ARKANSAS RIVER CORRIDOR

Appendix N: Climate Change Analysis

ARKANSAS RIVER CORRIDOR, TULSA COUNTY, OKLAHOMA

Introduction

The Arkansas River is a water resource serving numerous nationally significant purposes. The river has historically served as a nationally significant resource for aquatic and terrestrial habitat of the nation's wildlife that live, breed, and migrate through the Arkansas River ecosystem. This includes federally endangered Interior Least Tern (Least Tern, *Sterna antillarum*), a nationally significant resource, and one federally threatened bird species, the Piping Plover (*Charadrius melodus*) as well as a plethora of native species and migratory waterfowl that support a healthy and functional riverine ecosystem. Keystone Lake and its dam located along the Arkansas River play vital roles in supporting the continued provision for these species, as well as many other purposes. In particular, the lake and dam provide flood risk management benefits, contribute to the eleven reservoir system operation of the McClellan-Kerr Arkansas River Navigation System, provide clean and efficient power through the associated hydropower plant, and provide a source of water for municipal and industrial uses. However, construction, operation, and maintenance of the Keystone Dam, lake, associated hydropower operations and other multi-purposes have significantly degraded the riverine ecosystem structure, function, and dynamic processes below Keystone Dam on the Arkansas River within Tulsa County, Oklahoma.

Purpose

This study is in response to the Section 3132 authorization of the 2007 WRDA. The purpose of this study is to evaluate the aquatic ecosystem restoration components of the October 2005 Arkansas River Corridor Master Plan (ARC Master Plan) and determine if there is a Federal Interest that aligns with the Corps of Engineers' ecosystem restoration mission.

Study Authority

The Arkansas River Corridor study is authorized in the Water Resources Development Act (WRDA) of 2007, Section 3132.
Section 3132. Arkansas River Corridor.

(a) IN GENERAL. – The Secretary is authorized to participate in the ecosystem restoration, recreation, and flood damage reduction components of the Arkansas River Corridor Master Plan dated October 2005. The Secretary shall coordinate with appropriate representatives in the vicinity of Tulsa, Oklahoma, including representatives of Tulsa County and surrounding communities and the Indian Nations Council of Governments.

(b) AUTHORIZATION OF APPROPRIATIONS. – There is authorized to be appropriated $50,000,000 to carry out this section.

Non-Federal Sponsor

Tulsa County is the non-federal sponsor for the Arkansas River Corridor feasibility study. An amended feasibility cost-sharing agreement was executed in May 2015.

Recommended Plan

Alternative 5 is the National Ecosystem Restoration (NER) Plan and includes construction of a pool structure at River Mile 530 to regulate flow in the Arkansas River, a rock riffle feature associated wetland plantings at Prattville Creek, and construction of a sandbar island near Broken Arrow, OK. With the implementation of the NER plan, more natural river flow would return to 42 river miles of the Arkansas River within the study area. The NER plan would provide approximately 2,144 acres of additional riverine habitat, nearly doubling the amount of currently available habitat under low flow conditions. Also five acres of restored wetlands, and three acres of reliable sandbar island habitat where none currently succeed, would be restored as part of the NER plan. Shoreline, river, backwater, slackwater, wetland, and sandbar island habitat quality would all be improved generating an overall increase in the ecosystem quality and carrying capacity of the corridor. Current operation of Keystone Dam would not be changed. Additional water and flow would remain within the existing banks of the river and would not increase the flood elevation, nor downstream or backwater flooding.

Climate Change Assessment

Engineering Construction Bulletin (ECB) No. 2016-25 provides guidance for incorporating climate change information in hydrologic analyses in accordance with the USACE overarching climate change adaption policy. It calls for a qualitative analysis. The goal of a qualitative analysis of potential climate threats and impacts to USACE hydrology-related projects and operations is to describe the observed present and possible future climate threats, vulnerabilities, and impacts of climate change specific to the study goals or engineering designs. This includes consideration of both past (observed) changes as well as potential future (projected) changes to relevant climatic and hydrologic variables.

Project Background

Currently, when the Arkansas River watershed is not experiencing flood conditions, the Keystone Lake project is operated for hydropower. As a consequence of hydropower operation, during normal conditions the downstream portions of the river are currently experiencing 18+ hours of dry conditions on a daily basis. Without the proposed project these prolonged dry periods cause downstream refuge pools to dry out, thus placing stress on the ecosystems located in the study area. The downstream pool control structures being proposed as part of this study would serve to store and meter out hydropower releases at a minimum rate of 1,000 cfs throughout the day when no hydropower releases are occurring. The downstream pool control structures will prevent the drying out of the refuge pools.

The occurrence of peak flows provides the resource necessary to generate hydropower and to maintain the 1,000 cfs minimum release necessary to maintain downstream habitat. Thus, peak flows are the critical variable to consider to evaluate the effectiveness of the proposed downstream pool control structures and the effects of climate change on the proposed project.

Project Hydrologic Location and Gage Resources

The Arkansas River Corridor project is located within the 2-digit Hydrologic Unit Code (HUC) 11, the Arkansas-White-Red Region. This region encompasses all of Oklahoma and parts of Colorado, Kansas, Missouri, Arkansas, Louisiana, Texas, and New Mexico. This region includes the drainage area of the Arkansas River. The region is broken into a smaller subregion, HUC 1111, known as the Lower Arkansas subregion.

The nearest gage location to the project is the Arkansas River's Tulsa gage, operated by the U.S. Geological Survey (USGS) in cooperation with the City of Tulsa, Oklahoma and the US Army Corps of Engineers (USACE). The name and number for this gage is USGS Gage 07164500 Arkansas River at Tulsa, OK. This gage has been in place since October 01, 1925. This gage has a 74,460 square mile drainage area, with about 62,811 square miles contributing. Except for 109 mi^2 intervening area, flow is completely regulated by Keystone Lake (station 07164200) since September 1964. Prior to September 1964, the site was impacted by minor regulation by John Martin Lake in Colorado and by Great Salt Plains Lake (station 07150000) in Oklahoma.

A second gage was evaluated since the Tulsa gage is effected by regulation post-1964. USGS gage number 07160000 for the Cimarron River near Guthrie, Oklahoma was used in this study since the flows are not significantly impacted by regulation. This gage location is located on one of the two main tributaries to the Arkansas River, and climate change impacts at this gage would likely contribute to the impacts realized further downstream at the Tulsa gage. The drainage area for this gage location is 17,006 square miles. This gage drains to Lake Keystone, and subsequently to the Tulsa gage.

The areas upstream of both the Tulsa and Guthrie gages have historically been agricultural lands. These lands remain predominantly agricultural in nature and have not varied significantly over the last century. Tulsa is the only major urban center within the region. The areas which drain into these two gage locations, are hydrologically and climatologically similar. Because the Cimarron River is a tributary to the Arkansas River, the flow captured by the Guthrie gage contributes to the drainage area above the Tulsa gage.

The climate change assessment uses information related to the 2-digit and 4-digit Hydrologic Unit Code region and subregion of the Arkansas River Corridor. The tools used in the analysis apply characteristics of the region and subregion along with gage data to make climate change projections.

Literature Review

The USACE Climate Change and Hydrology Literature Synthesis for the Hydrologic Unit Code (HUC) 11 (Arkansas, White and Red Rivers Region 11) that encompasses the project area was reviewed to get a summarization of the observed and projected climate trends within the region. This USACE literature synthesis provides a summarization of reputable peer-reviewed literature focusing on a regional basis for project studies.

Observed temperatures in the project area are showing a slight cooling trend in the summer and fall months, and a slight warming trend in the winter and springtime. Mean temperatures are trending slightly upward. There has been no trend in maximum temperatures in the project area suggesting that the maximum temperatures are remaining relatively constant during the period of data evaluated (1949-2010). The occurrence of minimum temperature days was found to have increased slightly.

Observed rainfall trends have been widely reported for the Water Resources Region within HUC 11 (Arkansas, White and Red Rivers Region 11). The literature is inclusive of the region, but not specific to it. For the general project area, rainfall trends show an increase of 0 to 20%. A regionally focused study over a similar time period found an increase in precipitation of 6 to 20%. In terms of intensity, trends in the project area show that the rainfall events have slightly increased in intensity. Along with rainfall, observed average streamflow has shown an upward trend within the project area. However, there was no streamflow trend during the spring-summer time period.

The use of Global Circulation Models (GCMs) has provided a means of projecting climate trends into the future. These models incorporate various climate variables that influence the Earth's climate system. While there is significant uncertainty in these model projections, they are widely accepted as representing the best available science that can be utilized for planning purposes in conjunction with historical data.

Over the next century, the mean temperature in the project area is projected to increase, mostly in the latter half of that timeframe. The extreme maximum temperature is also expected to increase. Increases in minimum temperatures were also reported. In general, temperatures within the project area are expected to increase over the next century.

At the regional level, projected, average rainfall over the next century is expected to remain relatively consistent through the end of the 21st century. Major metropolitan areas are expected to see a slight increase in annual precipitation. Although there is no general rainfall trend for the region, peak rainfall is expected to increase and minimum rainfall is expected to decrease. The number of consecutive dry days is also expected to increase. Average rainfall is expected to remain relatively consistent in this region. Based on the variability in the projected, GCM based streamflow no concrete conclusions can be made regarding trends in average streamflow. However, with warmer temperatures and increased drying periods it is possible that average streamflow may decrease in the future as a result of more available overland and soil storage. Rainfall intensities are expected to increase, this might result in an increase in streamflow extremes.

The 3rd National Climate Assessment was also reviewed for a broader perspective on climate change. The project area is located within the Great Plains region. This assessment echoes the findings of the USACE Literature Synthesis. The number of extreme hot days is projected to increase and the number of warm nights is projected to increase. Precipitation is projected to increase for the heaviest rainfall events, but the number of rainfall days is not projected to increase significantly. Conversely, the number of consecutive dry days is projected to increase by mid-century.

A series of climate projection models were accessed from an archive maintained collaboratively by of the U.S. Bureau of Reclamation, Climate Analytics Group, Lawrence Livermore National Laboratory, Santa Clara University, Scripps Institution of Oceanography, U.S. Army Corps of Engineers, U.S. Geological Survey, and the National Center for Atmospheric Research to develop the projected temperatures for Tulsa, Oklahoma. These models provided projections for both temperature and rainfall for the Tulsa area. These projected temperatures were compared to observed temperature data from the National Weather Service (NWS) office in Tulsa as shown in Figure 1. A comparison of the observed and projected rainfall is shown in Figure 2.

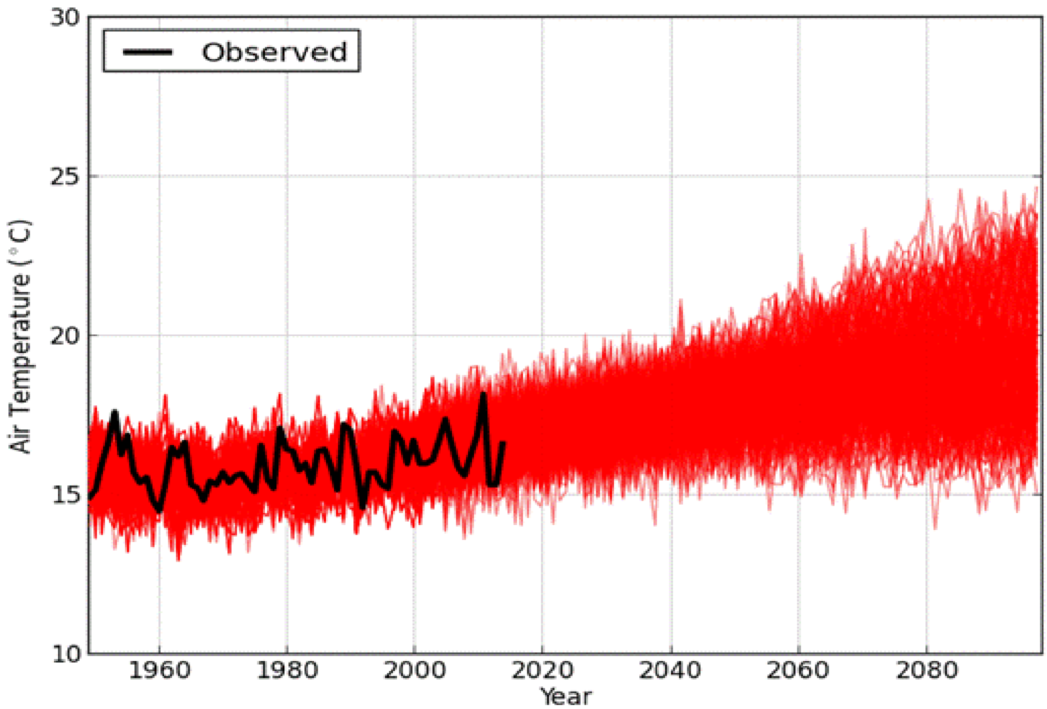


Figure 1. Observed and Projected Temperature for Tulsa, Oklahoma.

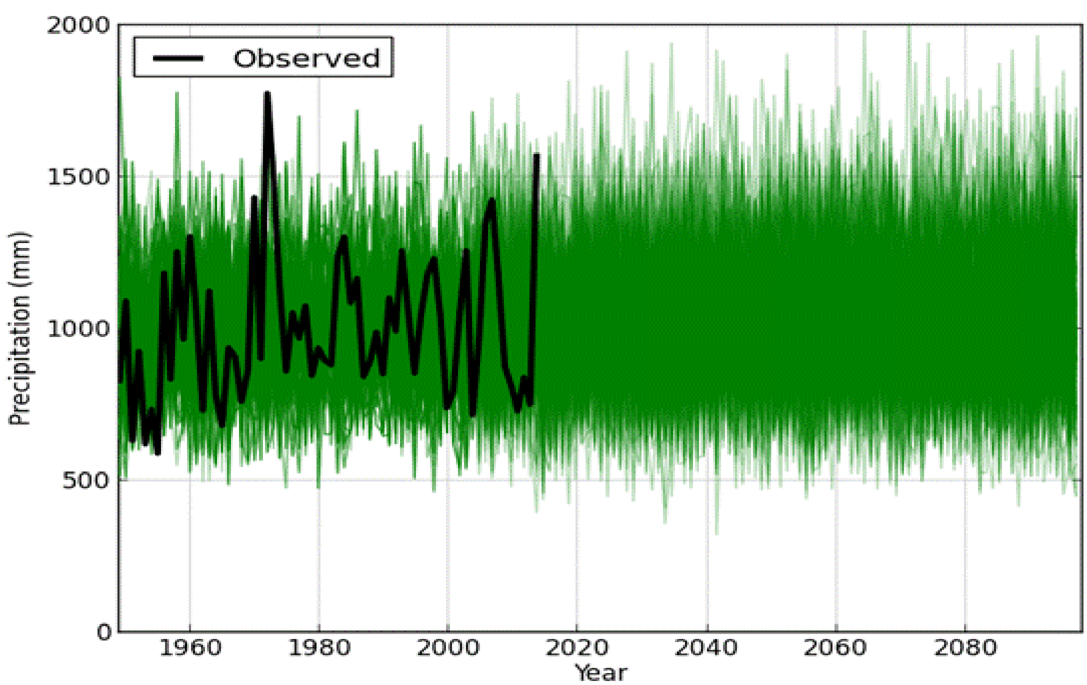


Figure 2. Observed and Projected Precipitation for Tulsa, Oklahoma.

Climate Hydrology Assessment
The USACE Climate Hydrology Assessment Tool 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 Climate Hydrology Assessment tool allows users to access data representing past (observed) changes, as well as potential future (projected) changes to relevant hydrologic inputs. 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 tool utilizes selected gage data located within the project area. For this project, the 4-digit HUC is 1111, the Lower Arkansas hydrologic subregion. The nearest gage location is the Arkansas River's Tulsa Gage, operated by the U.S. Geological Survey (USGS) in cooperation with the City of Tulsa, Oklahoma and the US Army Corps of Engineers. The name and number for this gage is USGS Gage 07164500 Arkansas River at Tulsa, OK. This gage has been continuously recording annual instantaneous peak flows since water year 1926. There was a historic peak recorded at this location in 1923. This gage has a 74,460 square mile drainage area, with about 62,811 square miles contributing. For this analysis, flow data from 1964-2015 was evaluated to represent the flow records following the construction of Keystone Dam. The reduced streamflow, as a result of the construction of Keystone Dam made it reasonable to only use data for the post construction period of record. Based on the proximity to the project area, and the flows being reflective of what is expected at the project site, the Tulsa gage data was evaluated for this qualitative assessment.

The observed annual peak streamflow for the Tulsa gage was evaluated using the Climate Hydrology Assessment tool. The peak streamflow measured at this gage is regulated flow released from Keystone Dam. A plot of the observed annual peak streamflow at the Tulsa gage are shown in Figure 3. The p-value for the annual peak instantaneous streamflow is 0.50, which is much greater than the typical threshold of 0.05 for statistical significance. There is no statistical trend for the annual peak instantaneous streamflow data.

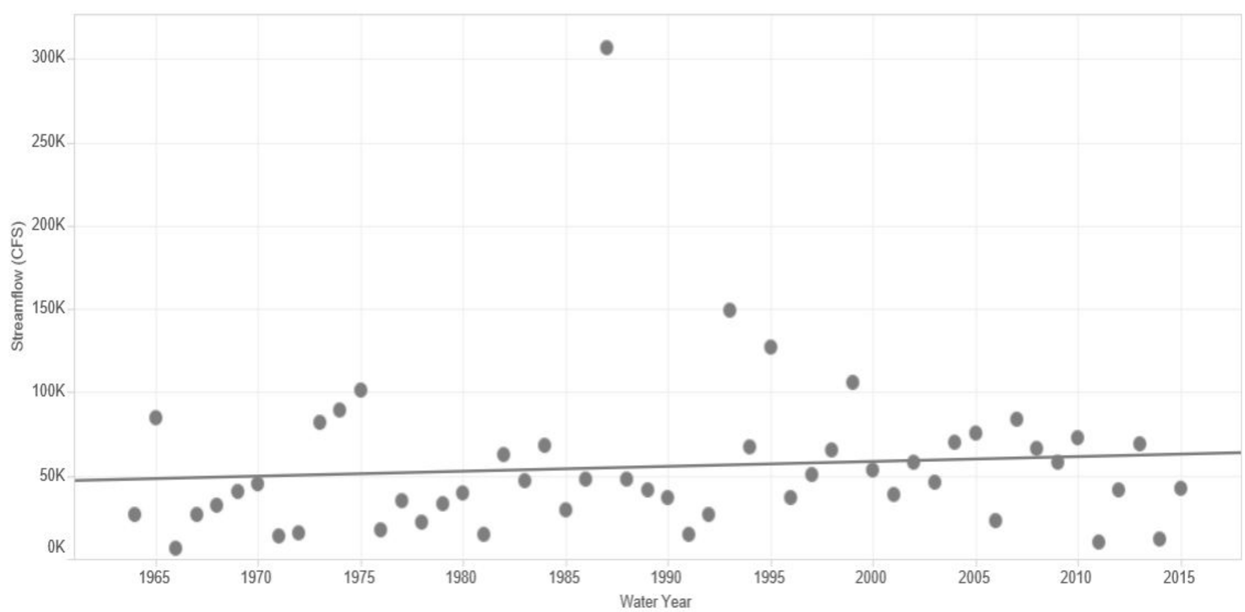


Figure 3. Annual Peak Instantaneous Streamflow at the Arkansas River Tulsa Gage.

The USACE Climate Hydrology Assessment Tool was also used to investigate potential future trends in streamflow for the Lower Arkansas watershed. Figure 4 displays the range of projected annual maximum monthly streamflow computed from 93 different climate changed hydrologic model runs for the period of 1950-2099. The projected streamflow computations are based on unregulated conditions and are computed at the HUC04 watershed scale. Climate changed hydrology output is generated using various greenhouse gas emission scenarios (RCPs) and global circulation models (GCM) to project precipitation and temperature data into the future. These meteorological outputs are spatially downscaled using the BCSD statistical method and then inputted in the U.S. Bureau of Reclamation's Variable Infiltration Capacity (VIC) precipitation-runoff model to generate a streamflow response. 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.

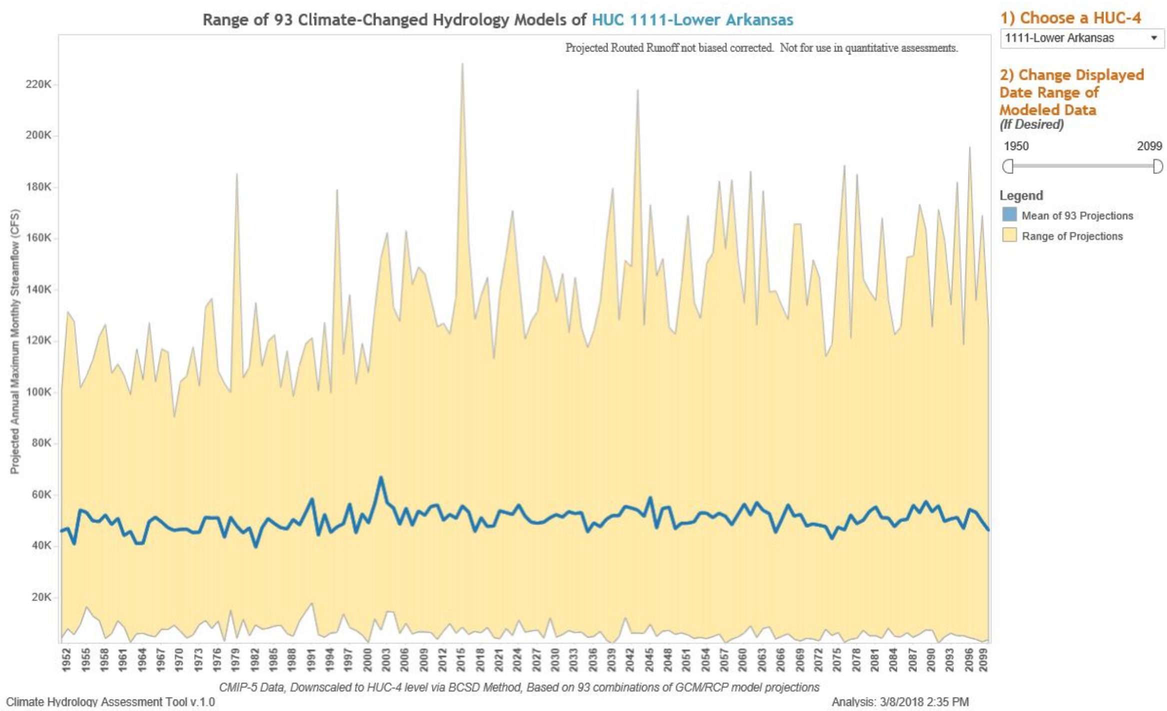


Figure 4. Range of Projected Unregulated Annual Maximum Monthly Streamflow among Ensemble of 93 Climate-Changed Hydrology Models, HUC 1111, the Lower Arkansas watershed.

The overall trend in the mean projected annual maximum monthly streamflow increases over time and is shown in Figure 5. There is a statistically significant increasing trend with a p-value of 0.0279 (less than the generally accepted threshold for significance of 0.05). This finding suggests that there is potential for annual maximum monthly streamflow to increase in the future in the study area, relative to the current conditions.

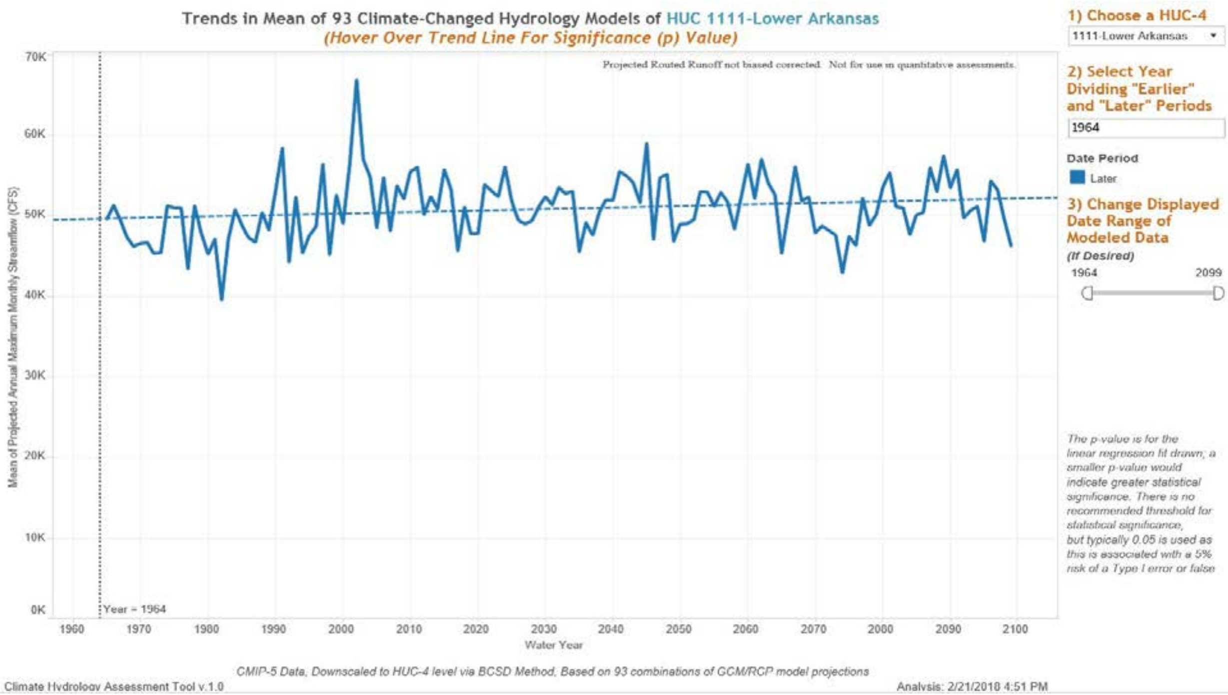


Figure 5. Mean Projected Annual Maximum Monthly Streamflow, HUC 1111, the Lower Arkansas watershed. Trendline Equation: Q = 18.4872*[Water Year] + 13248.5, p = 0.0279.

Since the Tulsa gage represents regulated flows, a cursory review of another HUC 11 based USGS gage station was completed using the Climate Hydrology Assessment Tool. USGS gage number 07160000 for the Cimarron River near Guthrie, Oklahoma was also analyzed as part of this study. The Guthrie gage is located in the Lower Cimarron watershed, HUC 1105. The Cimarron River is an unregulated tributary to the Arkansas River that reaches its confluence with the Arkansas River upstream of the Tulsa gage. There is 33 years (1983-2016) of continuous, observed streamflow data available at the Guthrie gage.

A plot of the observed annual peak streamflow at the Guthrie gage is shown in Figure 6. The p-value for the annual peak instantaneous streamflow is 0.26, so there is no statistical trend for the annual peak instantaneous streamflow data.

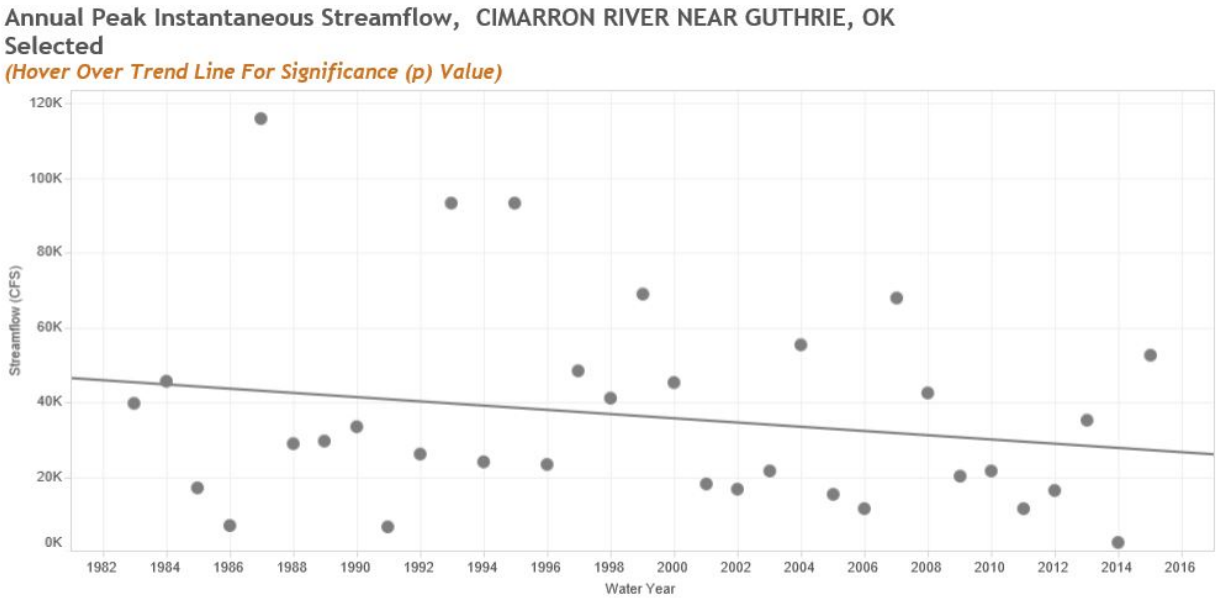


Figure 6. Annual Peak Instantaneous Streamflow at the Cimarron River near Guthrie, Oklahoma Gage.

Figure 7 displays the range of projected annual maximum monthly streamflow computed from 93 different climate changed hydrologic model runs for the period of 1950-2099, for HUC 1105, the Lower Cimmaron Subregion. The projected streamflow computations are based on unregulated conditions and are computed at the HUC04 watershed scale.

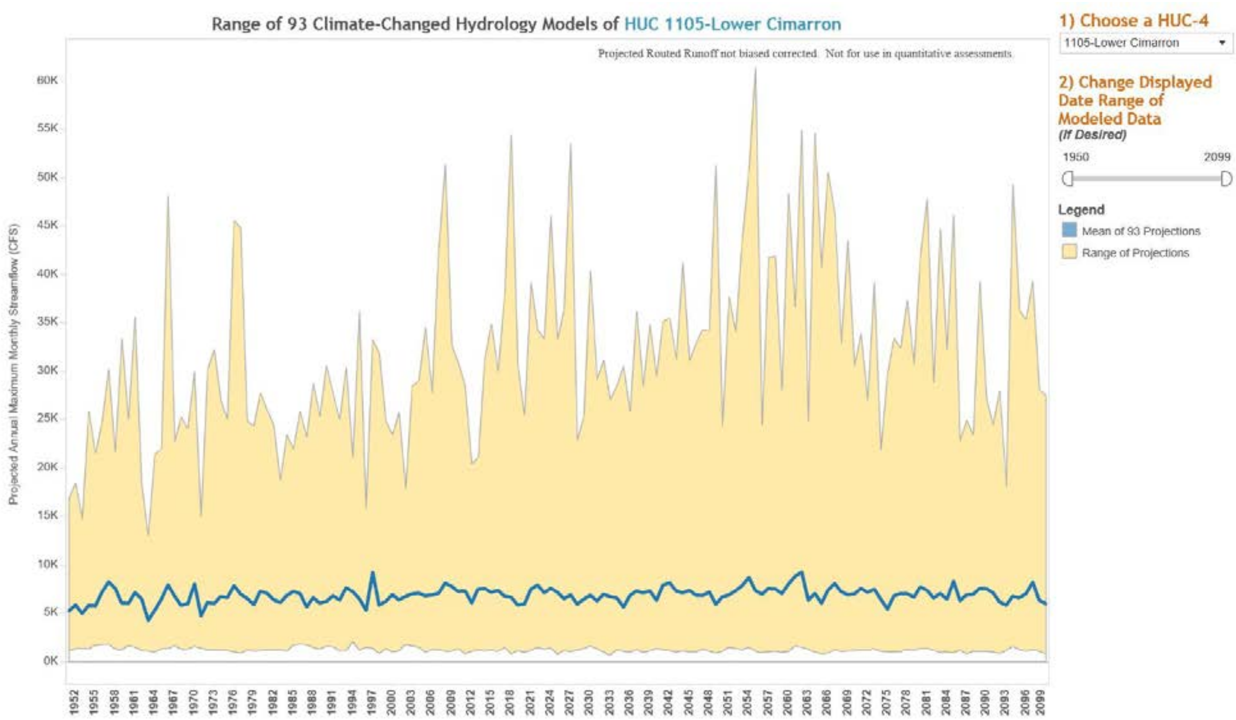


Figure 7. Range of Projected Unregulated Annual Maximum Monthly Streamflow among Ensemble of 93 Climate-Changed Hydrology Models, HUC 1105, the Lower Cimmaron Subregion.

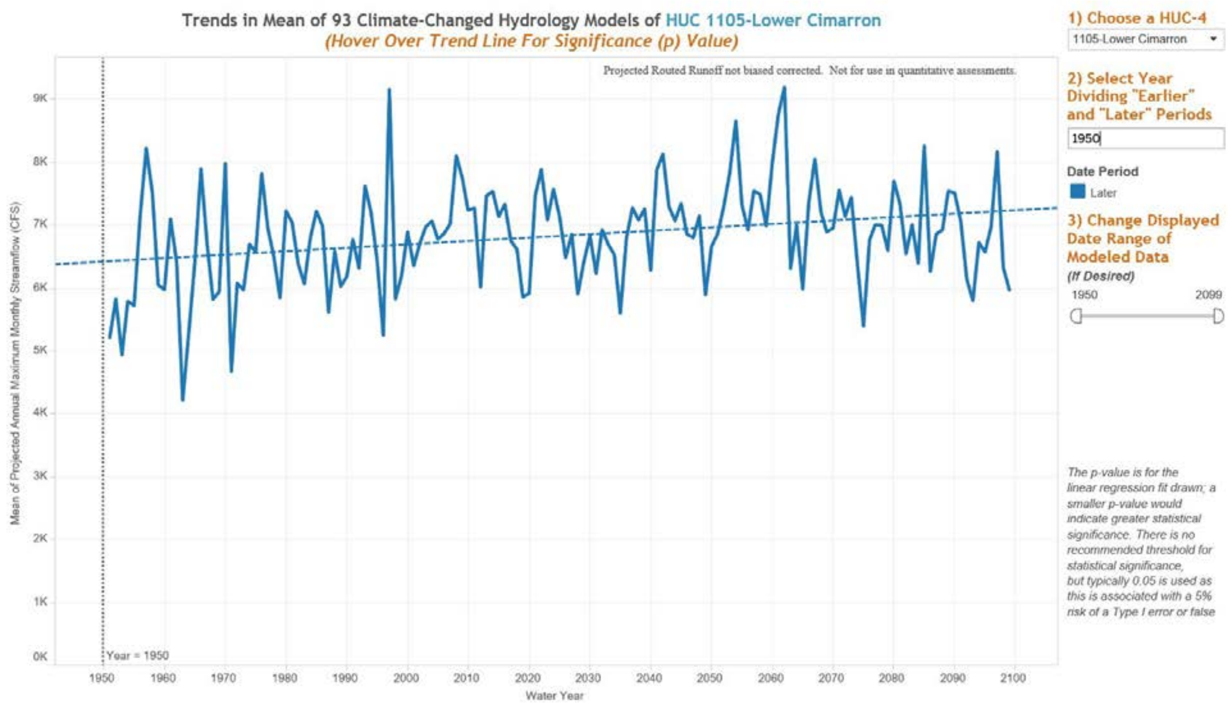


Figure 8. Mean Projected Annual Maximum Monthly Streamflow, HUC 1105, the Lower Cimarron Subregion. Trendline Equation: Q = 5.43991*[Water Year] – 4194.21, p = 0.000386.

Since the Cimarron is one of the main tributaries to the Arkansas River, the projected trends would likely be similar to the trends further downstream along the Arkansas River. The p-value is 0.000386, so there is a statistically significant trend of increasing maximum streamflow.

The USACE Nonstationarity Detection Tool was developed in conjunction with USACE Engineering Technical Letter (ETL) 1100-2-3, Guidance for Detection of Nonstationarities in Annual Maximum Discharges, to detect nonstationarities in maximum annual flow time series. This tool was also used to assess abrupt or slowly varying changes in observed peak flow data collected by the USGS gage located along the Arkansas River at Tulsa, OK for the period of record spanning 1964-2015; the time period following construction of Keystone Dam.

A series of twelve different nonstationarity detection tests were carried out on the peak annual discharge record collected at USGS gage 07164500 Arkansas River at Tulsa, OK using the USACE Nonstationarity Detection Tool. The tool did not detect nonstationarity using any of the statistical tests during the time period from 1964 to 2015, as shown in Figure 9. Default sensitivity parameters were applied for this evaluation. Similar to the Tulsa gage, no nonstationarity was detected for the Cimarron River gage near Guthrie, Oklahoma as shown in Figure 10. As expected, when the full period of record data is evaluated for the Tulsa gage, the tool detected a nonstationarity near the time when Keystone Dam was constructed, as shown in Figure 11. This non-stationarity is indicated by multiple tests targeting different statistical properties (mean and overall distribution). There is a significance decrease in the sample mean, resulting from the flood control operations of Keystone Dam.

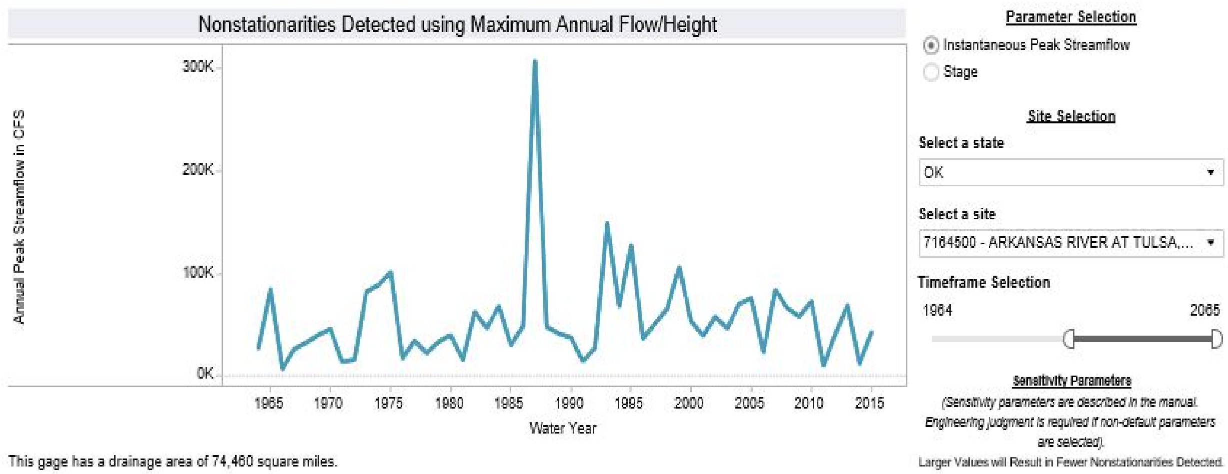


Figure 9. Nonstationarities detected using Maximum Annual Flow at the USGS Gage 07164500 Arkansas River at Tulsa, OK: Post-Dam Construction 1964-2015.

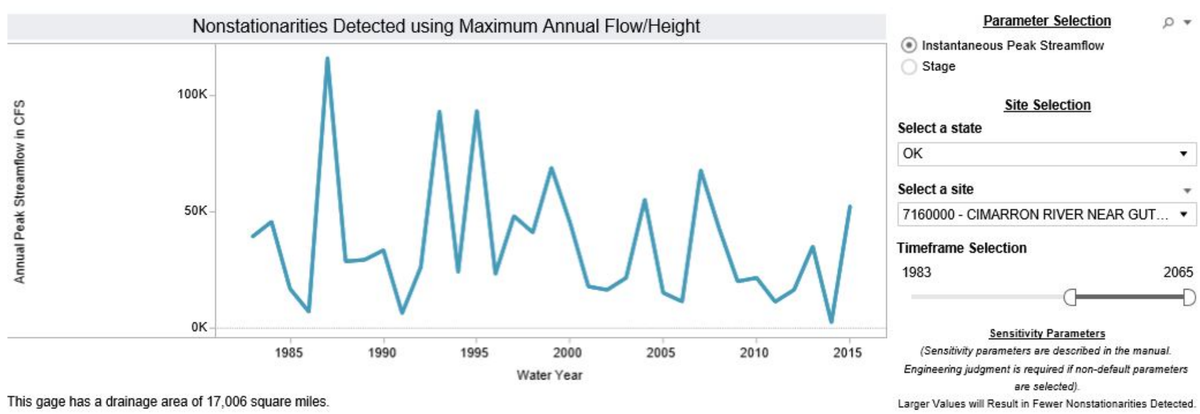


Figure 10. Nonstationarities detected using Maximum Annual Flow at the USGS Gage 07160000 Cimarron River near Guthrie, OK.

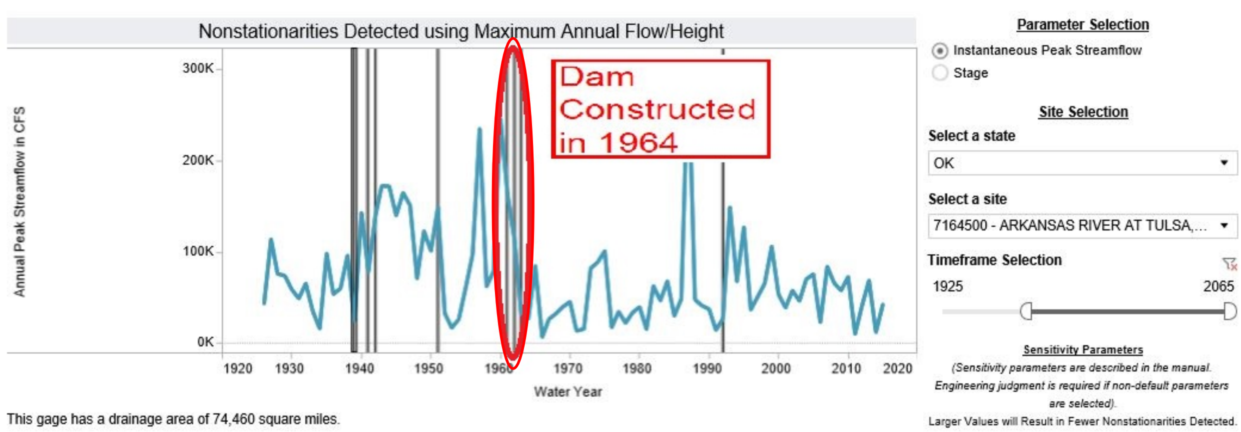
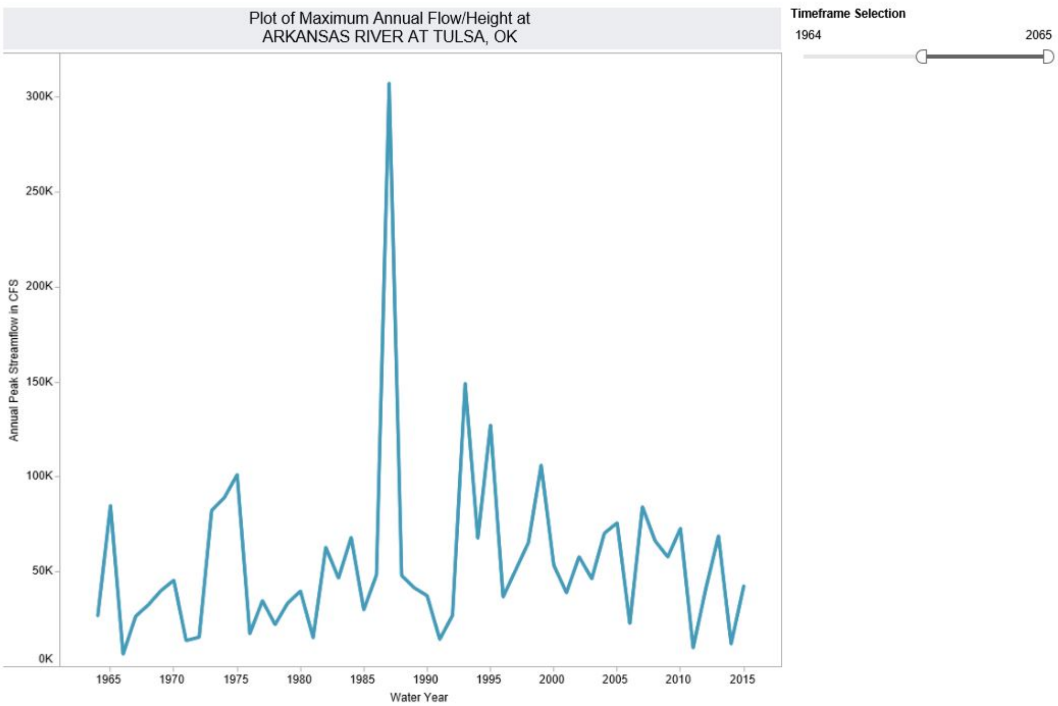


Figure 11. Nonstationarities detected using Maximum Annual Flow at the USGS Gage 07164500 Arkansas River at Tulsa, OK for the available, continuous period of record 1926-2015.

Based on the results of the monotonic trend analysis for maximum annual flow, this tool identifies no general trend as shown in Figures 12 and 13 for either the Tulsa (post construction of Keystone Dam, 1964-2015) or the Guthrie USGS gages, respectively.



Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.084.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.117.

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

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 12. Monotonic trend analysis for Maximum Annual Flow at the Arkansas River at Tulsa, Oklahoma USGS Gage.

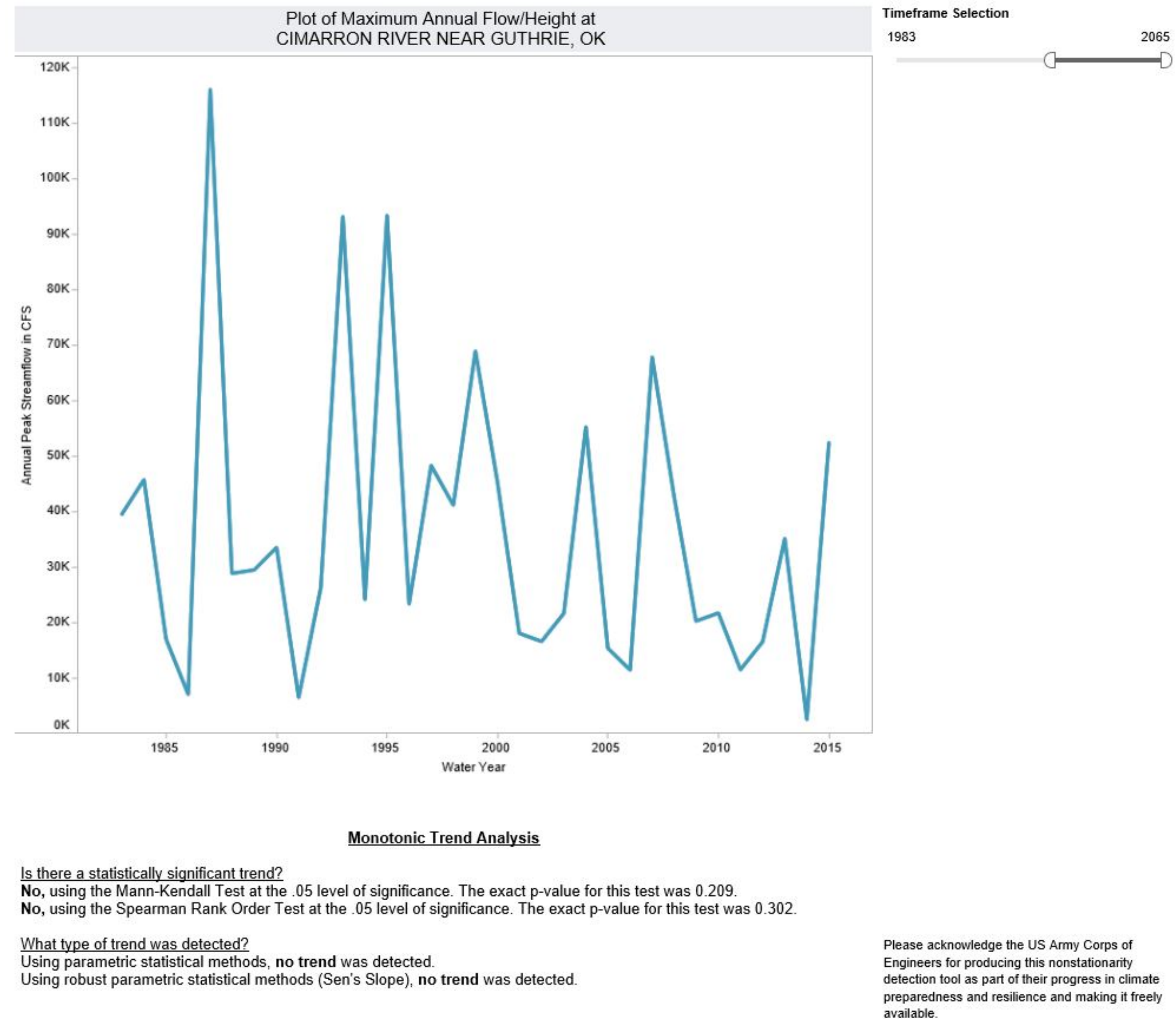


Figure 13. Monotonic trend analysis for Maximum Annual Flow at the Cimarron River at Guthrie, Oklahoma USGS Gage.

Vulnerability Assessment to Climate Change Impacts

The USACE Watershed Climate Vulnerability Assessment Tool was also used to compare the relative vulnerability of the HUC 1111, the Lower Arkansas watershed, to climate change to the other 201 HUC04 watersheds across the continental United States (CONUS). The tool facilitates a screening level, comparative assessment of how vulnerable a given HUC04 watershed is to the impacts of climate change. For this application, the tool is used to assess the vulnerability of the Lower Arkansas Watershed (HUC 1111) for the Corps' Ecosystem Restoration business line to projected climate change impacts relative to the effects that climate change might have on the Corps' ecosystem restoration business line in the other HUC04 watersheds in the CONUS. Assessments using this tool help to identify and characterize specific climate threats and particular sensitivities or vulnerabilities, at least in a relative sense, across regions and business lines. The 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 HUC-4 watersheds with the top 20% of WOWA scores are flagged as being vulnerable. Indicators considered within the WOWA score for Ecosystem Restoration include: change in sediment load, short-term variability in hydrology, runoff elasticity (ratio of streamflow runoff to precipitation), macroinvertebrate index (sum score of six metrics indicating biotic condition), two indicators of flood magnification (indicator of how much high flows are projected to change overtime), mean annual runoff, change in low runoff, and percent of at risk freshwater plant communities.

When assessing future risk projected by climate change, 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 HUC04 watershed is to the impacts of climate change for a given business line using climate hydrology based on a combination of projected climate outputs from the general circulation models (GCMs) and representative concentration pathway (RCPs) resulting in 100 traces per watershed per time period. 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. With the wet and dry traces, there is a combination of four epoch subset combinations, which provide for an indication of the variability/uncertainty in the outputs generated using the global circulation model based climate changed hydrology. Meteorological data projected by the GCMs is translated into runoff using the U.S Bureau of Reclamation's Variable Infiltration Capacity (VIC), Macroscale hydrologic model. For this assessment the default, National Standards Settings are used to carry out the vulnerability assessment.

Based on the results of the USACE Watershed Climate Vulnerability Assessment Tool presented in Figure 14, relative to the other 201 HUC04 watersheds in the CONUS, the Lower Arkansas watershed (HUC 1111) is relatively more vulnerable to the impacts of climate change on ecosystem restoration for the 2050 Dry epoch. The wet subsets tend to provide more water to the ecosystem, having a lesser impact on risk freshwater plants and macroinvertebrates - two of the major indicators in computing the vulnerability score.

For the Lower Arkansas watershed, the major drivers of the computed vulnerability score are, “At Risk Freshwater Plants”, “Runoff Elasticity”, and “the Macroinvertebrate Index”. Table 1 shows the vulnerability scores for the two 30 year epochs and the scores are relatively constant between both epochs and their wet and dry subsets of traces. Additionally, Table 2 shows the vulnerability score contributions of the different indicators for the 2050 epoch. The 2050 Dry epoch was the only epoch that was flagged as relatively vulnerable. As previously noted, At Risk Freshwater Plants has the largest contribution to the vulnerability score at about 36% of the total score, Runoff Elasticity contributes to 23% of the total score, and the Macroinvertebrate index contributes to 14% of the total score.

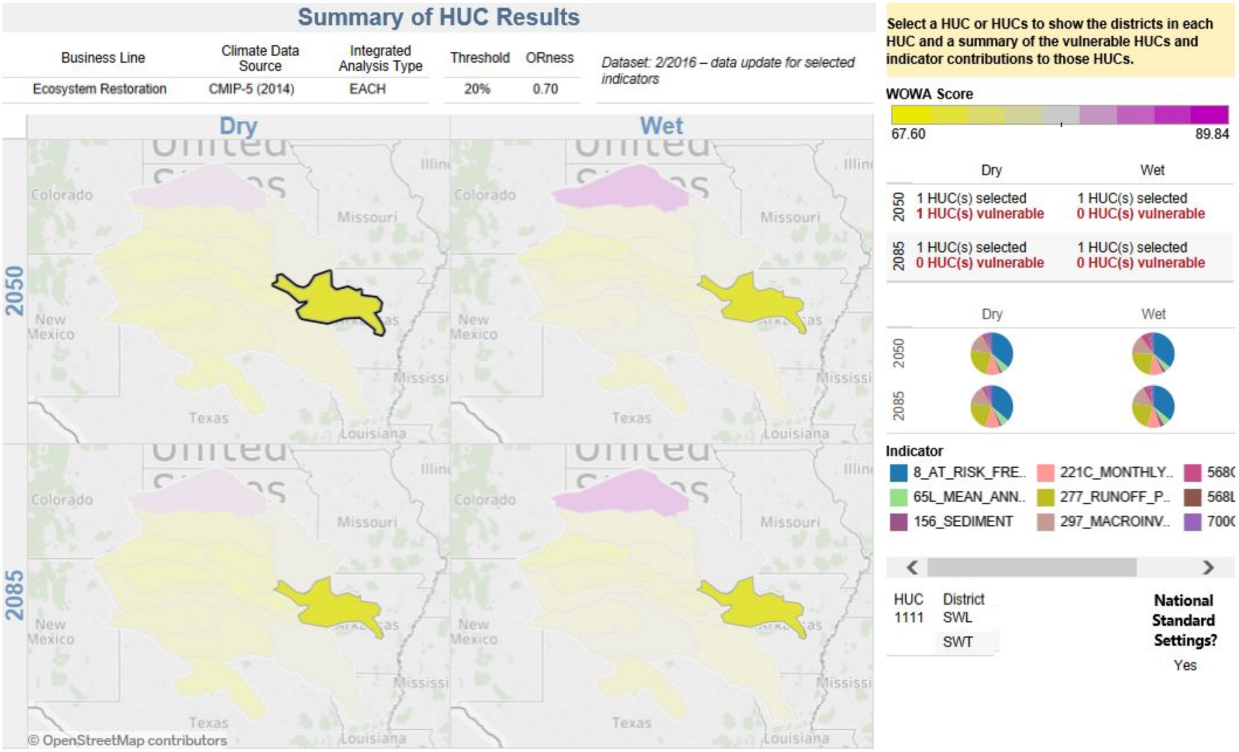


Figure 14. Projected Vulnerability for the Lower Arkansas (1111) with respect to Ecosystem Restoration

Table 1. Projected Vulnerability with respect to Ecosystem Restoration

HUC4 Watershed	Projected Vulnerability with Respect to Ecosystem Restoration			
	Ecosystem Reduction Vulnerability Score			
	2050 Dry	2050 Wet	2085 Dry	2085 Wet
Lower Arkansas (1111)	72.47	72.36	72.12	72.24

Table 2. Comparison of Different Indicators for the Lower Arkansas.

2050 Epoch	Lower Arkansas (1111)	
Indicator	Dry	Wet
	Contribution to WOWA Ecosystem Restoration Vulnerability Score	
Sediment (Change in Sediment Load / Current Load)	1.37	1.64
Short-term Variability in Hydrology (75th Percentile of Annual Ratios of StDev of Monthly Runoff)	7.75	7.62
Runoff Elasticity (% Change in Runoff / % Change in Precipitation)	16.76	16.21
Macroinvertebrate (Score of Six Metrics)	10.43	10.35
Flood Magnification - Cumulative	1.90	4.22
Flood Magnification - Local	0.80	0.94
Mean Annual Runoff	4.24	3.16
Change in Low Runoff	3.03	2.21
At Risk Freshwater Plants	26.19	26.01

In addition to ecosystem restoration, the Vulnerability Assessment Tool provides the capability to compute scores for several business lines associated with US Army Corps of Engineers projects. These include flood risk reduction, navigation, hydropower, recreation, water supply, regulatory, and emergency management business lines. The Arkansas River Corridor project is located downstream of Keystone Dam. Operations of Keystone Dam will not be altered with the implementation of this project. As a result, the only business line that is relevant to this project is that of ecosystem restoration.

Climate Change Impacts to the Project

One of the main purposes of the Arkansas River Ecosystem Restoration Project is to provide a minimum flow of 1,000 cfs in the Arkansas River downstream of Keystone Dam. The pool control structure, which would be located downstream of Keystone Dam is a key component in providing the available storage and release of this flow. The pool control structure will capture hydropower releases from Keystone Dam and release them at a rate of approximately 1,000 cfs to provide ecosystem benefits for the project area, preventing the river from going dry between hydropower releases. The operations of Keystone Dam will not be modified as a result of this ecosystem restoration project, so there would be no direct impacts to Keystone Dam operations.

The climate change analysis for this project identified that average temperatures are trending upward. As a result of peak cooling demand, hydropower releases are not anticipated to decrease as household energy requirements increase to cool homes in the warming climate. This continued demand for energy will maintain the need to generate hydropower, providing flow to the pool control structure.

Similar to the upward trend in average temperatures, the slightly upward trend in rainfall intensity will provide more runoff to the reservoir impounded by Keystone Dam. Much of this additional runoff will go to refilling the pool allocated to hydropower storage, providing the opportunity to generate hydropower more frequently. This additional runoff could help provide water for hydropower generation over dry periods and help to maintain the minimum release rate of 1,000 cfs and maintaining refuge pools since the number of consecutive dry days is projected to increase.

Increased rainfall intensity may increase the frequency of flood control releases, which will provide opportunities to lower the full height gates at the pool control structure to the river channel elevation and allow downstream sediment transport and open river fish passage conditions. This condition may help remove undesirable vegetation encroaching on tern islands.

Without the project, conditions in the Arkansas River corridor downstream of Keystone Dam, which is subjected to drying cycles between hydropower releases, would see the available refuge pools dry up more quickly as a result of the increasing temperatures. These refuge pools are where small fish and macroinvertebrates seek shelter and play a major role in the ecosystem. The project also includes construction of rock riffle structure that will be used to develop a wetland area downstream of the pool control structure. The project will provide some resiliency to the ecosystem that will allow it to thrive even with the impacts of the projected climate changes. With a minimum flow of 1,000 cfs, these refuge areas remain viable habitat locations.

Based on trend analysis and an assessment of the nonstationarity assumption, observed streamflow data is not indicating that peak flows in the Lower Arkansas River have been significantly impacted by climate change to date. However, based on projected trends in climate changed hydrology and a review of relevant literature, there is some evidence that streamflow and precipitation may increase in Lower Arkansas River Basin in the future. With temperatures in the Lower Arkansas River Basin likely to increase, thus presenting a higher hydropower demand and placing additional stress on already disturbed habitat structure, it is important to take into consideration what impact these factors may have on plant and animal communities in the study area. For some projected future scenarios, the Lower Arkansas River Basin is indicated as being highly vulnerable to the effects of climate change on ecosystems relative to the rest of the country. The proposed project will serve not only to remediate historic ecosystem degradation, but also to buffer the watershed from the effects that climate change could have on the watershed.

If left unaltered, the ecosystem will continue to have daily dry periods as a result of current hydropower operation. With the proposed downstream pool control structure in place, the channel will have a more continuous minimum 1,000 cfs flow, resulting in ecosystem improvements. Increasing temperatures as a result of climate change will result in drying out of the refuge pools more quickly, but with the project, the refuge areas remain wet, allowing the ecosystem to thrive.

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