Spearman Rank-Order	0.064044

- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.**

Figure 7. Time series toolbox output for yearly minimum flows for Mississippi River at Memphis, TN with non-stationarities removed. The period used for this analysis was 1969-2021.

1.4 CLIMATE HYDROLOGY ASSESSMENT TOOL (CHAT)

The USACE Climate Hydrology Assessment Tool (CHAT) derived historic and future streamflow, temperature, and precipitation outputs from 32 GCMs. GCMs use scenarios representing different pathways to a given atmospheric concentration of greenhouse gas emissions referred to as representative concentration pathways (RCPs). The CHAT produces timeseries for 2006 to 2099 using two future scenarios: RCP 4.5 (where greenhouse gas emissions stabilize by the end of the century) and RCP 8.5 (where greenhouse gas emissions continue to increase throughout the century). Simulated output representing the historic period of 1951 to 2005 is generated using a reconstitution of historic GHG emissions. The CHAT allows the user to select a stream segment within a given 8-digit HUC watershed. For this study the Mississippi River segment from the Hatchie River to the Wolf River was selected in the CHAT.

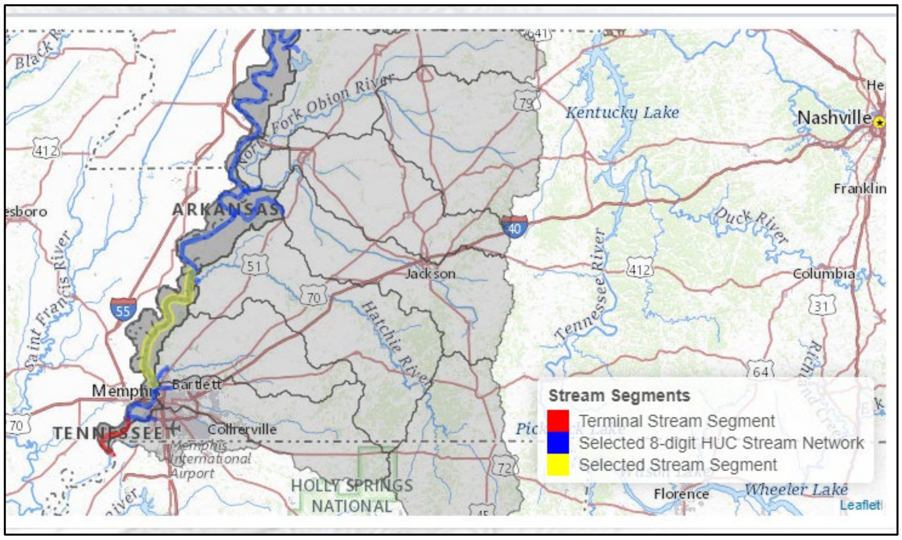


Figure 8. Stream segment used for CHAT tool

Three variables were selected for analysis: Annual mean streamflow, drought indicator, and annual mean temperature. Both RCP scenarios were analyzed. Figure 9 shows trends in annual average mean streamflow. No statistical trend (p<0.05) was observed for the simulated historical or the RCP 4.5 scenarios. The RCP 8.5 scenario did exhibit a statistically significant increasing trend, indicating the potential for an increase of approximately 25Kcfs in average annual streamflow by 2100.

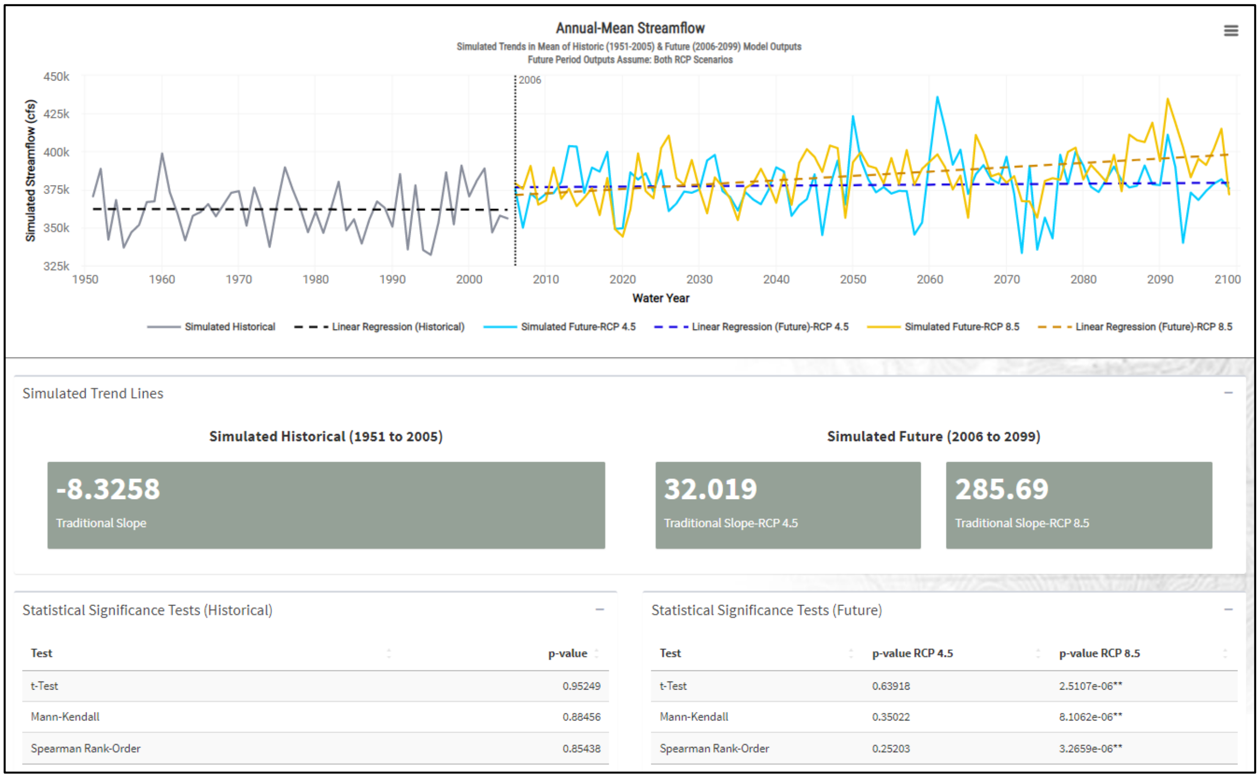
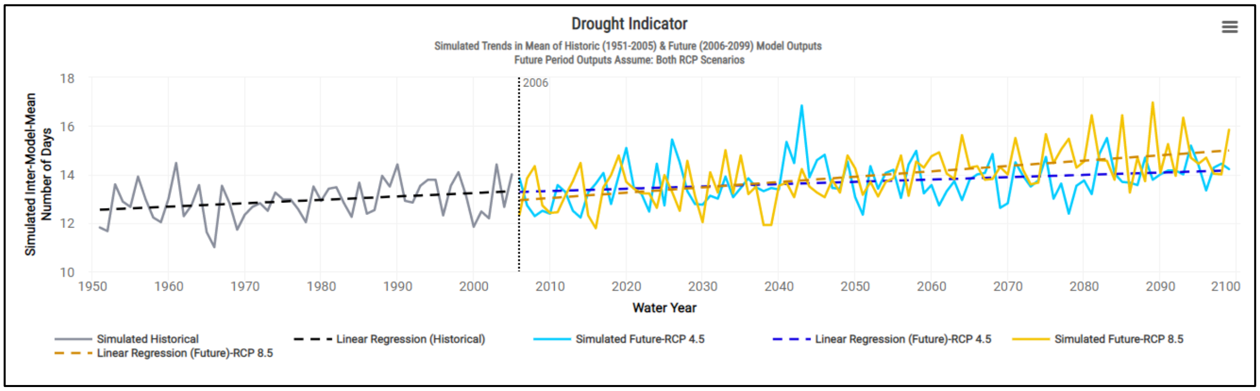


Figure 9. Annual mean streamflow trends and predictions for the Mississippi River from the CHAT

Figure 10 shows the historic and projected trends for the drought indicator in inter model mean number of days. The simulated historical and simulated future scenarios show a statistically significant increase over time. This indicates a slight increase in number of drought days over the next century.



Simulated Trend Lines

Simulated Historical (1951 to 2005)

0.014
Traditional Slope

Simulated Future (2006 to 2099)

0.0095
Traditional Slope-RCP 4.5

0.0221
Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

Test	p-value
t-Test	0.033127**
Mann-Kendall	0.038448**
Spearman Rank-Order	0.056309

Statistical Signficance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.0025106**	5.5526e-1< 2.2e-16**
Mann-Kendall	0.00033844**	< 2.2e-16**
Spearman Rank-Order	0.00036432**	1.3912e-09**

Figure 10. Drought indicator (number of days) trends and predictions for the Mississippi River from the CHAT

Figure 11 shows the historic and projected trends for the average annual temperatures. The simulated historical and simulated future scenarios show a statistically significant increase over time. The RCP 8.5 scenario projects a greater increase in temperature compared to the RCP 4.5. An increasing rate of temperature increase is show in the projected scenarios. This projected increase in temperature is supported by the literature review discussed in section 1.2.1.2.

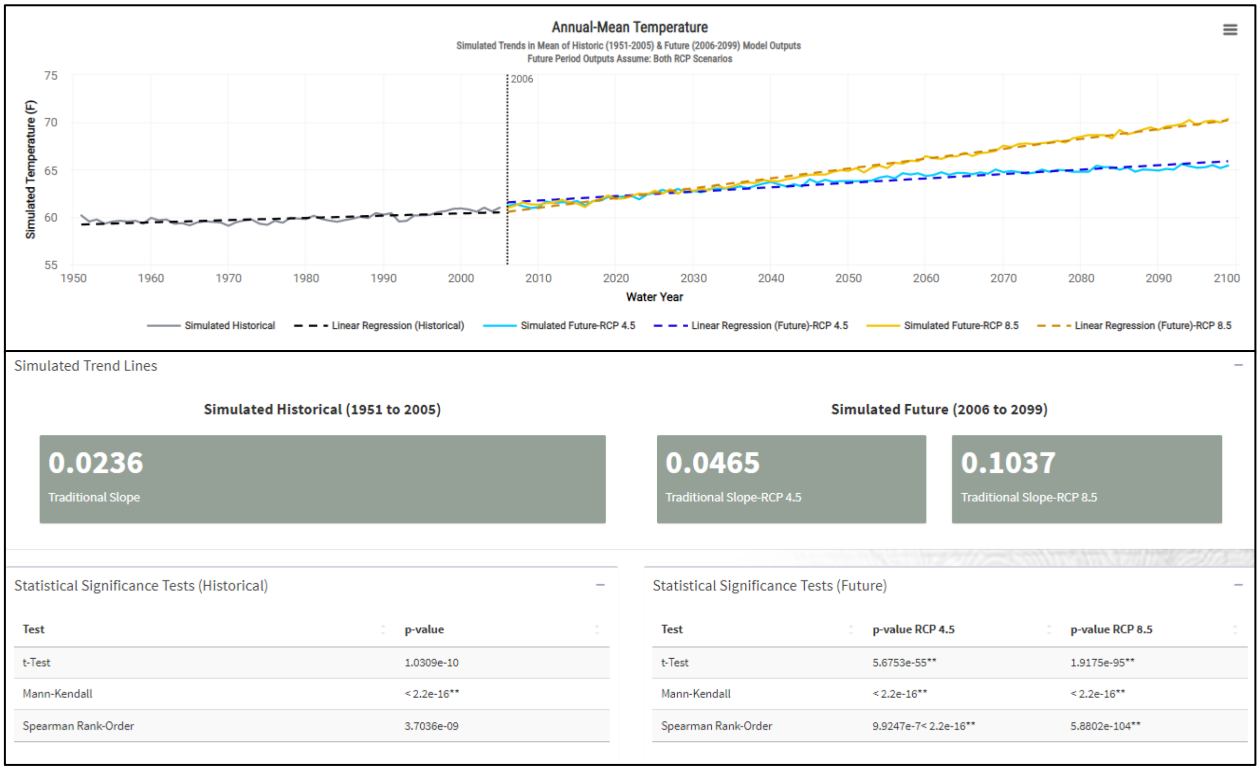


Figure 11. Annual mean temperature trends and predictions for the Mississippi River from the CHAT

The CHAT also allows the user to analyze some variables by month and compares change from historic simulation to future epochs. The change in mean monthly streamflow is shown in Figure 12. While annual average streamflow is projected to increase (Figure 11), a decrease in monthly average streamflow is projected for the months of July, August, and September. This has the potential to impact flow (and habitat) in the secondary channels in the project area during these months.

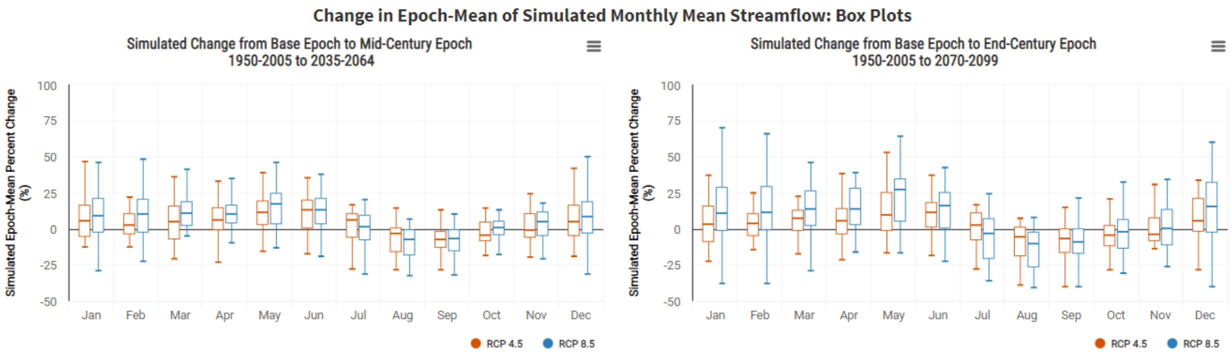


Figure 12. Change in monthly mean streamflow for the Mississippi River from the CHAT

1.5 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. Vulnerability with respect to the Ecosystem 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. For each epoch, the tool aggregates the results of 100 GCMs to produce results for each watershed. The results are sorted into cumulative runoff projections and the bottom 50% represent the “dry” scenario, while the top 50% represent the “wet” scenario. The tool uses specific indicators of vulnerability relative to the business line being considered. There are a total of 27 indicators in the tool, 9 of which are used to derive the vulnerability score respect to the Ecosystem Restoration business line. Table 1 lists the indicators and their descriptions.

Figure 13 shows the dominant indicators for the Ecosystem Restoration business line. The figure shows that At Risk Freshwater Plants is the prevailing indicator variable driving the Ecosystem 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. The results from the vulnerability scenario indicate that Lower Mississippi-Hatchie is not in the top 20% of vulnerable basins with respect to the ecosystem restoration business line.

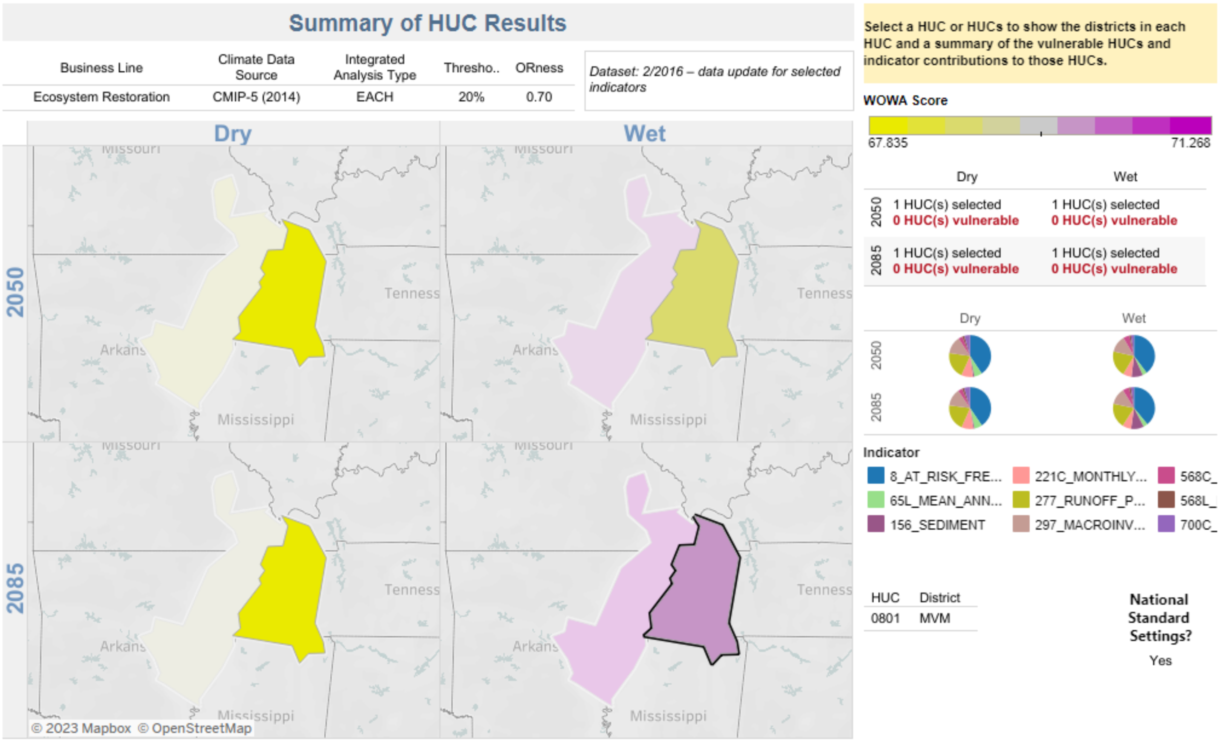


Figure 13. Vulnerability of Project HUC for Ecosystem Restoration Business Line

Table 1. Indicator variables used to derive the ecosystem restoration vulnerability score for the Lower Mississippi River-Hatchie basin

Indicator Short Name	Indicator Name	Indicator Description
8_AT_RISK_FRESHWATER_PLANT	% of freshwater plant communities at risk	Percentage of wetland and riparian plant communities that are at risk of extinction, based on remaining number and condition, remaining acreage, threat severity, etc.
65L_MEAN_ANNUAL_RUNOFF	Mean annual runoff (local)	Mean runoff: average annual runoff, excluding upstream freshwater inputs (local).
156_SEDIMENT	Change in sediment load due to change in future precipitation	The ratio of the change in the sediment load in the future to the present load.
221C_MONTHLY_COV	Monthly CV of runoff (cumulative)	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. 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.
297_MACROINVERTEBRATE	Macroinvertebrate index of biotic condition	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.
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.
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.
700C_LOW_FLOW_REDUCTION	Low flow reduction factor (cumulative)	Change in low runoff: ratio of indicator 570C (monthly runoff exceeded 90% of the time, including upstream freshwater inputs) to 570C in base period.

1.6 SUMMARY

Ultimately, the measures investigated for this project were selected to improve the aquatic and terrestrial ecosystems’ resilience to climate change. Table 2 discusses the potential impacts of climate change to each measure type. Expected reduction in flow to secondary channels and floodplain waterbodies during the summer months poses the greatest threat to the ecological integrity of the project area in the future without project scenario. However, many of the measures (culverts, channel excavation, river training structures, dike notching, etc.) are intended to be designed to increase flow connectivity to the secondary channels to address the impacts of climate change in the future with project scenario.

Table 2. Impacts of Climate Change on measures included in the tentatively selected plan

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Dike Notching	Drought, Streamflow	Decrease in Low flow	Potential loss of connectivity in secondary flow paths at during low flow. Threat to habitat of rheophilic fishes.	Likely
Woody Debris Trap	None	None	Woody debris trap locations were selected based on permanently inundated areas and increase habitat for macroinvertebrates during dry conditions	NA
Riprap Bank Protection	Increased Maximum streamflow	Increased velocities	The intent of the bank protection included in the TSP is to prevent erosion and reduce loss of land that contains beneficial vegetation. Bank protection is designed to withstand high velocities.	Unlikely
River Training Structure	Streamflow	Decrease in low flow	Less flow diverted to meander scarps during drought conditions. This measure is intended to divert more flow to secondary channels/meander scraps and should help mitigate the impacts of climate change	Unlikely
Weir and Stoplog Structures/Berm construction	Temperature Streamflow	Decrease in low flow Increased water Temperature	Weir and stop log structures are intended to increase connectivity and pond water. Increase in air temperature may could increase water temperature and threaten the health of some fish species.	Unlikely
Culverts	Decrease streamflow	Loss of connectivity	Potential loss of connectivity in secondary flow paths at during low flow. Threat to habitat of rheophilic fishes. These measure are intended to increase connectivity during low flow.	Unlikely
Channel Excavation	Increase in low flow frequency	Siltation	An increase in low flow frequency would reduce the self-scouring abilities of the channel and increase frequency of maintenance	Likely

Bridge Replacement	None	None	Bridge should not be impacted by climate variables. Bridge is being redesigned to increase connectivity.	NA
Recreational Measures	Increased temperature	Less use during higher temperature	Little to none. Less public involvement/ education	Likely
Floodplain vegetation	Decreased Precipitation Increase Temperature	Increase in invasive species (longer growing season) Decrease precipitation, less successful planting	Diverse plant communities might not be established. Certain species may not be tolerant to higher temperatures.	Likely

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