Three Forks of Beargrass Creek Ecosystem Restoration
Appendix E
Qualitative Analysis of Climate Change Impacts

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1. Qualitative Assessment of Climate Change Impacts

1.1. Introduction and Background

This qualitative assessment of climate change impacts is required by U.S. Army Corps of Engineers (USACE, “the Corps”) Engineering and Construction Bulletin (ECB) 2018-14, “Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects.” This assessment documents the qualitative effects of climate change on the hydrology in the region. The ECB 2018-14 analysis is targeted at identifying potential impacts and risks to the Three Forks of the Beargrass Creek Ecosystem Restoration (BGCER) Study from climate change.

USACE projects, programs, missions, and operations have generally proven to be robust enough to accommodate the range of natural climate variability over their operating life spans. However, recent scientific evidence shows that in some places and for some impacts relevant to USACE operations, climate change is shifting the baseline about which that natural climate variability occurs and may be changing the range of that variability as well. This is relevant to USACE because the assumptions of stationary climate conditions and a fixed range of natural variability, as captured in the historic hydrologic record may no longer apply. Consequently, historic hydrologic records may no longer be appropriately applied to carry out hydrologic assessments for flood risk management in watersheds such as the Ohio River Basin.

1.1.1. Beargrass Creek Ecosystem Restoration Background

In the mid-1800s, there were massive changes to the Beargrass Creek watershed’s native plant community land cover, natural waterways, and depressions with continual changes to the present. The biodiversity that remains in limited open spaces within the watershed is considered to be adapted to degraded habitat and non-native plant communities. Vestiges or remnant natural areas that retain native plant and animal species diversity are very limited but present several protected natural areas or preserves.

Numerous Federal laws and executive orders establish National policy for and Federal interest in the protection, restoration, and conservation and management of environmental resources. They also endorse Federal efforts to advance environmental goals, and a number of these general statements declare it national policy that full consideration be given to the opportunities which projects afford to ecological resources. The purpose of this ecosystem restoration study is to identify, evaluate, and recommend measures, alternatives, and plans necessary to reduce the consequences of land use and drainage system changes that have impacted native habitats and species.

1.1.2. Watershed Description

The Beargrass Creek watershed is located in the Louisville Metropolitan area which encompasses all of the Jefferson County, Kentucky. It is the most populous county in the commonwealth with over ¾ million residents in Louisville Metro. As previously discussed, massive changes to the watershed’s native plant community land cover and to natural waterways and depressions occurred throughout the mid-1800s with continual change to the present. More recently and within the timeframe of our available rainfall data, much of the watershed was converted into residential land use during the 1950s. According to the US census population data, the 1950s represent a period of peak population and growth for the City of Louisville.

The Beargrass Creek system contains three major sub-watersheds: the South Fork (27 sq. miles), the Middle Fork (25 sq. miles), and the Muddy Fork (7 sq. miles). The three forks converge just east of downtown Louisville before discharging into the Ohio River. It generally runs north through Audubon Park and Germantown neighborhoods to its convergence with the Middle Fork near the Butchertown and Irish Hill neighborhoods. The Middle Fork begins in the Middletown area. It runs through St. Matthews and Seneca and Cherokee Park to its convergence with the South Fork. The combined South Fork and Middle Fork flow northward from this convergence through the Butchertown neighborhood. The Muddy Fork begins near Windy Hills in eastern Louisville. It flows along Interstate 71 to where it converges with the combined South and Middle Fork just before discharging into the Ohio River. The watershed is depicted in Figure 1-1 below.

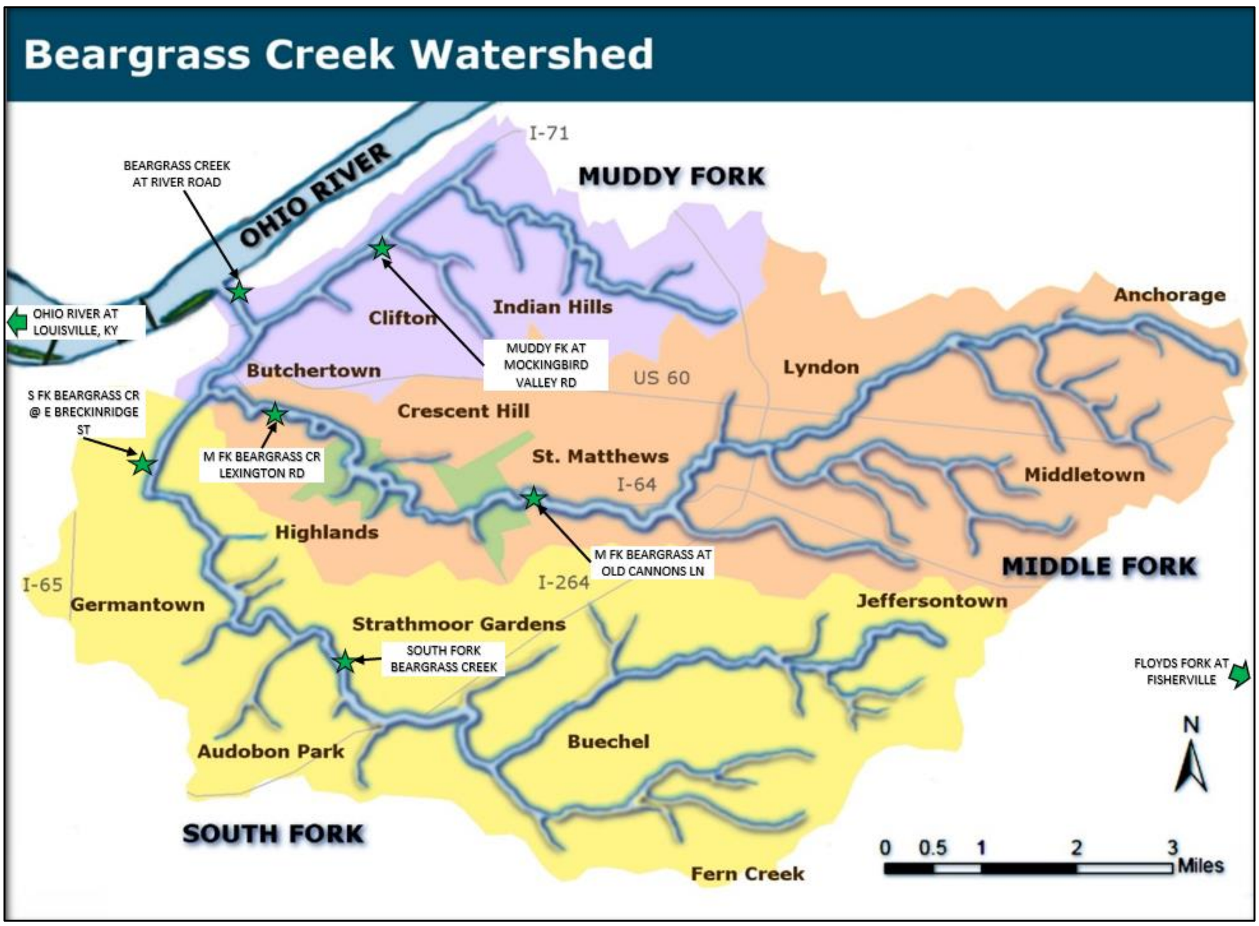

Figure 1-1: Beargrass Creek Watershed (South Fork watershed in yellow, Middle Fork watershed in red, Muddy Fork water shed in purple, Seneca and Cherokee Parks in green, gages – green stars)

The Beargrass Creek converges with the Ohio River near river mile 602, two miles upstream of McAlpine Locks and Dam. The Beargrass Creek watershed is located in the 4-digit Hydrologic Unit Code (HUC) 0514 Lower Ohio. The HUC-4 region is approximately 12,600 square miles and spans the Ohio River from Carrolton, KY to its confluence with the Mississippi River near Cairo, IL. Louisville is located approximately 60 miles downstream of Carrollton, KY. The watershed of the Ohio River at Louisville is roughly 91,000 square miles and covers portions of New York, Pennsylvania, Maryland, West Virginia, Virginia, North Carolina, Ohio, Indiana, and Kentucky.

Figure 1-2 displays a watershed map for the Ohio River Basin with the project area circled in red. Each pastel hue represents the portion of the Ohio River watershed under the authority of the various USACE districts. Yellow represents the Louisville District (LRL). There are 859 real-time stream gages located within the Ohio River watershed, 482 of which are located upstream of Louisville, KY. Many of the stream gages in the Ohio River watershed are affected by flood risk management projects.

Figure 1-2. Ohio River Watershed including USACE Districts and Political Boundaries (project area circled in red)

1.1.3. Regulation in the Study Area

The Beargrass Creek converges with the Ohio River near river mile 602. A series of navigation locks and dams (L&D) span the entire profile of the Ohio River from Olmsted L&D near the downstream confluence with the Mississippi River, upstream to Emsworth L&D near Pittsburgh, PA. 10 L&Ds are located within the Louisville District. L&D structures do not have an operationally significant impact on flood peaks within the Ohio River Basin. L&D structures are primarily operated for navigation as run-of-the-river structures. However, McAlpine L&D is located approximately 2 miles downstream of the confluence of the Beargrass Creek and is used to hold a normal pool on the Ohio River between elevations 419.7' and 420.5' NGVD29 which extends backwater up Beargrass Creek about 1.25 miles. During flood events on the Ohio River, Beargrass Creek and its main tributaries are protected from backwater flooding by a levee with gated structure and pump station, which was implemented by USACE in the 1950's. Muddy Fork is not protected from Ohio River flood events and regularly experiences backwater flooding annually.

Additionally, there are numerous flood risk management (FRM) reservoirs located within the Ohio River Basin watershed. Seventeen FRM Dams are located within Louisville District.

Table 1-1. LRL Flood Risk Management Reservoirs Upstream of Project Area
displays the eight Louisville District flood risk management reservoirs located on the Ohio River upstream of the project area, as well as their impoundment dates, drainage areas, storage capacities, proximity to the project area, and geospatial coordinates. These reservoirs, as well as others outside of Louisville District, work in coordination to reduce the flood risk on the Ohio River. These flood risk management reservoirs do not generally impact the sites evaluated within the Beargrass Creek, because most of the sites are upstream of any backwater impacts from the Ohio River. Primarily, the only areas of the Beargrass Creek watershed impact are at the confluence and the lower portions of Muddy Fork. Additional details regarding their impact can be found in the 2019 Louisville Levee System Semi-Quantitative Risk Assessment (SQRA).

Table 1-1. LRL Flood Risk Management Reservoirs Upstream of Project Area

Flood Risk Reservoir Name	Date of Impoundment	Drainage Area (sq. mi)	Flood Storage (acre-ft)	Distance from Project Area (mi)	Latitude	Longitude
West Fork	1952	29.5	985	88	39.26°	-84.50°
Buckhorn	1960	408	6,661	129	37.34°	-83.47°
Brookville	1974	379	20,100	86	39.44°	-85.00°
C.J. Brown	1974	82	3,800	151	39.95°	-83.75°
Cave Run	1974	826	147,300	109	38.12°	-83.53°
Carr Creek	1976	58.2	11,830	154	37.23°	-83.03°
Caesar Creek	1978	237	13,300	116	39.49°	-84.06°
W.M. Harsha	1978	342	18,760	91	39.02°	-84.15°

**Note: Reservoirs listed are within the Ohio River Watershed upstream of the Project Area. The only site on the Muddy Fork is located significantly upstream of the project. It is not anticipated that backwater effects from the Ohio River due to climate change will affect the Muddy Fork site.*

In addition to the large-scale FRM dams and L&Ds There are numerous detention and retention basins located within the Beargrass Creek watershed. These smaller retention basins are aimed at reducing runoff and have been constructed as a result of Jefferson County's stormwater ordinance requiring mitigation for development that would result in increased runoff and peak streamflow. These projects are distributed throughout the watershed and a vast majority of them were constructed starting in the late 1990's. Additional discussion regarding interior drainage structures can be found in the Appendix D –Hydrology and Hydraulics.

1.1.4. Streamflow Gages in the Study Area

In order to separate out the hydrologic influence of observed climate change from other significant anthropogenic impacts, such as upstream regulation and urbanization, an effort was made to identify relatively "pristine" gages. Pristine sites are largely free of the effects of watershed modification. These gages represent natural run-of-the-river morphologic conditions and have experienced relatively little development due to urbanization. Analyzing pristine flow records allows for greater insight into the impacts which may have been caused by climate change.

The pristine gage site chosen for this analysis was selected because of the lack of regulation and watershed modification within its contributing drainage area. The selected site also has a considerable record length and relatively large drainage areas. For this study, a stream gage located on Floyds Fork at Fisherville, KY was selected. This gage is located less than six miles to the southeast of the project area and is notably outside of the heavily urbanized I-265 corridor. The Floyds Fork watershed has not experienced the same rapid urban growth and development that has been observed within the project area. Land use in the drainage area above Floyds Fork is dominated by deciduous forest and agricultural. While this gage is not completely untouched by development or hydrologic alteration, it represents a relatively undeveloped area when contrasted with the surrounding region.

In addition to analyzing the relatively pristine gage, various other gages of interest were selected as hydrologically representative of the Beargrass Creek watershed. These gages are dispersed spatially throughout the watershed and capture data for the South Fork, Middle Fork, and Ohio River. These gages and relevant parameters such as drainage area and peak streamflow period of record (POR) are in
Table 1-2. Gages marked as "impacted" in the 6th column have experienced a high degree of commercial, residential, or industrial development within their watershed, as is common within Louisville. Additionally, these gages are impacted by a complex interaction of sub-surface storm drainage pipe network and numerous stormwater detention basins. It should also be noted that upstream reservoir operation on the Ohio River was assumed to be consistent and uniform across the Ohio River Reservoir System's period of operation. While there have been numerous deviations from the authorized water control plan, these changes were assumed to be relatively minor from a statistical and operational perspective. The 7th column in
Table 1-2 displays whether the watershed has been impacted by upstream regulation which includes large flood risk management reservoirs, as well as smaller stormwater mitigation retention and detention basins.

There are four additional gages in the Beargrass Creek watershed, but the period of record is not long enough in each gage for the data to be accurately analyzed for climate change effects. These gages are summarized in
Table 1-1-3 and are shown in Figure 1-1.

Table 1-2. Relevant Stream Gages used in Qualitative Analysis

USGS Gage Num.	USGS Site Name	Peak Streamflow POR	Peak Streamflow Observations	Drainage Area, mi^2	Impacted Land Use or morphology	Upstream Regulation Impacted
03294500	OHIO RIVER AT LOUISVILLE, KY	1832 - 2017	154	91,170	Impacted	Impacted
03292500	SOUTH FORK BEARGRASS CREEK AT LOUISVILLE, KY	1940 - 2019	76	17.2	Impacted	Impacted
03293000	M FK BEARGRASS CR AT OLD CANNONS LN	1943 - 2019	76	18.4	Impacted	Impacted
03298000	FLOYDS FORK AT FISHERVILLE, KY	1937 - 2019	77	138.0	Relatively Pristine	Pristine

Table 1-1-3. Stream Gage Data in the Beargrass Creek Watershed not used in Qualitative Analysis

USGS Gage Num.	USGS Site Name	Peak Streamflow POR	Peak Streamflow Observations	Drainage Area, mi^2	Impacted Land Use or morphology	Upstream Regulation Impacted
03293530	MUDDY FK AT MOCKINGBIRD VALLEY RD AT LOUISVILLE, KY	2005 – 2019	15	6.2	Impacted	Impacted
03293510	BEARGRASS CREEK AT RIVER ROAD AT LOUISVILLE, KY	2009 - 2019	11	60.1	Impacted	Impacted
03293500	M FK BEARGRASS CR AT LEXINGTON RD AT LOUISVILLE, KY	2004 – 2019	16	24.8	Impacted	Impacted
03292555	S FK BEARGRASS CR @ E BRECKINRIDGE ST @ LOUISVILLE	2018 - 2019	2	24.7	Impacted	Impacted

1.1.5. Seasonality of Flooding in the Study Area

Within the watershed, high water generally occurs within the winter and spring months. Table 1-4 displays data regarding the time of year in which annual peak flows occur and Figure 1-3 displays a histogram of their historic occurrence for the Ohio River at Louisville, Middle Fork of Beargrass Creek, and South Fork of Beargrass Creek. Flow recorded along the Ohio River at Louisville displays a strong seasonal trend of floods occurring between December and April, with more than 90% of annual peak floods occurring in these months based on 154 years of observed data. Beargrass Creek shows a less defined seasonal trend, but generally floods occur most frequently in the winter and spring, with some summertime flooding as well. Both gages on Beargrass Creek have an annual peak streamflow period of record of 76 years. Generally, the fall season represents the period of lowest flow within the project area. Floods within the tributaries to the Ohio River, such as Beargrass Creek, are largely generally driven by intense rainfall events, whereas flooding along the mainstem of the Ohio River is driven by large regional storms spread throughout the 91,170 mi^2 watershed. Snowmelt is not a large contributing factor to flood inducing runoff in the project area.

Table 1-4. Percent of Historic Annual Peak Flow Events Occurring in each Month

Month	Ohio River at Louisville	South Fork Beargrass Creek	Middle Fork Beargrass Creek
Jan	18.2%	6.6%	10.5%
Feb	23.4%	6.6%	11.8%
Mar	27.9%	13.2%	11.8%
Apr	14.9%	18.4%	10.5%
May	5.2%	14.5%	11.8%
Jun	1.9%	6.6%	6.6%
Jul	0.0%	7.9%	11.8%
Aug	0.6%	5.3%	7.9%
Sep	0.6%	6.6%	6.6%
Oct	0.0%	3.9%	1.3%
Nov	0.0%	2.6%	2.6%
Dec	7.1%	7.9%	6.6%

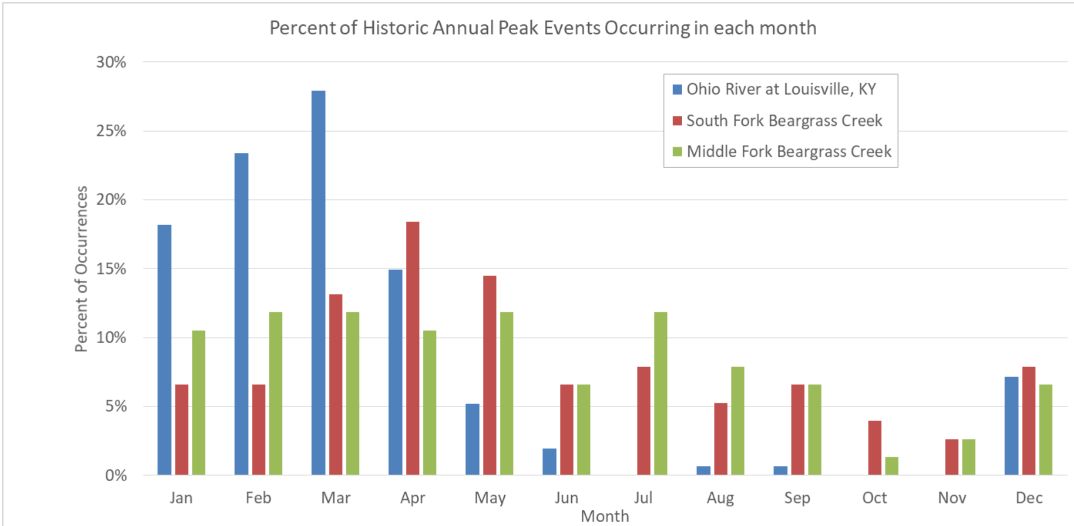

Figure 1-3. Percent of Historic Annual Peak Flow Events Occurring in each Month

1.1.6. Overall Climate within the Greater Louisville Area

Climate in Louisville, KY is humid subtropical with four distinct seasons. Spring-like conditions typically begin in mid-to-late March, summer from mid-to-late-May to late September, with fall in the October-November period. Seasonal extremes in both temperature and precipitation are not uncommon during early spring and late fall.

Records from the National Climatic Data Center for Louisville show an average annual rainfall of 44.91 inches and an average daily temperature of 58.2°F. These average values are based on a 29-year period from 1981 - 2010. Extremes from the entire period of record include a maximum observed temperature of 107°F in 1901, 1930, and 1936, as well as a minimum observed temperature of -22°F in 1994. Of the top ten wettest days in Louisville, KY one occurred in January, three in March, one in April, one in June, two in July, and two in October. The highest precipitation amount occurred on 1 March 1997, with 10.48 inches of rain in a single day. Figure 1-4 displays historic average monthly temperature and precipitation totals for the Bluegrass Region according to the Kentucky Climate Center for a period of record of 1895 – 2016.

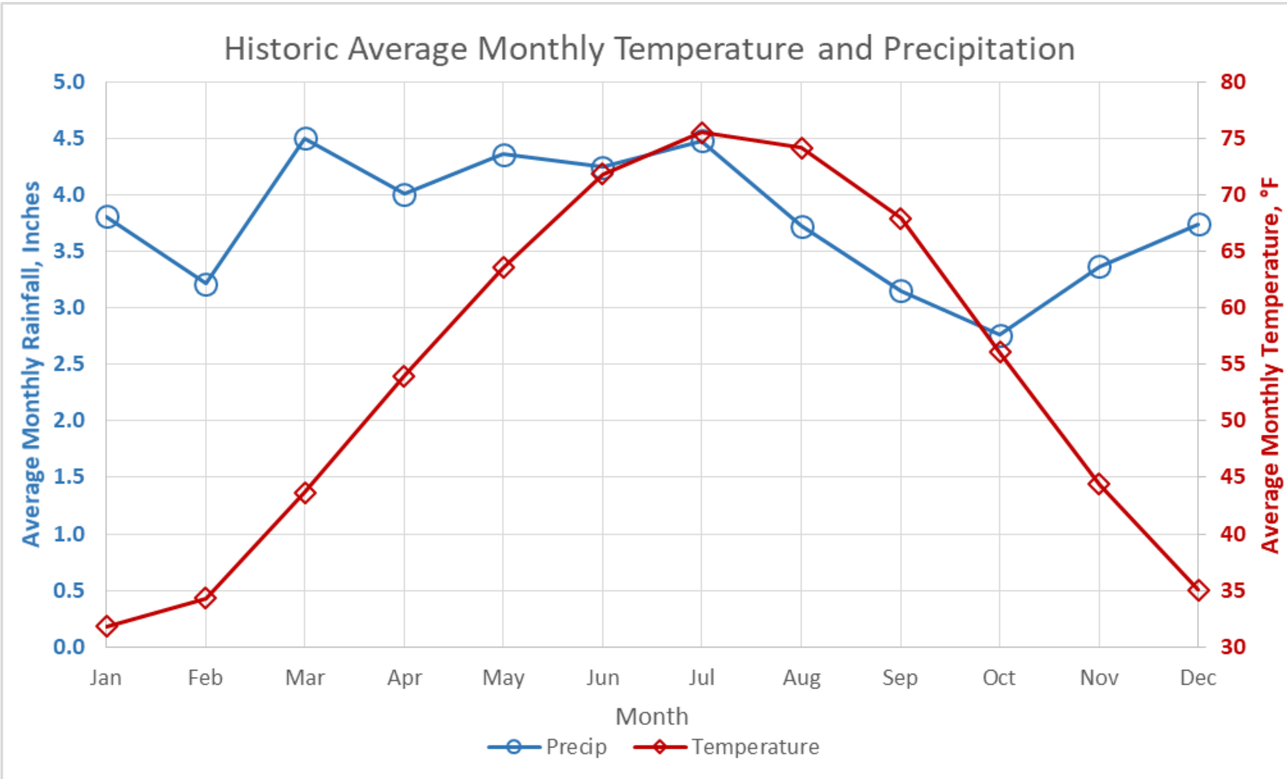

Figure 1-4. Historic Average Monthly Temperature and Precipitation

1.1.7. Observed Trends in Historic Temperature and Precipitation

An assessment of observed trends in historic temperature and precipitation was conducted using local climate data available from the National Weather Service (NWS) at the Louisville (KY) International Airport gage. The NWS publishes seasonal average temperature, precipitation, and snowfall beginning in 1872 until 2019. Seasons are defined within Table 1-5 below.

Temperature data analyzed includes seasonal mean and average annual temperatures. Precipitation data analyzed includes seasonal average, annual total, and maximum seasonal precipitation. This data, associated trends, and statistical significance values are displayed in Figure 1-5, Figure 1-6, and Figure 1-7.

A statistically significant, increasing trend was identified when examining spring mean seasonal temperatures. The annual change in temperature represented by this trend is relatively low, 0.011°F per year. Other seasons (winter, summer, and autumn) did not exhibit statistically significant trends at a 95% confidence level (p-value < 0.05), nor did the annual average temperature.

Trends in each of the four seasonal precipitation datasets are shown in the graphs included in Figure 1-6. Statistically significant increasing trends were detected in both spring (p-value = 0.0026) and autumn (p-value = 0.0322) precipitation datasets. Additionally, both the total annual precipitation and maximum seasonal precipitation (i.e. the precipitation value associated with the highest of the four seasons for each year) datasets showed statistically significant increasing trends at a 95% confidence level, see Figure 1-7. It should be noted that the magnitude of these precipitation trends is well below 0.1 inches per year, with the annual total precipitation regression trend line increasing 0.042 inches per year.

Table 1-5. Definition of Seasonal Time Period

Season	Months included
Winter	December – February
Spring	March – May
Summer	June – August
Autumn	September - November

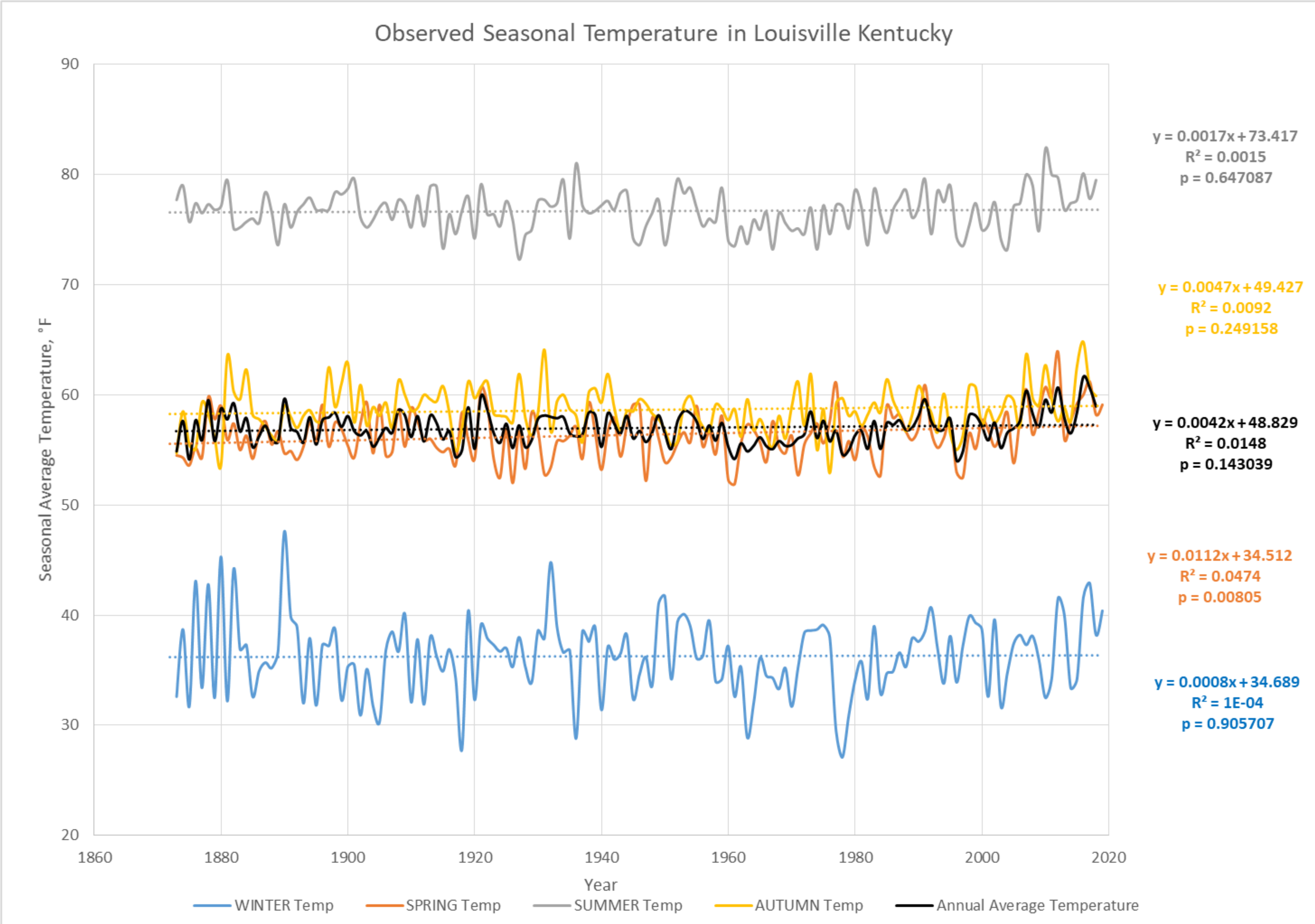

Figure 1-5. Trends in Observed Temperature

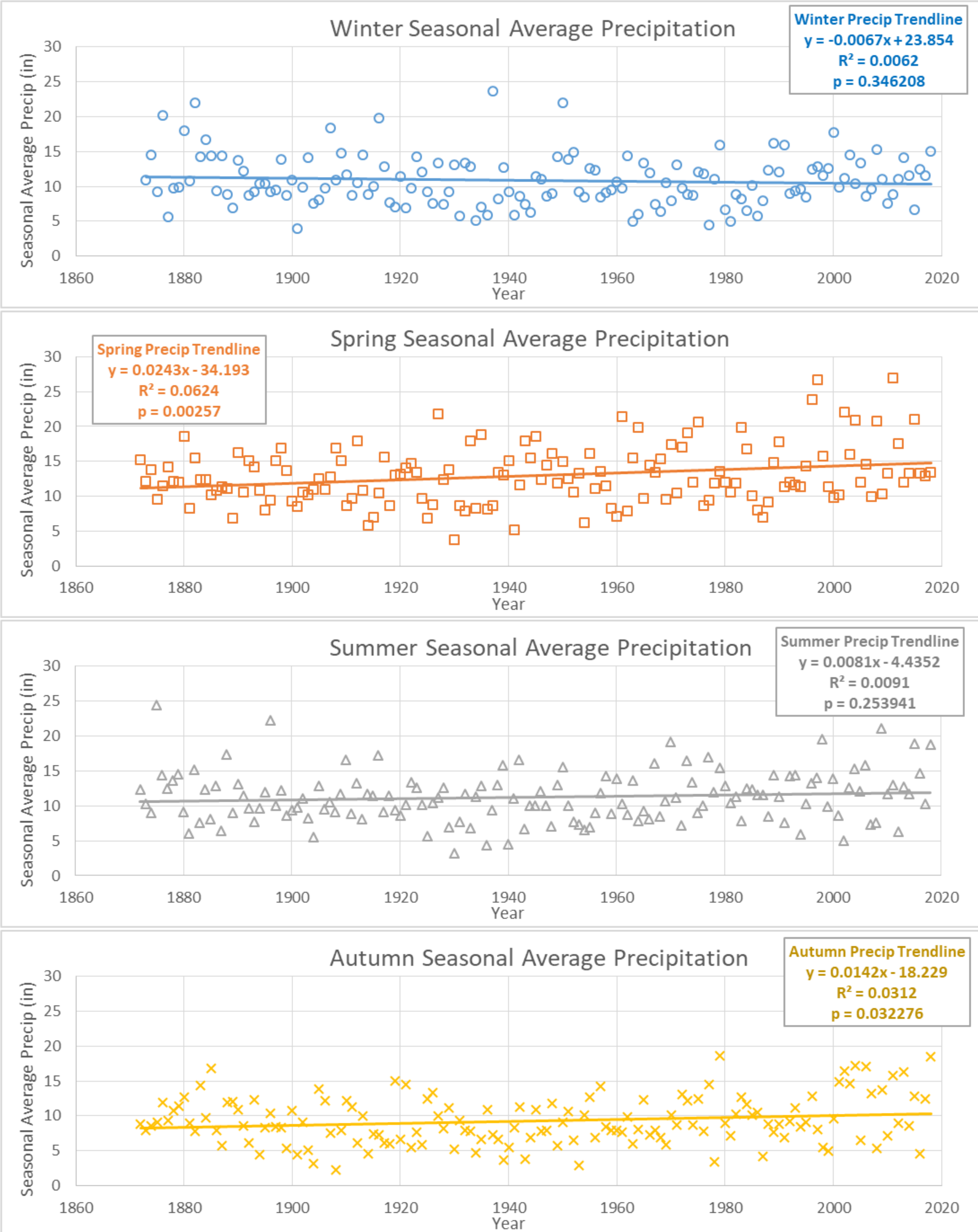

Figure 1-6. Trends in Seasonal Average Precipitation

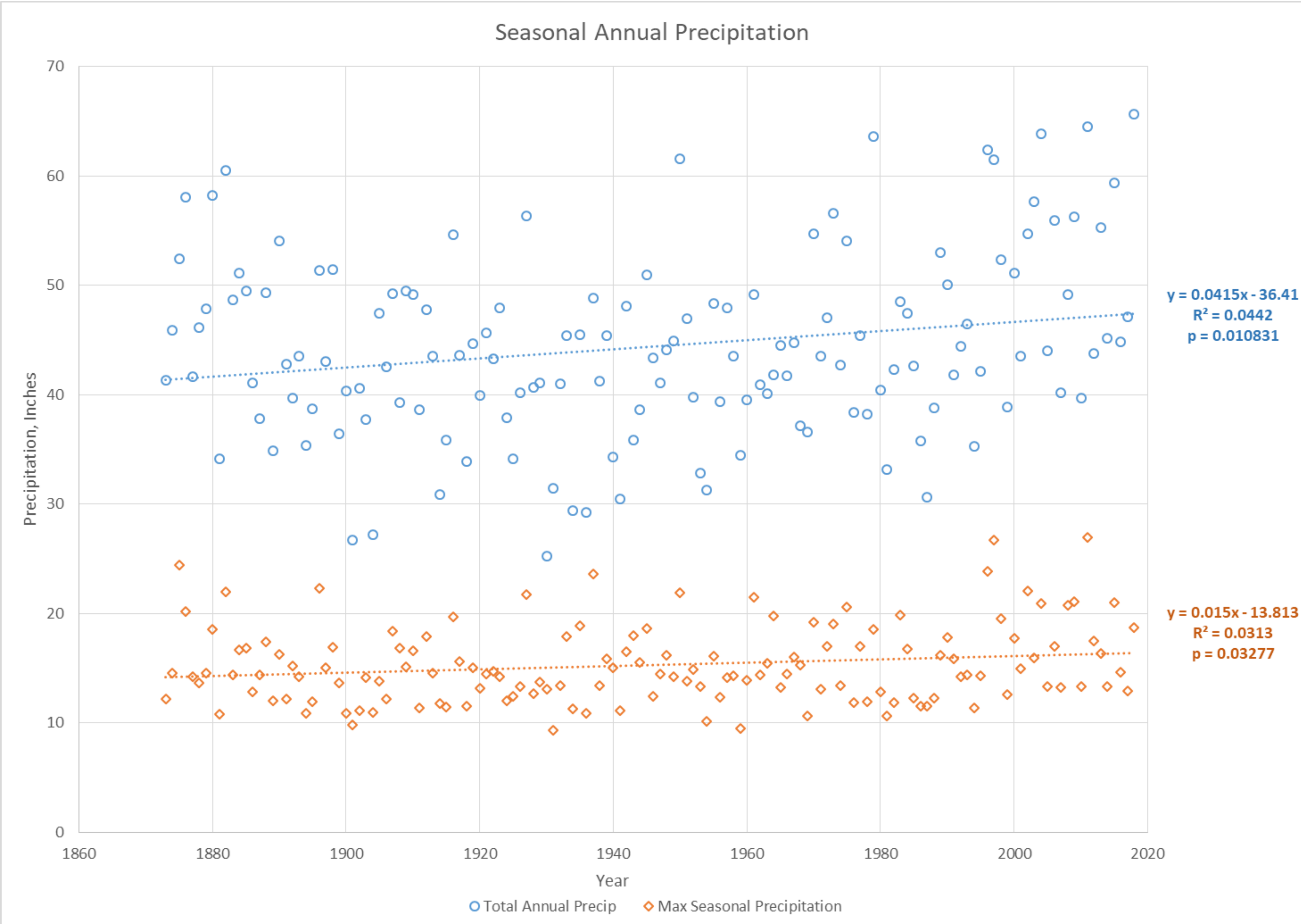

Figure 1-7. Trends in Total Annual and Maximum Seasonal Precipitation

1.2. Observed Trends in Current Climate and Climate Change

1.2.1. Literature Review

1.2.1.1. Recent US Climate Change and Hydrology Literature Syntheses

A September 2015 report conducted by the USACE Institute of Water Resources summarizes the available peer reviewed literature related to trends in both observed and projected hydrometeorological variables for the Ohio Region (HUC02 05), which includes the Ohio River and Beargrass Creek Project Area. Figure 1-8 below summarizes the findings from the literature synthesis and results are discussed in additional detail in the following paragraphs. It should be noted that this figure was produced in 2015 and substantial research has occurred since its publication. Were this figure to be updated, the number of relevant literature studies reviewed (n) would likely increase for all hydrologic variables.

Temperature. The 2015 USACE Literature Synthesis found that a majority of reports supported increasing trends in observed temperature for the Ohio Region. However, there is a general consensus that the Ohio Region spans a transition zone between a century-long warming trend of the north and a cooling trend of the south. There have been inconsistent findings about the geographic extent and seasonality of the warming and cooling zones.

Precipitation. According to the USACE Literature Synthesis: "A mild increasing trend in precipitation in the study region, in terms of both annual totals and occurrence of storm events, has been identified by multiple authors but a clear consensus is lacking. Results show increases in precipitation in some portions of the Ohio Region and show decreases in other portions. Recent reports indicate that rainfall may be concentrated more in larger events now than in the past."

Hydrology / Streamflow. The 2015 USACE Literature Synthesis found the studies reviewed were split on conclusions about streamflow trends in the Ohio Region for the past 60 years. However, more authors indicated an upward trend in streamflow for the region than did not.

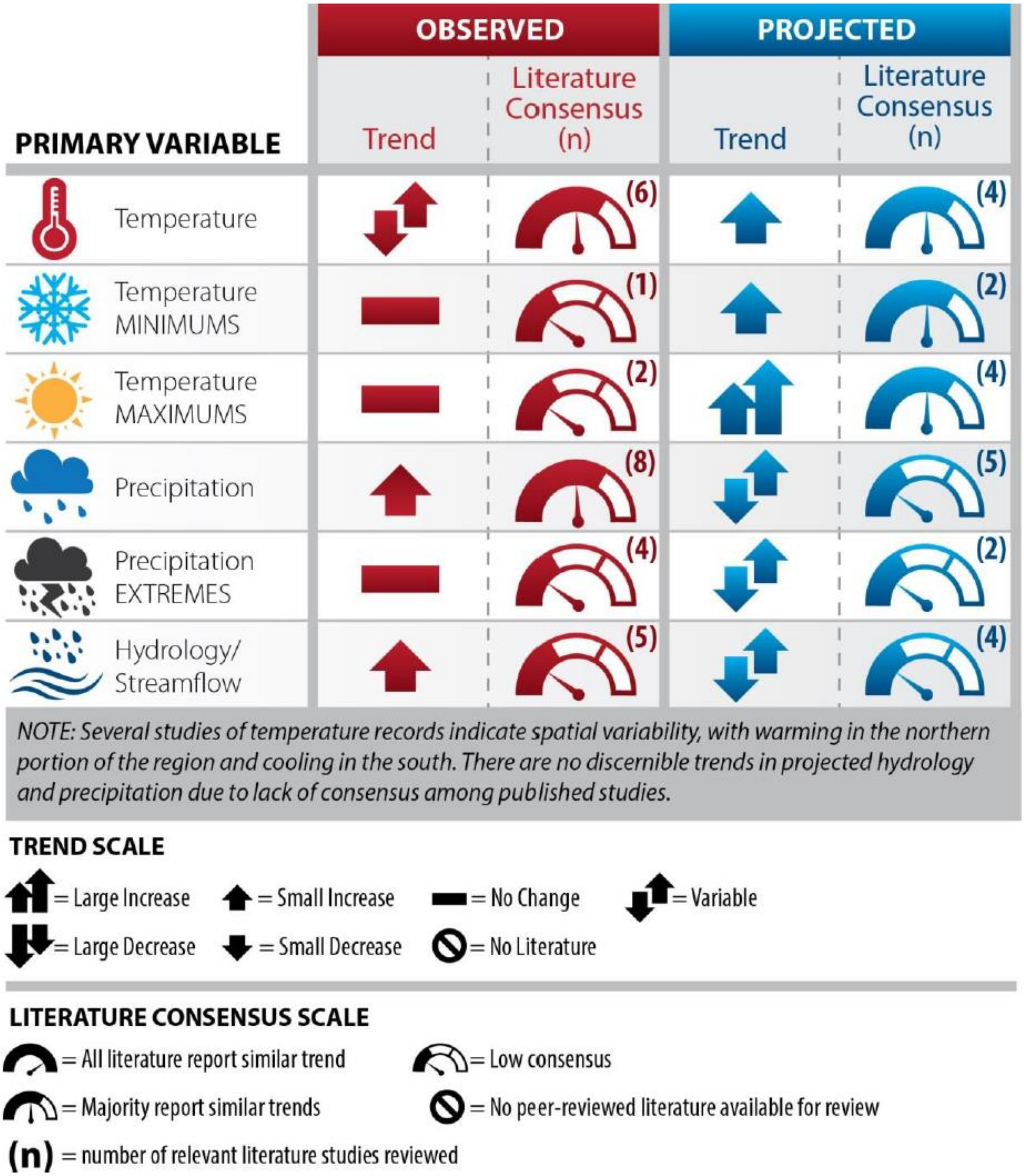

Figure 1-8. Summary of Findings from 2015 USACE Literature Synthesis, Ohio Region 05

1.2.1.2. Fourth National Climate Assessment

The Fourth National Climate Assessment (NCA4) Volume II, released in 2018, draws on science described in NCA4 Volume I and focuses on human welfare, societal, and environmental elements of climate change and variability for 10 regions and 18 national topics. Particular attention is paid to observed and projected risks, impacts, consideration of risk reduction, and implications under different mitigation pathways. Of interest to this qualitative analysis are the chapters regarding changing climate, water, and the Southeast region, which is fairly broad and includes the states of Kentucky, Tennessee, Arkansas, Louisiana, Mississippi, Alabama, Georgia, Florida, South Carolina, North Carolina, and Virginia. While Louisville is located within the Southeast region, it lies very near the border of the Midwest and Northeast regions as well.

Temperature. Nationally, annual average temperatures have increased over the continental U.S. by 1.2°F from 1986-2015 and 1.8°F relative to the beginning of the last century. Figure 1-9, adapted from NCA4, displays observed changes in temperature for the period from 1986 – 2016, as compared with the historic average from the period of 1901 – 1960 (for the continental U.S.). Note that the vicinity of the project area has experienced warming of 0- to 1-degree Fahrenheit. The magnitude of trends previously discussed and shown in Figure 1-5 (~0.3°F increase over the same period of time) closely matches the figure from the NCA4. The approximate study area is circled in red in the following figures.

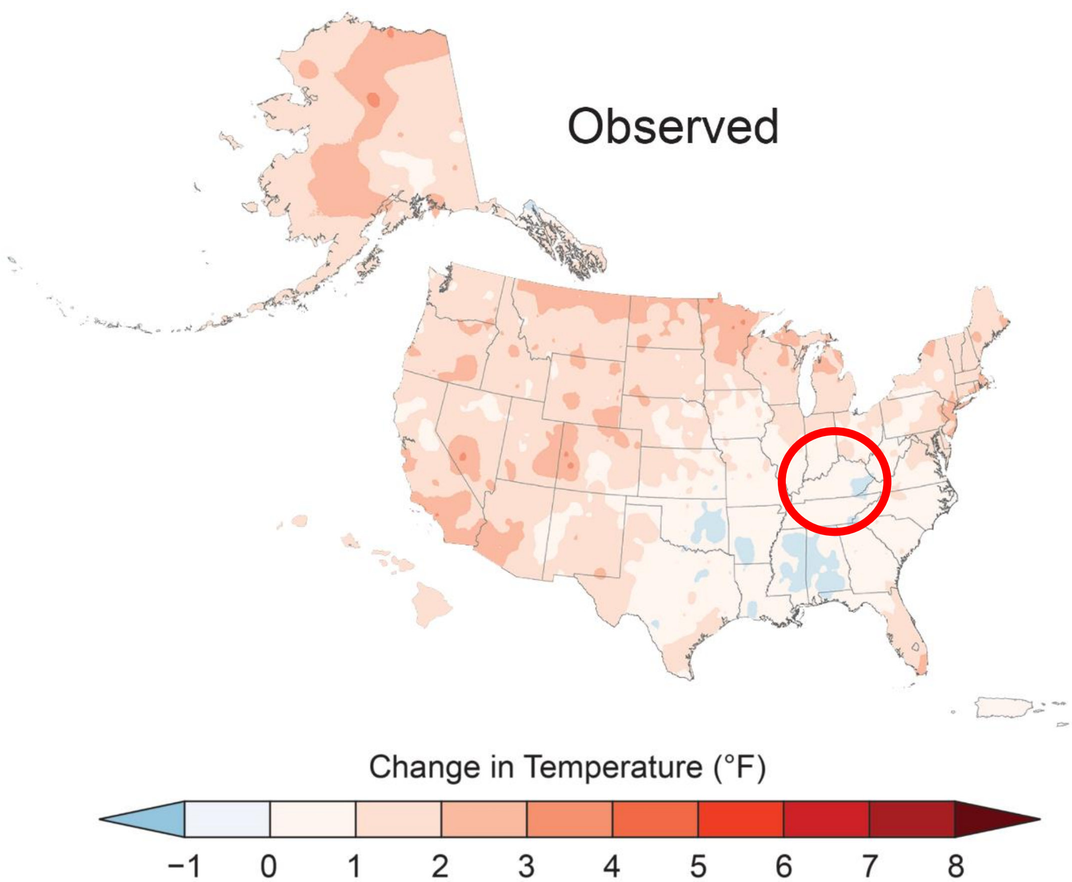

Figure 1-9. Observed changes in Temperature

Precipitation. Annual Precipitation since the beginning of the last century has increased across most of the northern and eastern U.S, whereas decreases have been observed across much of the southern and western U.S. There is much more regional variation in observed precipitation change as compared with observed temperature change, as the influence of temperature on precipitation varies greatly based upon terrain, elevation, and proximity to moisture sources. Figure 1-10 displays the percent change in annual precipitation for the period of 1986 – 2015, as compared with the historic baseline of 1901 – 1960. Looking more closely at the East-Central U.S., the Beargrass Creek watershed area has observed an increase in annual precipitation between 5% and 15%. The magnitude of trends previously discussed and shown in Figure 1-7 (~6.6% increase over the same period of time) closely matches the figure from the NCA4.

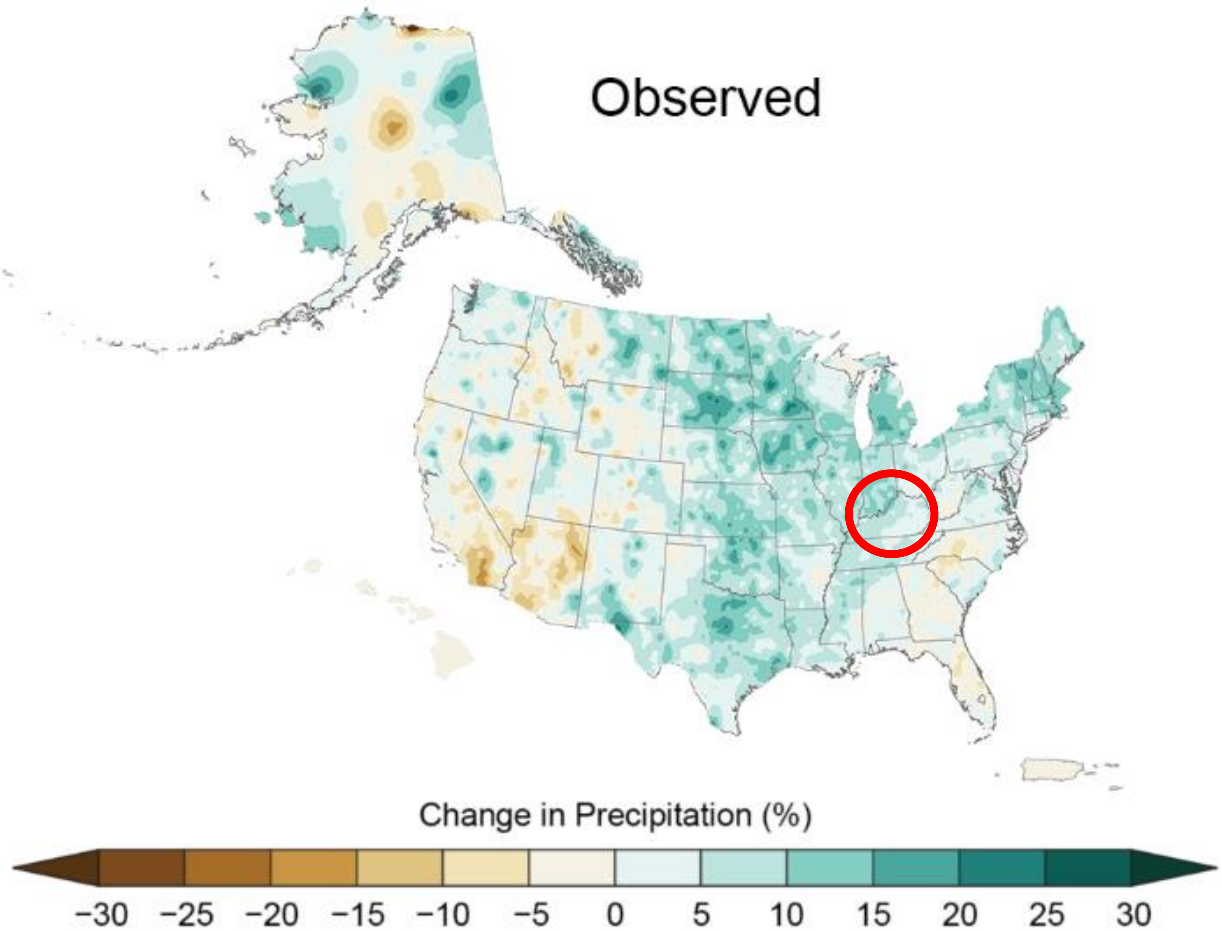

Figure 1-10. Observed changes in Precipitation

Additionally, there have been observed increases in the frequency and intensity of heavy precipitation events throughout much of the U.S. Figure 1-11 displays the percent increase in the amount of precipitation falling during the heaviest 1% of events (99^{th} percentile of the distribution). The left map within Figure 1-11 displays the percent difference between the 1901-1960 historic baseline versus the 1986-2016 period, whereas the right map displays linear trend changes over the period between 1958 and 2016. Note that in both the left and the right side of the figure, the project area has experienced a moderate increase in the precipitation falling during extreme events. This indicates that extreme events have been becoming increasingly intense over the past decades. The observed trends in heavy precipitation are supported by well-established physical relationships between temperature and humidity.

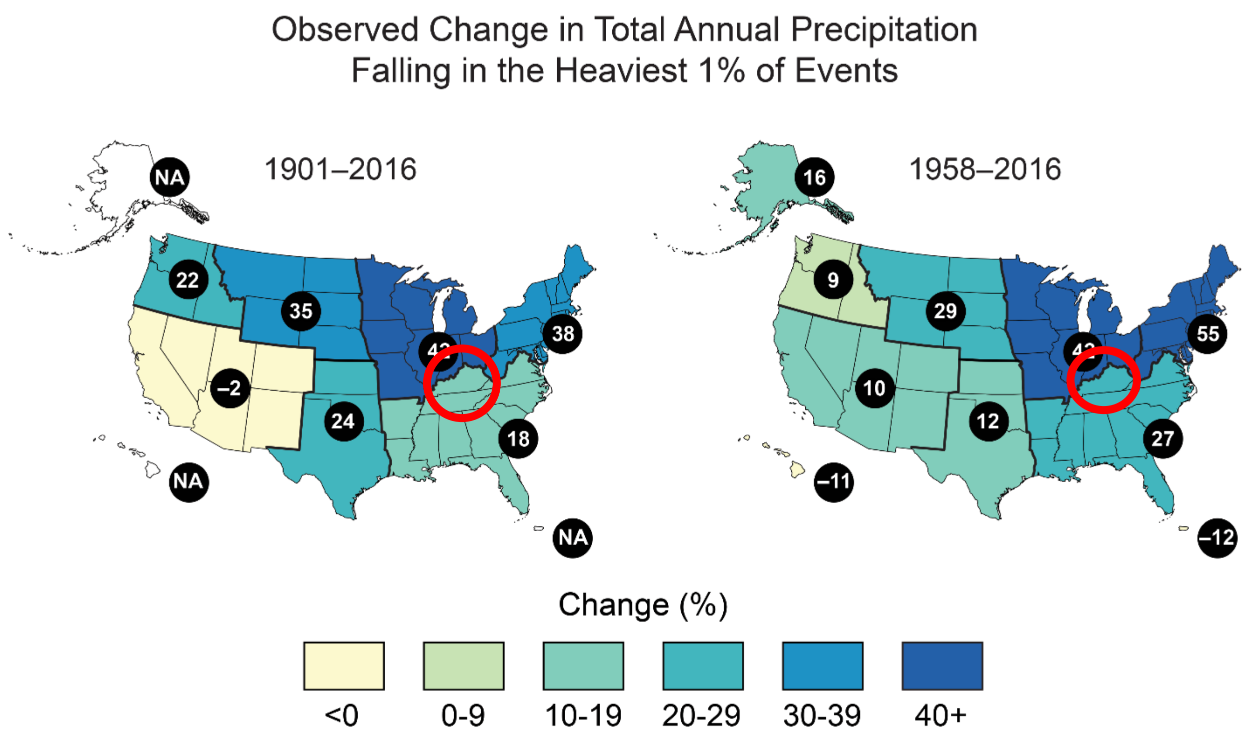

Figure 1-11. Observed percent change in the amount of precipitation falling during the heaviest 1% of events

1.2.1.3. Analysis of Historical Precipitation Intensity-Duration Frequency for Jefferson County, KY

In 2015, the Louisville Metropolitan Sewer District (MSD), using CH2M Hill as consultants, performed a study of historical precipitation trends within Louisville and recent changes to precipitation intensity-duration frequency (IDF) curves. This study utilized precipitation data from the National Weather Service (NWS) and MSD's climate stations to update IDF curves. They utilized the standard L-moment statistical techniques to generate these frequency curves from observed precipitation data. Additionally, the study examined trends in observed precipitation data with a specific emphasis on large and intense storm events.

Regarding the observed trends in precipitation, the study utilized data from the start of the station's period of record until 2014 and found that long term increasing trends were present in annual precipitation data on the 3 rain gages analyzed: Louisville Upper, Louisville WSO Airport, and Shepherdsville KY. Two of these trends were found to be statistically significant at a 90% confidence level, but the Louisville Upper gage was not. These findings are very similar to those discussed above in section 1.1.7 above and the total annual precipitation dataset displayed in Figure 1-7.

In addition to analyzing total annual precipitation, the study authors looked at trends in daily rainfall datasets and precipitation accumulation over a certain threshold. Daily rainfall datasets were analyzed using the annual maximum daily precipitation. Increasing trends were found for the annual maximum daily precipitation for all 3 gages, two of which showed statistical significance at a 90% confidence level, but the Louisville WSO Airport gage did not.

1.2.2. Climate Hydrology Assessment

The Climate Hydrology Assessment Tool (CHAT) developed by USACE and was utilized to examine trends in observed annual peak streamflow for the various gage locations shown in
Table 1-2. The CHAT tool is used to fit a linear regression to the peak streamflow data in addition to providing a p-value indicating the statistical significance of a given trend. Many of the gages selected for CHAT analysis have been heavily impacted by regulation and urban development over different periods of time. For gages where the observed period of record includes the effects of regulation, the annual peak streamflow dataset cannot be considered homogeneous and it is difficult to draw conclusions based upon the trends identified within these datasets. In addition to assessing the entire period of record at regulated gage sites, subsets of data prior to and after regulation were also analyzed.

The gage on the Ohio River at Louisville is impacted by reservoir regulation. Peak annual flow for this gage is available on a continuous basis from 1858 until 2014 in the CHAT. The annual peak data from 1858 – 1938 represents a pre-regulation dataset as no reservoirs were constructed upstream of the gage and large-scale levee construction did not start until after the flood of 1937. Many of the navigation L&D projects were built before this, but their run-of-the-river nature has a negligible impact on annual peak flows. The time period of 1937 – 1978 represents an era of substantial levee construction, dam building, and reservoir filling; this period disrupts the homogeneity and homoscedasticity of the streamflow dataset. After 1978, reservoir operations became established, most upstream levee construction was completed, and once again the period of record can roughly be considered homogeneous in terms of reservoir operation. For these reasons, the period of record for the Ohio River at Louisville was analyzed over 3 time periods: 1. complete heterogeneous period of record, 2. pre-regulation period, and 3. post-regulation period.

When dividing the period of record into different intervals of regulation for the Louisville gage, consideration was given to ensure that the shortened record length remained adequate for trend analysis. There is uncertainty regarding whether the post-regulation period of record reflects homogenous reservoir operation, since reservoir regulation is not always consistent over time and operational deviations are common. However, for the purposes of this analysis, reservoir operations were assumed to be consistent and the impacts of changes in regulation and deviations from typical operation were minor. Nonstationarity detection results, discussed below, offer further insight into the homogeneity of the peak streamflow dataset.

A summary of the regression trends and their statistical significance is shown in Table 1-6. Individual graphical output for each gage and period of record analyzed is shown in Figure 1-12 through Figure 1-17.

No statistically significant linear trend was detected when the entire period of record was analyzed for the Ohio River at Louisville. Additionally, no statistically significant trend was identified when the period of record was broken up to be representative of pre-regulation or post-regulation conditions. Two statistically significant trends (p-value < 0.05) were detected at Beargrass Creek gage locations. These two gages, South Fork Beargrass Creek and Middle Fork Beargrass Creek, are impacted by urbanization, land use change, channelization, and development within the floodplain. All of these factors contribute to the increasing streamflow over time. When the peak annual streamflow dataset was examined for Floyds Fork, which is located outside of the project area and is much less impacted by urbanization, no statistically significant trend was detected.

It is unclear whether the statistically significant increasing trends detected within the Beargrass Creek watershed have been driven by increasing urbanization and land use changes or by anthropogenic climate change. Evidence of urbanization within the watershed is apparent, however, statistically significant increasing trends in precipitation have also been observed. These trends in precipitation are considered independent of the changes in land use, which supports findings of a changing climate.

Although, climate change may contribute to the trends in streamflow peaks being observed, it is believed that the primary driver of the trends in flood peaks observed within the Beargrass Creek watershed is urban development. The majority of the interior drainage area in Jefferson County has been developed, limiting the possibility of future significant increases in impervious surfaces and resulting run-off. The future hydrologic condition within the study area will likely be held constant due to local regulations on development that MSD has in place. MSD requires all new development to provide mitigation for increased runoff, as well as floodplain compensation for development in both the existing and fully developed floodplains. For this reason and the lack of observed trends in the “pristine” reference gage near the project area, it is unlikely that the increasing trends observed in streamflow will continue into the future. However, future re-evaluation of peak streamflow data should be conducted regularly to validate these assumptions.

In addition to applying the simple linear trend analysis applied within the CHAT tool, trends were also verified within the monotonic trend analysis tab of the nonstationarity detection tool. The nonstationarity detection tool applies the Mann-Kendall and Spearman tests to assess streamflow data for the presence of monotonic trends. This is a slightly more robust approach relative to simple linear regression. Nonstationarity Detection Tool Monotonic Trend analysis results were consistent with CHAT tool results.

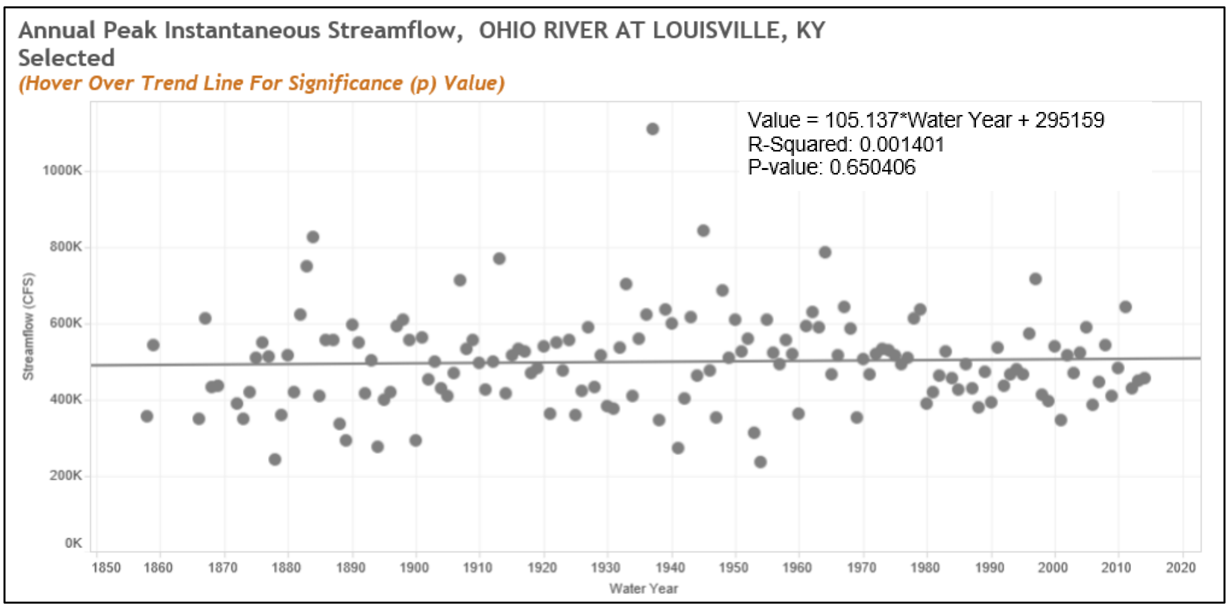

Figure 1-12: Annual Peak Streamflow on Lower Ohio River at Louisville, KY. Full POR (1858-2014). Statistically insignificant trend.

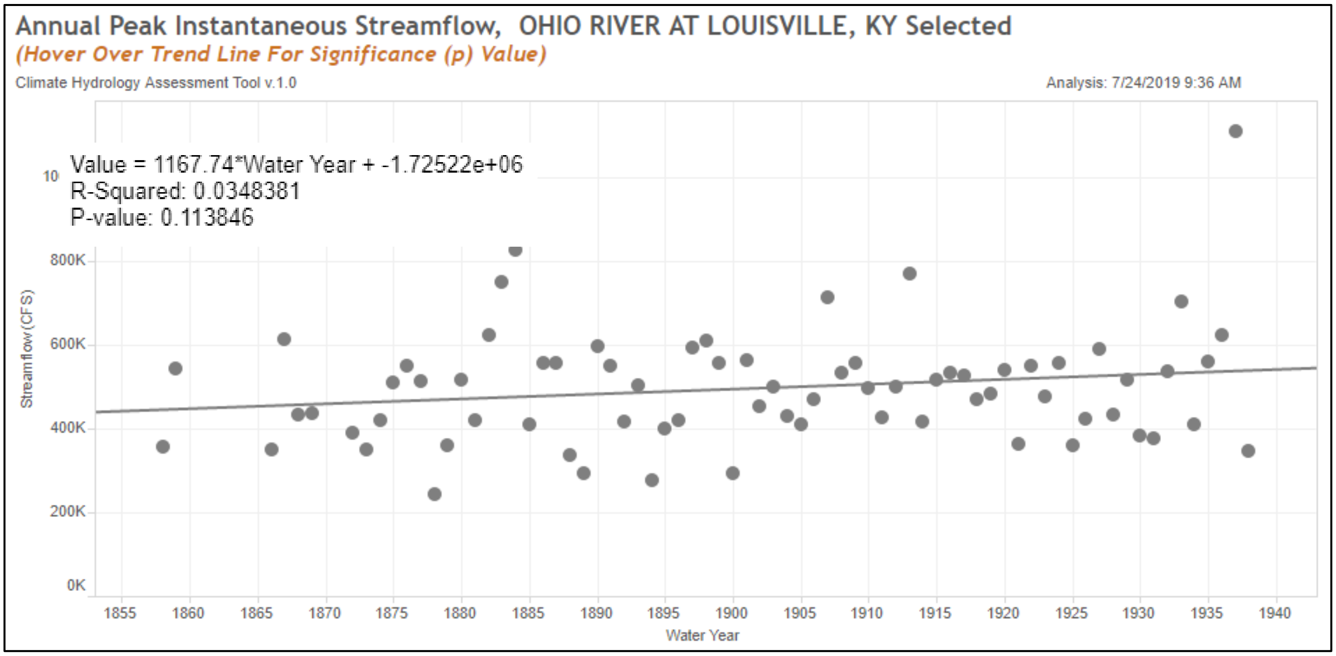

Figure 1-13: Annual Peak Streamflow on Lower Ohio River at Louisville, KY. Pre-regulation (1858-1938). Statistically Insignificant trend.

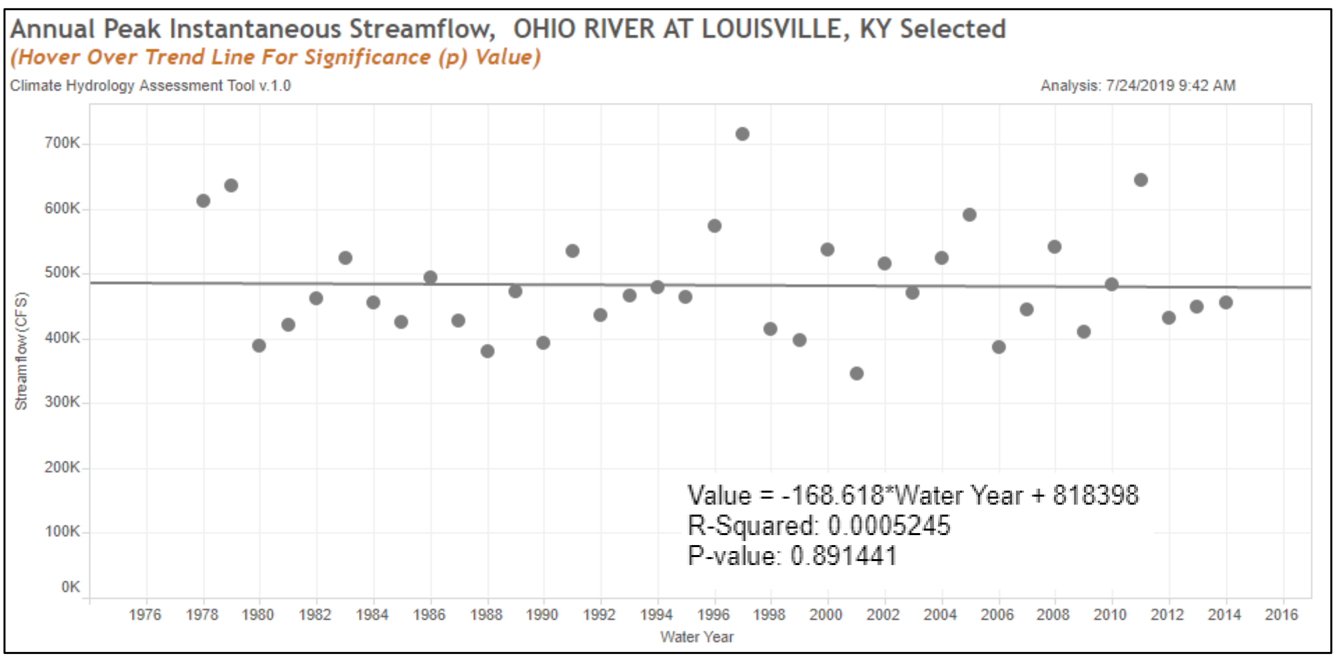

Figure 1-14. Annual Peak Streamflow on Lower Ohio River at Louisville, KY. Post-regulation (1978-2014). Statistically Insignificant trend.

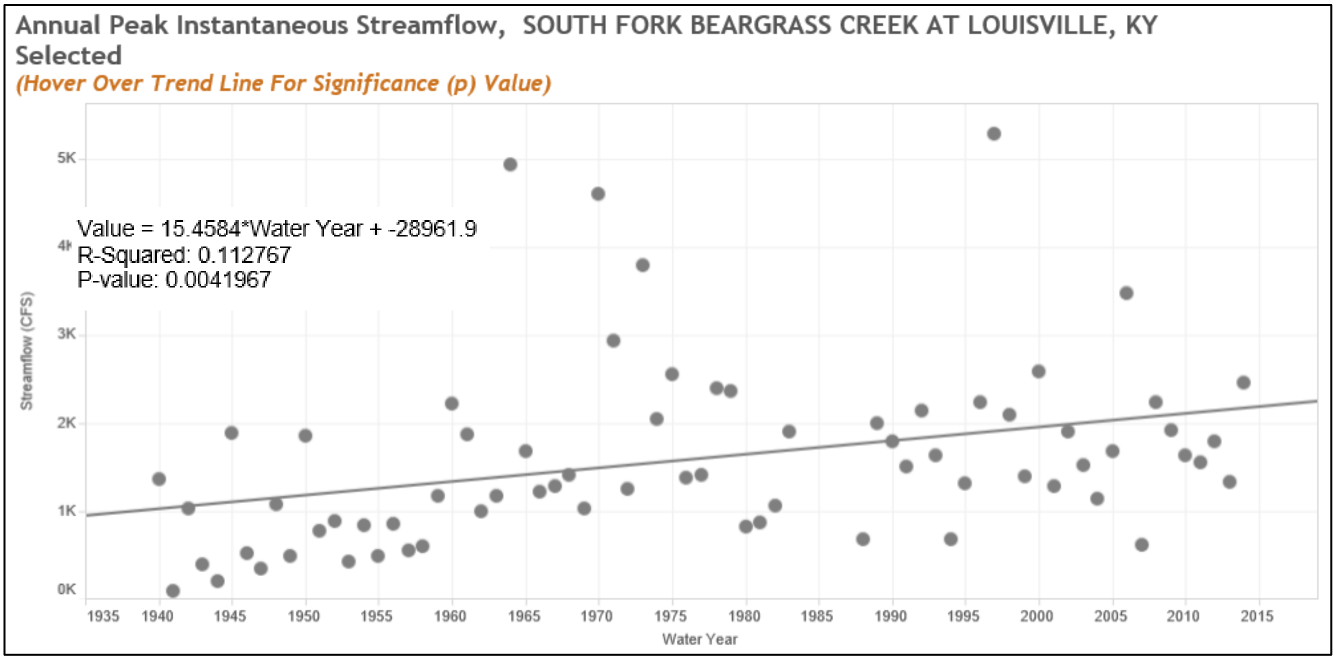

Figure 1-15: Annual Peak Streamflow at South Fork Beargrass Creek. Full POR (1940-2014). Statistically Significant increasing trend.

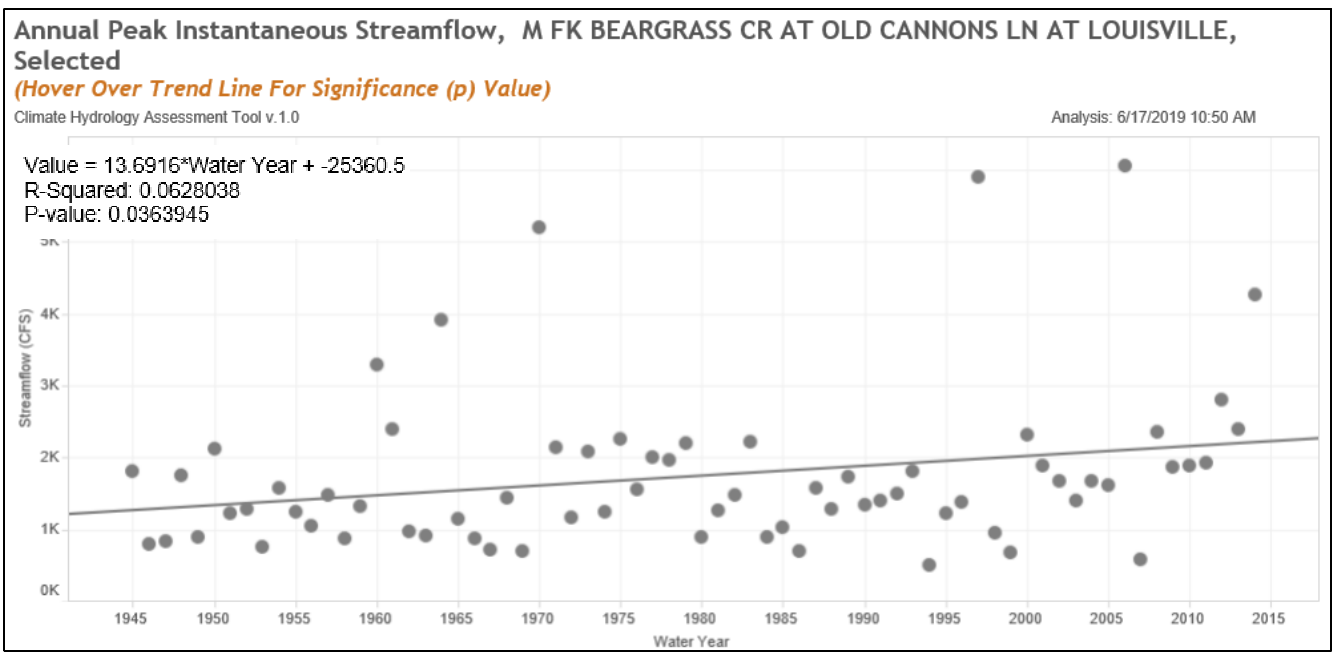

Figure 1-16: Annual Peak Streamflow at Middle Fork Beargrass Creek. Full POR (1945-2014). Statistically Significant increasing trend.

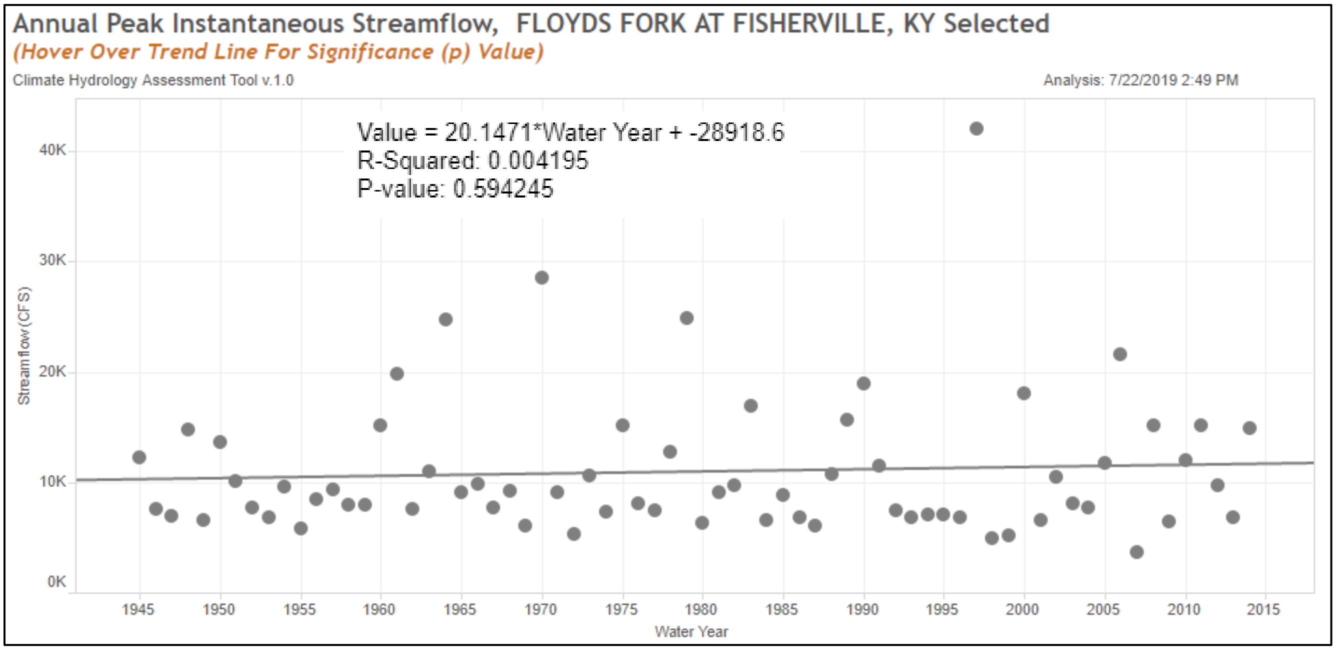

Figure 1-17: Annual Peak Streamflow at Floyds Fork at Fisherville. Full POR (1937-2014). Statistically Insignificant trend.

Table 1-6. Summary of Observed Streamflow Trends in Annual Peak Streamflow.

Gage Number	Gage Name and Location	POR Used for CHAT	POR Used for NSD	POR Note	Regression Slope	P-value	Trend Direction	Trend Significance	NSD Tool Trend?
03294500	Ohio River at Louisville, KY	1858 – 2014	1870 – 2014	Complete, minus gaps	105	0.650	Upward	Insignificant	No
		1858 – 1938	1870 – 1938	Pre-regulation	1168	0.114	Upward	Insignificant	No
		1978 – 2014	1978 – 2014	Post-regulation	-169	0.891	Downward	Insignificant	No
03292500	South Fork Beargrass Creek	1940 – 1984 1987 – 2014	1940 – 2014[1]	Complete	**15.5**	**0.004**	**Upward**	**Strong**	**Yes**
03293000	Middle Fork Beargrass Creek	1945 – 2014	1945 – 2014	Complete	**13.7**	**0.036**	**Upward**	**Strong**	**Yes**
03298000	Floyds Fork at Fisherville	1945 - 2014	1945 - 2014	Complete, minus gaps	20.1	0.594	Upward	Insignificant	No

[1]Data for the period of 1984 – 1987 is missing from POR and was interpolated from Middle Fork Beargrass Creek daily discharge data.

1.2.3. Nonstationarity Detection

The USACE Nonstationarity Detection (NSD) Tool was used to assess whether the assumption of stationarity, which is the assumption that the statistical characteristics of a time-series dataset are constant over the period of record, is valid for a given hydrologic time-series dataset. Nonstationarities are detected using 12 different statistical tests which examine how the statistical characteristics of the dataset change with time (Engineering Technical Letter (ETL) 1100-2-3, *Guidance for Detection of Nonstationarities in Annual Maximum Discharges*; *Nonstationarity Detection Tool User Manual*, version 1.2). Abbreviations of the 12 statistical tests are shown in the table below this section. The NSD Tool was applied to the same stream gage sites listed previously in Table 1-6.

A nonstationarity can be considered "strong" when it exhibits consensus among multiple nonstationarity detection methods, robustness in detection of changes in statistical properties, and a relatively large change in the magnitude of a dataset's statistical properties. Many of the statistical tests used to detect nonstationarities rely on statistical change points, these are points within the time series data where there is a break in the statistical properties of the data, such that data before and after the change point cannot be described by the same statistical characteristics. Similarly, to nonstationarities, change points must also exhibit consensus, robustness, and significant magnitude of change.

Figure 1-19 displays the NSD Tool output for the complete period of record (minus historic flows with large data gaps) for the Ohio River at Louisville, KY. Note that there are multiple nonstationarities detected throughout the period of record. However, these nonstationarity detections show neither consensus nor robustness and are thus not considered operationally significant. The nonstationarity detection results corroborate the trend analysis results indicating that the flow record observed along the Ohio River at Louisville can be considered stationary despite the changes in regulation that have occurred in the basin. This is likely because there is a substantial amount of drainage area between the closest source of regulation and the Louisville gage.

Figure 1-20 displays the NSD Tool output for the complete period of record for the South Fork Beargrass Creek. Note that there is a strong nonstationarity detected around 1958 detected by the following statistical methods: CVM, LP, END, MW, and SLW. This 1958 nonstationarity represents a relatively large increase in mean flow, from approximately 775 cfs to 1,900 cfs. This change in mean flow is likely driven by land use change and urbanization within the watershed. Anecdotally, much of the South Fork Beargrass Creek watershed was converted into residential land use during the 1950s and the corresponding increase in mean flow can be attributed to this change in watershed hydrologic parameters. According to US census population data, the 1950s represent a period of peak population and growth for the City of Louisville, population data is shown in Figure 1-18. The nonstationarity detection results corroborate the trend analysis results indicating an increasing trend within this watershed. Flows in the Beargrass Creek watershed are not representative of stationary hydrologic conditions.

There is a 4-year data gap in the South Fork Beargrass Creek annual peak flow period of record from 1984 – 1987. This gap in the data has the potential to undermine the nonstationarity detection algorithms. In order to avoid errors stemming from gaps in the observed record, the 4-

year period was estimated using a power regression relating daily flows between the stream gages on the Middle Fork and South Fork of Beargrass Creek. These two gages (03293000 and 03292500) are less than 3 miles apart and their daily flows respond to precipitation events in a similar manner (correlation coefficient = 0.93). Because estimated flows were used to fill the data gap, nonstationarity detection was performed using the USACE Time Series Toolbox as opposed to the NSD Tool.

Figure 1-21 displays the NSD Tool output for the complete period of record for the Middle Fork Beargrass Creek. While the nonstationarity detected for the South Fork in 1958 is not present in the Middle Fork record, a nonstationarity was detected by 2 tests (KS and LW) in 1998/1999. This NS represents an increase in mean flow from 1,600 cfs to 2,200 cfs. Anecdotally, the upper subbasins of this watershed experienced growth and urbanization more recently than other portions of the study area which supports the finding of this later nonstationarity in the late-1990s. The nonstationarity detection results corroborate the trend analysis results indicating an increasing trend within this watershed. Flows in the Beargrass Creek watershed are not representative of stationary hydrologic conditions.

Figure 1-22 displays the NSD Tool output for the complete period of record for Floyds Fork at Fisherville. This gage location represents a relatively "pristine" watershed near the study area. No nonstationarities are detected which are supported by either consensus or robustness in this watershed. The nonstationarity detection results corroborate the trend analysis results indicating that the flow record observed within the Floyds Fork watershed is representative of stationary hydrologic conditions.

For the South Fork Beargrass Creek gage and Middle Fork Beargrass Creek gage, where strong nonstationarities were detected, the subset of the period of record preceding and following the detected nonstationarity was examined for monotonic trends. No monotonic trends were detected within these data subsets. This implies that the datasets prior to and after the detected nonstationarities can be considered representative of stationary hydrologic conditions. However, it should be noted that when the entire period of record is analyzed, both the CHAT and monotonic trend analyses indicate increasing trends streamflow for the two gages mentioned above. This further supports the idea that the records at these sites are nonstationary.

After performing the nonstationarity detection analysis across the Beargrass Creek Ecosystem Restoration Study project area for streamflow multiple gages, various conclusions can be drawn. Nonstationarities are widespread throughout the project area where intense urbanization and land use change has occurred. The period of the 1950s is of note as nonstationarities were found at the South Fork Beargrass Creek gage. These nonstationarities were not present when the less urban "pristine" reference site was examined. Additionally, these nonstationarities were not detected in the large watershed of the Ohio River. Considering these related lines of evidence, it can be assumed that the detected nonstationarities cannot likely be attributed to climate change or long-term natural climate trends. Rather, land use/land cover changes are significant and are impacting historically observed peak streamflow records within the Beargrass Creek watershed.

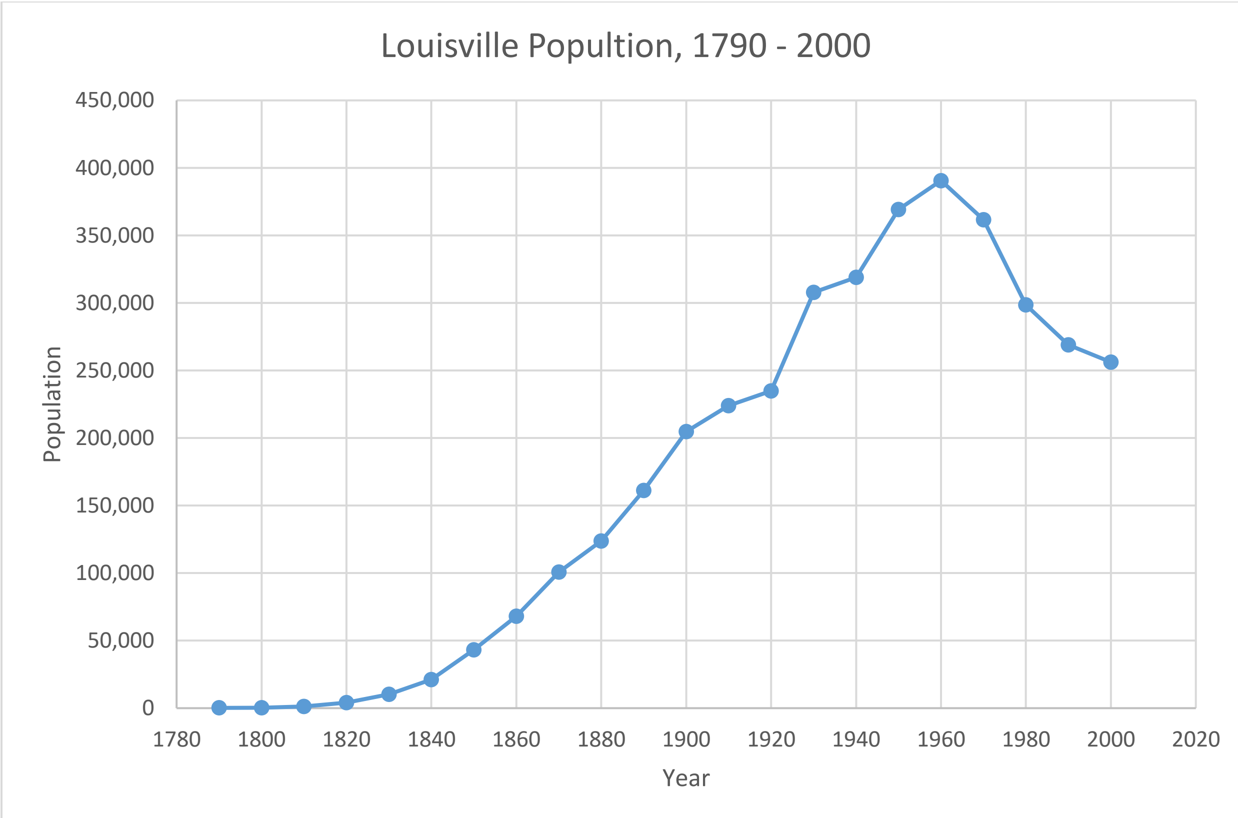

Figure 1-18. Population of Louisville over Time*

** It should be noted that data more recent than the year 2000 was omitted from this figure because the census changed their accounting methods to include all of Jefferson County, effectively doubling the population counted in 2010 compared with 2000. **

Nonstationarity Detection Method Abbreviation	Statistical Test Name
CVM	Cramer-Von-Mises (CPM)
KS	Kolmogorov-Smirnov (CPM)
LP	LePage (CPM)
END	Energy Divisive Method
LW	Lombard Wilcoxon
PT	Pettitt
MW	Mann-Whitney (CPM)
BAY	Bayesian
LM	Lombard Mood
MD	Mood (CPM)
SLW	Smooth Lombard Wilcoxon
SLM	Smooth Lombard Mood

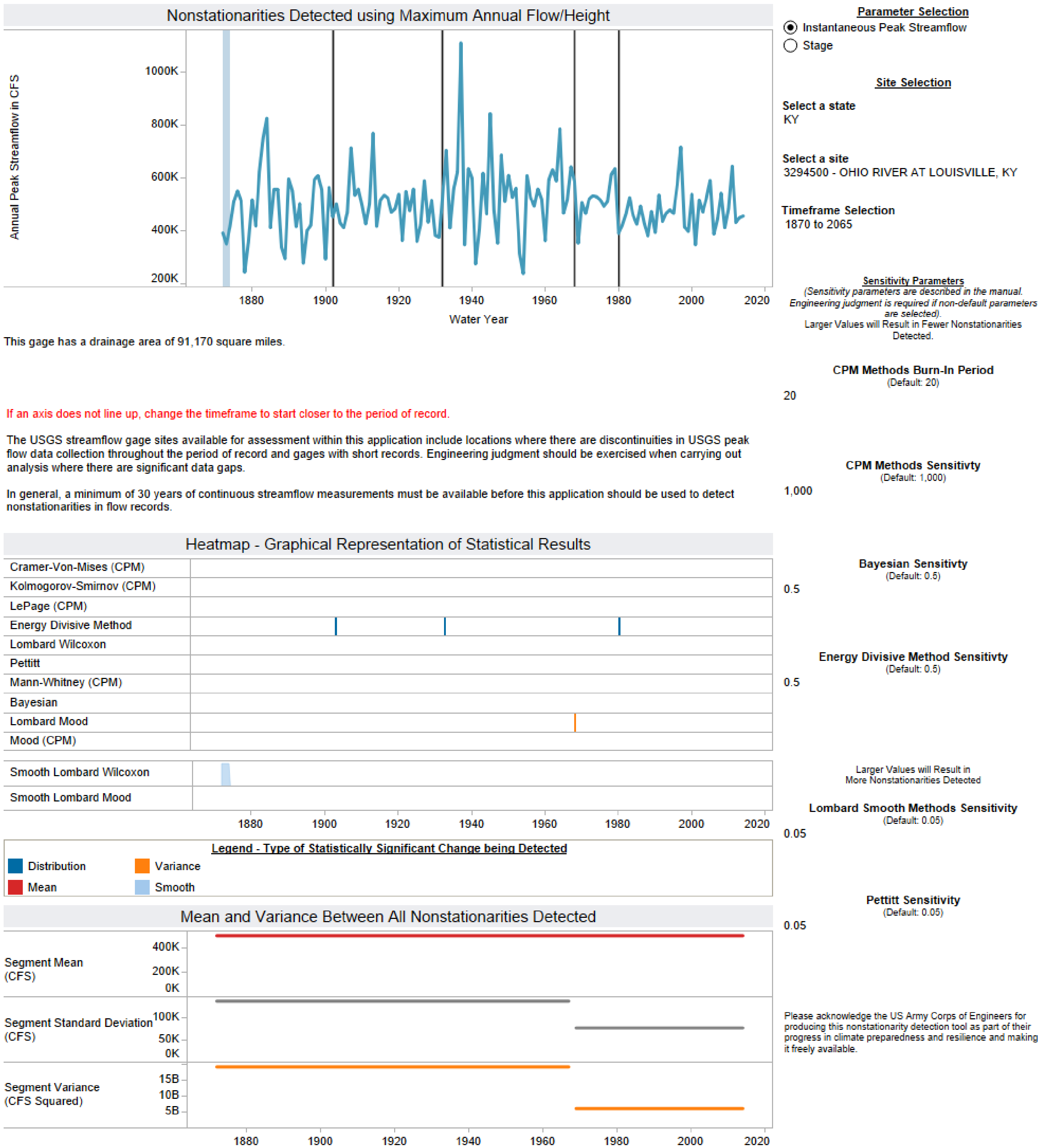

Figure 1-19. Nonstationarity Detection for Ohio River at Louisville. Complete Period of Record minus gaps, 1870 - 2014.

Figure 1-20. Nonstationarity Detection for the South Fork Beargrass Creek. NSD centered around 1958.

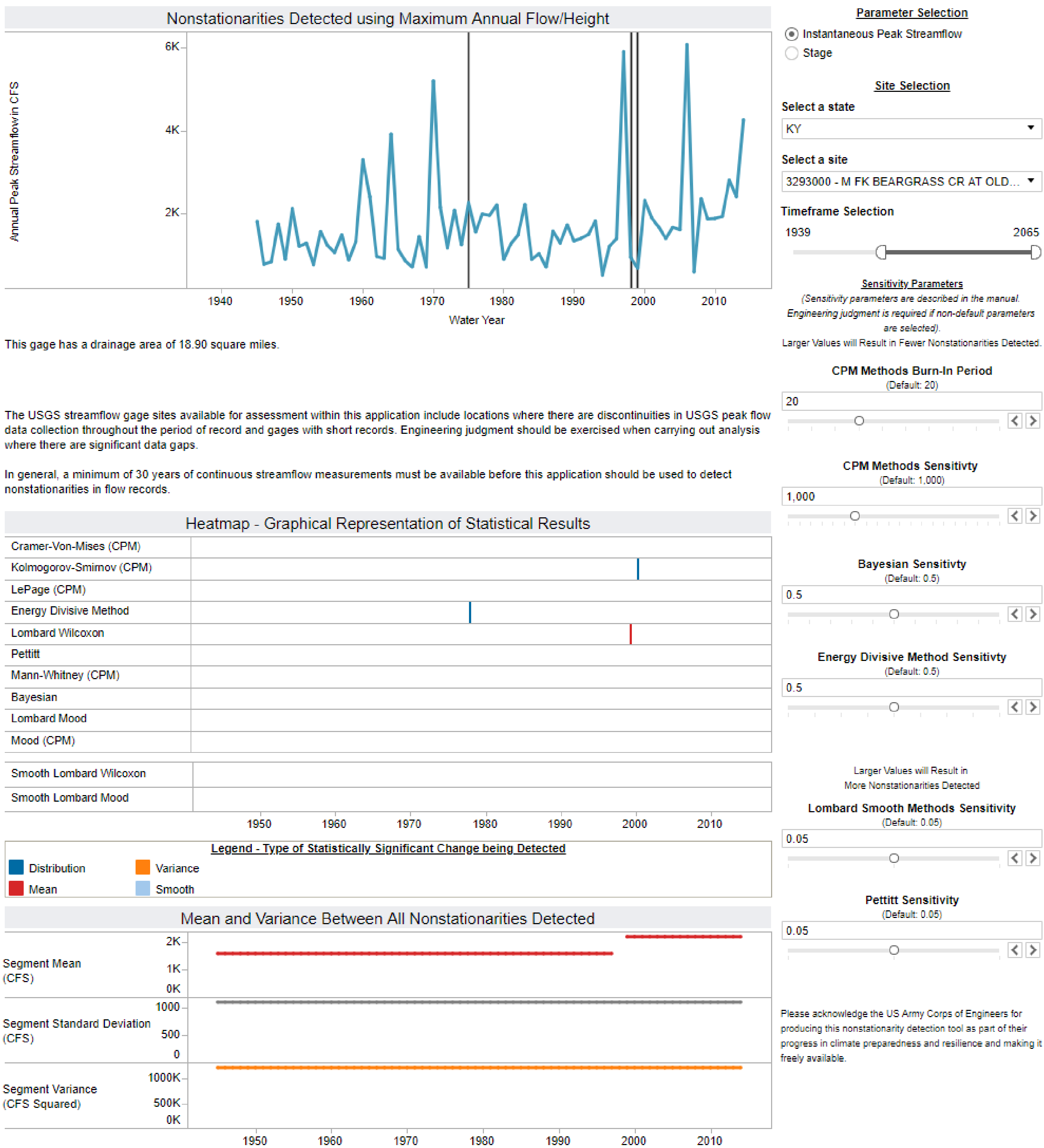

Figure 1-21: Nonstationarity Detection for Middle Fork Beargrass Creek.

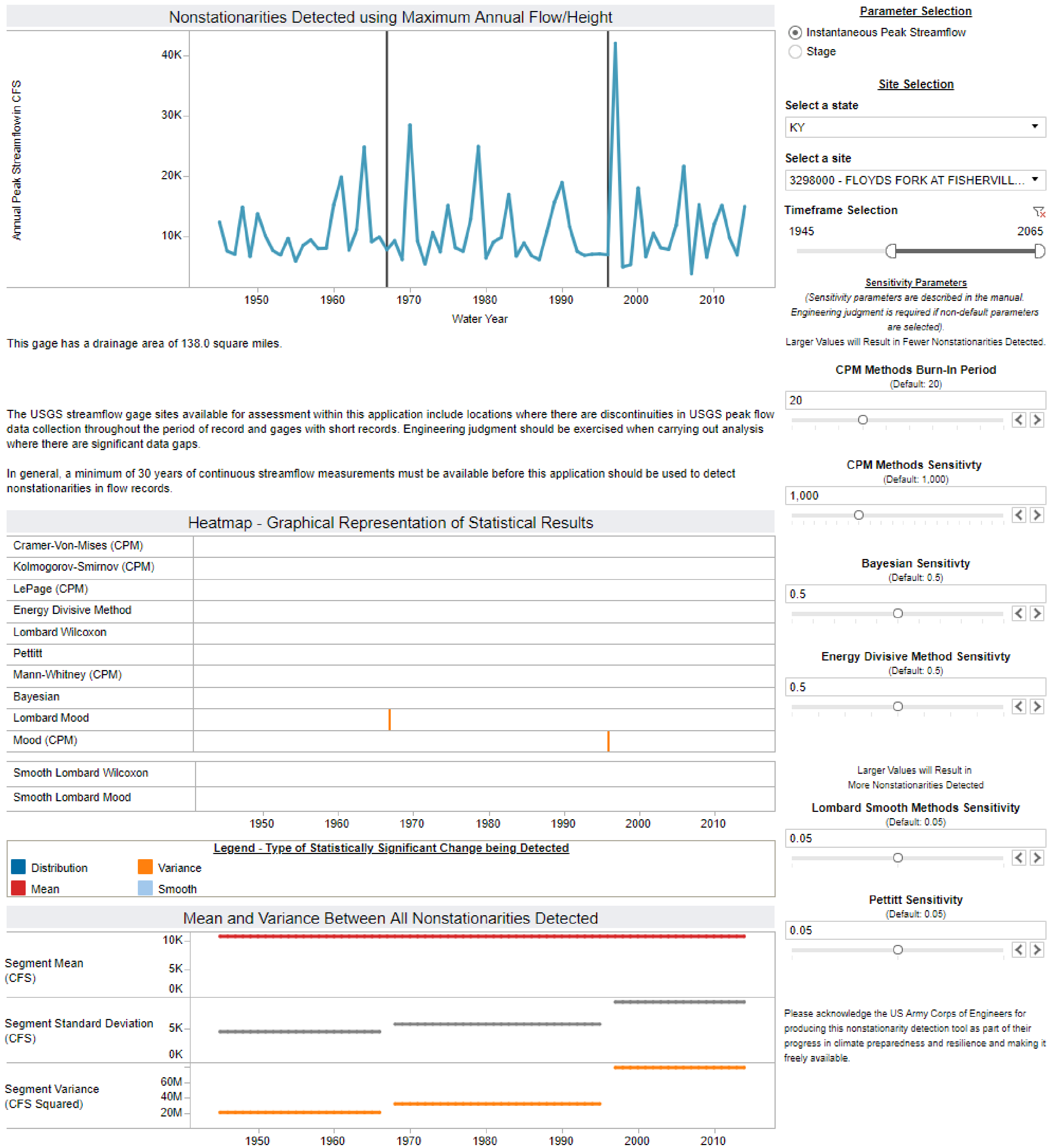

Figure 1-22. Nonstationarity Detection for Floyds Fork at Fisherville, KY

1.3. Projected Trends in Future Climate and Climate Change

1.3.1. Literature Review

1.3.1.1. Recent US Climate Change and Hydrology Literature Syntheses

In addition to the observed trends discussed previously, the 2015 USACE Literature Synthesis for the Ohio Region 05 also summarizes available literature for projected future trends in various hydrometeorological variables. These variables are projected using a variety of statistical methods in conjunction with global circulation models (GCMs). Figure 1-8 above summarizes the findings of the literature synthesis regarding projected climatic trends. Additional discussion is provided in the following paragraphs.

Temperature. The 2015 USACE Literature Synthesis found strong consensus in the literature that temperatures will increase in the study area over the next century. "The projected increase in mean annual air temperature ranges from 0 to 8°C (0 to 14.4°F) by the latter half of the 21st century. The largest increases are generally projected for the summer months. Reasonable consensus is also seen in the literature with respect to projected increases in extreme temperature events, including more frequent, longer, and more intense summer heat waves in the long-term future compared to the recent past."

Precipitation. "Projections of precipitation in the study region are less certain than those associated with air temperature. Most studies project increases, but some predictions are for decreases, or for increases in some portions of the region and decreases in others. Similarly, while the projections trend toward more intense and frequent storm events than the recent past, some show a reduction in parts of the Ohio Region."

Hydrology / Streamflow. Low consensus exists amongst the literature with regards to projected changes in hydrology for the region. Large variability in the projected hydrologic parameters (e.g. runoff, streamflow, SWE) exist across the literature and varied with location, hydrologic modeling approach, GCM used, and adopted emission scenario.

1.3.1.2. Fourth National Climate Assessment

In addition to the observed trends discussed previously, the NCA4 offers climatic projections, as well as the implications of these projections on risk, infrastructure, engineering, and human health.

Temperature. Increases in temperature of about 2.5°F are expected over the next few decades regardless of future greenhouse gas emissions. Temperature increases ranging from 3° to 8°F are expected by the end of the century, depending on whether the world follows a higher or lower future emission scenario. Extreme temperatures are expected to increase proportionally to the average temperature increases. Figure 1-23 displays future projected, annual, average temperatures for two future time periods, the mid-21st century and late 21st century. These are compared with the historic baseline period of 1986-2015. Additionally, projections are shown for two emission scenarios, or representative concentration pathways (RCPs) of greenhouse gases. RCP8.5 is a higher emission scenario and RCP4.5 is a moderate emission scenario.

Note that in general, increases in projected temperature are greater in higher latitudes and lessen farther south in the country. The project area tends to span a north-south transitional area of warming. Regardless of spatial variation, temperature increases are projected for the entire country under all emission scenarios.

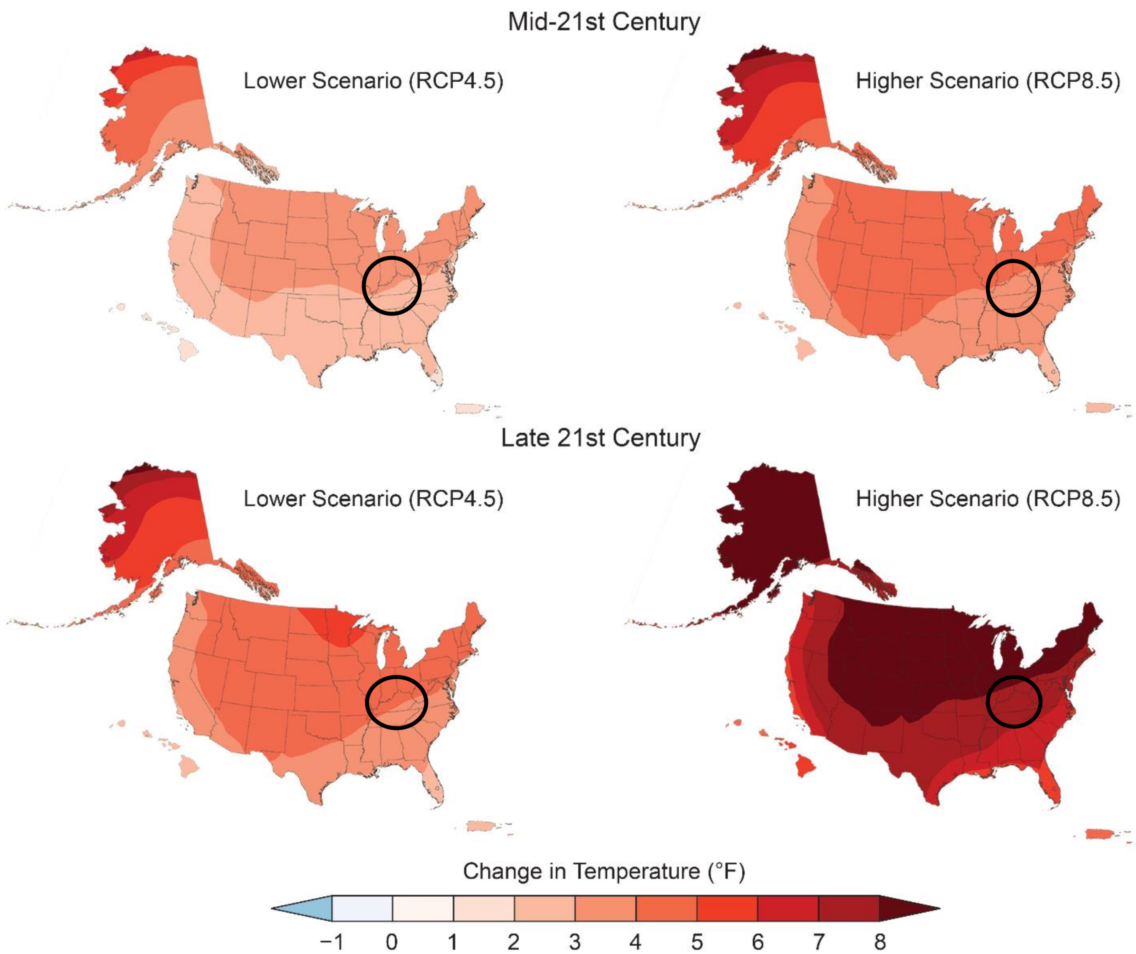

Figure 1-23. Future projections of temperature for various time frames and emission scenarios

Precipitation. Both increase and decreases in average annual precipitation are expected over the coming decades depending on location, season, and various other factors. Figure 1-24 displays the seasonal variation in annual precipitation in the later part of the century as compared with the historic period of 1986-2015. Note that there is significant variation in projections depending on location and season. Also note that red dots indicate that the projected trends due to climate change are considered to be large as compared with natural variations in climate, whereas the hatched areas show areas where the projected trends due to greenhouse gas emissions are considered to be relatively insignificant when compared to natural climate variability. Looking more closely at the LMFS project area, most of the trends in precipitation during the summer and fall months can be considered relatively insignificant. However, winter and spring precipitation both show projected increases in annual rainfall of approximately 10% - 20%. Surface soil moisture is expected to decrease across most of the U.S. and will be accompanied by large declines in snowpack in the western U.S. as winter precipitation shifts from falling as snow to falling as rain. This hydrologic shift may cause changes in the behavior of the Ohio River and other systems influenced by snow melt.

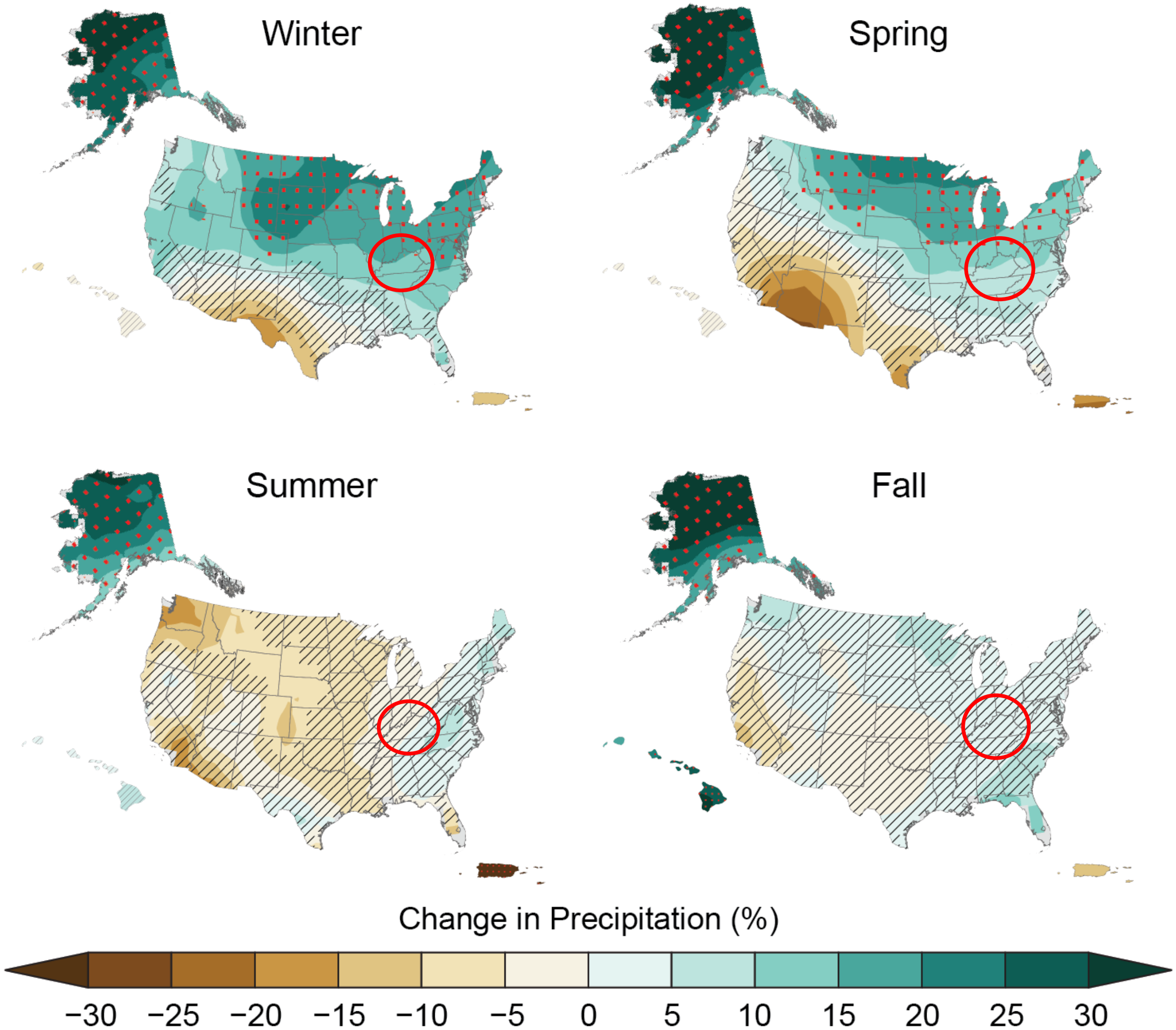

Figure 1-24. Projected percent change in future precipitation for different seasons under a high emission scenario (RCP8.5)

The observed increases in frequency and intensity of heavy precipitation discussed earlier are projected to continue, with higher emission scenarios producing stronger increasing trends. Figure 1-25 displays the projected change in total annual precipitation falling during the heaviest 1% of storms for a time period between 2070 and 2099. Note in the vicinity of the LMFS project area, under a moderate emission scenario (RCP4.5), the annual precipitation falling during the heaviest 1% of events is expected to increase by approximately 20% to 29%. Under a higher emission scenario (RCP8.5), the basin is expected to experience extreme event precipitation increases in excess of 40%. These trends are consistent with what would be expected with warmer temperatures, as increased evaporation rates lead to higher levels of water vapor in the atmosphere which in turn leads to more frequent and intense precipitation events.

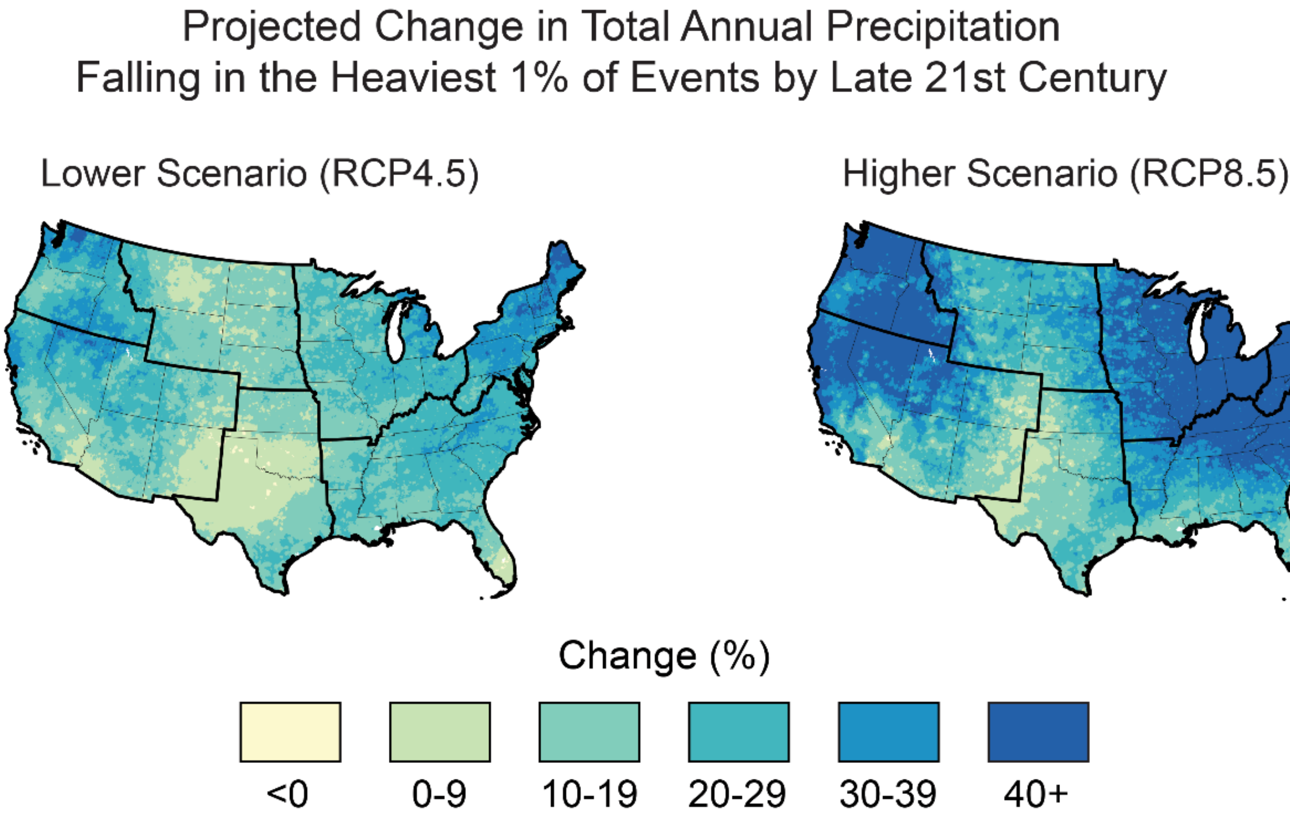

Figure 1-25. Observed percent change in the amount of precipitation falling during the heaviest 1% of events under various emission scenarios

The NCA4 qualitatively discusses some of the risks associated with projected, future climate conditions. The NCA4 report emphasizes that the likelihood of hydrometeorological phenomena like droughts, extreme storms and flood events may be misrepresented when defined using historic records that are limited in length (approximately 10-100 years). Selected points from the discussion relevant to this project are below.

Ecosystem

There is potential for climate change driven changes to hydrologic conditions to increase stress on ecosystems within the Beargrass Creek watershed. Warming winter temperature extremes can negatively impact ecosystems. Warmer air temperatures will also affect the movement and interactions between different types of organisms. Warmer air temperatures can also disturb or misalign ecosystem phenology, impacting organisms' lifecycles and potentially threatening native species' success. The altered migration patterns and misaligned phenology may cause a reduction in the native species population. Climate change is expected to intensify the hydrologic cycle and increase the frequency and severity of extreme events like drought and heavy rainfall. Drought and extreme heat can lead to tree mortality, and aquatic life mortality and transform a region's forested ecosystems. Extreme conditions may favor invasive species that can be more resilient, driving out native plant species and reducing biodiversity. Prolonged inundations and lack of oxygen can similarly result in mortality and dieback of critical foundation, low-lying plant species. Essentially, extreme drought and precipitation could transform a region's ecosystems.

Flood Risk Reduction

There is also potential for climate change driven changes to hydrologic conditions to increase stress on infrastructure within the Beargrass Creek watershed. As higher temperatures increase the proportion of cold season precipitation falling as rain rather than snow, higher streamflow is projected to occur in many basins, raising flood risks. The more extreme drought and heavy rainfall events can compromise the reliability of flood risk management and navigation. The growing number of extreme rainfall events is stressing the deteriorating infrastructure in the Southeast United States. Many transportation and storm water systems have not been designed to withstand these events which poses a greater risk of failure. Statistical methods have been developed for defining climate risk and frequency analysis that incorporate observed and/or projected changes in extremes. However, these methods have not yet been widely incorporated into infrastructure design codes, risk assessments, or operational guidelines.

The procedures used to design water resources infrastructure, estimations of probability of failure, and risk assessments for infrastructure typically rely on 10-100 years of observed data to define flood and rainfall intensity, frequency, and duration. This approach assumes that frequency and severity of extremes do not change significantly with time. However, numerous studies suggest that the severity and frequency of climatic extremes, such as precipitation and heat waves, have in fact been changing due to human-driven climate change. These changes represent a regionally variable risk of increased frequency and severity of floods and drought. Additionally, tree ring based reconstructions of climate over the past 500 years for the U.S. illustrates a much wider range of climate variability than does the instrumental record (beginning around 1900). This historic variability includes wet and dry periods with statistics very different from those of the 20th century. Infrastructure design that uses recent historic data may underrepresent the risk seen from the paleo record, even without considering future climate change.

1.3.1.3. Ohio River Basin – Formulating Climate Change Mitigation/Adaptation Strategies – Climate Change Pilot Study Report (Drum et. al., 2017)

In 2017 the USACE Institute for Water Resources (IWR) in coordination with Huntington District, Lakes and Rivers Division (LRD), Ohio River Basin Alliance, and various other agencies, published a multidisciplinary report providing downscaled climate modeling information for the entire Ohio River Basin with forecasted precipitation and temperature data, along with streamflow at various gaging points throughout the basin. The projections are presented at the HUC-4 subbasin level through three 30-year time periods between 2011 and 2099.

In general, the modeling results indicate a gradual increase in annual mean temperatures from 2011 to 2040 of an approximate magnitude of one-half degree per decade. From 2041 to 2099, the rate of warming increases to one-full degree per decade. Changes in streamflow show much more variability than temperature across the Ohio River Basin. HUC-4 watersheds in the northeast, east, and south of the Ohio River are expected to see increases in precipitation and streamflow of up to 50%. Conversely, HUC-4 watersheds located to the north and west of the Ohio River are expected to experience decreasing precipitation, particularly in the fall-season, resulting in decreasing streamflows – up to 50% reductions – during the coming decades.

Regarding ecosystems, the study states that in the face of changing land use and energy development, and where these projected air temperature and flow changes deviate more than 25% from the current levels, it is likely the fish and mussel populations, wetland complexes, reservoir fisheries, trans-boundary organisms such as migratory fish and water body-dependent birds, and human use and safety will also be noticeably impacted. Streamflows are expected to increase in the basin with some low flows/droughts experienced in the summer/fall. Without connected floodplains, higher flows and increased flooding can be devastating to stream habitat because stream power is confined, and increased stream bank and bed scouring occurs. The projected high flows across the basin in the spring is beneficial for fish reproduction because they provide access to unique types of habitat niches and spawning substrates. However, very high flows can be detrimental to mussels and fish if stream scouring occurs, and higher turbidities may lead to lower reproductive success for mussels. Water quality can be negatively impacted from higher rainfall intensity due to the increased transport of sediments and nutrients. As for wetlands, increased precipitation can restore greater connectivity to this part of aquatic ecosystems as long as human engineers allow natural “flexing” in the frequency and duration of connectivity. Conversely, the increased precipitation may increase the rate of eutrophication and eventual filling of wetlands and shorten the lifespan of these valuable habitats.

1.3.1.4. Analysis of Projected Changes in Precipitation IDF Values Based on Climate Change Projections

In addition to the 2015 CH2M Hill analysis discussed in the Observed Trends Literature Review section above, CH2M Hill performed an analysis projecting precipitation values into the future and developing precipitation frequency estimates, comparable with Atlas 14, from these projected values. The future climate projections were accomplished using a circulation model known as SimCLIM, which utilizes 22 daily general circulation models and two emission scenarios at two different future time periods, 2035 and 2065. Selected emission scenarios include Representative Concentration Pathway (RCP) 8.5, which represents a “high” growth scenario for greenhouse gasses, and RCP 6.0 representing a “moderate” growth scenario.

When compared with the CH2M Hill precipitation frequency estimates discussed in Section 1.2.1.3, the estimates increase from 10% to 16% by the year 2065. For example, for the 100-yr 24-hr storm, the precipitation depth is projected to increase from 7.81 inches to between 8.56 and 9.05 inches. Figure 1-26 displays a comparison between the precipitation projections and the “historical” baseline for a range of return periods. Note that the “historical” baseline is referring to the 2015 study previously discussed where CH2M Hill updated Atlas 14 estimates with new data and stations through 2014. All projections were done using a 3-station average of the previously analyzed gages. Incorporation of these updated rainfall values as a basis of design for the FFERS is outside the scope of this qualitative assessment of climate change.

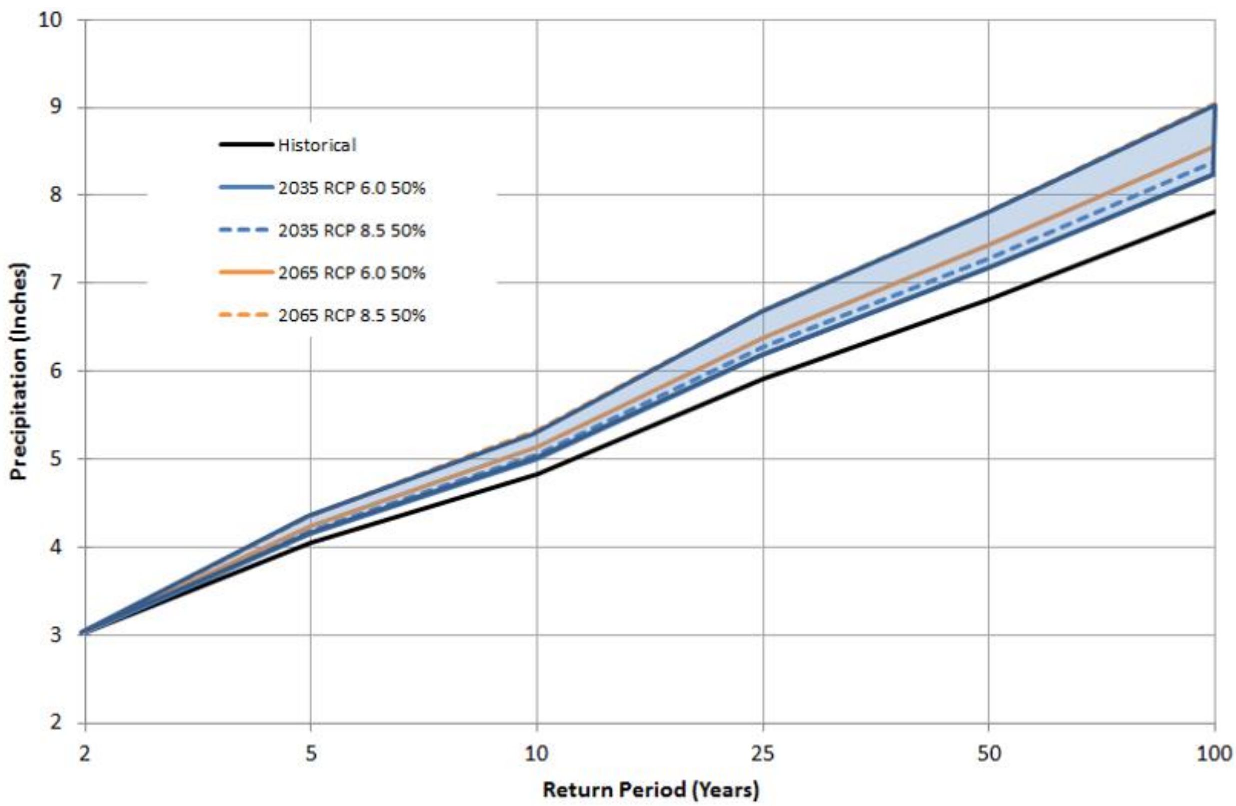

Figure 1-26. Comparison between Historical (2015 CH2M Hill Study) and Projected 24-hr Precipitation Frequency EstimateClimate Hydrology Assessment

1.3.2. Projected Climate Hydrology Assessment

The USACE Climate Hydrology Assessment Tool (CHAT) was used to assess projected, future trends within the Lower Ohio River Basin watershed, HUC-0514. The tool displays the range of projected annual maximum monthly streamflows from 1950 - 2099, with the projections from 1950 – 1999 representing hindcast projections and 2000 – 2099 representing forecasted projections.

Figure 1-27 displays the range of projections for 93 combinations of CMIP5 GCMs and RCPs produced using BCSD statistical downscaling. These flows are simulated using an unregulated VIC hydrologic model at the outlet of the Lower Ohio River Basin (HUC-0514) which is near the confluence of the Ohio River and Mississippi River near Cairo, IL. At this outlet, the Ohio River has a drainage area of approximately 203,000 mi^2 (according to the national hydrography dataset), as compared with the drainage area Louisville of 91,170 mi^2. It should be noted that the hindcast projections do not replicate historically observed precipitation or streamflow and should therefore not be compared directly with historical observations. This is in part because observed streamflows are impacted by regulation, while the VIC model used to produce the results displayed in Figure 1-27 is representative of the unregulated condition.

Upon examination of the range of model results, there is a clear increasing trend in the higher projections, whereas the lower projections appear to be relatively stable and unchanging through time. The spread of the model results also increases with time, which is to be expected as uncertainty in future projection increases as time moves away from the model initiation point. Sources of variation and the significant uncertainty associated with these models include the boundary conditions applied to the GCMs, as well as variation between GCMs and selection of RCPs applied. Each GCM and RCP independently incorporate significant assumptions regarding future conditions, thus introducing more uncertainty into the climate changed projected hydrology. Climate model downscaling and a limited temporal resolution further contribute to the uncertainty associated with CHAT results. There is also uncertainty associated with the hydrologic models. The large spread of results shown in Figure 1-27 highlights current climatic and hydrologic modeling limitations and associated uncertainty.

Figure 1-28 displays only the mean result of the range of the 93 projections of future, climate-changed hydrology which are shown in Figure 1-27. A linear regression line was fit to this mean and displays an increasing trend with a slope of approximately 49 cfs/yr. It should be noted that the p-value associated with this trend is less than 0.0001, indicating that the trend should be considered as statistically significant.

These outputs from the CHAT qualitatively suggest that annual maximum monthly flows, and therefore annual peak flows, are expected to increase in the future relative to the current time. Another important caveat is that the CHAT tool is simulating an unregulated watershed. Reservoir operations can be expected to decrease the variance of flows shown in the CHAT, as well as decrease the magnitude of their peaks.

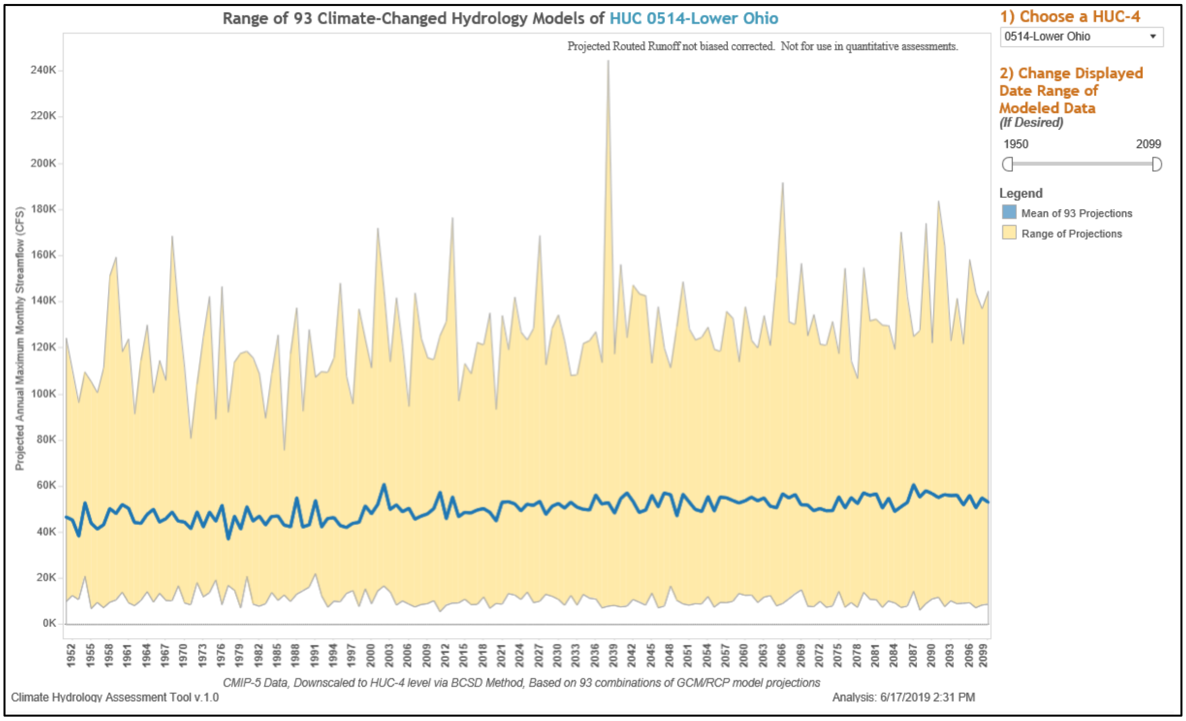

Figure 1-27. Range of GCM/RCP projections for the Lower Ohio, HUC-0514.

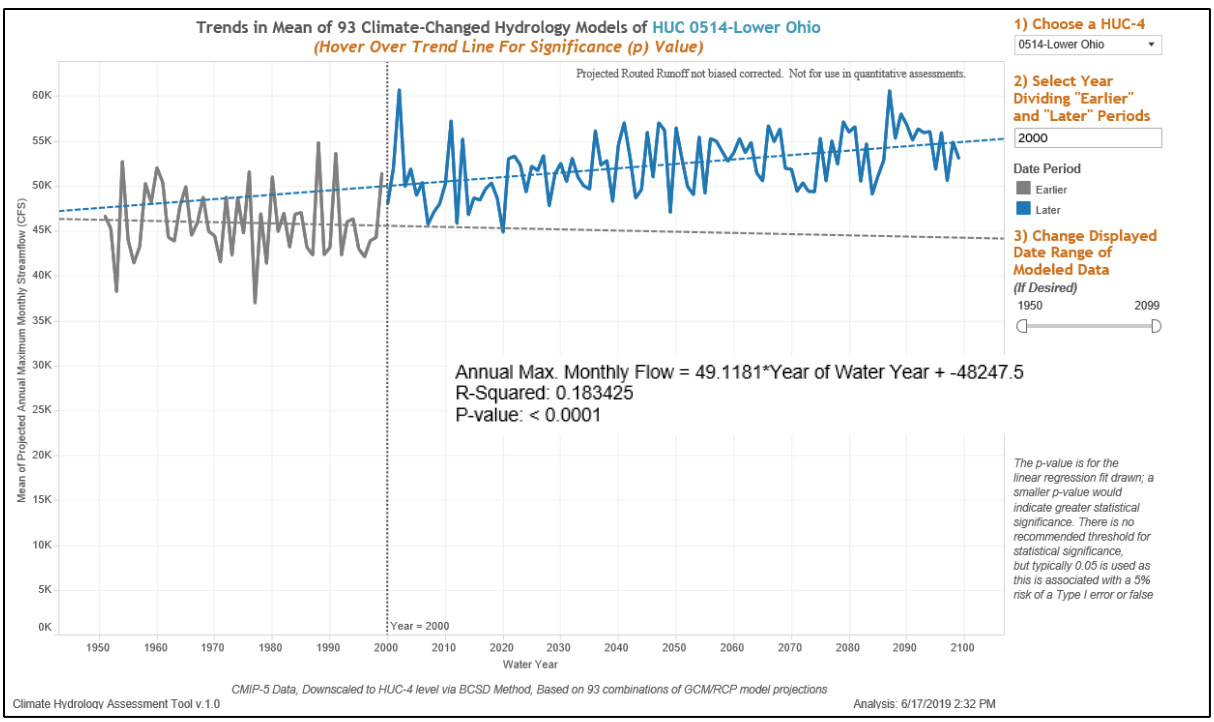

Figure 1-28. Mean of GCM/RCP projections for the Lower Ohio, HUC-0514.
Mean of Projections Regression: [Q = 49.1181*(Water Year) – 48247.5] [R^2 = 0.183425] [P-value = <0.0001]

1.3.3. Vulnerability Assessment

The USACE Watershed Climate Vulnerability Assessment Tool (VA Tool) facilitates a screening level, comparative assessment of how vulnerable a given HUC-4 watershed is to the impacts of climate change relative to the other 202 HUC-4 watersheds within the continental United States (CONUS). The tool can be used to assess the vulnerability of a specific USACE business line such as "Flood Risk Reduction" or "Navigation" to projected climate change impacts. Assessments using this tool help to identify and characterize specific climate threats and particular sensitivities or vulnerabilities, at least in a relative sense, across regions and business lines. The tool uses the Weighted Ordered 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.

Ecosystem Restoration and Flood Risk Reduction (Management) are the two most relevant business lines to the BGCER Study and are the primary business lines analyzed with the USACE Climate Vulnerability Assessment Tool. Business lines included in the VA tool include: ecosystem restoration, emergency management, flood risk reduction, hydropower, navigation, recreation, regulatory, and water supply. While only the ecosystem restoration and flood risk reduction business lines are discussed in detail, all business lines available within the VA tool were examined for outstanding vulnerability, and none was found

When assessing future risk projected by climate change, the USACE Climate Vulnerability Assessment Tool makes an assessment for two 30-year epochs of analysis centered at 2050 and 2085. These two periods were selected to be consistent with many of the other national and international analyses. The Vulnerability Assessment tool assesses how vulnerable a given HUC-4 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 "wet" and the bottom 50% of the traces is called "dry." Meteorological data projected by the GCMs is translated into runoff using the Variable Infiltration Capacity (VIC) macro-scale hydrologic model. For this assessment, the default National Standards Settings are used to carry out the vulnerability assessment.

For the Ecosystem Restoration and Flood Risk Management business lines, the Ohio River Basin (HUC 0514) is not within the top 20% of vulnerable watersheds within the CONUS for any of the four scenarios, which is not to say that vulnerability to future climate change does not exist within the basin. Table 1-7 displays the overall vulnerability scores for the two business lines relevant to this study under both wet and dry scenarios and under both time epochs. The indicators driving the residual vulnerability for the flood risk management and emergency management business lines are shown in Figure 1-29 and Figure 1-30, respectively. Table 1-1-8 and Table 1-9 display the indicators contributing to vulnerability within the Lower Ohio Basin for the ecosystem restoration and flood risk reduction business lines; the tables are generally sorted from largest to smallest average indicator contribution to vulnerability. Additionally, the tables display the indicator code, name, and a brief description of the indicator's meaning.

Regarding the Ecosystem Restoration business line, the primary indicator driving vulnerability within the watershed, as well as nearly all of the United States, is the percent of freshwater plant communities at risk (indicator 8). This factor shows that 49.4% of the freshwater plant communities are at risk for all epochs and scenarios in the HUC 0514 watershed. The percent at risk range from 11.9% to 72.2% for all the watersheds in the nation. This risk for extinction for a plant community is based on the remaining number and condition of occurrences in the community, the remaining acreage covered by the community, and the severity of threats to the community. The rainfall/runoff elasticity is the secondary indicator (indicator 277) which measures the tendency for small changes in precipitation to result in large changes in runoff. The indicator value for the HUC 0514 watershed ranges from 2.07 to 2.3 which means that for a 1% increase in precipitation, the runoff will increase from 2.07% to 2.3%. The elasticity ranges from 0.81 to 4.18 for all the watersheds in the nation. Ecosystem restoration vulnerability is further increased by the intra-annual variability of runoff (indicator 221C) which can be a result of shifting temperature and precipitation and lead to frequent flash floods. This indicator value is the 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff and in the HUC 0514 calculates to 0.91-0.92 for the 2050 epoch for both conditions and then increases to 0.95-0.96 for the 2085 epoch for both scenarios. The values range from 0.38 to 1.78 for all the watersheds in the nation. Another vulnerability indicator is the biological condition of the macroinvertebrate (indicator 297) which is associated with the overall biological condition of streams. These four factors contribute to approximately 83% of the vulnerability for this business line. Additional information regarding indicators can be found within the Vulnerability Assessment Tool Users Guide (U.S. Army Corps of Engineers, 2016).

Regarding the Flood Risk Reduction business line, the primary indicators driving vulnerability within the watershed are the flood magnification factor (indicators 568C and 568L) and the large elasticity between rainfall and runoff (indicator 277). The flood magnification factor represents how the monthly flow exceeded 10% of the time is predicted to change in the future; a value greater than 1 indicates flood flow is predicted to increase, which is true for the Lower Ohio Basin. The rainfall/runoff elasticity (indicator 277) measures the tendency for small changes in precipitation to result in large changes in runoff. These three factors contribute to approximately 92% of the vulnerability for this business line.

Note that some of the indicators contain a suffix of "L" (local) or "C" (cumulative). Indicators with an "L" suffix reflect flow generated within only one HUC-4 watershed, whereas indicators with a "C" suffix reflect flow generated within a HUC-4 watershed and any upstream watersheds. In the case of the Lower Ohio River (HUC 0514), there is a substantial drainage area upstream of the 4-digit HUC.

It is important to note the variability displayed in the VA tool's results (Table 1-7, Table 1-1-8, Table 1-9) highlights some of the uncertainty associated with the projected climate change data used as an input to the VA tool. Because the wet and dry scenarios each represent an average of 50% of the GCM outputs, the variability between the wet and dry scenarios underestimates the larger variability between all the underlying projected climate changed hydrology estimates. This variability can also be seen between the 2050 and 2085 epochs, as well as various other analysis within this report, such as output from the CHAT (Figure 1-27).

Table 1-7. Overall Vulnerability Scores for all Epochs and Scenarios

	Ecosystem Restoration		**Flood Risk Reduction**	
Epoch	**2050**	**2085**	**2050**	**2085**
Dry	70.88	70.28	46.34	44.74
Wet	70.22	70.67	49.36	52.21

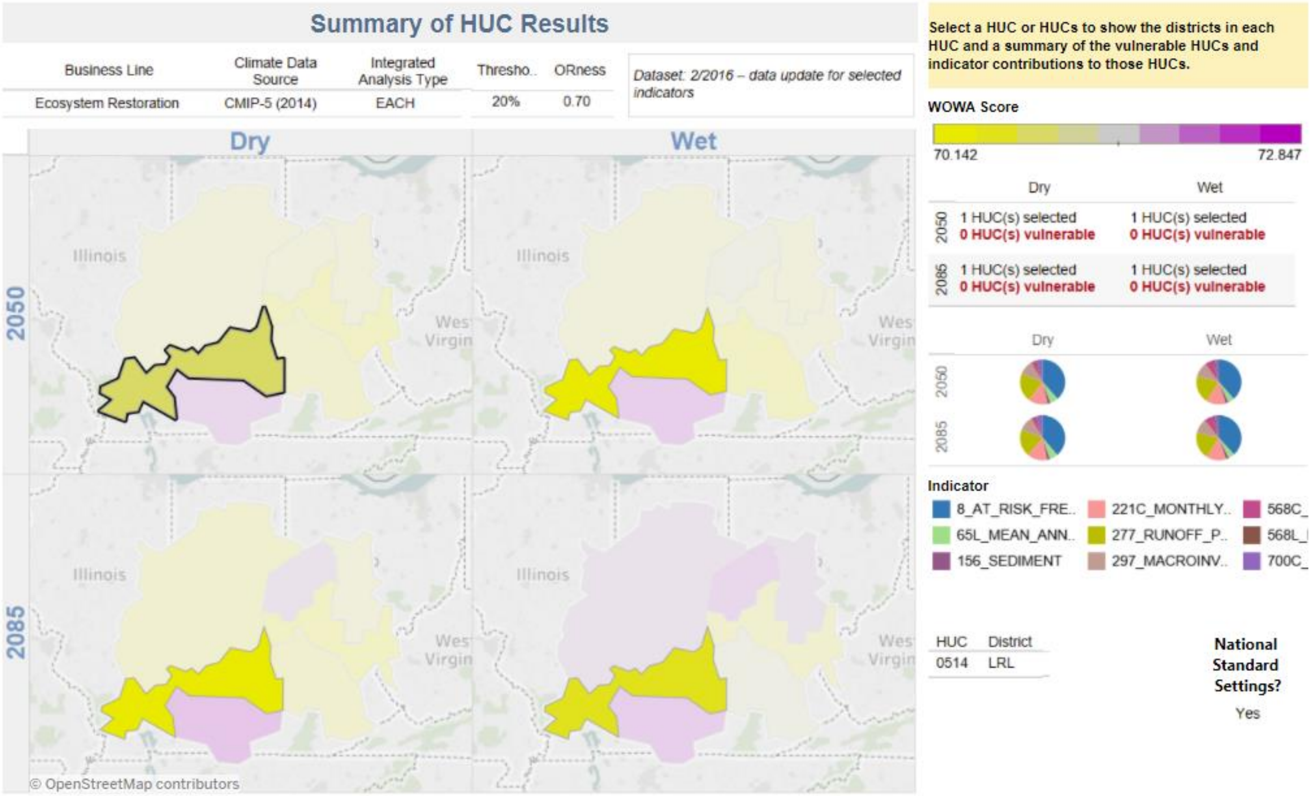

Figure 1-29. VA Tool Summary of HUC Results for Ecosystem Restoration Business Line

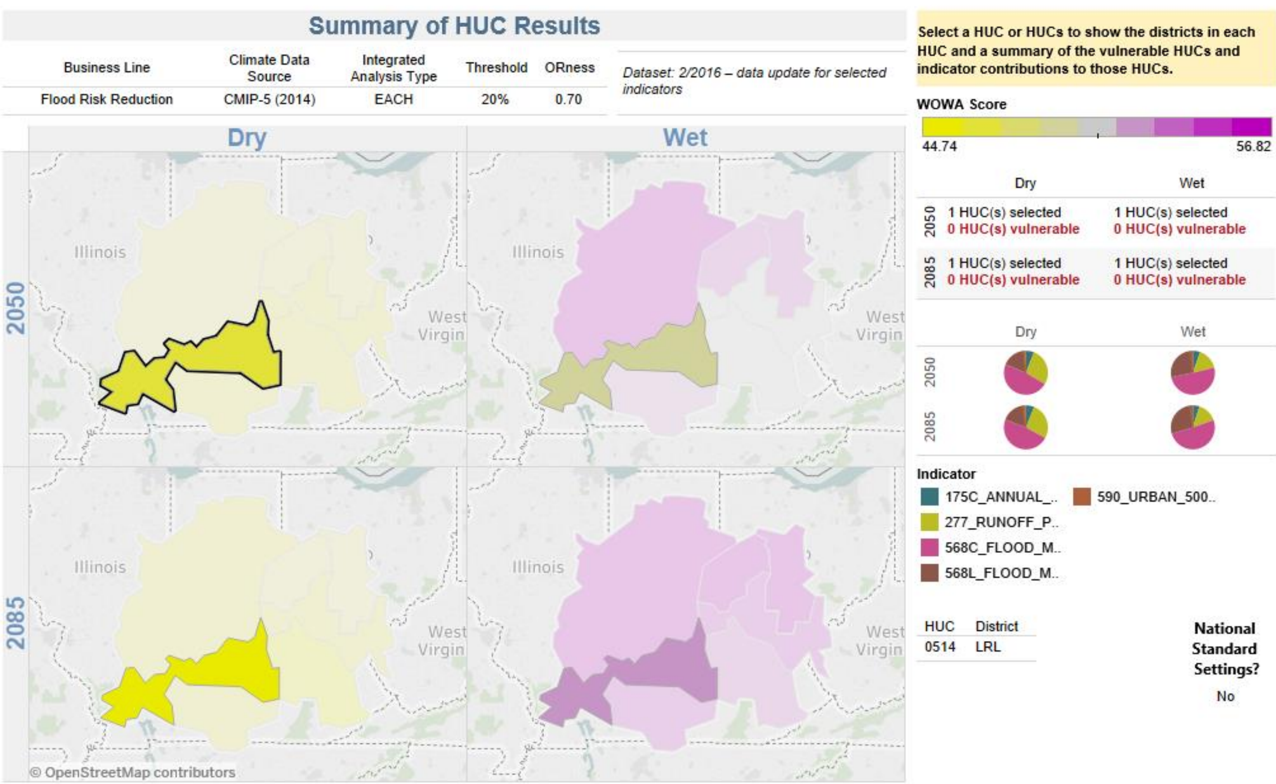

Figure 1-30. VA Tool Summary of HUC Results for Flood Risk Reduction Business Line

Table 1-1-8. Vulnerability Indicators for Ecosystem Restoration Business Line. Sorted by highest to lowest indicator contribution to vulnerability.

Ecosystem Restoration			2050	2050	2085	2085
Indicator Code	**Indicator Name**	**Description**	**Dry**	**Wet**	**Dry**	**Wet**
8	Percent of Freshwater Plant Communities At Risk	Percentage of wetland and riparian plant communities that are at risk of extinction, based on remaining number and condition, remaining acreage, threat severity, etc.	38.47%	38.56%	38.80%	38.31%
277	Percent Change in Runoff Divided by the Percent Change in Precipitation	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	20.60%	19.99%	19.51%	19.50%
221C	Cumulative Monthly Coefficient of Variation of Runoff	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes upstream freshwater inputs (cumulative).	13.85%	14.00%	14.35%	14.31%
297	Macroinvertebrate Index of Biotic Condition	The sum (ranging 0-100) of scores for six metrics that characterize macroinvertebrate assemblages: taxonomic richness, taxonomic composition, taxonomic diversity, feeding groups, habits, pollution tolerance.	10.59%	10.62%	10.68%	10.55%
65L	Local Mean Annual Runoff	Mean runoff: average annual runoff, excluding upstream freshwater inputs (local).	5.87%	4.46%	5.94%	4.43%
568C	Cumulative Flood Magnification Factor	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	2.99%	5.82%	2.91%	6.16%
700C	Low Flow Reduction Factor	Change in low runoff: ratio of indicator 570C (monthly runoff exceeded 90% of the time, including upstream freshwater inputs) to 570C in base period.	4.19%	2.95%	4.36%	3.01%
156	Change in Sediment Load due to Change in Future Precipitation	The ratio of the change in sediment load in the future to the present load.	2.18%	2.19%	2.20%	2.17%
568L	Local Flood Magnification Factor	Change in flood runoff: ratio of indicator 571L (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571L in base period.	1.26%	1.42%	1.24%	1.56%

Table 1-9. Vulnerability Indicators for Flood Risk Reduction Business Line. Sorted by highest to lowest indicator contribution to vulnerability.

Flood Risk Reduction Business Line			2050	2050	2085	2085
Indicator Code	**Indicator Name**	**Description**	**Dry**	**Wet**	**Dry**	**Wet**
568C	Cumulative Flood Magnification Factor	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	47.76%	50.41%	47.81%	50.76%
277	Percent Change in Runoff Divided by the Percent Change in Precipitation	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	27.54%	15.87%	26.80%	14.73%
568L	Local Food Magnification Factor	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	16.78%	26.56%	16.92%	27.71%
175C	Cumulative Annual Covariance of Unregulated Runoff	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).	5.99%	5.38%	6.16%	4.86%
590	Acres of Urban Area Within 500-Year Floodplain	Acres of urban area within the 500-year floodplain.	1.93%	1.77%	2.31%	1.93%

1.4. Summary and Conclusions

Summary of Historic Trends in Hydrometeorology.

Based on the literature review, there is consistent consensus among the available sources supporting trends of increasing, historically observed temperatures within the region. Observed changes in historic precipitation and streamflow have more uncertainty associated with them. There are substantial indications that increasing trends in rainfall have occurred. The increasing trends indicated within the literature review appear to be validated by analysis of observed rainfall data collected within the project area; as statistically significant increasing trends were found in the spring and autumn seasonal average precipitation datasets.

Significant changes in urban streamflow have also been observed by the nonstationarity detection tool as well as by the climate hydrology assessment tool, however these changes are largely attributed to changes in land use and urbanization and cannot be attributed solely to the impact of anthropogenic climate change. Other nearby stream gages outside of the project area, such as Floyds Fork at Fisherville, which did not experience the same extent of urban development, do not exhibit the same increasing trends or nonstationarities within their periods of record. No trends were found within the period of record reported along the Ohio River at Louisville. Therefore, the observed changes in streamflow detected within the streamflow records collected along tributaries to the Ohio River are thought to be caused largely by the localized, rapid urban development and changes to land usage within the interior drainage area beginning in the 1950's, and the future hydrologic condition within the study area will likely be held constant due to local regulations on development that MSD has in place. MSD requires all new development to provide mitigation for increased runoff, as well as floodplain compensation for development in both the existing and fully developed floodplains.

Summary of Projected Trends in Hydrometeorology.

Regarding projected future trends, there is generally a consensus of increasing trends in temperature and precipitation. Additionally, the frequency of intense storms is projected to increase. These changes will likely vary seasonally, with greater increases in the winter and spring months. There is less consensus regarding trends in streamflow, however an assessment of projected mean annual maximum monthly streamflows within the study area demonstrates evidence of increasing streamflow peaks. It should be noted that substantial uncertainty exists within future climate projections, this uncertainty is effectively illustrated by the range of GCM peak annual streamflow projections shown in Figure 1-27. At this time, each of the 93 climate projections included in this figure's range can be considered equally likely to occur.

Results from the USACE Vulnerability Assessment tool were analyzed for the project area and found no outstanding vulnerabilities compared with other HUCs across the continental United States. While the project area is not within the top 20% of vulnerable HUCs nationally, that does not imply that vulnerability to climate change does not exist. The VA tool indicates that the percent of freshwater plant communities at risk, combined with the rainfall/runoff elasticity, intra-annual variability of runoff, and biological condition of macroinvertebrate are driving ecosystem restoration vulnerability. Likewise, vulnerability for the flood risk reduction business line is driven by future streamflow and precipitation.

Summary of Residual Risk/Implications to the Study Area.

Beargrass Creek flows into the Ohio River and is a part of the HUC 0514 Lower Ohio Watershed, so in addition to being affected locally, the Beargrass Creek Watershed is affected regionally due to the backwater on the Ohio River. Generally, the literature supports trends of increasing observed temperatures and precipitation in the region. Additionally, projected climate change trends for the HUC 0514 watershed and region estimate a mean annual air temperature increase from 0 to 14.4°F by the latter half of the 21st century. Most studies project increases in precipitation, especially during the winter and spring seasons, and most projections trend toward more intense precipitation events which results in more common floods and droughts. The observed streamflow from the CHAT has not historically been increasing, but the streamflow from the CHAT is projected to increase Risks associated with the projected climate change were discussed in the different literature and are summarized in the sub-sections and table below.

Residual Risk/Implications for Ecosystem Restoration

The projected increase in the mean annual air temperature can allow for less temperate plant species to move northward and replace more temperate species. Warmer air temperatures will also affect the movement and interactions between different types of organisms. Warmer air temperatures can also misalign the phenology the ecosystem and organisms which can cause a reduction in native species. Higher temperatures and drought periods will increase evapotranspiration and could stress ecosystem restoration implementations. The projected increased intensity of rainfall events and droughts can make it difficult for wetlands to survive and can disrupt riverine communities. Without connected floodplains, higher flows and increased flooding can be devastating to stream habitat because stream power is confined, and increased stream bank and bed scouring occurs. The potential increased flow can be beneficial for fish reproduction but can be detrimental to mussels and fish is stream scouring occurs. Additionally, higher turbidity can stress organism reproduction. Higher precipitation can restore greater connectivity for wetland implementation but can also increase the rate of eutrophication and eventual sedimentation of the wetlands shortening the lifespan of these habitats. Extreme precipitation can lead to increased sediment and nutrient runoff, affecting the water quality of the streams. Drought and extreme heat can lead to tree mortality, and aquatic life mortality. Prolonged inundations can lead to lack of oxygen also leading to mortality in plant communities and aquatic life. Temperature and precipitation change can lead to an increase of more resilient invasive species and a decrease in native species, which will in turn lead to less biodiversity.

Residual Risk/Implications for Flood Risk Reduction

An increase in temperatures will cause more precipitation to be rain versus snow which can lead to an increase in streamflow. The growing number of extreme rainfall events is stressing deteriorating infrastructure in the Southeast United States. Many transportation and storm water systems have not been designed to withstand the events which poses a greater risk of failure. Statistical methods have been developed for defining climate risk and frequency analysis that incorporate observed and/or projected changes in extremes. However, these methods have not yet been widely incorporated into infrastructure design codes, risk assessments, or operational guidelines. The CHAT on the observed data shows no significant trend, so infrastructure design that uses recent historic data may underrepresent the risk.

Vulnerability Assessment Indicators

The vulnerability assessment focused on the ecosystem restoration and flood risk reduction business lines as these business lines directly relate to the study project and can be affected by future with or without project. The significantly contributing indicators pertain to the conditions of the ecosystem such as the percent of at risk freshwater plant communities (contribution ~38.5%) and the biological condition of the macroinvertebrate (contribution ~10.6%), as well as the hydrologic conditions such as the rainfall/runoff elasticity (contribution ~ 20%), and the intra-annual variability of runoff (contribution ~14%).The flood risk reduction vulnerability significantly contributing indicators pertain to the hydrologic conditions such as the flood magnification factor, both local and cumulative, (contribution ~71.2%) and the large elasticity between rainfall and runoff (contribution ~21.2%).

It is important to note, that despite the potential risk due to the projected climate change, most ecosystem restoration project implementations would relieve some of the residual risk for the ecosystem restoration and flood risk reduction business lines. Designs should be flexible and resilient enough to accommodate the potential effects of climate change.

Table 1-10 displays the residual risk table to the project due to climate change. This table lists potential climatic triggers, hazards, harms, and approximate qualitative likelihood of occurrence. The table is primarily focused on the business line of interest, ecosystem restoration, however that is not to say that other USACE business lines will not be impacted by climate change. Because this qualitative analysis is focused on the Beargrass Creek Ecosystem Restoration study as a whole, only generic project features have been identified within the table. The right-most column of the table indicates the qualitative likelihood that an event will occur, these are based largely upon the findings within the literature review and various climate assessment tool outputs.

Summary of Recommended Plan Improvements to Climate Change Resilience.

In response to potential impacts due to climate change, various considerations can be made to improve features' resilience to future conditions. These conditions may include increases in variability of precipitation and changes to the frequency and magnitude of extreme flood and drought events. Variation in wetland depth and diverse native plantings improve the project's ability to be flexible to changing future conditions. Other aspects of design to increase resilience will be considered during future engineering design phases of this project.

Many risks to ecosystem function and form are expected as a result of climate change; however, the Recommended Plan alternatives proposed through this study enable the Beargrass Creek Watershed environment to be more resilient to the impacts of climate change. In general, these ecosystems have been evolving and adapting to changes in the environment and can shift to a changing climate in the future depending on the extent to which the climate changes. In addition to these communities' natural resilience, the alternatives proposed reduce some of the non-climate related stressors such as urbanization, invasive species, and degraded stream form and function. Reducing these stressors allows for the various plant and animal communities to be more resilient to a changing climate.

The overall objective of this study is to improve riverine and riparian habitat through higher quality native communities and better connectivity. Although, more frequent intense precipitation events are expected and could result in higher velocities and more extreme bank erosion, the implementations of R2 and R4 alternatives proposed cut banks down and removes obstructions to the floodplain allowing flood waters to access to the floodplain at lower elevations making the channel more resilient against increased precipitation and more frequent precipitation events. The proposed riverine alternatives should result in reduced velocities, which will protect the channel from harmful bank erosion through advancing channel evolution from a degraded channel to an ecologically improved and more sustainable state. In-stream habitat features will need to be anchored-in or strategically placed to accommodate a future condition of increased streamflow. Creation and improvement of riffle-pool complexes will be valuable for biologic communities during both flood and drought events, where slow moving water and deep pools can offer shelter and relief from unforgiving conditions. This increase in habitat diversity and refugia will be of increased value in a future where stream flow and temperature conditions may be more harsh than they are currently.

More frequent intense rainfall events will most likely result in greater nutrient loading to the stream. The improvements proposed to riparian areas and addition of wetland structure within the watershed will also make the system more resilient to these increased nutrient loads through natural filtering. Specifically for wetlands, the projected increase in precipitation and runoff could lead to rates of eutrophication being higher than present values. This eutrophication is driven by nutrient loading to the wetland and could increase stress of these habitats. Increased runoff, and deposition of sediment carried by this runoff, can also shorten the lifespan of wetlands as they fill in with sediment at an increased rate. Although sedimentation and eutrophication can threaten wetland habitat, it should be noted that these wetlands still act as buffers for stream habitat which would otherwise receive the sediments and nutrients were the wetlands not present.

A few of the proposed H2 alternatives include the removal of impervious surface, specifically at the confluence site (X2) and the concrete channel site (X22). Removal of impervious surface reconnects the surface to baseflow recharge, which improves the baseflow conditions within the stream. Removal of impervious surface also improves the riparian buffer around streams improving riverine habitat.

A major risk to the ecosystem from climate change is increased temperatures and is probably the most likely change based on the literature synthesis. The proposed Recommended Plan alternatives provide resilience to increased temperatures in several ways. The reduction in impervious area and increase in areas of native plant communities will help to reduce the urban heat island effects. Shading from riparian plantings such as bottomland hardwood forest will provide shading to streams, which will allow the streams to maintain lower more normal temperatures and healthy dissolved oxygen levels. More frequent and sustained droughts are a potential risk of climate change. The improvement of the riparian areas of the streams and increase areas of wetland structure will retain water longer making the impacts of drought less severe. Consideration should be given to projected climate change when selecting plant species. Additionally, increasing the connectivity and size of natural plant communities provides corridors for migration of plant and animal populations as their ranges change in response to climate changes.

Urbanization within Beargrass Creek Watershed is relatively intense and is generally built out from a hydrologic perspective. The construction of the proposed Recommended Plan alternatives will include an easement that protects these lands in perpetuity. Additionally, through the process of urbanization, carbon has been stripped from the soil over years of clearing, regrading, and the addition of hardened surfaces. The addition of native trees and plant communities will return carbon back to the soil healing the soil and providing increased carbon sequestration.

Adaptive management planning is part of plan formulation and alternatives and includes a maximum of 10 years of monitoring plan prior to release of the project to the non-federal sponsor. Most of the time only acute changes in weather are addressed during this adaptive management period. However, if changes resulting from climate change are observed, improvements to the implementations can be made more resilient to the observed changes. Beyond the adaptive management period, USACE will provide an O&M manual where indicators of climate change and retroactive responses to climate change can be documented for the non-federal sponsor.

Table 1-10. Residual Risk Table for the Beargrass Creek Ecosystem Restoration Study

Feature or Measure	Trigger	Hazard	Harm	Likelihood
Riparian and riverine implementations	Frequent drought periods, higher temperatures Increased precipitation Increased extreme precipitation events	Future evapotranspiration may be larger than present Future rates of eutrophication can be higher than present Increased duration and intensity of flooding	Riparian implementations could have difficulty surviving in drought; riverine implementations could have disrupted connectivity Increased rates of filling of riparian implementations and shortening lifespan of these habitats Riparian project implementations could have difficulty surviving in extreme flood conditions.	Likely, but Recommended provides resilience Likely, but Recommended Plan provides resilience Likely, but Recommended Plan provides resilience
Riverine aquatic habitat	Increased extreme precipitation events and increased streamflow	Future velocities may be larger than present and increased stream bank scouring	Establishment of a normal life cycle would be more difficult. Normal life cycle includes spawning, embryo and larva, and juvenile development. Additionally, could stress the reproductive and feeding processes of adult species. Temporary changes to streams through bank erosion or channel reforming; however, species will temporarily adjust and then return to normal riverine state once the system returns to a dynamic equilibrium.	Likely, but Recommended Plan provides resilience
Aquatic organisms and plant communities	Increased temperatures	Phenology can be misaligned	Organisms dependent on certain phases of plant cycles and seasonal timing will be stressed when phenology of the plant community changes.	Likely, but not expected to be outside of habitable ranges

Feature or Measure	Trigger	Hazard	Harm	Likelihood
	Increased temperatures	Frequent drought and extreme heat periods	Tree and aquatic life mortality	Likely, but not expected to be outside of habitable ranges
	Increased extreme precipitation events	Increased duration and intensity of floods	Prolonged inundations can lead to lack of oxygen leading to mortality in plant communities and aquatic life	Likely, but not expected to be outside of habitable ranges
Native vegetation	Overall increase in precipitation, and more frequent extreme precipitation and drought events	Stress native vegetation	Could result in loss of native vegetation/biodiversity and the re-establishment of invasive species better suited for future hydrologic conditions	Likely, but Recommended Plan provides resilience
Floodwater storage area	Increased urbanization within existing flood prone areas	Increased urbanization leads to further development of flood prone areas	Increased development within flood prone areas increases flood damages and frequency of flooding.	Likely, but Recommended Plan provides resilience

1.5. References

Drum, R. G., J. Noel, J. Kovatch, L. Yeghiazarian, H. Stone, J. Stark, P. Kirshen, E. Best, E. Emery, J. Trimboli, J. Arnold, and D. Raff (2017), Ohio River Basin–Formulating Climate Change Mitigation/Adaptation Strategies Through Regional Collaboration with the ORB Alliance, Civil Works Technical Report, CWTS 2017-01, U.S. Army Corps of Engineers, Institute for Water Resources. May 2017.

Fourth National Climate Assessment, Volume II, Chapter 2, National Topics: Our Changing Climate, 2018.

Fourth National Climate Assessment, Volume II, Chapter 3, National Topics: Water, 2018.

Fourth National Climate Assessment, Volume II, Chapter 24, Southeast Region, 2018.

Laughlin S, Loechle J, Buckler J. CH2M Hill. (2015) Analysis of Historical Precipitation Intensity-Duration Frequency for Jefferson County, Kentucky.

Laughlin S, Loechle J, Buckler J. CH2M Hill. (2015) Analysis of Projected Changes in Precipitation IDF Values Based on Climate Change Projections.

U.S. Army Corps of Engineers, Climate Hydrology Assessment Tool (CHAT). Issued 2016.

U.S. Army Corps of Engineers, Climate Preparedness and Resilience (CPR) Community of Practice (CoP) Applications Portal. https://maps.crrel.usace.army.mil/projects/rcc/portal.html

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

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

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

U.S. Army Corps of Engineers, Nonstationarity Detection (NSD) Tool and User Guide. Version 1.2. Issued May 2016, updated September 2018.

U.S. Army Corps of Engineers, Semi-Quantitative Risk Assessment (SQRA) of Louisville Flood Protection System. November 2019.

U.S. Army Corps of Engineers, Vulnerability Assessment (VA) Tool and User Guide. Version 1.1. Issued November 2016.

U.S. Army Corps of Engineers, Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions, Ohio Region 05. January 2015.

U.S. Army Corps of Engineers, Time Series Toolbox, Trend Analysis and Nonstationarity Detection. 2018.

U.S. Army Corps of Engineers website with climate impact analysis tools: https://maps.crrel.usace.army.mil/projects/rcc/portal.html

U.S. Army Corps of Engineers Louisville District, Qualitative Assessment of Climate Change Impacts on the Willamette River Basin, Oregon. 2019.

U.S. Census Bureau, Decennial Census, Population for Louisville Kentucky. 2019.

White K, Arnold J, CDM Smith (2015) Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Ohio Region 05.