US Army Corps of Engineers ®
Little Rock District
Hydrology and Hydraulics Section

Appendix A: Engineering

Continuing Authorities Program (CAP)
Section 14

Mortar Creek Emergency Streambank Erosion Protection and Prevention

Quitman, Faulkner County, AR

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Appendix A: Hydrology and Hydraulics Design

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Appendix A: Hydrology and Hydraulics Design

A.1. Introduction

The authority for this project is Section 14 of the Flood Control Act of 1946, as amended as administered under the U.S Army Corps of Engineers Continuing Authorities Program (CAP).

The natural stream alignment in conjunction with the west tributary appear to be causing the erosion behind the wingwalls of the existing bridge. The west tributary shown in Figure 1 runs parallel to the road from west to east before flowing into Mortar creek just upstream of the old bridge abutments with a drainage area of around 100 acres. When the water gets high, the west roadside ditch flow goes over the old west bridge abutment and directly attracts the existing bridge west wingwall. This flow causes and eddie behind the wingwall and corresponding erosion of the embankment. During this higher flows, the old bridge abutments are submerged, and their effects are proportionally drowned out, so the damaging erosion is caused by that west roadside ditch and would occur with or without the old bridge abutments.

There is erosion on the east abutment of the existing bridge as well; however, this erosion is developing slower due to the alignment of the channel and the flood plain flows on the east side. Even though this erosion is happening at a slower rate, it has propagated to a tipping point, that when exceeded, will result in bridge failure.

In the channel, the flow is being constricted to a small area directly upstream of the Mortar Creek Road Bridge due to the existing abutments from an old bridge over the creek. The deck of the old bridge was removed when the current bridge was built approximately 30 feet downstream; however, the old bridge abutments were left in place for reasons not recorded. The top of the old bridge concrete abutments are approximately 3-5 feet lower than the new bridge abutments and have an opening width about 10-15 less than the new bridge.

During low flows, the velocity through the bridge is increased due to the old abutment constriction. This can be simple shown by the equation Q=VA where Flow (Q) is equal to Velocity (V) times Area (A). The old bridge abutments decrease the area of flow and in turn increase the velocity. This increased velocity appears to be contributing to erosion downstream of the bridge along the banks. At this point, the erosion downstream of the bridge does not appear to be threatening to the bridge. There is some erosion around the downstream wingwalls that should be addressed as the material behind the wingwalls is crucial to bridge and roadway integrity.

During higher flows, the old bridge abutments are overtopped. Based on the erosion seen around the old bridge abutments, overtopping appears to occur often.

The watershed is a mix of pasture and woods. The channel appears to have a riparian buffer of at least 50-80 feet for most of its course. There appears to be two inline ponds on mortar creek upstream of the bridge about 2 miles and 3.5 miles respectively. The areas of creek bank with no trees consist of powerline/utilities crossings and the ponds mentioned above.

A.1.1. Location

Mortar Creek Bridge runs over Mortar Creek and is experiencing erosion around the upstream abutments and to a lesser extent around the downstream abutments. The bridge is location on Mortar Creek Road, also known as Old Springfield Road, which is a County Road off Arkansas State Highway 107 near Enders, AR. The project location is approximately 3.5 miles south of Quitman, AR and 7.5 miles west of Rose Bud, AR. The bridge is in a rural location and experiences mostly local vehicle and farm traffic. Mortar Creek eventually flows into the Cadron Creek and is Discharged into the Arkansas River around Navigation Mile 158.7 in Pool 8. A location map is shown in Figure 1.

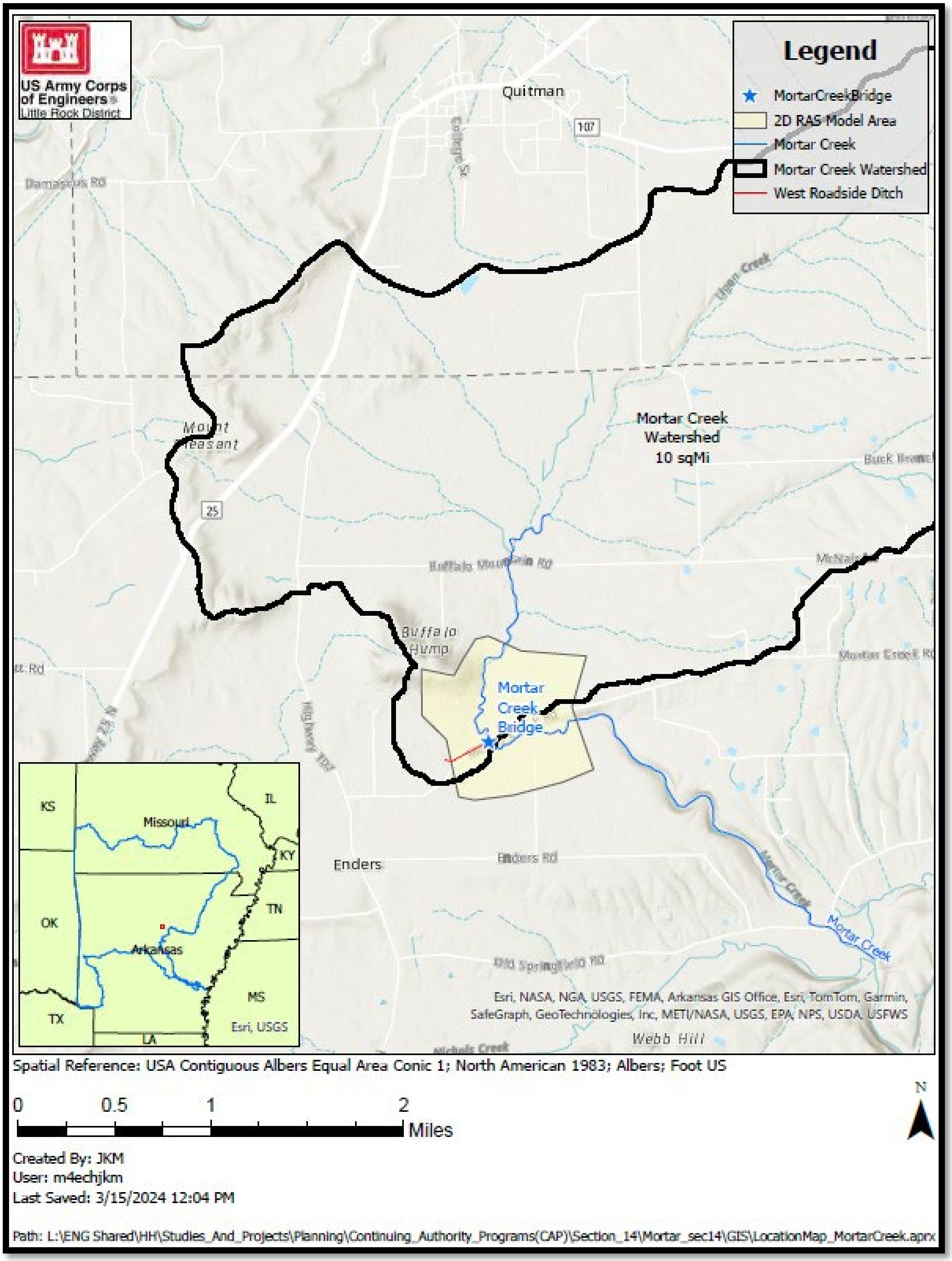


Figure 1. Mortar Creek Location Map

A.1.2. Design Guidance and Reference

This analysis considers the without-project and with-project conditions to determine whether flooding will be induced and to what degree per ER 1110-2-1150. All design, guidance, regulations, and project references are listed below:

US Army Corps of Engineers, Engineering Regulation 1110-2-1150, Engineering and Design for Civil Works Projects

US Army Corps of Engineers, Engineering Regulation 1110-2-1450, Hydraulic Design for Local Flood Protection Projects

US Army Corps of Engineers, Continuing Authorities Programs (CAP) Section 14, 33 U.S.C. §701r, Streambank erosion and shoreline protection of public works and nonprofit services

US Geological Survey, USGS StreamStats, https://streamstats.usgs.gov/

Multi-Resolution Land Characteristics Consortium, National Land Cover Database, https://www.mrlc.gov/data

National Oceanic and Atmospheric Administration's National Weather Service, Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS), Atlas 14-point precipitation frequency estimates, https://hdsc.nws.noaa.gov/pfds/

A.1.3. Description of Problem and Hydrology and Hydraulic Goals

Mortar Creek is funded under the Section 14 Continuing Authorities Programs streambank erosion and shoreline protection. The local sponsor, Faulkner County, provided a Letter of Interest to the Little Rock District Engineer on 14 Dec 2017 requesting a Section 14 study.

The new bridge at Mortar Creek was built between October 2010 and November 2012 according to google earth imagery shown in Figure 2. The problem that is happening today with the erosion around the abutments seems to be due to the alignment of Mortar creek and the roadside ditches. The new bridge is built with a hydraulic capacity that closer represents that of the channel at lower flows; therefore, the old bridge acts as a constriction in the channel. The goal of this section 14 project is to remove the old bridge abutments and place riprap on the approach of the existing bridge upstream where the old abutments are removed as well as overlay riprap around all four wingwalls of the current bridge. Doing this should help low flows not be as erosive downstream of the bridge and help pass high flows without causing turbulence and eddies on the upstream side of the bridge.

Figure 2. Original and Current Road Alignment

A.2. Background Information

Mortar Creek is a county road. The county government is able to approve closures and work within the right-of-way for the road.

A.3. Hydrology

An analysis was done on local rainfall and flow gages to determine what the precipitation trends are for the region. Based on the annual maximum 1, 2, 3, and 4-day precipitation data, the trends have been increasing slightly over the past 130 years.

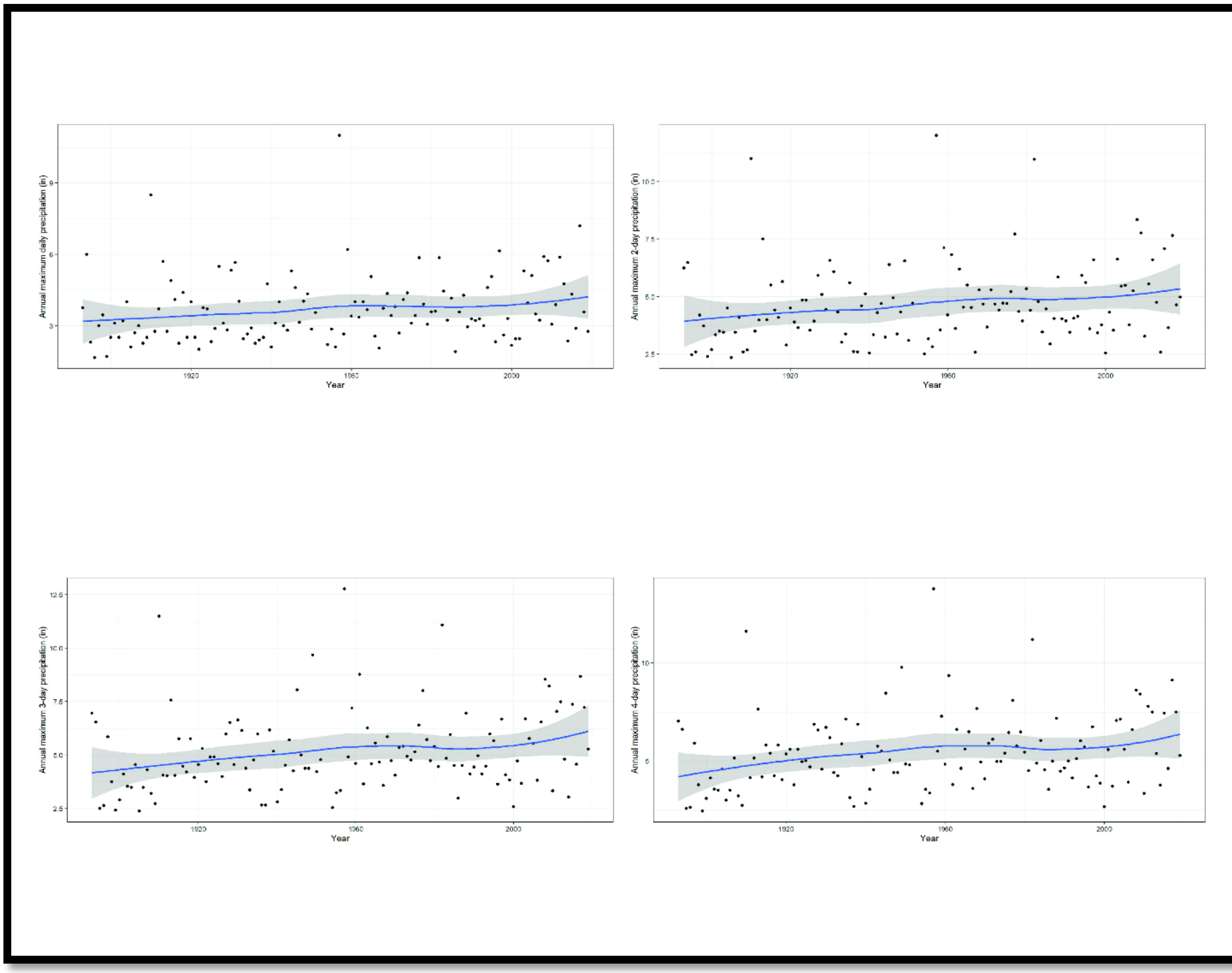


Figure 3. Co-Located Precipitation Gages at Damascus and Bee Branch, AR Analysis

The frequency flows used in the hydraulic modeling came from the USGS Stream Stats website. The StreamStats website can calculate a wide range of flow statistics for a given point of interest.

Frequency precipitation data was pulled from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14. NOAA Atlas 14 has a website where a location can be pinpointed spatially on a map. Tables and statistics are then generated for the location of interest. The reoccurrence-duration table pulled from Atlas 14 can be found in Table 1 in the hydrology results. This was pulled more for a reference to make sure our flows from stream stats within the realm of reason.

Table 1. Example NOAA Atlas 14, Volume 9, Version 2-Point Precipitation Frequency Estimates

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)					
Duration	Annual Exceedance Probability				
	50%	10%	4%	2%	1%
5-min	0.496	0.675	0.784	0.868	0.95
15-min	0.886	1.21	1.4	1.55	1.7
1-hr	1.69	2.3	2.69	3	3.31
2-hr	2.09	2.84	3.33	3.72	4.13
3-hr	2.34	3.18	3.75	4.22	4.7
6-hr	2.84	3.9	4.64	5.26	5.91
12-hr	3.47	4.85	5.81	6.59	7.42
1-day	4.16	5.88	7.05	8	8.99

A.3.1. Methodology

In StreamStats, a point of interest is determined, and the contributing watershed is calculated with corresponding flow statistics. A report is generated and can be exported and printed to a PDF document. The frequency flows pulled from StreamStats for Mortar creek at the bridge site are shown in Table 1 in the hydrology results.

A.3.2. Results

Below are the tables of hydrologic data used for the analysis of Mortar Creek erosion at the Mortar Creek bridge.

Table 2. Watershed Flows for Mortar Creek Bridge

	50% AEP	10% AEP	4% AEP	2% AEP	1% AEP
USGS Stream Stats (cfs)	1180	2900	4000	4900	5840

A.4. Hydraulics

A two dimensional (2D) mathematical hydraulic model was developed for the Mortar Creek Analysis. A survey was conducted by the United States Army Corps of Engineers (USACE) Southwestern Division Little Rock (SWL) survey crew, obtaining accurate channel bathymetry for Mortar Creek and area around the bridge to better inform the hydraulic modeling.

A.4.1. Methodology

The hydraulic modeling software used for the analysis, River Analysis System (RAS), was developed by the USACE Hydraulic Engineering Center (HEC). The version of software used was HEC-RAS 6.4.1.

The Li-DAR terrain used in the model was downloaded from the USGS servers and dated circa 2016. The grid cell sizes in the model are 25 feet for the overbank and 10 ft for the channel and around the structures.

A manning's n coefficient of 0.04 was used for the channel based on what was seen in the field and the National Land Cover Database (NLCD) 2019 was used for the overbank region.

Due to the lack of stream flow gages on Mortar Creek, the hydraulic model could not be calibrated to flow. It should be noted that this model should not be used to forecast or predict future flooding events or water surface elevations (WSE) for frequency events. The intent of this 2D hydraulic model was to get the best representation of flow in the channel and around the structure at various elevations. The results of the model were then compared to what was seen in the field before moving forward.

A sensitivity analysis was performed on the downstream boundary condition of the model. A normal depth slope of 0.01 and 0.001 was analyzed. An image of the downstream boundary conditions sensitivity analysis is shown in Figure 4. The dark blue line represents the normal depth slope, at the downstream boundary condition, of 0.01ft/ft and the teal line represents a normal depth slope, at the downstream boundary condition, of 0.001ft/ft. As can be seen from Figure 4, the normal depth range of reason does not affect what is going on at the area of interest around the bridge.

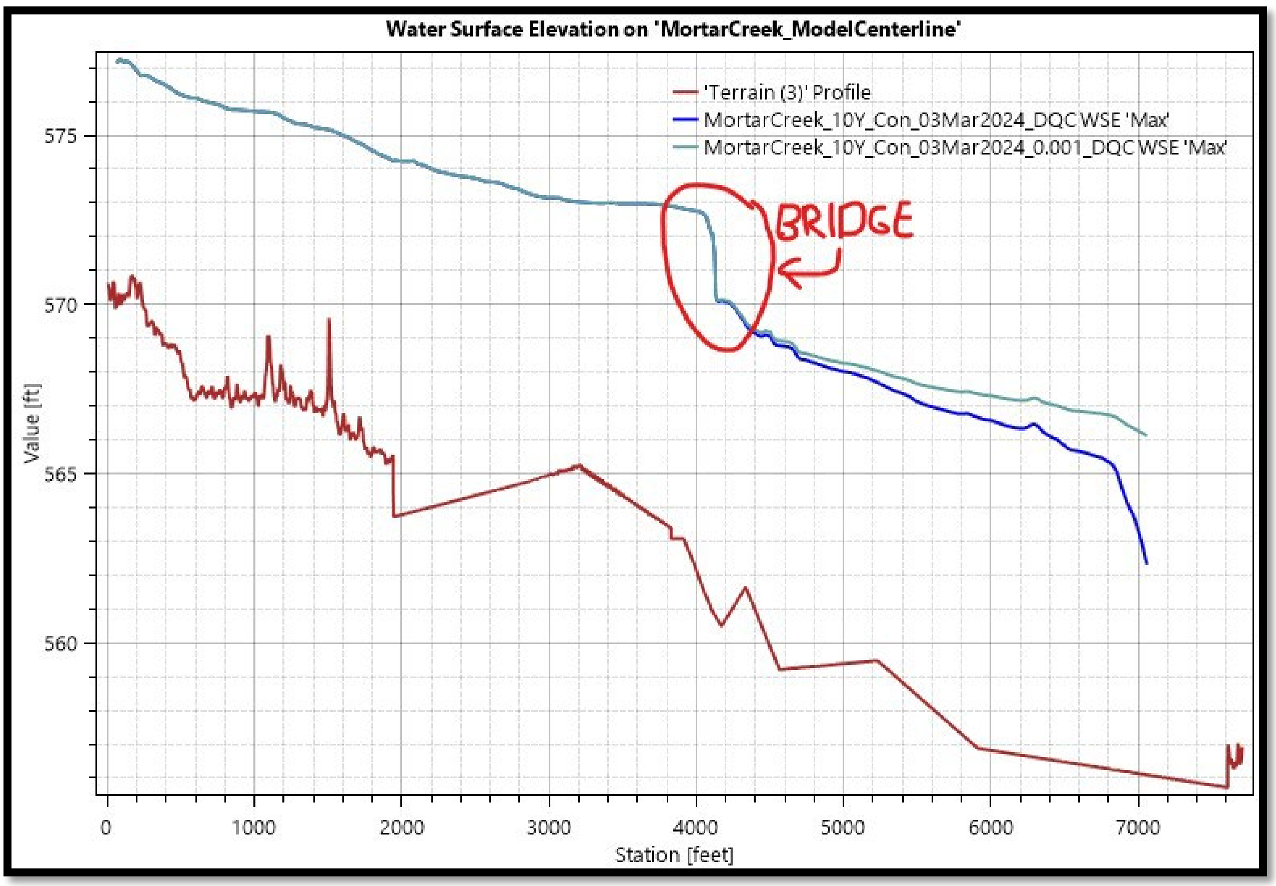


Figure 4. Downstream Boundary Condition Sensitivity

A.4.2. Results

The hydraulic model confirmed the suspicion that the flow from the west ditch was attacking the riprap behind the west wing wall. This is shown in Figure 5 below. The white lines are called particle tracers.

The density and lengths of the lines help to show the velocity and flow paths. The colored in portion of the map shows the extent of the water surface and the color corresponds to a velocity.

This picture shows that with around a 50% Annual Exceedance Probability (AEP) flow, the west bank has flow parallel to it cutting in behind the west wingwall and the east wingwall has an eddie forming around it.

The flow was input into the model using a steady state flow file with a constant value so that the flow at the bridge could obtain a stable state at the Stream States value for the given AEP flow.

It should be noted that this hydraulic model has a flow input upstream where flow enters the model and is not a rain-on-grid model. This means that local runoff is not shown flowing over the surface. The flows and velocities around the wingwalls, while still accurate, are not fully representative of what is happening during a high-water event.

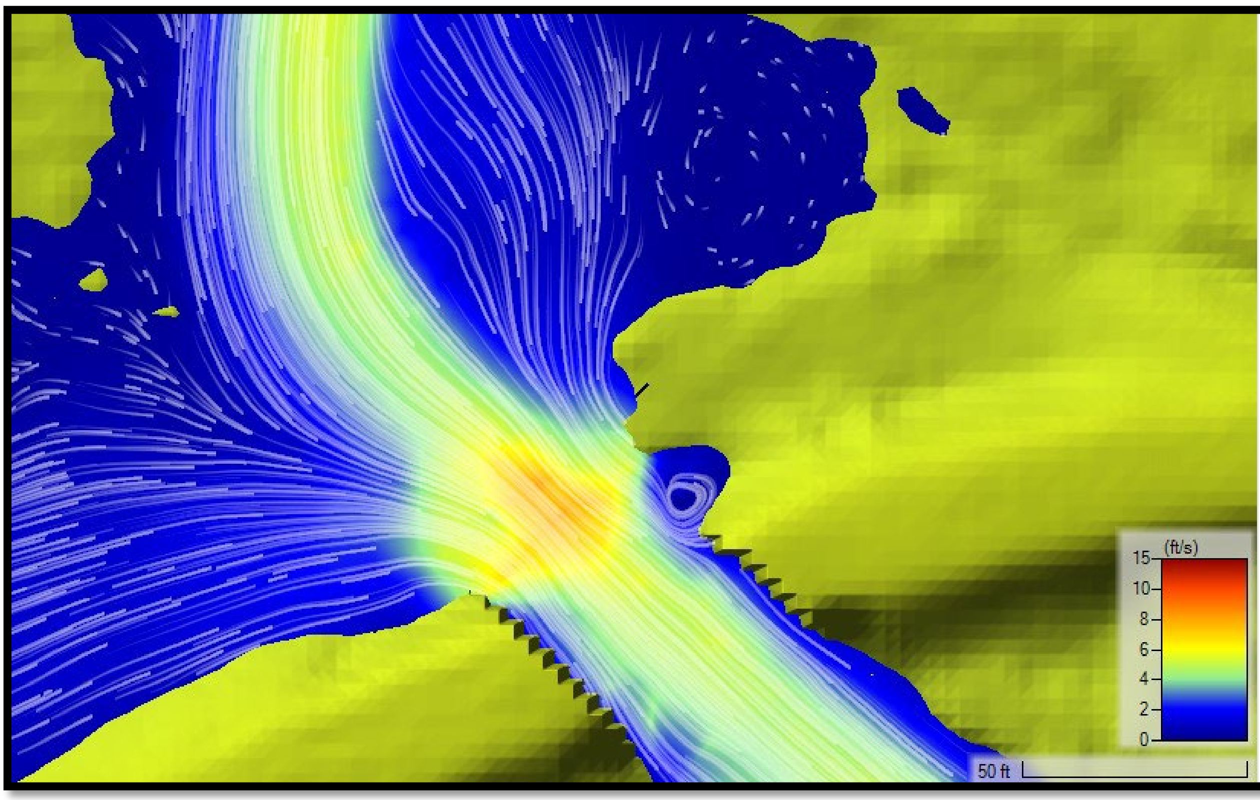


Figure 5. Screenshot from 2D RAS Model with Particle Tracers and Velocity Map for 50% AEP Flow

There is still some refinement that needs to be done around the bridge and the old abutments, but a screenshot of the initial model is shown in Figure 6. The entire 2D model domain can be seen in Figure 1.

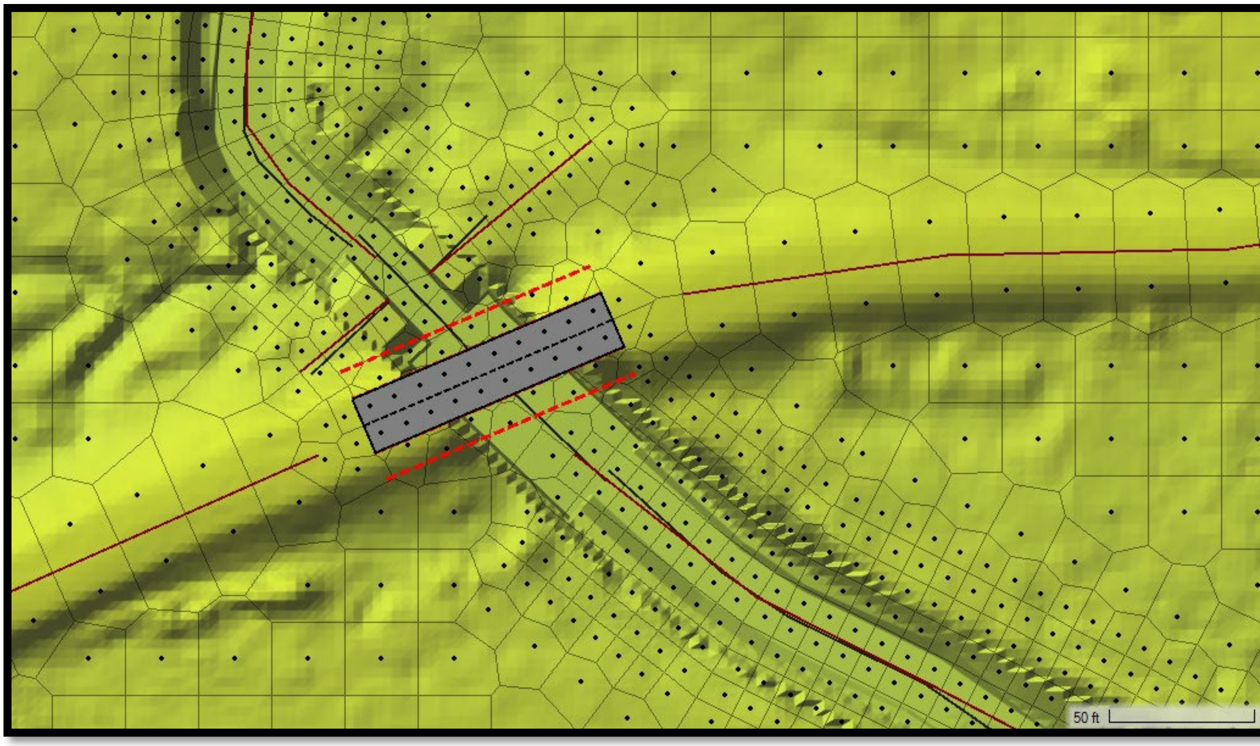


Figure 6. Hydraulic Model Mesh

A.5. Erosion Protection

Erosion protection was defined based on the velocities and elevations seen in the model runs as well as what was seen by the team during site visits. There were multiple conversations with hydraulic and civil engineers that went into developing the initial design.

A.5.1. Methodology

The hydraulic model was used to inform the erosion protection. Because this project is a section 14, the erosion protection that is designed needs to meet the goal of stabilizing the bridge and roadway in the wake of active erosion. That means that while there is erosion of the banks downstream of the bridge because it is not affecting the integrity of the structure or roadway, it is not included in this design.

The Isbash method was used to determine the stone size for the proposed riprap erosion protection. The Isbash recommendation for high turbulence flow was used for this design. A copy of the Isbash standard gradations is given in section A.7.1 of the calculations at the end of the H&H portion of the report.

The Isbash method was double checked by using the HEC-RAS Riprap Calculator. A screenshot of the results is given in section A.7.1 of the calculations at the end of the H&H portion of the report.

As far as the footprint of the erosion protection is concerned, as of now it was based off existing riprap and over the proposed removal of the old bridge abutments. The 30% design footprint of the Riprap can be found on Figure 6 in the Design Recommendations portion of the appendix.

A.5.2. Results

The velocities in the model appeared to be in the 8-10 ft/s range for the medium to higher flows. The Isbash equation was used to determine a riprap size of R400. A table for the gradation of R400 is given in Table 3.

Table 3. R400 Gradation

Percent Lighter by Weight (%)	Weight Range (lbs)
100	400-160
50	160-80
10	80-30

A.6. Design Recommendations

The old bridge abutments upstream should be removed, and the bank restored to the natural channel. The area where the old abutments are removed shall receive a layer of R400. The four wingwalls of the existing bridge should receive an overlay or R400 riprap. All riprap should be a minimum of 30 inches thick and placed no steeper than a 2:1 (H:V) slope.

It is recommended to remove two trees. One tree is interlocked with the west abutment of the old bridge and has an exposed root system. The second tree is located around the southeast wingwall and could be a point of failure for the erosion protection due to it being in the middle of the embankment.

Figure 7 gives a rough overview of the 30% H&H design recommendations overlayed on a Civil Desing rendering of the site.

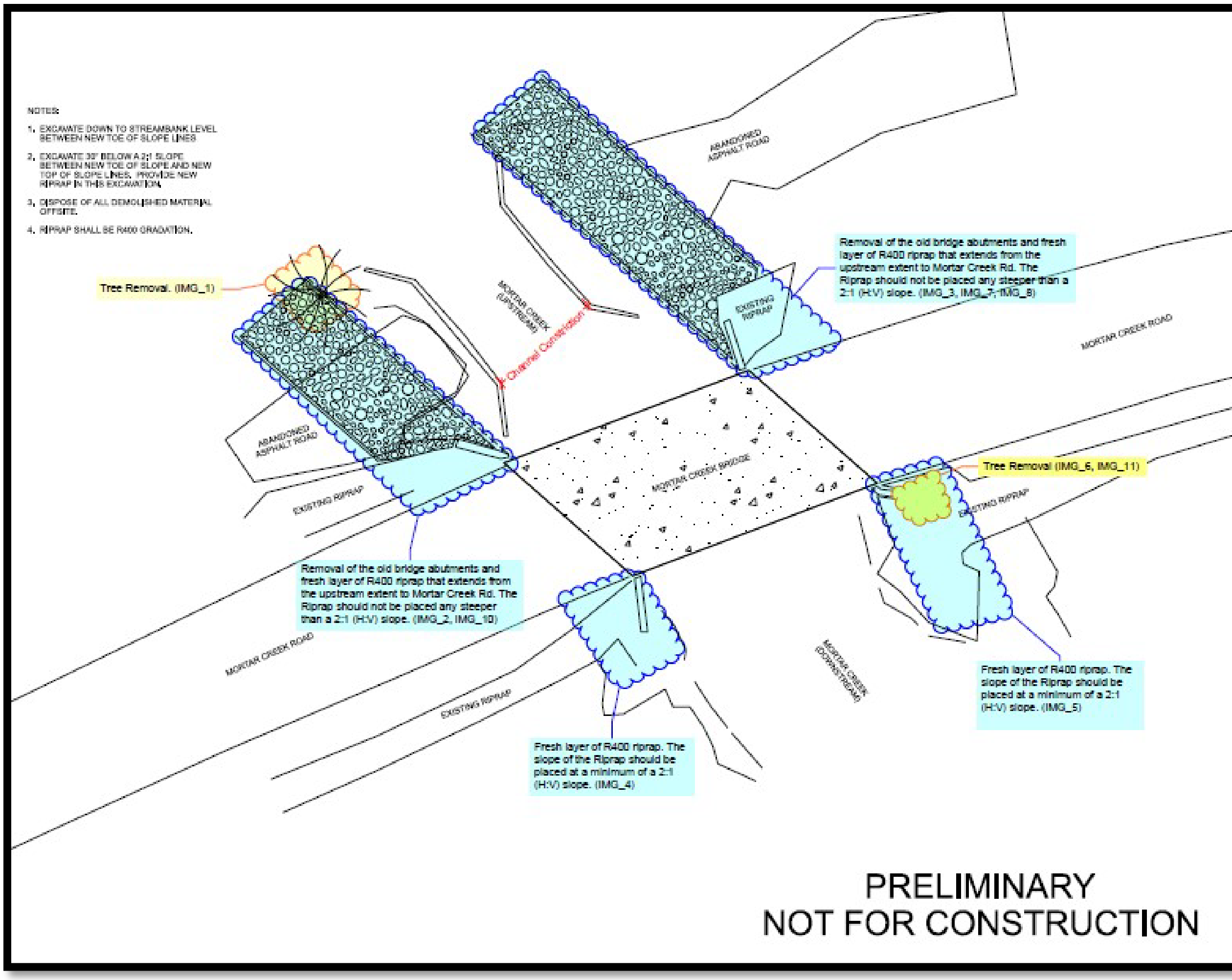


Figure 7. 30% H&H Recommendation

A.7. Calculations

A.7.1. Type of Calculation or Figures

12 November 81

STANDARD RIPRAP GRADATIONS

(Design Specific Weight 155 pounds per cubic foot)

	GRADATION NORMALLY PRODUCED MECHANICALLY								GRADATIONS NORMALLY REQUIRING SPECIAL HANDLING				
			R90		R200	R400	R650		R1500	R2200			R7400
Layer Thickness in Inches HIGH TURBULENT FLOW	12	15	18	21	24	30	36	42	48	54	63	72	81
Layer Thickness in Inches Low Turbulent Flow			12	14	16	20	24	28	32	36	42	48	54
Percent Lighter by Weight													
100	25 10	50 20	90 40	140 60	200 80	400 160	650 260	1000 400	1500 600	2200 900	3500 1400	5000 2000	7400 3000
50	10 5	20 10	40 20	60 30	80 40	160 80	280 130	430 200	650 300	930 440	1500 700	2200 1000	3100 1500
15	5 2	10 5	20 5	30 10	40 10	80 30	130 40	210 60	330 100	460 130	700 200	1100 300	1500 500
Velocity, fps, HIGH TURBULENCE	5.3	5.9	6.7	7.1	7.5	8.4	9.1	9.8	10.5	11.1	12.0	12.8	13.7
Velocity, fps, low turbulence	7.4	8.3	9.3	9.9	10.4	11.7	12.7	13.6	14.6	15.6	16.8	17.8	19.1

(Note: Shaded areas of the table reflect gradations and the low-turbulence layer thicknesses and velocities less frequently used by MVM)

Figure 8. Isbash Method

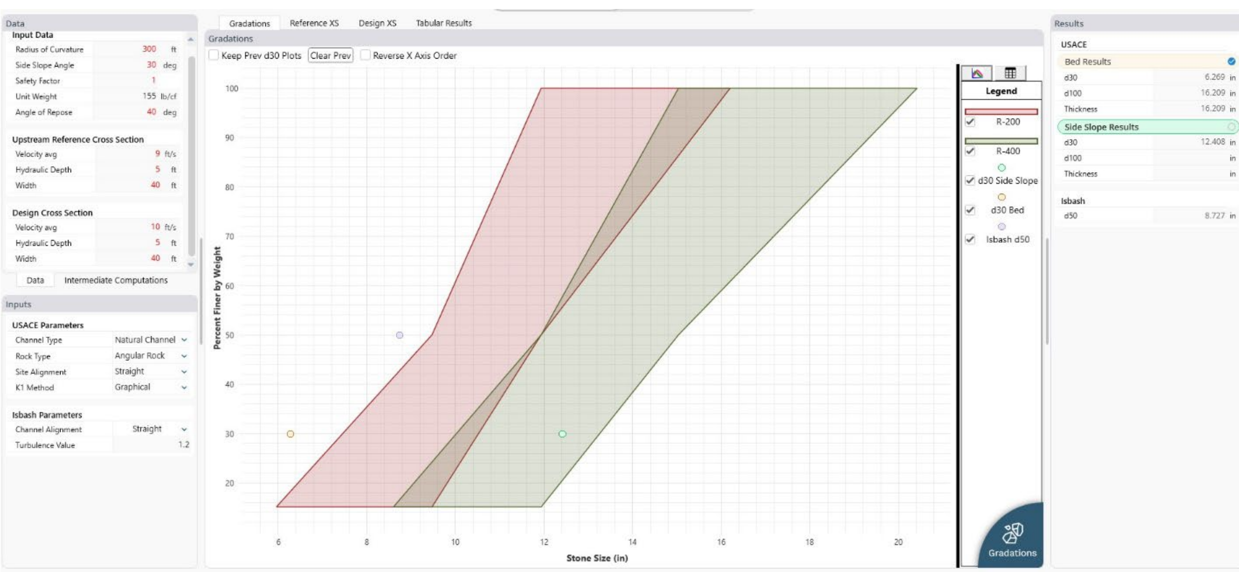


Figure 9. HEC-RAS Riprap Calculator

A.8. Climate Assessment

A.8.1. Introduction

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

The hydrologic 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. The objective is to mainstream climate change adaptation in all activities to help enhance the resilience of our built and natural water-resource infrastructure and reduce its potential vulnerabilities to the effects of climate change and variability.

A.8.1.1. Climate

Mortar Creek Road Bridge is located near Enders, Arkansas. The Mortar Creek watershed above the bridge is around 10 mi^2. Arkansas experiences a humid subtropical climate with hot humid summers that reach an average temperature of 93°F. Winters are mild but occasionally drop to freezing.

A.8.2. Qualitative Climate Assessment

Engineering and Construction Bulletin No. 2018-14 “Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects” 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 objective of ECB-2018-14 is to enhance USACE climate preparedness and resilience by incorporating relevant information about observed and expected climate change impacts in hydrologic analyses for planned, new, and existing USACE projects. This includes consideration of both past (observed) changes as well as potential future, climate-changed, conditions to relevant climatic and hydrologic variables. The ECB helps support a qualitative assessment of potential climate change threats and impacts, focusing on those aspects of climate and hydrology relevant to the project’s problems, opportunities, and alternatives, and include consideration of both past (observed) changes as well as projected, future (modeled) changes. Analyses of future climate conditions often report the results of two different representative concentration pathways (RCP). The first, RCP 4.5, is where greenhouse gas emissions stabilize by the end of the century, the second, RCP 8.5, is where greenhouse gas emission continue to increase through the end of the century.

A.8.2.1. Project Location and Gaging Information

The Mortar Creek Emergency Streambank Erosion Protection and Prevention project area is located within the Hydrologic Unit Code (HUC) 11110205 - Cadron. Figure 10 shows the HUC location map for Arkansas and the location of the study area. Mortar Creek eventually flows into the Cadron Creek and is Discharged into the Arkansas River around Navigation Mile 158.7 in Pool 8.

Figure 10. HUC Location in Arkansas

A.8.2.2. Literature Review

A literature search was conducted to locate information related to observed and projected climate trends.

Natural ecosystems in the southeast region will be transformed by climate change. In the southeast, reductions in the frequency and intensity of cold winter temperatures can allow tropical and subtropical species to move northward and replace more temperate species. Drought and extreme heat can result in tree mortality and can also affect aquatic and wetland ecosystems. Increases in extreme rainfall can affect wetland plant mortality because of the prolonged inundation and lack of oxygen. Natural systems in the region will have to become resilient to both too little water and too much water. (Reidmiller, 2018)

According to "Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Arkansas, White and Red Rivers Region 11" the general consensus for the for this region is a mild upward trending for average precipitation and extreme precipitation events as well as an upward trending for average streamflow, Figure 11.

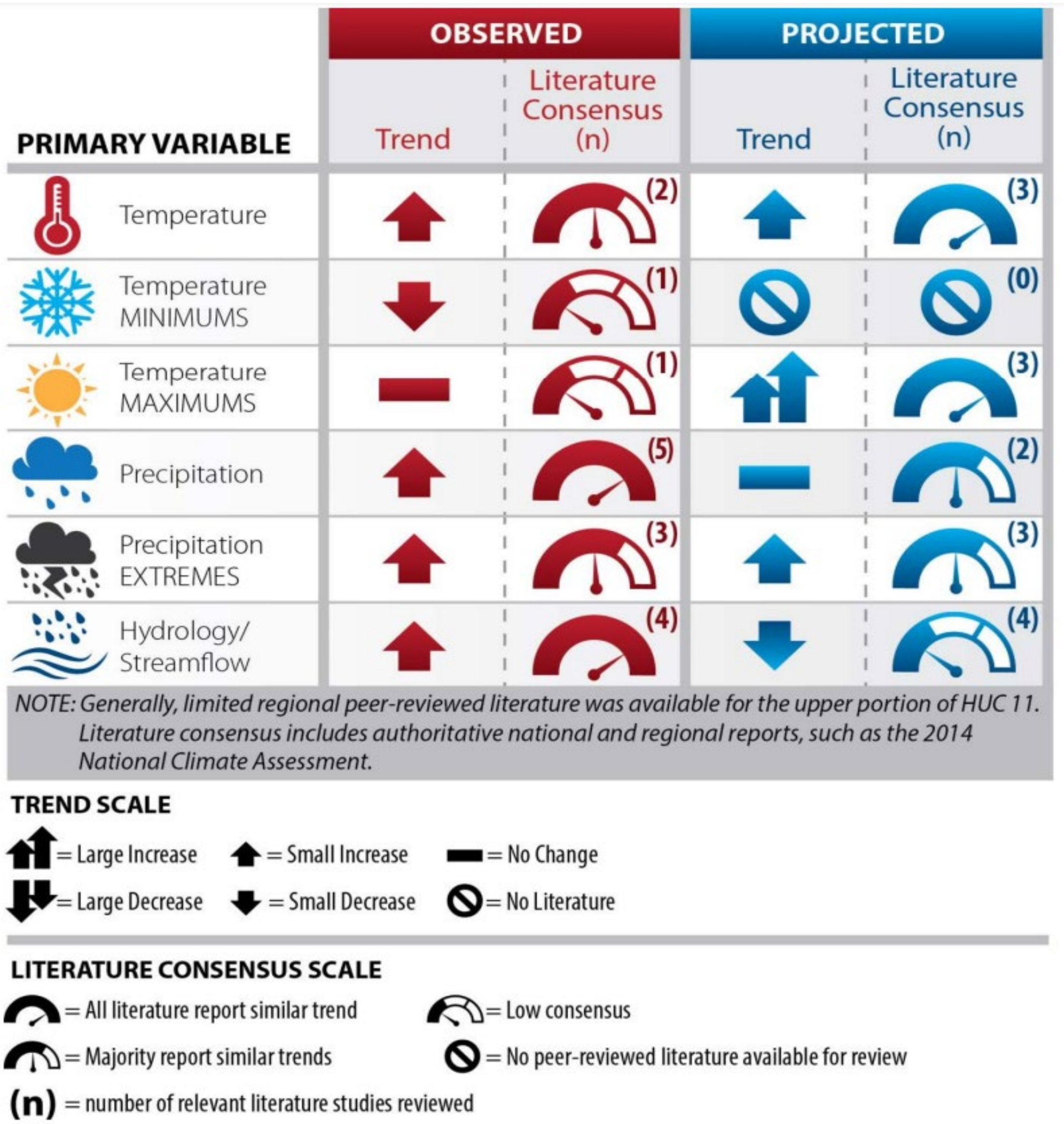


Figure 11. Observed and Projected Climate Trends in HUC 11 and Literary Consensus.

A.8.2.2.1. Temperature

On a larger scale, there has been an increase in the average temperature of the contiguous United States over the past several decades. Figure 12 show the change in annual average temperature across the United States. Table 4 shows an increase in the average annual temperatures in the Southeast region, though it is a comparatively smaller increase than what has occurred in the rest of the U.S.

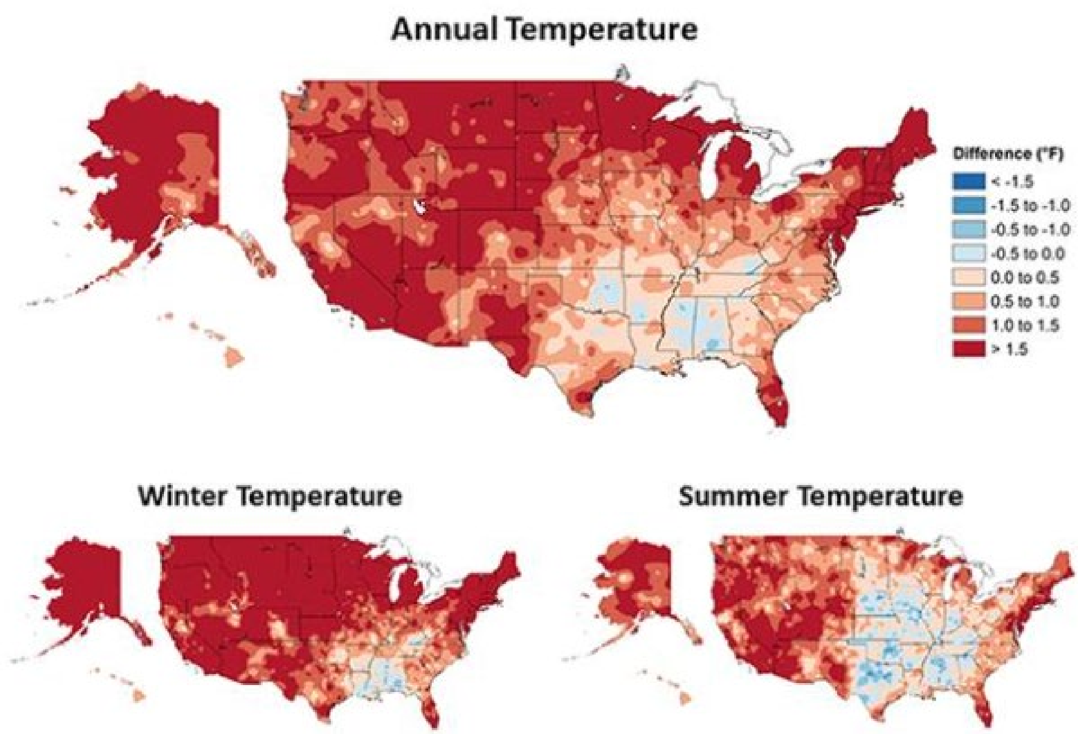


Figure 7. Observed changes in annual, winter, and summer temperature (°F). Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i). Estimates are derived from the nClimDiv dataset.(Vose et al., 2014 ; Bose et al., 2017,), (Figure source: NOAA/NCEI). (NCA4 Vol.1, Chapter 6: Temperature Changes in the United States, Fig 6.1)

Figure 12. Observed Changes in Annual Temperature

Table 4. Observed Changes in Annual Average Temperatures by Region

NCA Region	Change in Annual Average Temperature	Change in Annual Average Maximum Temperature	Change in Annual Average Minimum Temperature
Contiguous U.S.	**1.23°F**	**1.06°F**	**1.41°F**
Northeast	1.43°F	1.16°F	1.70°F
Southeast	**0.46°F**	**0.16°F**	**0.76°F**
Midwest	1.26°F	0.77°F	1.75°F
Great Plains North	1.69°F	1.66°F	1.72°F
Great Plains South	0.76°F	0.56°F	0.96°F
Southwest	1.61°F	1.61°F	1.61°F
Northwest	1.54°F	1.52°F	1.56°F
Alaska	1.67°F	1.43°F	1.91°F
Hawaii	1.26°F	1.01°F	1.49°F
Caribbean	**1.35°F**	**1.08°F**	**1.60°F**

Table 1. Observed changes in annual average temperature (°F) for each National Climate Assessment region. Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska, Hawai'i, and the Caribbean). Estimates are derived from the nClimDiv dataset. (Vose et al., 2014 ; Vose et al., 2017) (NCA4 Vol.1 Table 6.1)

Temperature data wasn't available at Mortar Creek but analysis of observed daily temperature at the Little Rock weather station shows trends that are consistent with those observed for the United States. Table 5 and Figure 13 shows the monthly and yearly average temperatures from 1879 – 2021 for the Little Rock area. The data trend to the increase of average temperature for the Little Rock area in the future.

Table 5. Yearly and Average Temperatures for Little Rock, AR

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
1879	M	M	M	M	M	M	83.8	76.2	71.5	66.8	57.0	48.2	67.3
1880	56.0	49.9	54.1	66.1	75.0	77.4	79.4	79.0	69.9	62.0	42.1	41.4	62.7
1881	35.8	44.4	52.3	62.7	73.5	81.1	83.5	85.0	77.3	68.5	51.2	49.5	63.7
1882	44.8	54.1	59.0	64.8	66.8	79.7	77.8	77.2	71.4	67.1	53.3	44.8	63.4
1883	40.4	45.1	53.0	63.8	69.1	79.0	81.0	78.4	71.1	67.3	56.3	49.1	62.8
1884	35.7	47.7	54.5	60.6	69.9	77.1	82.9	78.7	77.0	66.5	52.4	41.6	62.0
1885	37.6	41.9	51.6	63.8	68.9	80.4	84.7	81.7	75.0	61.2	52.6	43.5	61.9
1886	29.8	41.1	49.5	61.3	73.5	75.6	80.2	80.5	75.1	63.1	49.2	38.2	59.8
1887	41.0	48.5	55.2	63.0	72.2	76.6	81.7	80.0	75.4	62.0	52.3	40.7	62.4
1888	38.8	46.1	50.0	65.9	68.6	75.8	81.9	79.9	71.3	58.7	50.2	44.7	61.0
1889	44.0	43.8	54.3	64.6	67.7	73.8	80.6	76.8	70.8	60.7	47.4	59.2	62.0
1890	50.7	52.6	50.6	62.3	69.1	78.1	81.3	78.1	70.7	61.6	55.3	46.2	63.1
1891	42.4	48.2	47.8	63.8	67.6	78.8	76.8	76.3	74.5	61.3	49.2	47.7	61.2
1892	36.2	50.8	48.9	61.8	67.5	77.0	79.0	78.4	71.6	64.2	50.2	41.0	60.6
1893	39.9	42.8	50.8	65.5	68.3	76.5	81.0	77.9	74.4	61.0	50.1	46.4	61.2
1894	45.4	42.3	55.6	63.3	70.4	77.6	78.6	78.1	73.8	63.8	50.7	45.6	62.1
1895	38.1	35.3	52.5	63.5	68.6	77.3	79.3	79.6	78.3	58.8	50.8	44.6	60.6

1896	41.9	46.1	49.4	68.5	75.6	77.9	84.2	82.7	73.8	61.8	53.2	46.7	63.5
1897	39.9	46.8	56.5	61.8	68.9	78.9	83.9	80.3	77.9	69.3	52.5	40.3	63.1
1898	46.0	46.1	55.5	59.5	73.0	79.4	80.1	80.2	75.7	60.7	48.3	40.4	62.1
1899	39.9	32.9	51.0	60.9	73.1	77.5	79.5	82.4	72.4	66.6	55.5	41.1	61.1
1900	44.3	40.6	52.4	63.4	70.3	76.6	79.9	81.0	78.2	66.6	53.0	46.3	62.7
1901	47.0	41.4	51.8	59.3	68.8	79.5	83.8	81.1	72.9	64.8	52.4	39.8	61.9
1902	39.2	36.1	54.2	62.7	74.6	78.6	80.4	81.5	69.7	63.9	57.8	41.7	61.7
1903	42.5	42.6	56.5	62.0	68.6	71.6	80.0	79.1	71.4	62.4	49.0	41.6	60.6
1904	41.3	45.6	56.1	58.0	68.5	76.4	78.6	78.8	76.1	64.0	53.3	44.1	61.7
1905	34.3	33.5	58.8	62.4	71.8	78.5	77.3	80.0	75.0	62.5	54.8	40.0	60.7
1906	45.1	42.5	46.0	65.1	69.5	77.6	77.5	78.8	76.5	59.3	51.5	48.0	61.4
1907	50.5	46.0	63.1	55.7	64.4	76.3	82.5	82.3	74.9	63.3	50.7	46.2	63.0
1908	43.9	46.0	60.9	63.8	70.4	77.1	80.1	80.0	74.5	60.6	55.1	47.5	63.3
1909	43.9	49.4	54.2	61.7	67.6	77.8	82.5	83.0	74.8	64.1	60.3	37.1	63.0
1910	44.1	40.4	62.3	60.4	66.8	74.5	79.1	79.0	76.9	64.0	52.6	42.3	61.9
1911	48.3	50.6	57.0	60.7	72.2	81.7	78.5	78.5	79.5	63.2	47.0	44.3	63.5
1912	35.1	38.9	46.6	62.7	70.5	73.9	82.0	79.0	74.8	64.7	51.9	43.2	60.3
1913	45.1	42.3	51.4	61.8	70.0	78.2	81.5	82.1	71.7	60.7	58.2	44.8	62.3
1914	47.0	41.7	51.0	61.8	70.6	83.9	82.7	78.3	74.6	63.3	54.2	36.9	62.2
1915	40.2	46.3	43.3	65.5	70.3	76.2	80.0	75.3	76.0	65.4	55.5	46.0	61.7
1916	45.2	43.9	54.8	60.7	72.3	76.5	83.6	81.3	72.9	63.3	53.5	43.5	62.6
1917	45.0	44.8	54.1	61.2	64.0	76.2	80.1	77.7	72.5	57.9	52.9	35.4	60.1
1918	28.6	48.0	58.8	60.7	74.1	80.6	80.3	82.8	69.0	66.5	51.0	49.5	62.5
1919	43.2	45.0	53.8	61.7	67.1	77.3	82.2	81.0	75.3	66.6	52.7	40.6	62.2
1920	40.8	46.3	53.0	60.3	70.9	75.4	80.4	77.3	75.3	65.4	48.4	44.6	61.5
1921	47.2	49.0	61.3	60.4	70.9	79.0	82.2	81.4	79.6	62.9	55.9	48.0	64.8
1922	39.7	48.1	52.3	64.1	71.5	79.4	80.5	81.5	77.7	65.2	54.2	48.4	63.6
1923	49.7	42.4	49.6	62.4	67.4	77.5	80.0	81.5	73.2	60.8	52.6	51.1	62.4
1924	36.9	44.1	47.3	62.6	65.6	79.3	79.9	82.7	69.9	67.2	54.3	41.8	61.0
1925	41.8	50.0	56.8	68.2	69.0	82.9	81.5	81.1	81.9	59.3	51.3	40.9	63.7
1926	41.5	49.2	48.7	59.2	70.7	77.9	81.2	81.3	77.4	65.8	47.8	43.6	62.0
1927	42.9	52.2	54.0	66.2	71.8	76.2	80.5	76.7	76.6	67.2	56.3	42.3	63.6
1928	43.9	45.8	53.9	57.7	70.3	74.8	81.0	81.7	71.6	67.1	51.3	44.3	62.0
1929	38.9	36.6	56.8	64.7	67.7	77.0	82.3	81.7	74.5	64.1	47.5	46.1	61.5
1930	35.0	54.0	52.1	66.4	69.9	78.8	86.4	82.8	76.5	61.1	51.6	42.3	63.1
1931	44.1	49.6	48.2	60.6	66.0	80.1	81.7	77.8	79.9	68.2	58.8	49.8	63.7
1932	48.0	53.3	49.4	65.4	70.6	79.8	83.6	82.8	74.5	61.7	47.4	40.2	63.1
1933	50.1	42.0	52.7	61.4	72.2	79.4	80.9	79.3	79.3	63.3	53.7	48.9	63.6
1934	44.7	41.6	49.7	62.4	71.3	81.2	85.0	84.6	72.1	68.2	54.4	42.2	63.1
1935	43.5	46.4	59.7	60.2	67.0	75.5	82.3	82.2	73.8	64.3	49.9	38.4	61.9
1936	38.2	36.8	58.0	59.9	72.2	80.7	82.6	84.9	79.4	62.2	49.6	46.1	62.6
1937	41.8	44.2	48.8	62.0	72.3	79.7	80.7	83.1	73.5	61.0	48.7	43.0	61.6
1938	43.0	50.9	60.5	62.8	70.9	76.6	82.9	84.0	76.6	68.0	51.5	44.6	64.4
1939	46.3	44.0	56.6	59.5	69.9	78.8	82.4	80.8	80.8	66.0	50.1	47.0	63.5

1940	29.1	42.5	52.4	60.4	66.6	76.0	78.8	78.6	72.6	66.6	51.0	48.2	60.2
1941	44.3	41.0	47.8	64.7	72.5	77.0	81.4	81.3	76.1	68.7	51.2	45.8	62.7
1942	39.7	42.0	54.1	63.2	68.8	78.2	82.5	79.4	72.4	63.8	54.3	43.1	61.8
1943	41.9	48.6	47.3	63.2	72.6	81.7	84.3	85.4	72.2	62.1	49.8	40.5	62.5
1944	42.6	48.9	51.6	60.9	71.4	81.0	82.7	81.0	75.7	65.4	52.9	38.1	62.7
1945	40.8	43.5	59.6	63.9	67.1	76.7	79.3	79.9	74.4	61.4	53.8	38.0	61.5
1946	41.7	48.5	59.4	65.6	67.4	76.8	81.5	79.8	72.5	64.1	54.3	49.2	63.4
1947	43.9	38.1	45.7	62.4	68.5	77.7	79.3	85.0	75.8	69.8	48.2	45.5	61.7
1948	34.9	42.3	51.8	67.5	69.9	79.8	82.1	79.2	73.8	61.1	52.5	45.9	61.7
1949	43.5	48.2	52.0	62.0	73.1	79.5	82.1	79.0	70.1	64.4	54.1	45.9	62.8
1950	49.7	47.6	49.9	60.6	71.1	77.7	78.8	77.0	71.2	67.1	48.4	38.7	61.5
1951	43.2	45.9	52.4	59.2	71.0	77.6	81.9	82.8	72.6	63.6	45.9	45.0	61.8
1952	47.9	49.9	51.1	59.3	70.5	84.1	83.6	82.0	73.2	57.0	50.2	44.0	62.7
1953	46.9	46.6	57.0	59.0	71.8	85.0	81.8	81.5	77.1	66.3	51.0	42.1	63.8
1954	41.8	51.6	52.7	67.8	66.6	82.3	86.7	87.2	78.7	65.0	52.7	44.2	64.8
1955	42.5	44.6	54.0	67.0	73.2	74.7	83.4	81.4	77.4	63.6	50.9	42.5	62.9
1956	40.0	47.5	53.0	60.8	74.0	78.1	82.6	83.5	74.1	67.4	50.6	49.4	63.4
1957	39.8	50.4	51.0	62.9	72.4	78.8	82.7	80.1	72.6	60.8	52.2	49.1	62.7
1958	40.4	38.8	46.6	61.5	71.5	77.5	81.9	81.1	74.8	63.2	54.7	40.3	61.0
1959	39.7	45.0	53.1	62.2	74.7	77.4	79.6	81.9	75.2	64.1	47.0	46.6	62.2
1960	41.1	39.8	41.3	64.9	68.3	78.4	80.7	81.4	76.3	63.5	50.6	37.6	60.3
1961	35.8	47.6	55.9	60.4	67.8	75.8	80.6	78.7	74.3	63.4	51.0	41.6	61.1
1962	37.1	49.2	49.5	59.5	75.3	77.6	81.8	82.8	73.2	66.3	50.7	41.8	62.1
1963	34.0	39.4	57.7	64.3	71.3	80.4	81.5	81.1	74.7	70.0	53.3	33.3	61.8
1964	40.8	41.6	52.7	64.7	72.3	80.6	83.2	79.2	73.6	60.1	53.9	43.9	62.2
1965	44.2	43.2	44.4	65.8	72.7	78.1	82.9	81.7	74.3	61.6	56.5	46.6	62.7
1966	35.4	42.9	54.5	62.4	68.4	78.0	84.2	77.8	72.0	59.2	54.7	43.2	61.1
1967	41.6	40.4	58.8	66.6	68.6	79.4	77.9	75.5	69.0	60.9	49.1	42.7	60.9
1968	37.7	37.9	50.8	60.9	67.5	77.8	77.8	81.4	70.7	62.9	51.1	42.2	59.9
1969	43.5	42.9	45.5	61.8	69.9	77.6	84.8	79.0	72.9	62.4	49.4	40.7	60.9
1970	35.7	42.1	48.1	63.1	71.9	78.7	79.9	81.2	78.1	61.4	50.3	47.2	61.5
1971	40.9	44.4	49.9	59.3	65.6	79.3	80.0	78.0	76.4	69.3	50.5	49.9	62.0
1972	43.6	46.7	53.3	62.5	69.7	79.4	80.4	81.1	75.8	62.6	47.2	41.0	61.9
1973	39.6	42.0	58.2	59.9	68.2	78.6	81.1	80.4	75.7	67.5	56.6	42.7	62.5
1974	42.4	45.7	58.0	60.7	71.3	74.3	83.2	79.0	69.0	62.3	51.9	44.3	61.8
1975	44.6	44.5	48.7	60.7	72.5	78.6	80.1	79.5	69.1	62.9	51.4	42.9	61.3
1976	39.7	52.5	56.4	61.1	64.6	74.4	80.2	78.7	72.1	57.8	45.9	41.8	60.4
1977	31.3	46.8	56.4	64.7	73.7	80.0	82.0	80.4	77.3	62.6	52.9	42.0	62.5
1978	31.7	34.0	51.0	65.9	71.4	78.9	84.1	83.0	76.6	62.0	54.6	43.3	61.4
1979	29.8	38.6	55.5	62.7	70.1	77.9	80.9	79.0	72.7	65.2	50.3	45.8	60.7
1980	43.9	40.8	50.3	61.5	70.6	79.4	88.1	86.9	78.6	60.4	50.4	43.0	62.8
1981	39.7	44.6	52.5	67.4	67.4	80.1	83.5	79.9	75.3	61.3	55.5	43.2	62.5
1982	37.4	41.3	57.1	58.0	72.7	76.6	83.1	82.1	74.2	64.6	53.2	48.3	62.4
1983	39.2	43.8	51.1	54.4	67.6	77.4	82.5	86.0	76.0	64.0	50.8	30.9	60.3

1984	36.6	46.5	50.1	59.6	68.0	79.7	79.7	78.1	71.0	65.0	48.9	52.0	61.3
1985	33.7	39.3	57.6	63.0	69.9	78.1	81.2	80.8	72.5	66.1	56.1	38.1	61.4
1986	42.4	48.2	55.4	63.6	71.3	79.7	86.2	78.1	77.6	63.1	49.6	42.4	63.1
1987	40.1	47.1	53.4	62.4	76.3	79.9	82.2	84.4	74.8	59.1	53.0	45.2	63.2
1988	35.6	42.8	52.2	61.5	70.3	78.8	81.7	82.4	75.8	60.3	53.3	44.4	61.6
1989	46.2	38.4	52.4	62.6	69.6	76.2	79.3	80.2	71.1	63.3	55.3	35.7	60.9
1990	48.1	51.3	55.4	62.0	68.0	80.6	83.1	82.2	77.5	61.4	56.3	43.1	64.1
1991	39.0	49.1	56.2	64.3	74.1	79.5	82.7	80.0	73.7	64.3	49.2	46.7	63.2
1992	42.7	50.5	54.4	62.6	68.9	76.5	81.0	76.5	72.7	64.4	50.1	43.8	62.0
1993	40.4	43.1	51.2	58.3	68.8	78.7	86.0	83.7	73.5	61.4	48.3	44.9	61.5
1994	38.2	45.2	53.9	64.4	68.3	81.7	80.0	78.8	72.6	64.3	56.1	46.3	62.5
1995	43.0	46.4	55.5	62.4	70.6	77.6	83.0	86.7	72.5	64.1	50.1	42.1	62.8
1996	40.0	46.2	48.2	60.4	74.3	79.3	81.9	80.8	73.4	63.6	48.4	46.4	61.9
1997	41.0	47.2	56.7	58.2	68.3	77.0	84.0	80.4	76.4	63.9	49.8	42.6	62.1
1998	46.6	48.8	51.6	62.0	75.9	83.1	87.2	83.9	80.5	65.7	54.8	44.9	65.4
1999	43.8	50.9	50.0	65.1	70.1	78.3	83.5	83.2	74.0	64.0	56.8	46.1	63.8
2000	43.0	50.7	55.8	61.1	72.2	76.5	82.7	86.5	75.4	65.7	47.9	32.0	62.5
2001	38.6	46.3	49.4	67.2	71.3	76.9	83.2	82.0	72.7	60.6	55.7	45.8	62.5
2002	44.4	42.9	49.3	64.6	67.9	77.9	81.5	81.2	76.8	61.2	49.6	43.3	61.7
2003	38.0	40.5	52.2	63.7	71.8	74.7	81.7	83.1	72.5	65.3	55.6	44.1	61.9
2004	42.9	42.1	58.1	62.5	72.1	77.4	80.0	77.5	75.3	67.3	54.7	43.3	62.8
2005	45.8	49.3	53.0	62.6	70.1	80.1	82.1	84.8	78.5	64.3	55.4	43.1	64.1
2006	49.8	42.6	55.5	68.2	72.4	79.0	84.0	84.4	73.0	62.1	53.3	47.1	64.3
2007	41.5	43.5	61.7	59.6	73.5	80.2	80.1	87.2	76.8	65.7	54.4	45.3	64.1
2008	40.6	45.5	53.8	60.6	70.6	79.8	83.4	80.4	73.7	62.7	50.7	42.9	62.1
2009	40.5	49.0	54.7	61.9	69.7	81.2	79.0	79.1	73.8	59.4	55.4	40.2	62.0
2010	38.8	38.3	53.9	66.1	74.4	84.9	86.0	86.5	77.4	65.6	53.1	41.0	63.8
2011	39.3	46.1	54.0	66.0	69.6	84.2	86.9	84.7	72.0	63.0	55.8	45.7	63.9
2012	46.5	49.3	64.3	66.6	75.6	80.4	87.3	82.6	75.0	61.5	51.7	48.2	65.8
2013	43.7	44.8	49.0	60.1	69.4	79.6	80.7	81.2	78.1	63.7	49.3	42.9	61.9
2014	37.9	40.8	48.8	61.7	70.0	79.1	77.5	81.5	75.6	66.1	47.9	45.2	61.0
2015	41.4	38.1	52.5	64.7	72.2	81.1	84.6	81.9	78.3	66.4	55.9	52.0	64.1
2016	42.1	49.3	58.2	64.6	70.3	82.7	85.8	83.7	79.7	67.8	55.1	43.3	65.2
2017	46.2	53.2	56.4	64.8	69.1	76.5	81.8	78.3	74.9	64.0	55.2	43.0	63.6
2018	37.2	46.2	55.9	56.3	76.4	80.8	82.8	79.7	75.7	63.8	47.3	44.8	62.2
2019	41.8	46.9	50.2	62.0	71.7	77.0	80.1	81.9	81.2	62.0	47.3	46.2	62.4
2020	44.4	45.5	57.2	59.6	68.4	77.5	82.4	80.3	73.4	60.7	54.7	43.8	62.3
2021	42.9	36.0	56.1	59.7	68.5	78.7	81.4	82.5	76.4	67.3	50.3	54.8	63
2022	42.2	44.7	55.2	63.1	73.7	80.8	86.6	82	M	M	M	M	66

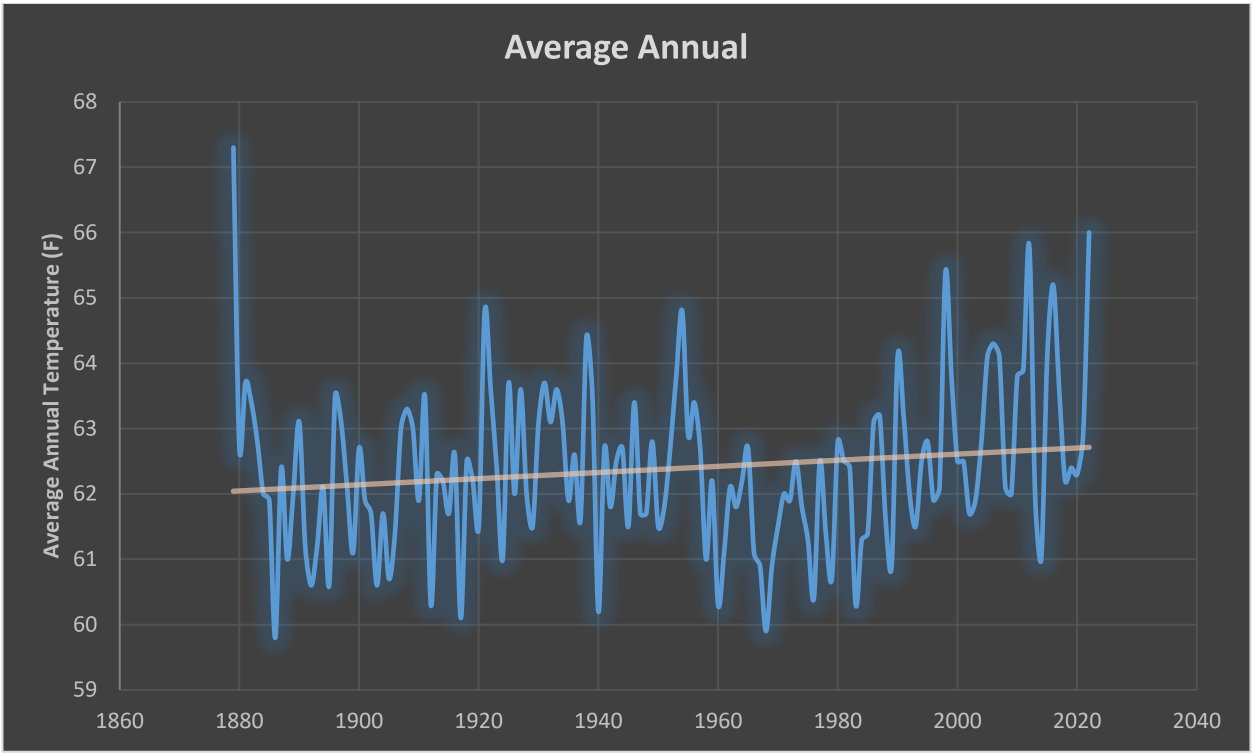


Figure 13. Trend in Average Annual Temperatures in Little Rock, AR

Figure 14 and Table 6 show the projected increase in average temperatures across the U.S. The temperature of the southeast region is expected to increase to between 3.40ºF and 4.30ºF in the middle part of the century and between 4.43ºF and 7.72ºF in the late part of the century. The number of nights above 75ºF is expected to increase between 50 and 100 nights/year by the later part of the century.

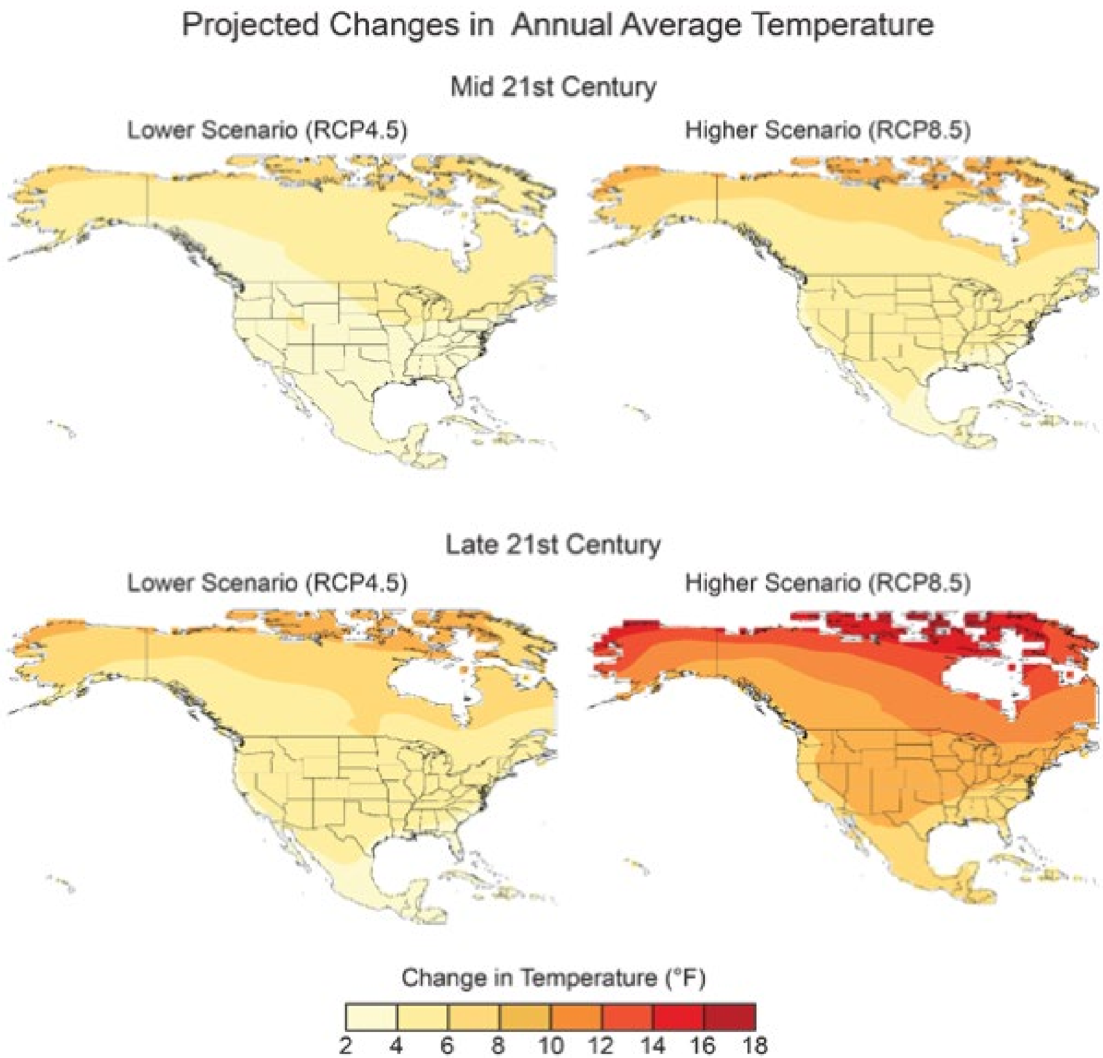


Figure 14. Projected Changes in annual Average Temperature for two RCPs

Table 6. Projected Temperature Changes in Mid-Century and Late-Century for Two RCPs

NCA Region	RCP4.5 Mid-Century (2036–2065)	RCP8.5 Mid-Century (2036–2065)	RCP4.5 Late-Century (2071–2100)	RCP8.5 Late-Century (2071–2100)
Northeast	3.98°F	5.09°F	5.27°F	9.11°F
Southeast	**3.40°F**	**4.30°F**	**4.43°F**	**7.72°F**
Midwest	4.21°F	5.29°F	5.57°F	9.49°F
Great Plains North	4.05°F	5.10°F	5.44°F	9.37°F
Great Plains South	3.62°F	4.61°F	4.78°F	8.44°F
Southwest	3.72°F	4.80°F	4.93°F	8.65°F
Northwest	3.66°F	4.67°F	4.99°F	8.51°F

Table 2. Projected changes in annual average temperature (°F) for each National Climate Assessment region in the contiguous United States. Changes are the difference between the average for mid-century (2036–2065) or late-century (2071–2100) and the average for near-present (1976–2005) under the higher scenario (RCP8.5) and a lower scenario (RCP4.5). Estimates are derived from 32 climate models that were statistically downscaled using the Localized Constructed Analogs technique (Pierce et al., 2014). Increases are statistically significant in all areas (that is, more than 50% of the models show a statistically significant change, and more than 67% agree on the sign of the change; Sun et al., 2015). (NCA4 Vol.1 Table 6.4)

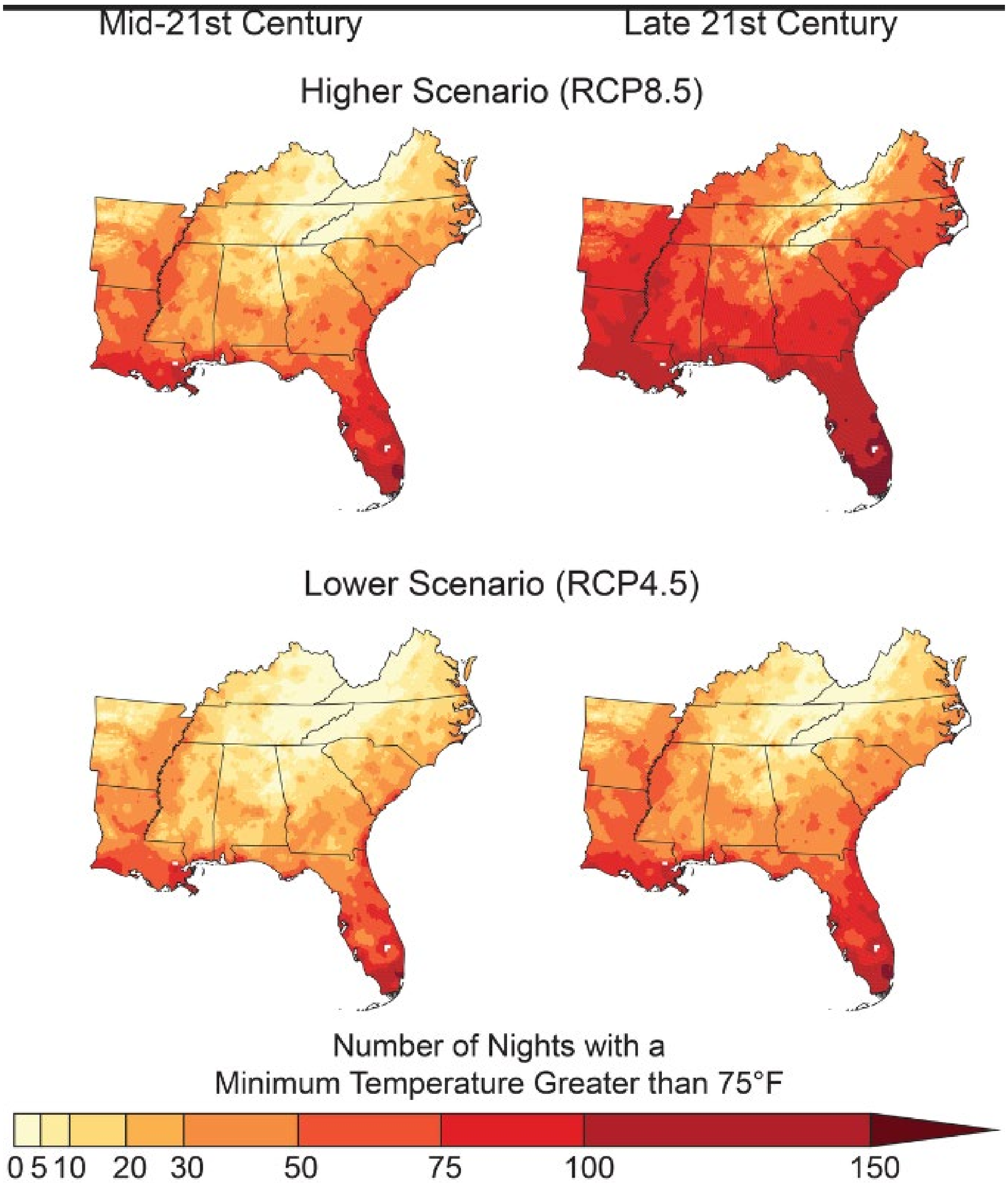


Figure 15. Projected Number of Warm Nights Per Year in the Southeast for the mid- and late-21st Century Under Two Different Climate Change Variable Conditions

A.8.2.2.2. Precipitation

Mortar Creek is situated right at the junction of the Ozarks with the Arkansas Valley. The average annual precipitation for the Mortar Creek area is around 49 inches. Precipitation extremes vary from 28.26 inches in 1963 to 81.79 inches in 2009. During some of these events, rain has exceeded 5 inches in several hours and caused flash flooding. Monthly and yearly precipitation totals from 2000 to 2019 are shown in Table 7. Yearly precipitation totals from 1876 – 2022 are shown in Figure 16.

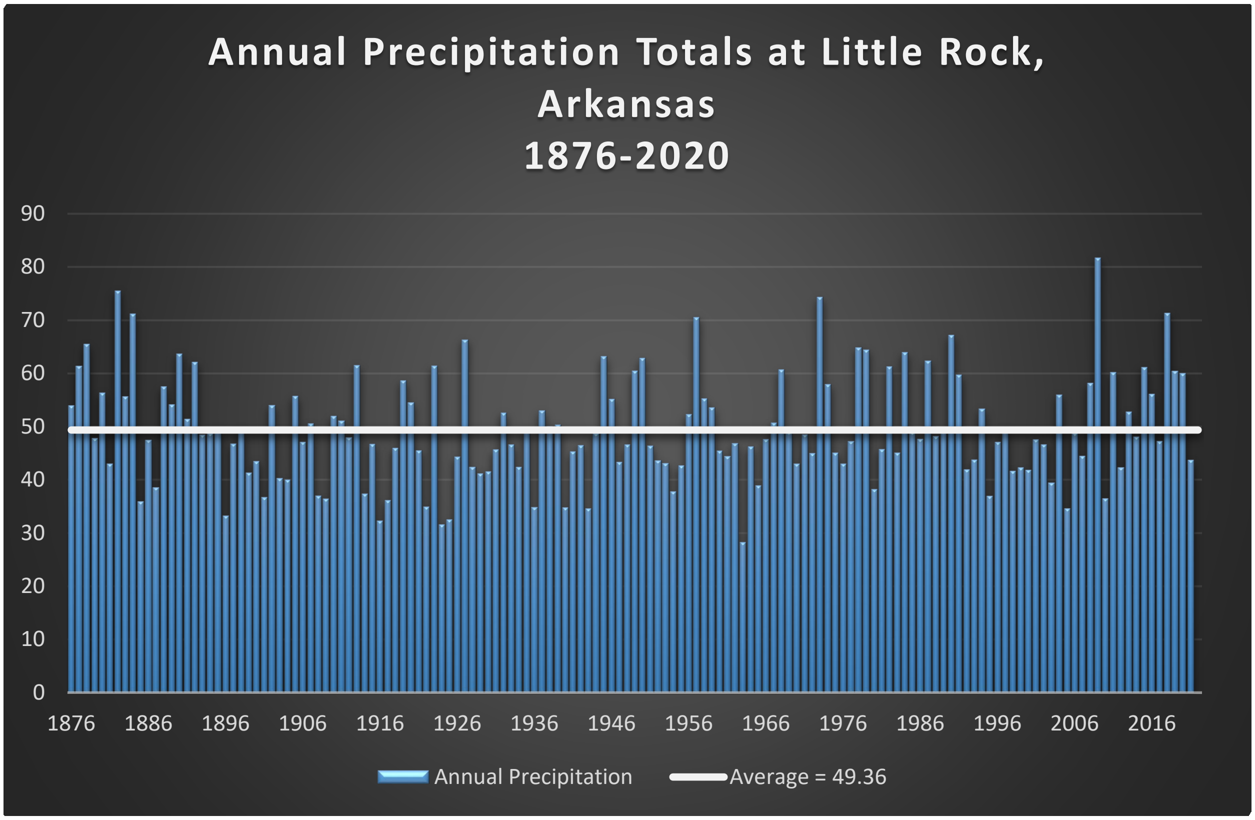


Figure 16. Annual Precipitation at Lake Maumelle Arkansas

Table 7. Monthly and Yearly Precipitation 1876-2022

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1876	8.5	2.6	9.6	4.0	6.0	3.7	5.9	2.7	0.6	7.0	1.5	2.0
1877	2.7	2.1	2.8	13.9	0.7	10.5	0.7	3.4	7.2	6.8	5.6	5.0
1878	3.9	2.1	6.7	14.3	9.9	6.4	5.5	5.2	1.6	2.5	3.7	3.7
1879	6.6	1.7	3.6	4.9	3.3	9.0	2.7	7.4	0.4	1.0	3.9	3.5
1880	4.6	8.0	7.6	4.7	2.4	3.2	3.4	5.5	5.0	2.1	6.8	3.0
1881	2.1	6.3	2.4	1.9	5.5	6.0	2.0	1.4	1.9	4.7	6.5	2.3
1882	8.2	12.7	6.3	5.6	15.9	2.0	5.2	3.2	3.0	6.1	6.2	1.3
1883	5.4	6.5	4.2	8.9	4.2	3.0	4.8	2.3	3.7	5.6	3.1	3.9
1884	3.5	9.8	4.7	10.2	7.3	2.2	4.2	3.3	5.0	1.3	2.8	16.9
1885	4.4	2.4	3.8	6.0	3.3	3.4	1.1	2.0	2.1	1.0	2.6	3.7
1886	4.0	4.3	3.5	3.1	1.1	9.3	3.0	5.3	6.2	1.1	5.8	0.9
1887	2.3	6.4	4.5	0.5	6.1	2.2	1.7	1.2	1.0	1.0	4.5	7.1
1888	4.9	2.5	5.1	0.8	5.1	7.3	3.8	11.1	1.3	2.4	8.8	4.4
1889	7.3	1.5	6.2	4.3	3.0	3.1	7.6	3.1	6.0	2.0	10.2	0.1

1890	8.5	6.5	5.8	7.8	6.2	8.3	1.8	2.6	5.6	2.8	5.2	2.8
1891	7.7	4.0	5.5	3.3	2.4	2.8	9.2	2.7	0.9	1.3	5.3	6.4
1892	3.9	3.4	2.6	7.5	9.6	2.5	3.1	6.6	3.5	2.8	8.0	8.5
1893	0.8	5.5	4.5	5.8	13.3	4.8	2.3	2.3	2.2	1.6	3.8	1.7
1894	3.2	5.0	9.1	4.2	3.8	0.3	6.6	6.5	2.4	3.2	0.6	4.0
1895	7.1	0.6	7.8	1.5	2.9	9.3	6.1	4.0	0.4	2.2	5.3	2.5
1896	4.9	2.9	4.3	2.7	1.3	3.3	0.9	1.8	3.9	3.1	3.8	0.5
1897	8.5	1.8	10.4	5.9	1.2	3.1	1.0	4.1	0.3	2.0	3.0	5.6
1898	8.1	1.2	2.6	2.8	7.5	3.0	2.6	2.1	10.2	5.0	2.9	1.4
1899	7.0	1.7	2.8	3.2	5.7	1.0	7.3	1.8	2.9	1.2	2.1	4.6
1900	2.6	4.5	1.2	3.5	4.1	5.5	3.8	4.3	3.3	2.5	4.9	3.3
1901	2.1	1.7	4.4	5.0	2.5	1.2	2.9	1.4	7.1	1.6	2.8	4.2
1902	7.1	2.2	4.9	2.9	4.8	4.1	7.5	0.2	5.8	2.3	7.0	5.3
1903	2.6	6.5	5.1	1.6	5.7	0.8	6.2	4.5	2.1	2.0	0.7	2.6
1904	2.6	3.1	5.3	3.7	3.0	8.0	3.7	2.1	0.9	0.7	1.4	5.6
1905	4.0	1.9	3.3	7.7	8.1	7.2	3.6	4.0	1.3	3.5	5.7	5.3
1906	4.4	2.1	3.6	1.6	5.0	4.5	6.5	3.4	3.2	3.2	4.3	5.2
1907	8.3	3.9	2.6	5.7	10.3	2.1	0.5	1.5	1.1	3.3	8.8	2.6
1908	5.0	3.3	4.3	4.3	4.6	2.3	1.1	2.6	3.3	0.4	5.0	0.8
1909	0.7	5.2	3.7	4.2	4.5	2.8	1.2	1.7	3.2	0.8	3.0	5.3
1910	2.8	4.6	0.9	5.7	7.2	7.3	4.7	3.8	3.1	6.4	0.1	5.4
1911	1.0	4.3	2.1	10.7	0.8	3.1	3.2	8.9	6.4	0.4	4.0	6.2
1912	3.5	2.7	9.1	10.8	1.8	3.8	1.9	5.0	2.6	3.9	0.6	2.2
1913	11.3	3.8	4.5	11.5	2.3	2.1	3.7	2.4	9.3	4.8	3.1	3.0
1914	1.4	2.9	4.6	5.2	2.3	0.0	3.7	4.8	1.9	1.5	2.4	6.9
1915	4.6	2.5	2.9	2.9	4.4	3.7	1.0	10.3	1.2	2.2	5.6	5.4
1916	8.5	2.1	1.6	2.6	1.5	3.0	0.4	3.6	2.0	2.9	2.1	2.2
1917	2.5	1.7	6.4	3.9	3.3	3.8	4.5	4.4	0.3	2.0	2.1	1.2
1918	5.5	1.0	1.5	8.4	0.6	6.8	0.9	1.4	4.6	4.1	3.1	8.0
1919	2.7	3.6	6.4	4.1	4.7	2.8	2.4	3.5	2.8	15.3	8.2	2.3
1920	9.2	1.2	4.8	6.6	8.2	4.3	3.1	3.3	2.9	3.2	0.9	7.0
1921	1.5	6.9	7.0	7.4	0.8	4.7	1.4	7.1	2.2	0.1	3.9	2.6
1922	1.9	4.0	8.3	3.6	4.7	2.2	2.4	0.8	0.9	0.8	2.1	3.4
1923	7.4	6.4	5.0	7.7	10.5	1.8	7.9	2.6	3.9	1.0	2.6	4.7
1924	3.6	1.6	2.7	5.4	2.4	2.9	1.3	1.7	5.4	0.1	2.5	1.9
1925	1.5	3.8	0.5	1.1	1.4	2.5	5.5	0.9	3.4	5.7	5.2	1.0
1926	4.4	3.5	5.1	3.1	1.6	1.5	3.4	4.0	1.2	4.0	3.2	9.5
1927	4.5	3.0	6.9	14.8	6.8	5.7	1.1	8.8	1.4	1.4	8.2	3.8
1928	1.2	2.6	1.7	7.0	3.9	6.7	2.8	4.7	0.5	3.1	2.6	5.7

1929	3.7	2.4	4.7	4.9	6.2	4.3	1.2	2.0	1.4	4.8	1.9	3.8
1930	12.5	4.4	2.0	0.2	11.1	0.1	0.0	0.7	2.9	3.1	2.4	2.3
1931	1.0	4.0	4.5	6.4	2.1	2.8	3.7	1.3	0.6	1.8	8.3	9.1
1932	11.4	4.8	5.2	1.7	3.2	3.7	7.8	1.3	2.7	3.3	1.2	6.4
1933	3.3	2.7	5.3	5.1	5.9	1.0	4.0	6.5	6.0	1.6	1.7	3.5
1934	2.6	1.4	6.8	5.8	2.7	3.2	2.3	2.2	4.0	0.5	4.9	5.9
1935	6.4	2.4	6.1	3.5	10.3	5.5	2.3	2.1	3.4	3.5	2.4	1.9
1936	0.9	1.3	2.4	3.1	1.2	3.3	7.5	0.3	1.9	4.4	3.7	4.9
1937	18.0	2.0	2.2	1.9	2.8	1.7	1.6	4.7	5.8	5.0	3.7	3.6
1938	9.8	4.9	7.2	4.0	3.4	2.9	2.5	3.5	1.0	1.4	6.1	3.3
1939	7.9	8.6	2.5	8.0	7.0	3.1	2.1	2.9	2.4	0.7	3.9	1.4
1940	1.4	3.2	1.3	5.6	3.3	2.3	1.6	3.6	2.2	1.9	5.6	3.0
1941	2.2	2.7	1.6	5.0	4.1	6.0	6.0	3.2	2.4	6.1	1.3	4.9
1942	2.7	3.5	4.1	10.8	3.8	3.9	0.9	5.0	1.1	3.3	2.8	4.7
1943	1.2	1.0	7.6	4.6	4.4	2.8	1.9	0.4	2.2	4.4	0.8	3.3
1944	2.1	6.0	7.9	4.7	5.0	1.5	3.4	2.8	1.1	0.0	6.1	8.3
1945	2.3	7.4	7.0	6.6	7.0	7.8	4.6	3.0	9.0	2.2	4.5	1.9
1946	8.2	3.1	8.2	4.8	9.7	3.4	2.6	0.7	0.8	2.6	7.9	3.2
1947	2.1	0.5	1.5	6.1	6.9	5.0	1.0	1.1	3.0	5.6	6.3	4.3
1948	1.6	7.1	6.4	4.5	4.6	2.3	3.4	3.3	1.2	1.5	8.0	2.7
1949	11.9	4.0	7.3	2.1	2.4	5.7	3.6	6.0	2.8	9.7	0.3	4.8
1950	12.5	9.3	4.9	2.8	8.4	2.1	1.9	7.6	6.8	1.3	3.9	1.6
1951	4.3	4.1	2.0	3.8	1.6	4.9	7.6	0.8	4.0	3.7	4.4	5.3
1952	3.5	5.0	5.6	4.1	4.7	T	2.9	2.5	2.6	0.6	6.8	5.4
1953	6.1	3.3	9.5	7.3	6.2	0.1	1.2	2.7	1.1	1.0	1.7	3.0
1954	7.8	3.8	2.1	4.1	6.7	0.6	1.3	0.3	1.8	3.6	1.5	4.2
1955	1.5	4.2	4.8	3.7	11.6	3.8	2.2	1.2	4.8	1.2	1.8	1.9
1956	5.8	11.0	3.8	4.6	3.2	5.1	5.5	2.3	0.3	3.0	5.1	2.7
1957	6.0	5.3	5.1	11.3	11.6	3.4	2.8	4.3	2.0	5.4	9.5	3.9
1958	4.4	1.9	4.2	8.2	7.8	7.2	3.6	3.8	7.2	0.3	5.4	1.3
1959	3.6	7.1	3.3	2.6	1.7	6.2	6.4	3.3	7.0	2.1	2.3	8.1
1960	4.2	4.4	3.7	1.1	5.3	7.3	2.4	2.2	6.2	3.0	1.8	4.1
1961	0.8	3.7	8.1	3.4	5.7	1.5	2.6	3.1	1.6	0.9	6.1	7.2
1962	6.8	7.2	5.2	2.9	2.3	6.3	3.1	2.4	3.8	3.5	1.7	1.7
1963	0.9	2.7	3.8	3.3	1.3	1.3	5.5	0.6	1.8	0.1	4.5	2.5
1964	1.0	2.9	8.2	11.1	1.4	0.3	3.8	3.7	5.5	0.4	3.7	4.4
1965	4.5	5.7	3.6	1.2	5.4	2.5	2.5	2.0	7.7	0.2	1.5	2.1
1966	3.0	5.0	0.7	7.3	2.2	0.7	3.5	14.5	1.4	2.0	3.1	4.2
1967	2.1	2.3	3.1	7.6	8.7	3.0	4.3	1.7	6.3	5.0	1.7	5.0

1968	4.8	1.1	5.6	4.9	12.7	6.8	6.0	0.3	6.0	2.8	5.3	4.6
1969	8.1	2.4	3.7	4.3	3.6	3.0	3.4	2.7	2.3	3.6	3.9	8.1
1970	1.1	4.6	4.9	8.0	0.7	2.3	3.0	2.2	2.8	7.7	2.1	3.9
1971	2.1	2.2	3.2	1.7	5.4	7.7	4.0	8.6	0.8	2.6	3.4	7.0
1972	1.7	1.6	3.3	1.8	2.1	2.6	1.8	3.6	6.4	7.6	7.4	5.1
1973	5.6	3.0	7.9	14.2	4.0	2.7	6.6	1.3	9.1	5.9	9.0	5.2
1974	5.8	2.6	2.1	9.8	6.3	7.8	4.1	3.2	4.3	3.4	5.7	3.0
1975	4.6	4.4	7.7	4.1	5.9	1.6	4.0	2.7	1.9	1.6	3.7	3.0
1976	2.5	3.6	5.5	1.9	5.6	6.6	1.8	1.6	3.4	6.5	1.8	2.3
1977	2.7	2.0	6.8	4.5	2.9	4.3	5.1	1.4	6.4	0.6	9.3	1.4
1978	5.4	1.5	3.6	4.2	6.3	5.4	2.7	6.4	10.2	1.0	6.6	11.6
1979	4.1	5.7	3.1	9.6	11.5	4.5	4.3	6.5	4.4	3.4	4.0	3.5
1980	2.7	0.9	6.6	5.9	4.6	0.5	1.0	0.2	5.1	2.6	6.3	1.9
1981	1.1	3.9	4.0	2.8	9.7	7.8	3.2	2.9	1.4	6.1	1.6	1.3
1982	8.7	3.4	2.9	9.3	5.6	4.1	1.0	4.5	1.5	2.3	9.7	8.3
1983	2.3	1.5	4.2	6.7	7.6	3.3	1.1	0.8	0.4	3.7	4.5	9.1
1984	1.3	3.5	5.6	3.8	8.2	1.1	4.2	5.7	3.3	15.4	8.5	3.5
1985	3.1	2.8	5.3	8.6	3.0	2.4	3.3	3.5	4.4	3.9	5.8	3.0
1986	0.5	3.5	3.7	7.3	4.1	6.4	0.1	4.6	1.9	6.1	5.7	3.9
1987	2.1	7.1	3.5	0.5	4.6	4.6	1.6	2.1	7.6	1.4	11.0	16.5
1988	3.7	3.4	3.5	3.8	2.1	1.0	8.0	2.2	2.5	2.0	13.1	2.9
1989	3.0	9.6	7.6	2.6	4.0	4.0	7.9	1.2	3.6	1.7	2.0	2.2
1990	6.5	4.8	10.4	7.7	7.7	0.8	4.6	1.6	4.1	8.8	3.3	6.9
1991	6.9	3.1	3.6	12.4	2.9	2.3	2.0	6.8	3.0	7.0	5.2	4.6
1992	1.8	2.1	6.5	1.9	3.7	5.1	6.8	2.1	2.9	0.7	4.7	3.9
1993	5.1	2.4	3.1	5.4	5.5	2.0	1.2	2.8	1.4	4.1	6.3	4.4
1994	4.9	3.2	5.6	5.2	4.0	5.6	4.3	4.0	2.1	3.9	6.1	4.6
1995	3.9	2.4	3.7	5.0	4.6	1.9	3.0	T	1.9	5.5	2.3	2.8
1996	2.6	2.1	3.6	4.2	4.0	2.8	3.6	1.2	6.4	6.4	7.4	2.8
1997	1.9	4.7	6.5	7.7	3.9	5.4	1.9	2.2	3.8	4.4	3.9	3.7
1998	4.7	4.1	4.8	3.3	2.9	2.2	3.0	3.2	3.5	3.4	2.3	4.4
1999	6.1	1.1	4.9	5.3	3.4	6.1	2.4	0.9	1.6	5.0	0.3	5.3
2000	1.0	3.9	3.9	2.9	5.8	5.7	0.9	0.0	2.4	0.8	11.0	3.4
2001	3.0	8.5	3.9	1.4	4.0	2.1	1.6	1.8	2.5	5.2	5.3	8.3
2002	3.4	1.9	9.5	1.8	5.4	2.6	3.5	2.9	1.5	4.5	1.8	7.7
2003	0.3	5.6	2.5	1.8	4.3	7.7	2.1	1.3	3.5	2.2	4.9	3.5
2004	3.3	4.4	4.1	6.9	4.0	5.0	3.3	3.2	0.5	9.3	9.6	2.5
2005	4.9	3.0	3.4	3.1	1.1	2.8	4.0	4.0	3.7	1.0	3.0	0.6
2006	3.8	2.0	4.4	8.6	4.1	3.0	1.6	2.0	4.3	3.1	6.1	6.0

2007	9.6	1.6	1.6	4.5	3.5	2.0	3.3	0.1	4.7	6.2	2.5	5.0
2008	1.4	3.9	7.6	9.7	4.8	4.2	2.2	5.8	7.5	4.9	2.6	3.7
2009	2.6	2.2	4.6	5.3	13.1	3.1	11.7	2.8	6.4	16.6	1.2	12.3
2010	3.2	4.3	2.2	4.7	4.8	2.4	1.2	1.5	1.3	2.1	6.7	2.1
2011	0.9	4.0	4.2	7.2	11.1	1.2	0.2	5.6	1.2	2.3	14.6	7.7
2012	2.1	4.5	8.1	2.9	1.2	0.9	1.5	5.7	5.4	2.6	1.9	5.6
2013	4.8	4.8	4.6	4.3	7.2	3.2	2.2	3.6	3.2	3.3	4.7	6.9
2014	2.3	3.2	5.3	5.0	6.6	5.5	7.2	2.0	2.0	3.6	2.2	3.2
2015	3.0	3.8	8.1	5.4	9.5	2.8	4.8	0.6	0.1	3.8	11.1	8.4
2016	3.6	2.1	12.3	7.7	3.4	1.8	7.4	7.6	1.3	1.9	2.6	4.4
2017	1.5	3.5	3.9	10.1	6.8	3.2	4.8	3.5	0.5	1.4	0.4	7.7
2018	2.2	14.0	3.9	6.0	2.5	2.9	3.3	6.6	7.0	8.2	4.6	10.3
2019	3.8	6.4	3.3	11.6	8.6	4.5	2.8	5.3	1.4	7.0	4.2	1.6
2020	6.8	6.0	5.4	6.4	6.0	6.7	2.4	6.0	3.4	3.9	2.1	4.8
2021	2.5	5.0	4.6	4.0	4.5	7.1	3.6	1.3	1.1	3.9	2.0	4.1
2022	4.3	5.3	6.3	5.2	4.9	4.2	3.2	1.4	M	M	M	M

Observed precipitation information from the Fourth National Climate Assessment for the Southeast region is shown in Figure 17. By every metric, there has been an increase in heavy precipitation in Arkansas; the five-year maximum daily precipitation has increased by 10-19%, the 99% precipitation has increased between 20-29%, and the number of 5-year, 2-day events has increased 40+%

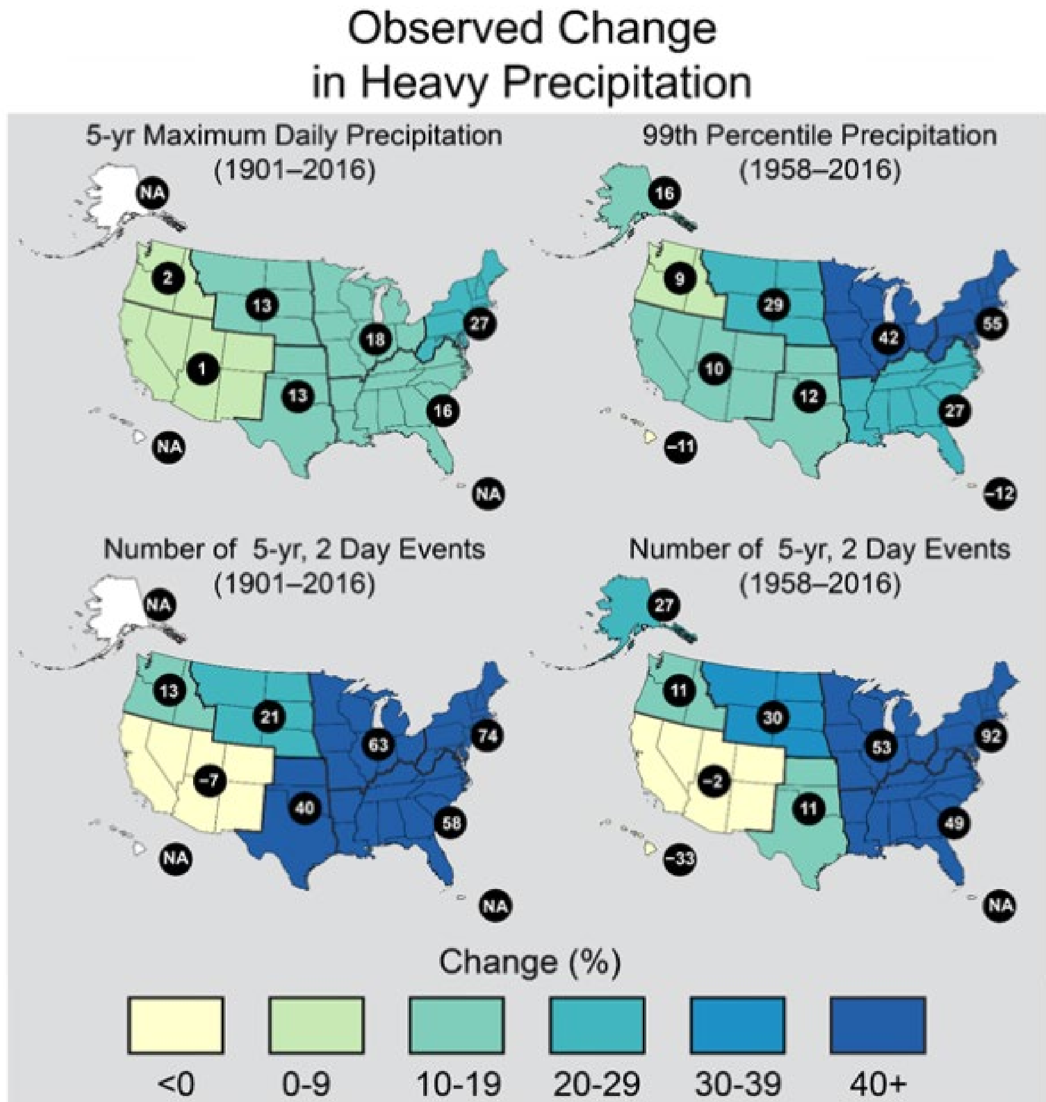


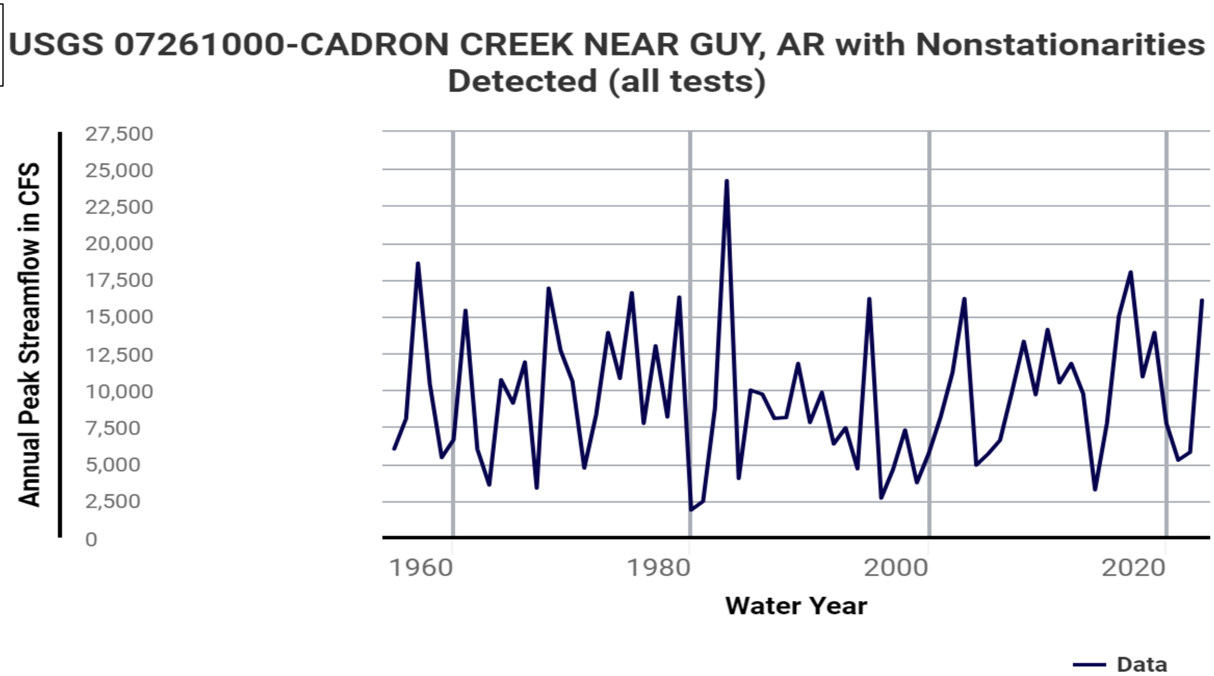
Figure 5. These maps show the change in several metrics of extreme precipitation by NCA4 region, including (upper left) the maximum daily precipitation in consecutive 5-year blocks, (upper right) the amount of precipitation falling in daily events that exceed the 99th percentile of all non-zero precipitation days, (lower left) the number of 2-day events with a precipitation total exceeding the largest 2-day amount that is expected to occur, on average, only once every 5 years, as calculated over 1901–2016, and (lower right) the number of 2-day events with a precipitation total exceeding the largest 2-day amount that is expected to occur, on average, only once every 5 years, as calculated over 1958–2016. The numerical value is the percent change over the entire period, either 1901–2016 or 1958–2016. The percentages are first calculated for individual stations, then averaged over 2° latitude by 2° longitude grid boxes, and finally averaged over each NCA4 region. Note that Alaska and Hawai'i are not included in the 1901–2016 maps owing to a lack of observations in the earlier part of the 20th century. (Figure source: CICS-NC and NOAA NCEI). (NCA4 Vol.1, Chapter 7: Precipitation Change in the United States, Fig 7.4)

Figure 17. Observed and Changes of Several Metrics of Extreme Precipitation

A.8.2.3. Time Series Analysis

The USACE Time Series Toolbox includes the Non-stationarity Detection Tool was developed in conjunction with USACE Engineering Technical Letter (ETL) 1100-2-3, Guidance for Detection of Non-stationarities in Annual Maximum Discharges, to detect non-stationarities in maximum annual flow time series (USACE, Time Series Toolbox, 2023). This tool was also used to assess abrupt or slowly varying changes in observed peak flow data collected by the USGS gage located along Cadron Creek for the period of record spanning 1955 – 2023. Figure 18 shows that there were no abrupt nonstationarities detected using maximum annual flow analysis for the USGS 07261000 Cadron Creek near Guy, AR.

A



B

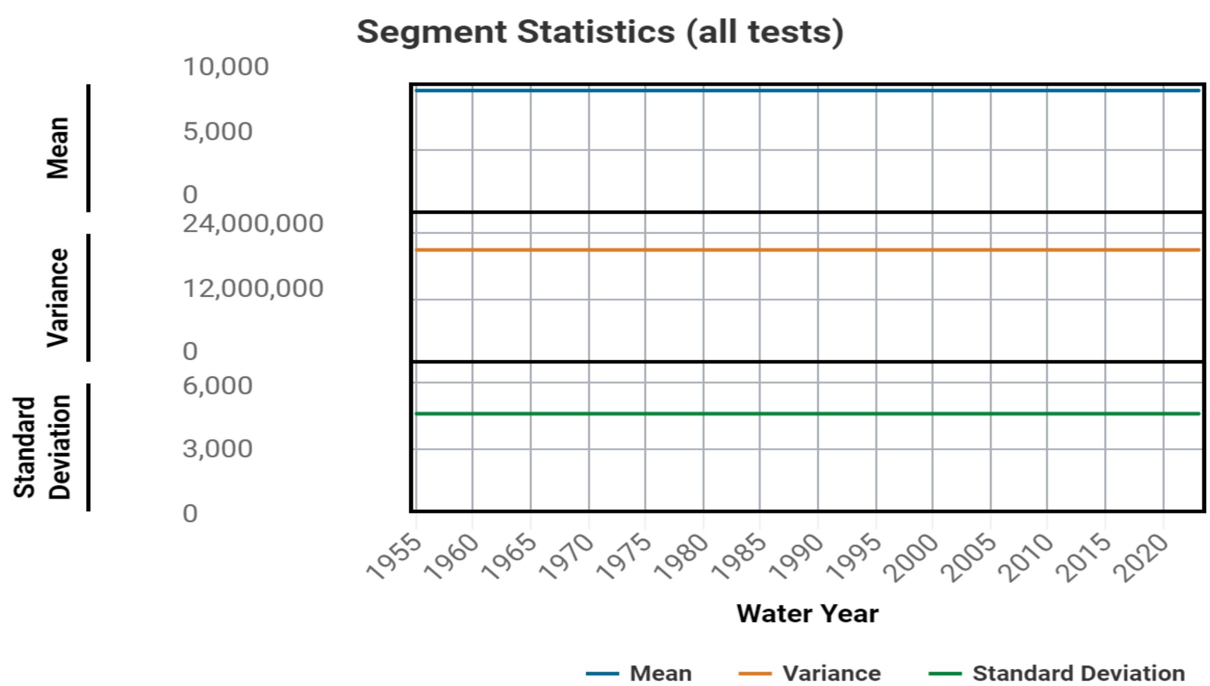
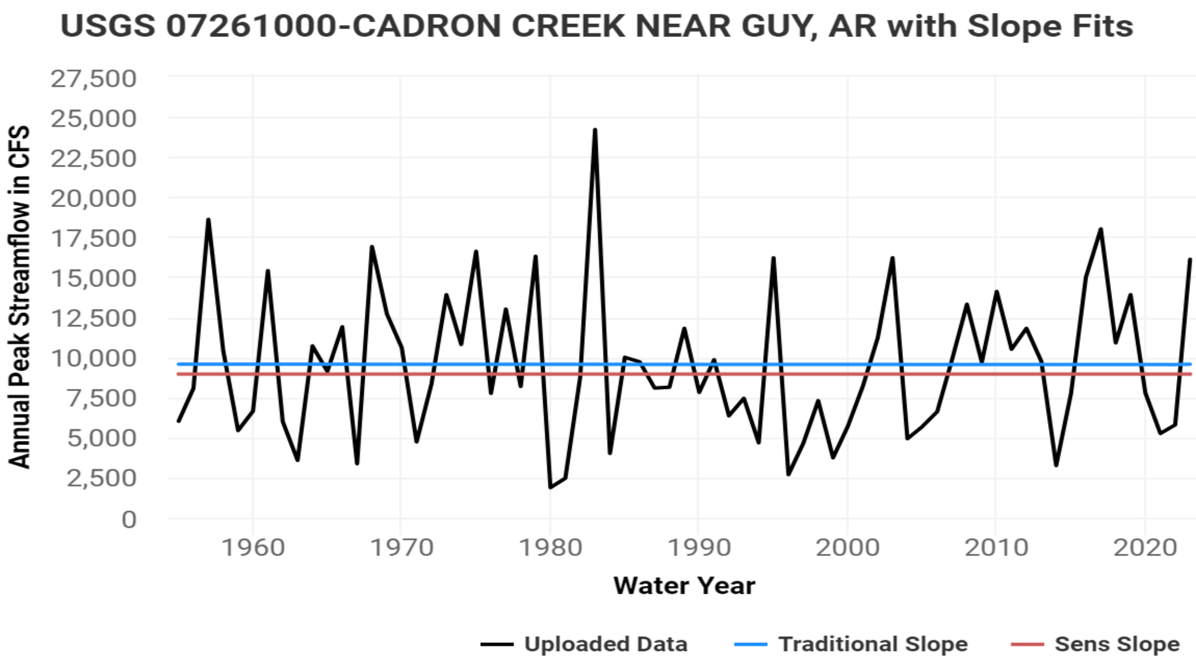


Figure 18. Non-Stationarity Detected at Cadron Creek near Guy, AR in the two graphs. A) Non-stationarities shown by gray lines B) shows the mean, variance, and deviation between the non-stationarities.

The trend analysis tool utilizes two different statistical methods for trend detection. A plot of the observed annual peak streamflow at the Cadron Creek near Guy, AR with a linear regression fit is shown in Figure 19. The t-test, Mann-Kendall test, and Spearman Rank-Order test all indicate no statistically significant increasing trend in the annual peak stream flow.



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Negative	-0.371	10294
Sen's Slope	Positive	0	8950

Trend Hypothesis Test

Test	P-Value
t-Test	0.99
Mann-Kendall	0.996
Spearman Rank-Order	0.983

Figure 19. Observed Annual Peak Streamflow Cadron Creek near Guy, AR

Figure 20 shows the Auto Regressive Integrated Moving Average (ARIMA) Model Forecast for the annual peak streamflow based on the past 68 years of peak streamflow data. The model is run 12 years into the future. The blue line is the fitted peak streamflow, and the red line is the predicted peak streamflow. The blue hatching is the 95% Confidence Interval for Fitted Values and the grey hatching is the 97% Confidence Interval for the Forecasted Horizon.

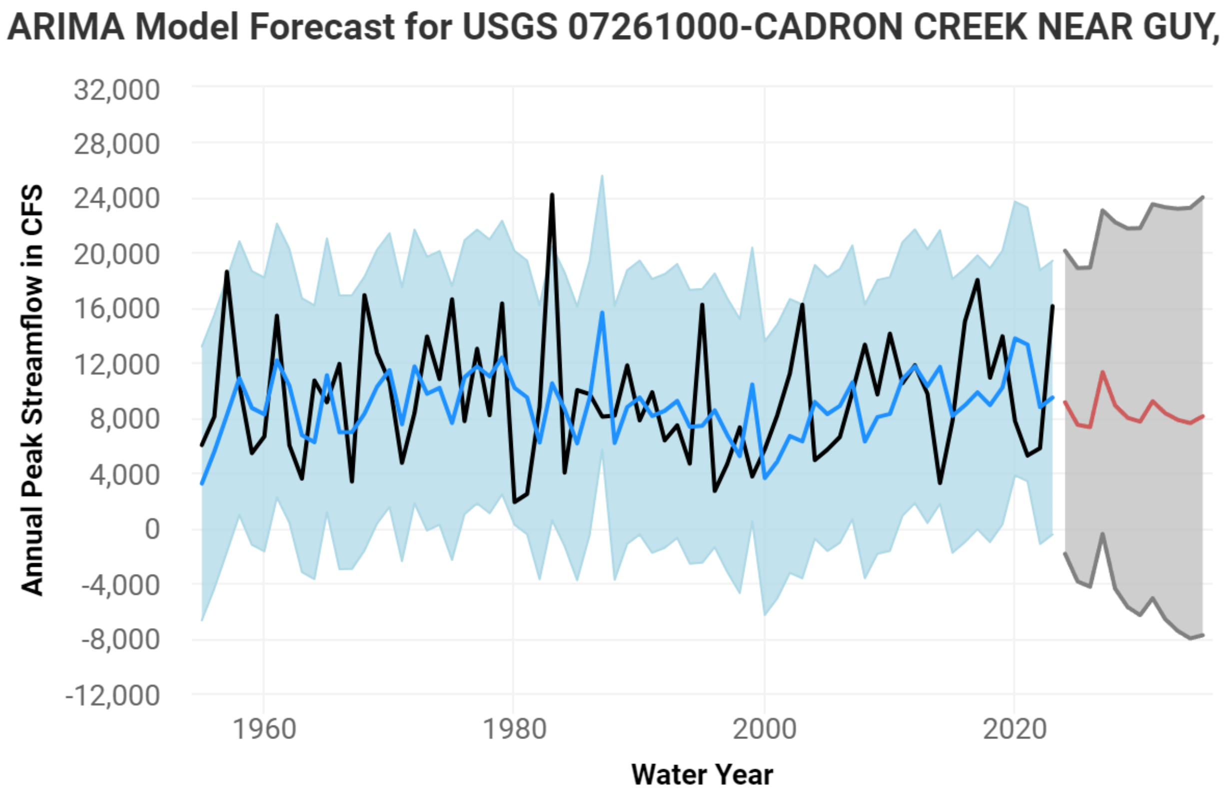


Figure 20. Auto Regressive Integrated Moving Average (ARIMA) Model Forecast for Cadron Creek near Guy, AR

A.8.2.4. Climate Hydrology Assessment Tool

The USACE Climate Hydrology Assessment Tool (CHAT) was used to enhance USACE climate preparedness and resilience. This tool aids in preparing a qualitative analysis regarding climate change impacts for projects with hydrologic based aspects. The CHAT tool "displays various simulated historical and future, climate-changed streamflow, temperature, and precipitation outputs derived from 32 global climate models" (USACE, Climate Hydrology Assessment Tool, 2023). This provides qualitative information about future climate conditions and provides a tool to develop repeatable analytical results using consistent information. The tool reduces potential error, while increasing the speed of information development so that data can be used earlier in the decision-making process.

The USACE CHAT was also used to investigate potential future trends in streamflow for the Maumelle River watershed. Figure 21 displays the range of projected annual maximum monthly streamflow computed from 32 global climate models. The projected streamflow computations are computed at the HUC8 watershed scale, 11110205. 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.

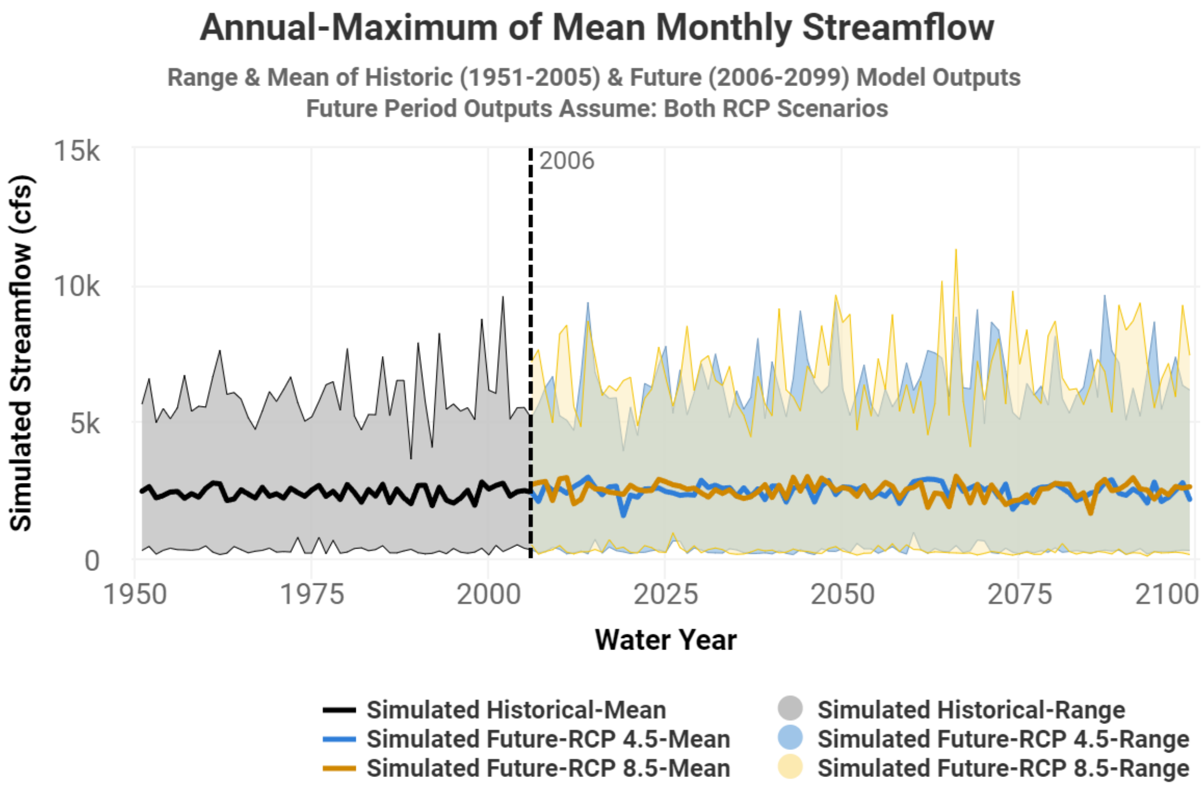
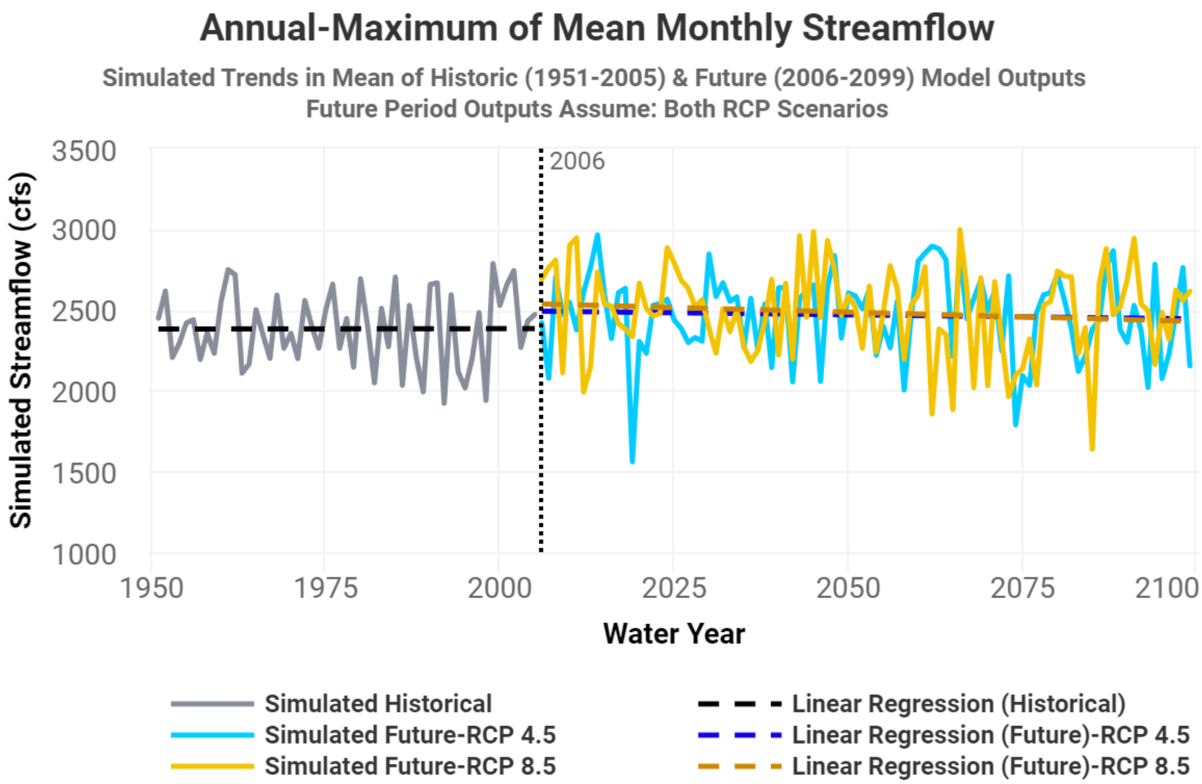


Figure 21. Range of Projected annual Maximum Monthly Streamflow



Simulated Trend Lines

Simulated Historical (1951 to 2005)	Simulated Future (2006 to 2099)	
0.044 Traditional Slope	**-0.508** Traditional Slope-RCP 4.5	**-1.1565** Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

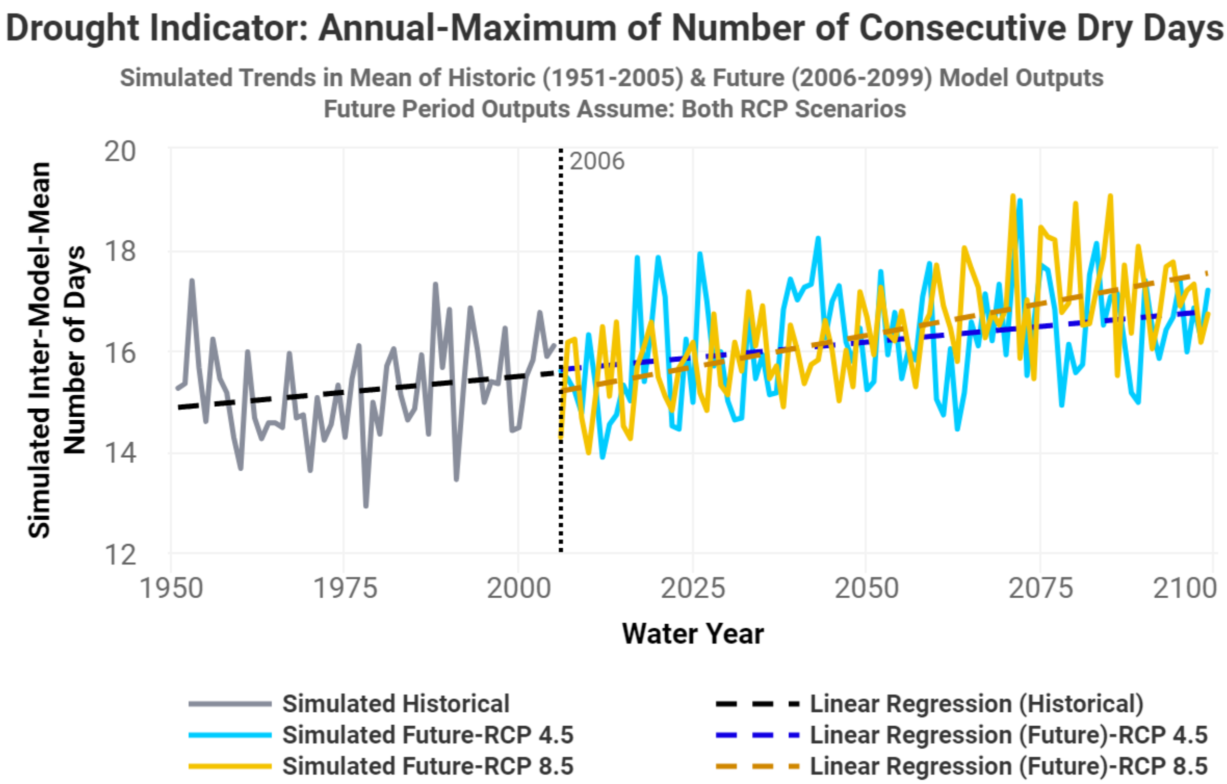
Test	p-value
t-Test	0.982
Mann-Kendall	0.919
Spearman Rank-Order	0.84

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.612	0.277
Mann-Kendall	0.501	0.389
Spearman Rank-Order	0.51	0.41

Figure 22. Mean Projected Annual Maximum Monthly Streamflow for HUC 11110205

The overall trend in the mean projected annual maximum monthly streamflow over time is shown in blue in Figure 22. The t-test, Mann-Kendall test, and Spearman Rank-Order test all indicate a statistically insignificant trend for historical and climate changed mean monthly streamflow trendline for the Cadron Creek region.



Simulated Trend Lines

Simulated Historical (1951 to 2005)	Simulated Future (2006 to 2099)	
0.0125 Traditional Slope	0.0124 Traditional Slope-RCP 4.5	0.0252 Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

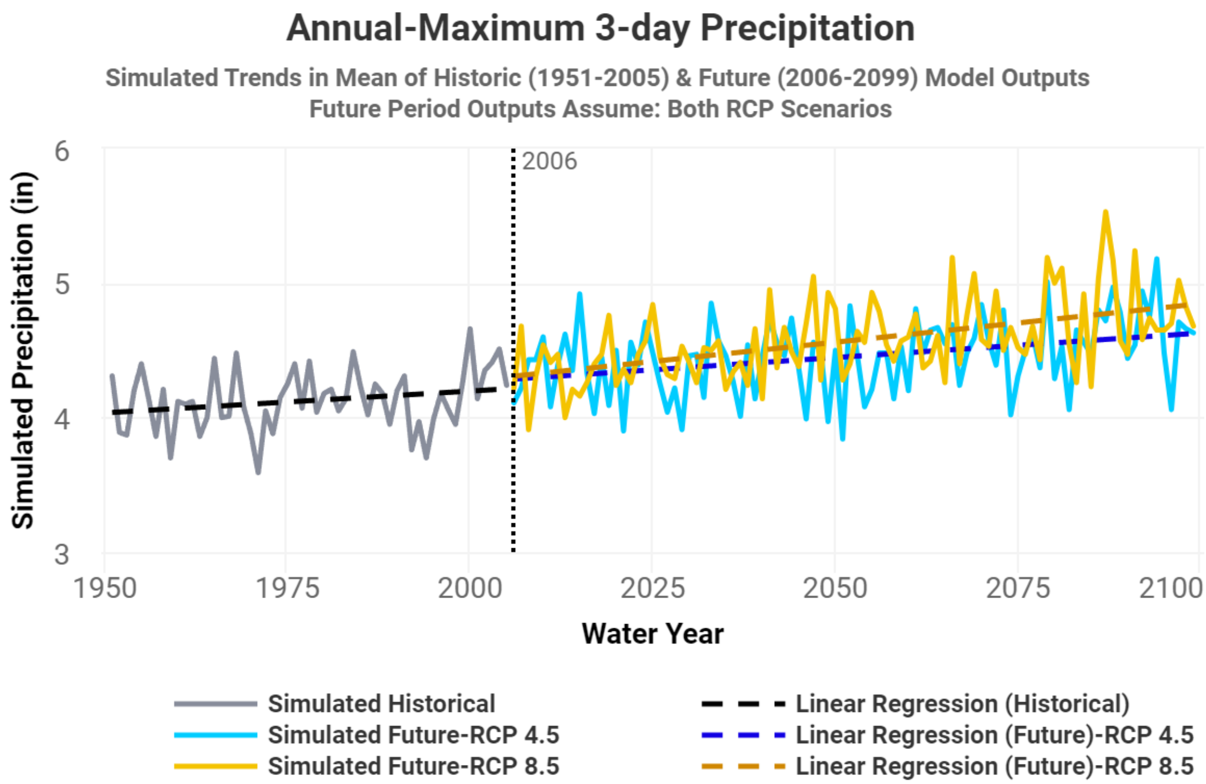
Test	p-value
t-Test	0.121
Mann-Kendall	0.0879
Spearman Rank-Order	0.0874

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.00183**	5.11e-12**
Mann-Kendall	0.00238**	< 2.2e-16**
Spearman Rank-Order	0.00179**	1.94e-12**

Figure 23. Drought Indicator for HUC 11110205

Figure 23 shows a statistically significant upward trend for number of days in drought per year for HUC 11110205.



Simulated Trend Lines

Simulated Historical (1951 to 2005)	Simulated Future (2006 to 2099)	
0.0032 Traditional Slope	0.0036 Traditional Slope-RCP 4.5	0.0057 Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

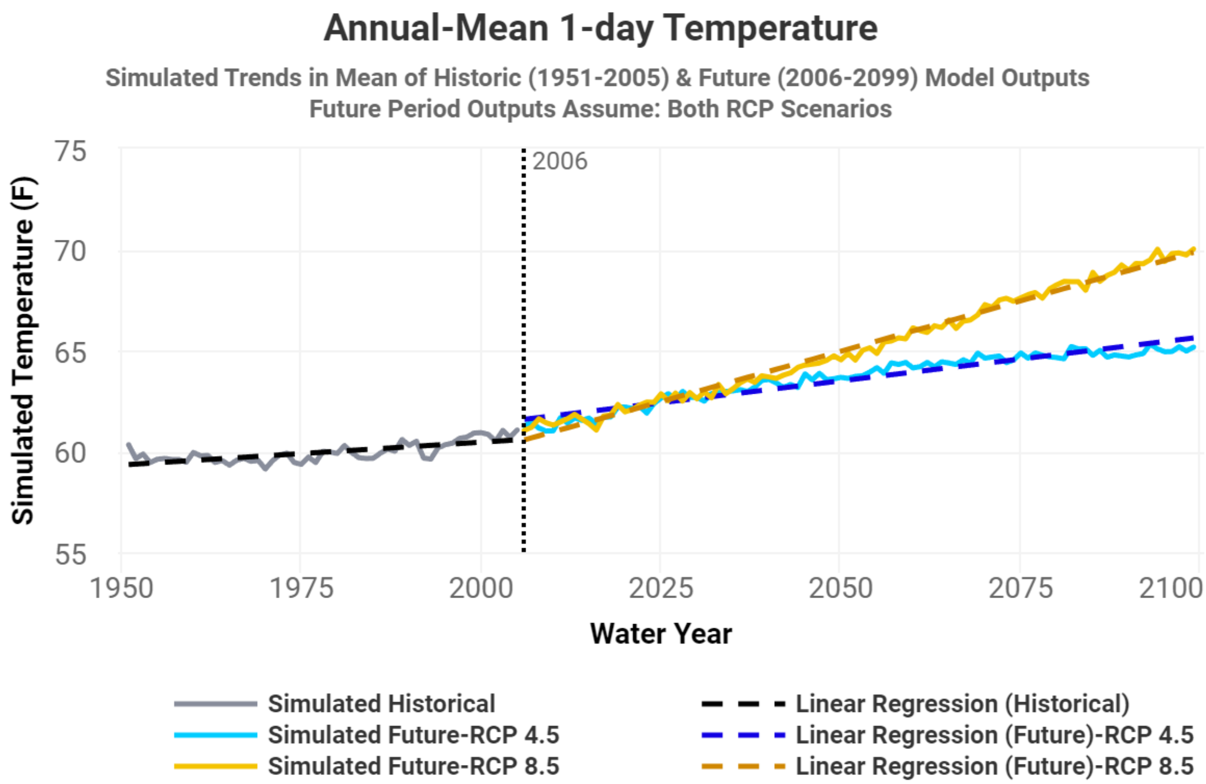
Test	p-value
t-Test	0.0874
Mann-Kendall	0.0892
Spearman Rank-Order	0.0876

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.000388**	5.67e-08**
Mann-Kendall	0.000256**	1.19e-07**
Spearman Rank-Order	0.000199**	4.37e-08**

Figure 24. Annual-Maximum 3-day Precipitation for HUC 11110205

Figure 24 shows statistically significant increasing trend for the climate changed annual-maximum 3-day precipitation for HUC 11110205.



Simulated Trend Lines

Simulated Historical (1951 to 2005)

0.0226
Traditional Slope

Simulated Future (2006 to 2099)

0.0433
Traditional Slope-RCP 4.5

0.0999
Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

Test	p-value
t-Test	2.14e-10**
Mann-Kendall	< 2.2e-16**
Spearman Rank-Order	2.47e-09**

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	< 2.2e-16**	< 2.2e-16**
Mann-Kendall	< 2.2e-16**	< 2.2e-16**
Spearman Rank-Order	< 2.2e-16**	< 2.2e-16**

Figure 25. Annual-Mean Temperature for HUC 11110205

Figure 25 shows statistically significant increasing trend for the climate changed annual-mean temperature for HUC 11110205.

A.8.2.5. Vulnerability Assessment to Climate Change Impacts

The USACE Watershed Climate Vulnerability Assessment Tool was used to compare the relative vulnerability of the HUC 1111, Lower Arkansas, to climate change to the other watersheds across the continental United States. The tool facilitates a screening level, comparative assessment of how vulnerable a given watershed is to the impacts of climate change. The Climate Vulnerability Assessment Tool is used to assess the vulnerability of the Lower Arkansas Region for the USACE Flood Risk Reduction business line to projected climate change impacts relative to the effects that climate change might have on the USACE flood risk reduction business line in the other watersheds in the continental United States. The tool uses the Weighted Order Weighted Average (WOWA) method to represent a composite index of how vulnerable a given HUC-4 watershed (Vulnerability Score) is to climate change specific to a given business line. The USACE Climate Vulnerability Assessment Tool makes an assessment for two 30-year epochs of time 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 watershed is to the impacts of climate change for a given business line for all global climate models. The top 50% of the traces is called the “wet” subset of traces and the bottom 50% of the traces is called the “dry” subset of traces. There is a combination of four epoch subset combinations, which provide for an indication of the variability/uncertainty in the outputs.

For a given scenario and a given business line, only the top 20% of the HUCs are marked as vulnerable. In Figure 26 the WOWA score for flood risk reduction line for HUC-1111 does not change appreciably across the 4 scenarios. HUC-1111 is considered vulnerable in the Dry 2050 and Dry 2085 Forecast.

The indicators that drive vulnerability for HUC-1111 and their relative contributions to the WOWA score for Dry 2050 and Dry 2085 forecast are shown in Figure 27. The indicators for flood risk reduction vulnerability for HUC-1111 is the percent change in runoff to the percent change in precipitation.

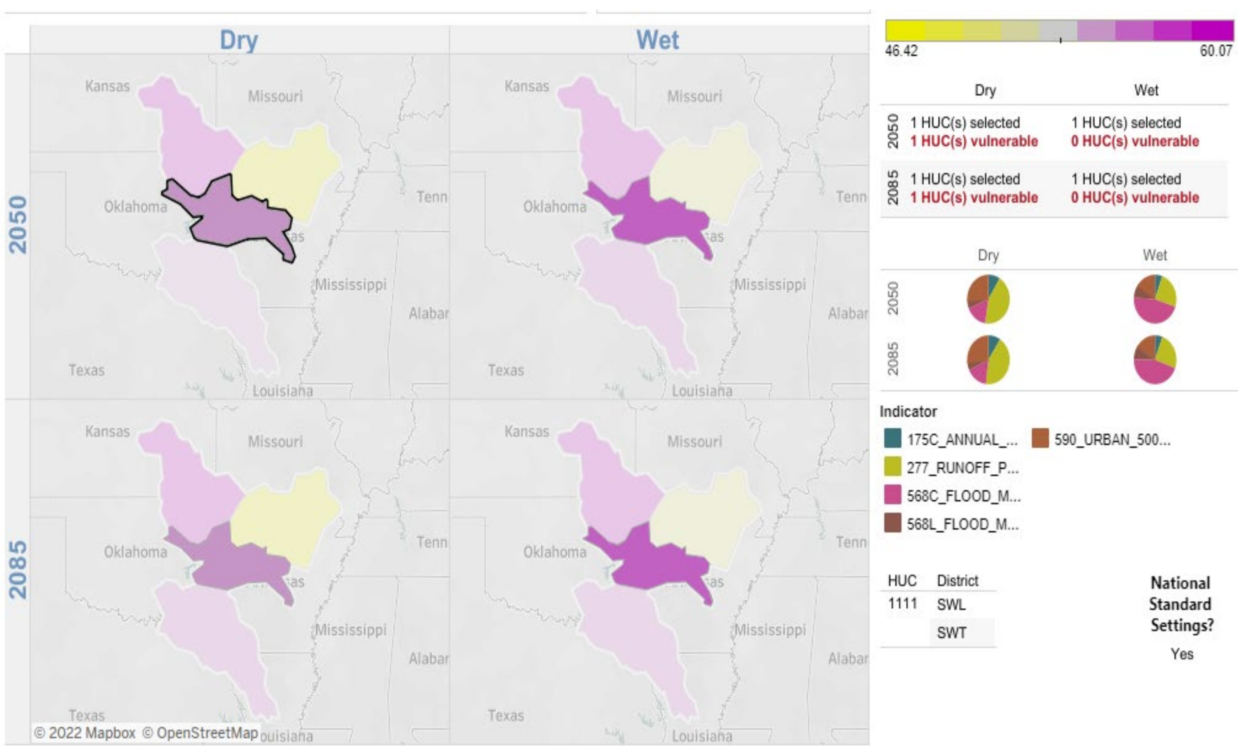


Figure 26. Summary of HUC-1111 Results

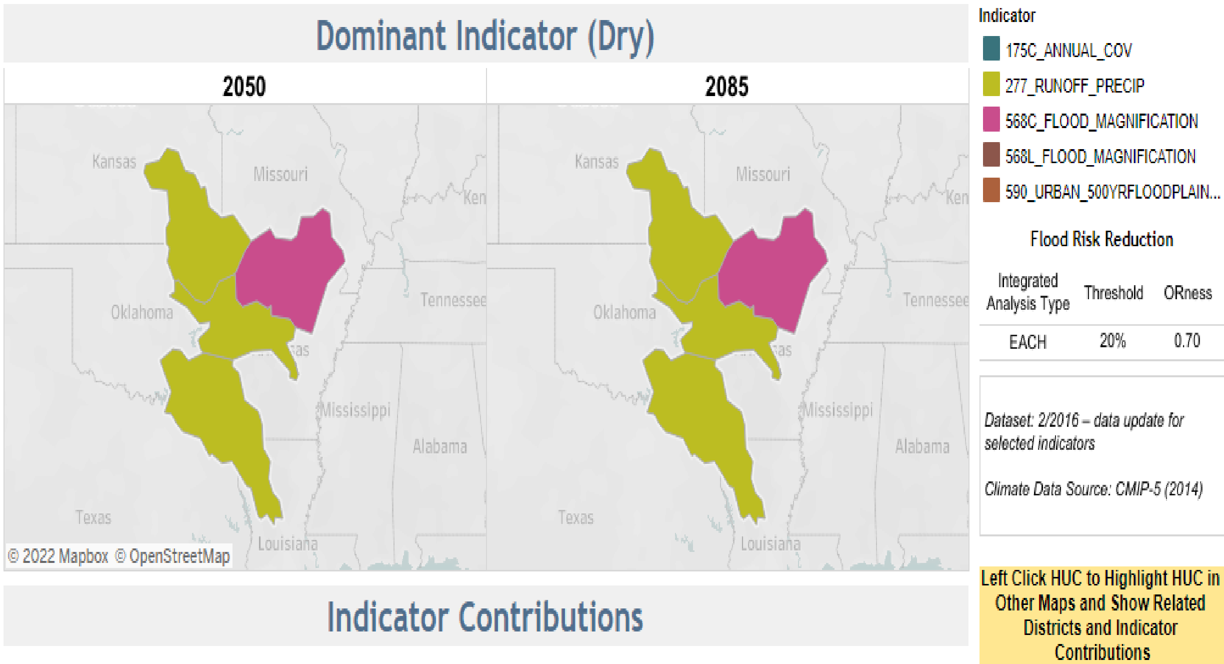


Figure 27. Indicators that Drive Vulnerability in a Dry Forecast 2050 and 2085

The results of the USACE Watershed Climate Vulnerability Assessment Tool are presented in Table 8.

Table 8. Projected Vulnerability with Respect to Ecosystem Restoration

HUC4 Watershed	Projected Vulnerability with Respect to Ecosystem Restoration			
	Ecosystem Reduction Vulnerability Score			
Lower Arkansas 1111	2050 Dry	2050 Wet	2085 Dry	2085 Wet
	54.97	54.56	56.46	55.85

In the drier global climate models, the potential for increased runoff is a driving factor in vulnerability from climate change.