US Army Corps of Engineers ®
Wilmington District

PHILPOTT LAKE, VIRGINIA
WATER STORAGE REALLOCATION
FEASIBILITY STUDY AND ENVIRONMENTAL ASSESSMENT

DRAFT - APPENDIX F - CONSIDERATION OF POTENTIAL IMPACTS OF CLIMATE CHANGE OF THE PHILPOTT LAKE REALLOCATION

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Wilmington District – U.S. Army Corps of Engineers

Qualitative Climate Change Assessment

To effectively incorporate climate change adaptation and to increase resiliency and decrease vulnerability of Philpott Lake Reallocation Project, the first step was to identify where vulnerability exists. The current USACE Screening-Level Climate Change Vulnerability Assessment (VA) Tool and other tools described in Engineering & Construction Bulletin (ECB) 2018-14 were used in this analysis, including the Nonstationarity Detection Tool (NSD). This discussion will start with a literature review of climate observations and predictions before moving onto an analysis starting at the broad regional scale and finishing at the project level with the analysis.

Literature Review

The Smith River Basin and the Philpott Dam are in Water Resource Region number 03, the South Atlantic-Gulf Region. A January 2015 report conducted by the USACE Institute for Water Resources summarizes the available climate change literature for this region. The report covers both observed and predicted changes using data available through 2014. Figure 1 shows a summary matrix of the observed and projected trends used in the report.

Multiple studies focused on observed mean temperature, mean seasonal temperature and extreme temperatures. Generally, the studies concurred on increased average annual temperature (Carter et al, 2014, Patterson et al, 2012, Laseter et al, 2012). However, there are conflicting results on observed seasonal changes with some results showing warmer summers and colder winters (Wang et al, 2009) and others showing no observed seasonal changes (Westby et al, 2013). Analysis of global climate model (GCM) projections generally agree that over the next century mean annual temperatures will rise with the largest increases in summer months (Carter et al, 2014; Elguindi and Grundstein, 2013; Qi et al, 2009; Tebaldi, 2006).

Precipitation trend analysis for the South Atlantic-Gulf region showed mixed results with no clear trend for annual precipitation totals, precipitation intensity, and extreme high precipitation events (Wang and Zhang, 2008; McRoberts and Nielsen-Gammon, 2011; Pryor et al., 2009). Wang and Zhang (2008) found an increase in extreme precipitation event frequency and Pryor et al. (2009) found a statistically significant increase in the number of precipitation days per year. Wang, Killick, and Fu (2013) investigated high and low extreme precipitation in the South-Atlantic Gulf region and supported the findings of Wang and Zhang (2008) with an increase in high extreme precipitation events but found no statistically significant change in the low extreme precipitation events. Analysis of GCM projections are also split on future precipitation with some models showing more annual precipitation and others showing less (Bastola et al, 2007; Jayakody et al, 2013; Qi et al, 2009). There is general consensus on more intense and frequent storm events (Gao et al 2012; Tebaldi 2006; Wang and Zhang 2008).

Studies of stream gages in the regions have shown mixed results. Xu et al (2013) showed no statistically significant trend in stream flows. Kalra et al (2008) found a negative statistically significant trend in annual and seasonal stream flows. Small et al (2006) found a statistically significant negative trend for annual low flows at several gages across the region. Similar to precipitation projections, GCM projections coupled with macro-scale hydrologic models show no clear consensus on future stream flow trends (Bastola et al, 2007; Carter et al, 2014; Hagemann et al, 2013; Irizarry-Ortiz et al, 2013; Qi et al, 2009; Wang et al 2013a; Wang et al 2013b).

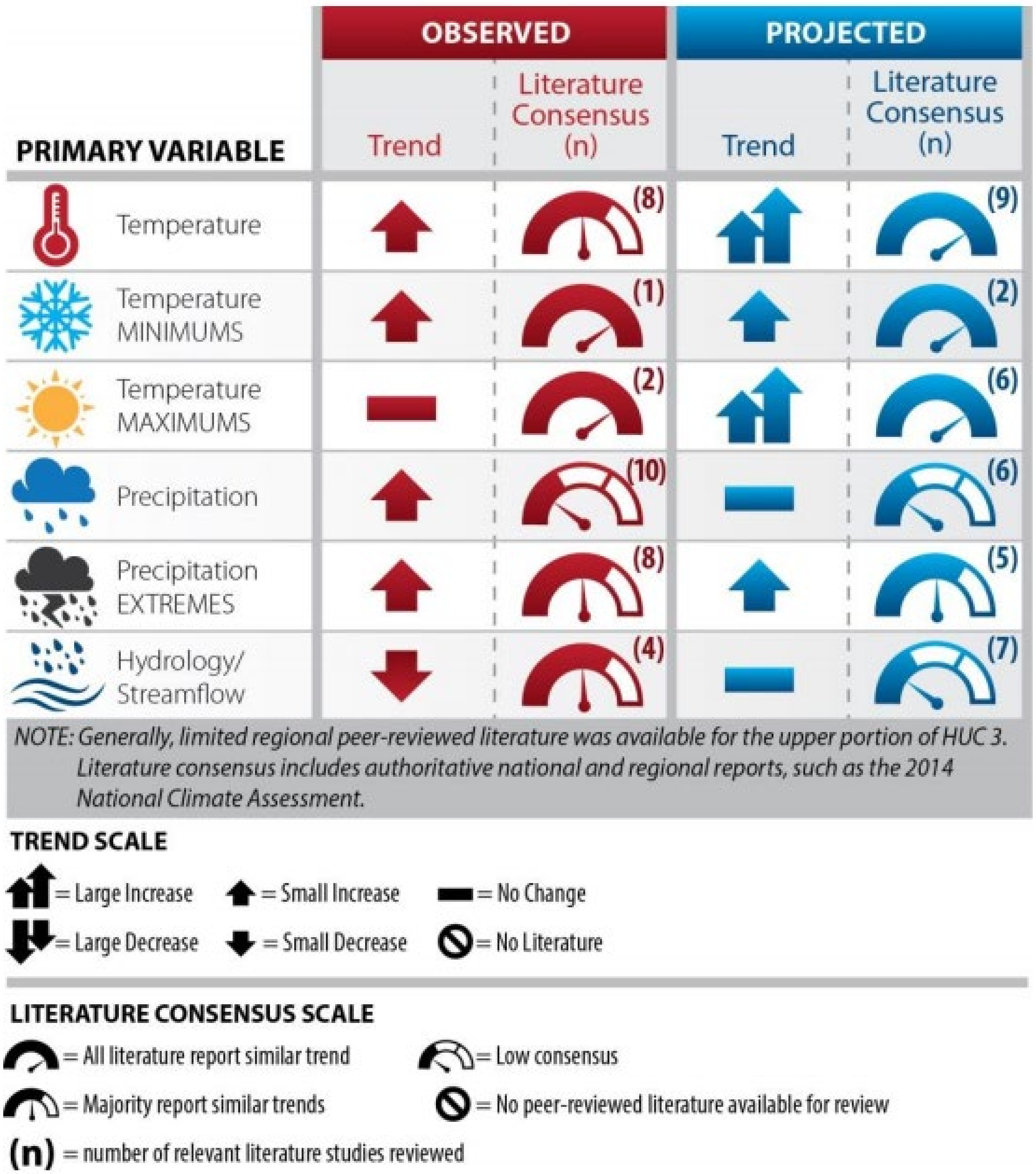

Figure 1- Summary matrix of observed and projected climate trends.

Vulnerability Assessment

With the knowledge that climate information and understanding is constantly evolving, USACE has developed the USACE Screening-Level Climate Vulnerability Assessment at the Watershed-Scale. The preliminary, screening-level nationwide analysis is built on existing, national-level tools and data that include indicators or processes to identify vulnerabilities in watersheds with respect to climate change.

The USACE Watershed Vulnerability Assessment Tool was used to examine the future water supply-related vulnerability of the project area (Figure 2). For the Chowan-Roanoke watershed (HUC 0301), this tool shows that the area is projected to be relatively less vulnerable compared to the entirety of the USACE portfolio with respect to water supply business line for the 21st century for all wet and dry projected scenarios. While there is an increase in the Weighted Order Weighted Average (WOWA) scores between year 2050 and year 2085 for both the Dry and Wet scenarios (43.7 to 50.38 for Dry and 53.8 to 56.6 for Wet, respectively), the future increases still do not exceed the threshold for inclusion among the 20% most vulnerable HUC-4 watersheds represented by the water supply business line.

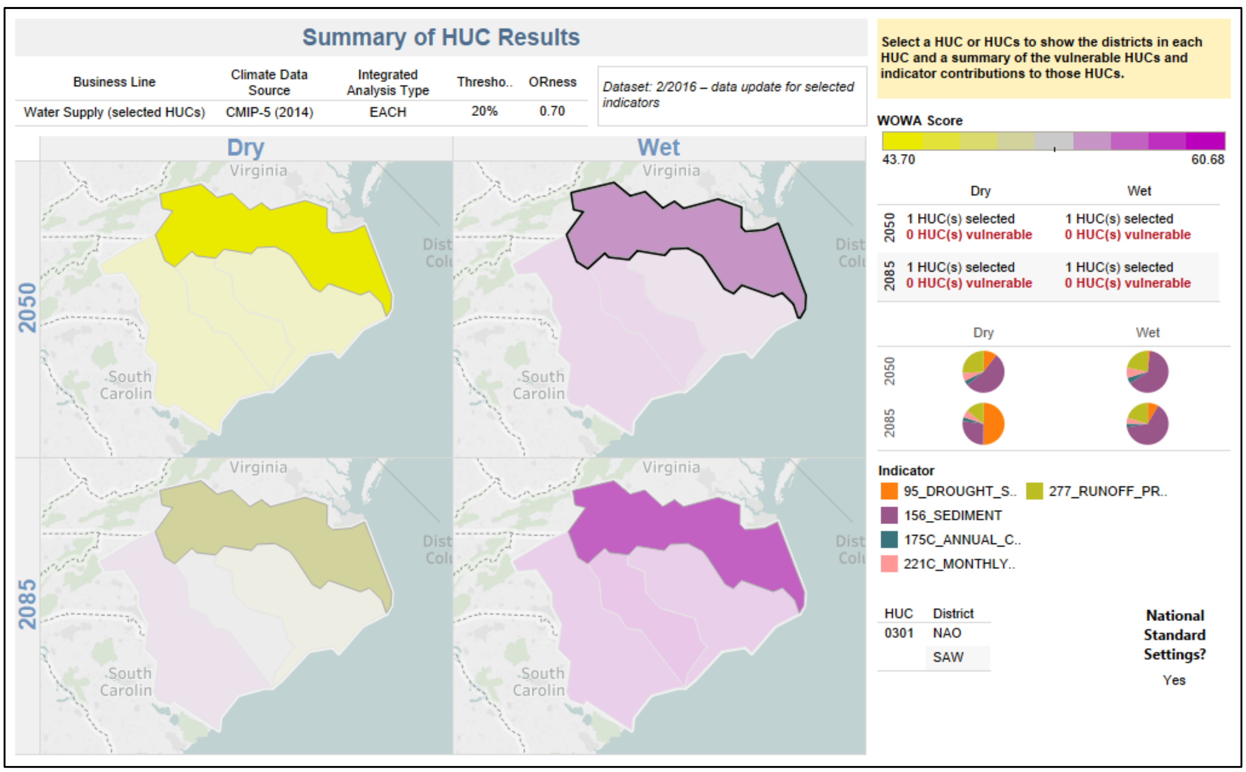

Figure 2- Projected Vulnerability for Chowan-Roanoke Watershed with respect to Water Supply.

While the VA tool identifies watersheds that may or may not be relatively vulnerable, it may not be appropriate to cascade those results to the project by default, because projects exist at finer spatial scales than the HUC-4 watersheds, evidenced by the fact that the watershed for Philpott Lake is such a relatively small portion of the overall Chowan-Roanoke watershed (212 square miles compared to over 18,000 square miles). To give a fuller picture of the potential vulnerabilities at this project, additional tools were employed to assess conditions by investigating other data and projections.

Climate Hydrology Assessment Tool

The USACE Climate Hydrology Assessment Tool (CHAT) was used to examine observed and projected trends in Chowan-Roanoke watershed hydrology to support the qualitative assessment, based on analysis of projected annual maximum monthly mean flows for 93 combinations of general circulation model and emissions scenario (representative concentration pathway) through the year 2099. As expected for this type of qualitative analysis, there is considerable variability in these maximum flows (Figure 3); however, numerous maximum flows after year 2024 do exceed all maximum flows prior to 2040, resulting in the overall projected upward trend in mean annual maximum monthly flows over time for the Chowan-Roanoke watershed (Figure 4). The simulated hindcast period (1959-2005) has a statistically significant ($p<0.05$) increasing slope of 60 cfs/year, while the simulated future period (2006-2099) has a statistically significant increasing slope of 34.1 cfs/year indicating that the magnitude of the yearly increase in flow will slow but continue in the future. While this may suggest potential for flood risk impacts in the future, it is not anticipated to have adverse water supply impacts. Water supply is more vulnerable to low flow conditions limiting the availability of water, however higher flood risks could lead to potential damage to water supply lines or infrastructure. The result is qualitative only.

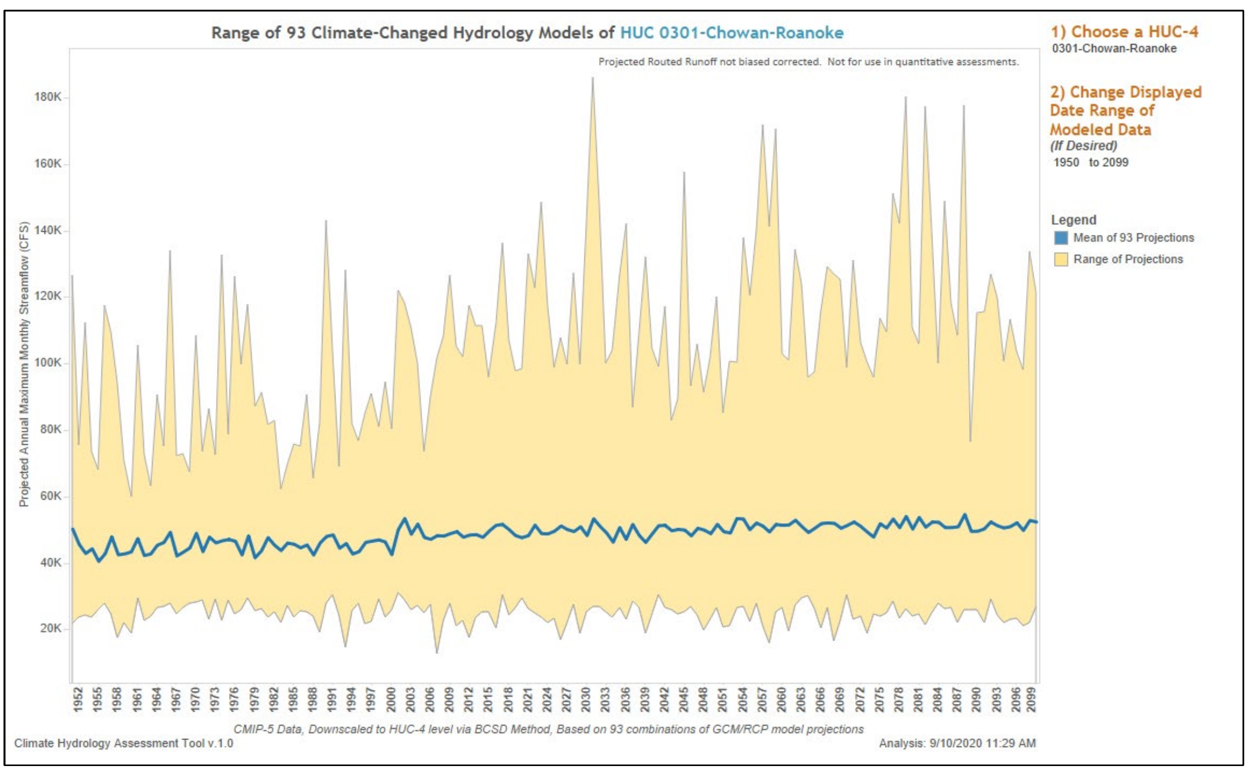

Figure 3 - Range of Projected Annual Maximum Monthly Streamflow for Chowan-Roanoke Watershed. Predicted Annual Maximum Monthly Flow is shown on the y-axis (cfs) with the range of predictions shaded in yellow and the mean of 93 projections in blue.

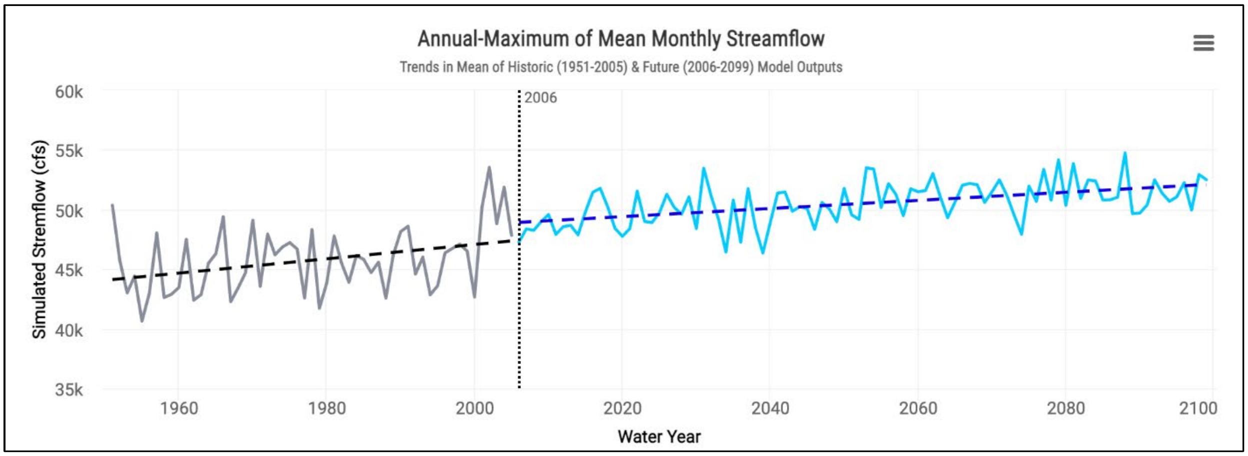

Figure 4 – Trends in Mean Projected Annual Maximum Monthly Streamflow for the Chowan-Roanoke Watershed.

Figures 6, 7, 8, 9, and 10 come from the CHAT and show the annual maximum streamflow and the trend line associated with the annual values for one of the larger tributaries into Philpott Lake (USGS 02071530 Smith River at Smith River Church near Woolwine VA) and three nearby unregulated gage stations (USGS 02069700 South Mayo River near Nettleridge VA, USGS 02070000 North Mayo River near Spencer VA, and USGS 02056900 Blackwater River near Rocky Mount VA) (Figure 5). For each gage trendlines for the full period were analyzed for statistical significant ($p<0.05$) which would indicated changes in the annual maximum streamflow over time. Over the full period of record for these gages, the trend lines for these gages do not show statistically significant changes in annual maximum streamflows ($p>0.05$). The downstream operational control point for both flood operations and minimum flows for Philpott Dam (USGS 02072500 Smith River near Bassett VA) was also evaluated (Figure 10). Not surprisingly, there is a statistically significant ($p<0.0001$) downward trend in annual maximum streamflows downstream of Philpott when evaluating the entire period of record (since 1920) due to flood control operations at Philpott; however, when the period of analysis is reduced to reflect only the regulated period since Philpott went into operation, then there is no statistically significant ($p>0.05$) trend for this downstream gage either.

Figure 5 – USGS gage locations used in this analysis.

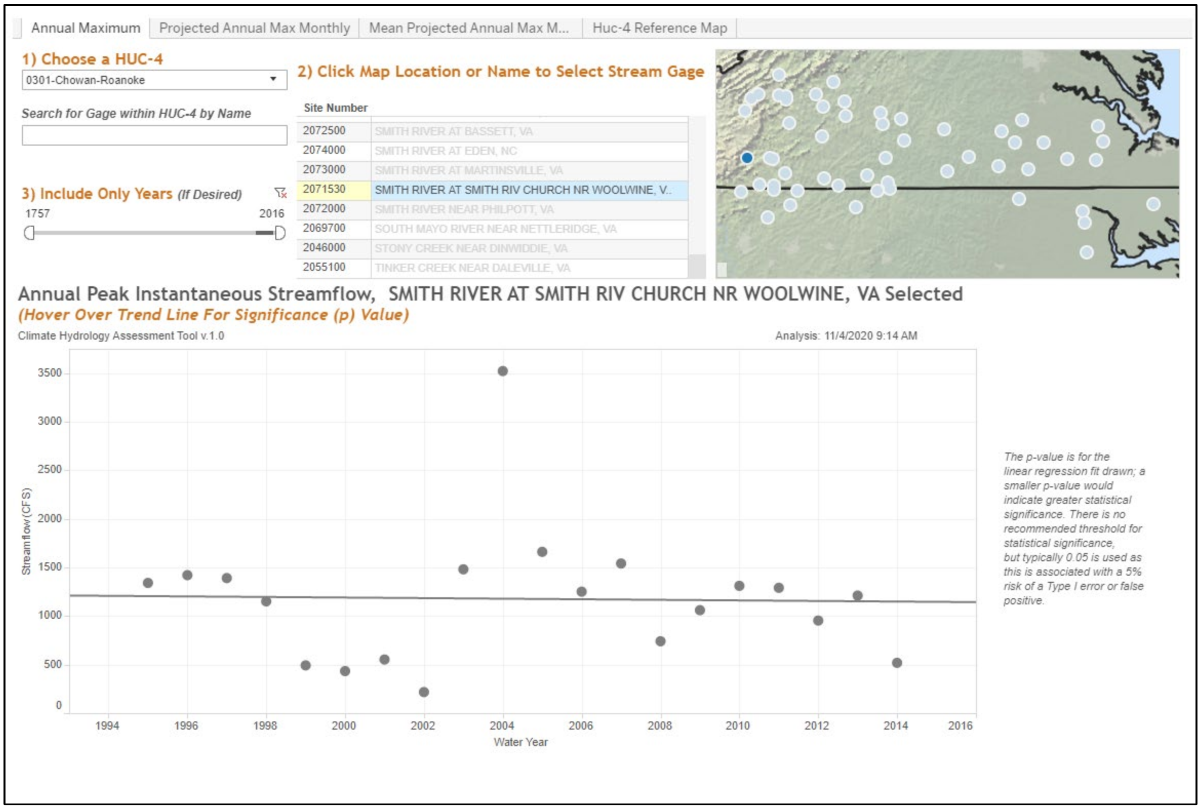

Figure 6 - Annual Maximum Streamflow for Smith River at Smith River Church near Woolwine, VA. P-value=0.916.

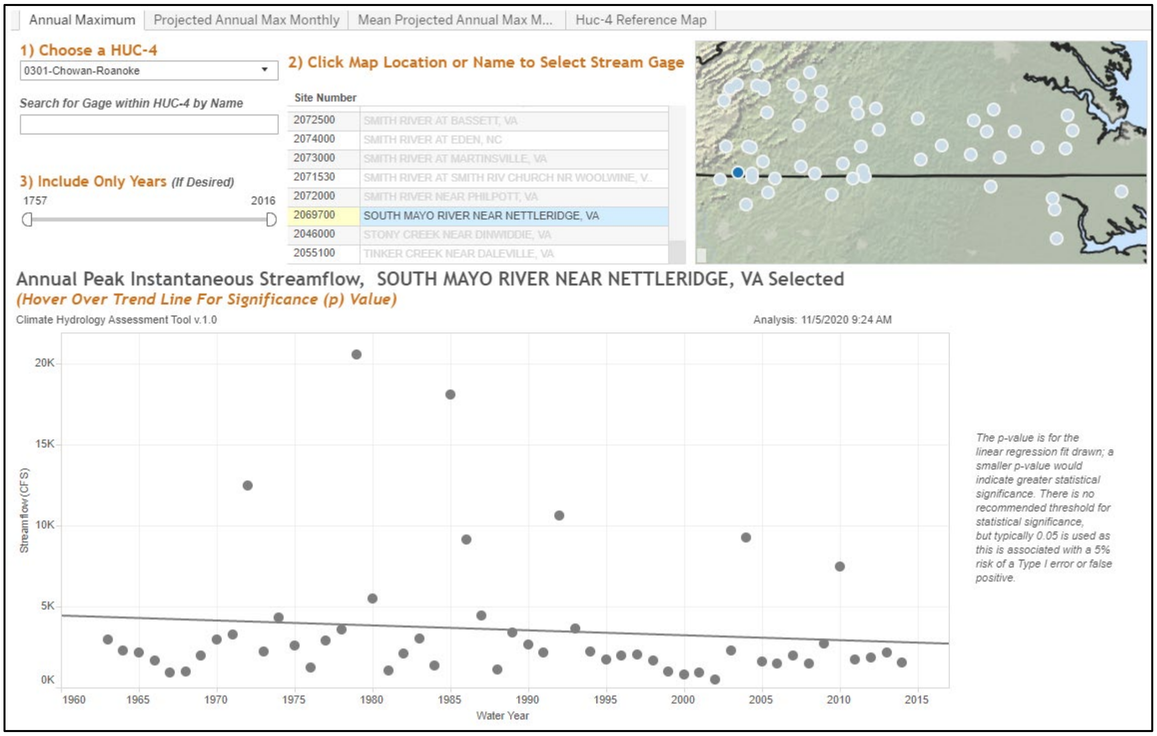

Figure 7 - Annual Maximum Streamflow for South Mayo River near Nettleridge, VA. P-value=0.424.

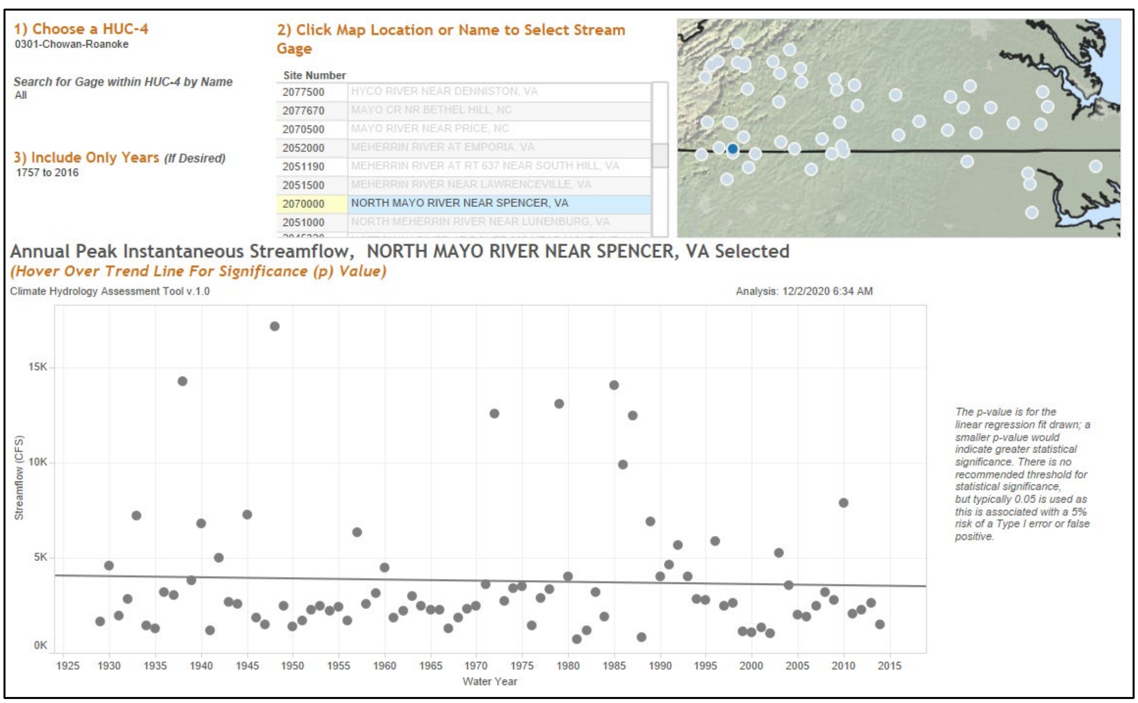

Figure 8 - Annual Maximum Streamflow for North Mayo River near Spencer, VA. P-value=0.681.

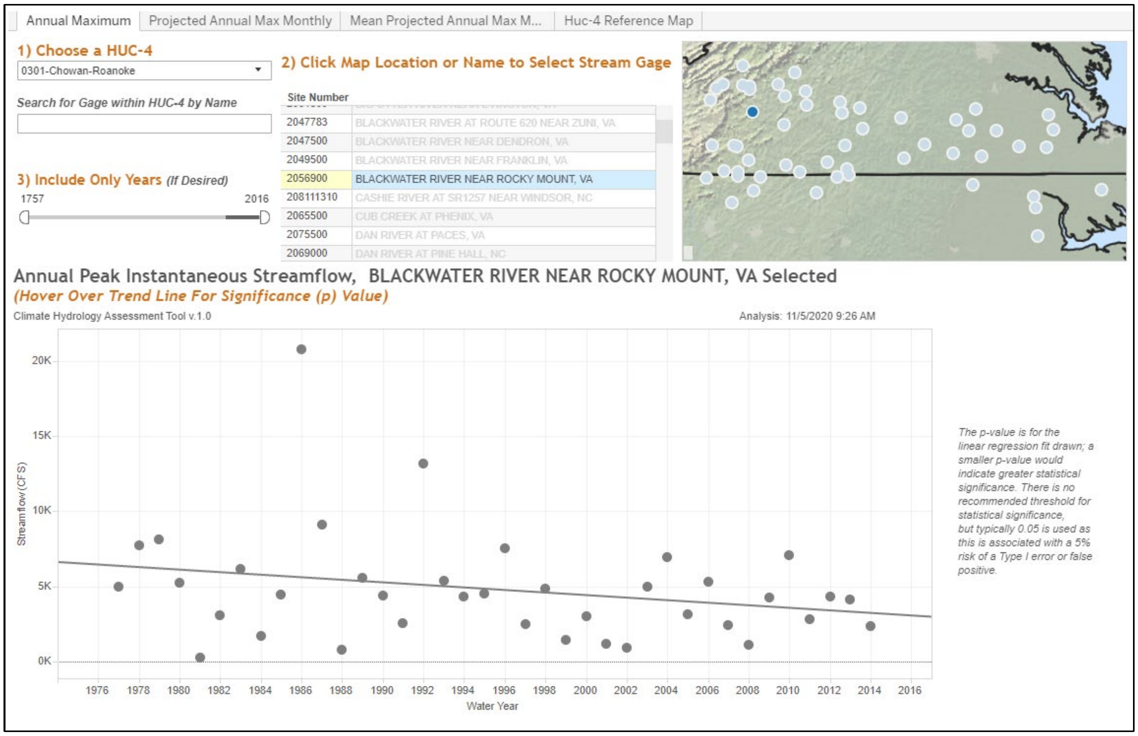

Figure 9 - Annual Maximum Streamflow for Blackwater River near Rocky Mount, VA. P-value=0.129.

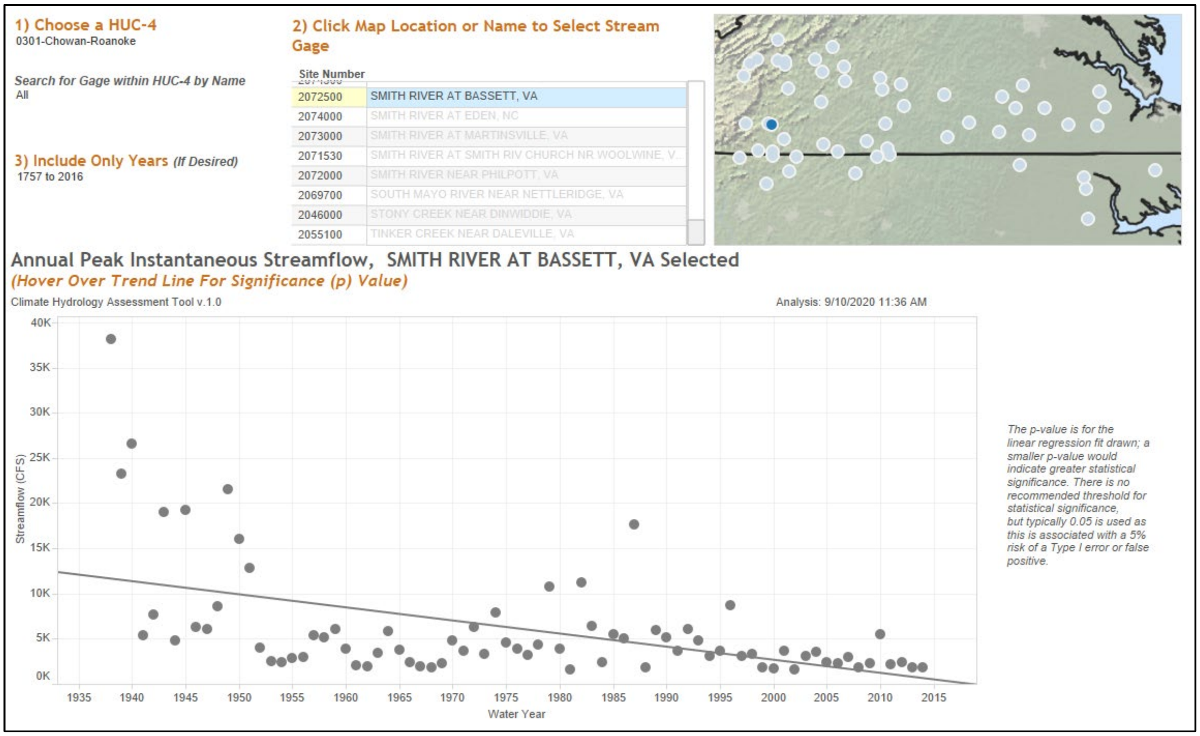

Figure 10 - Annual Maximum Streamflow for Smith River near Bassett, VA, P-value<0.0001.

Nonstationarity Detection

The Nonstationarity Detection Tool (NSD) is used to look at hydrologic time series data for stationarity, or the assumption that the statistical characteristics of hydrological time series data are constant through time. Stationarity in data enables the use of well-accepted statistical methods for water resources planning and design where future conditions are reliant on observed records (Friedman, et al. 2018).

The NSD was not available for Smith River at Smith River Church near Woolwine, VA due to a lack of sufficient data. The NSD was also used to examine the hydrologic time series of annual maximum instantaneous peak streamflows at the same three nearby unregulated gages (Figure 11 – South Mayo River near Nettleridge, VA, Figure 12- North Mayo River near Spencer VA, and Figure 13 – Blackwater River near Rocky Mount VA) as were investigated in the CHAT as described above.

Nonstationarities in the mean were detected for South Mayo River (Figure 11) using the LePage and Lombard Wilcoxon methods for annual maximum instantaneous peak streamflow. The LePage method detects changes in underlying distribution types, and a nonstationarity was detected in 1999. The Lombard Wilcoxon method detects changes in the mean and a nonstationarity was detected in 1992 using a sensitivity of 0.01 with the mean before 1992 near 4000 cfs, and after 1992 near 2000 cfs. A monotonic trend analysis was performed for data for the entire data set, from 1963-1993, and 1993-2015 and no statistically significant trend was found for any set using both the Mann-Kendall Test and the Spearman Rank Order Test with a significance level of 0.05.

Nonstationarities in the distribution of the annual maximum instantaneous peak streamflow and annual maximum stage mean were detected for North Mayo River (Figure 12) using the LePage, Kolmogorov-Smirnov, and Energy Divisive methods, however no nonstationarities for the mean were detected. The LePage method detects changes in underlying distribution types, and a nonstationarity was detected for the annual maximum instantaneous peak streamflow in 1998. The Kolmogorov-Smirnov method detects changes in the underlying distribution types, and a nonstationarity was detected for the annual maximum instantaneous peak streamflow in 1984. The Energy Divisive method detects changes in the underlying distribution types, and a nonstationarity was detected for the annual maximum instantaneous peak streamflow in 1971. In addition, the Smooth Lombard Wilcoxon method detected a smooth change in the underlying distribution of the mean from 1995-1998. A monotonic trend analysis was performed for the entire data set, 1946-1971, 1971-1984, 1984-1998, 1998-2015, and 1971-2015 and no statistically significant trend was detected for any data set using both the Mann-Kendall Test and the Spearman Rank Order Test with a significance level of 0.05. A monotonic trend analysis for 1984-2015 did show a statistically significant trend using the Mann-Kendall Test with a p-value of 0.023, and the Spearman Rank Order Test with a p-value of 0.042, however this result was sensitive to the exact years chosen and is driven by maximum annual flows in 1985 and 1987 which are among the 5 highest flows recorded in the 69 year record.

No nonstationarities in the mean, standard deviation, or variance were detected for Blackwater River (Figure 13). A monotonic trend analysis was performed for the entire data set and no statistically significant trend was found for either set using both the Mann-Kendall Test and the Spearman Rank Order Test with a significance level of 0.05.

The NSD was also used to examine annual maximum instantaneous streamflows at the Smith River at Philpott VA gage immediately downstream of the Philpott Dam and, as expected, detected nonstationarities between pre- and post-construction of Philpott Lake; for the post-construction period no nonstationarities or statistically significant trends were detected. Downstream of Philpott Lake at Smith River near Bassett VA, the NSD detected nonstationarities between pre- and post- construction and additional nonstationarities of the mean, variance, standard deviation, and underlying distribution in 1998 with multiple methods.

There is a nonstationarity in the underlying distribution of the maximum annual flows around 1998 present in multiple gage locations and detected using multiple methods. While two gage locations show a nonstationarity in the mean detected around 1998 one of those locations is downstream of a regulated gage and no monotonic trends were statistically significant for any location. The nonstationarities detected at this time period may be due to a multi-year drought from 1998-2003.

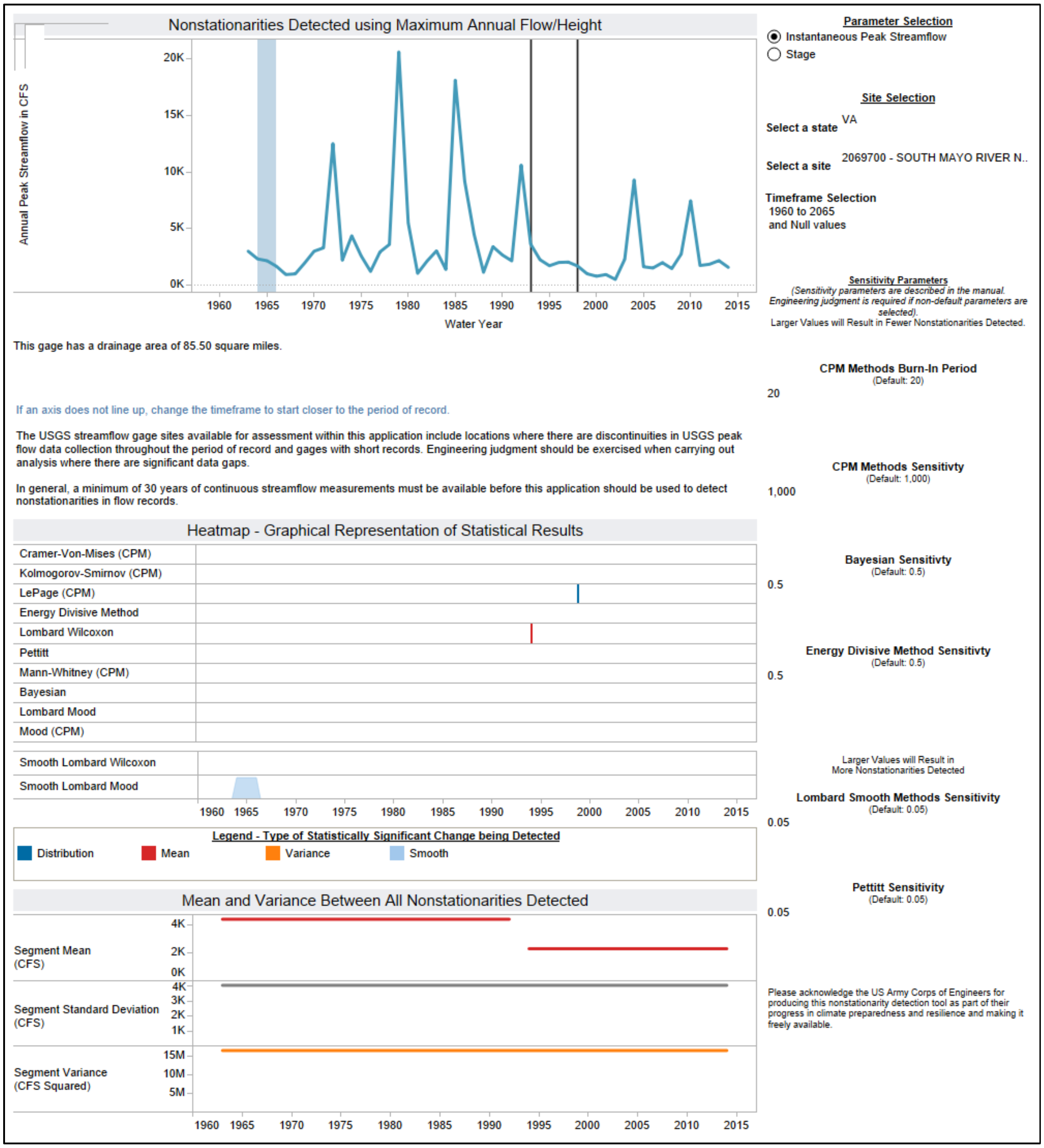

Figure 11 – Nonstationarity Analysis of Maximum Annual Flow for South Mayo River near Nettleridge, VA.

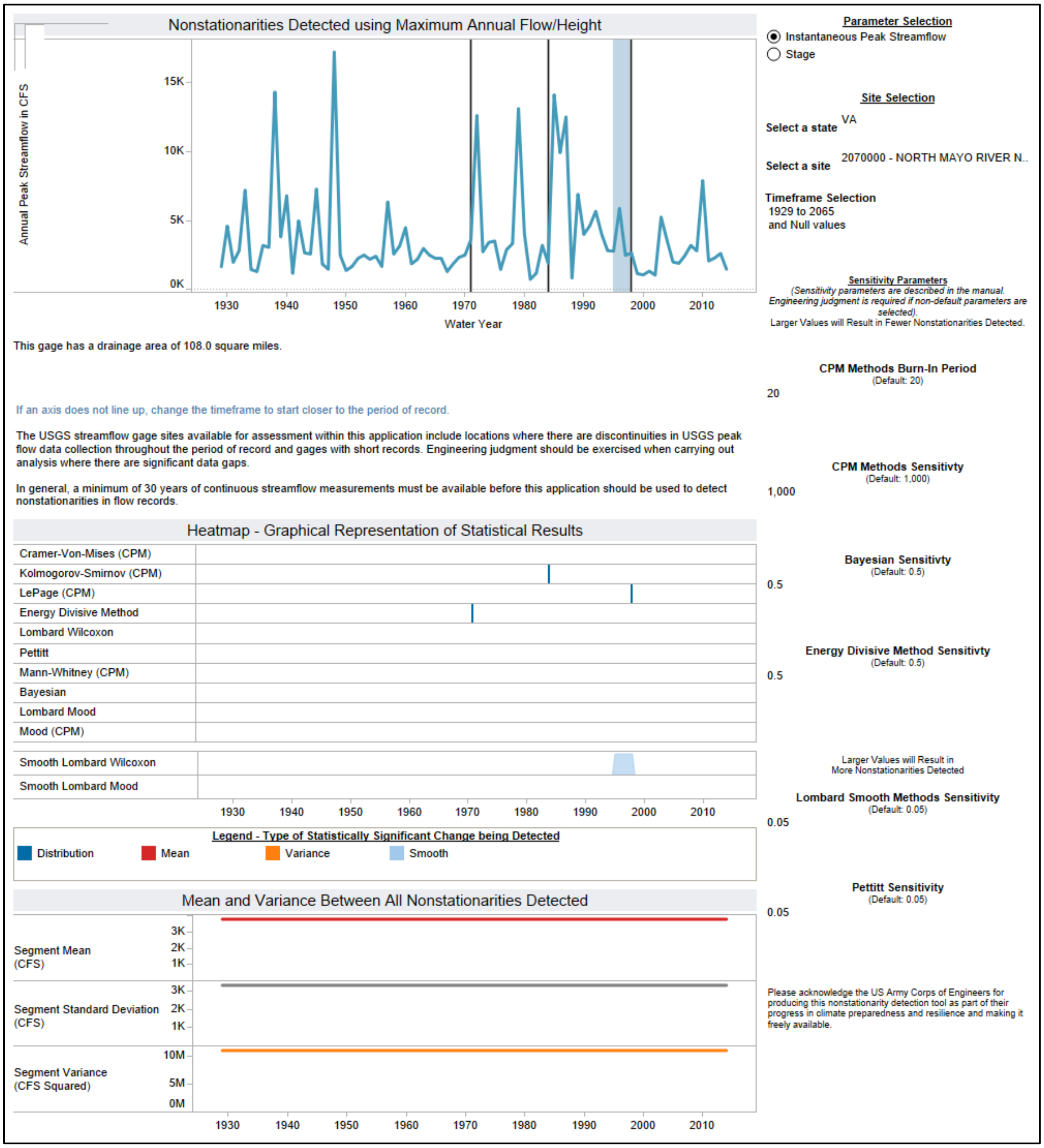

Figure 12 – Nonstationarity Analysis of Maximum Annual Flow for North Mayo River near Spencer, VA.

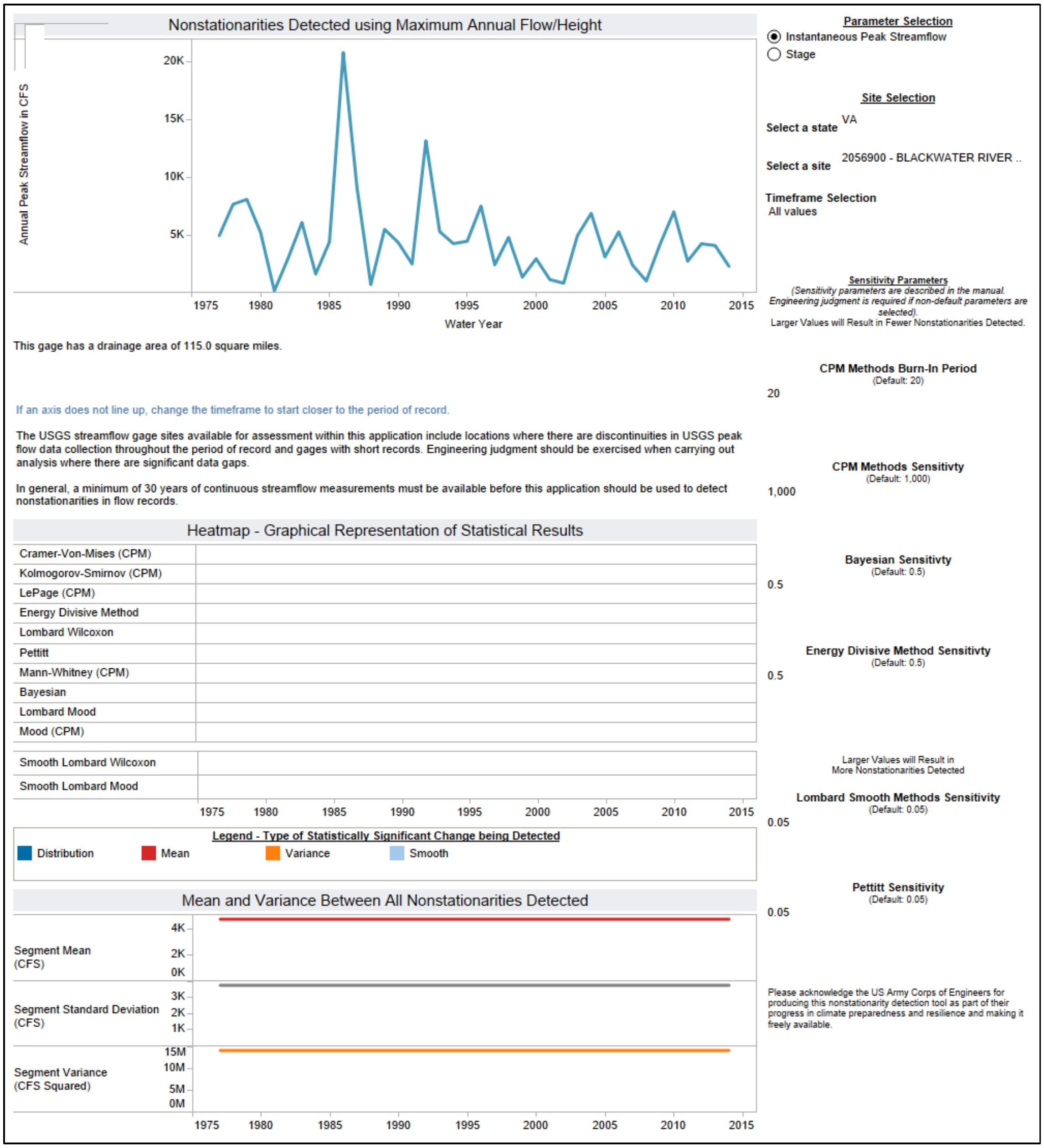

Figure 13 – Nonstationarity Analysis of Maximum Annual Flow for Blackwater River near Rocky Mount, VA.

Conclusion

While temperatures are forecasted to increase in the future with more extreme rain events, there is less consensus on future annual precipitation totals and streamflow. The changing climate could lead to more flood events at Philpott Lake. Henry County has their water intake structure on Smith River downstream from Philpott Dam making damage to the equipment due to flooding less likely with flood operations at Philpott Dam.

An analysis of watershed climate vulnerability has shown the area to be relatively less vulnerable for the water supply business line compared to the entire USACE portfolio.

The nonstationarities are for annual maximum streamflows which are more relevant to flood risk impacts and do not necessarily indicate any increased water supply impacts. In addition, a drought period the duration identified in the nonstationarity detection is extremely unusual in this region, and there is no apparent indication of a trend towards more protracted droughts than those already represented in the existing historical record.

Accordingly, no adjustments are proposed to the existing hydrologic data set to be used in the reallocation study.

Table 1- Climate Risks to Philpott Dam

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Conservation Pool	Increased sedimentation	Increased watershed erosion in warmer, drier future	Loss of storage in conservation pool	Low, accumulation likely in sedimentation pool
Conservation Pool	Decreased Inflow	Decreased inflows leading to slower refilling to guide curve	Extended periods of drought with slower refilling	Moderate
Inactive Pool	Increased sedimentation	Increased watershed erosion in warmer, drier future	Loss of storage in sedimentation pool	Moderate
Inactive Pool	Decreased Inflow	Decreased inflows leading to slower refilling to guide curve	Extended periods of drought with slower refilling	Moderate

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