Appendix H
Yorkinut Slough Habitat Rehabilitation and Enhancement Project Climate Assessment

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ECB 2018-14 Analysis of Potential Climate Vulnerability
This report is an evaluation of potential climate vulnerabilities facing the Yorkinut Slough Habitat Rehabilitation and Enhancement Project site. The study area is located on the Illinois River approximately four river miles above the confluence of the Illinois and Mississippi rivers. This assessment was performed to highlight existing and future challenges facing the Project as the result of past and future climatic changes, in accordance with the guidance in Engineering Construction Bulletin (ECB) 2018-14 (revised 10 September 2020). Background information on the study can be found in the main report, and background information on climate-affected risks to projects and assessments thereof can be found in the ECB.

The Yorkinut Slough site is operated by the U.S. Fish and Wildlife Service (USFWS) as part of the Two Rivers National Wildlife Refuge. The site manages Moist Soil Units (MSUs) that are flooded and dewatered annually. Drainage capabilities of the MSUs and nearby Swan Lake are heavily dependent on the conditions of the Illinois River as a result of the reliance on gravity drainage. The Yorkinut Slough site is located upstream of the Melvin Price Locks & Dam that is located on the Mississippi River near Alton, Illinois. The navigation pool that is created by the structure extends into the Illinois River and affects the condition at the site.

The area has seen a reduction in the diversity and quality of wetlands, meadow grasslands, floodplain woodlands, and floodplain forests as a result of human activity. The Yorkinut Slough HREP aims to restore and increase early successional and emergent wetland, floodplain forest, and floodplain woodland as well as improve the hydrologic conditions for wildlife. The operation of the site is constrained by the ability to manage the water level of various components. High flow conditions on the Illinois River negatively impact the ability to gravity drain the system and flood events deposit sediment onto the site. Upland runoff from precipitation events also add to the amount of water that must be drained.

<u>Literature Review</u>
The Yorkinut Slough Project is located in Water Resource Region (i.e., HUC-2 watershed) number 07, the Upper Mississippi Region. A January 2015 report conducted by the USACE Institute for Water Resources (USACE 2015b) summarizes the available climate change literature for this region, covering both observed and projected changes. The *Fourth National Climate Assessment* (NCA4) considers climate change research and the impacts of climate change at both a national and regional scale (USGCRP 2018). Literature reviewed as part of the 2015 USACE effort, as well as the NCA4, are summarized below.

Temperature. Observed increases in temperature are reported in multiple studies. A study by Wang et al. (2009) reported an increasing trend in temperatures for the winter through summer months and a slightly decreasing trend in temperatures in the fall. These findings were supported by later studies and an average temperature increase of 1.5°F between 1895 and 2012 was also reported (Pryor et al., 2014). General Circulation Models (also known as Global Climate Models, both terms use the acronym GCM) were used to project temperatures in the study region. GCM projections show a consensus on a significant warming trend on a national scale throughout the 21st century, with studies including the Upper Mississippi Region generally agreeing with this trend (USACE 2015). A study by Gao et al. (2012) showed a projected increase in heat wave intensity, duration, and frequency. Additionally, Pryor et al. (2014) reported a statistically significant increase in projected annual average temperature and number of extreme heat days. The same study showed a projected increase in the length of the frostfree season and a projected increase in the number of days with an average temperature above 65°F for the study region.

Precipitation. A significant increasing trend in the observed total annual precipitation was identified by various reports (USACE 2015). A study by McRoberts and Nielsen-Gammon (2011) reported an increase in annual precipitation of 5 – 20% per century for the region. There is a reasonable consensus among literature that the annual precipitation totals and frequency, as well as the extreme precipitation totals and frequency, are projected to increase (USACE 2015). Multiple studies reported both a projected increase in precipitation as well as a projected increase in droughts. A study by Wilson and Weng (2011) projected that the summer months will be drier, while the winter months will be wetter. A study by Easterling et al. (2017) projected that winter and spring precipitation would increase by up to 30 percent by the end of this century in the Midwest region. Joetzjer et al. (2013) reported an increase in the frequency and extent of droughts in the region, noting that the impact of projected temperature increases appears to exceed the impact of projected precipitation increases for the latter half of the 21st century.

Streamflow. There is a reasonable consensus among literature of a general increasing trend in observed streamflow data for the Upper Mississippi Region (USACE 2015). Xu et al. (2013) identified statistically significant positive trends in the annual streamflow and baseflow in the region. A later study by Frans et al. (2013) aimed to examine how climate change and land use changes contributed to the positive trend. The study suggested that the increase in precipitation in the region contributed more than changes in land use to the observed trends. There is a lack of consensus among literature regarding the projected streamflow in the region, with both increasing and decreasing projected trends being reported.

Summary. Within the literature reviewed, there is consensus that observed temperature, precipitation, and streamflow have increased within the Upper Mississippi Region. There is a strong consensus that air temperatures are projected to increase in the region over next century. There is a reasonable consensus on a projected increase in extreme temperature events, including more frequent, longer, and more intense summer heat waves. Additionally, there is a reasonable consensus of a projected increase in annual and extreme precipitation. There is a lack of consensus on projected streamflow in the region. The 2015 USACE *Civil Works Technical Report CWTS-2015-13* provides a visual summary of the trends in observed and projected hydrometeorological variables as shown in Figure 1.

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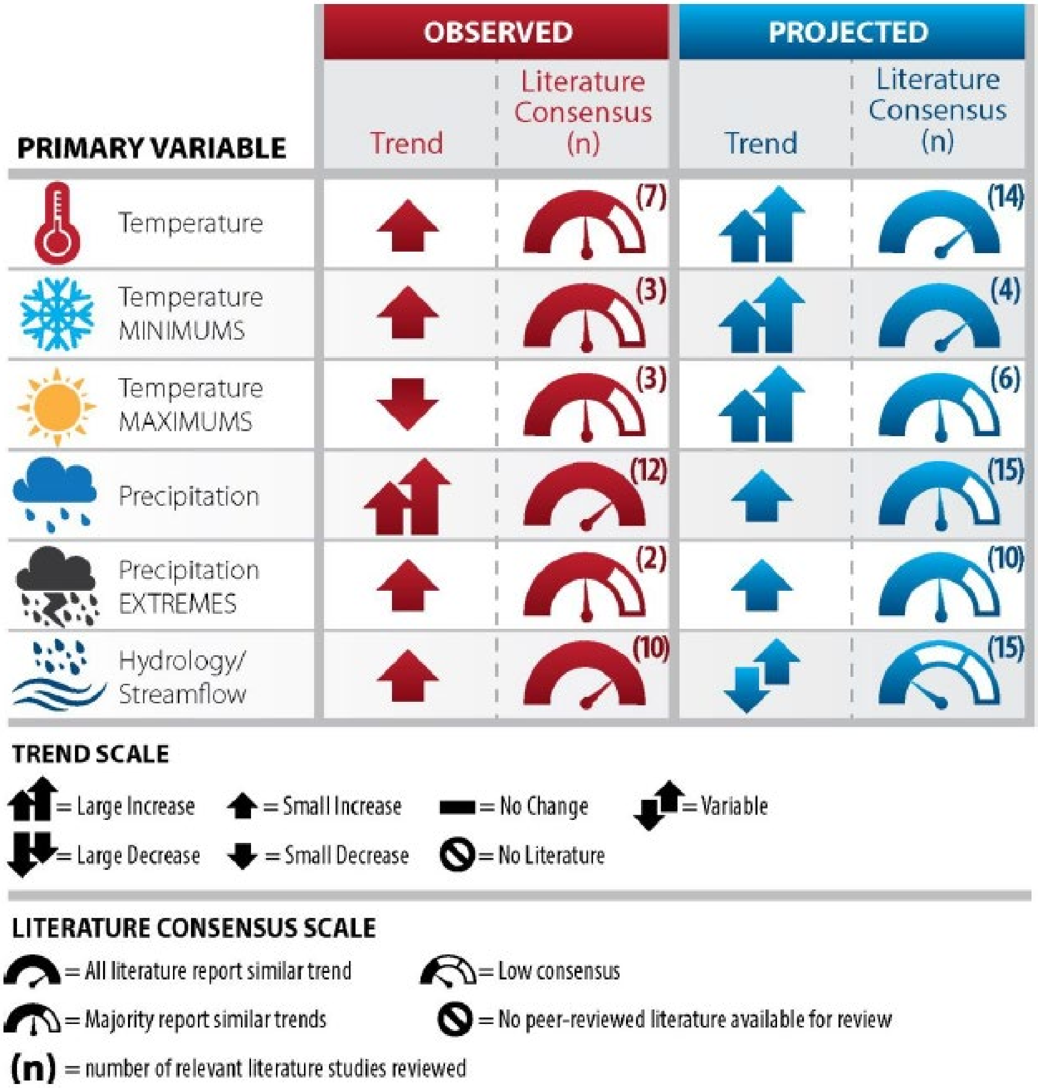


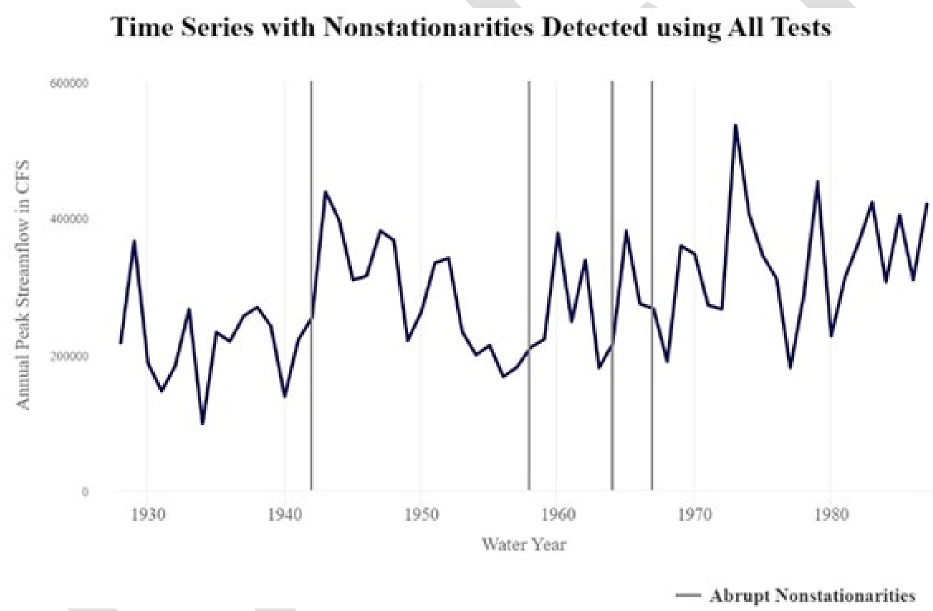
Figure 1. Summary Matrix of Observed and Projected Climate Trends (USACE 2015).

<u>Nonstationarity Detection</u>

The assumption that discharge datasets are stationary (i.e., their statistical characteristics are unchanging) in time underlies many traditional hydrologic analyses. Statistical tests can be used to test this assumption using techniques outlined in Engineering Technical Letter (ETL) 1100-2-3. The Nonstationarity Detection (NSD) tool is a web-based tool to perform these tests on datasets of annual peak streamflow at U.S. Geological Survey (USGS) stream gages. The primary objective of this project is to restore habitat and the ability to do so is impacted by the conditions of the Illinois River. Therefore, the focus of this investigation is the high-flow regime that is best represented by annual instantaneous peak flows.

For this Project, the NSD tool was applied using annual peak streamflow data from USGS gage 05587450, Mississippi River at Grafton, IL. The gage captures 171,300 square miles of drainage area and is located at the confluence of the Illinois and Mississippi rivers, five miles downstream of the Yorkinut Slough site. Natural flow of the Mississippi River is affected by many navigation dams in upper Mississippi River Basin. Also, natural flow of the Illinois River is affected by many navigation dams along its length. USGS gage 05587450 is the closest gage to the Project. Annual peak data has been collected since 1928. The annual peak streamflow was reported as USGS gage 05587500, Mississippi River at Alton, IL from 1928 to 1987 and as USGS gage 05587450 from 1987 onward. The NSD tool applies analysis to the period of record from 1928 to 1986 for USGS gage 05587500 and from 1987 to 2020 for USGS gage 05587450.

As shown in Figure 2, USGS gage 05587500 has strong evidence of a nonstationarity at water year 1942. A strong nonstationarity is one that demonstrates a degree of consensus, robustness, and a significant increase or decrease in the sample mean and/or variance. The 1942 nonstationarity is identified by multiple tests targeted at identifying a change in the overall statistical distribution and mean, indicating consensus. The 1942 nonstationarity can be considered robust because tests targeted at identifying nonstationarities in different statistical properties identify a change in overall distribution and mean. The magnitude of the mean annual peak flow increases by 60,000 cfs, from 220,000 cfs between 1928 and 1941 to 280,000 cfs between 1943 and 1963. Nonstationarities are also indicated in water years 1958, 1964, and 1967. However, there is a lack of consensus or robustness among tests for these years, indicating insufficient evidence to reject the null hypothesis of statistical stationarity.



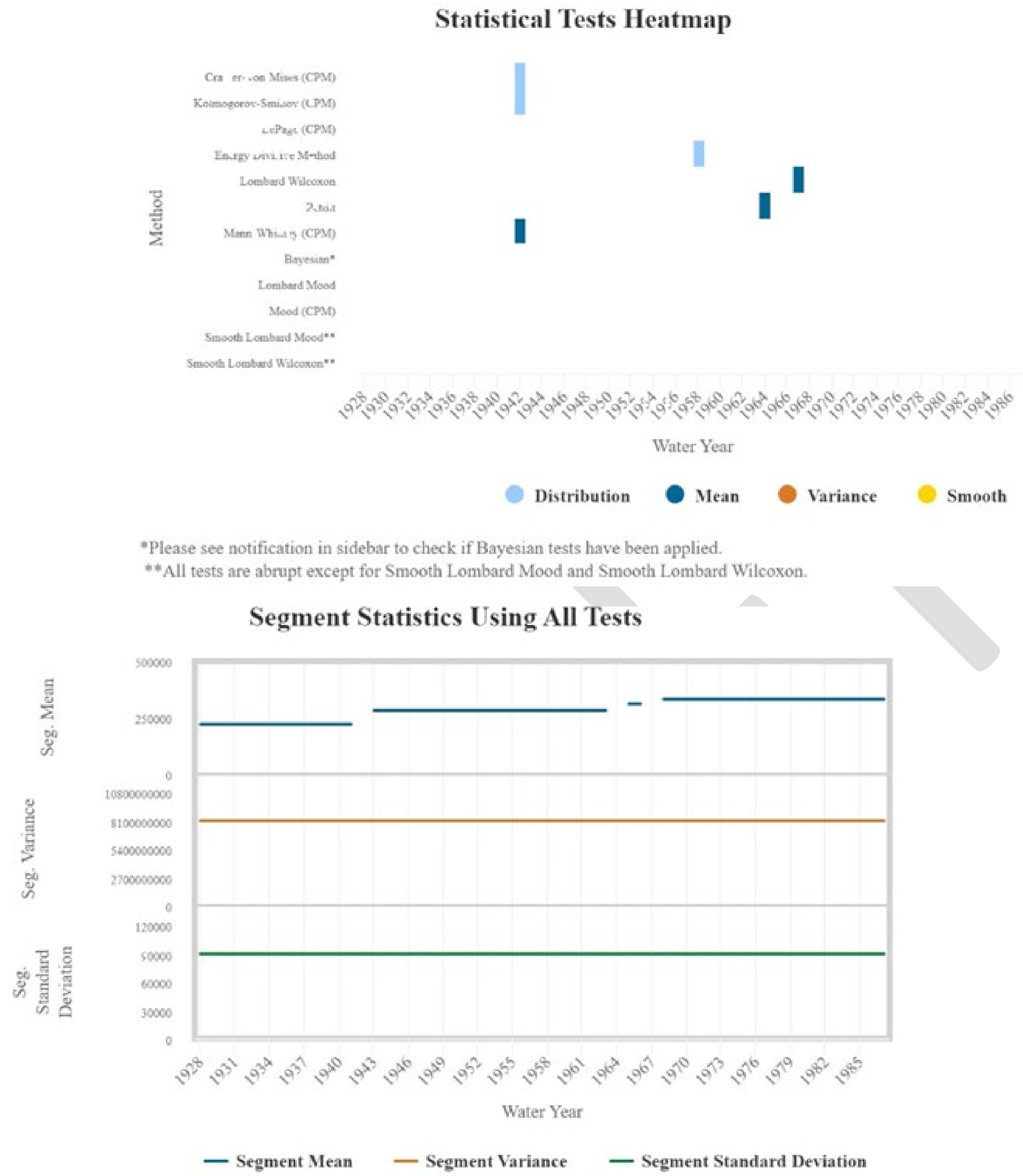
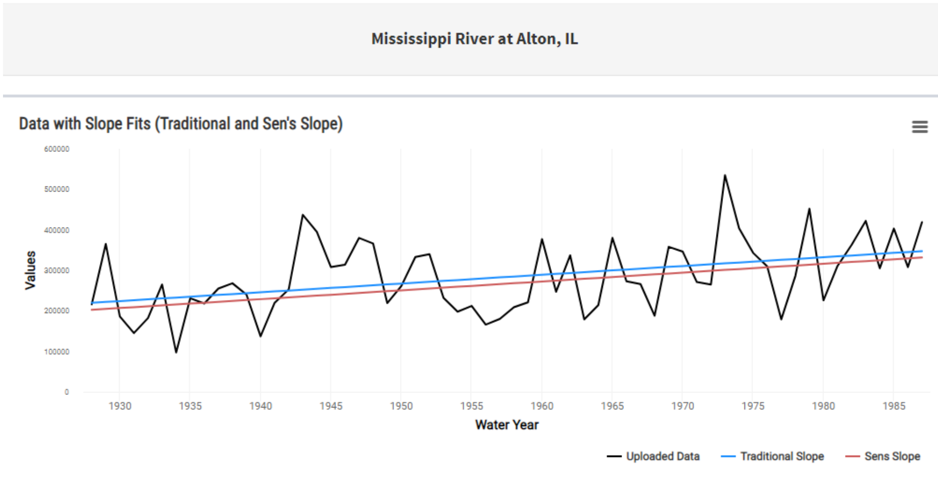


Figure 2. Output of the Nonstationarity Detection Tool for USGS Gage 05587500.

Statistically significant trends are detected in the peak streamflow dataset between 1928 and 1986 using the t-Test (p-value = 0.0017<0.05), Mann-Kendall (p-value = 0.0017<0.05), and Spearman Rank Order (p-value = 0.00083<0.05) tests applied using a 0.05 level of significance. Figure 3 shows the trend for USGS gage 05587500. A strong nonstationarity indicates that it could be beneficial to analyze the data as two subsamples. Analyzing the subsets of record from 1928 to 1942, as well as from 1943 to 1986, found no statistically significant trends nor additional nonstationarities.



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	2164	-3951787
Sen's Slope	Positive	2186	-4011123

Trend Hypothesis Test

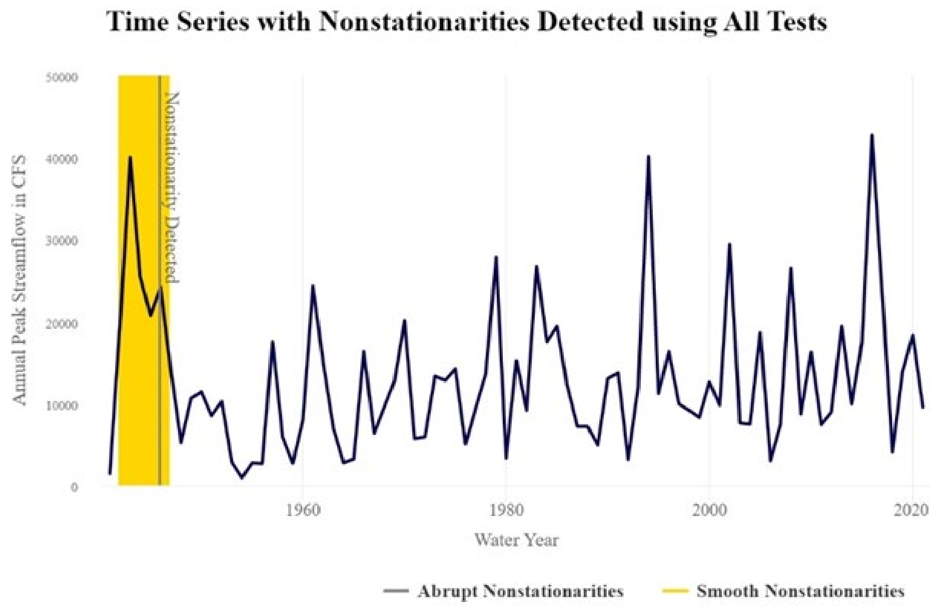
Test	P-Value
t-Test	0.00082585
Mann-Kendall	0.0016633
Spearman Rank-Order	0.0012239

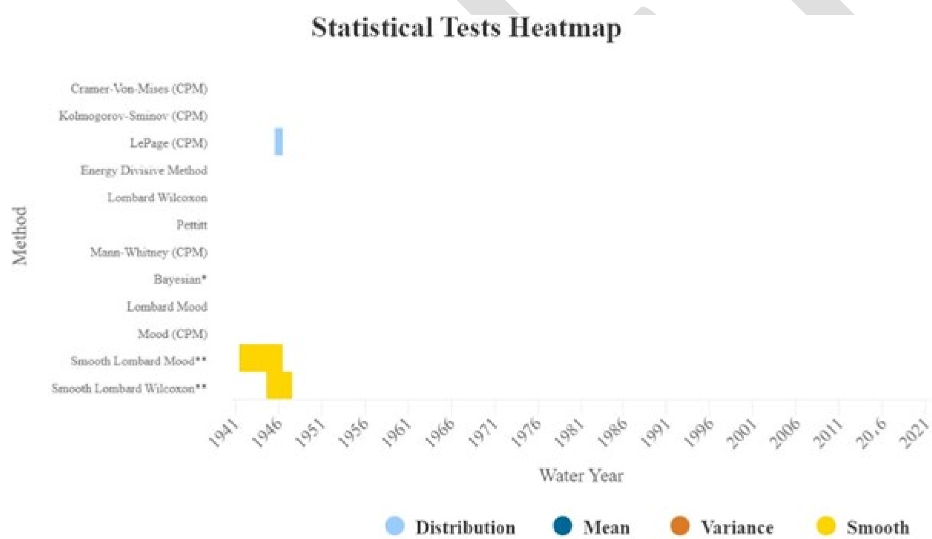
Figure 3. Output of the Trend Analysis Tool for USGS Gage 05587500.

No strong nonstationarities were detected at USGS gage 05587450 between 1987 and 2020. No monotonic trends are detected in the peak streamflow dataset between 1987 and 2020 using the t-Test (p-value = 0.22>0.05), Mann-Kendall (p-value = 0.15>0.05), and Spearman Rank Order (p-value = 0.16>0.05) tests applied using a 0.05 level of significance.

For this Project, the NSD tool was also applied using annual peak streamflow data from USGS gage 05587000, Macoupin Creek near Kane, IL. The USGS gage on the Mississippi River at Grafton was selected because of its proximity to the site, but it has a very large watershed. The USGS gage on Macoupin Creek near Kane was chosen as a representation of a small, local watershed. The gage near Kane captures 868 square miles of drainage area and is located on Macoupin Creek, a tributary of the Illinois River, downstream of the State Highway 267 bridge. The gage is 34.11 miles upstream of the Yorkinut Slough site. Streamflow data is missing for the period of 1934 to 1940. Therefore, the period of record for the NSD tool analysis is from 1941 to 2021.

As shown in Figure 4, USGS gage 05587000 has evidence for a smooth nonstationarity in water years 1941 through 1947. A smooth nonstationarity is indicated by both tests in water years 1945 and 1946. Additionally, an abrupt nonstationarity is indicated in year 1946. However, there is a lack of consensus or robustness among abrupt tests for that year. No monotonic trends are detected in the peak streamflow dataset between 1941 and 2021 using the t-Test (p-value = 0.35>0.05), Mann-Kendall (p-value = 0.25>0.05), and Spearman Rank Order (p-value = 0.25>0.05) tests applied using a 0.05 level of significance.





*Please see notification in sidebar to check if Bayesian tests have been applied.
**All tests are abrupt except for Smooth Lombard Mood and Smooth Lombard Wilcoxon.

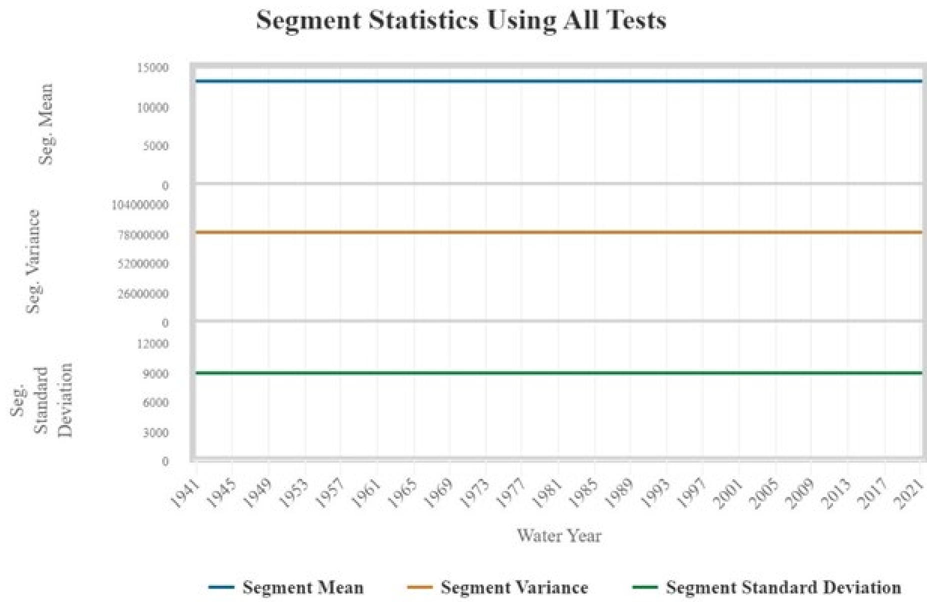
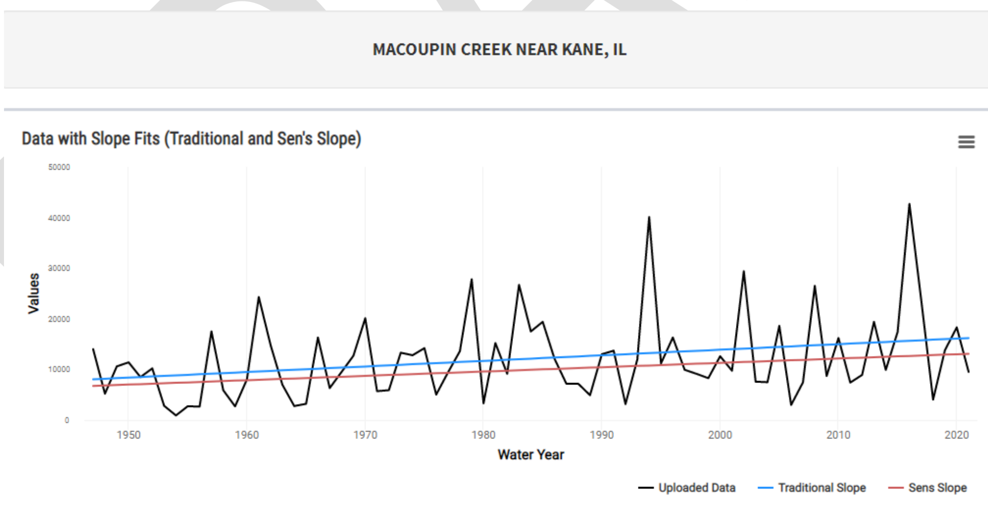


Figure 4. Output of the Nonstationarity Detection Tool for USGS Gage 05587000.

Analysis of a subset of the record was also performed on years 1947 to 2021. This analysis did not indicate any significant nonstationarities, but did detect statistically significant trends using the t-Test (p-value = 0.010<0.05), Mann-Kendall (p-value = 0.018<0.05), and Spearman Rank Order (p-value = 0.013<0.05) tests applied using a 0.05 level of significance. Figure 5 shows the trend for USGS gage 05587000 using the subset record of years 1947 to 2021.



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	110	-206367
Sen's Slope	Positive	86	-160137

Trend Hypothesis Test

Test	P-Value
t-Test	0.010447
Mann-Kendall	0.017808
Spearman Rank-Order	0.012985

Figure 5. Output of the Trend Analysis Tool for Subset Record of USGS Gage 05587000.

Climate Hydrology Assessment Tool

The USACE Climate Hydrology Assessment Tool (CHAT) can be used to assess projected, future changes to streamflow in the watershed. Projections are at the spatial scale of a HUC-8 watershed, with flows generated using a Variable Infiltration Capacity (VIC) model from temperature and precipitation data statistically downscaled from GCMs using the Bias Corrected, Spatially Disaggregated (BCSD) method. The VIC model is setup to simulate unregulated basin conditions. The Yorkinut Slough site is in HUC 07130011 (Lower Illinois). Figure 6 shows the range of output presented in the CHAT using 64 combinations of GCMs and representative concentration pathways (RCP) of greenhouse gas emissions applied to generate climate-changed hydrology using the VIC model. The range of data is indicative of the uncertainty associated with projected, climate-changed hydrology.

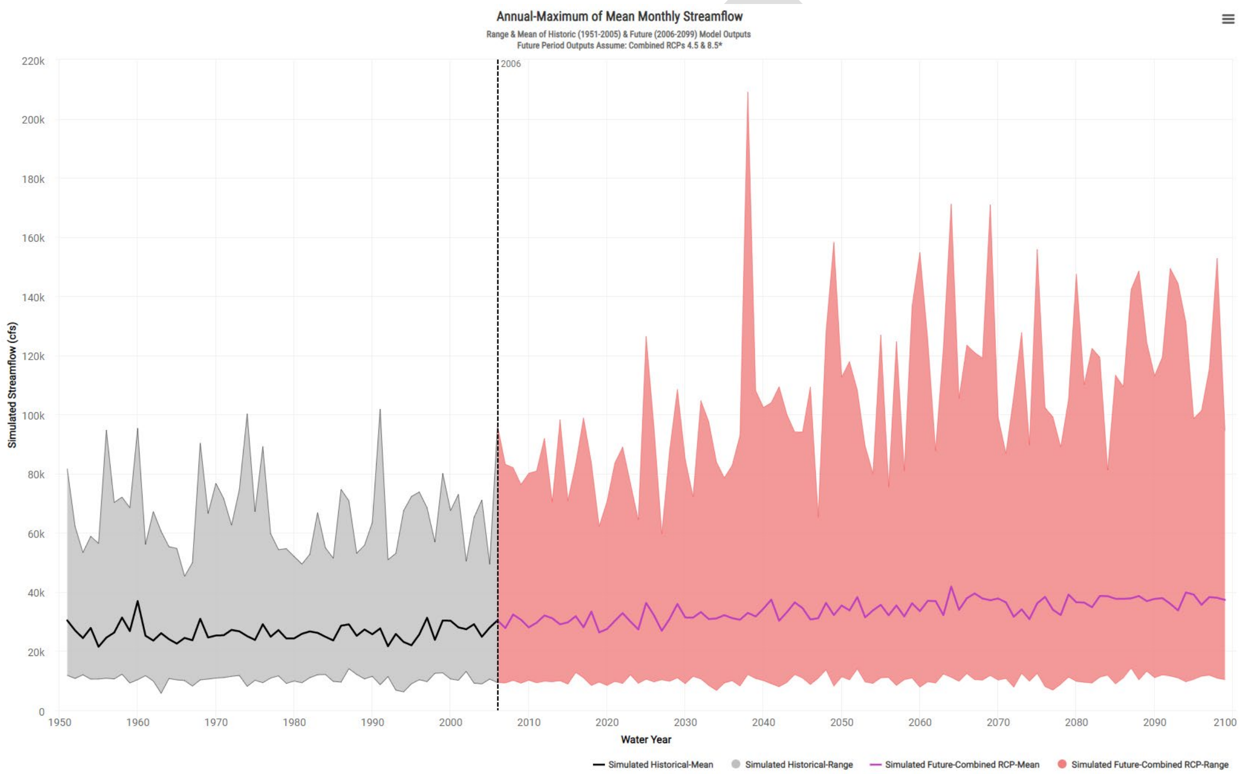


Figure 6. Range of 64 Combinations of Climate-Changed Hydrology Model Output for Lower Illinois (HUC 07130011).

Figure 7 shows the average of 64 combinations of GCM and emissions scenario used to generate annual maxima of monthly average discharge for the Lower Illinois (HUC 07130011) watershed. The gray line in the "earlier" period refers to simulations using observed levels of atmospheric carbon pre-2005 (hindcast period), while the blue line (the "later" period) refers to simulations using projected carbon emissions according to the RCPs. The "earlier" trend line does not have a statistically significant trend detected using the t-Test (p-value = 0.80>0.05), Mann-Kendall (p-value = 0.40>0.05), or Spearman Rank Order (p-value = 0.42>0.05) tests using a 0.05 level of significance. The "later" trend does have a statistically significant trend per the t-Test (p-value = 5.27e-18<0.05), Mann-Kendall (p-value = 2.2e-16<0.05), or Spearman Rank Order (p-value = 7.19e-19<0.05) tests.

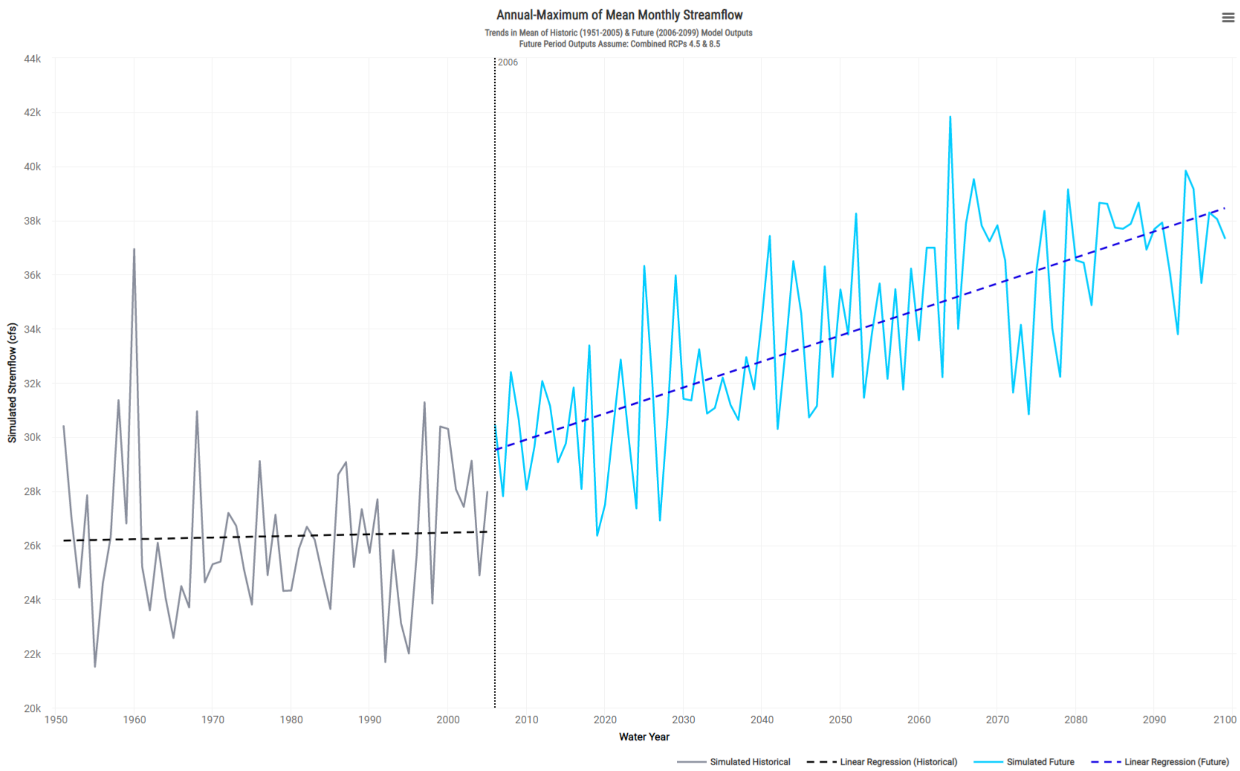


Figure 7. Projected Mean Annual Maximum Monthly Flows for the Lower Illinois Watershed (HUC 07130011).

<u>Vulnerability Assessment</u>
The USACE Watershed Climate Vulnerability Assessment (VA) Tool facilitates a screening-level, comparative assessment of the vulnerability of a given business line and HUC-4 watershed to the impacts of climate change, relative to the other HUC-4 watersheds within the continental United States (CONUS). It uses the Coupled Model Intercomparison Project (CMIP5) GCM-BCSD-VIC dataset (2014) to define projected hydrometeorological inputs, combined with other data types, to define a series of indicator variables to define a vulnerability score.

Vulnerabilities are represented by a weighted-order, weighted-average (WOWA) score generated for two subsets of simulations (wet—top 50% of cumulative runoff projections; and dry—bottom 50% of cumulative runoff projections). Data are available for three epochs. The epochs include the current time period (“Base”) and two 30-year, future epochs (centered on 2050 and 2085). The Base epoch is not based on projections and so it is not split into different scenarios. For this application, the tool was applied using its default, National Standards Settings. In the context of the VA Tool, there is some uncertainty in all the inputs to the vulnerability assessments. Some of this uncertainty is already accounted for in that the tool presents separate results for each of the scenario-epoch combinations rather than presenting a single aggregate result.

As shown in Figure 8, the Lower Illinois (HUC 0713) watershed is not considered relatively vulnerable to climate change impacts for the flood risk reduction business line, as it is not among the 20% most vulnerable watersheds for this business line in the CONUS (202

HUC04s). This conclusion is true for both the wet and dry scenarios and both the 2050 and 2085 epochs. Indicators used to compute the Flood Risk Reduction WOWA score include: the acres of urban area within the 500-year floodplain, the coefficient of variation in cumulative annual flow, runoff elasticity (ratio of streamflow runoff change to precipitation change), and two indicators of flood magnification (indicator of how much high flows are projected to change over time). One of the indicators of flood magnification is contributions from upstream watersheds, while the other is focused only on the change in flood frequency within the watershed of interest. The dominant indicator contributing to the Lower Illinois' vulnerability score for all scenarios is Flood Magnification. For the wet scenarios, Flood Magnification contributes 46%–47% of the score, while for the dry scenarios Flood Magnification contributes 50%–51% of the score.

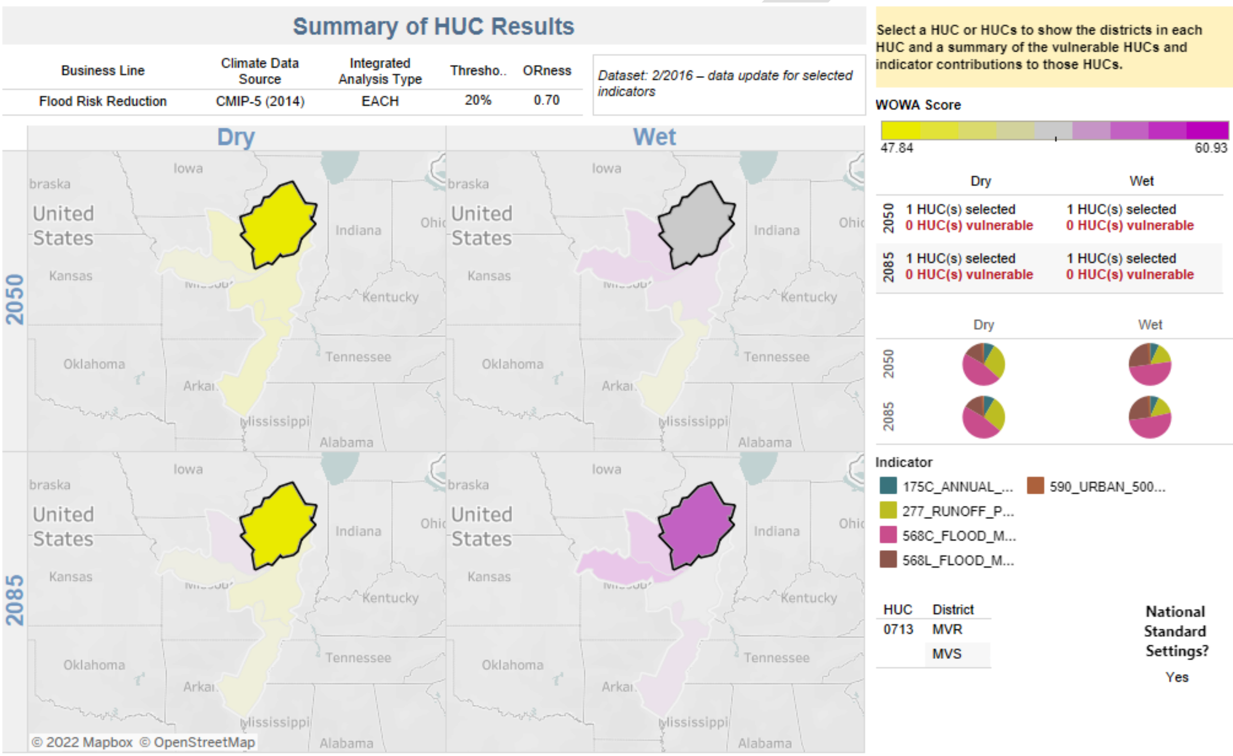


Figure 8. Output of the VA Tool indicates that the Lower Illinois Watershed is not among the 20% Most Vulnerable CONUS Watersheds for the Flood Risk Reduction Business Line.

<u>Conclusion</u>

The literature reviewed indicated a reasonable consensus on an increasing trend in observed temperature, precipitation, and streamflow. There was also a consensus that temperatures and precipitation are projected to increase in the future, with warmer, drier summers and wetter winters. There was no consensus among the literature on the projected future streamflow. The USACE CHAT Tool showed a statistically significant trend of increasing streamflow for the "later" period. The USACE VA Tool indicated that the Lower Illinois (HUC 0713) watershed is not within the 20% most vulnerable watersheds, and thus not considered relatively vulnerable when compared to other watersheds in the CONUS. Not being considered relatively vulnerable does not mean that the watershed is not susceptible to climate change. Flood magnification was the dominant indicator in all scenarios.

Observed annual peak streamflow data was reviewed from 1928 to 2020 for USGS gages on the Mississippi River near the study area. Annual peak data has been collected since 1928. The annual peak streamflow was reported as USGS gage 05587500, Mississippi River at Alton, IL from 1928 to 1987 and as USGS gage 05587450 from 1987 onward. The NSD tool applies analysis to the period of record from 1928 to 1986 for USGS gage 05587500 and from 1987 to 2020 for USGS gage 05587450. The peak streamflow data for the Grafton gage for the period of 1987 to 2020 did not indicate any monotonic trends or nonstationarities. A statistically significant trend was detected for the Alton gage for years 1928 and 1986. Additionally, a nonstationarity was identified in water year 1942. This nonstationary may be caused by the period of drought in the years prior, as well as by construction of locks and dams on the Mississippi River.

Observed annual peak streamflow data was also reviewed for the USGS gage on Macoupin Creek near Kane, IL from years 1947 to 2021. No monotonic trends were indicated. However, a smooth nonstationarity was indicated by both tests in water years 1945 and 1946. The smooth nonstationarities may be explained by the data starting at the end of a drought, immediately followed by very wet years.

Table 1 indicates potential residual risks for this Project as a result of climate change along with a qualitative rating of how likely those residual risks are to occur. The residual risk resulting from climate change is classified as low. The risk to the Swan Lake outlet structure enlargement is low as a result of the lack of consensus of increased streamflow.

Table 1. Residual Risk to Yorkinut Slough as a Result of Climate Change.

Project Feature	Trigger	Hazard	Harm	Qualitative Likelihood Rating	Justification for Rating
Swan Lake Outlet Structure	Projected increases in precipitation	Future flow may be larger than present, and floods may occur more frequently	Flood waters lower the effectiveness of gravity drainage structures	Low	Observed and projected precipitation data show increase over time. However, projected hydrology does not show evidence of increasing flows, suggesting other variables are mitigating the impacts of climate change on peak flows.

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