CORALVILLE LAKE
WATER CONTROL UPDATE REPORT
WITH INTEGRATED ENVIRONMENTAL ASSESSMENT

CORALVILLE LAKE
IOWA CITY, IOWA

APPENDIX A

CLIMATE CHANGE IMPACT ASSESSMENT

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APPENDIX A

CLIMATE CHANGE IMPACT ASSESSMENT

I. BACKGROUND

Recent scientific evidence shows that in some places and for some impacts relevant to U.S. Army Corps of Engineers (Corps) operations, climate change is shifting the climatological baseline about which natural climate variability occurs, and may be changing the range of variability as well. This is relevant to the Corps because the assumptions of stationary climatic baselines and fixed range of natural variability, as captured in the historic hydrologic record may no longer be appropriate for long-term projections of flood risk, drought and environmental flows. An assessment of climate change impacts, described herein, is needed to support an update to the Coralville Lake Water Control Plan. Specifically, this assessment is needed to verify the appropriate period of analysis for the updated Regulated Flow Frequency Study found in Appendix B, *Hydrology & Hydraulics*.

Climate Change impacts on the hydrology of the Iowa-Cedar River Basin were evaluated in accordance with the Corps' Engineering and Construction Bulletin 2018-14, *Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs and Projects* (Reference 7), and Engineering Technical Letter (ETL) 1100-2-3 *Guidance for Detection of Nonstationarities in Annual Maximum Discharges* (Reference 8).

The Corps' current policy is to interpret and use climate change information for hydrologic analysis through a qualitative assessment of potential climate change threats and impacts potentially relevant to the particular Corps project for which the hydrologic analysis is being performed. As indicated in Figure A-1, qualitative analysis required includes consideration of both past (observed) changes as well as potential future (projected) changes to relevant hydrologic inputs.

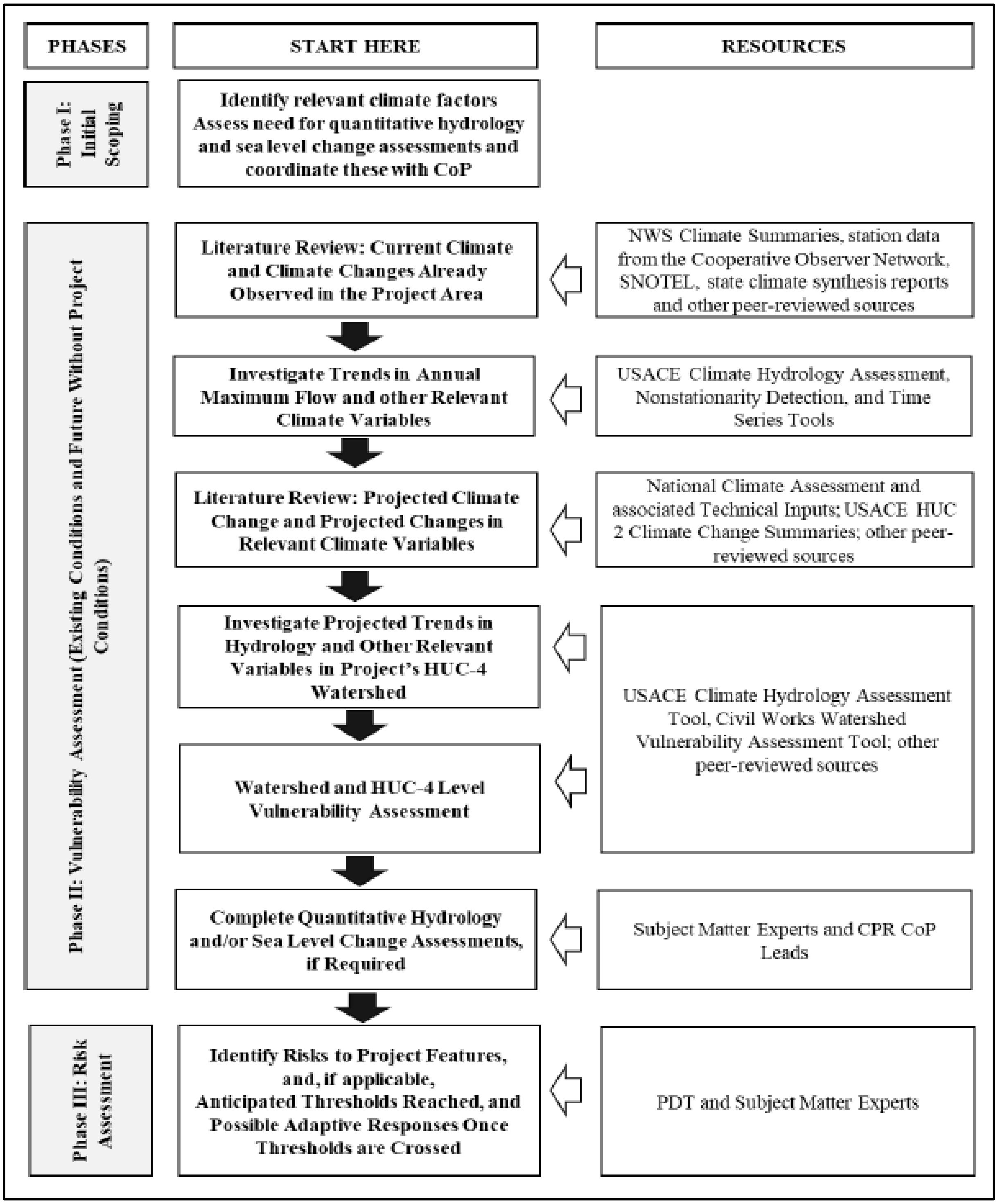

Figure A-1: Flowchart for Conducting a Qualitative Assessment of Climate Change Impacts In Inland Hydrologic Analyses (Reference 6)

II. PHASE I ASSESSMENT: RELEVANT CLIMATE VARIABLES

Reservoir regulation and release considers several constraints including downstream channel capacity, flood stage at downstream control points, pool level, maximum outflow change requirements and minimum low-flow requirements. Changes to the frequency and/or magnitude of incoming flows, due to both land use/land cover and climate change, have the potential to change the frequency of reservoir operations. Relevant climate variables for assessing changes in inflow to Coralville Reservoir include streamflow in addition to precipitation and temperature. Although streamflow is the primary climate variable driving reservoir release, precipitation and temperature influence the temporal distribution and abundance of streamflow. Temperature and precipitation are unique variables in that they reflect trends influenced purely by climate, whereas changes in land use/land cover as well as climate can influence trends in streamflow.

III. PHASE II ASSESSMENT: LITERATURE REVIEW

A literature synopsis was generated to summarize published conclusions regarding observed trends as well as projected trends in climate variables for the Iowa-Cedar River Basin.

A. Corps Climate Change and Hydrology Literature Applicable to U.S. Army Corps of Engineers Mission – Upper Mississippi Region 07 (Reference 5)

The Corps Climate Change and Hydrology Literature Synthesis for Upper Mississippi Region 07 summarized the climate change literature for the region regarding observed temperature, precipitation, and hydrology and projected temperature, precipitation, and hydrology (Figure A-2).

- Summary of Observed Temperature: the majority of authors reported increasing trends in observed air temperature including increasing daily minimum and mean temperatures, and a decreasing trend in maximum temperatures.

- Summary of Observed Precipitation: strong consensus between authors of a large increasing trend in precipitation.

- Summary of Observed Hydrology: strong consensus between authors showing an increasing trend in observed low, mean, and peak streamflow.

- Summary of Projected Temperature: strong consensus between authors showing an increase in temperatures over the next century.

- Summary of Projected Precipitation: general consensus between authors showing an increase in projected annual and extreme precipitation.

- Summary of Projected Hydrology: no clear consensus between authors as some studies project an increase in streamflow as a result of higher precipitation while other studies project a decrease in streamflow as a result of increased evapotranspiration. Multiple authors suggest increases in streamflow in the winter and spring and decreases in summer streamflow.

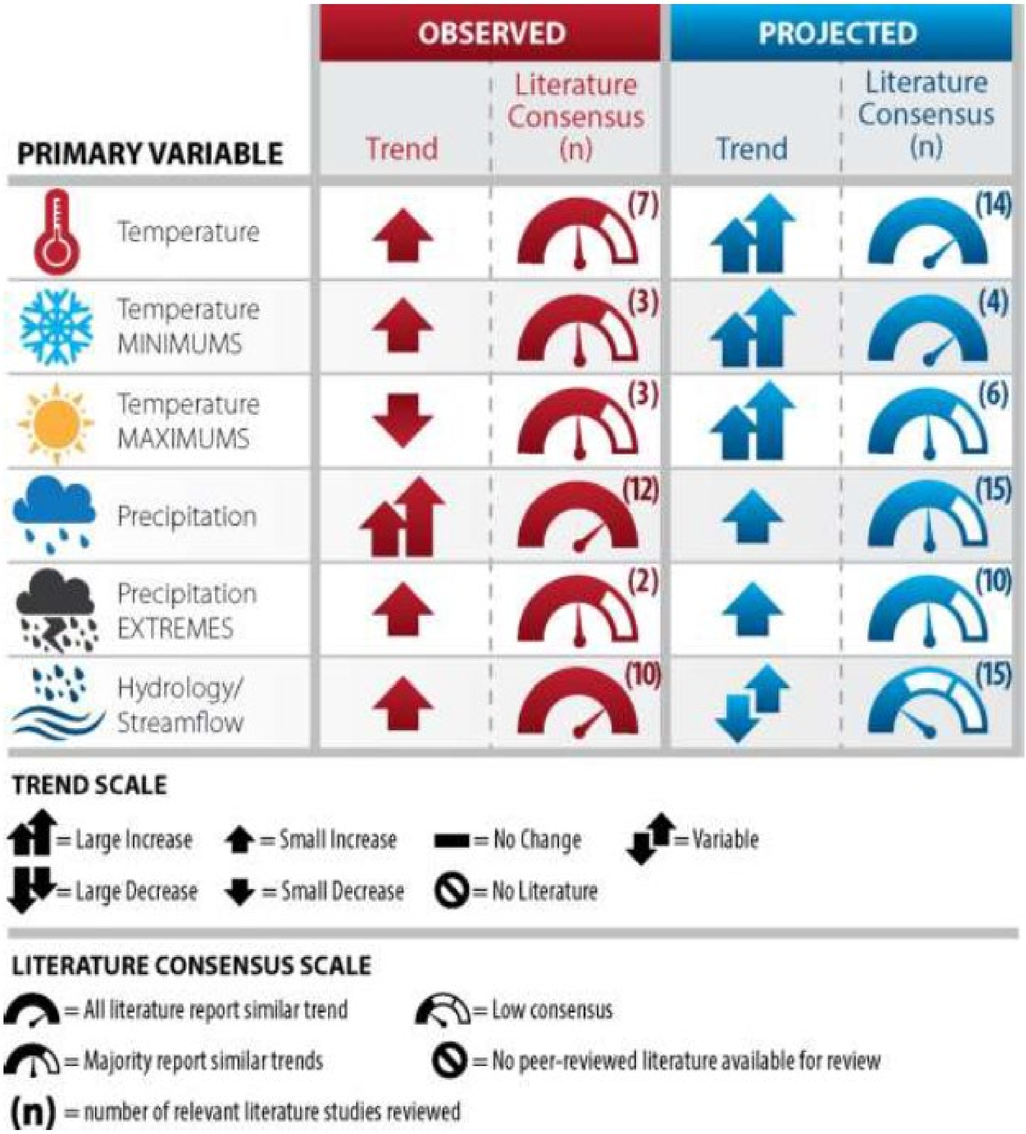

Figure A-2: Summary of Climate Literature Consensus for the Upper Mississippi Region 07 (Reference 6, page 41)

B. USGS Flood Trends Report: Fragmented Patterns of Flood Change Across the United States (Reference 1)

The USGS conducted an assessment to determine if changes in flood magnitudes were consistent across certain geographic regions of the United States. The study concluded that there were changes in trends at specific locations for peak magnitude, frequency, duration and volume of frequent floods. However, the study indicated no evidence that these sites were related geographically.

The study analyzed regions of the United States based on grid cells and the stream gages located within each cell (Figure A-3). The Iowa-Cedar River Basin is spread over three cells in this analysis; there is no consensus among the cells showing there is or is not statistically significant trends in flood frequency, peak magnitude, duration, or volume. The grid cell that covers the southeast portion of the Iowa-Cedar River Basin shows a statistically significant trend (p<0.1) for flood frequency, peak magnitude, duration, and volume. However, the majority of this grid cell is located in western Illinois and northeastern Missouri and covers only the mouth of the Iowa-Cedar River Basin. Therefore, the gages in this grid cell may not be an accurate representation of the Iowa-Cedar River Basin. In addition, the detailed gage analysis conducted in the Phase II Assessment and outlined in Part IV of this appendix is more representative of the observed hydrology in the Iowa-Cedar River Basin than this generalized USGS streamflow study.

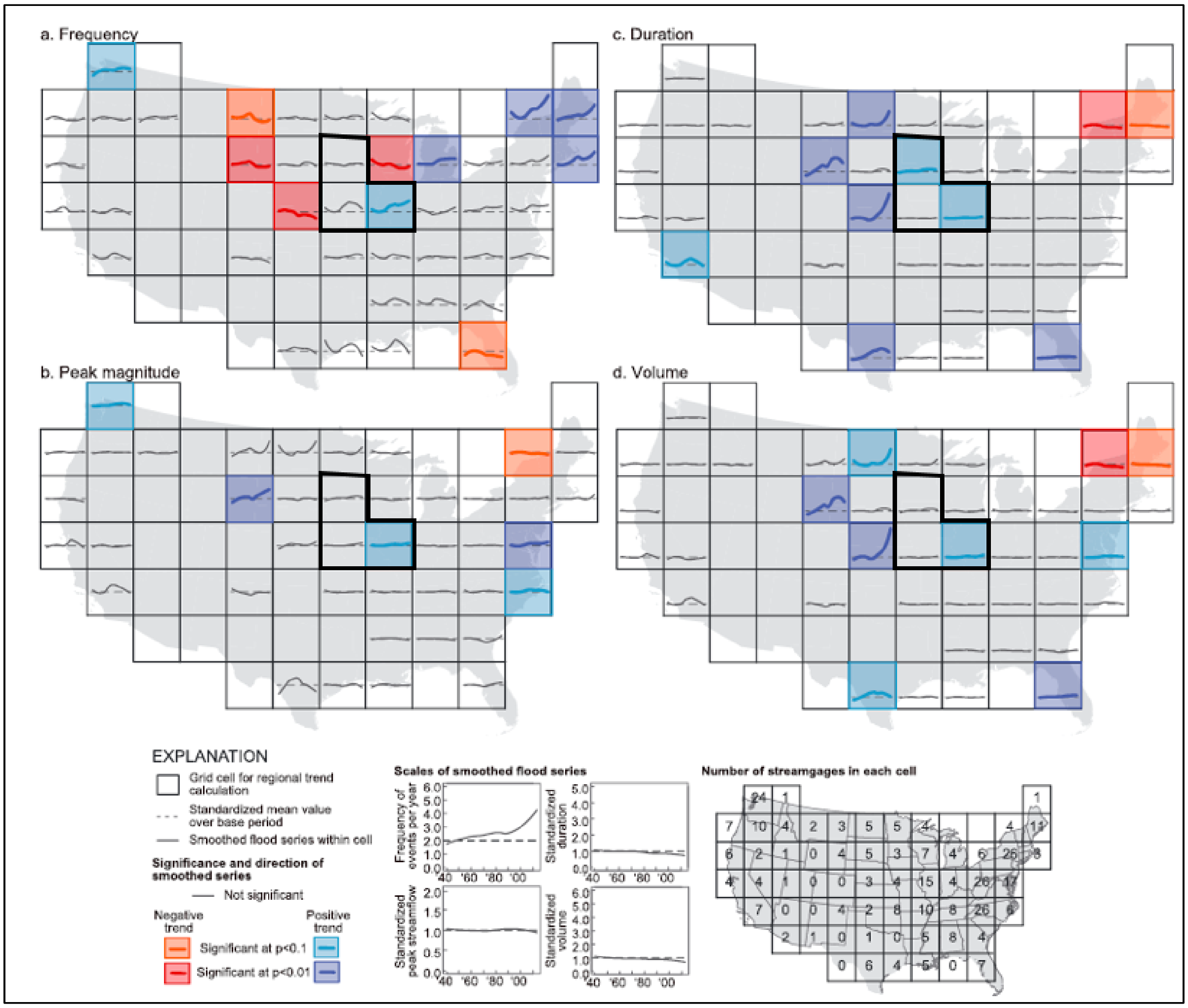

Figure A-3: Regional Changes in Floods Across the United States (1940-1969 vs 1970-2013)
(Reference 1, page 10,234)

C. Climate Change Impacts in the United States: The Fourth National Climate Assessment – Chapter 21: Midwest (Reference 3)

The Forth National Climate Assessment (NCA4), Volume II was released in 2018 and assessed climate impacts across the different regions of the United States. The Iowa River Basin is located entirely within the Midwest region for the National Climate Assessment.

The Forth National Climate Assessment reports observed increasing humidity, with dew point temperatures increasing in all seasons throughout the Midwest. Throughout the United States, projected changes in annual average temperature, annual maximum temperature and 0.1 probability 5-day maximum temperature are highest in the Midwest. Annual precipitation across the Midwest region has observed increases of 5% to 15%, with similar increases projected by late century (2070-2089). Since 1901, both frequency and intensity of heavy precipitation events have increased and are projected to continue to increase. There is very high confidence that increases in warm-season absolute humidity and precipitation very likely have resulted in soil erosion. The NCA4 reports there is very high confidence that flood risk is increasing in the Midwest, however the relative contributions from climate change and land-use change remain uncertain. Projected increases in the frequency and magnitude of heavy precipitation are likely to further increase flood risk in the future.

D. 2010 Climate Change Impacts on Iowa 2010 (Reference 4)

The 2010 Climate Change Impacts on Iowa documents a long-term upward trend in temperature and further reports that long-term winter temperatures have increased six times more than summer temperatures (Figure A-4). Since 1970, nighttime temperatures have increased more than daytime temperatures, driving the upward trend in daily average temperatures. The 2010 Climate Change Impacts on Iowa report illustrates a long-term upward trend in precipitation for the state, with Eastern Iowa having an even higher upward trend than the statewide average. Over the last 40 years, an increase in summer heavy precipitation has been documented. Increased extreme precipitation events have the potential to cause increased erosion of agricultural fields and runoff of nutrients, pesticides and herbicides.

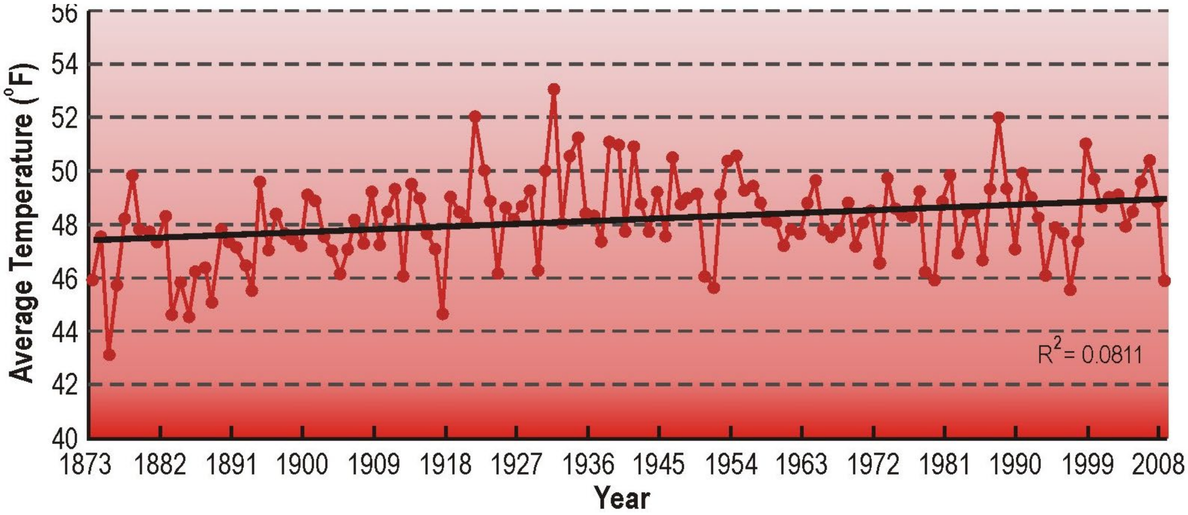

Figure A-4: Annual Average of Iowa's State-wide Daily Average Temperatures (°F) from 1873-2008 (Reference 4, page 10)

E. 2017: Iowa State Climate Summary (Reference 5)

National Oceanic and Atmospheric Association's (NOAA) 2017: Iowa State Climate Summary reported an increase in average annual temperatures of about 1°F over the last two decades (Figure A-5). Average annual temperatures are projected to increase, resulting in projections of increased intensity of future droughts. NOAA's 2017 State Climate Survey for Iowa reports an observed increase in the frequency of extreme precipitation events and projects increased precipitation, with the largest increases expected in spring and winter as well as an increase in the frequency of extreme precipitation in the future. The occurrence of more frequent extreme precipitation during spring could produce increased erosion in agricultural watersheds when delays in planting result in fallow fields.

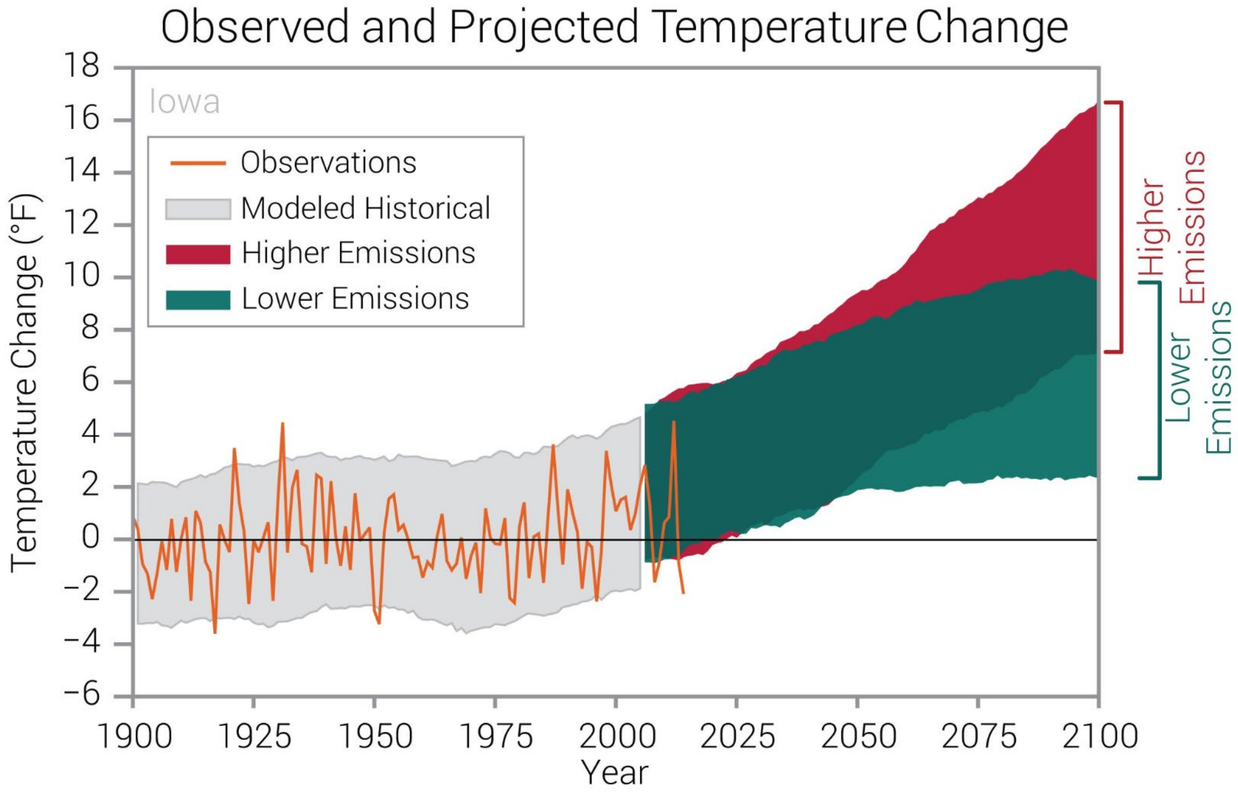

Figure A-5: Observed and Projected Average Annual Temperature in Iowa (Reference 5, page 1)

IV. PHASE II ASSESSMENT: TRENDS IN OBSERVED CLIMATE VARIABLES

This portion of the climate change assessment focuses on carrying out first order statistical analyses using streamflow records observed at USGS gages within the Iowa-Cedar River Basin, daily inflows to the Coralville Reservoir computed by the Rock Island District's (District) HEC-ResSim model, and temperature and precipitation records observed at the Iowa City National Weather Service (NWS) Coop Gage (#134101).

A. Assessment of Trends and Detection of Nonstationarities in Observed Streamflow Records (References 2 and 9)

The Corps' Time Series Toolbox (TST) statistical tests were applied to assess for monotonic trends in observed annual maximum discharge at each of the long-term gage sites (Reference 9). The regression tests used by the TST include the test for traditional simple linear regression used by the Climate Hydrology Assessment Tool (CHAT) and the Mann-Kendall and Spearman-Rank Order tests (Reference 10) for monotonic trend significance as used by the Nonstationarity Detection (NSD) Tool (Reference 2). In addition to performing the same trend analysis functions as the CHAT and NSD, the TST uses a Sen's slope regression to fit the data.

The TST was also used to apply tests for nonstationarity to determine whether observed flows in the Iowa-Cedar River Basin between water years (WY) 1905 and 2019 are representative of stationary hydroclimatic conditions. The statistical tests for nonstationarity applied by the TST are the same as those applied by the Corps' NSD Tool (Reference 2). However, the TST allows the user to extend the period of record (POR) beyond the current NSD analysis period (WY 2014/2015), and the option to analyze different annual time series datasets, such as volume-duration or meteorologic data. The TST applies these same statistical tests for nonstationarity to other annual time series of interest. Reservoir water control operations are generally driven by longer term flood volumes, therefore the TST was used to assess stationarity of the 7-day and 15-day volume-duration annual maximum flow records.

Stationarity of the flow records within the Iowa River Basin assessed using the TST apply a series of nonparametric statistical tests to the observed flow record at three, relatively "pristine", long-term gage sites upstream of Coralville Reservoir, as well as to daily inflows to the Coralville Reservoir computed by the District's HEC-ResSim model. Streamflow records are described as "pristine" when there are minimal man-made flood control structures impacting flows. The flow records at these "pristine" sites may be affected by other anthropogenic activities, such as land use changes and alterations in agricultural practices, and this is why they are referred to as "relatively pristine"; only known man-made flood control structures were considered in identifying relatively "pristine" gage sites. All three of these "pristine" sites are on the Iowa River. A fourth gage also located on the Iowa River was excluded from the analyses due to an insufficient length of record (Iowa River at County Highway E49 near Tama, IA). Statistical tests were also applied to flow records from four gage sites on the Iowa River, downstream of Coralville Dam, in order to determine if the detection tool identifies the construction of the dam as a change point. Two "pristine" gage sites along the Cedar River, and one gage on the English River were also included in the nonstationarity assessment. For the assessment of the "pristine" gage sites and the HEC-ResSim-computed inflows, any detected nonstationarities should not be caused by the construction of a water resource project. A detected nonstationarity could be associated with a widely distributed land use/land cover change and/or climate change. Figure A-6 and Table A-1 describe the gages located within the basin, identify those that were included in the trend assessment and nonstationarity detection analyses, and describe why certain gages were excluded.

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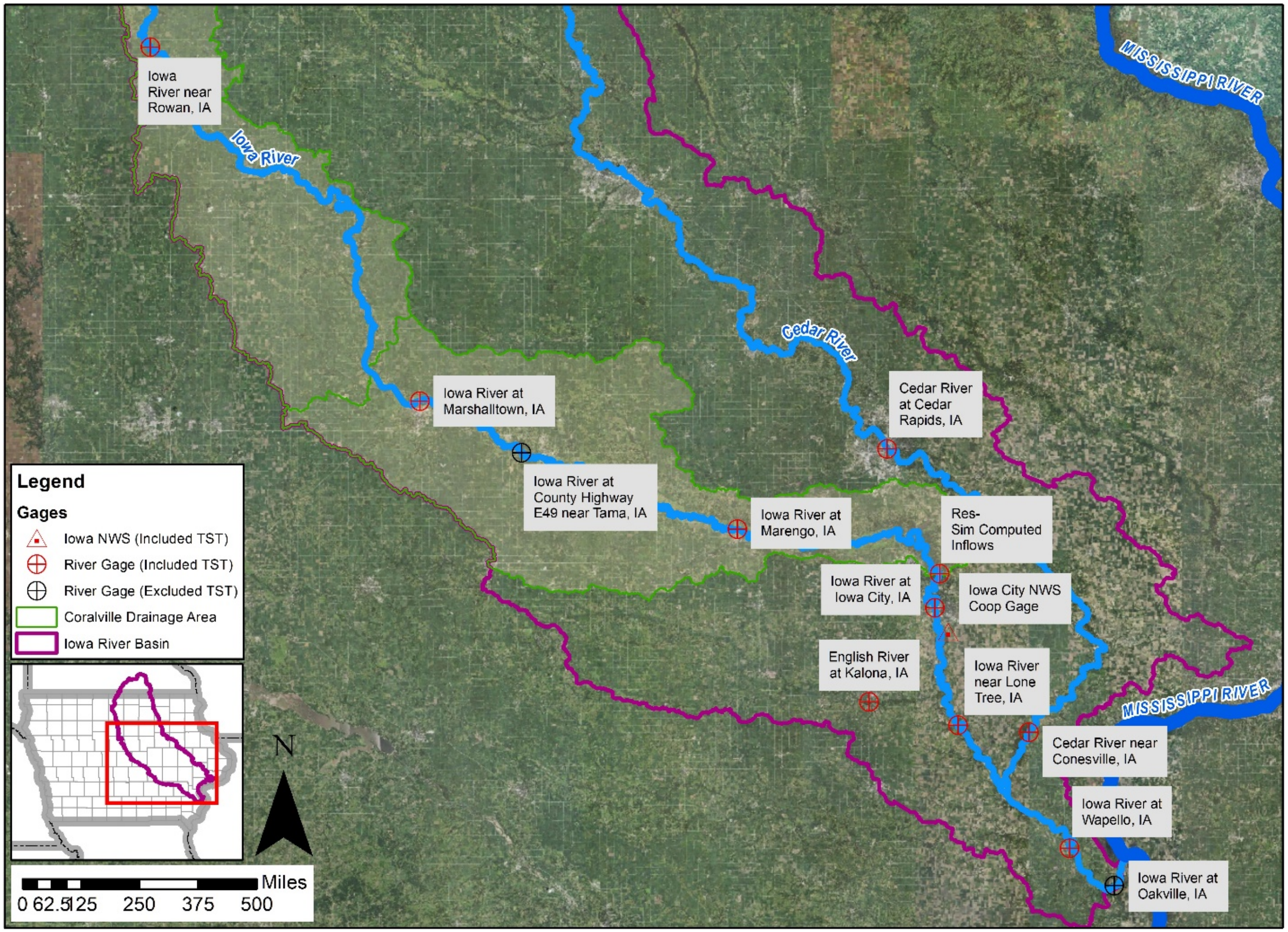


Figure A-6: Current USGS flow gages for the Iowa River Basin and Major Tributaries from Rowan, IA to Oakville, IA Gages included in the Nonstationarity Detection Analysis are highlighted in red.

Table A-1: USGS Stream Gages on Iowa River, Major Tributaries and Cedar River from Rowan, IA to Oakville, IA (upstream to downstream)

Current gages included only annual peak streamflows through 2019 at the time of the analysis.

USGS Gage Name	USGS Gage Number	Period of Record (WY)	Included in Nonstationarity Detection	Reason for Exclusion/*Notes
Upstream of Coralville				
Iowa River near Rowan, IA	05449500	1941-2019*	Yes	*1977 missing, analysis completed for 1941-2019
Iowa River at Marshalltown, IA	05451500	1915-2019*	Yes	*1928, 1931 & 1932 missing, analysis completed for 1915-2019
Iowa River at County Hwy E49 near Tama, IA	05451770	2012-2019	No	Short POR
Iowa River at Marengo, IA	05453100	1957-2019	Yes	
HEC-ResSim Computed Inflows	CRVI4	1905-2019	Yes	
Downstream of Coralville				
Iowa River at Iowa City, IA	05454500	1903-2019	Yes	
English River at Kalona, IA	05455500	1940-2019	Yes	
Iowa River near Lone Tree, IA	05455700	1957-2019	Yes	
Iowa River at Wapello, IA	05465500	1903-2019	Yes	
Iowa River at Oakville, IA	05465700	2008-2019	No	Short POR
Cedar River				
Cedar River at Cedar Rapids, IA	05464500	1903-2019	Yes	
Cedar River near Conesville, IA	05465000	1940-2019	Yes	

1. Gages Upstream of Coralville Reservoir. The gages upstream of Coralville Reservoir include the Iowa River near Rowan, IA; Iowa River at Marshalltown, IA; Iowa River at County Highway E49 near Tama, IA; and Iowa River at Marengo, IA. The most upstream gage site is USGS gage 05449500, located along the Iowa River near Rowan, IA. The peak annual discharge period of record for the gage near Rowan begins in WY 1941 and continues to WY 2019, and captures a drainage area of 429 square miles. Peak annual discharge during the 1977 WY for the Rowan gage was missing, however the monotonic trend and change point analyses using the TST utilized the full record (1941-2019), as only one year during this period was missing.

Figure A-7 shows the trend analysis results for the Rowan gage, including the linear regression equation, significance of the linear regression and the Sen's slope equation. The simple linear regression trend line is assessed using a hypothesis test (t-Test) (α=0.05 level of significance) for a slope equal to zero (i.e. linear regression p-value <0.05 is a rejection of the null hypothesis, with 95% confidence of a slope not equal to zero). A p-value <0.05 is a typical threshold for significance and with no compelling reason to depart from this standard, it was maintained for these analyses. Within the TST, further evaluation of the trend is carried out using the Mann-Kendall Test (α=0.05 level of significance) and the Spearman Rank Order Test (α=0.05 level of significance). Each of these three tests can be individually assessed for significance at the α=0.05 level. However, trend significance at an overall p-value of 0.05 based on all three tests requires a rejection of the null hypothesis by any one of the three tests at a p-value <0.0167 (0.05/3=0.0167), in accordance with the Bonferroni correction. Table A-2 summarizes significance tests for the TST trend analyses at each of the gages. Results for the Rowan gage suggest an upward trend in annual peak flow, however the linear regression t-Test, as well as the Mann-Kendall and Spearman Rank Order Tests indicate no significant evidence of an upward trend. Figure A-8 shows the nonstationarity detection results for the Rowan gage, with no change points identified.

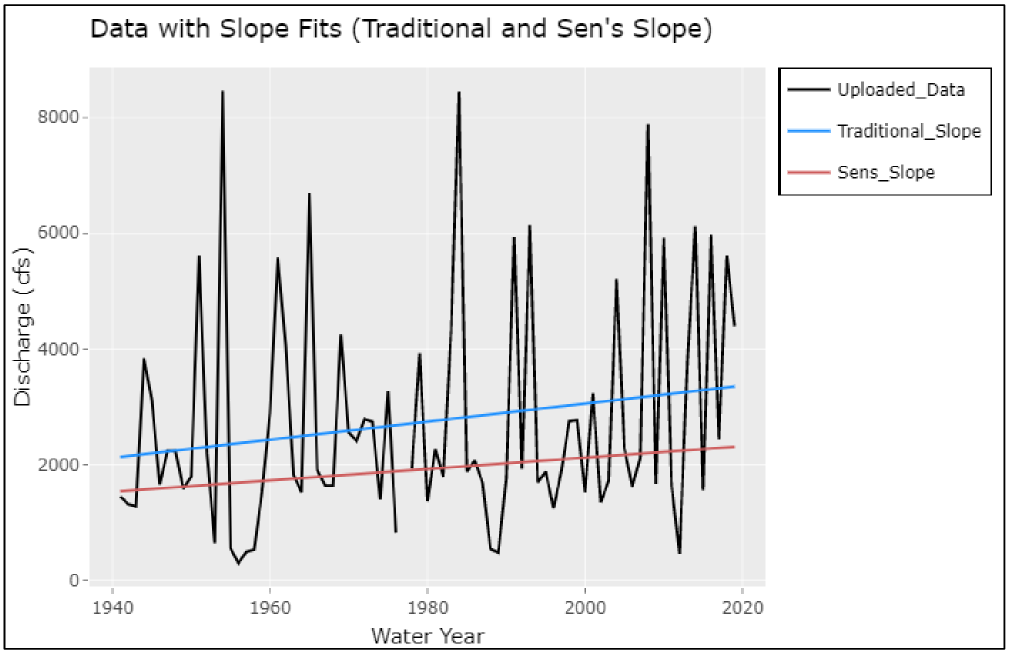
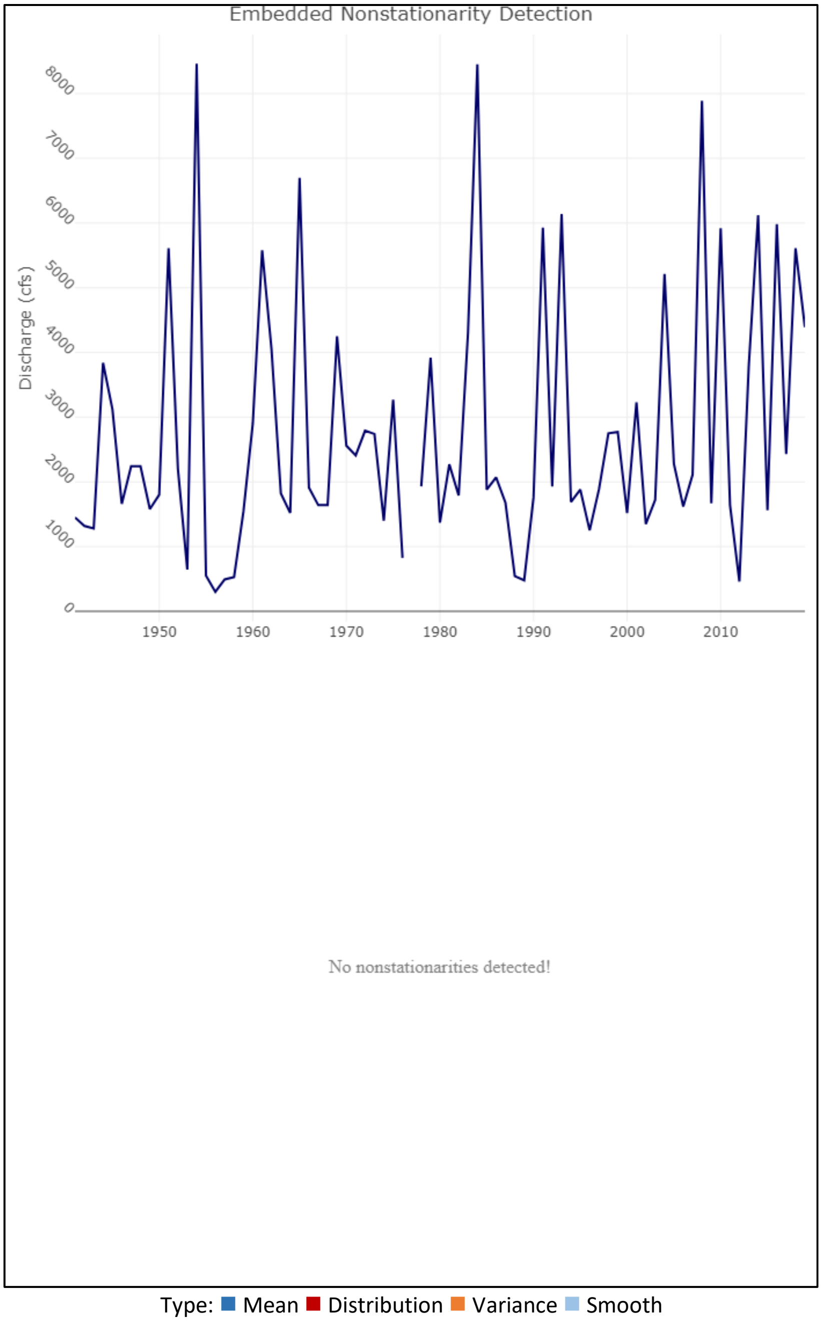


Figure A-7: Annual Peak Streamflow for Iowa River near Rowan, IA. (Linear Regression Equation: Q = 15.6*[Water Year] – 28145, p=0.10412. Sen's Slope Equation: Q = 9.8529*[Water Year] – 17584) (Reference 9)



Abbreviation	**Statistical Method**	**Abbreviation**	**Statistical Method**
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-8: Nonstationarity Analysis of Maximum Annual Flow, USGS gage 05449500 – Iowa River near Rowan, IA (Reference 9)

Table A-2: Significance of Linear Regression and Monotonic Trend

Gage Site	POR Assessed	Trend Direction	Linear Regression P-value (Significance)	Mann-Kendall P-value (Significance)	Spearman Rank-Order P-value (Significance)
USGS gage 05449500 Iowa River near Rowan, IA	1941-2019	Upward	0.10412 (No)	0.099297 (No)	0.079074 (No)
USGS gage 05451500 Iowa River at Marshalltown, IA	1915-2019	Upward	0.61652 (No)	0.43668 (No)	0.40368 (No)
USGS gage 05453100 Iowa River at Marengo, IA	1957-2019	Upward	0.37539 (No)	0.68234 (No)	0.61028 (No)
CRVI4 HEC-ResSim-Computed Inflow to Coralville Reservoir	1905-2019	Upward	0.01164 (Yes)	0.016603 (Yes)	0.013822 (Yes)
CRVI4 HEC-ResSim-Computed 7-Day Volume Inflow to Coralville Reservoir	1905-2019	Upward	0.0042055 (Yes)	0.014343 (Yes)	0.0094539 (Yes)
CRVI4 HEC-ResSim-Computed 15-Day Volume Inflow to Coralville Reservoir	1905-2019	Upward	0.0011967 (Yes)	0.0056466 (Yes)	0.0030618 (Yes)
USGS gage 05454500 Iowa River at Iowa City, IA	1903-2019	Downward	0.11141 (No)	0.046513 (Yes)	0.041987 (Yes)
USGS gage 05455500 English River at Kalona, IA	1940-2019	Upward	0.044411 (Yes)	0.072014 (No)	0.05895 (No)
USGS gage 05455700 Iowa River near Lone Tree, IA	1957-2019	Upward	0.093636 (No)	0.30762 (No)	0.26506 (No)
USGS gage 05465500 Iowa River at Wapello, IA	1903-2019	Upward	0.02177 (Yes)	0.15961 (No)	0.16592 (No)
USGS gage 05464500 Cedar River at Cedar Rapids, IA	1903-2019	Upward	0.0073125 (Yes)	0.020444 (Yes)	0.017167 (Yes)
USGS gage 05465000 Cedar River near Conesville, IA	1940-2019	Upward	0.007874 (Yes)	0.020883 (Yes)	0.019873 (Yes)

"No" indicates no significance at $p<0.05$ significance level
"Yes" indicates significance at $p<0.05$ significance level

The next downstream gage site is USGS gage 05451500, located along the Iowa River at Marshalltown, IA. The Marshalltown gage has a POR for peak annual flow from 1915 to 2019 (WY) and captures a drainage area of 1,532 square miles. Water years 1928, 1931 and 1932 are missing in the record, however the trend and nonstationarity analyses still utilized the lengthened 1915-2019 record, consideration of missing data was given when interpreting results. Figure A-9 and Table A-2 show trend analysis results for the Marshalltown gage. Results for the Marshalltown gage suggest a slight upward trend in annual peak flow, however the linear regression t-Test, as well as the Mann-Kendall and Spearman Rank Order Tests indicate no significant evidence of an upward trend. Figure A-10 shows the output of the TST nonstationarity detection analysis for the Marshalltown gage, with no change points detected.

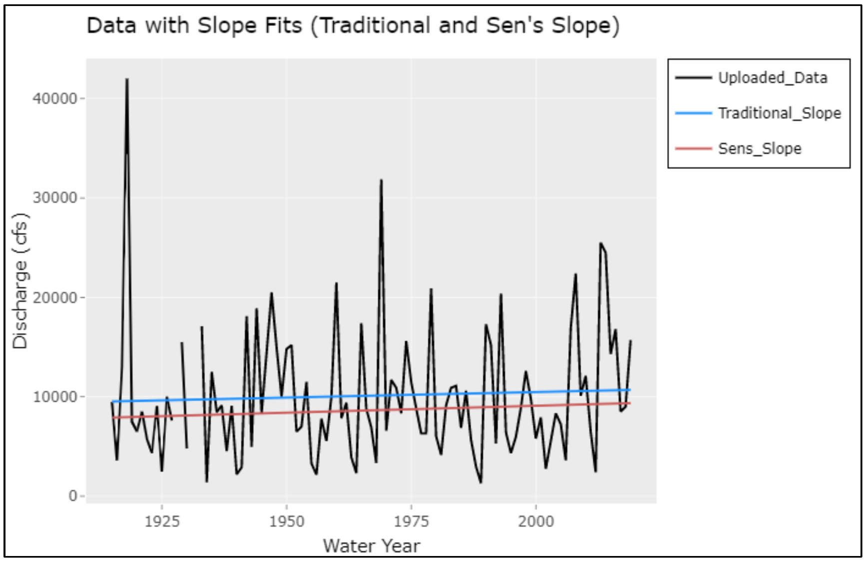
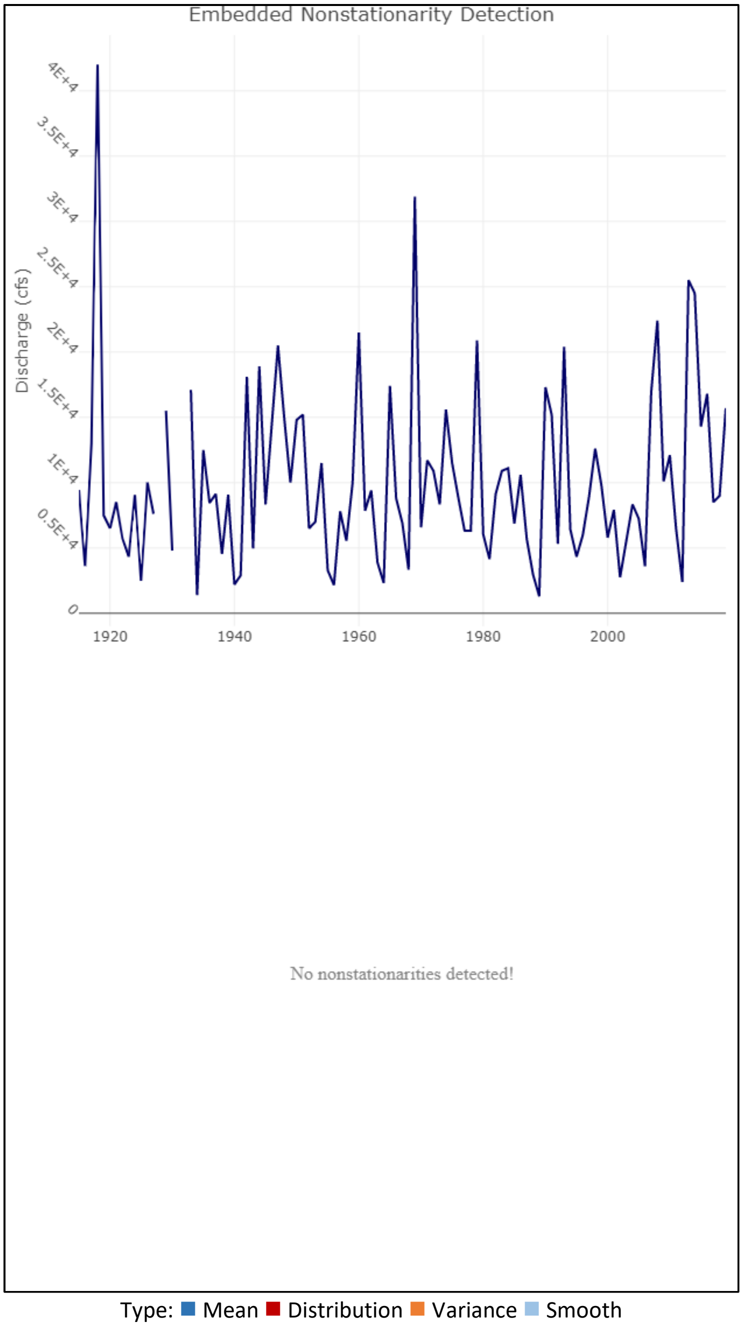


Figure A-9: Annual Peak Streamflow for Iowa River at Marshalltown, IA. (Linear Regression Equation: Q = 11.144*[Water Year] – 11812, p=0.61652. Sen's Slope Equation: Q = 13.962*[Water Year] – 18830) (Reference 9)



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END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-10: Nonstationarity Analysis of Maximum Annual Flow,
USGS gage 05451500 – Iowa River at Marshalltown, IA (Reference 9)

USGS gage 05451770, located along the Iowa River at County Highway E49 near Tama, IA is the next downstream gage and has a POR of less than 30 years (2012-present). Due to the short POR, this gage was excluded from the trend analyses and statistical tests for non-stationarity.

The downstream-most gage site upstream of Coralville Reservoir is USGS gage 05453100, located along the Iowa River at Marengo, IA. The Marengo gage has a continuous POR from 1957 to 2019 (WY) and captures a drainage area of 2,794 square miles. Figure A-11 and Table A-2 show trend analysis results for the Marengo gage. Results for the Marengo gage suggest a slight upward trend in annual peak flow, however the linear regression t-Test, as well as the Mann-Kendall and Spearman Rank Order Tests indicate no significant evidence of an upward trend. Figure A-12 shows the output of the nonstationarity detection analysis for the Marengo gage, with no change points detected.

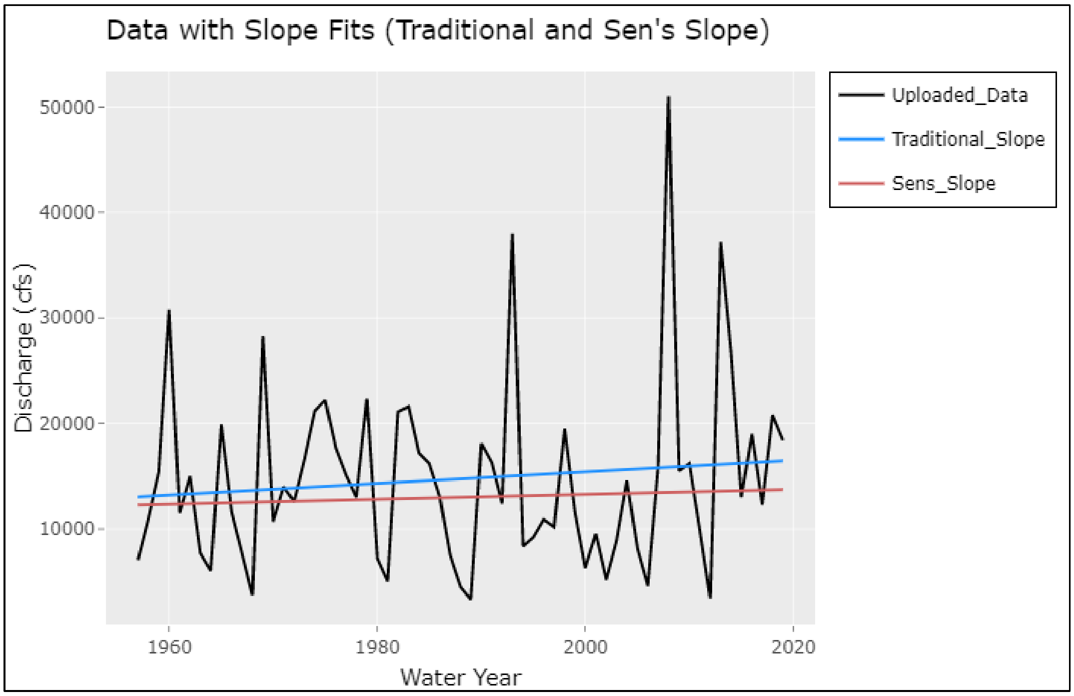
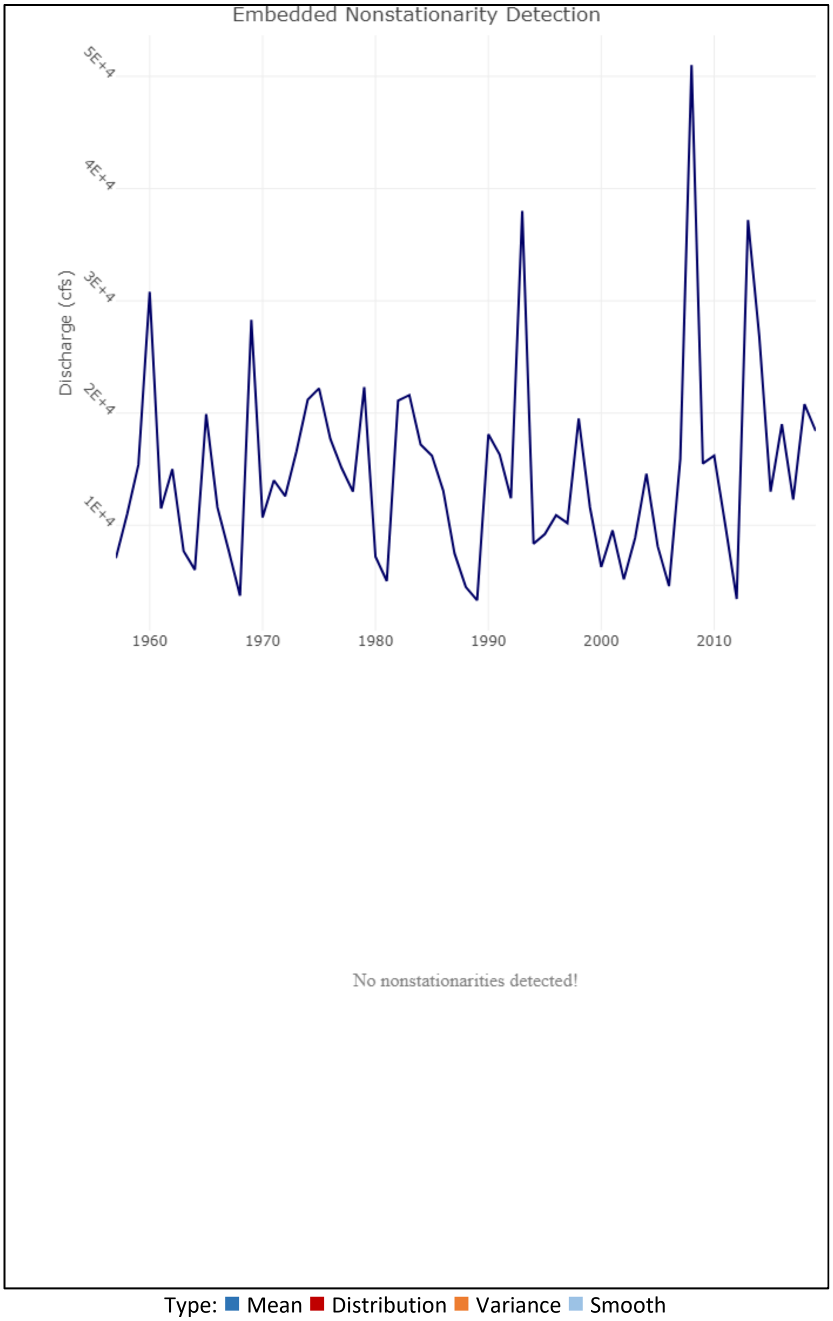


Figure A-11: Annual Peak Streamflow for Iowa River at Marengo, IA. (Linear Regression Equation: Q = 54.832*[Water Year] – 94259, p=0.37539. Sen's Slope Equation: Q = 23.333*[Water Year] – 33387) (Reference 9)



Abbreviation	**Statistical Method**	**Abbreviation**	**Statistical Method**
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END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-12: Nonstationarity Analysis of Maximum Annual Flow, USGS gage 05453100 – Iowa River at Marengo, IA (Reference 9)

Daily inflows to the Coralville Reservoir computed by the District's HEC-ResSim model at CRVI4 were evaluated for monotonic trends and nonstationarities in the flow record. The POR for computed inflows is 1905 through 2019 (WY). The drainage area contributing to CRVI4 is 3,115 square miles. As mentioned previously, peak outflows from Coralville Lake are more closely correlated to longer duration inflow volumes than to peak daily inflow, therefore the TST was used to assess nonstationarities in annual peak 7-day and 15-day volume-duration inflows in addition to annual maximum inflow.

Trend analysis results for annual maximum, annual peak 7-day volume-duration, and annual peak 15-day volume duration inflows are shown in Figures A-13, A-16 and A-18, respectively, and Table A-2. Results for each of these inflow records suggest a statistically significant upward trend. These trends are considered significant at an overall $p<0.05$ based on all three tests (linear regression, Mann-Kendall and Spearman Rank-Order), in accordance with the Bonferroni correction as previously described ($\alpha=0.0167$ level of significance). In addition to increasing annual maximum inflows over the historic period, Figure A-14 demonstrates an increasing trend in cumulative inflow volumes during the fall pool raise period (August 1-December 31) for 1917-2019 (note that success of the fall pool raise was assessed with the HEC-ResSim model, not based upon a threshold inflow volume).

Results from the nonstationarity detection analysis for the peak annual inflow record indicates distribution change points in 1958 & 1968, mean change points in 1957 & 1968 and a variance change point in 2010 (Figure A-15). Nonstationarity test results are further assessed to evaluate how "strong" a change point is, to help establish how meaningful the results are to the study. A "strong" change point requires: (1) consensus; (2) robustness; and (3) an operationally significant change in magnitude. Consensus indicates two or more tests of the same statistical property detect a change point. Robustness indicates that tests targeting two or more different statistical properties identify the same change point. Assessments of the magnitude of change in terms of operational significance were generally not made for this study. Due to the number of different constraints influencing reservoir release other than inflow, reservoir operational significance was not determined. Although change points were identified for a downstream control point used for reservoir operation, the results did not indicate consensus or robustness and therefore an assessment of magnitude was unnecessary. Concurrent change points in both distribution and mean in 1957/1958 and in 1968 demonstrate robust change points, however there is no consensus in either of these change points. Table A-3 summarizes the evaluation of nonstationarity detection results for all records.

Figure A-17 shows nonstationarity results for annual peak 7-day volume-duration inflow. A distribution change point in 1958, a mean change point in 1957 and a variance change point in 2010 were all identified, indicating a robust 1957/1958 change point, but no consensus (Table A-3).

Figure A-19 shows nonstationarity results for annual peak 15-day volume-duration inflow. Table A-3 shows mean change point in 1957 and a variance change point in 1958 suggest robustness, but no consensus.

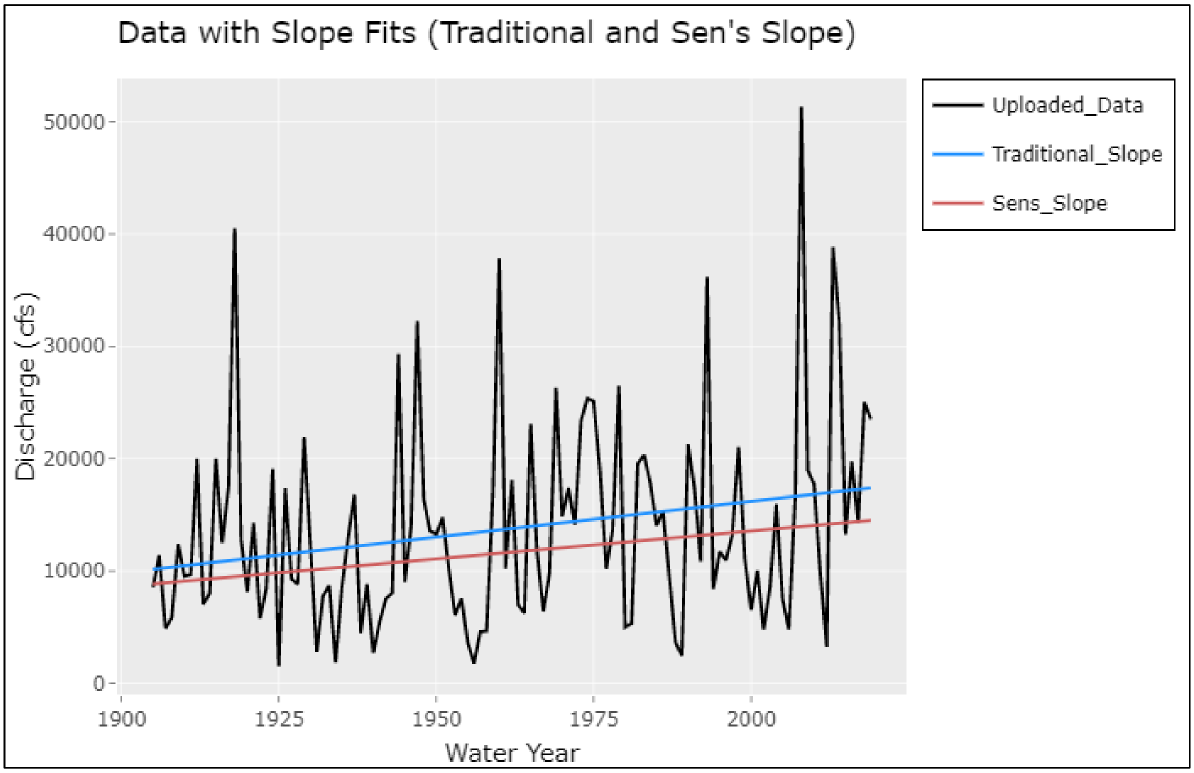


Figure A-13: Annual Peak Computed Inflow to Coralville Reservoir
(Linear Regression Equation: Q = 63.611*[Water Year] – 111020, p=0.01164
Sen's Slope Equation: Q = 49.597*[Water Year] – 85633) (Reference 9)

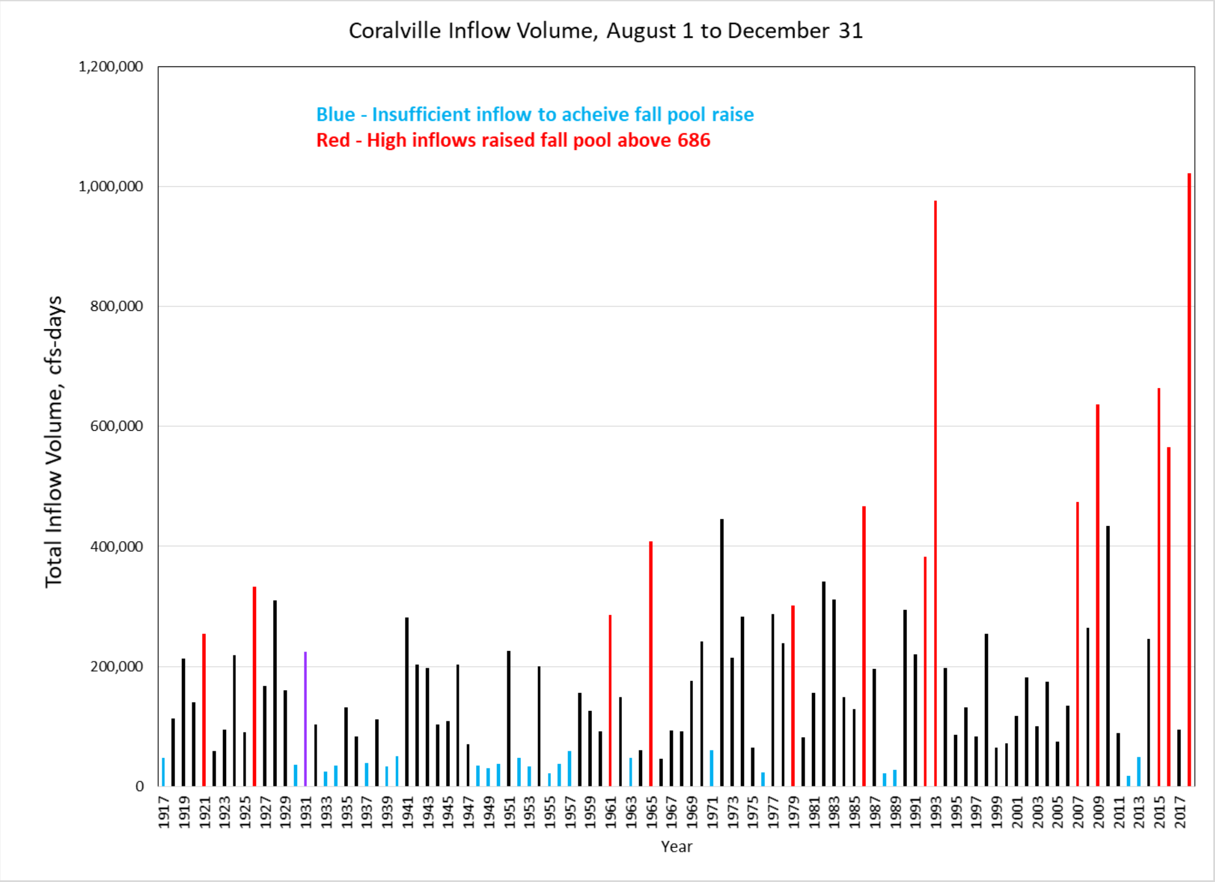
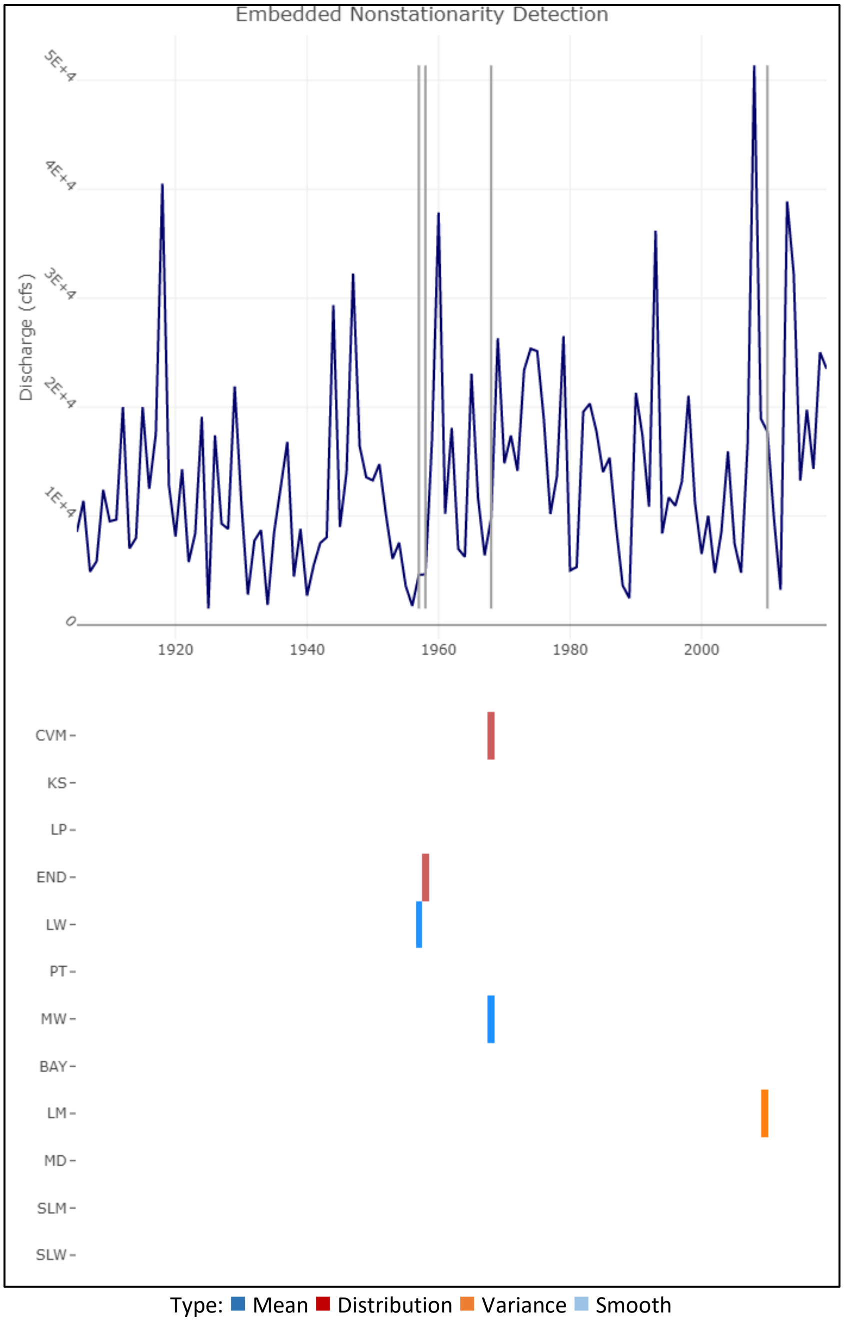


Figure A-14: Total Inflow Volume to Coralville Reservoir from August 1 to December 31



Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-15: Nonstationarity Analysis of Maximum Annual Flow, CRVI4 – HEC-ResSim-Computed Inflows to Coralville Reservoir (Reference 9)

Table A-3: Nonstationarity Detection Results Evaluation

Gage Site	POR Assessed	Consensus (Year)	Robust (Year)
USGS gage 05449500 Iowa River near Rowan, IA	1941-2019	-	-
USGS gage 05451500 Iowa River at Marshalltown, IA	1915-2019	-	-
USGS gage 05453100 Iowa River at Marengo, IA	1957-2019	-	-
CRVI4 HEC-ResSim-Computed Inflow to Coralville Reservoir	1905-2019	-	1957/1958 1968
CRVI4 HEC-ResSim-Computed 7-Day Volume Inflow to Coralville Reservoir	1905-2019	-	1957/1958
CRVI4 HEC-ResSim-Computed 15-Day Volume Inflow to Coralville Reservoir	1905-2019	-	1957/1958
USGS gage 05454500 Iowa River at Iowa City, IA	1903-2019	1951/1953	1953
USGS gage 05455500 English River at Kalona, IA	1940-2019	-	-
USGS gage 05465500 Iowa River at Wapello, IA	1903-2019	-	-
USGS gage 05464500 Cedar River at Cedar Rapids, IA	1903-2019	2005-2007	1954
USGS gage 05465000 Cedar River near Conesville, IA	1940-2019	-	-

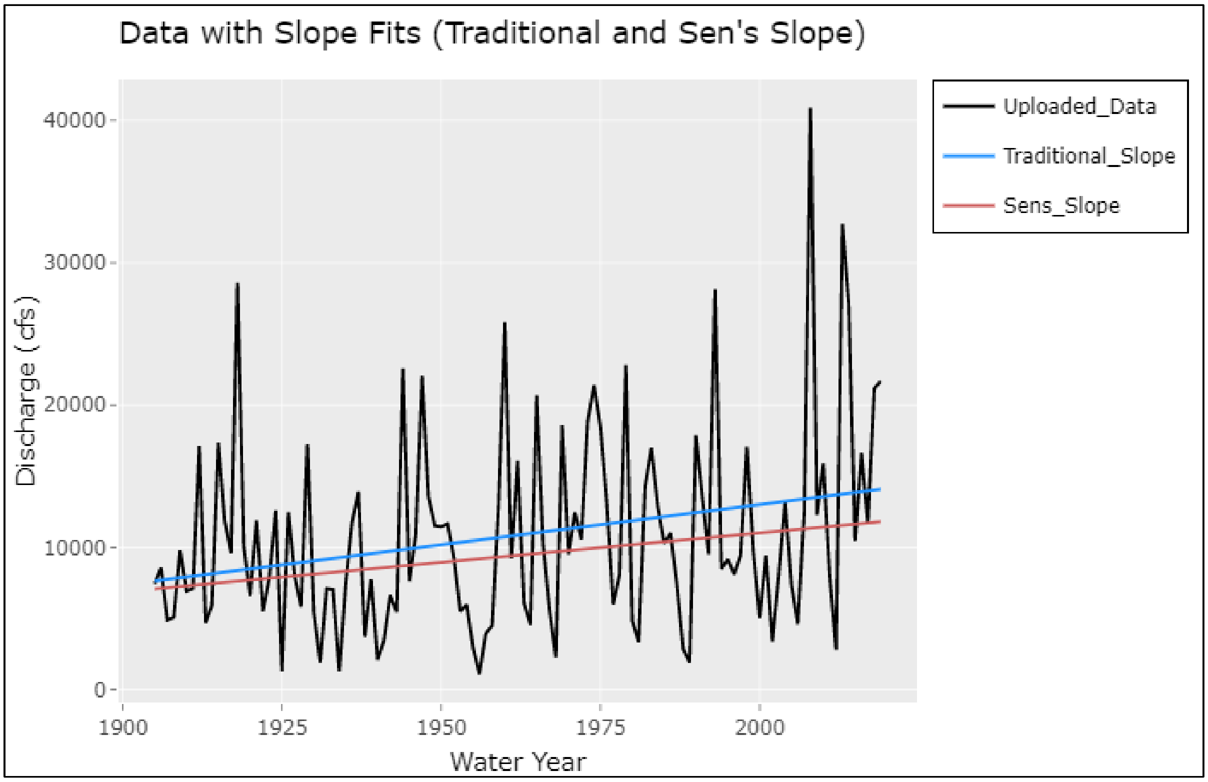
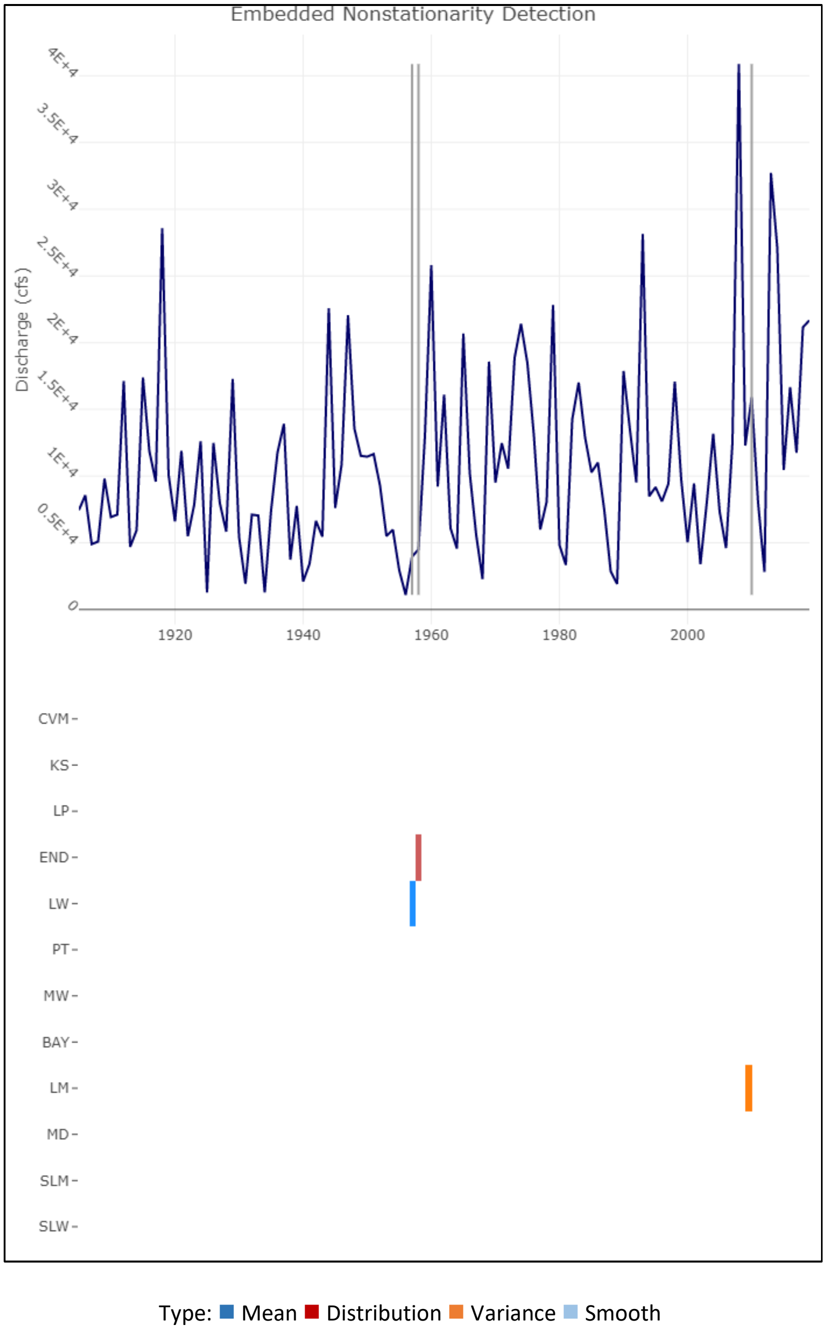


Figure A-16: Annual 7-day Volume-Duration Maximum Computed Inflow to Coralville Reservoir
(Linear Regression Equation: $Q = 56.464*[\text{Water Year}] - 99920$, $p=0.0042055$
Sen's Slope Equation: $Q = 41.309*[\text{Water Year}] - 71601$) (Reference 9)



Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-17: Nonstationarity Analysis of Maximum Annual 7-day Volume-Duration Flow, CRVI4 – HEC-ResSim-Computed Inflows to Coralville Reservoir (Reference 9)

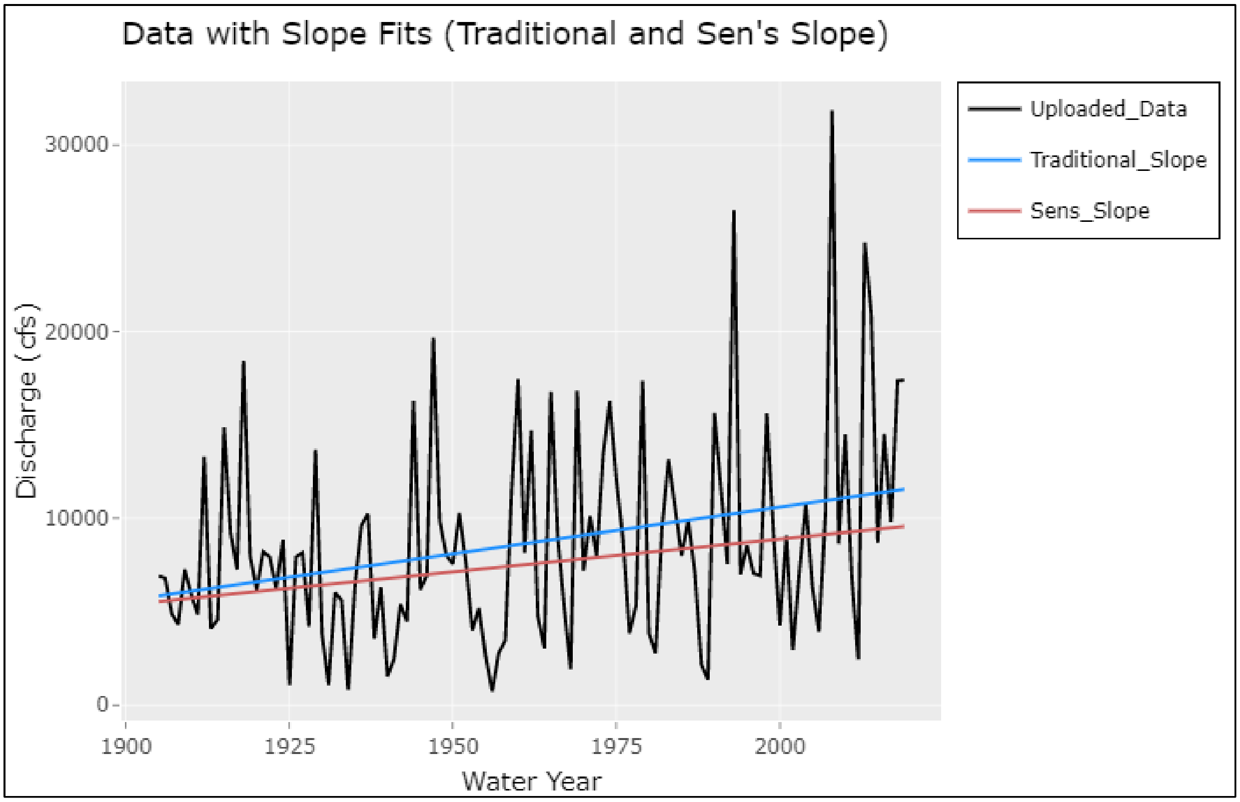
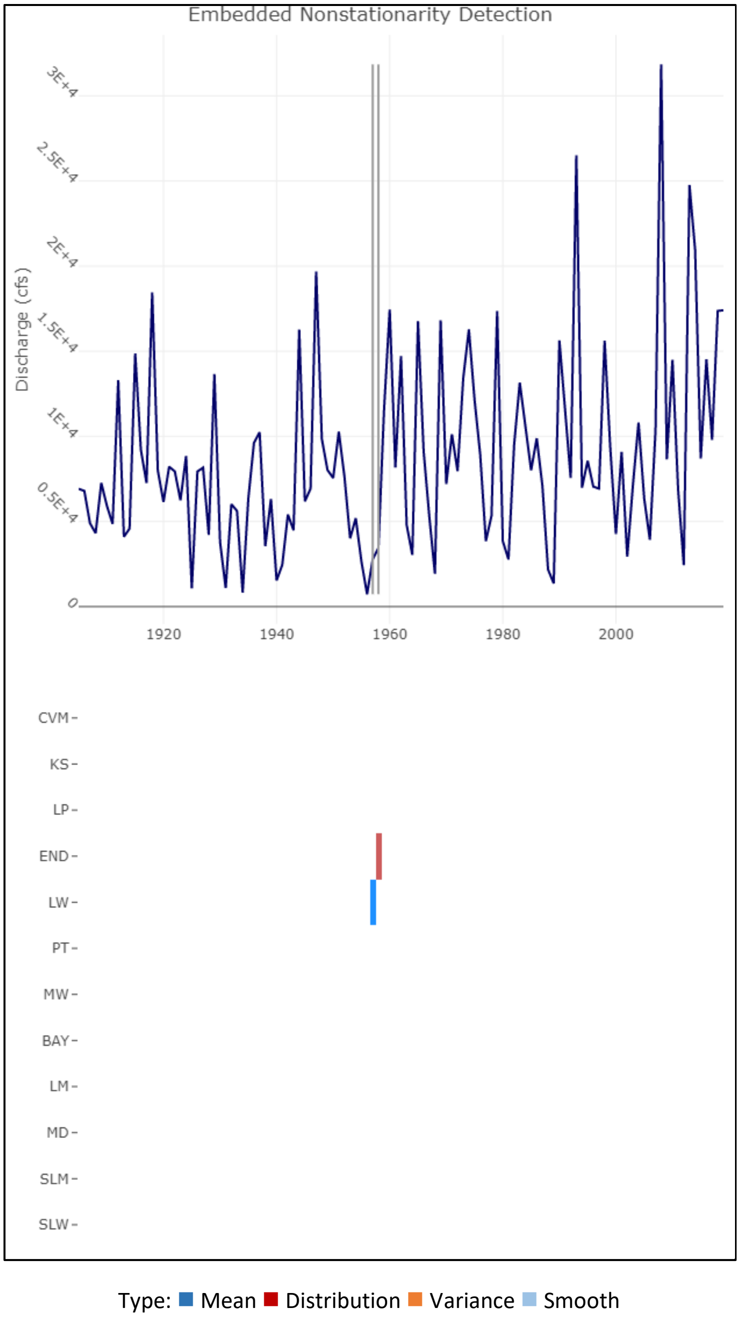


Figure A-18: Annual 15-day Volume-Duration Maximum Computed Inflow to Coralville Reservoir (Linear Regression Equation: Q = 50.066*[Water Year] – 89527, p=0.0011967 Sen's Slope Equation: Q = 35.204*[Water Year] – 61513) (Reference 9)



Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-19: Nonstationarity Analysis of Maximum Annual 15-day Volume-Duration Flow, CRVI4 – HEC-ResSim-Computed Inflows to Coralville Reservoir (Reference 9)

2. Gages Downstream of Coralville Reservoir. Several gages located downstream of Coralville Reservoir provided long-term annual peak flow records for trend analysis and nonstationarity detection. Analysis of potential change points at gages on the Iowa River, downstream of the reservoir, would potentially identify when the dam went into operation in 1958 as one of the change points. Three gages along the Iowa River and one gage on the English River tributary were analyzed using the TST for monotonic trends and nonstationarities in peak annual flow.

The first gage downstream of Coralville Dam is USGS gage 05454500, located on the Iowa River at Iowa City, IA. The Iowa City gage has a POR from WY 1903 to WY 2019 and captures a drainage area of 3,271 square miles. Figure A-20 and Table A-3 show trend analysis results. The linear regression and Sen's Slope indicate a downward trend in annual peak streamflow, likely due to the influence of Coralville Lake for years after 1958. The Mann-Kendall and Spearman-Rank Order Tests for the Iowa River at Iowa City, IA each indicated a significant trend in the negative direction for peak annual flow for the POR, despite the linear regression test indicating no significant evidence of a downward trend. The Mann-Kendall and Spearman Rank Order Tests are considered more robust to outliers in the data.

Figure A-21 shows results from the TST nonstationarity detection analysis indicating a mean change point in 1929, a distribution change point in 1951 based on the Lombard Wilcoxon test, two distribution change points in 1953 based on the Cramer-von-Mises and Energy Divisive tests, a mean change point in 1953 and a variance change point in 1957. Consensus in the distribution tests and robustness in the mean and distribution tests support a "strong" 1951/1953 change point (Table A-3). The nonstationarity statistical test sensitivity parameters were relaxed to determine if additional change points closer to 1958, when the dam went into operation, could be identified if parameters other than the default were used. Even when using extreme sensitivity parameters, no other tests identified change points. The identified dates may be influenced by the drought conditions that existed during the mid- to late-1950s which the detection tests would not be able to differentiate from the peak reduction effects of the reservoir that began immediately thereafter.

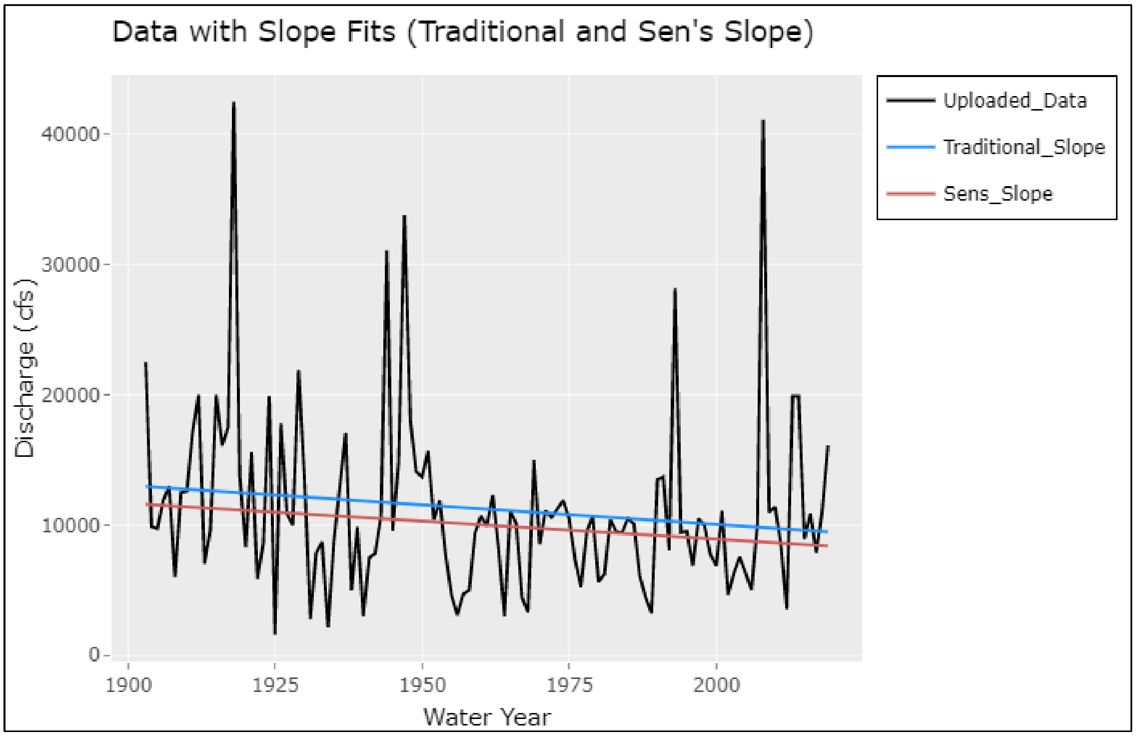
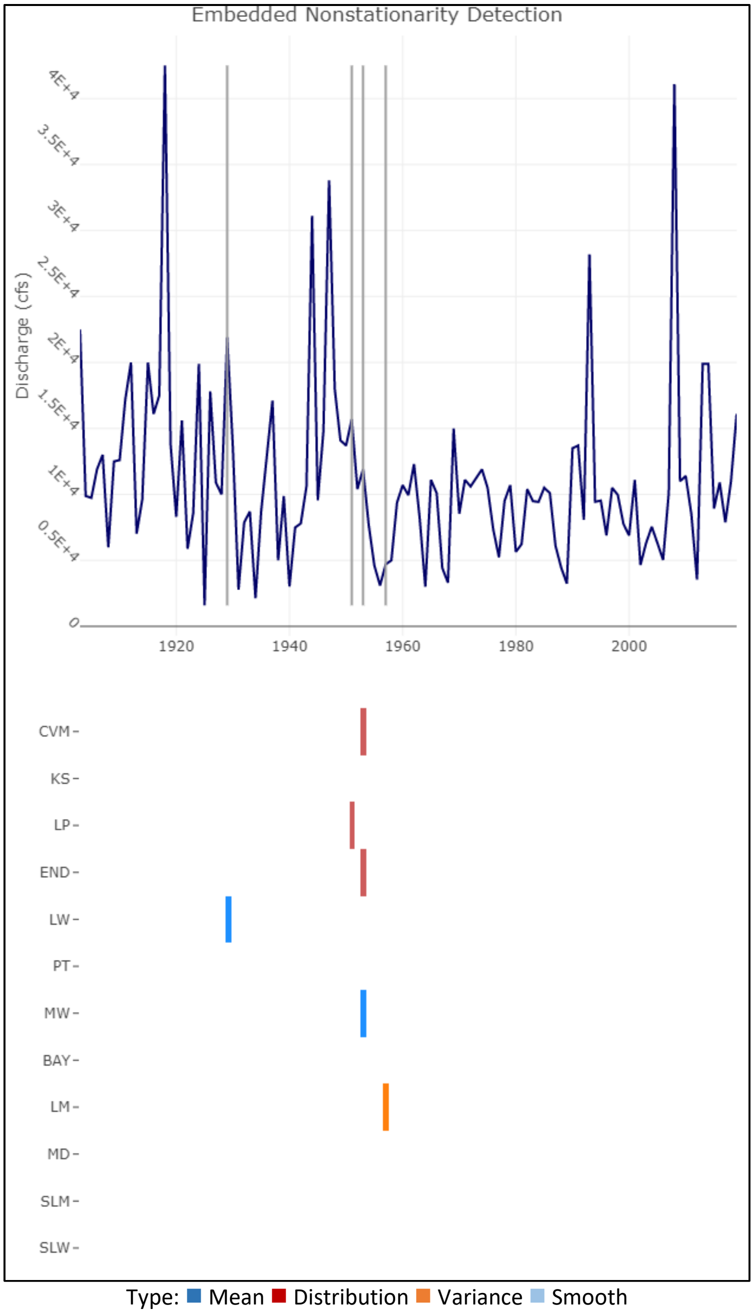


Figure A-20: Annual Peak Streamflow for Iowa River at Iowa City, IA
(Linear Regression Equation: Q = -30.051*[Water Year] + 70156, p=0.11141
Sen's Slope Equation: Q = -27.518*[Water Year] – 63963) (Reference 9)



Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-21: Nonstationarity Analysis of Maximum Annual Flow, USGS Gage 05454500 – Iowa River at Iowa City, IA (Reference 9)

USGS Gage 05455500 is located on the English River at Kalona and flows into the Iowa River downstream of Iowa City. The English River gage has a POR beginning in WY1940-2019 and a drainage area of 574 square miles. Figure A-22 and Table A-2 show trend analysis results for the English River gage. Results for the English River gage indicate an upward trend in annual maximum flow. The linear regression t-Test indicates a significant trend in the positive direction, whereas both the Mann-Kendall and Spearman Rank Order Tests do not support a significant positive trend. Figure A-23 and Table A-3 show results from the TST nonstationarity detection, with a single change point in the mean in 2005.

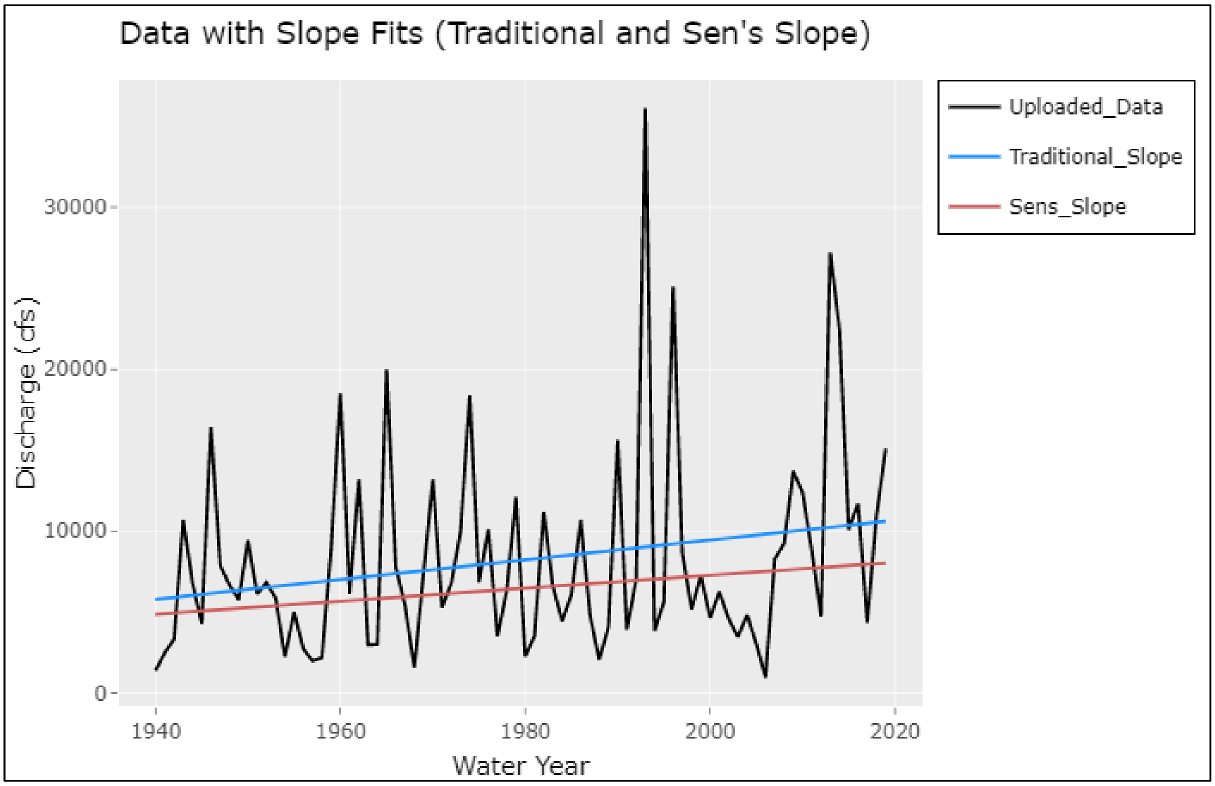
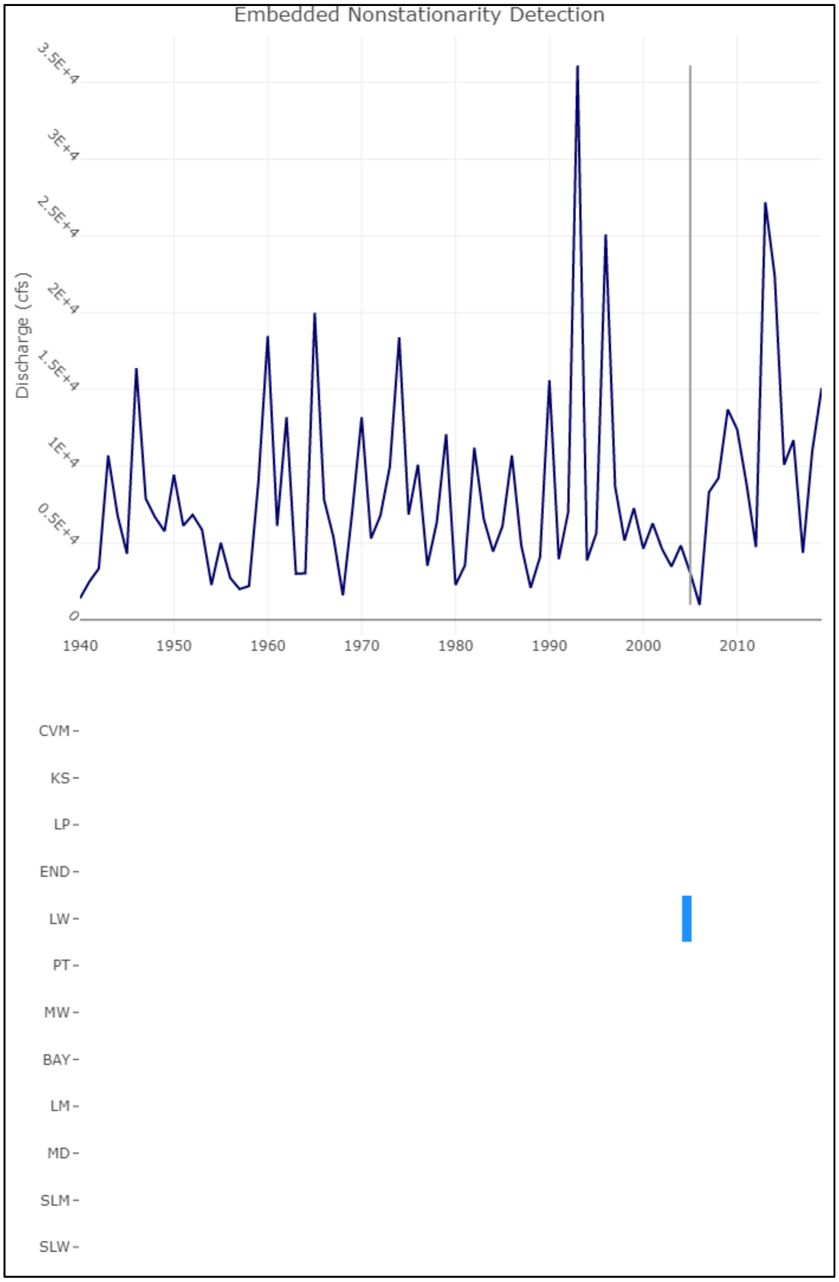


Figure A-22: Annual Peak Streamflow for English River at Kalona, IA
(Linear Regression Equation: Q = 60.945*[Water Year] – 112430, p=0.044411
Sen's Slope Equation: Q = 40*[Water Year] – 72715) (Reference 9)



Type: 🟦 Mean 🟥 Distribution 🟧 Variance 🟦 Smooth

Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-23: Nonstationarity Analysis of Maximum Annual Flow, USGS Gage 05455500 – English River at Kalona, IA (Reference 9)

The downstream-most gage on the Iowa River before its confluence with the Cedar River is USGS gage 05455700 near Lone Tree, IA. The Lone Tree gage has a POR from WY1957 to 2019 and a drainage area of 4,293 square miles. Figure A-24 shows trend analysis results, illustrating an upward trend. However, the trend significance results summarized in Table A-2 indicate no significant upward trend based on each of the three tests. Figure A-25 illustrates the results of the nonstationarity detection analysis, showing no detected change points.

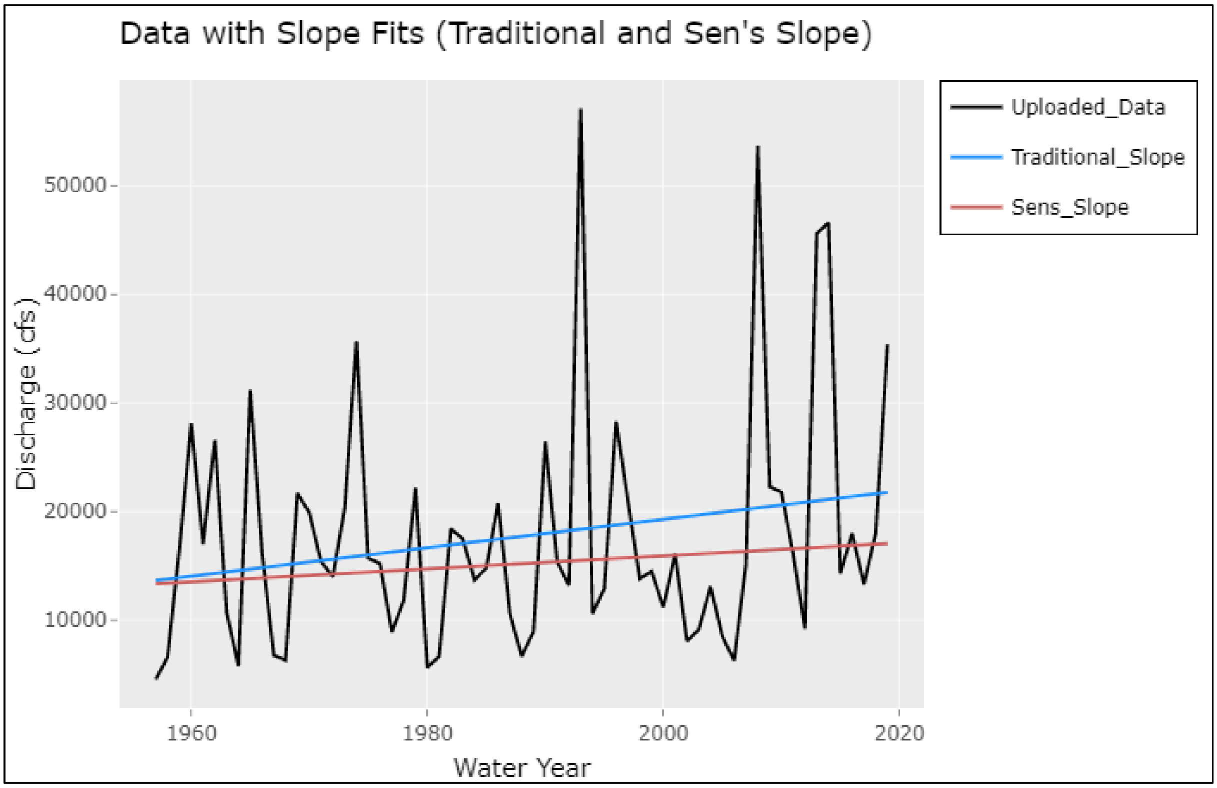
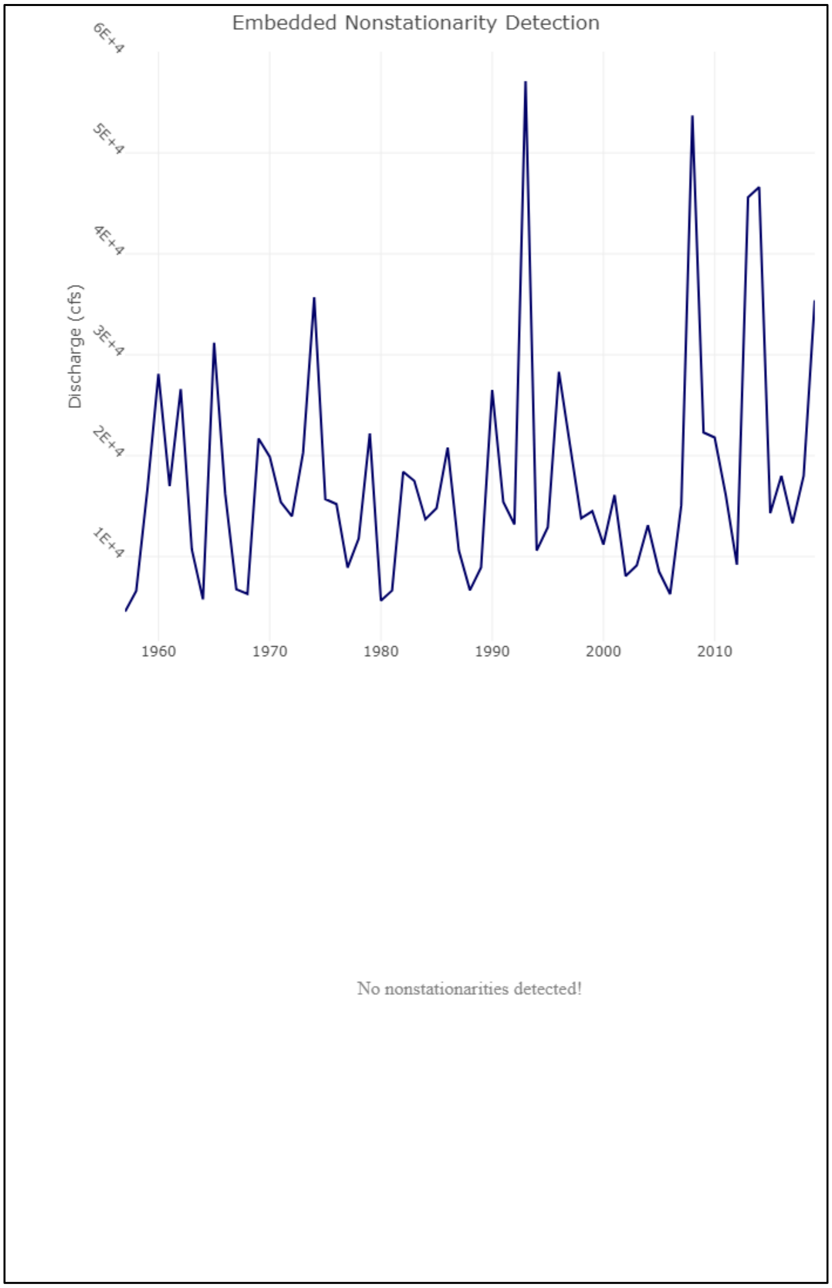


Figure A-24: Annual Peak Streamflow for Iowa River near Lone Tree, IA
(Linear Regression Equation: Q = 130.98*[Water Year] – 242680, p=0.093636
Sen's Slope Equation: Q = 59.73*[Water Year] – 103540) (Reference 9)



No nonstationarities detected!

Type: 🟦 Mean 🟥 Distribution 🟧 Variance 🟦 Smooth

Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-25: Nonstationarity Analysis of Maximum Annual Flow, USGS Gage 05455700 – Iowa River near Lone Tree, IA (Reference 9)

Downstream of the confluence with the Cedar River, the next downstream gage on the Iowa River is USGS gage 05465500 Iowa River at Wapello, IA. The Wapello gage has a POR from WY1903-2019 and a drainage area of 12,500 miles. Figure A-26 and Table A-2 show trend analysis results. Results for the Wapello gage indicate a statistically significant positive trend in annual maximum streamflow, based on the linear regression t-Test. The Mann-Kendall and Spearman-Rank Order tests did not show a statistically significant upward trend for the Wapello gage. The nonstationarity detection results for the Wapello gage indicate a variance change point in 1927 and a mean change point in 1988 (Figure A-27 and Table A-3). No change point associated with Coralville Lake beginning operation was identified in, or around, 1958. This is likely due to the significant unregulated tributary inflows (notably the Cedar River) between Coralville Lake and Wapello. At Wapello, only 25% of the contributing watershed is located above Coralville Dam.

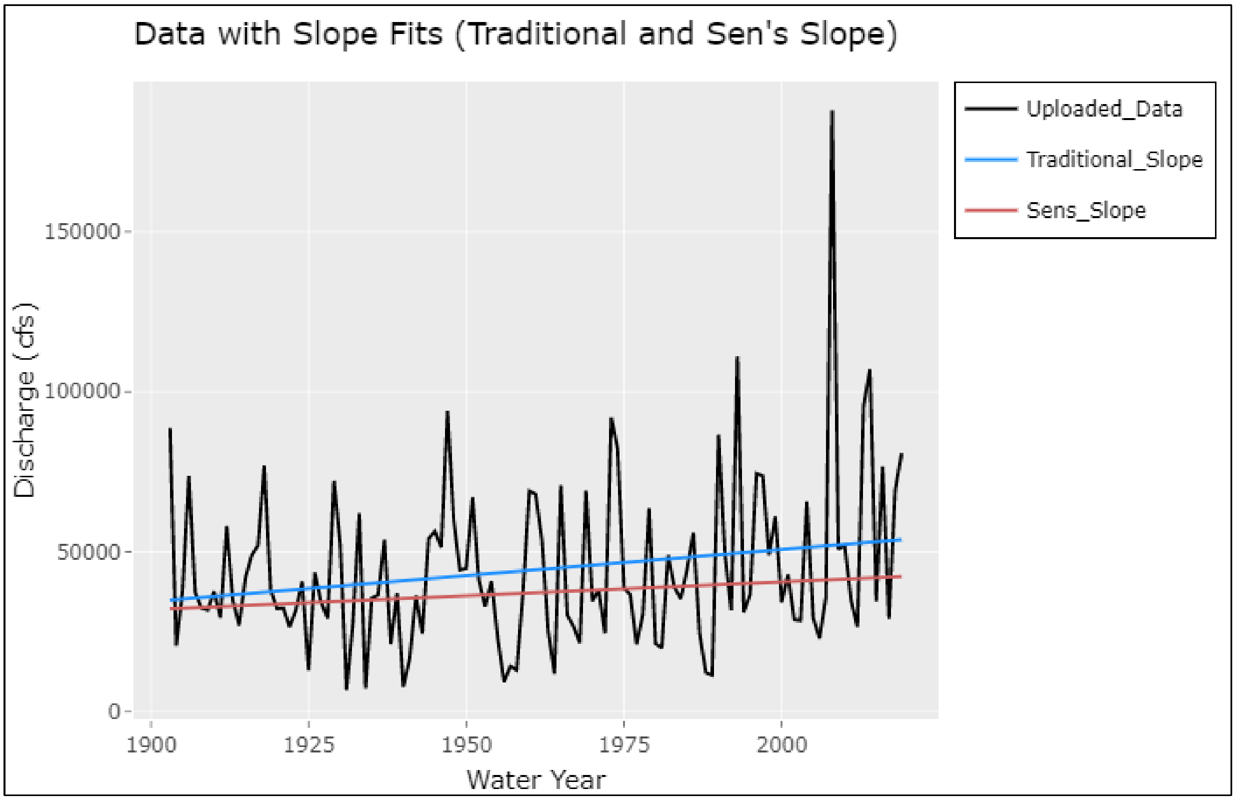
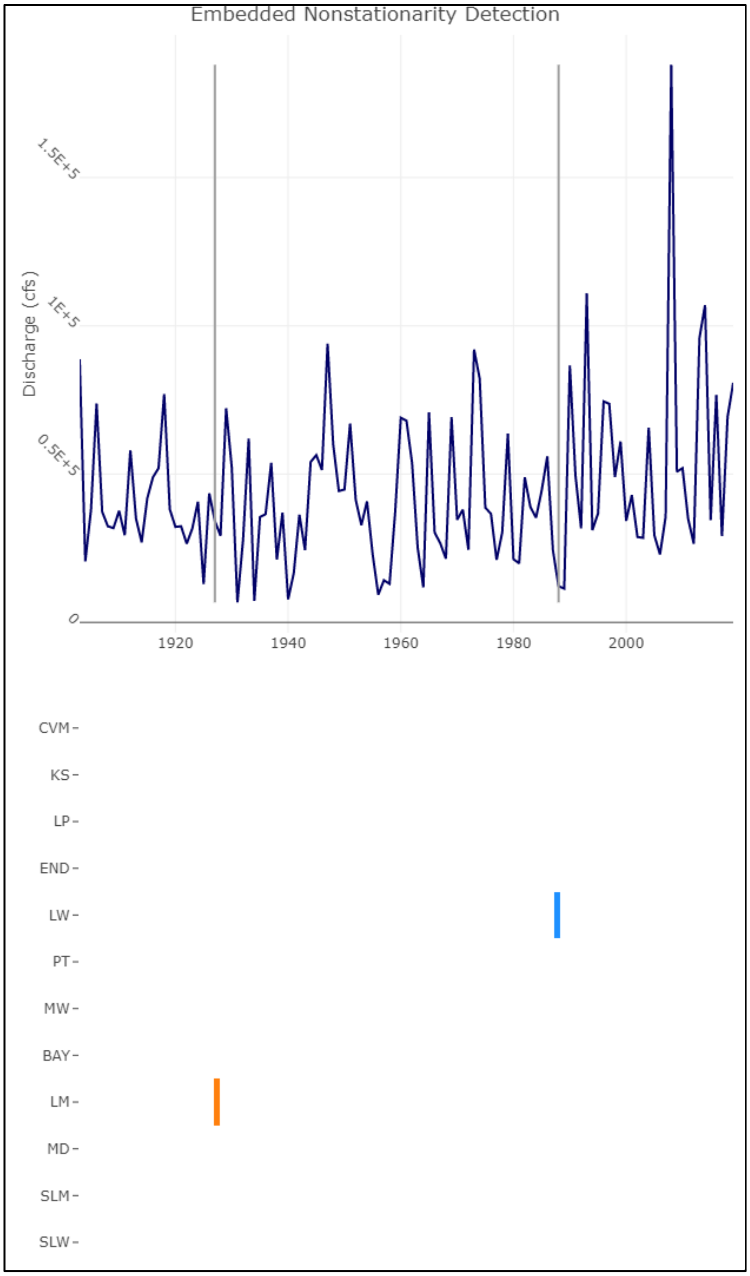


Figure A-26: Annual Peak Streamflow for Iowa River at Wapello, IA
(Linear Regression Equation: Q = 162.87*[Water Year] – 275030, p=0.02177
Sen's Slope Equation: Q = 86.826*[Water Year] – 133070) (Reference 9)



Type: ■ Mean ■ Distribution ■ Variance ■ Smooth

Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-27: Nonstationarity Analysis of Maximum Annual Flow, USGS Gage 05465500 – Iowa River at Wapello, IA (Reference 9)

USGS gage 05465700, located on the Iowa River at Oakville, IA is the next downstream gage and has a POR of less than 30 years (2008-present). Due to the short POR, this gage was excluded from the trend analyses and statistical tests for non-stationarity.

3. Gages on the Cedar River. The most upstream gage analyzed on the Cedar River is USGS gage 05464500, located at Cedar Rapids, IA. The Cedar River joins the Iowa River downstream of Coralville Reservoir, near Columbus Junction, IA. The Cedar Rapids gage has a continuous POR from the 1903 WY to 2019 WY and captures a drainage area of 6,510 square miles. Figure A-28 and Table A-2 show the trend analysis results, indicating a statistically significant positive trend in annual maximum flow. This trend is considered significant at an overall $p<0.05$ based on all three tests (linear regression, Mann-Kendall and Spearman Rank-Order), in accordance with the Bonferroni correction as previously described ($\alpha=0.0167$ level of significance). Results of the nonstationarity detection analysis for the Cedar Rapids gage are shown in Figure A-29, with variance change points identified in 1923, 1954 and 1965; distribution change points identified in 1954 and 1958; a mean change point in 2006 and a smooth mean change point from 2005-2007. As summarized in Table A-3, these results indicate consensus in a 2005-2007 change point and robustness in a 1954 change point.

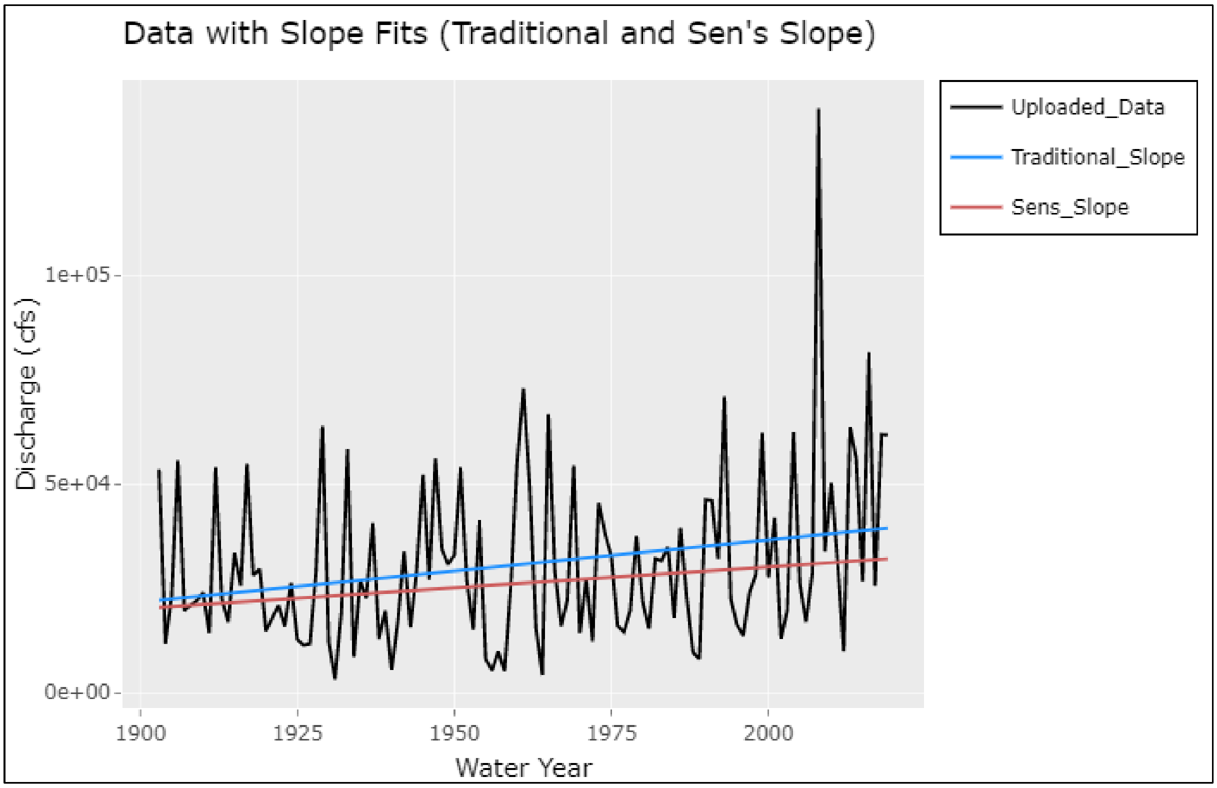
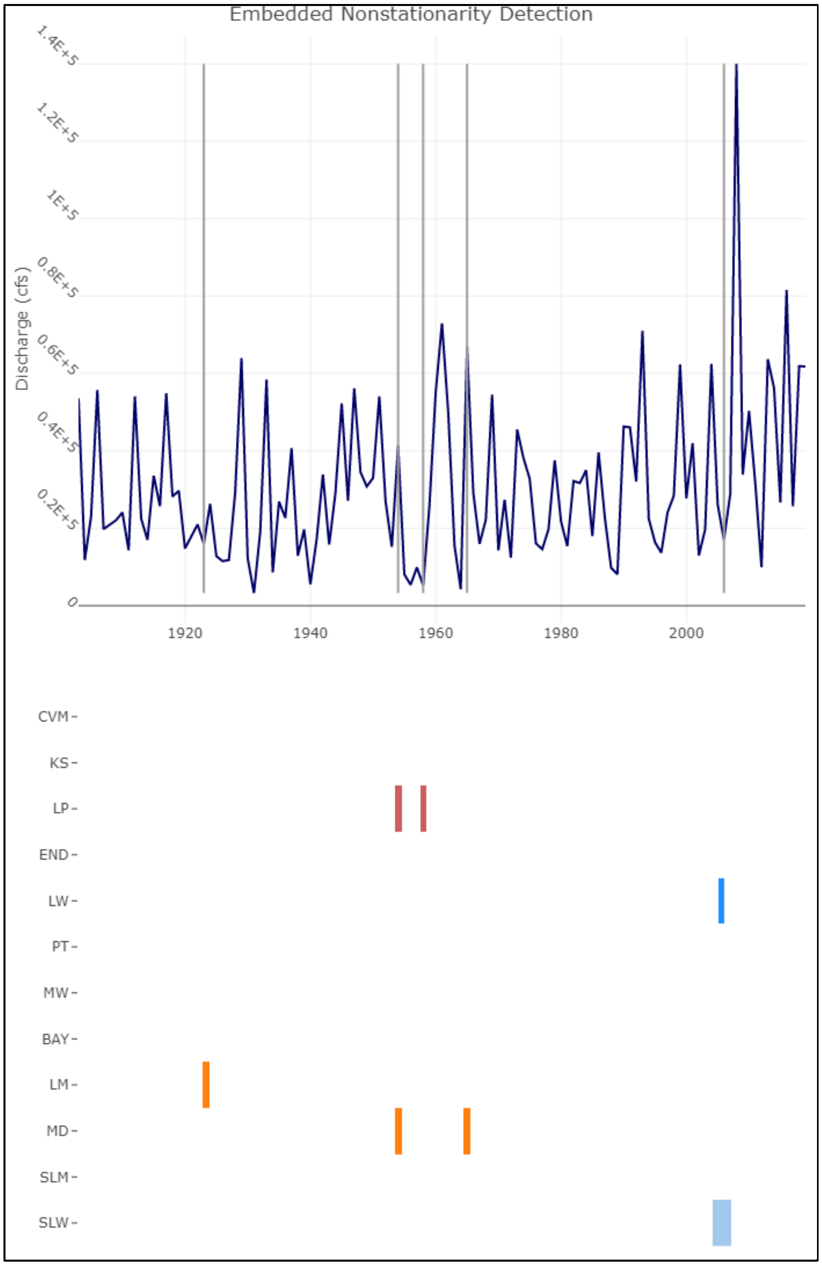


Figure A-28: Annual Peak Streamflow for Cedar River at Cedar Rapids, IA
(Linear Regression Equation: Q = 148.81*[Water Year] – 260950, p=0.0073125
Sen's Slope Equation: Q = 100*[Water Year] – 169800) (Reference 9)



Type: 🟦 Mean 🟥 Distribution 🟧 Variance 🟦 Smooth

Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-29: Nonstationarity Analysis of Maximum Annual Flow, USGS gage 05464500 – Cedar River at Cedar Rapids, IA (Reference 9)

The most downstream gage site on the Cedar River is USGS gage 05465000, located near Conesville, Iowa. The Conesville gage has a continuous POR from WY 1940 to 2019 and captures a drainage area of 7,787 square miles. The results of the trend analysis, as shown in Figure A-30 and Table A-2 indicate a statistically significant positive trend in annual maximum flow. This trend is considered significant at an overall $p<0.05$ based on all three tests (linear regression, Mann-Kendall and Spearman Rank-Order), in accordance with the Bonferroni correction as previously described ($\alpha=0.0167$ level of significance). Results of the nonstationarity detection analysis, shown in Figure A-31 and Table A-3, illustrate a distribution change point in 1989 and a mean change point in 2011.

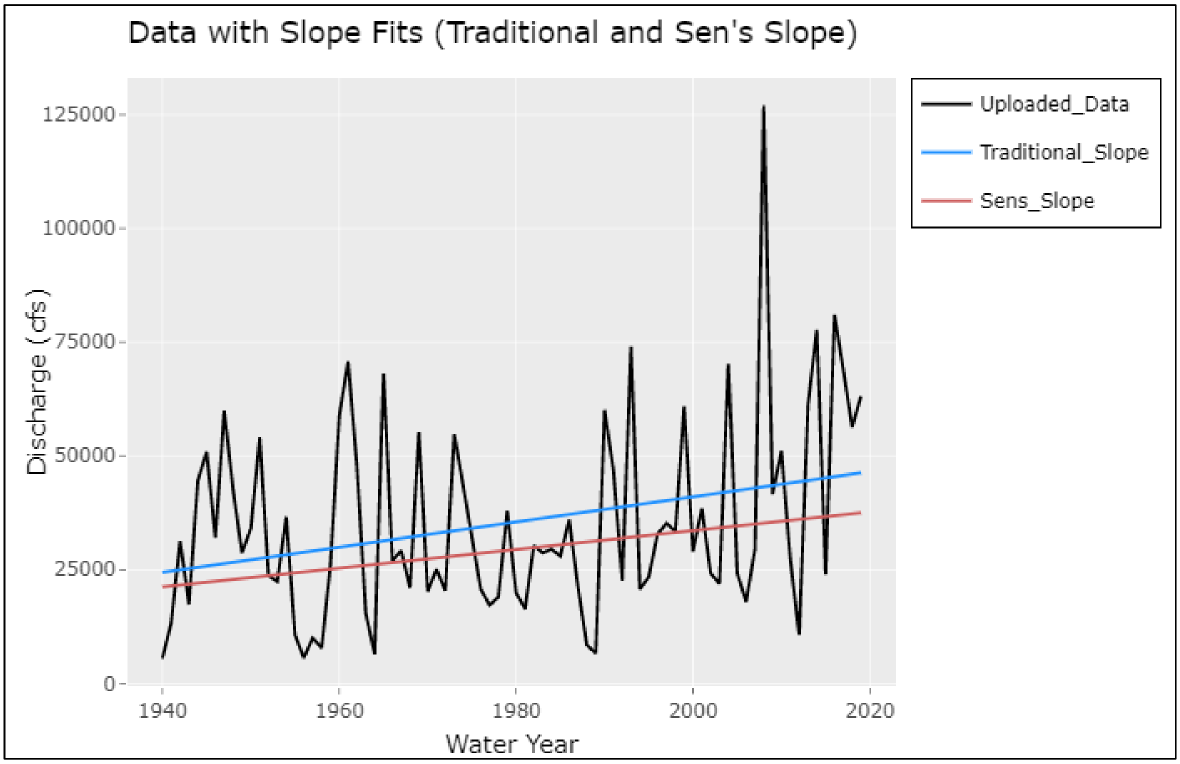
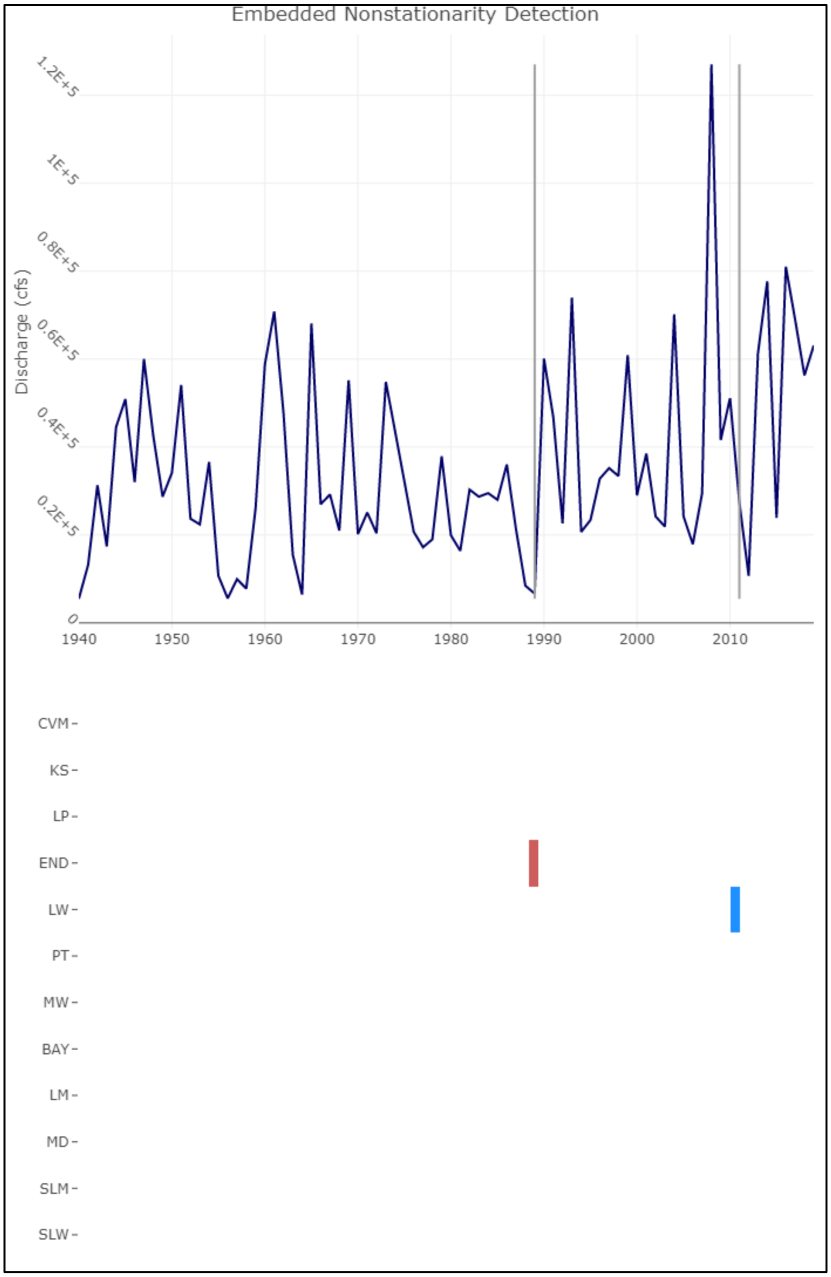


Figure A-30: Annual Peak Streamflow for Cedar River near Conesville, IA
(Linear Regression Equation: Q = 276.82*[Water Year] – 512620, p=0.007874
Sen's Slope Equation: Q = 206.07*[Water Year] – 378560) (Reference 9)



Type: 🟦 Mean 🟥 Distribution 🟧 Variance 🟦 Smooth

Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-31: Nonstationarity Analysis of Maximum Annual Flow, USGS gage 05465000 - Cedar River near Conesville, IA (Reference 9)

B. Trends and Detection of Nonstationarities in Observed Precipitation Records (Reference 9)

The Iowa City NWS Coop Gage #134101, located just southeast of Iowa City, provided long-term total annual precipitation records from WY 1894-2019 for analysis of long-term trends and change points using the TST. The record showed missing data in 1896, and 1948-1951 and therefore the nonstationarity detection used a shortened POR, beginning in WY 1952. Results of the trend analysis indicate an upward trend in annual precipitation (Figure A-32). This trend is considered significant at an overall $p<0.05$ based on all three tests (linear regression [$p=0.0084754$], Mann-Kendall [$p=0.030799$] and Spearman Rank-Order [$p=0.034443$]), in accordance with the Bonferroni correction as previously described ($\alpha=0.0167$ level of significance). Figure A-33 shows results of the nonstationarity detection analysis. The Bayesian test for change in the mean, identified two change points in 1992 and 1993.

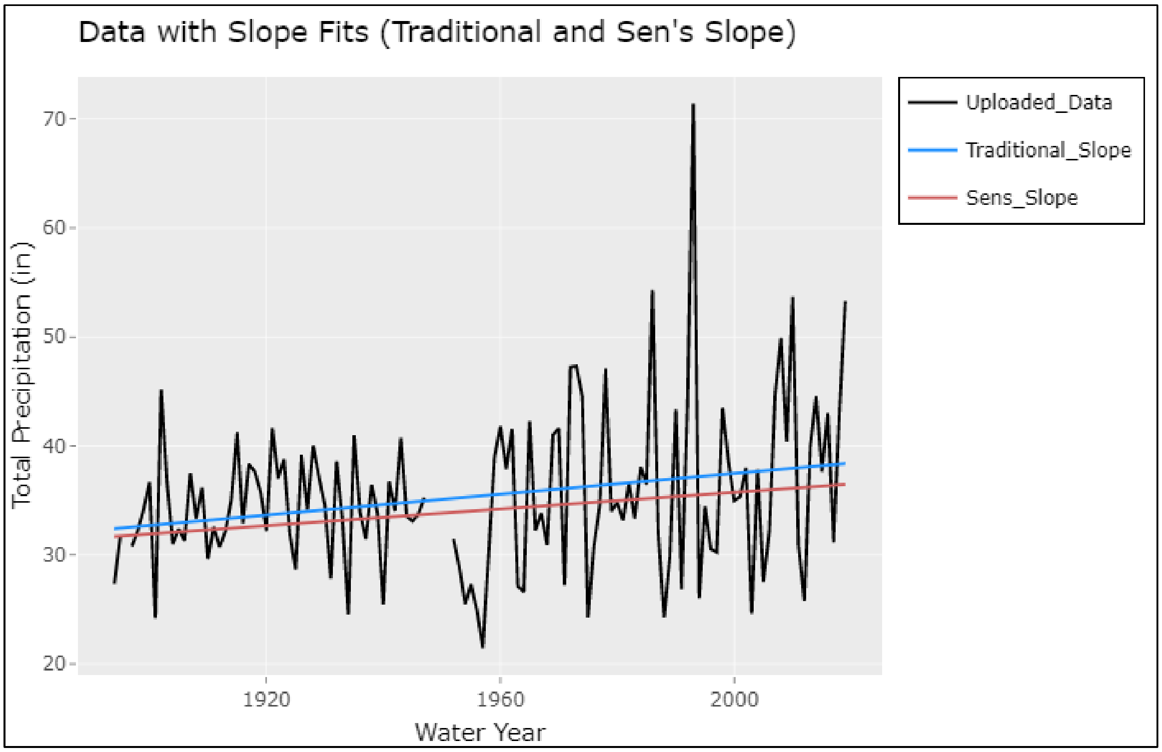
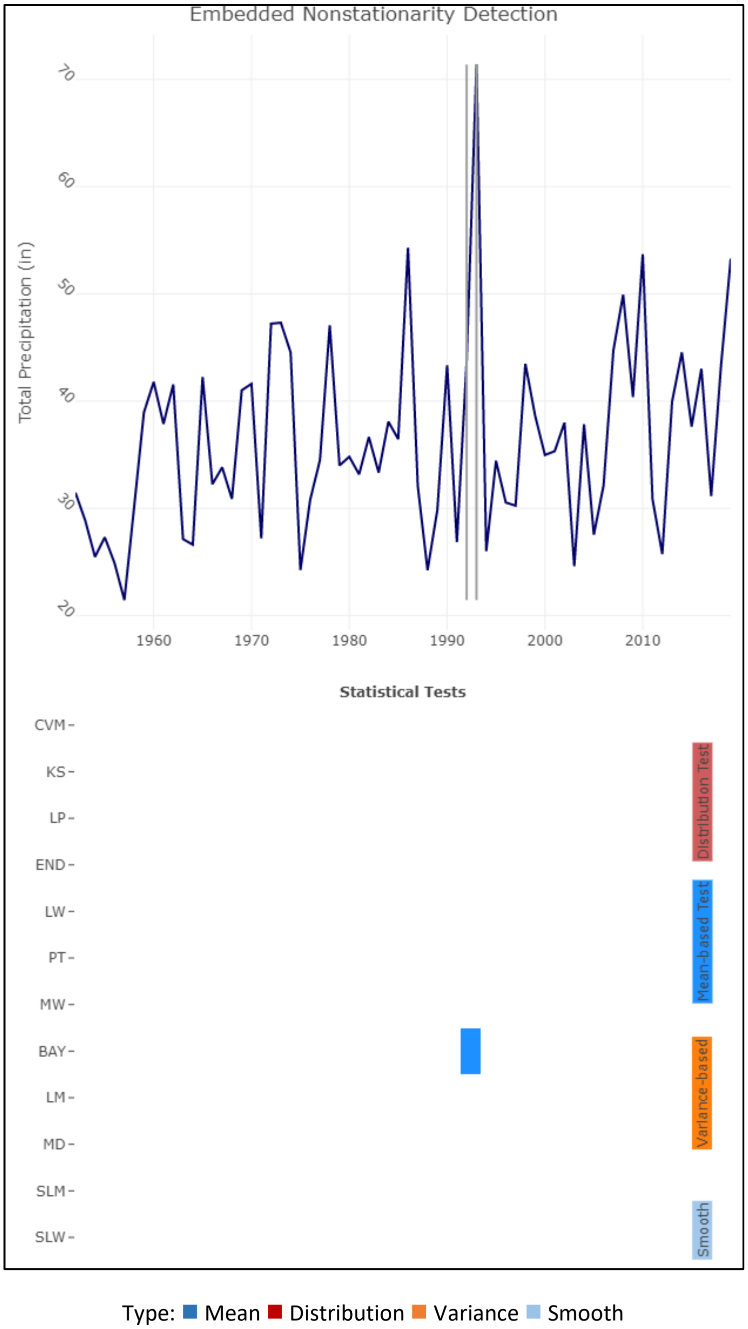


Figure A-32: Annual Total Precipitation for Iowa City NWS Coop gage #134101
(Linear Regression Equation: $P = 0.047738*[\text{Water Year}] - 58$, $p=0.0084754$
Sen's Slope Equation: $P = 0.038207*[\text{Water Year}] - 40.677$) (Reference 9)



Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-33: Nonstationarity Analysis of Total Annual Precipitation, Iowa City NWS Coop Gage #134101 (Reference 9)

C. Trends and Detection of Nonstationarities in Observed Temperature Records (Reference 9)

Annual average maximum and annual average minimum temperature data from the Iowa City NWS Coop Gage #134101, provided long-term temperature records for analysis of trends and change points using the TST. The POR available for annual average maximum and minimum temperature included WY 1894-2019, with missing data from 1948-1951, therefore nonstationarity detection analyses of temperature records used a shortened POR beginning in WY 1952. Figure A-34 illustrates a positive linear trend in annual average maximum temperature. This trend is considered significant at an overall $p<0.05$ based on all three tests (linear regression [$p=0.0013602$], Mann-Kendall [$p=0.0043542$] and Spearman Rank-Order [$p=0.0051407$]), in accordance with the Bonferroni correction as previously described ($\alpha=0.0167$ level of significance). Figure A-35 shows results of the nonstationarity detection analysis for the annual average maximum temperature record, indicating a variance change point in 1974, as well as 2011 and 2012 change points in the mean identified by the Bayesian test.

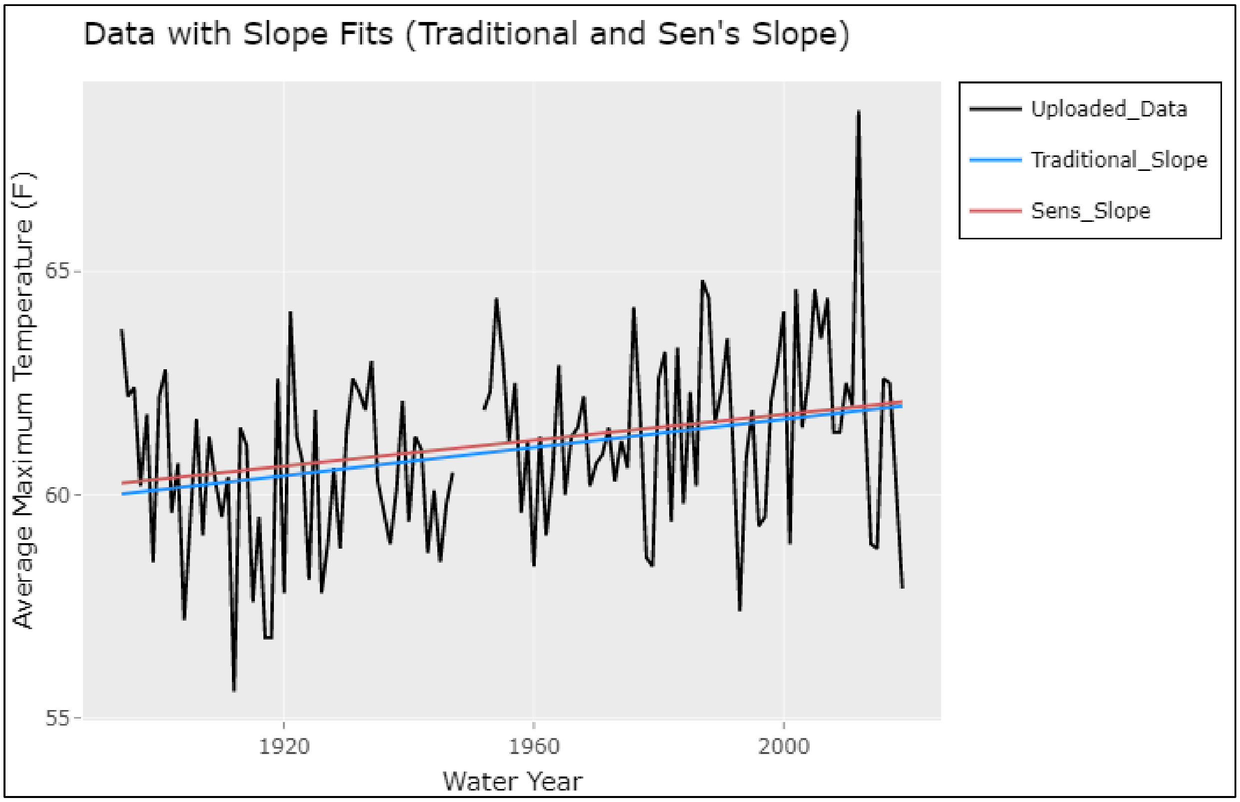
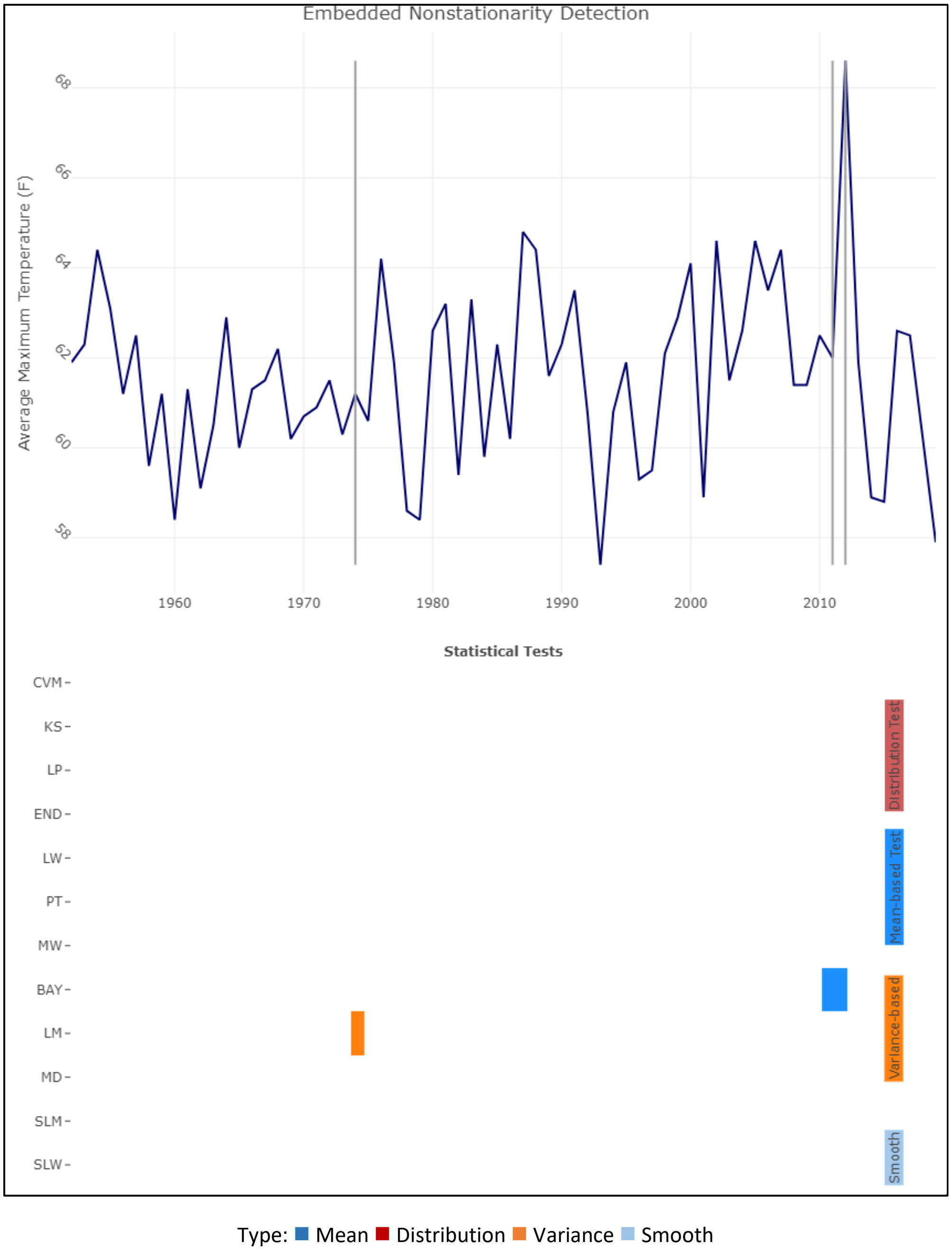


Figure A-34: Annual Average Maximum Temperature for Iowa City NWS Coop Gage #134101 (Linear Regression Equation: T = 0.015764*[Water Year] – 30.161, p=0.0013602 Sen's Slope Equation: T = 0.014493*[Water Year] – 32.816) (Reference 9)



Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-35: Nonstationarity Analysis of Annual Average Maximum Temperature, Iowa City NWS Coop Gage #134101 (Reference 9)

Figure A-36 illustrates a positive linear trend in annual average minimum temperature. This trend is considered significant at an overall $p<0.05$ based on all three tests (linear regression [$p=1.123e^{-9}$], Mann-Kendall [$p<2.2e^{-16}$] and Spearman Rank-Order [$p=1.8059e^{-9}$]), in accordance with the Bonferroni correction as previously described ($\alpha=0.0167$ level of significance). Figure A-37 shows results of the nonstationarity detection analysis for the annual average minimum temperature record. Results indicate consensus in a 1965-1972 change point in the mean based on the Mann-Whitney (1967) and Smooth Lombard Wilcoxon, and consensus in a 1971 distribution change point based on the Cramer-von Mises, Lepage and Energy Divisive tests. A 1997 distribution change point and a 2012 mean change point were also identified.

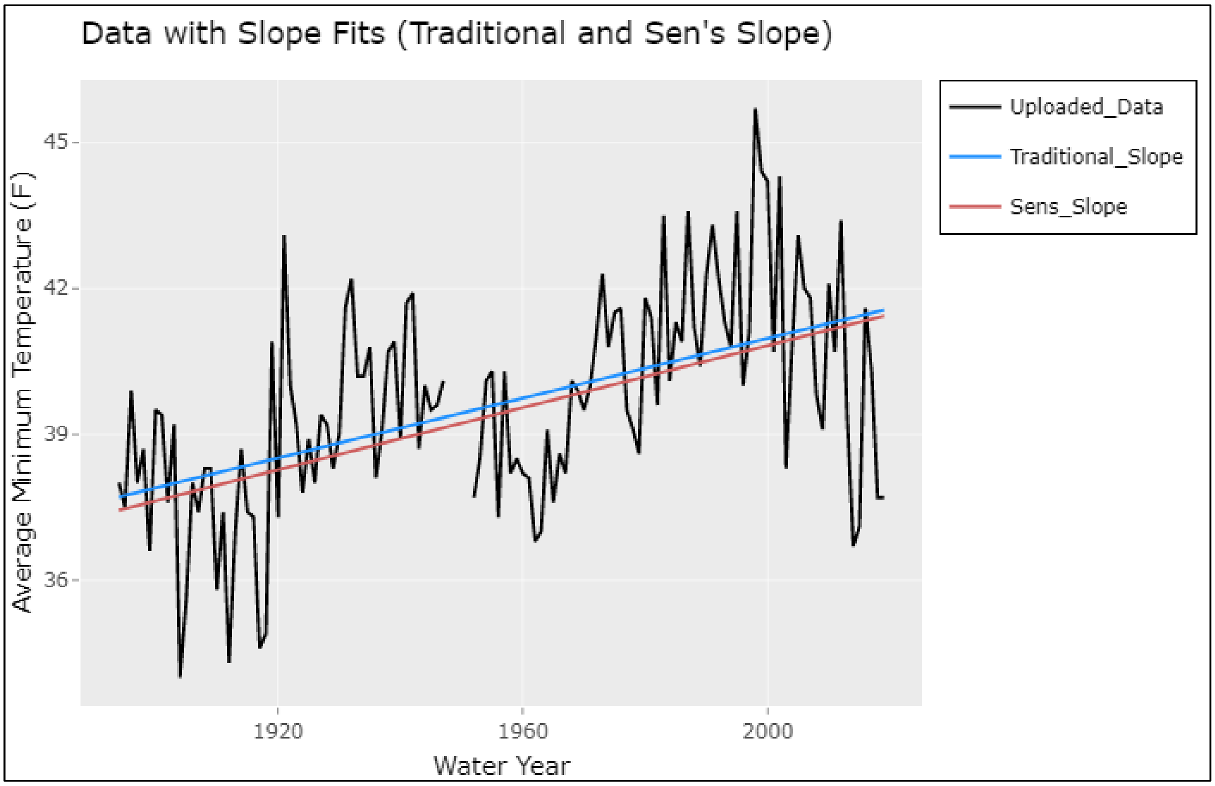
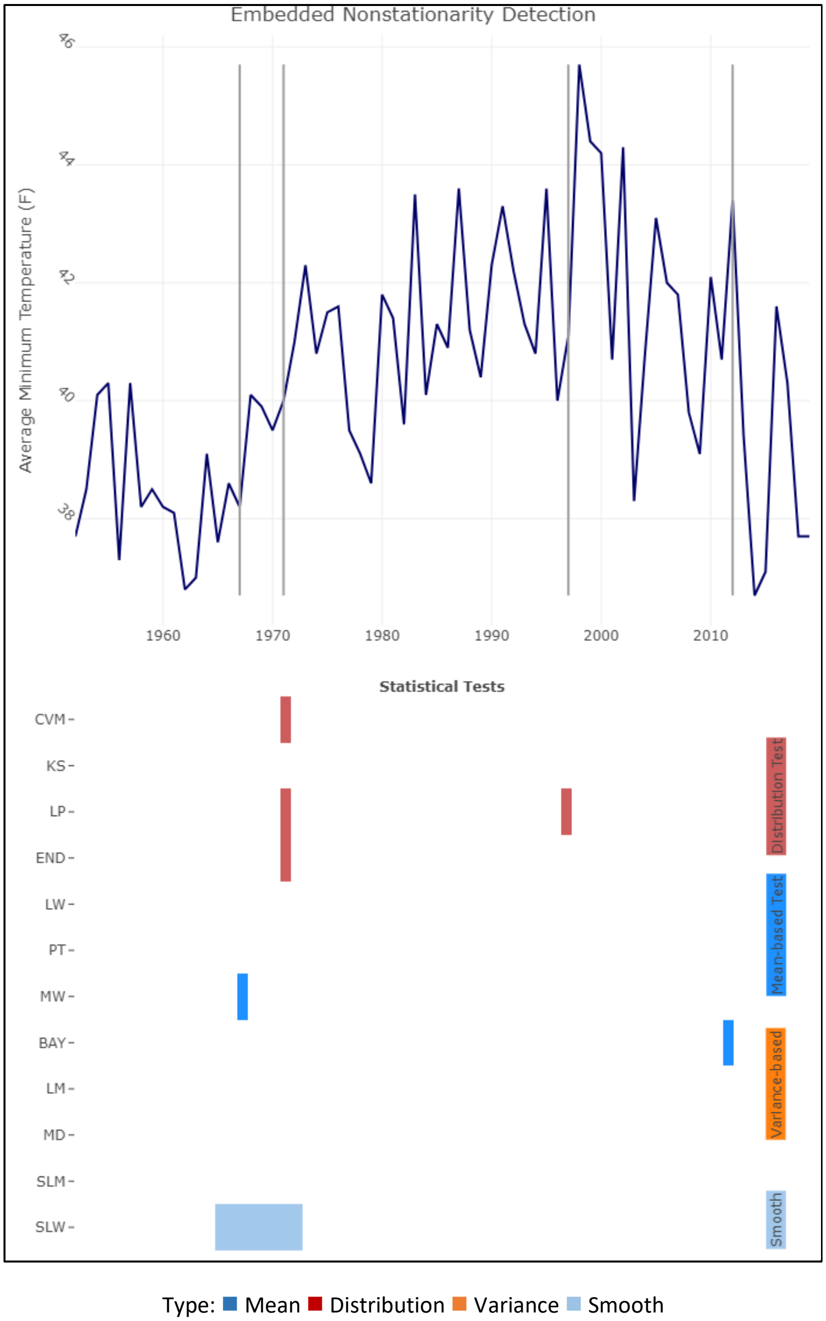


Figure A-36: Annual Average Minimum Temperature for Iowa City NWS Coop Gage #134101
(Linear Regression Equation: T = 0.030733*[Water Year] – 20.493, $p=1.123e^{-9}$
Sen's Slope Equation: T = 0.031944*[Water Year] – 23.063) (Reference 9)



Abbreviation	Statistical Method	Abbreviation	Statistical Method
CVM	Cramer-von-Mises	**BAY**	Bayesian
KS	Kolmogorov-Smirnov	**LM**	Lombard Mood
LP	Lepage	**MD**	Mood
END	Energy Divisive	**SLM**	Smooth Lombard Mood
LW	Lombard Wilcoxon	**SLW**	Smooth Lombard Wilcoxon
PT	Pettitt	**MW**	Mann-Whitney

Figure A-37: Nonstationarity Analysis of Annual Average Minimum Temperature, Iowa City NWS Coop Gage #134101 (Reference 9)

V. PHASE II: PROJECTED CHANGES TO WATERSHED HYDROLOGY AND ASSESSMENT OF VULNERABILITY TO CLIMATE CHANGE

This part of the climate change assessment focuses on carrying out an analysis of projected future streamflow datasets at the HUC-4 watershed scale.

A. Corps Climate Hydrology Assessment of Projected Data (Reference 10)

The Corps Climate Hydrology Assessment Tool was used to analyze potential future changes to flood flows in the Upper Mississippi-Iowa-Skunk-Wapsipinicon Basin (Reference 10). Figure A-38 shows the range of projected annual maximum monthly streamflows developed from 93 different hydrology climate model runs from 2000-2099. Hydrologic climate model output is generated using a variety of greenhouse gas emission scenarios (RCPs) and general circulation models or Global Climate Models (GCMs) to project precipitation and temperature in the future. These outputs are spatially downscaled using the BCSD statistical method and then used in the U.S. Bureau of Reclamation's Variable Infiltration Capacity precipitation-runoff model to generate a streamflow response. There is a considerable spread in the projected annual maximum monthly flows, and the variability is increasing towards the end of the 21st century (Figure A-38).

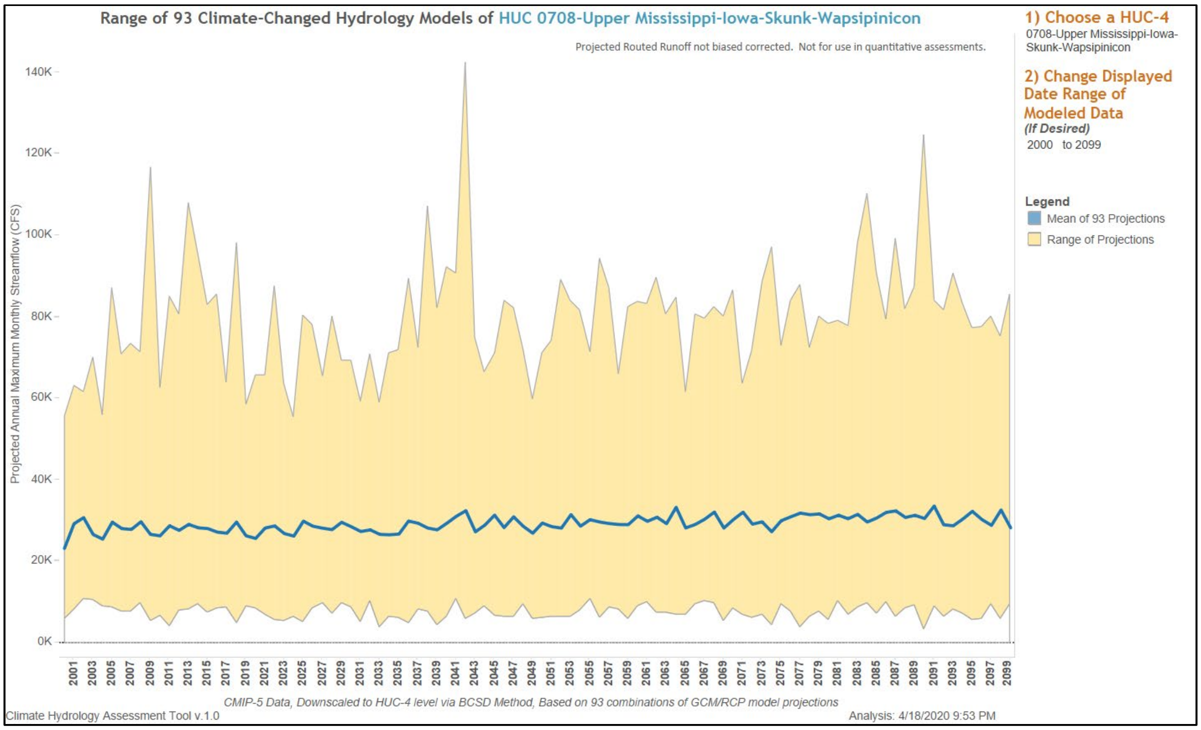
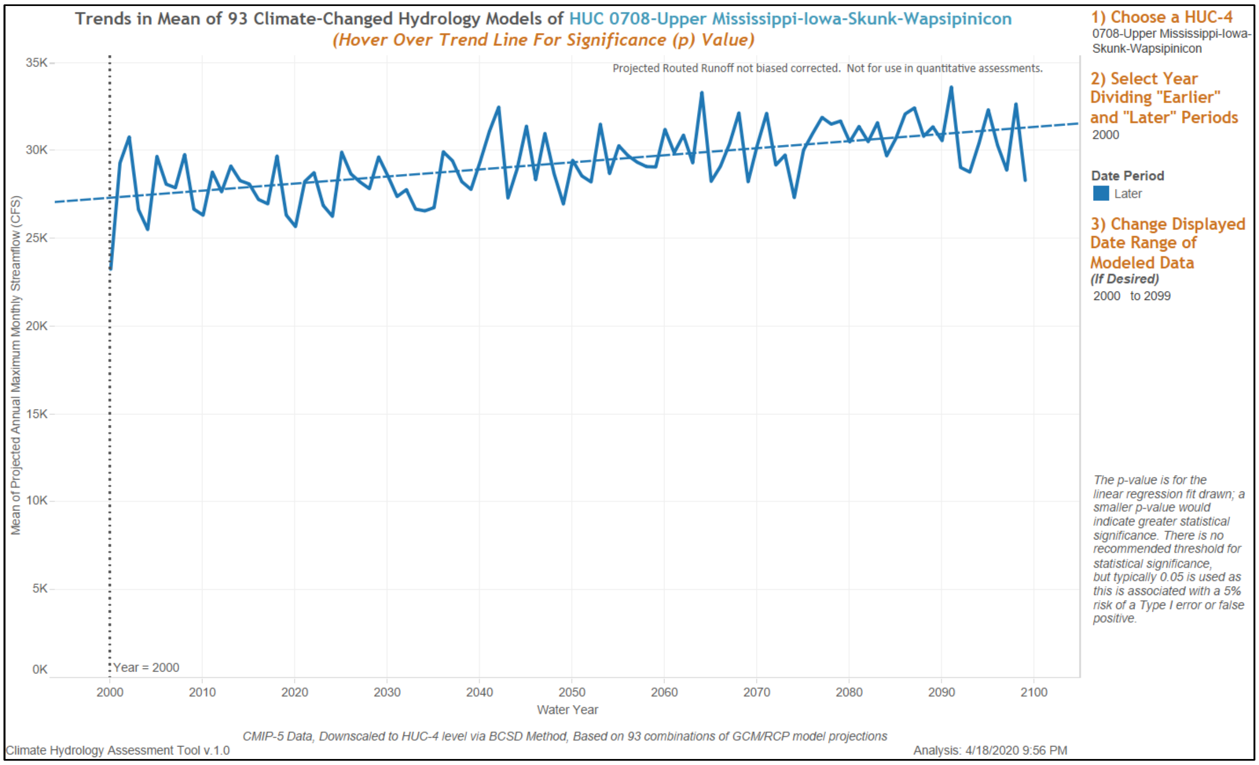


Figure A-38: Range of Projected Annual Maximum Monthly Streamflow among Ensemble of 93 Climate-Changed Hydrology Models, HUC 0708 Upper Mississippi-Iowa-Skunk-Wapsipinicon Basin (Reference 10)

The overall projected trend in the mean projected annual maximum monthly streamflow increases over time (Figure A-39). This increase is statistically significant as the p-value for the linear regression t-Test is considerably less than 0.05 ($p<0.0001$). This suggests that there will be an increased chance of flood risk in the future for the Upper Mississippi-Iowa-Skunk-Wapsipinicon River Basin compared to the current time. Although the p-value indicates that a positive trend is statistically significant, there is uncertainty in the magnitude of the trend. The most likely value of the trend in the data is the best fit line of the data, which indicates an increase of approximately 40 cfs/yr. This result is not relatively large in magnitude, but does indicate an increase over time. This result is qualitative only. This analysis was done at the HUC 04 level and therefore cannot be directly applied to the regulation of Coralville Dam. However, the projected increase in variability of annual maximum monthly flows through the 21st century should be considered when identifying the potential climate vulnerabilities of Coralville Lake.



The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive.

CMIP-5 Data, Downscaled to HUC-4 level via BCSD Method, Based on 93 combinations of GCM/RCP model projections

Figure A-39: Mean Projected Annual Maximum Monthly Streamflow, HUC 0708
Upper Mississippi-Iowa-Skunk-Wapsipinicon Basin
(Linear Regression Equation: $Q = 40.3183*[\text{Water Year}] - 53326.3$, $R^2=0.376668$, $p<0.0001$) (Reference 10)

B. Corps Watershed Climate Vulnerability Assessment Tool (Reference 11)

The Corps' Watershed Climate Vulnerability Assessment 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 Corps business line such as "Flood Risk Management" 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 Watershed Vulnerability Tool uses the Weighted Order Weighted Average (WOWA) method to represent a composite index of how vulnerable a given HUC-4 watershed (Vulnerability Score) is to climate change specific to a given business line. The HUC-4 watershed with the top 20% of WOWA scores are flagged as being vulnerable. Indicators considered within the WOWA score for Flood Risk Management include the acres of urban area within the floodplain, the coefficient of variation in cumulative annual flow, runoff elasticity (ratio of streamflow runoff to precipitation), and two indicators of flood magnification (indicator of how much high flows are projected to change over time).

When assessing future risk projected by climate change, the Corps' 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 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 GCMs and RCPs resulting in 100 traces per watershed per time period. The top 50% of the traces are referred to as the "wet" scenario and the bottom 50% of the traces are referred to as the "dry" scenario. Meteorological data projected by the GCMs is translated into runoff using the Variable Infiltration Capacity Macroscale hydrologic model. The default National Standard Settings were used to carry out this Vulnerability Assessment.

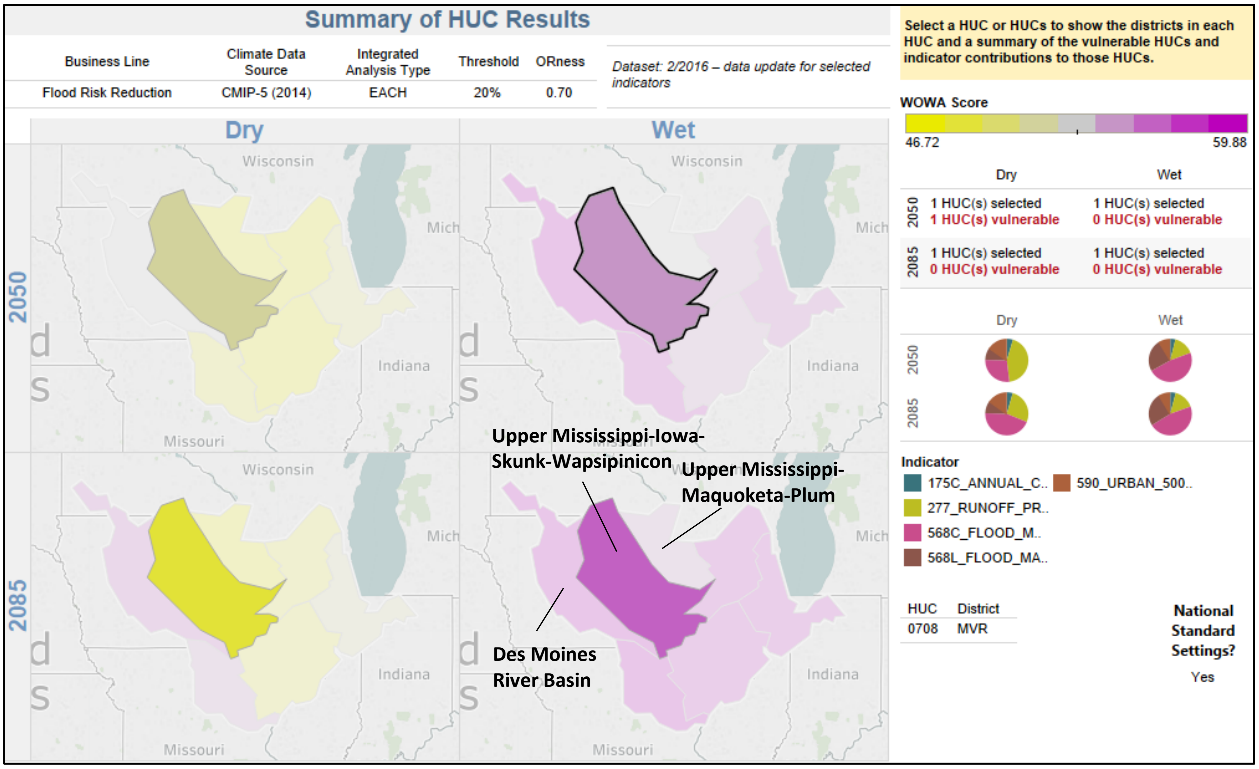
Results of the Climate Vulnerability Assessment Tool as summarized in Figure A-40 suggests that relative to other basins in the CONUS, within the Upper Mississippi-Iowa-Skunk-Wapsipinicon River Basin (HUC 0708) the flood risk management business line is moderately vulnerable to the impacts of climate change. As illustrated by the vulnerability index scores in Table A-4 Upper Mississippi-Iowa-Skunk-Wapsipinicon River Basin has moderate vulnerability scores for all scenarios/epochs relative to other watersheds in the District and in the Mississippi Valley Division (Division). The difference in the vulnerability score for the Upper Mississippi-Iowa-Skunk-Wapsipinicon River Basin compared to the rest of the District is likely due to the different indicators driving the vulnerability scores and differences in the future projected streamflow and precipitation used as inputs to the vulnerability tool. The Upper Mississippi-Iowa-Skunk-Wapsipinicon River Basin has relatively less variation in cumulative annual flow than the neighboring Des Moines River Basin (Figure A-40), and more urban area in 0.2% floodplain than both the Des Moines and Upper Mississippi–Maquoketa-Plum River Basins (Table A-5). These indicator results lend to the Upper Mississippi-Iowa-Skunk-Wapsipinicon River Basin having an overall moderate vulnerability to increased flood risk relative to neighboring HUC-4 watersheds within the District.

Table A-4: Projected Vulnerability for the Upper Mississippi-Iowa-Skunk-Wapsipinicon River Basin (HUC 0708) with Respect to Flood Risk Management Compared to the National, Division, and District Ranges (Reference 11)

Scenario - Epoch	Vulnerability Score (WOWA Score)	National Range	Division Range	District Range
Dry – 2050	52.41	35.15-70.08	42.18-54.37	46.72-53.80
Dry – 2085	49.56	35.66-69.10	42.13-55.98	47.38-55.65
Wet – 2050	55.00	39.80-92.85	47.13-59.88	52.99-59.88
Wet - 2085	55.69	40.86-86.71	48.07-60.93	54.70-58.88

Table A-5 Comparison of Different Indicators for the Upper Mississippi-Iowa-Skunk-Wapsipinicon, Des Moines and Upper Mississippi-Maquoketa-Plum River Basins (Reference 11)

2050 Epoch	**Upper Mississippi-Iowa-Skunk–Wapsipinicon (0708)**		**Des Moines River (0710)**		**Upper Mississippi-Maquoketa-Plum (0706)**	
Indicator	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
	Contribution to WOWA Flood Risk Vulnerability Score					
Variation in Cumulative Annual Flow	2.12	2.43	4.96	8.33	3.28	3.52
Runoff Elasticity (% Change in Runoff/% Change in Precipitation)	8.50	22.78	15.10	23.81	8.50	13.69
Flood Magnification-Cumulative	26.19	14.30	28.31	14.50	26.60	21.23
Flood Magnification-Local	13.41	4.89	9.29	4.76	13.18	6.99
Urban Area in 0.2% Floodplain	4.78	8.02	2.21	2.41	1.42	1.45
Total (WOWA Score)	55.00	52.41	59.88	53.80	52.99	46.88



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Flood Risk Reduction	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

46.72 59.88

	Dry	Wet
2050	1 HUC(s) selected 1 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable
2085	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable

Indicator
- 175C_ANNUAL_C..
- 590_URBAN_500..
- 277_RUNOFF_PR..
- 568C_FLOOD_M..
- 568L_FLOOD_MA..

HUC	District
0708	MVR

National Standard Settings?
Yes

Figure A-40: Projected Vulnerability for the Upper Mississippi-Iowa-Skunk-Wapsipinicon River Basin (HUC 0708) with Respect to Flood Risk Management (Reference 11)

VI. CONCLUSIONS

A. Observed Changes. The literature review identified the following general trends in Iowa and the Upper Mississippi Region:

- Increasing trends in observed air temperature including increasing daily minimum and mean temperatures with faster rates of warming during winter and nighttime temperatures.
- A mild observed upward trend in precipitation with an observed increase in frequency of extreme precipitation events.
- An increasing trend in observed low, mean, and peak streamflow.

Analyses were performed for stream gages in the Iowa-Cedar River Basin to evaluate the streamflow records for long-term trends in peak annual flows and to detect potential nonstationarities in the data that may warrant consideration of utilizing only the more recent portion of the observed record to estimate flow statistics. These analyses involve detection of potential "change points" that represent the presence of statistically significant changes in the mean, variance, or distribution of the streamflow data. ETL 1100-2-3, *Guidance for Detection of Nonstationarities in Annual Maximum Discharges; Section B-5,* states that "a "strong" change point is one for which there is a consensus among multiple change point detection methods, robustness between changes in statistical properties, and for which an operationally significant change in magnitude is determined."

For the Iowa-Cedar River Basin, potential changepoints meeting one or more of the three necessary criteria to define a "strong" changepoint were identified (Table A-3) at three of the nine gage locations analyzed. Change points most likely to be attributable to climatic change effects are around 1957/1958 for the Coralville Lake inflow (CRVI4) records and in 1954 in the Cedar Rapids gage record. Neither of these change points meet the definition of a "strong" change point, per ETL 1100-2-3, due to a lack of consensus or robustness. The strong change point around 1951/1953 identified in the Iowa City gage record likely reflects the construction of Coralville Lake (located immediately upstream) and the significant drought that occurred immediately prior.

The majority of streamflow gages evaluated exhibit upward trends in annual peak flow (Table A-2). The exception being the Iowa City gage, located immediately below Coralville Lake, which exhibited a downward trend in peak annual streamflow due to the regulating effects of the reservoir. The statistical significance of the computed upward trends was mixed. Evaluation of historical precipitation trends identified a statistically significant upward trend, reinforcing the upward trend in annual peak streamflow.

B. Projected Changes. Projected climate changes are described through Corps of Engineers tools and the literature at a regional level or HUC 04 watershed scale. According to the Climate Hydrology Assessment Tool, for the Iowa River watershed, there is projected to be an increase in variability and an upward trend of annual maximum monthly flow through the 21st century. According to the Vulnerability Assessment tool, the Iowa River watershed is moderately vulnerable to climate change impacts on flood risk management as compared to other HUC 04 watersheds.

The literature review indicated that precipitation is projected to increase, but there is less consensus on the projection of future streamflows. Multiple authors suggest that there may be seasonal changes in streamflow with higher flows in the winter/spring and lower flows in the summer/fall. The literature does suggest that there is more uncertainty in projected streamflow (compared to projected temperature or precipitation) and that there is a possibility of more extreme events.

VII. RECOMMENDATIONS

During the public scoping and stakeholder meetings conducted for this study, numerous questions and comments were received related to perceived increases in the frequency of flooding and how the study team would consider this in identifying recommended changes to the water control plan. Based on the qualitative assessment discussed above, there is no consensus among the gages in the Iowa River basin to suggest that trends in observed data or detected nonstationarity change points should be applied to the entire watershed such that only the more recent portion of the observed record should be used to estimate flow statistics for alternative evaluation. However, the prevalence of an upward trend in streamflow and precipitation records points to the hydrologic uncertainty of simply utilizing the full period of record and assuming stationarity, and does not fully address the comments related to perceived increases in flooding and the potential effects on selection of the preferred water control plan for Coralville Lake.

In order to better address the public and stakeholder comments, a hydrologic sensitivity analysis was conducted to determine the effect of the evaluated record length on the study conclusions (i.e., evaluation and selection of which alternative minimizes flood risk along the system). The sensitivity analysis consisted of fully analyzing the hydrologic and economic performance of the alternative plans utilizing two time periods. The first is the full period of record (1917-2019) for which systemic flow data is available. The second focusses on the latter part of the record which has been wetter with higher inflow volumes into Coralville Lake. The period selected for the more recent, wetter, period was 1959 to 2019.

This is due to the occurrence of potential change points at various dates within the 1950s, identified at the various gages, as well as the timing of Coralville Lake going into operation (1959 was the first full year of operation). As a result of the lake going into operation, additional gages were established that provide for a higher resolution of flow data than existed prior to the lake's construction. Some of the inflow records prior to 1959 were, out of necessity, estimated from surrounding gages (see Section II.A.1.a, Appendix B). The results of the hydrologic analyses are presented in Appendix B. Evaluation of the two time periods allows the study team to evaluate the robustness of the study findings (i.e., do both time periods favor the same alternative or does consideration of the wetter period tend to favor a different alternative) as future projected climate changes indicate a long term upward trend in precipitation and the potential for more extreme flood events. As discussed in the main report, both time periods identified the same preferred alternative (Alternative 2C).

In addition to identifying a preferred alternative, the Recommended Plan developed as part of the study includes modifications to add additional flexibility, where possible, to the water control plan through establishment of a conservation pool operating band, expanded fall pool raise limits at Coralville Lake, and higher maximum seasonal releases during normal flood operations. The collective changes allow Coralville Lake to reduce average annual flood damages and provide for opportunities to enhance fish and wildlife management during non-flood or drought periods in a more flexible framework that allows these operations to better respond to conditions experienced within a particular year.

In evaluating the hydrologic sensitivity of the project to potential effects of future climate change, it is important to recognize that the scope of the study is to evaluate how to best manage the existing Coralville Lake project to support the authorized operating purposes. Many of the operational parameters contained in the Coralville Lake Water Control Plan are not controlled by estimates of current or future hydrology but rather are related to physical constraints in the system. These include the physical capacity of the dam conduit and gates, the downstream carrying capacity of the Iowa River below Coralville Dam, and downstream stage constraints that represent thresholds above which there are significant changes in the consequences of flooding. The importance of the hydrologic estimates is in helping to characterize the likelihood of flow conditions, which, along with consequence information, facilitate understanding, and communication of flood risk.

In addition, per ER 1110-2-240, *Water Control Management*, water control manuals should be periodically reviewed and administrative updates performed not less than every 10 years. Historically, major revisions to the water control manual (i.e., revisions that resulted in changes to the water control plan) occurred in 1958 (original plan), 1963, 1982, and 1993. The frequency with which the water control plans are reviewed and updated helps to reduce the risks associated with long-term climate predictions due to the ability to continuously adapt the water control plans over the life of Coralville Lake to reflect not only hydrologic changes, but also changes in land use (and associated consequences).

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