Appendix B
Climate Change

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Appendix B. Climate Change

A qualitative climate change analysis was undertaken in accordance with the USACE Engineering and Construction Bulletin No. 2018-14 (USACE, 2018) and Engineering Technical Letter 1100-2-3, *Guidance for Detection of Nonstationarities in Annual Maximum Discharges*. This analysis included both a literature review and analysis of USGS gauges near the project site. The River Des Peres General Re-Evaluation Report (GRR) includes an update of hydrologic and hydraulic conditions, flood damages with and without a project and the related economic benefits, environmental and cultural impacts and required permits, design considerations and possible non-structural solutions to reduce flood damages. To acknowledge changes in climate, the team will also assess climate change impact to the River Des Peres watershed. While this assessment does not change the numerical results of the alternatives evaluated, it helps to inform alternative selection by providing information on possible trends in flood flows with time.

Climate change characteristics that could impact the River Des Peres GRR reliability include temperature, precipitation, stream flow and changes in seasonality.

1.1 CURRENT CLIMATE

The nearest climate gaging station to University City, Missouri is at the Airport in Bridgeton, Missouri. Bridgeton, Missouri has a continental climate characterized by cold winters and hot summers. The average annual rainfall is 40.96 inches with May being the month of highest rainfall (U.S. Climate Data, 2020). However, precipitation is highly variable from year to year with the statewide average ranging as low as 25.52 inches in 1901 and as high as 51.18 inches in 1993. The driest 5-year period in history was from 1952 to 1956 and the wettest 5-year period ranged from 2007 to 2011. The average annual snowfall is 11 inches with the majority falling in December through February (monthly average 3 to 4 inches). Figure 1 shows the monthly climate patterns for Bridgeton, Missouri (U.S. Climate Data, 2020). The figure illustrates monthly high and low temperature and precipitation averages.

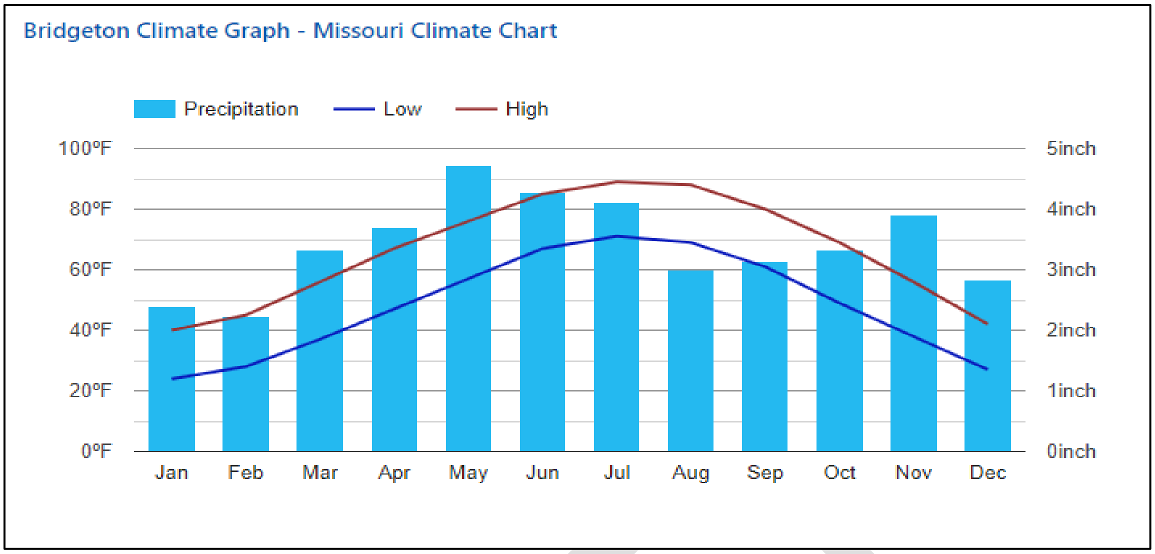


Figure 1. Average High and Low Temperature and Precipitation Averages for Bridgeton, MO.

1.2 OBSERVED CLIMATE TRENDS

The *Climate Science Special Report from the Fourth National Climate Assessment* (USGCRP, 2017) and the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions Upper Mississippi Region 7* (USACE, 2015) were referenced for observed trends in precipitation, temperature, stream flow, and changes in seasonality.

Figure 2 shows that annual temperature in the study area has increased over time and that the largest increases have been in the winter opposed to the summer. Since the beginning of the 20th century, temperatures in Missouri have risen approximately 0.5°F and temperatures in the 2000s have been higher than any other historical period except for the early 1930s Dust Bowl era. This warming trend has been concentrated in the winter and spring while average summer temperatures have not increased substantially in the state until the most recent 5 years, a feature characteristic of much of the Midwest. Figure 3 shows that the trends in observed minimum temperatures show upward trends. Figures 4 shows the number of extremely hot days above 100 °F and Figure 5 shows the number of extremely cold nights below 0 °F. From these figures it can be seen that the number of cold nights and hot days show consistent downward trends over time. (NOAA NCICS, State Climate Summaries 2020).

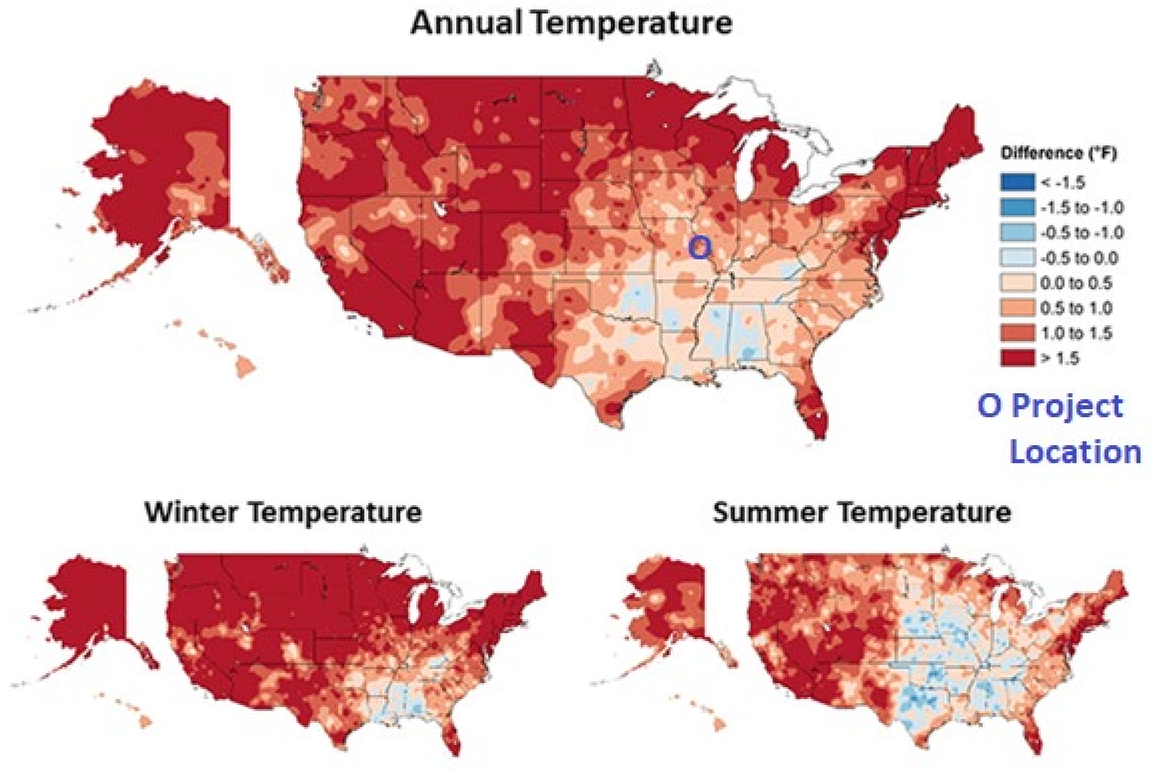


Figure 5. Observed changes in annual, winter, and summer temperature (°F). Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i). Estimates are derived from the nClimDiv dataset (Vose et al. 2014, Vose et al. 2017) (NCA Vol 2 Figure 6.1, Figure source: NOAA NCDC / NCEI).

Figure 2. Observed changes in temperature

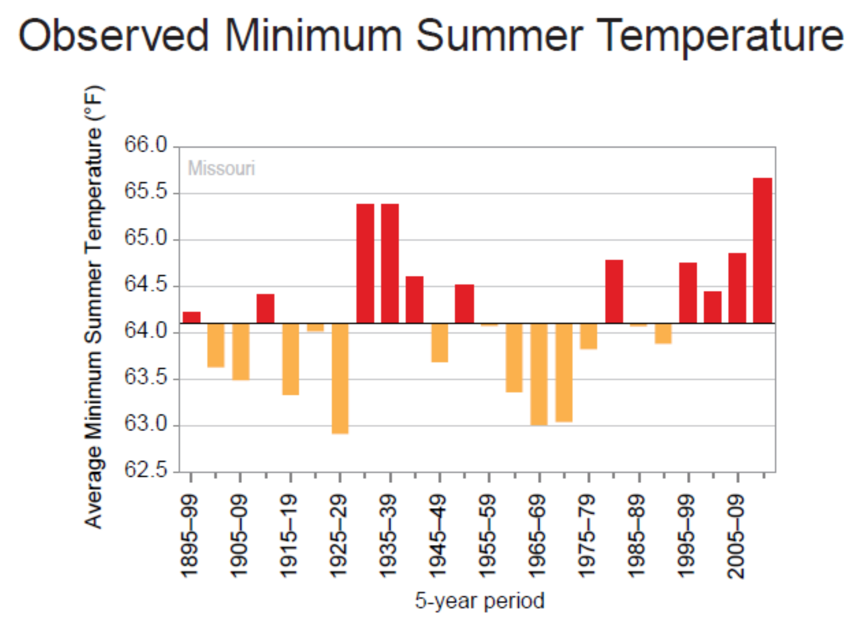


Figure 3. Observed Minimum Summer Temperatures Trends

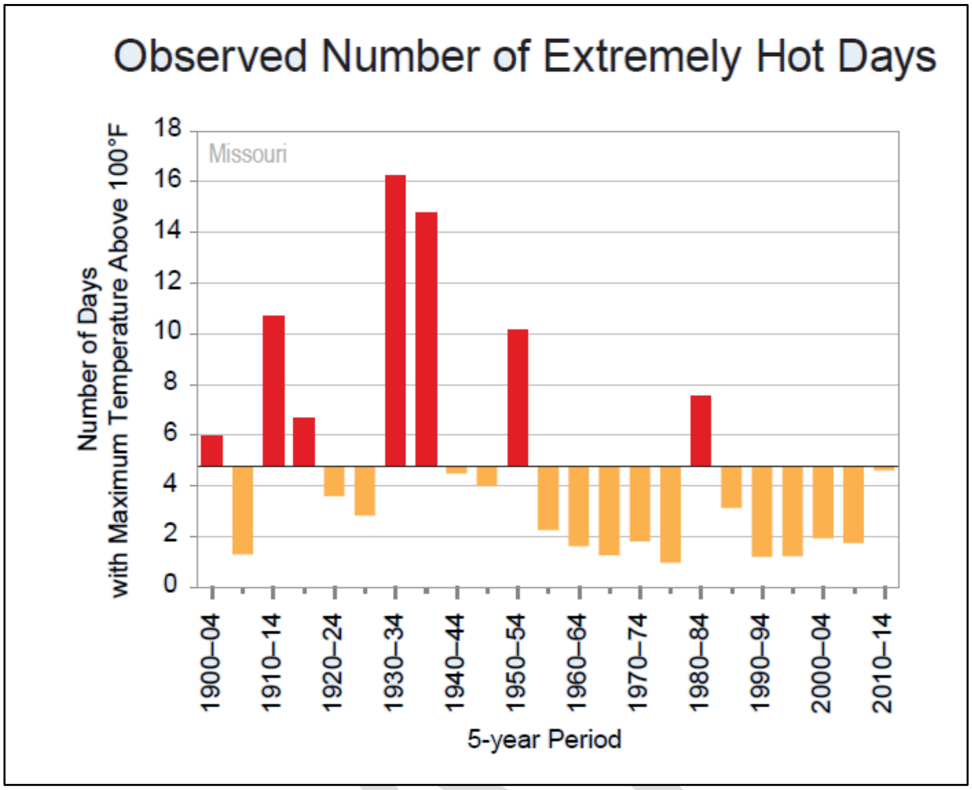


Figure 4. Number of Extremely Hot Days above 100º F

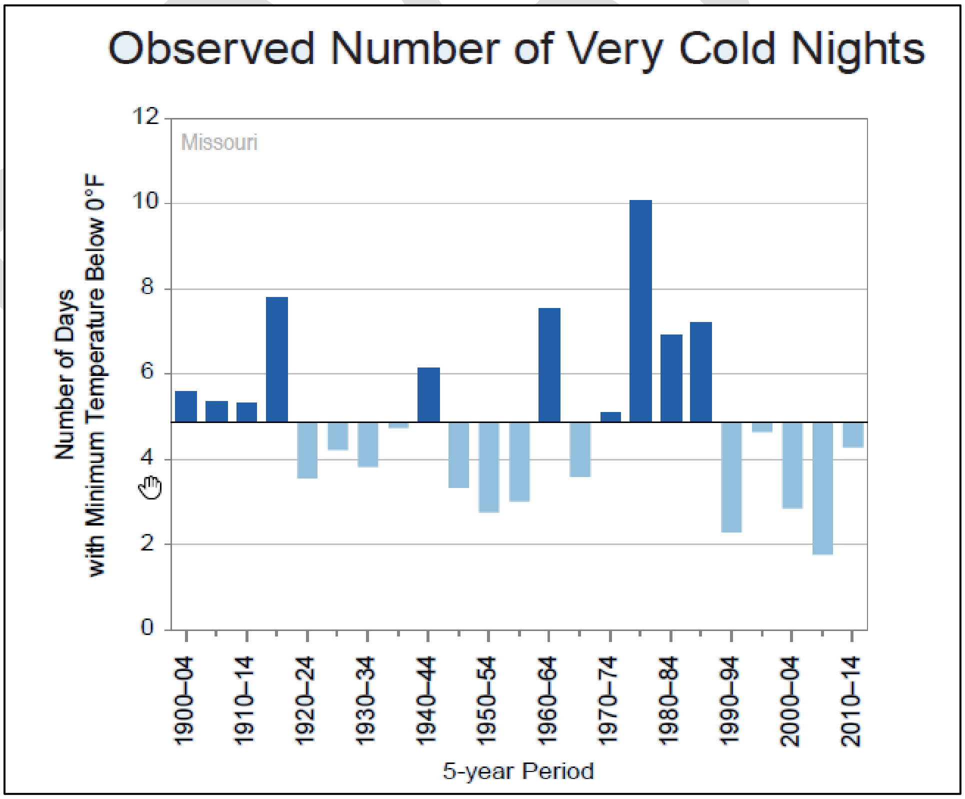
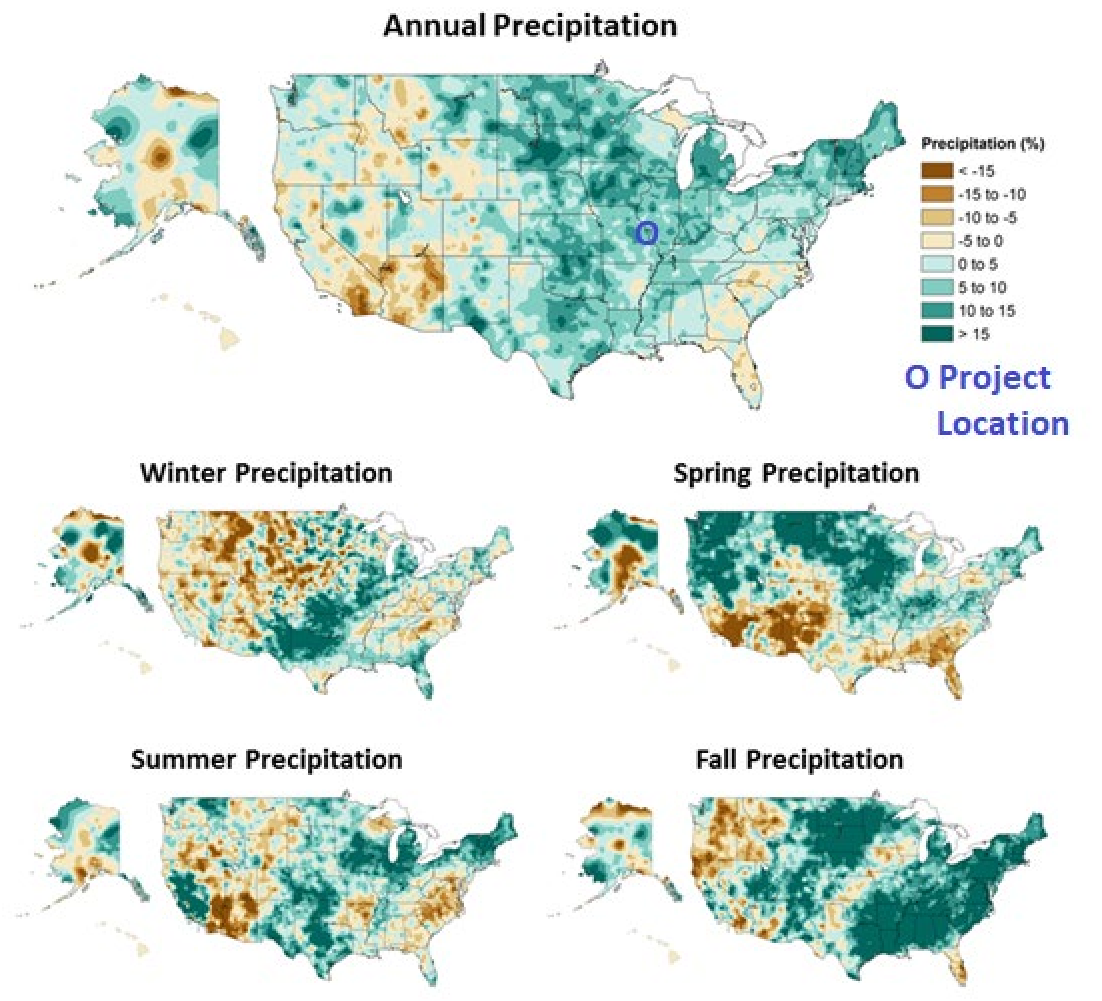


Figure 5. Number of Extremely Cold Nights below 0^{o} F

Missouri’s economy is dependent on agriculture, and consequently precipitation conditions. Missouri has experienced an increase in the number of heavy rain events and the state’s position in the lower river basins of several large Midwestern rivers makes downstream flooding an extreme hazard in this state. Figure 6 illustrates the changes over time to average annual precipitation. Figure 7 shows an increasing overall trend over average in annual precipitation for the last 20 years. (NOAA NCICS, State Climate Summaries 2020).


Annual Precipitation

Winter Precipitation

Spring Precipitation

Summer Precipitation

Fall Precipitation

Annual and seasonal changes in precipitation over the United States. Changes are the average for present-day (1986–2015) minus the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i) divided by the average for the first half of the century. (Figure source: [top panel] adapted from Peterson et al. 2013,[6] © American Meteorological Society. Used with permission; [bottom four panels] NOAA NCEI, data source: nCLIMDiv].

Figure 6. Observed changes in precipitation

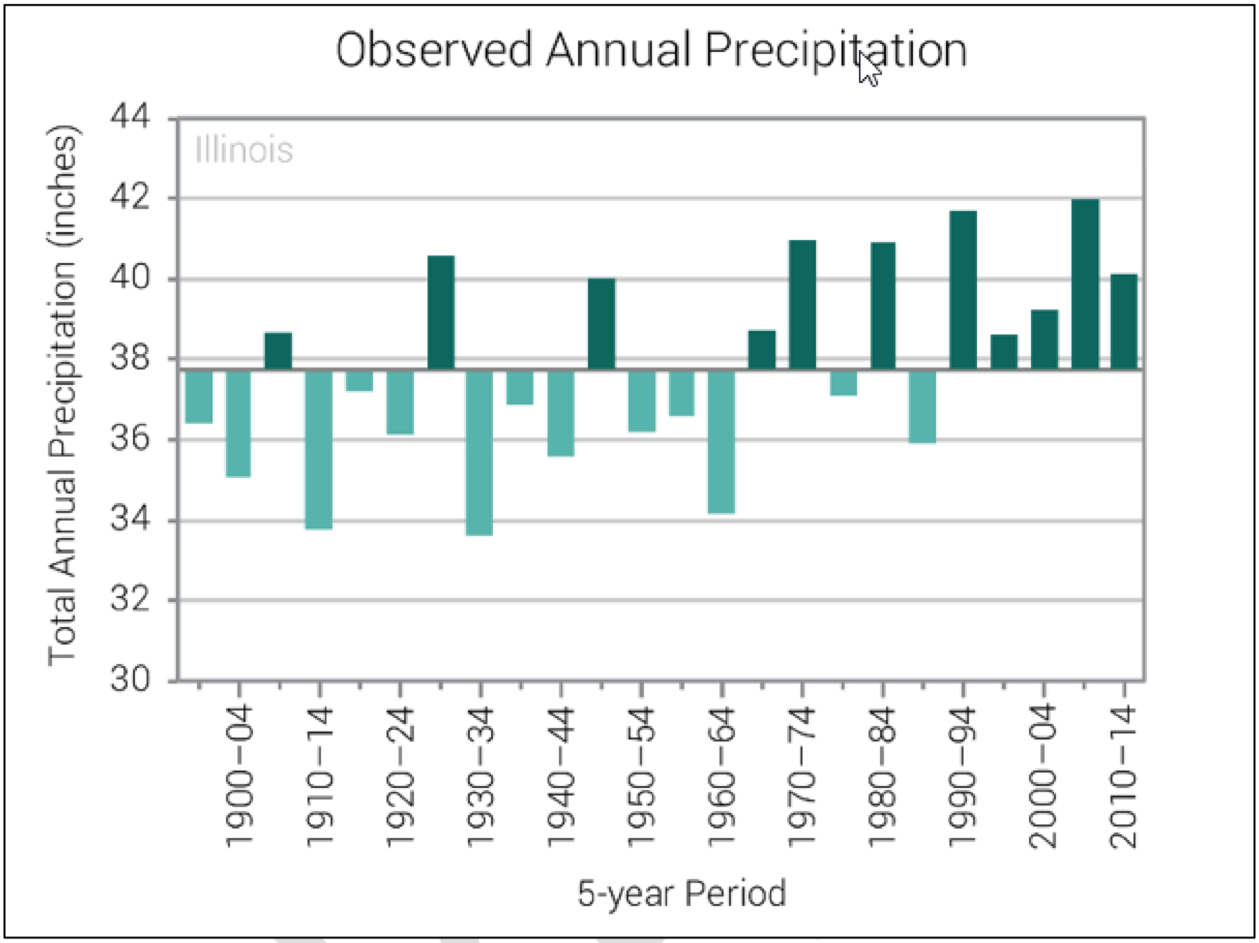


Figure 7. Observed Annual Precipitation

1.3 LITERATURE REVIEW CONCLUSIONS

Based on the observed trends mentioned above, important hydrologic variables for River Des Peres which may be impacted by climate change include intensity, duration, and frequency of precipitation events. Changes in precipitation, a function in temperature, may cause impacts to the River Des Peres as more frequent higher magnitude storm events will lead to higher channel water surfaces. It is therefore appropriate to investigate the potential impacts of global climate change on River Des Peres watershed.

The literature review indicates that:

- Though temperature observations were inconclusive in demonstrating an overall trend toward increased temperature in Missouri, the effects of climate change can be seen in the extremes of cold and hot days. An increase in the average hot and cold temperature averages were observed.
- The consensus in recent literature points toward moderate increases in temperature and precipitation in the Upper Mississippi Region over the past century (Figure 8).
- Some evidence points to an increased frequency in the occurrence of extreme storm events (Villarini et al., 2013).

- Multiple authors identified a transition point in climate data trends in 1970 where rates of increase changed significantly.

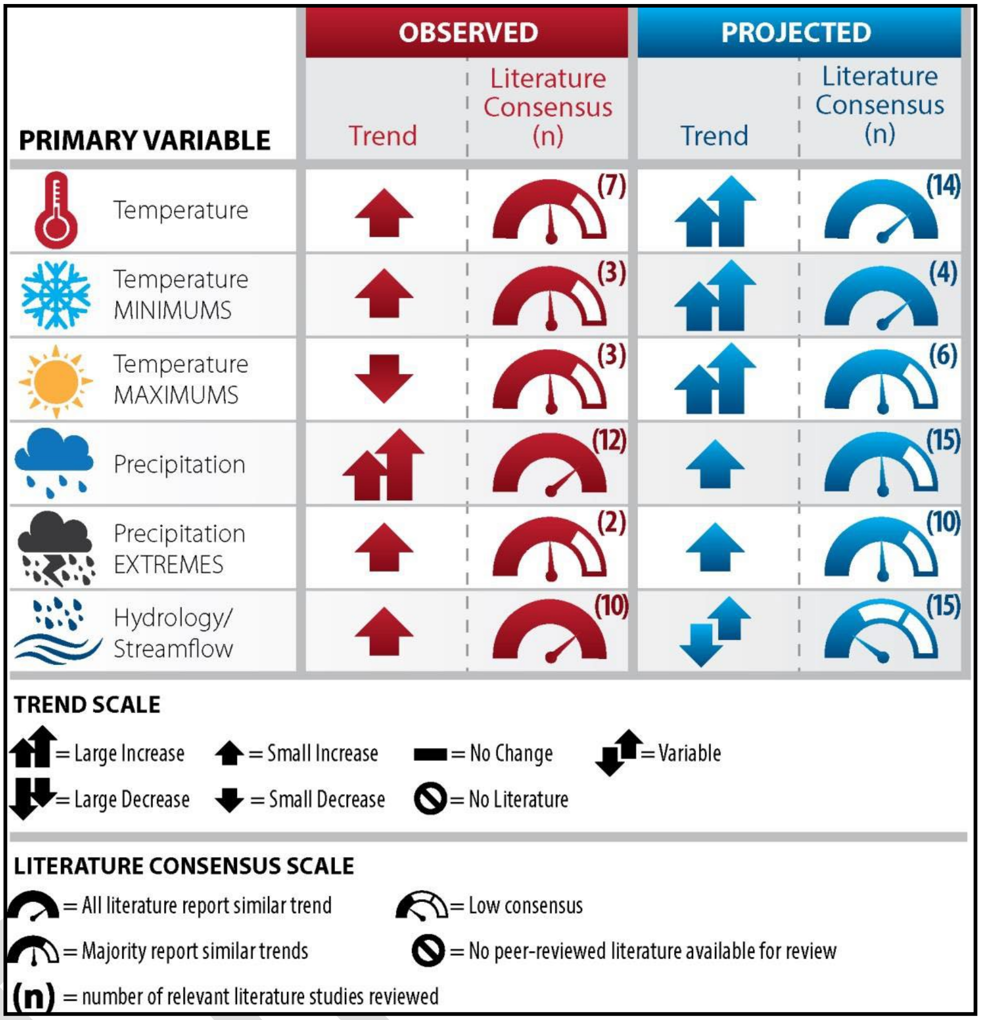


Figure 8. Summary matrix of observed and projected regional climate trends and literature consensus (USACE, 2015)

1.4 CLIMATE PROJECTIONS

There is strong consensus in the literature that air temperatures will continue to increase in the study region over the next century (Figure 9). A function of emissions, the studies reviewed generally agree on an increase in mean annual air temperature of approximately 2 to 6 ºC (3.6 to 10.8 ºF) by the latter half of the 21st century in the Upper Mississippi Region. 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.

Increased air temperatures and increased frequencies of drought, particularly in the summer months, will result in increased water temperatures. Outside of the combined sewer overflow problems, increased water temperatures will further degrade water quality, particularly for the dissolved oxygen levels. Dissolved oxygen and increased water temperature is an important water quality parameter for aquatic life. Increased temperatures are also associated with the growth of nuisance algal blooms and influence wildlife and supporting food supplies.

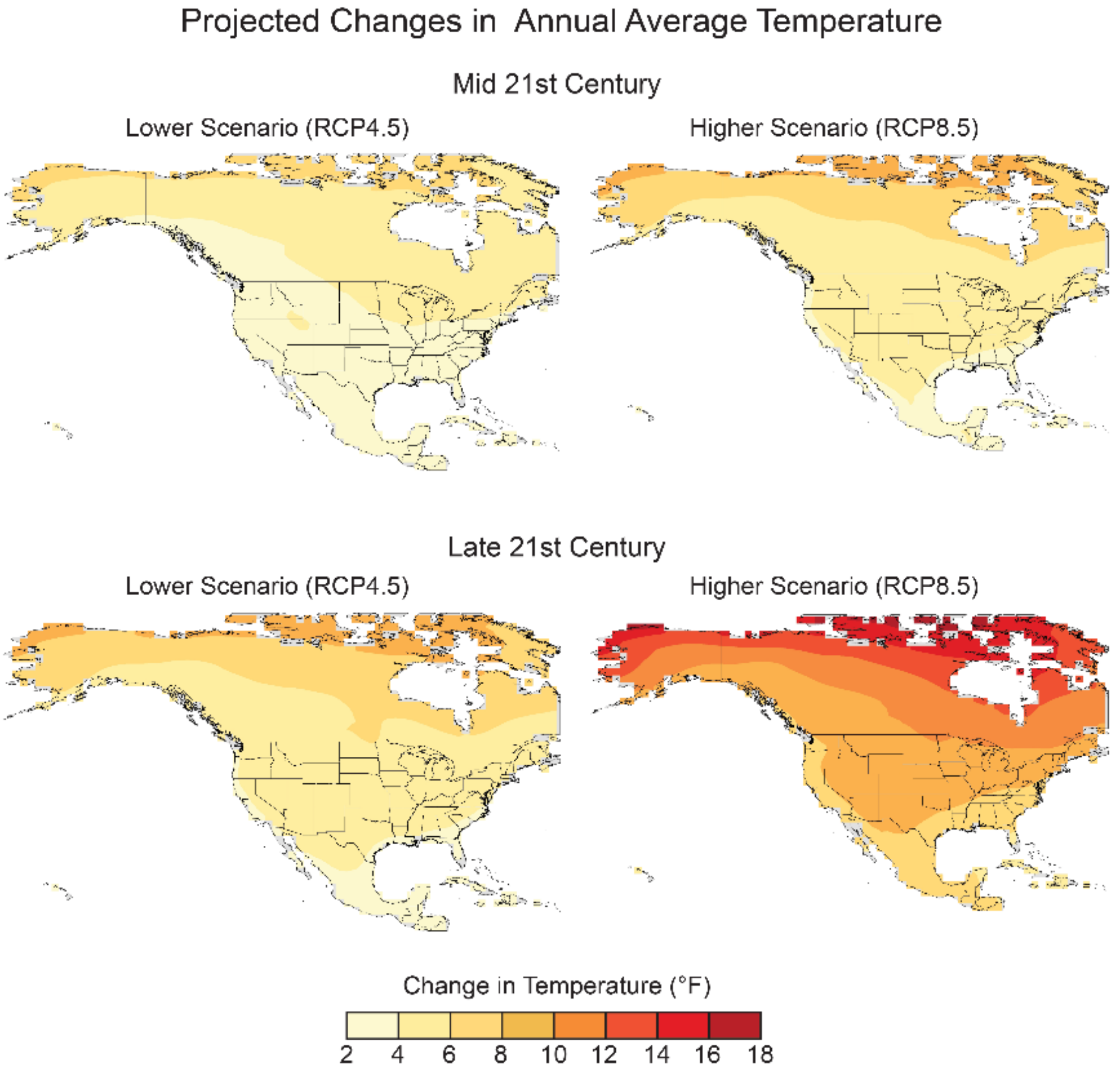
Projections of precipitation found in a majority of the studies forecast an increase in annual precipitation and in the frequency of large storm events. However, there is some evidence presented that the northern portion of the Upper Mississippi Region will experience a slight decrease in annual precipitation. Additionally, seasonal deviations from the general projection pattern have been presented, with some studies indicating a potential for a decrease in precipitation in the summer. Lastly, despite projected precipitation increases, droughts are also projected to increase in the basin because of increased temperature and evapotranspiration rates.

Figure 9 and Figure 10 show projected trends in temperature and precipitation for different emission scenarios. Temperature at the project site are projected to increase in all greenhouse emission scenarios and time projections, from 2-4 degrees F for the low emission scenario by Mid-21st Century and from 8-10 degrees for the high emission scenario by Late-21st Century.

Precipitation projections shown in Figure 11 from the World Climate Research Programs Coupled Model Intercomparison Project (NOAA NCEI) are less conclusive. Precipitation is forecasted to increase in all seasons except summer but the confidence of the results are not strong and, in the case of fall and summer, may not be stronger than the natural variability of the site’s climate. Increases in spring precipitation and consequently flooding appear to be the most likely scenarios to noticeably trend upward.

A clear consensus is lacking in the hydrologic projection literature. Projections generated by coupling Global Climate Models with macro scale hydrologic models in some cases indicate a reduction in future streamflow but in other cases indicate a potential increase in streamflow. Of the limited number of studies reviewed here, more results point toward reduction than increase, particularly during the summer months.

Given the high degree of variability and uncertainty in weather patterns in general and in predictions of future weather patterns in particular, quantifying future project impacts is inexact.



Projected changes in annual average temperatures (°F). Changes are the difference between the average for mid-century (2036–2065; top) or late-century (2070-2099, bottom) and the average for near-present (1976–2005). Each map depicts the weighted multimodel mean. Increases are statistically significant in all areas (that is, more than 50% of the models show a statistically significant change, and more than 67% agree on the sign of the change[78]). (Figure source: CICS-NC and NOAA NCEI).

Figure 9. Projected Changes in Temperature

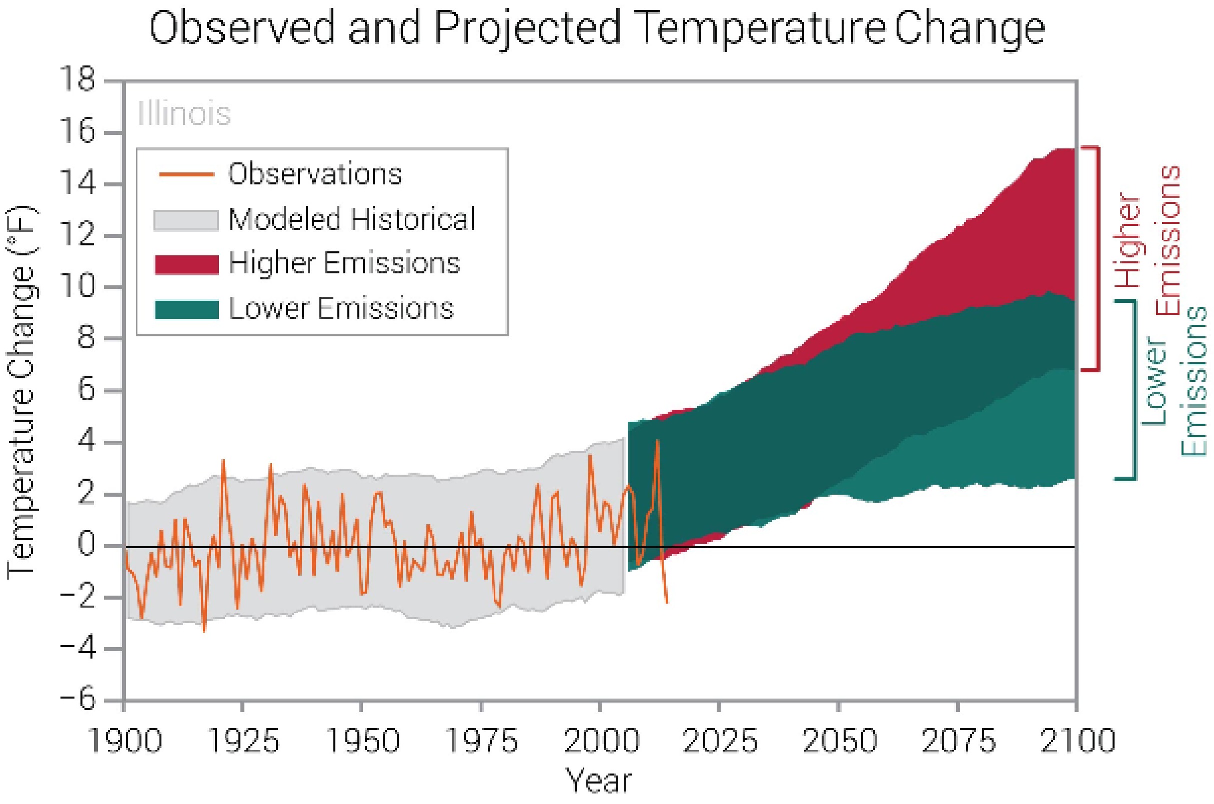
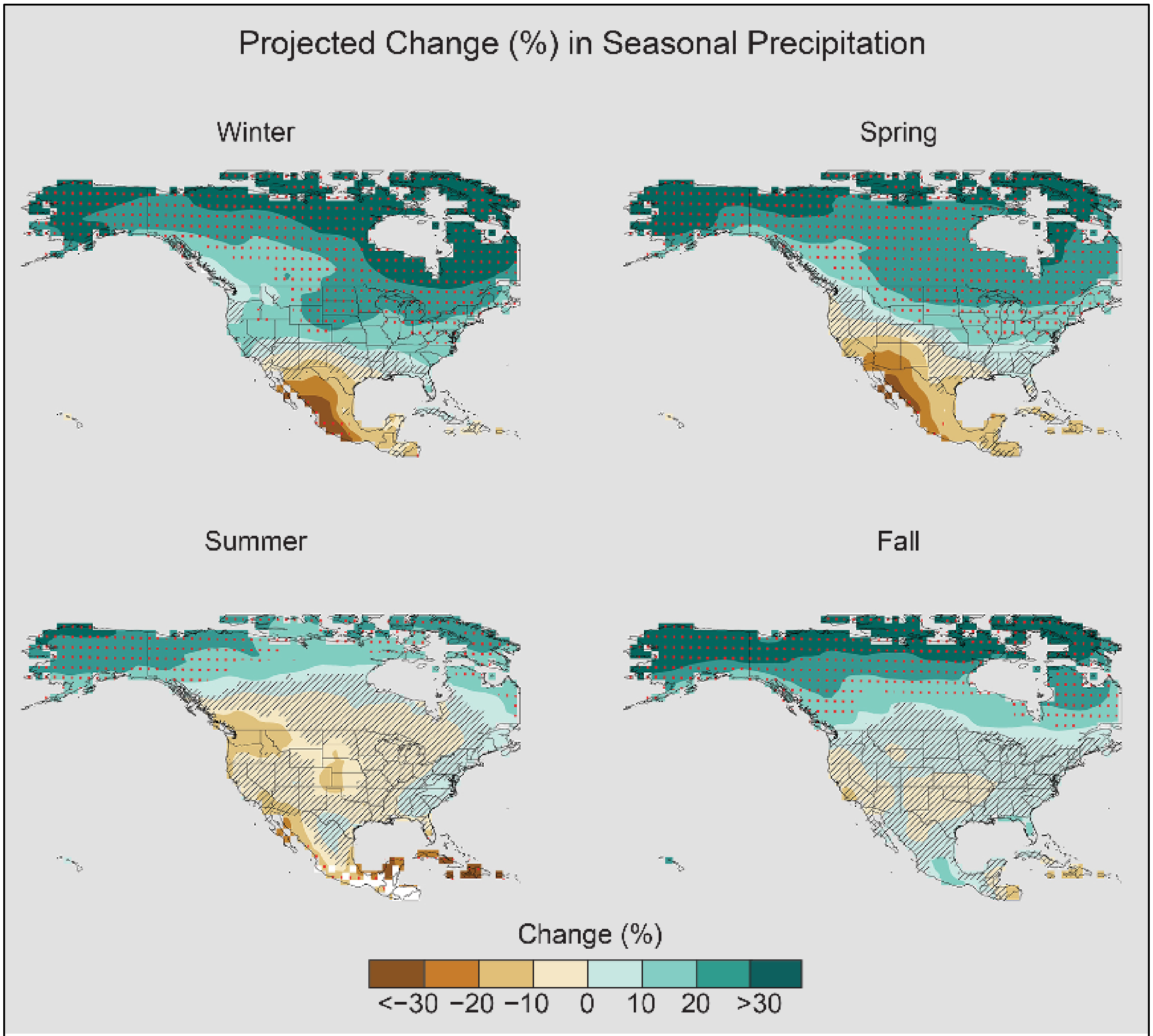


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Illinois. Observed data are for 1900–2014. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Illinois (orange line) have risen about 1°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during the 21st century,. Less warming is expected under a lower emissions future (the coldest years being about as warm as the hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest years being about 10°F warmer than the hottest year in the historical record; red shading). Source: CICS-NC and NOAA NCEI.

Figure 10. Observed and Projected Temperature Change for Illinois (U.S. Climate Data, 2020)



Projected change (%) in total seasonal precipitation from CMIP5 simulations for 2070–2099. The values are weighted multimodel means and expressed as the percent change relative to the 1976–2005 average. These are results for the higher scenario (RCP8.5). Stippling indicates that changes are assessed to be large compared to natural variations. Hatching indicates that changes are assessed to be small compared to natural variations. Blank regions (if any) are where projections are assessed to be inconclusive. Data source: World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project. (Figure source: NOAA NCEI).

Figure 11. Projected Changes in Precipitation

1.5 OBSERVED LOCAL TRENDS

The USACE Climate Hydrology Assessment Tool was used to examine observed first-order streamflow trends in the vicinity of the project area. The tool only has capability to assess the annual peak instantaneous streamflow; additional hydrologic variables of interest will be added in the future. 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.

Table 1 shows the USGS stream gauges used in this analysis and Figure 12 shows a map of their locations. The observed gages near University City, Pagedale, and Wellston, MO were chosen because they were the 3 closest gauges to the River Des Peres project area watershed.

The historical streamflow was analyzed and is summarized in Table 2. The analysis from the gage at University City, MO had an upward trend over time, but the trend was not statistically significant with a p-value = 0.572 (Figure 13). The analysis from the gage at Pagedale, MO also had an upward trend over time, but the trend was not statistically significant with a p-value = 0.139 (Figure 14). The downward trend illustrated in Figure 15 trend line is almost flat and with the worst p-value of 0.900, inconclusive. Lack of gage period record contributed to the lack of statistical significance at these stream flow gage locations. It is only plausible that there is an upward trend in streamflow overtime.

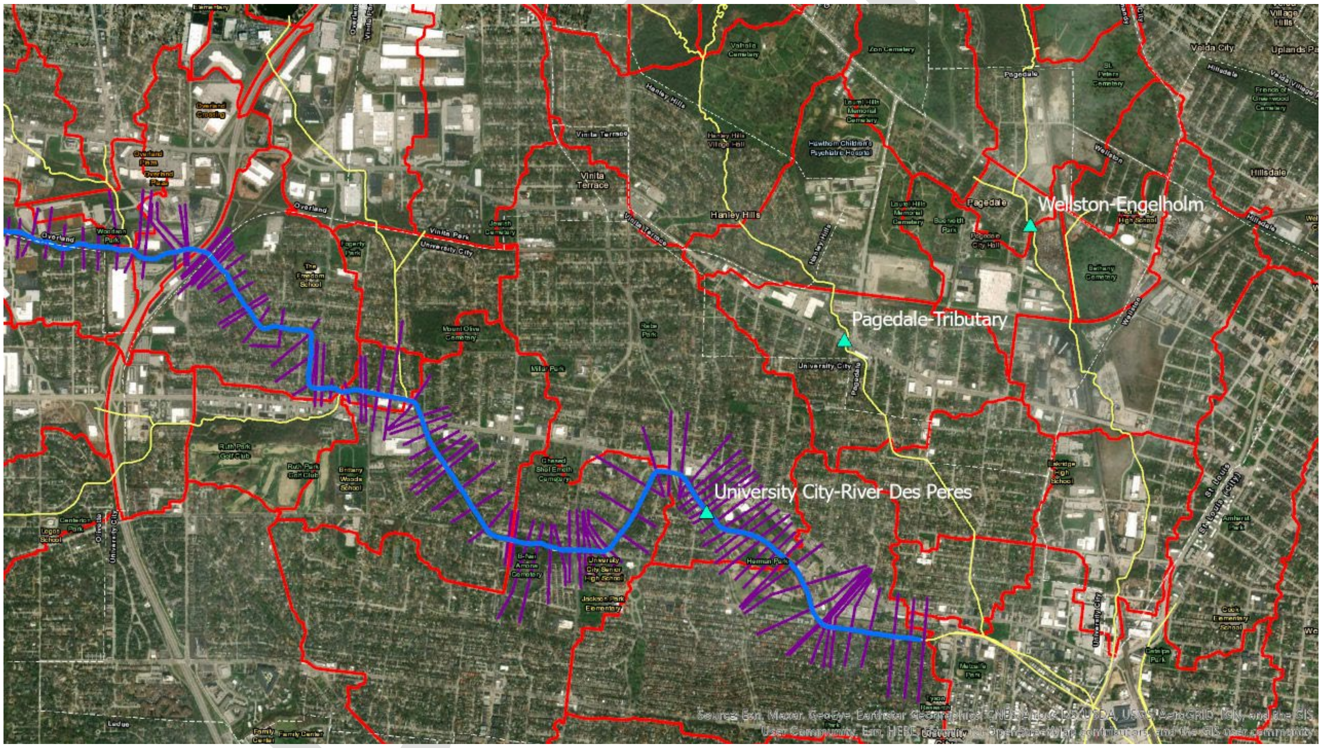


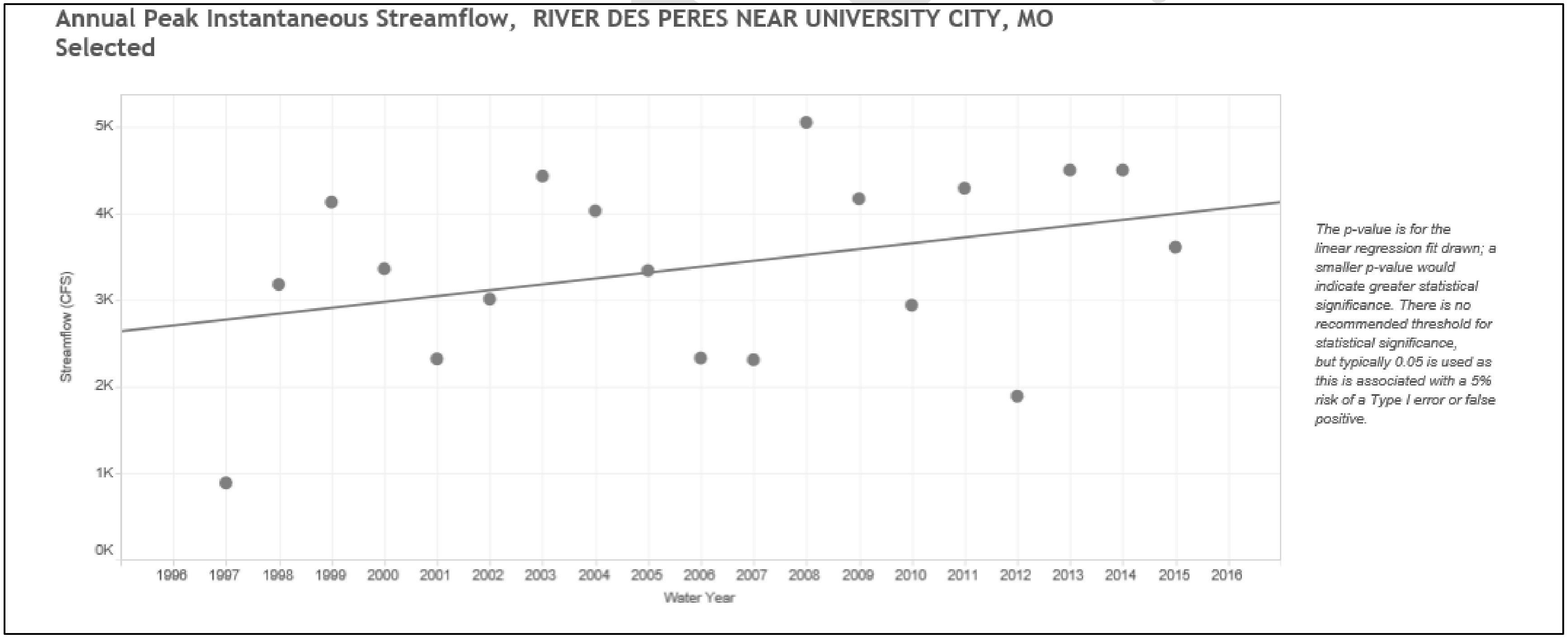
Figure 12. Upper River Des Peres Stream Gages

Table 1. Nearest USGS Stream Gauges

Stream Gauge	Station ID	Upstream Area (mi^2)	Period of Record (POR)	Observed Years
River Des Peres near University City, MO	07010022	8.94	1997-2020	23
Tributary to River Des Peres at Pagedale, MO	07010030	2.01	1997-2020	23
Engelholm Creek near Wellston, MO	07010035	1.40	1998-2020	22

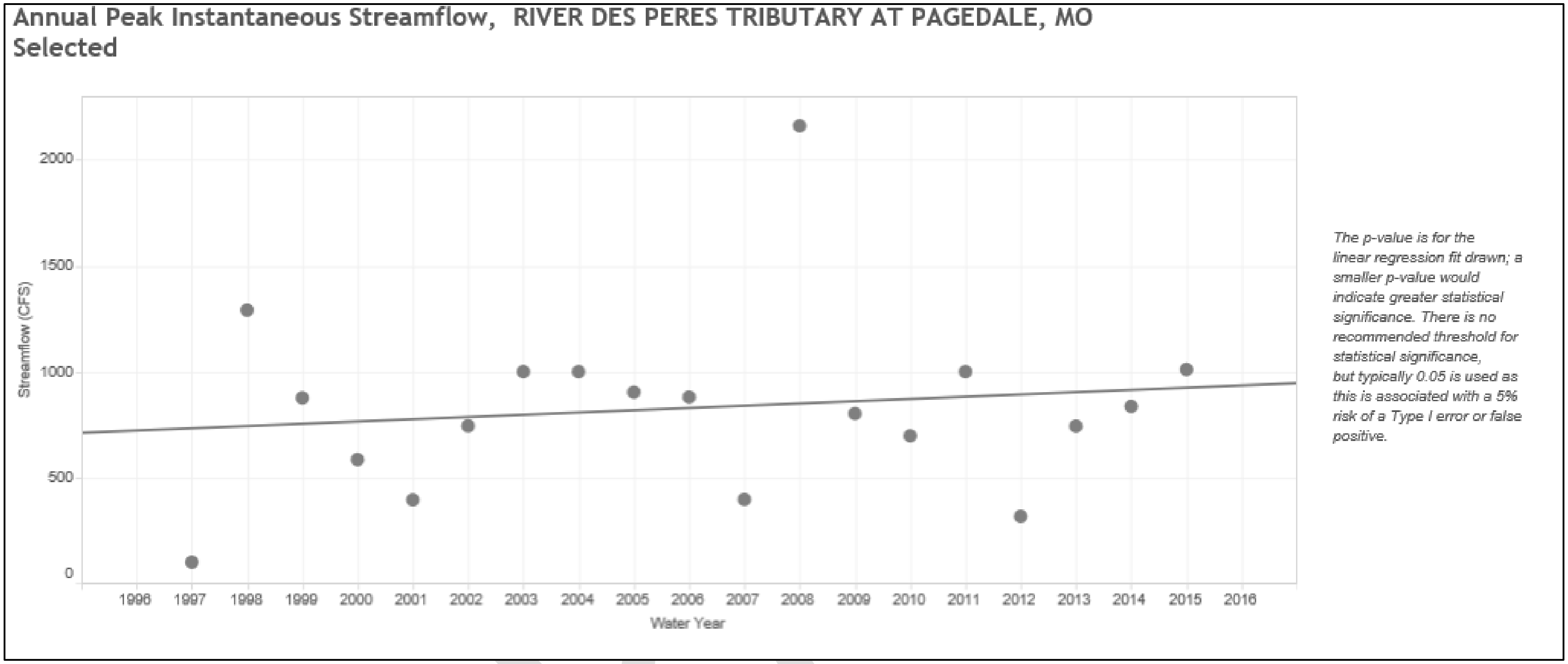
Table 2. Stream Flow Trends

Stream Gauge	Station ID	Adopted Period of Record	P-Value	General Trend	Statistically Significant
River Des Peres near University City, MO	07010022	1997-2016	0.572	Upward	No
Tributary to River Des Peres at Pagedale, MO	07010030	1997-2016	0.139	Upward	No
Engelholm Creek near Wellston, MO	07010035	1998-2016	0.900	Downward	No



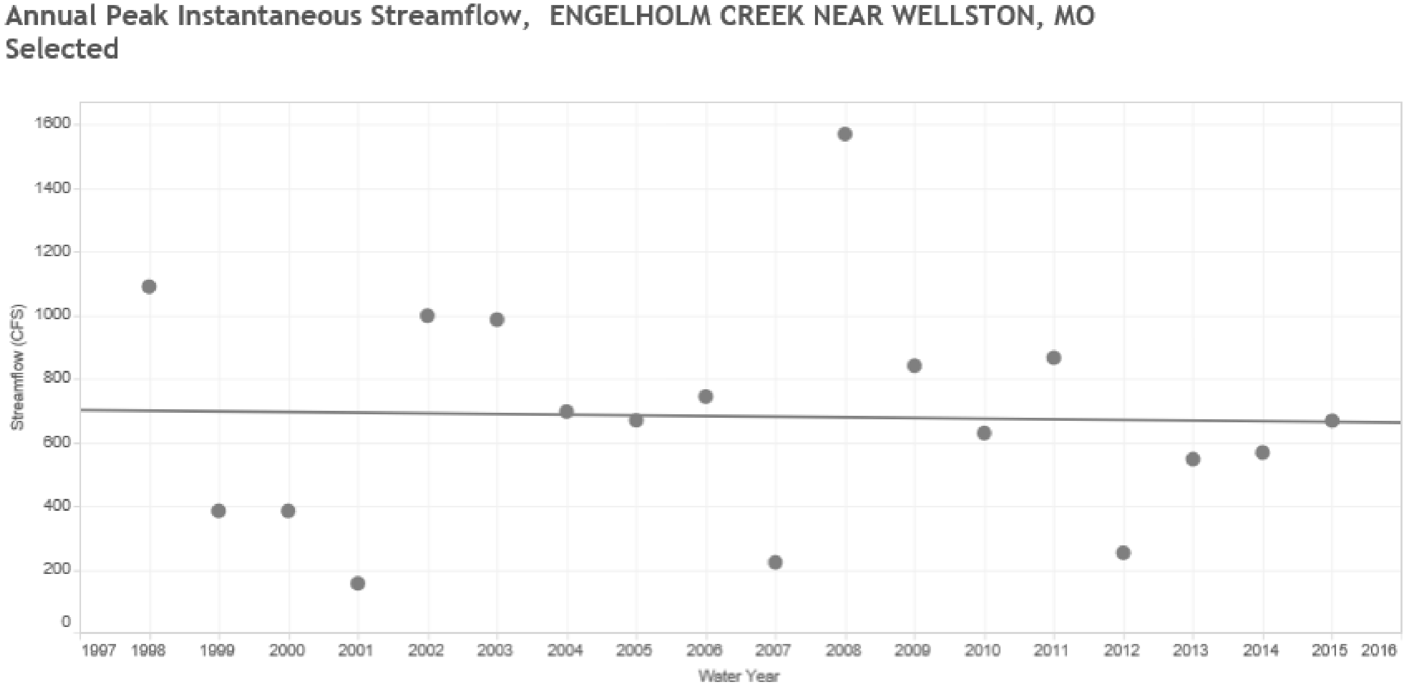
The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive.

Figure 13. Annual Peak Instantaneous Streamflow, River Des Peres near University City, MO (p = 0.138833).


Annual Peak Instantaneous Streamflow, RIVER DES PERES TRIBUTARY AT PAGEDALE, MO Selected

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.

Figure 14. Annual Peak Instantaneous Streamflow, Tributary to River Des Peres near Pagedale, MO (p = 0.572213).


Annual Peak Instantaneous Streamflow, ENGELHOLM CREEK NEAR WELLSTON, MO
Selected

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.

Figure 15. Annual Peak Instantaneous Streamflow, Engelholm Creek near Wellston, MO (p = 0.900394).

1.6 PROJECTED REGIONAL TRENDS

The USACE Climate Hydrology Assessment Tool was used to examine observed and projected trends in watershed hydrology to support the qualitative assessment. This tool was used on the greater upper Mississippi-Kaskaskia-Meramec Rivers Hydrologic Unit Code (HUC). As expected for this type of qualitative analysis, there is considerable but consistent spread in the projected annual maximum monthly flows (Figure 16). The overall projected trend in annual peak instantaneous streamflow increases over time (Figure 17). This increase is statistically significant (p-value <0.0001). This finding suggests that there may be potential for higher peak streamflows in the future. The default year of 2000 separates where emissions were held constant (1950-1999) and where the projected pathway of emissions is being applied (2000-2099) in the Global Circulation Models (GMC). The projected hydrology used was produced from the Global Circulation Model (GCM) Coupled Model Intercomparison Project Phase 5 (CMIP-5) suite of model simulations of temperature and precipitation, downscaled from the global scale to the HUC-4 watershed scale using the Bias Correction and Spatial Downscaling (BCSD) method, based on 93 combinations of GCMs and Representative Concentration Pathway of Greenhouse Emissions (RCP) translated to a hydrologic response using the U.S. Bureau of Reclamation's CONUS wide Variable Infiltration Capacity (VIC) model.

It should be kept in mind that these projected stream flows have a large amount of uncertainty. This uncertainty is shown visually in the spread of flow results for the HUC4 presented in Figure 17. Uncertainty is introduced with each step of the dataset generation including the boundary conditions used in the GCMs used to produce projections of temperature and precipitation, the RCPs selected for the modeling, the downscaling method used to convert the global results to regional HUC 4 scale results, and the uncertainties in the hydrologic model used to generate the stream flow. The hydrologic model used in the case of these 93 stream flow projections was the U.S. Bureau of Reclamation's CONUS wide Variable Infiltration Capacity (VIC) model.

The USACE Watershed Vulnerability Assessment Tool was used to examine the vulnerability of the project area to ecosystem decline (Figure 19). The tool was also used to assess indicators affecting Flood Risk Management (Figure 18). The USACE Vulnerability Assessment (VA) Tool provides a nationwide, screening-level assessment of climate change vulnerability related to the USACE mission, operations, programs, and projects.

The USACE vulnerability assessment tool flags watersheds as being vulnerable to climate change across a specific USACE business lines (flood risk reduction and ecosystem restoration in the case of this study). When that HUC 4 watershed vulnerability score falls within the top 20% of vulnerability scores as compared to the other 201 HUC 4 watersheds in the contiguous United States (CONUS), the watershed is flagged, and vulnerability assessed. The vulnerability score is calculated using a weighted order weighted area (WOWA) method based on a series of indicator variables. The tool uses climate changed hydrology determined using 100 traces of CMIP5 GCM based climate outputs converted to a hydrologic response using the U.S. Bureau of Reclamations CONUS wide Variable Infiltration Capacity (VIC) models. The uncertainty in the modeling is partially communicated by providing output for two epochs of time and for both the top 50% of traces of flow (WET scenario) and bottom 50% of traces (Dry scenario). The default national standard settings were used in the tool.

Upper Mississippi-Kaskaskia-Meramec Watershed (HUC 0714) is not among the top 20% of HUCs at greatest risk for ecosystem decline under either a wet or dry climate scenario. While the watershed is not among the top 20% of greatest risk, it is still vulnerable to climate change. The driving indicators to this vulnerability are illustrated in Figure 18 and Figure 19. The indicator most impacting the Flood Risk Management business line shows the greatest impact to be flood magnification over time. Also, further development in the 500 year floodplain is expected to increase as well, which only worsens the vulnerability projections for the Flood Risk business line. The indicator most impacting the Ecosystem Restoration business line is the risk affecting at-risk freshwater plants. A general increase in precipitation runoff was also indicated, leading to future further degradation of the ecosystem.

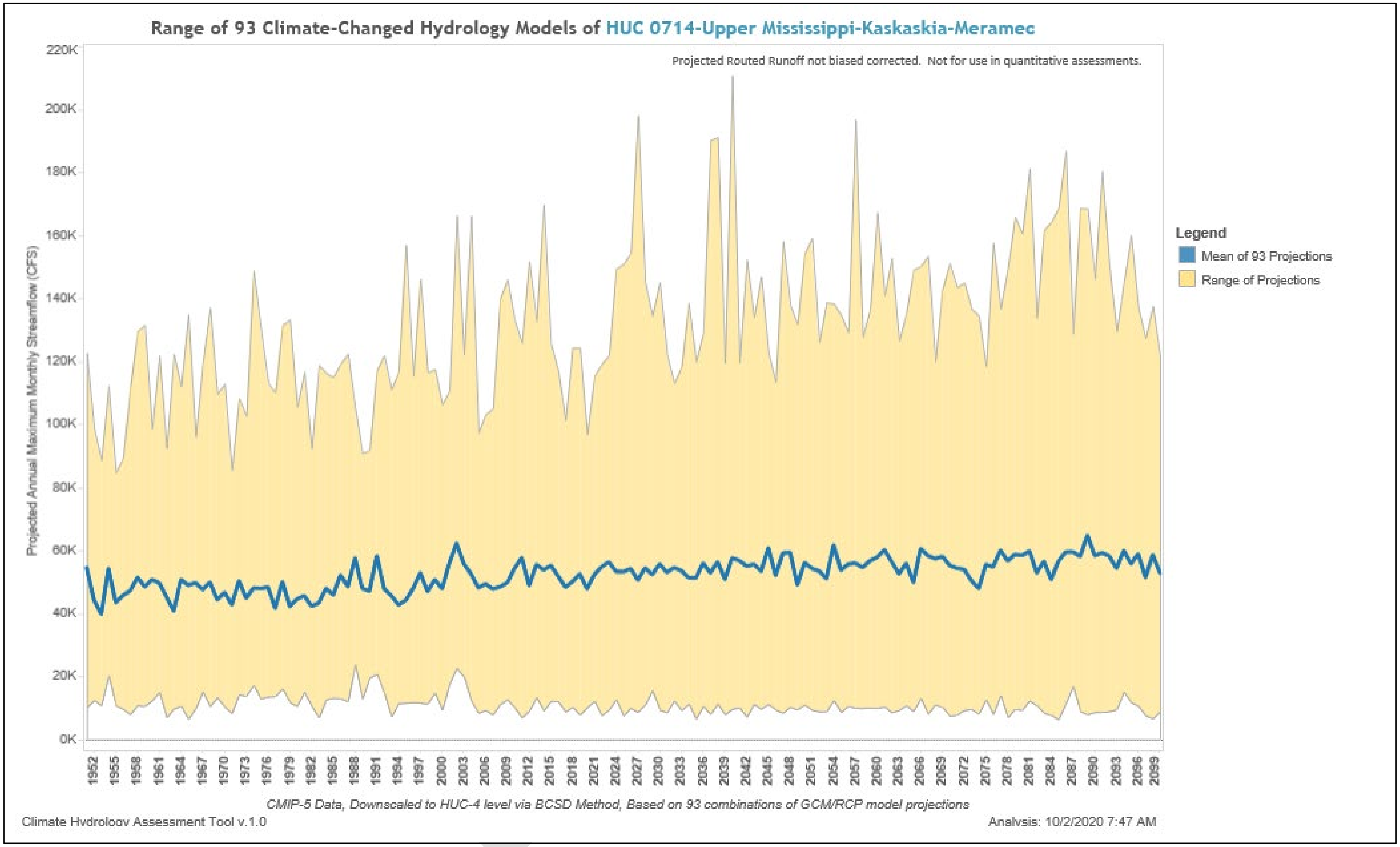
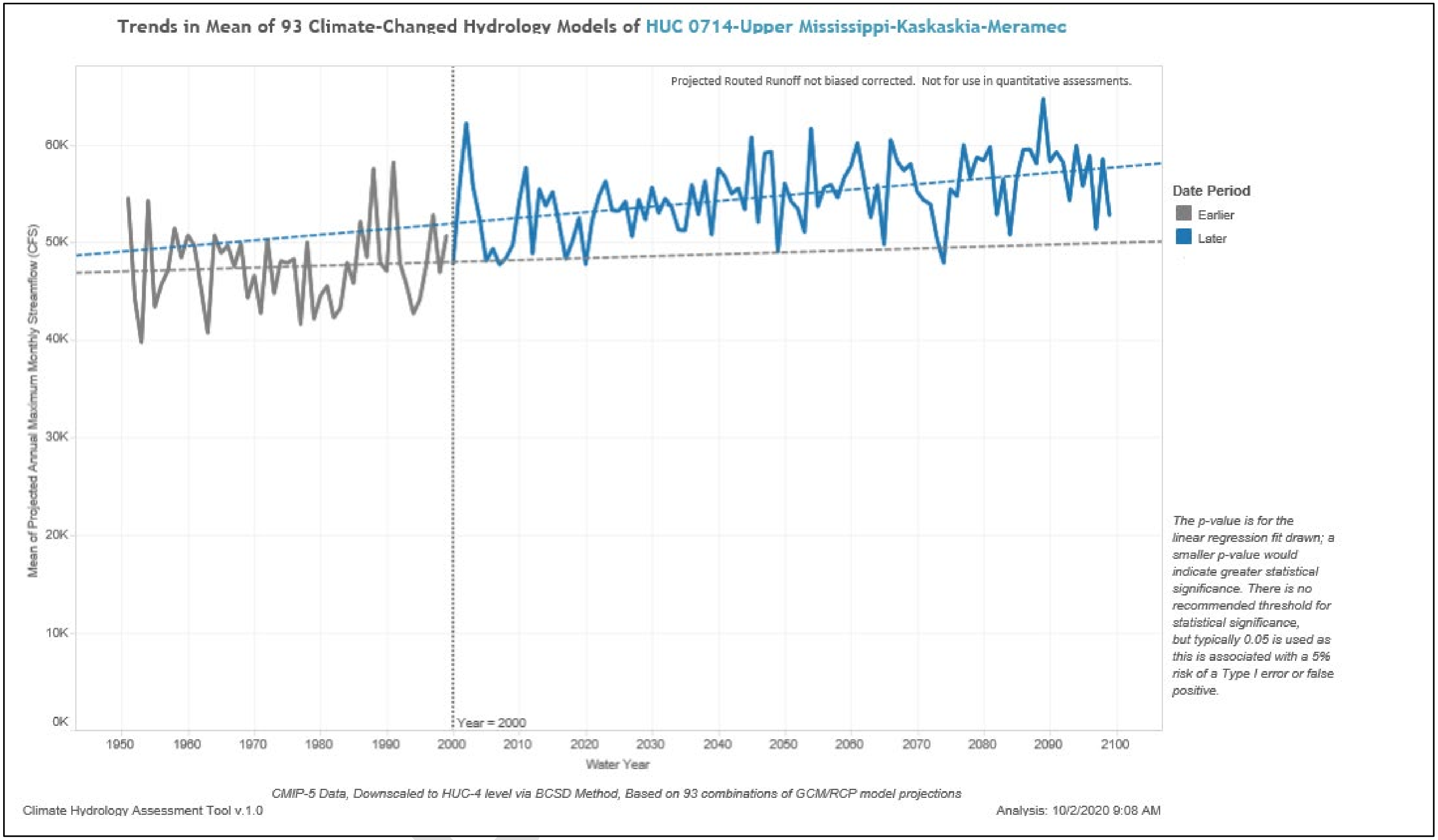


Figure 16. Range in the Projected Annual Maximum Monthly Flows, HUC 0714 Upper Mississippi-Kaskaskia--Meramec



Trends in Mean of 93 Climate-Changed Hydrology Models of HUC 0714-Upper Mississippi-Kaskaskia-Meramec

Projected Routed Runoff not biased corrected. Not for use in quantitative assessments.

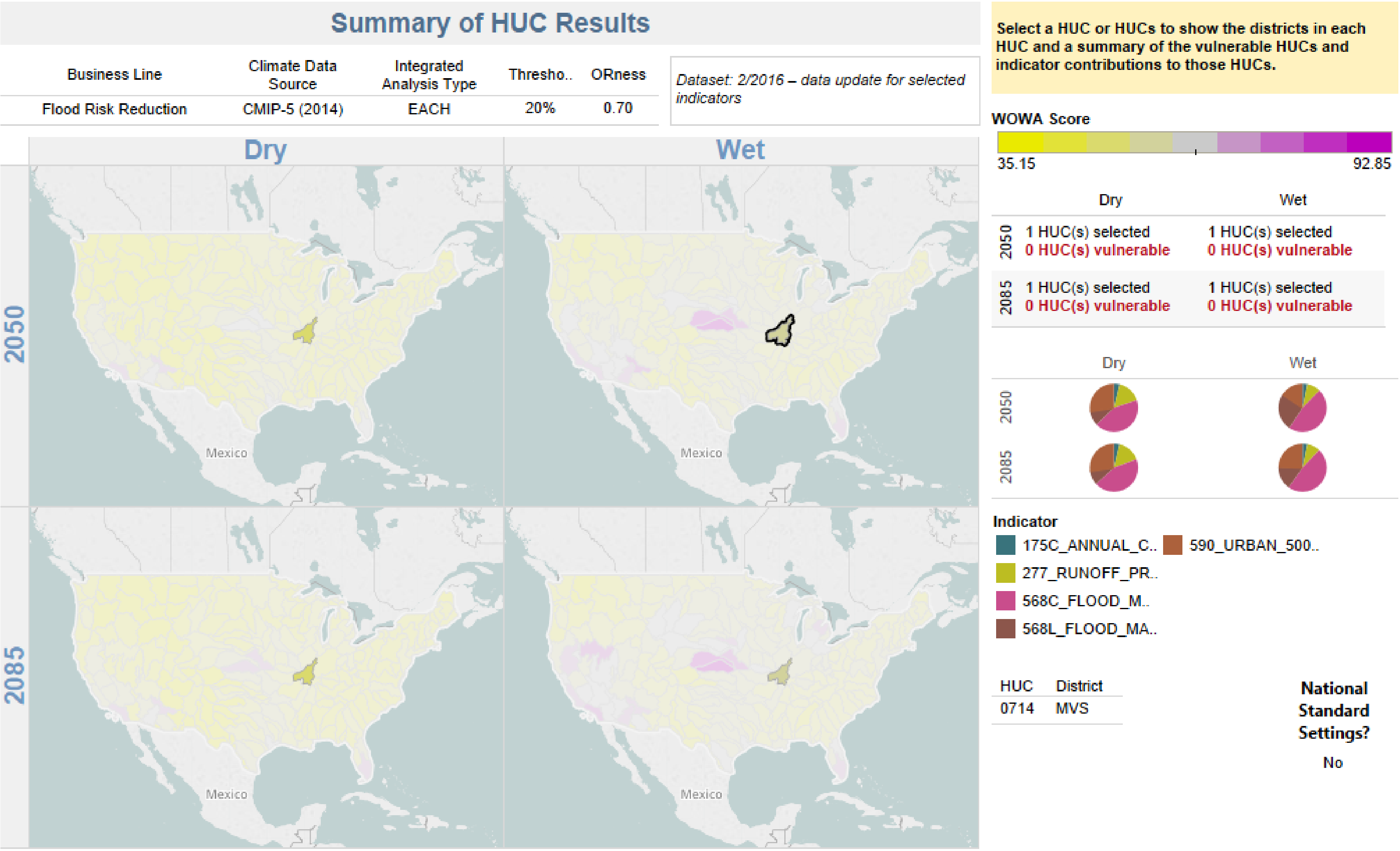
The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive.

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

Climate Hydrology Assessment Tool v.1.0

Analysis: 10/2/2020 9:08 AM

Figure 17. Mean Projected Annual Maximum Monthly Streamflow, HUC 0714 Upper Mississippi-Kaskaskia-Meramec. $p < 0.00014$



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Thresho..	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.

	Dry	Wet
2050	1 HUC(s) selected 0 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

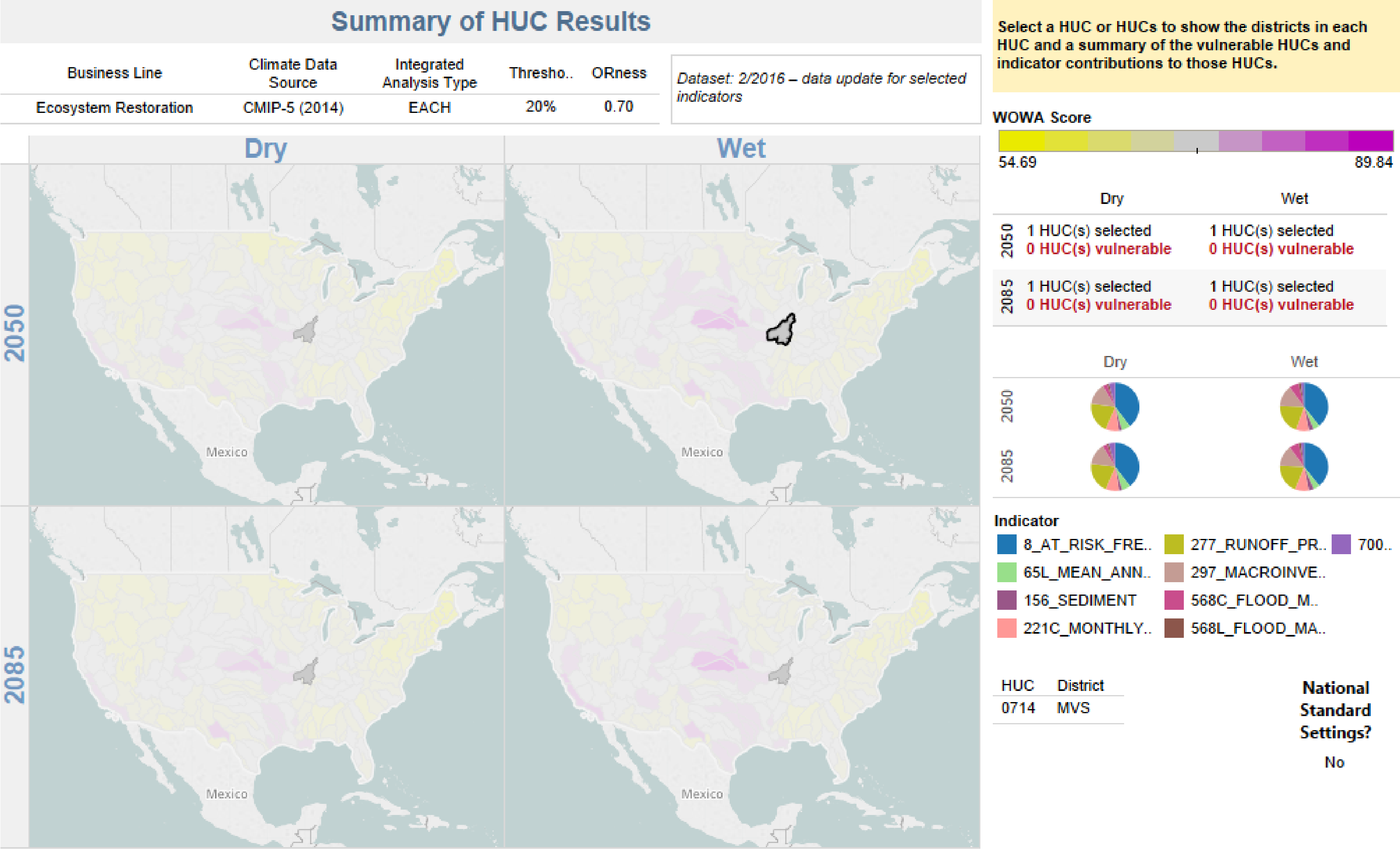
- ■ 175C_ANNUAL_C..
- ■ 277_RUNOFF_PR..
- ■ 568C_FLOOD_M..
- ■ 568L_FLOOD_MA..
- ■ 590_URBAN_500..

HUC	District
0714	MVS

National Standard Settings?

No

Figure 18. Flood Risk Reduction Business Line Projected Vulnerability for the Upper Mississippi-Kaskaskia-Meramec (HUC 0714)



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Thresho..	ORness
Ecosystem Restoration	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

54.69 89.84

	Dry	Wet
2050	1 HUC(s) selected 0 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

8_AT_RISK_FRE..	277_RUNOFF_PR..	700..
65L_MEAN_ANN..	297_MACROINVE..	
156_SEDIMENT	568C_FLOOD_M..	
221C_MONTHLY..	568L_FLOOD_MA..	

HUC	District
0714	MVS

National Standard Settings?

No

Figure 19. Ecosystem Restoration Business Line Projected Vulnerability for the Upper Mississippi-Kaskaskia-Meramec (HUC 0714)

1.7 NONSTATIONARITY OF MONTHLY MAXIMUM PRECIPITATION

Because of the limited period of record for the stage and flow measurements in the Upper River Des Peres, there is not enough data to effectively use the Nonstationarity Detection Tool (NSD) accurately on the University City, MO River Des Peres gage observation. To analyze nonstationarity, the analysis was performed on monthly maximums in precipitation (a function of runoff volume) using the Time Series Toolbox.

USACE nonstationarity detection tools apply a series of statistical tests to assess the stationarity of annual instantaneous peak streamflow for gage sites with more than 30 years of annual instantaneous peak records. The statistical methods are used to identify if a dataset contains a strong nonstationarity. A strong nonstationarity is one for which there is a consensus among multiple nonstationarity detection methods, robustness in detection of changes in statistical properties, and relatively large change in the magnitude of a dataset's statistical properties. Output from the tools offers insight which can be used to help the user select a homogenous dataset that can be used for hydrologic analysis. Results of the analysis are illustrated in figures 20 through 22.

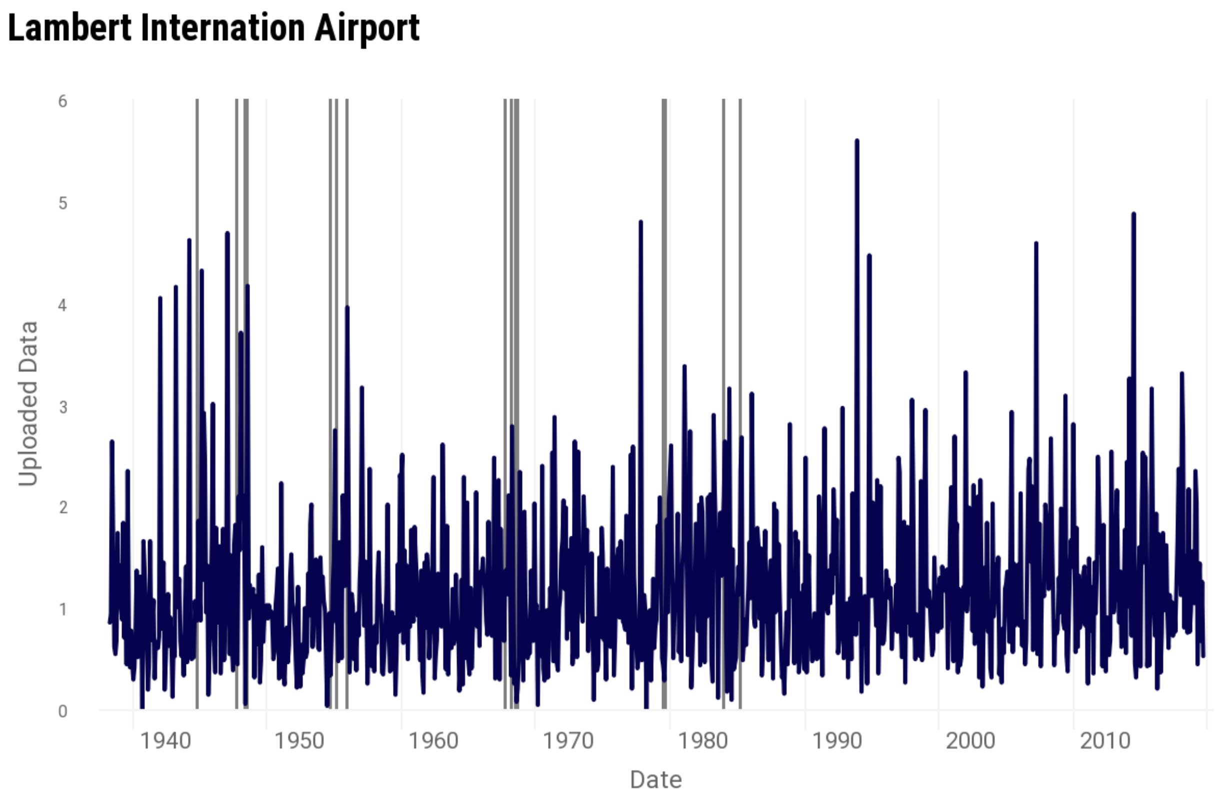


Figure 20. Monthly Maximum Precipitation (Lambert International Airport)

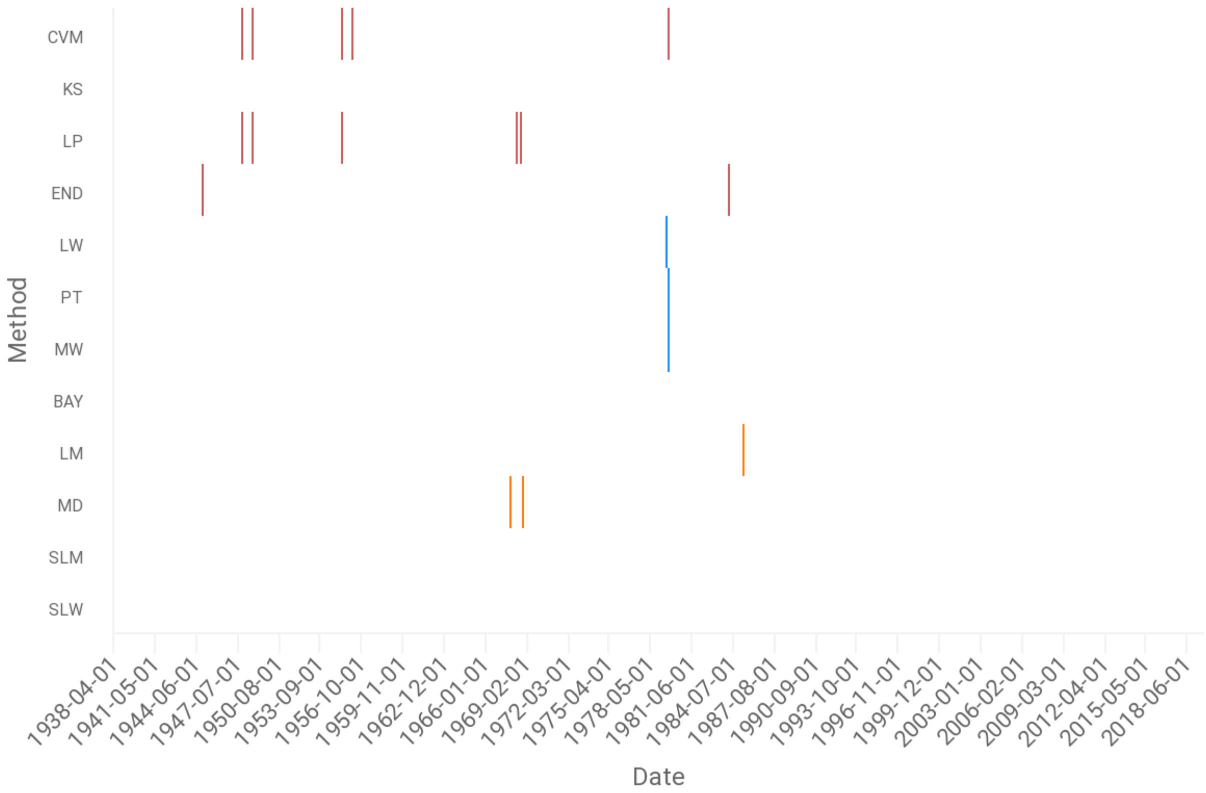


Figure 21 - Significance Statistical Testing (Lambert International Airport)

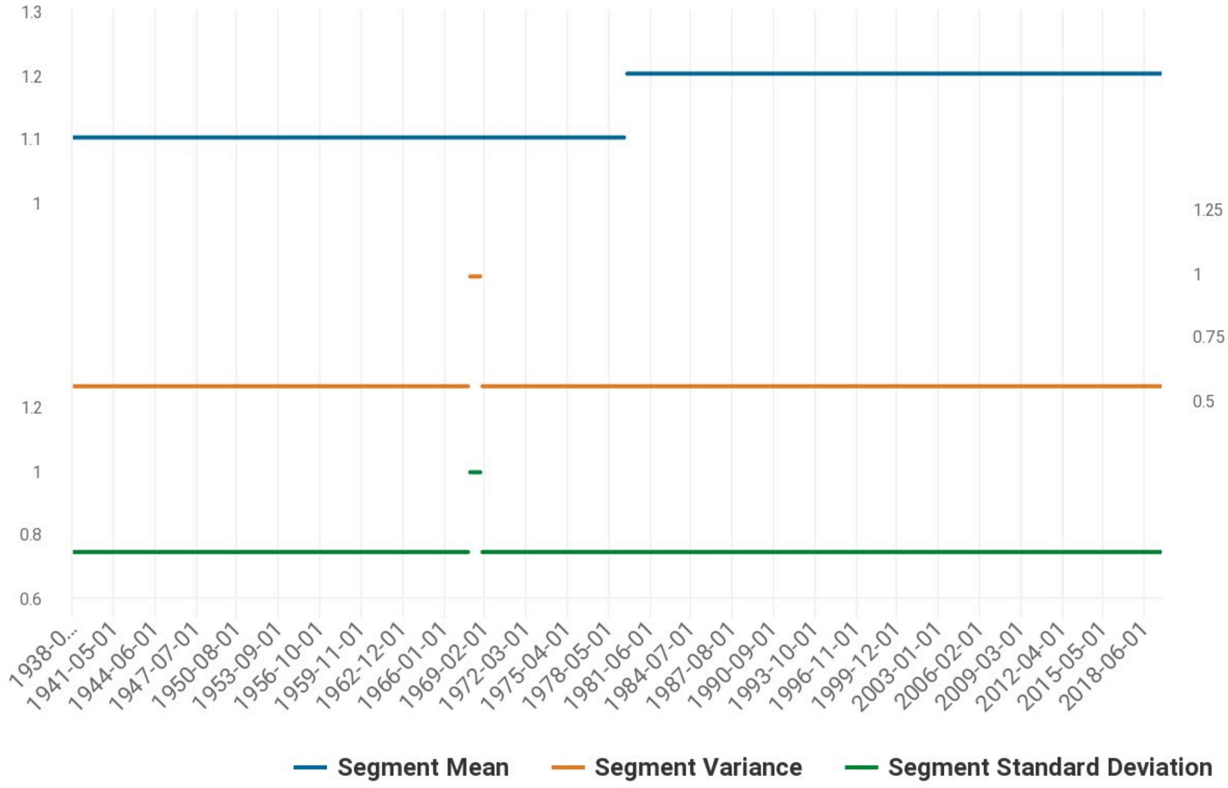


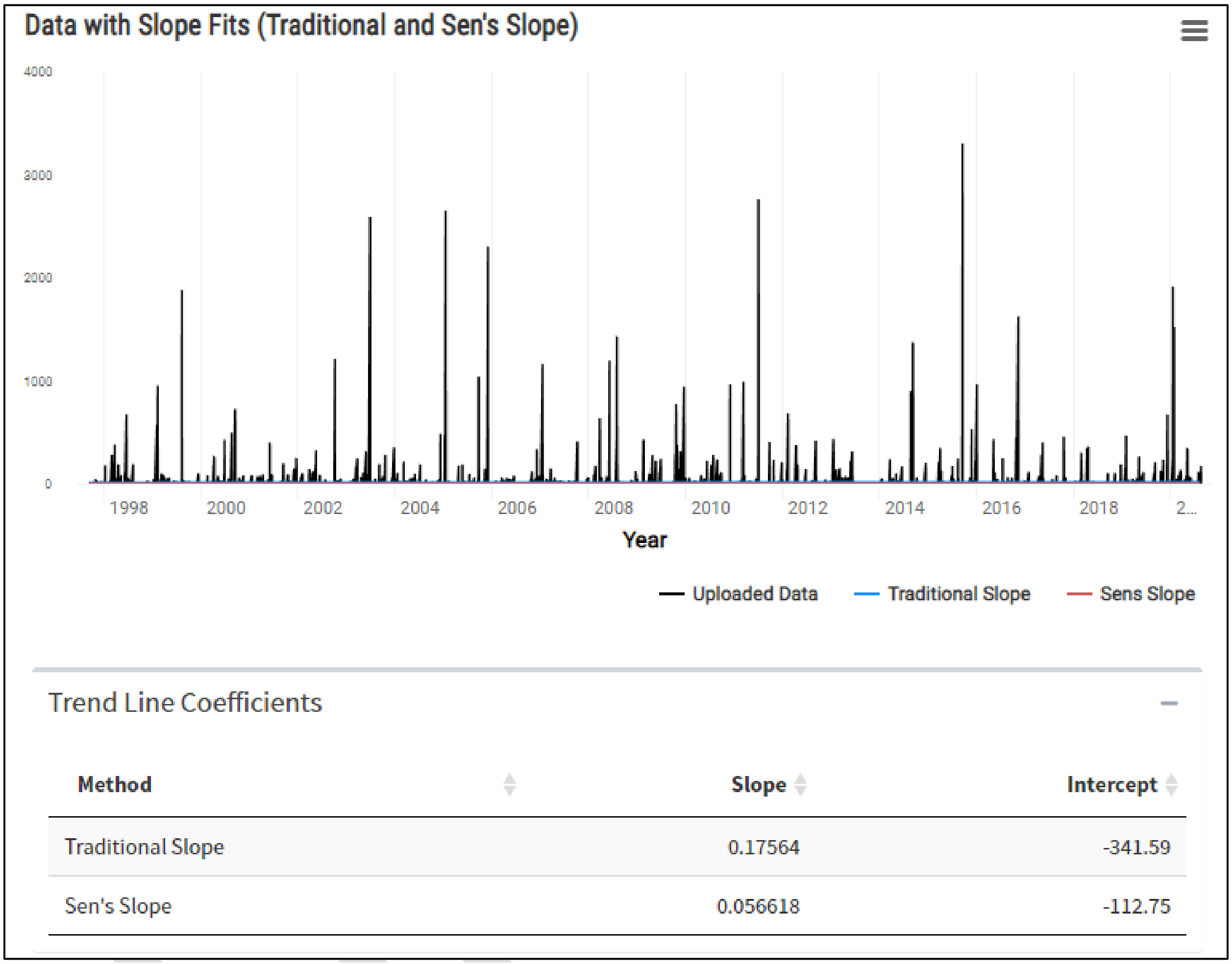
Figure 22 - Segment Statistics (Lambert International Airport)

Results of the analysis show some statistical significance in prior to 1990. The results show stationarities in the maximum monthly precipitation data. More importantly is the trend in the segments means to increase post 1985. As a streamflow is a function of precipitation, an overall trend will also lead to increased stream flow can be inferred.

Based on review of the non-stationary detection results with period of records around 20 years for the three gages discussed in Section 1.14, the results of the tests predicted the time series as stationary.

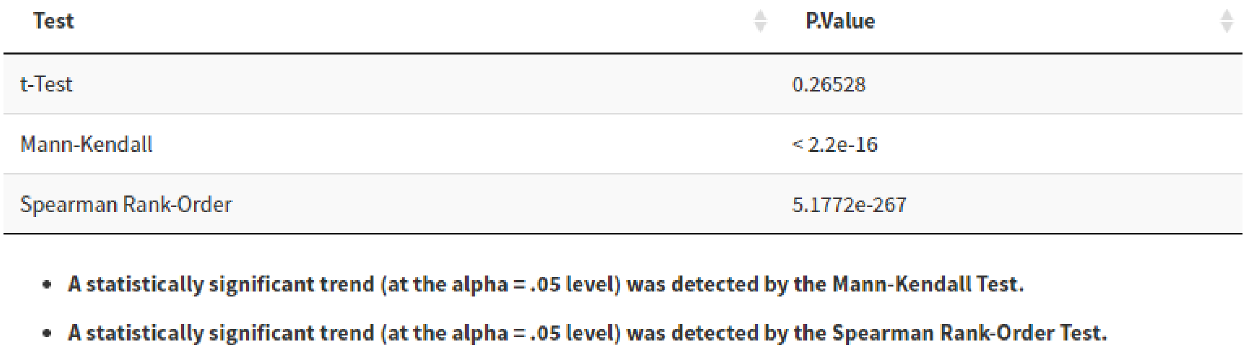
1.8 ANALYSIS OF TRENDS IN DAILY FLOW DATA

The Time Series Toolbox was used to analyze the trends in the daily flow data used in the duration analysis. The three gauges used for this analysis and their POR are discussed in Section 1.5. The best slope fits and data plots for daily flow data are shown in figures 23 through 25. The results of the River Des Peres gages near University City, MO and Wellston, MO show positive slopes in the daily flow trends and exhibited statistically significance in the Mann-Kendall and Spearman Rank-Order tests. The Pagedale, MO River Des Peres Tributary gage presented with a negative Sen's slope in stream flow trends. The daily flow trends exhibited statistically significance in the Mann-Kendall and Spearman Rank-Order tests, and the results of the slope trends matched the results of the peak instantaneous flow trend analysis. Of the three gages, the Pagedale, MO gage was the closest to having a zero slope and along with such a slight negative slope should be considered inconclusive. Because of the proximity and small watershed size, additional period of record should push the streamflow trend positive as was observed in the Wellston and University City gages.



Trend Line Coefficients

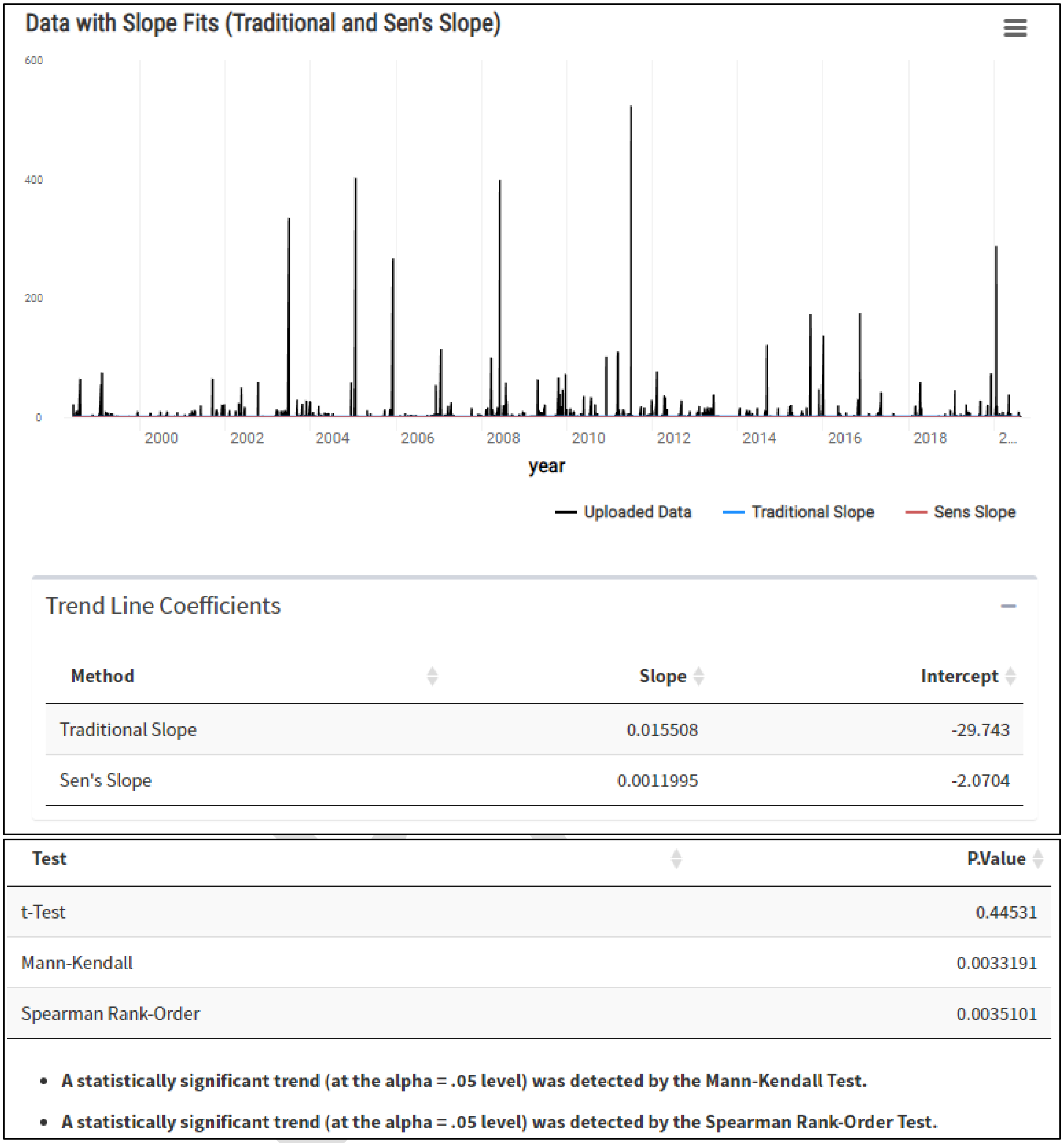
Method	Slope	Intercept
Traditional Slope	0.17564	-341.59
Sen's Slope	0.056618	-112.75



Test	P.Value
t-Test	0.26528
Mann-Kendall	< 2.2e-16
Spearman Rank-Order	5.1772e-267

- **A statistically significant trend (at the alpha = .05 level) was detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Spearman Rank-Order Test.**

Figure 23. River Des Peres near University City, MO



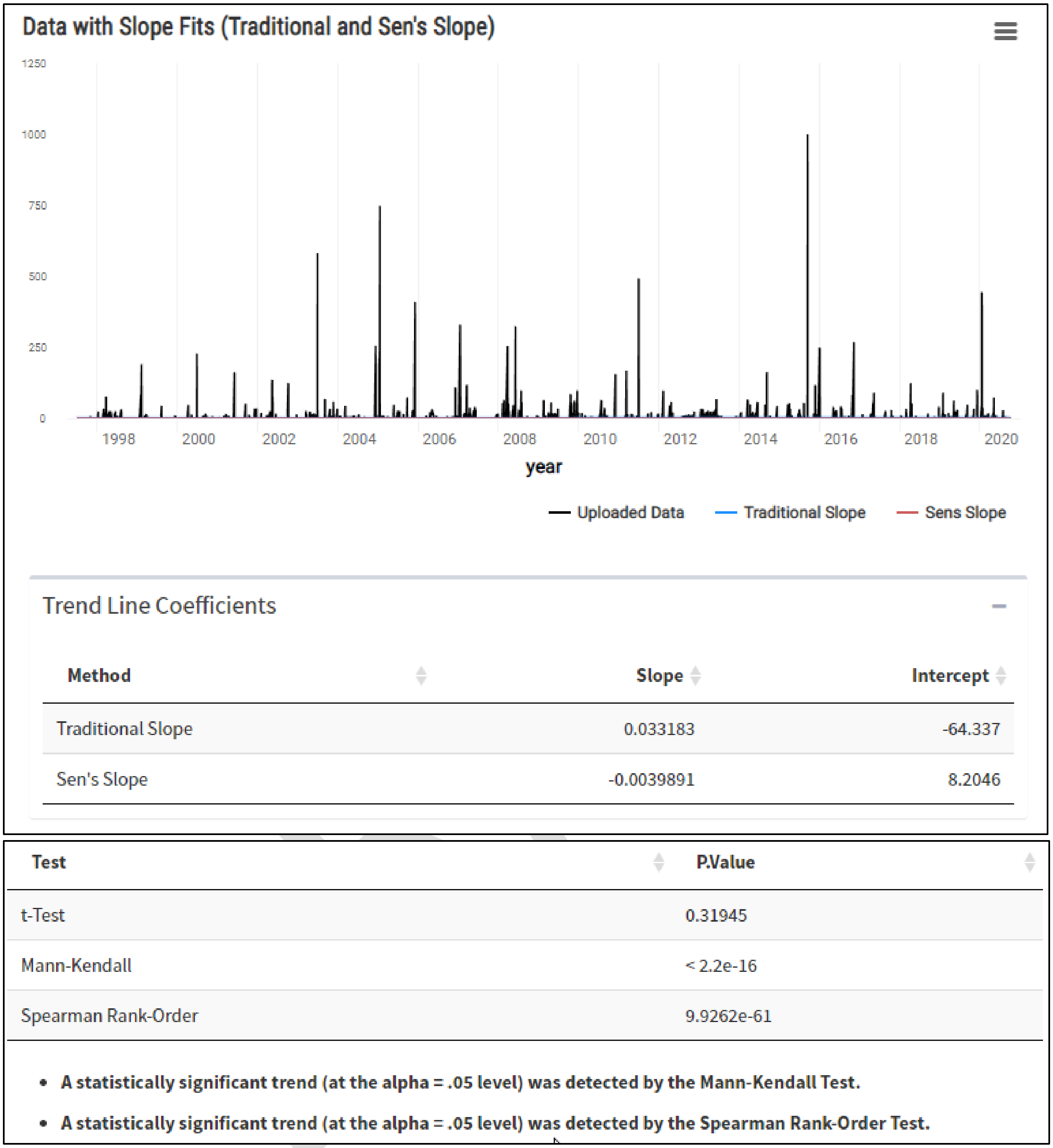
Trend Line Coefficients

Method	Slope	Intercept
Traditional Slope	0.015508	-29.743
Sen's Slope	0.0011995	-2.0704

Test	P.Value
t-Test	0.44531
Mann-Kendall	0.0033191
Spearman Rank-Order	0.0035101

- **A statistically significant trend (at the alpha = .05 level) was detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Spearman Rank-Order Test.**

Figure 24. Engelholm Creek near Wellston, MO Trend Analysis



Trend Line Coefficients

Method	Slope	Intercept
Traditional Slope	0.033183	-64.337
Sen's Slope	-0.0039891	8.2046

Test	P.Value
t-Test	0.31945
Mann-Kendall	< 2.2e-16
Spearman Rank-Order	9.9262e-61

- **A statistically significant trend (at the alpha = .05 level) was detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Spearman Rank-Order Test.**

Figure 25. River Des Peres Tributary near Pagedale, MO

1.9 CLIMATE CHANGE RISK AND THE PROPOSED PROJECT CONDITIONS

The effects of climate change on future conditions along the River Des Peres is predicted to only get worse. Since future changes in development are not expected to significantly change its hydrologic characteristics in the future, the overall expected trend in precipitation increase over time is the main driving factor of worsening existing flooding conditions.

Climate change can be shown to affect these projects alternatives in similar ways. Table 3 tabulates the risk associated with the different structural components of the project. The underlying message to take away is that flood water duration as well as level will increase overtime.

The study area is already largely developed, and future changes in development are not expected to significantly change its hydrologic characteristics in the future. The consensus in recent literature points toward moderate increases in precipitation in the Upper Mississippi Region over the past century. Some evidence shows an increased frequency in the occurrence of extreme storm events (Villarini et al., 2013). Project-specific analysis shows upward trends in precipitation and runoff in the River Des Peres watershed which will only further exacerbate existing flooding problems. Climate change impacts to flood risk in the example study area are ambiguous with respect to future flood risk. While there is a reasonable chance that some storm events may occasionally deliver large quantities of precipitation to the watershed, the likelihood and magnitude of this change cannot be assessed with the current information. What this suggests is that storms may become more intense in the future.

Table 3. Climate Risk to Project Conditions

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Levee/Floodwall	Increased Precipitation from larger, slower moving storms.	Future flood volumes may be larger. Large flood volumes may occur more frequently	Flood waters may remain on the levee for longer durations. Overtime level of protection will lower.	Likely
Detention Basin			Detention basin use will steadily increase. Higher volume of runoff degrades capacity of detention storage.	Likely
Flood Proofing			Higher volume of runoff degrades level of protection of flood proofed or	Likely

			elevated structures.	
No Change			Higher volume of runoff will start to yield higher river stages.	Likely

1.10 CLIMATE CHANGE CONCLUSIONS

The literature review indicates:

1. The consensus in recent literature points toward moderate increases in temperature and precipitation in the Upper Mississippi Region over the past century.
2. In some studies and some locations, statistically significant trends have been quantified. In other studies and locales within the Upper Mississippi Region, apparent trends are observed graphically, but are not statistically quantified.
3. Some evidence points to an increased frequency in the occurrence of extreme storm events (Villarini et al., 2013).
4. Multiple authors identified a transition point in climate data trends in 1970 where rates of increase changed significantly. Project specific results generated using USACE tools indicate the following:
    a. Nonstationarity analysis and monotonic trend analysis of annual peak streamflow records observed at sites in the vicinity of the project area showed the flow observation to behave as stationary. Note that period of record was less than 20 years which does not yield a high enough accuracy in the nonstationarity analysis results.
    b. Nonstationarity was detected in an analysis of annual monthly maximums of precipitations. From which a general overall increase in runoff and stream flow can be inferred.
    c. The HUC4 basin containing the River Des Peres shows the indicator that contributes the most to the climate risk is flood risk magnification. This would be indicative of positive increase in runoff overtime.
    d. Using the Two of the observed stream gage records showed statistically significant results ($p < 0.05$). Both displayed an upward trend. Climate change and land use changes yielding higher runoff are potential drivers for the upward trends in higher magnitude flow observations.

Future Without Project Conditions may be impacted by changes in climate at some indeterminate point in the future. Based on analysis, upward trends in temperature, precipitation, and runoff in the River Des Peres would only further exacerbate existing flooding problems. Regardless of future conditions flooding will get worse.