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Assessment of How Trends in the Brazos River Basin May Affect Surface Water Availability and Attainment of Environmental Flow Standards

TWDB Contract Number 2100012466

August 2021

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Pursuant to House Bill 1, as approved by the 86th Texas Legislature, this study report was funded for the purpose of studying environmental flow needs for Texas rivers and estuaries as part of the adaptive management phase of the Senate Bill 3 process for environmental flows established by the 80th Texas Legislature. The views and conclusions expressed herein are those of the author(s) and do not necessarily reflect the views of the Texas Water Development Board.

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Texas Water Development Board

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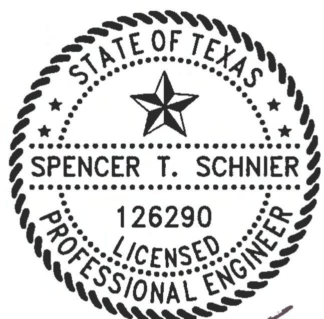

Spencer Schnier 9/4/2021

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EXECUTIVE SUMMARY

The Texas Water Development Board (TWDB) is responsible for implementing the State's Regional Water Planning process, which relies on the firm yield of supply sources based on historical hydrology to determine current and future water availability. However, recent droughts and observed lower inflows in some lakes in western Texas raise doubts about whether this approach is still valid for long-range water planning. A recent study by Harwell et al. (2020) found some gages in the upper basin of the Brazos River Basin had significant decreasing trends in streamflow. Long-term decreasing trends in streamflow could mean that the existing method underestimates future water shortages, and that the attainment frequency of environmental flow standards will decrease over time.

The purpose of this study is to assess potential impacts of trends in streamflow and other hydrologic and climatic variables on water supplies and environmental flows in the Brazos River Basin. Specifically, the study assesses the availability of existing water supplies throughout the basin, as well as the attainment of environmental flow standards in the middle and lower Brazos River Basin (Possum Kingdom Lake and downstream).

The availability of surface water supplies and the attainment of environmental flow standards discussed in this report represent a reasonable forecast of what might happen if observed trends continue. These findings do not reflect modeled future projections of changing climate trends. The observed trends reported here show:

- Significant increasing trends in temperature and evaporation throughout the Brazos River Basin,
- Variability in precipitation trends,
- Significant decreasing trends in runoff in the upper Brazos River Basin (upstream of Possum Kingdom Lake),
- Slight increasing trends in runoff in the middle and lower Brazos River Basin, and
- Increasing trends in groundwater elevation in portions of the Seymour, Trinity, Sparta, and Yegua-Jackson Aquifers. Decreases in runoff in the Upper Basin do not appear to be the result of falling groundwater levels.

The observed trends were used to adjust naturalized streamflow and net reservoir evaporation at various locations throughout the basin to use as inputs to the Brazos River Basin Water Availability Model (Brazos WAM). Changes in naturalized flows are summarized in Figure 2-1 and are discussed in detail in ***Section 2.1***. Changes in net reservoir evaporation are illustrated in Figure 2-22 and are discussed in detail in ***Section 2.2***.

We assessed the potential impacts on surface water supplies in the Brazos G and Region H Regional Water Planning Areas under 2050, 2060, and 2070 conditions. If observed trends continue, the firm yields of upper basin reservoirs are expected to decrease by a total of 31 percent in estimated 2070 conditions. Impacts to reservoirs in the middle basin vary, but overall, the combined firm yield of these reservoirs decreases by less than 1 percent in 2070 when trends are considered. The incremental yield of the BRA System Operations permit will increase, but this increase is offset by a larger decrease in individual reservoir yields, resulting in a net decrease in reliable yield from the system. Minimum annual diversions of run-of-river rights experience varying changes in Brazos G (middle and upper basin) but consistently increase in Region H (lower basin). Changes to reservoir yields are discussed in detail in ***Section 2.4.4*** and changes to run-of-river supply reliability are discussed in ***Section 2.4.5***.

TWDB used the daily Brazos WAM to evaluate the change in environmental flow metrics given the trend-adjusted hydrology for 2050. Their findings indicate that the trend-adjusted 2050 hydrology generally decreases environmental flow attainment at upstream control points (BRSB23, BRPP27, and BRGR30), but increases attainment for downstream locations. The impact on tributaries was minimal. These results are consistent with the trends embedded in the 2050 hydrology.

If the observed trends in streamflow, temperature, and precipitation since 1940 continue forward through 2070, surface water supply reliability in the Upper Brazos Basin and run-of-river supply reliability in the Middle Brazos Basin may decrease which could warrant consideration of additional water management strategies in the Brazos G Water Planning Area to provide resiliency. Safe yield, which is a more conservative estimate of the reliable supply from a reservoir than firm yield, is currently used by the Brazos G Water Planning Group for planning for many reservoirs in the Upper Brazos Basin and Lake Palo Pinto in the Middle Brazos Basin. Off-channel storage and aquifer storage and recovery are potential ways to increase the reliability of run-of-river rights subject to decreasing streamflow trends in the Upper and Middle Brazos Basin. Potential increases in the reliability of large run-of-river rights in Region H could be considered as possible sources to support resiliency and redundancy.

The report has four chapters summarizing the analyses and findings of the study:

1. Literature Review and Assessment Methodology
2. Trend Analysis Results and Impacts of Observed Trends on Surface Water Supply Sources in Regions G and H
3. Attainment of Environmental Flow Standards Under Changed Hydrological Conditions and Full Utilization of Permitted Diversions
4. Summary of Findings

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CHAPTER 1

Literature Review and Assessment Methodology

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1.0 LITERATURE REVIEW AND ASSESSMENT METHODOLOGY

1.1 INTRODUCTION

This first chapter presents the Literature Review and Assessment Methodology. The assessment methodology presented in this chapter was used to assess the impacts of trends on water supplies and environmental flows, and the results of this assessment are presented in subsequent chapters.

This study used the Brazos River Basin Water Availability Model (Brazos WAM) to evaluate impacts of trended hydrology on existing and future water supplies and attainment of environmental flow metrics. Pursuant to Senate Bill 1 enacted by the Texas Legislature in 1997, the Texas Commission on Environmental Quality (TCEQ), which was known at that time as the Texas Natural Resource Conservation Commission (TNRCC), implemented a statewide water availability modeling system. TNRCC selected the Water Rights Analysis Package (WRAP), a set of computer programs used to simulate allocation of water for a river and reservoir system, as the model for the statewide WAM system. Dr. Ralph Wurbs at Texas A&M University developed the WRAP model.

The generalized WRAP modeling system combined with a dataset for a particular river system is referred to as a water availability model (WAM). From 1998 to 2003, TNRCC hired consulting engineering firms to develop WRAP input datasets for all the river basins in Texas. The dataset for a particular river system is a collection of text files that contain basin-specific information for input to WRAP. Specifically, historical hydrologic data, including naturalized flows and evaporation, represent a significant portion of the basin-specific information. The WAMs (executed within WRAP) are the river and reservoir modeling systems used by TCEQ to assess new water right applications and are also used to determine existing and future water supplies in the State of Texas as part of the Regional Water Planning process.

The literature review informs a pivotal piece of this study: adjusting the historical WAM hydrology for trends in naturalized flow and precipitation (FLO file) and trends in temperature and precipitation (EVA file) for the decades starting in 2050 and 2070. The FLO and EVA files are two of the text file inputs required to run the Brazos WAM.

1.2 LITERATURE REVIEW AND TRENDS APPROACH

1.2.1 Literature Review

The project team reviewed the available literature to determine how observed trends in streamflow and groundwater within a river basin might be incorporated into the assessment of future surface water availability and attainment of environmental flow standards. Specifically, the literature review focused on how to adjust historical hydrology for trends in streamflow. The review included scientific studies published in peer-reviewed journals, hydrologic loss studies for the Brazos River Basin, groundwater availability modeling reports, regional water plans from multiple planning cycles, other regional planning studies, and reports from the Basin and Bay Area Expert Science Team (BBEST) and the Basin and Bay Area Stakeholder Committee (BBASC) (particularly regarding the relationship between flow regime and ecological health). The findings from the literature review informed the methodology for assessing future surface water availability and the attainment frequency of environmental flow standards in the mid- and lower Brazos River Basin.

The current study called for adjustments to naturalized flows that are input into the Brazos WAM. The difference between historical flows and naturalized flows is that naturalized flows are developed by adjusting historical flows to remove the impacts of reservoirs, water use, and return flows. Naturalized flows can be thought of as the flows that would be in the stream in the absence of humans. However, naturalized flows input to the WAM do not directly include adjustments for changes in climate with time, changes in groundwater-surface water interaction, increasing urbanization, or other land use changes during the simulation period. These changes, while reflected through the gaged streamflow records, are not individually accounted for during the naturalization process. A list of factors that could theoretically be causing trends in naturalized flows is included below.

<u>Factors that Could Conceivably be Causing Trends in Naturalized Flows</u>:

- Changes in climate
  - temperature (Furnans et al., 2019)
  - precipitation (Furnans et al., 2019)
  - wind speed (Hobbins et al., 2004, McVicar et al., 2012)
  - cloud cover and aerosol concentration (Roderick and Farquhar, 2002)
- Land use changes (Furnans et al., 2019)

- increasing urbanization (Gooch and Albright, 2011)
- removal of natural vegetation (Gooch and Albright, 2011)
- increase in noxious brush (Furnans et al., 2019; Vaugh and Huckabee, 2000a, 2000b, 2000c)
- increased antecedent soil moisture due to landscape irrigation (Gooch and Albright, 2011)
- increased number of ponds, detention structures, or small reservoirs (Furnans et al., 2019)

- Changes in channel losses
    - Changes in groundwater-surface water interaction (Furnans et al., 2019; Vaugh and Huckabee, 2000b, 2000c)
    - Infrastructure improvements (e.g., dams, levees, canals, and other drainage infrastructure) that reduce losses (Gooch and Albright, 2011)
    - Changes to channel losses due to channels having greater baseflows supported by wastewater return flows (Gooch and Albright, 2011)
- Return flows not accounted for in the flow naturalization process

Harwell et al. (2020)

Harwell et al. (2020) analyzed trends in streamflow, precipitation, temperature, groundwater-level elevation, and flood storage through 2017 for seven river basins in Texas, including the Brazos. The primary purpose of the Harwell et al. (2020) report was to document long-term trends in streamflow data. Harwell et al. (2020) also analyzed trends in the ratio of streamflow volume to precipitation volume (Q/P). The report analyzed other variables, including precipitation and mean air temperature at the climate division-scale from 1900 through 2017, and aquifer-averaged groundwater elevation, for trends that might help to explain changes seen in streamflow. Kendall's tau and the p-value were used to assess the strength and statistical significance of trends in datasets. The Harwell et al. (2020) analysis considered multiple timescales: annual, three seasons, individual months, wet years, and dry years. The analysis found decreasing trends in annual streamflow in the upper Brazos River Basin, increasing trends in annual precipitation in the lower and middle sections of the basin, increasing trends in annual minimum streamflow in the upper sections of the basin and mostly decreasing trends in annual minimum streamflow in the lower sections of the basin. Decreasing trends in annual peak streamflow and Q/P were also found in the upper sections of the Brazos Basin. Moderate increasing trends in annual precipitation were indicated in climate divisions 4104 (East Texas) and 4108 (Upper Coast), which both intersect the Brazos Basin. Increasing trends in annual mean air temperature were indicated within all climate divisions across Texas. For the aquifer-averaged annual mean groundwater elevations analyses, decreasing trends were found in the Carrizo-Wilcox, Edwards (Balcones) Fault Zone, Gulf Coast, and Ogallala aquifers and increasing trends were found in the Seymour and Trinity aquifers.

Harwell et al. (2020) provides an especially informative touchstone because they analyzed trends in the same variables (P, Q, Q/P, T), using the same method (Kendall's tau) and the same timescales (annual, seasonal, wet and dry years) in the same basin (the Brazos). The trend analysis period for this study was constrained to the start year in the WAM (1940), whereas Harwell et al. (2020) analyzed trends from the beginning period of datasets (approximately 1900 for Q, P, and T; ranges for groundwater elevation) through 2017. Harwell et al. (2020) also studied several other basins (Colorado, Big Cypress, Guadalupe, Neches, Sulphur, and Trinity). Their findings in those basins indicate the types of trends that exist in other basins, which vary from their findings in the Brazos River Basin. For these other basins, results of precipitation trend analyses on an annual time step in basin sections were primarily increasing trends (lower Guadalupe, Neches Sulphur, Trinity) or exhibited no trend (Colorado, Big Cypress). Despite increasing trends in precipitation in sections of these other basins, trends in annual streamflow varied. They found increasing trends in annual streamflow in the upper Trinity basin and one station in the upper Big Cypress and upper Guadalupe basins, decreasing trends in the upper Colorado basin and one station in the upper Big Cypress and Sulphur basins, and no trends in the lower Colorado, lower Big Cypress, lower Guadalupe, Neches, and lower Trinity basins.

Zhu and Fernando (2017)

Zhu and Fernando (2017) developed a methodology for incorporating long-term trends in observed streamflow into stochastic hydrological forecasting to estimate the firm yield of reservoirs under projected future conditions. They used the best-fit trendline of observed streamflows from 1948 through 2012 and extrapolated forward to scale randomly resampled observed annual streamflows to extend the period of analysis to 2069. Zhu and Fernando used Lake Meredith as a case study, and the best-fit trendline through annual flows was the exponential equation. The flow estimated for a given year in the future (Q_2) is the flow from a randomly selected year from the historical record (e.g., Q_1) multiplied by a ratio: the value of the trendline at time t2 (V_2) divided by the value of the trendline at time t1 (V_1) as shown in Equation 1-1.

$$Q_2 = \frac{V_2}{V_1} \cdot Q_1$$ Equation 1-1

Zhu et al. (2021) improved on the methodology by using a reconstructed Palmer Drought Severity Index (PDSI) from years 1400 – 2003 to develop drought transition probabilities and then they applied Markov Chain Monte Carlo (MCMC) methods to generate 10,000 synthetic hydrologic time series as inputs to the Canadian WAM. Reconstructed PDSI provided a means to assess regional drought variability over an extended time period. Drought duration in the study was defined as the number of years where the summer PDSI is continuously below zero. From this information, they calculated 10,000 potential reservoir firm yields for each planning decade and assigned exceedance probabilities to each yield.

The Zhu and Fernando (2017) study and the Zhu et al. (2021) study address a similar problem as the current study, namely, how to translate trends in historical streamflow data into projected future flows for water supply evaluations. Their approach, which was to multiply flows from the historical period by a ratio that uses future values expected based on extrapolated trends as the numerator, is an approach considered for this current study. The goal of both the current study and the Zhu and Fernando (2017) study is to use historical hydrology adjusted for future conditions to compute the potential reduction in reliable supplies from reservoirs.

Wurbs et al. (2005)

Wurbs et al. (2005) considered how to incorporate climate change projections into water availability modeling. The paper is especially relevant to the current study because Wurbs et al. (2005) addressed how to adjust WAM hydrology to account for changing hydrology, and they used the Brazos River Basin as a case study. Wurbs et al. (2005) analyzed historical naturalized flow data for trends by using Kendall's test to detect monotonic trends and Mann-Whitney's test for stepwise trends. They found no trends in historical naturalized flows in the Brazos River Basin, which was consistent with findings from the consulting engineering firms that assembled the flows (Freese and Nichols et al. 2001), but they did identify "hidden but significant" multi-year cycles.

Wurbs et al. (2005) used a single climate model (The Canadian Center for Climate Modeling and Analysis Global Circulation Model, CCCMA GCM) to project increasing temperature, more varied precipitation, and higher evapotranspiration rates for the decades from 2040 to 2060. They then input those projections into a watershed model (the Soil and Water Assessment Tool, SWAT) to forecast that these changes would lead to an increase in more extreme streamflow conditions (both very wet and very dry), but generally resulted in decreased streamflows on average. The factors applied by Wurbs et al. (2005) were developed for individual months (January – December) for individual gages. Because of the relevance to the current study, it is worth taking a close look at how Wurbs et al. (2005) modeled projected future climate in the WAM. The steps followed by Wurbs et al. (2005) are outlined below.

1. A baseline set of 2040 – 2060 precipitation and temperature *without* increased CO_2 and a set of 2040 – 2060 precipitation and temperature *with* increased CO_2 were developed. Projections for the climate change scenario came from the CCCMA GCM assuming a 1 percent per year increase in CO_2.

2. They computed the precipitation multiplier for each of the 12 months of the year.

$$precipitation\ multiplier = \frac{2040 to 2060\ average\ monthly\ precip\ with\ climate\ change}{2040 to 2060\ average\ monthly\ precip\ without\ climate\ change}$$

3. They computed daily temperature additions for each of the 12 months of the year (1 of 12 values for minimum temperature and 1 of 12 values for maximum temperature).

$$\begin{aligned} temperature\ addition &= average\ daily\ min/max\ temperature\ per\ month\ with\ climate\ change \\ &- average\ daily\ min/max\ temperature\ per\ month\ without\ climate\ change \end{aligned}$$

4. They multiplied the precipitation ratio (1 of 12 values) by the historical precipitation from 1971 – 1990 to develop precipitation for a ‘with climate change’ scenario.

5. They added the temperature additions to the historical temperature from 1971 – 1990 to develop temperature estimates for a ‘with climate change’ scenario.

So now they have adjusted historical precipitation and temperature (minimum and maximum) for expected changes due to climate change.

6. They calibrated a SWAT model to monthly naturalized flows given historical weather.

7. Then daily historical precipitation and temperature data from 1971 – 1990 was run through SWAT to get <u>modeled flows without climate change.</u>

8. Then, they took the same model and used the adjusted historical precipitation and temperature to get modeled flows with climate change.

9. Daily flows were aggregated to months and multiplication factors were developed for the 12 months of the year computed as:

$$flow\ multiplier = \frac{1971 to 1990\ average\ monthly\ modeled\ flow\ with\ climate\ change}{1971 to 1990\ average\ monthly\ modeled\ flow\ without\ climate\ change}$$

10. The flow multiplier was multiplied by the monthly naturalized flow from 1940 – 1997 to estimate **naturalized flow with climate change**.

11. Additive adjustment factors for net reservoir evaporation-precipitation rate were developed by combining separate precipitation and evaporation adjustments. This particular detail was left out of the paper, but was assumed to be calculated as:

$$\begin{aligned} &addition\ for\ gross\ reservoir\ evaporation \\ &\qquad = average\ evaporation\ with\ climate\ change \\ &\qquad - average\ evaporation\ without\ climate\ change \end{aligned}$$

$$\begin{aligned} &addition\ for\ precipitation \\ &\qquad = average\ precipitation\ with\ climate\ change \\ &\qquad - average\ precipitation\ without\ climate\ change \end{aligned}$$

$$\begin{aligned} &addition\ for\ net\ reservoir\ evaporation \\ &\qquad = addition\ for\ gross\ reservoir\ evaporation - addition\ for\ precipitation \end{aligned}$$

12. The net evaporation addition, which can be negative, was added to the monthly net evaporation rates from 1940 – 1997 to estimate **net evaporation with climate change**.

Vogl and Lopes (2009)

Vogl and Lopes (2009) analyzed changes in flow regimes and probable historical drivers of these changes (precipitation, dam construction, population growth, changing water demands) across the Brazos River Basin over the past 100 years. They divided streamflow time series into two periods (earliest data to 1969 and 1975 to 2005) to represent historic (pre-impact) and current (post-impact) periods of unregulated and regulated flows on the Brazos River. They also compared historical monthly flows to naturalized flows to assess impacts of human activities on Brazos River streamflows. For precipitation, they assessed long-term trends using linear regression and assessed short-term trends using ten-year moving averages. They used the cumulative sum of squared recursive residuals (CUSUMQ) test as a tool to detect change-points in regimes of flow and precipitation data (Greene, 1997; Kianifard and Swall, 1996) and the two-sample Kolmogorov-Smirnov (KS) test to test for the significance of these change-points.

Results from the Vogl and Lopes (2009) study showed that the greatest impacts to flow regimes between the two periods have occurred in the upper reach of the Brazos. Flows in the upper Brazos have decreased and become more variable, even though precipitation has increased and become more stable. No significant changes in precipitation distributions were observed in the middle and lower reaches, even though flows generally increased. Thus, changes in precipitation cannot be assumed to be a primary driver of streamflow changes in these areas. Additionally, when comparing median historical gaged flows to naturalized flows, there is an apparent shift in seasonality of flow regimes. Most gages showed historical flows lower than naturalized flows in the spring and higher than naturalized flows in the winter and summer, particularly at the Waco gage (located in the middle basin), which is downstream of major regulating reservoirs.

Mishra et al. (2011)

Mishra et al. (2011) analyzed seasonal streamflow at stations located in Texas river basins, including the Brazos River Basin, for possible changes in uncertainty, trends, and correlations to climate indices. Similar to Vogl and Lopes (2009), Mishra et al. (2011) compared flows and changes in two periods: pre-industrial (1925 – 1964) and post-industrial (1965 – 2003). They found some seasonal trends in mean and extreme (peak) flow during these periods across the Brazos River Basin. For example, at most stations analyzed in the upper Brazos River Basin, mean streamflow during the spring and summer was higher in the pre-industrial period than in the post-industrial period. Conversely, at most gages analyzed in the lower and middle Brazos, mean flows during the spring and summer were greater in the post-industrial period. In the fall, most gages across the Brazos River Basin demonstrated a higher mean flow in the pre-industrial period, whereas during the winter, few changes occurred between pre-industrial and post-industrial mean flows.

Mishra et al. (2011) applied the Mann-Kendall test to assess trends in extreme flows. In winter streamflow extremes, the study found distinct increasing trends during post-industrial periods across all stations. Most Brazos River stations showed negative trends in 1-day extremes during the spring season in pre-industrial periods and negative trends in 7-day extremes in fall and spring seasons in post-industrial periods. In comparison, Vogl and Lopes (2009) found decreasing maximum streamflows in July through December at the Hempstead, Palo Pinto and Richmond gages. Similar statistical techniques as Mishra et al. (2011) (e.g., Mann-Kendall) to assess trends in streamflow across different temporal and spatial scales in the Brazos River Basin would be appropriate for the current TWDB study. Studies such as Harwell et al. (2020), Vogl and Lopes (2009), and Mishra et al. (2011) specifically analyzed trends in streamflow and precipitation, and their variability by season, in areas of the Brazos River Basin and could be used to validate the findings from this study.

Rodgers et al. (2020)

Rodgers et al. (2020) analyzed spatial and temporal trends in mean daily streamflow at 139 streamflow gages across the southern and southeastern United States from 1950 to 2015. 58 of these gages were located in Texas, some of which were located in the Brazos River Basin. In this analysis, daily streamflow data from these sites were aggregated into five clusters with similar temporal variability and were transformed into Z-scores (the difference from the sample mean divided by the standard deviation). Data were divided into six multi-decadal subsets based on time periods starting in 1950, 1960, 1970, 1980, 1990, 2000, and each ending in 2015. The Mann-Kendall trend test was used to identify significant monotonic trends in the dataset and the Pearson correlation coefficient was used to quantify relationships between two time-series (e.g., mean streamflow and climate indices) during these multi-decadal periods. Rodgers et al. (2020) also introduced a new analysis, termed the Quantile-Kendall (Q-K) analysis, to analyze trends over a full range of quantiles of streamflow distribution. The Q-K analysis was used to define a trend departure index (TDI), which compared 17 reference sites (i.e., gages that were classified as "least disturbed" by anthropogenic impacts) to other non-reference sites (i.e., all other gages in the analysis) in a cluster to assess the extent to which temporal variations were due to climate factors versus anthropogenic impacts (e.g., changes in land use, water use, streamflow alterations).

Results from the Mann-Kendall and Q-K trend analyses found that trends in monthly and seasonal mean streamflow across the study area were predominantly decreasing throughout all multi-decadal analysis periods. Significant decreasing trends in mean streamflow were dominant for all months and seasons in each multi-decadal period, except for 1950 to 2015, which showed a mix of increasing and decreasing trends. Most increasing trends during this period were attributed to gages in Texas. In fact, the Mann-Kendall trend test of the Z-scores of mean seasonal streamflow time series (1950 to 2015) indicated that cluster 5 (where all Texas gages were located) had a significant increasing trend. Furthermore, Pearson correlation indices indicated that seasonal streamflow in cluster 5 had a significant correlation to multiple climate indices, such as the Pacific Decadal Oscillation (PDO), Atlantic Multi-decadal Oscillation (AMO), El Nino-Southern Oscillation (ENSO), and Pacific-North American Index (PNA), which explained a small fraction of the temporal variability in streamflow in this cluster.

The TDI analysis identified that 88% of the non-reference sites in the analysis have been influenced by non-climatic factors (i.e., anthropogenic impacts). In addition, the 17 reference sites (i.e., where anthropogenic changes are not expected to drive changes in streamflow) exhibited almost no significant trends for the period from 1950 to 2015, but showed a predominant number of significant decreasing trends for the period from 1970 to 2015 and in all subsequent multi-decadal trend analysis. This finding is consistent with previous studies (McCabe and Wolock, 2002) that have documented a one-time step change in streamflow and precipitation in 1970.

Nielsen-Gammon et al. (2020)

Nielsen-Gammon et al. (2020) analyzed historical trends in climate conditions (average and extreme temperatures, precipitation, and drought) across Texas since 1895, and then projected these existing trends forward to 2036 using a climate model output. The study looked at annual, linear trends across three periods: since 1895, since 1950, and since 1975. Projections of future conditions (in 2036) were expressed as a change compared to average conditions in 1950 – 1999 and 2000 – 2018. Analyses of historical climate data (e.g., temperature, precipitation, cumulative drought severity) by Nielsen-Gammon et al. (2020) indicated that the start year of the trend can significantly influence the trend slope and direction. Trends from this study showed that average historical temperatures have increased and are expected to be about 1.6 ^{o}F warmer statewide by 2036 compared to the 2000 – 2018 average and 3.0 ^{o}F warmer compared to the 1950 – 1999 average. Depending on the region in Texas, this increasing trend could be greater. Statewide, extreme heat and extreme cold temperatures are becoming more frequent and severe and are generally as large or larger in urban areas compared to rural areas. Statewide precipitation was variable; central and eastern Texas have experienced precipitation increases of 15% or more, while much of western Texas has a long-term flat or downward trend. Positive long-term precipitation trends suggest that rainfall in Texas over the next two decades will tend to be greater than what was experienced from 1998 to 2012. However, the tendency for increasing precipitation in Texas is not consistent with other global climate models, which on average show a slightly decreasing trend in precipitation per century across Texas, indicating that there is not a model consensus. The majority of influential factors on drought (temperature, carbon dioxide, evapotranspiration, runoff) indicate that drought severity will increase in Texas, but it is impossible to make a quantitative statewide projection.

Ultimately, multidecadal variability in precipitation and drought severity are so large across Texas that they are likely to have a greater impact than any underlying long-term trends.

U.S. Bureau of Reclamation (2016)

In the 2016 SECURE Water Act Report to Congress, the U.S. Bureau of Reclamation (USBR) characterized the impacts of changes in climate and hydrology across western U.S. basins, including impacts of warmer temperatures, changes in precipitation and snowpack, and changes to timing and quantity of runoff. The USBR found increasing trends in temperature since the 1970s, with some increasing since records began. They concluded that temperature increases are expected to continue with observed trends. Projected changes in precipitation are much less consistent and have greater uncertainty; however, wet and dry extremes are expected to substantially increase in western U.S. basins.

Additionally, the 2016 USBR study found that in most western U.S. basins, projections indicated that runoff (flow) will increase in cooler seasons (November through April), and decrease in warmer seasons (May through September). Although the study area of the 2016 USBR report is different than this study, the trends found in this report are similar to the trends in climate variables (e.g., temperature, precipitation) reported in Nielsen-Gammon et al. (2020). Furthermore, the trends reported in this study highlight the importance of considering the seasonality and timing of changes in historical flow and precipitation.

Furnans et al. (2019)

Furnans et al. (2019) evaluated the trends in rainfall-runoff relationships in the Upper Colorado River Basin of Texas as part of a study for TWDB. Similar to Wurbs et al. (2005) and Mishra et al. (2011), they used the Mann-Kendall test to statistically analyze trends (monthly, seasonal, annual) in various climate variables, including air temperature (minimum and maximum), precipitation, gaged streamflow (non-naturalized), soil moisture, and land use/land cover (using curve numbers). They also developed the Upper Colorado Water Balance Model (UCWBM) to assess potential impacts on streamflow of various watershed parameters, including land use, small ponds, soil moisture content, and rainfall patterns.

Furnans et al. (2019) found that most temperature gages throughout the Upper Colorado Basin exhibited increasing minimum temperatures and stable maximum temperatures. This suggests that watersheds are retaining more heat, which could affect evapotranspiration. The total annual precipitation volume in watersheds was stable or slightly increasing over time; however, rainfall events were more frequent and the duration of dry periods between rainfall events was correspondingly decreasing, which caused the static trend in annual rainfall volume. Most watersheds showed a decreasing trend in annual streamflow, which could be caused by a number of factors, such as an increase in the number of dry days, decreases in groundwater baseflow, or flow regime changes (i.e., impoundment of a reservoir). Most watersheds also exhibited an increasing trend in soil moisture and minimal change in land use/land cover. This study concluded that soil moisture content, which was highly variable temporally and spatially, can significantly impact rainfall-runoff response. The UCWBM results indicated that land use changes or small ponds were the most impactful to streamflow reductions. For future work, the authors recommended plotting flows against rainfall to identify periods in time when the rainfall-runoff response noticeably changed within a given watershed. The findings from Furnans et al. (2019) informed this study regarding how changes in watershed parameters, such as precipitation, land use, soil moisture, and groundwater baseflow, can potentially influence rainfall-runoff trends.

Gooch and Albright (2011)

Gooch and Albright (2011) studied the relationship between naturalized flow and rainfall in watersheds across Harris County, Texas for the Harris County Flood Control District. They found no long-term trends in rainfall but did find significant increasing trends in runoff. They also identified several “short-term trends” from 20 to 24 years long, which may be similar to the “hidden but significant” cycles identified by Wurbs et al. (2005). Similar to the suggestion by Furnans et al. (2019), Gooch and Albright (2011) used a scatterplot of naturalized flows versus rainfall to assess the relationship between runoff and rainfall in watersheds in Harris County. The outcome of these analyses showed that watersheds either had definitive increases, probable increases, or did not show trends. No watersheds had decreasing trends in flow. The study found that the most likely explanation for increasing trends in flow in these watersheds is urbanization over time. Urbanization impacts infiltration (e.g., more concrete), as well as antecedent conditions (e.g., irrigation on green spaces keeps the ground wetter) and evapotranspiration (e.g., less vegetation). If observed trends in naturalized flow can be attributed to land use changes, like in the Gooch and Albright (2011) study, then projections of land use change could potentially be used to forecast trends in streamflow.

Vaugh and Huckabee (2000a, 2000b, 2000c)

Vaugh and Huckabee (2000a, 2000b, and 2000c) assessed the statistical significance of potential trends in annual rainfall and natural streamflow per unit rainfall in thirteen Edwards Aquifer, Frio River, and Nueces

River watersheds and sub-watersheds. Statistical tests applied include the non-parametric Kendall tau, linear regression and sample partitioning which may be classified as parametric tests. Sample partitioning, in this case, simply involved subdivision of the available historical record into halves so that the means and variances from the earlier and later sub-periods could be compared to one another. Assessment of statistical significance in sub-period means and variances was accomplished using standard t-tests and F-tests, respectively. Similarly, the statistical significance of the slope of a trendline obtained by linear regression of annual rainfall or natural runoff per unit rainfall versus time was evaluated using the t-test.

All of the headwater watersheds in the Texas Hill Country showed increasing rainfall trends while downstream Nueces and Frio River sub-watersheds did not. Natural runoff per unit rainfall showed increasing trends in most of the headwater watersheds in the Texas Hill Country and decreasing trends in the downstream sub-watersheds. Decreasing trends in natural runoff per unit rainfall are generally attributed to brush proliferation and/or groundwater production. Increased variances in rainfall and natural runoff per unit rainfall were statistically significant in about half of the Hill Country and downstream watersheds and sub-watersheds evaluated.

Turco et al. (2007), Ewing et al. (2016)

Turco et al. (2007) is a USGS report that analyzed groundwater-surface water interactions in the Brazos River Basin. Turco et al. (2007) estimated the fraction of annual mean streamflow that could be attributed to baseflow, the base flow index (BFI), using a hydrograph separation technique at various locations on the Brazos River. The authors compared baseflow and BFI at different locations to determine which reaches of the river might be gaining flow from or losing flow to groundwater. They found that reaches of the Brazos River crossing the Carrizo-Wilcox, Queen City, Sparta, and Yegua-Jackson aquifer outcrops appear to be gaining streamflow from the aquifer.

In the 2016 Brazos River Alluvium Aquifer (BRAA) Groundwater Availability Model (GAM) report, Ewing et al. (2016) re-analyzed the gain/loss study by Turco et al. (2007) and also found gaining conditions for reaches along the Brazos that intersect the Carrizo-Wilcox and Yegua-Jackson. Turco et al. (2007) and Ewing et al. (2016) did not perform temporal analysis of trends in baseflow. However, FNI assessed the data provided in Table 3 of Turco et al. (2007), which included annual mean streamflow, base flow, and the base flow index at gages near Highbank, Hempstead, and Richmond. FNI did not identify any significant temporal trend in baseflow or the base flow index, indicating that the contribution of groundwater to the river at these locations has not changed significantly over time.

Albright (2014)

Similar to Turco et al. (2007) and Ewing et al. (2016), Albright (2014) analyzed base flows for gages on the main stem of the Brazos River between Lake Whitney and Richmond (i.e., the lower Brazos River Basin) within the area of influence of the BRAA. This study found that base flows are highly dependent on climatic conditions, with much lower base flows during drought periods. In particular, there appeared to be a consistent reduction in base flows between gages in Hempstead and Richmond during dry years. Overall, the base flow data at these gages also did not show any increasing or decreasing trends.

Miller et al. (2021)

Miller et al. (2021) investigated how future GCM climate projections impact streamflow and subsequently the ability to meet water demand and water compliance agreements in the southwestern United States. The authors showed that projected streamflow changes in the southwest United States did not occur linearly and can spatially vary over time. In their study, they applied seven GCMs and two greenhouse gas Representative Concentration Pathways (RCPs) with a regionally calibrated regression model to evaluate water supplies through year 2080. The "Spatially Referenced Regressions on Watershed attributes" model ("SPARROW") is a statistical and process-based model using a nonlinear least squares regression and mass balance approach to estimate streamflow against watershed characteristics and water source. It can estimate and route streamflow on ungaged streams using statistical relationships of watershed characteristics and streamflow. The source of streamflow (e.g., runoff, inflows, spring and wastewater discharges), delivery control (air temperature, soil clay content, impervious surfaces, precipitation intensity, distance to flowline), and within-stream removals (e.g., loss from intermittent streams, irrigation and municipal withdrawals, reservoir evaporation) were assessed under long-term conditions for each stream reach. The authors assumed the explanatory variables of a watershed remained constant over time. Derived coefficients for each of these variables were then fit to the model by minimizing the average differences between simulated and observed predictions of mean annual streamflow. The model was used to generate a range of total streamflow and incremental catchment yields for the sub-continental region. Total streamflow was the cumulative streamflow for all upstream reaches and the streamflow generated within the catchment of interest. Delivered incremental yield is the catchment area normalized streamflow that makes it to the stream network outlet.

Temperature, precipitation, actual and potential evapotranspiration were direct inputs to the model. Monthly temperature and precipitation data underwent bias-correction fitted with downscaled GCM data from CMIP5. A monthly water balance model estimated actual evapotranspiration. Potential evapotranspiration was calculated from the temperature dataset (based on Oudin et al., 2005). SPARROW was calibrated using climate data from 2000-2014 and set to 2012 hydrologic conditions. To determine projected streamflows, the calibrated model coefficients were run with the projected temperature, precipitation, actual and potential evapotranspiration from the climate models for the periods: 1975 – 2005, 2020 – 2049, 2040 – 2069, and 2070 – 2099. The future time periods are centered around 2030, 2050 and 2080. Data was presented as anomalies to the historical period (1975 – 2005) due to the process-based biases from the seven climate models.

Decreasing total streamflow was found in the majority of subbasins. Projected streamflow increases occurred over a limited spatial extent, including central and southern Texas, mostly in the 2030s. Streamflow recovery occurred in the 2080s but was much smaller than the increases in the 2030s. Streamflow increases occurred most often at downstream or internally draining catchments. Conversely, greatest streamflow loss was under RCP8.5 and at higher elevations. Models forced with RCP8.5 exhibited larger changes than RCP4.5 across all regions most likely as it represents the more aggressive greenhouse gas scenario. Thus, the narrower range of projected streamflow for RCP4.5 can be attributed to the lower greenhouse gas concentrations under the RCP4.5 compared to RCP8.5. While the range of model projections varied among climate models, the overall direction of decreasing streamflow was somewhat consistent.

The authors concluded that even potential future increases in precipitation may not be able to offset the water shortages brought on by human demand and "thermodynamically induced aridification."

Kiem et al. (2020)

Kiem et al. (2020) developed an approach for generating stochastic hydroclimate data at seasonal time scales in current climate and near-future climate change conditions. In this study, they utilized observed relationships between a climate change covariate (e.g., annual average maximum temperature) and hydroclimate variable (e.g., streamflow) to develop their stochastic model, rather than much less certain climate projections for rainfall from GCMs. This allowed the model to account for non-stationarity in the historical record. They applied their approach to three water supply catchments in Sydney, Australia.

The stochastic model was calibrated and simulated for three different scenarios:

(1) a stationary condition (observed streamflow with no conditioning to temperature)

(2) a 1 °C warming condition, based on the period from 1910 to 2018

(3) a 2 °C warming condition, based on the period from 2000 to 2018.

Results of the stochastic model showed that the recent 2 °C warming trend from 2000 to 2018 shifted the streamflow distribution for the current climate to be 43% less than the 1 °C warming condition representative of the entire period of record. In addition, both warming simulations showed a significant decline in surface water resources over the 50-year horizon compared to the stationary condition. One key limitation to the approach used in that study was that it was based on the observed historical relationship between the climate covariate (average daily maximum temperature) and hydroclimate variables (flow), which may not account for potential shifts in the trends of the climate covariate away from the observed range.

Prairie et al. (2008)

Prairie et al. (2008) utilized reconstructed data from tree rings to determine the transition probabilities between dry and wet states and then applied those to resampled gaged streamflow data to generate stochastic streamflow sequences for a stream gage on the Colorado River in Arizona. The approach they used resamples various epochs (wet and dry periods) of different transition probabilities from tree ring data. Transition probabilities are directly estimated from data by counting the transitions for four probability distributions: a wet year following a dry year, a wet year following a wet year, a dry year following a wet year, and a dry year following a dry year.

The study did not use any future climate projections, therefore, there is not a projected forward trend in the synthesized sequences. Rather, the results from this approach provided a greater range of uncertainty and/or larger distribution of potential outcomes. In other words, it showed the range of possibilities based on a longer view of the past than just 80 years of stream gage data. The authors suggested that this stochastic approach could be modified to generate streamflow sequences based on climate change (future) projections and could be disaggregated spatially to other gages and temporally from annual to monthly flow scenarios. Prairie et al. (2008) emphasized the value of considering historical dry and wet periods when developing future streamflow projections, as well as the high degree of uncertainty associated with these projections.

The Washita Basin Project by the Bureau of Reclamation (2018) used the approach developed by Prairie et al. (2008) and computed reservoir firm yields given historical hydrology resampled based on transition probabilities from tree ring data. Patskoski and Sankarasubramanian (2018) extended streamflow records backwards beyond the historical period using tree ring data, but recognized the limitation that streamflow reconstructed from tree rings tends to underestimate high flow events.

Wu et al. (2007)

Wu et al. (2007) proposed a simple and logical definition of "trend" for nonstationary nonlinear data and applied different trend analysis techniques (linear, overall adaptive, multidecadal) on annual Global Surface Temperature Anomaly (GSTA) data. They detrended the GSTA data using these techniques to compare the variability (deviation) in the data about the trend line. Wu et al. (2007) defined a trend as "an intrinsically fitted monotonic function or a function in which there can be at most one extremum within a given data span," where the data span could be the entire length or part of the dataset. They defined detrending as "the operation of removing the trend" and variability as "the residue of the data after the removal of the trend within a given data span." Wu et. al (2007) asserted that the key to applying this definition is to understand that the trend is one of many local properties of a dataset and it has to be associated with a reference time scale; without a reference time scale, a trend will be interlaced with local cycles. Kundzewicz and Robson (2000) showed that detrending can be useful to visualize more subtle types of change in data, particularly when the reason for the underlying variation is well known (e.g., seasonality).

According to Wu et al. (2007), the most commonly applied trend is the simple trend, which is a straight-line best fit to a dataset, and the most common detrending process usually consists of removing the straight-line best fit from the raw dataset, yielding a zero-mean residual with variability shown around the mean. Functions for linear detrending are built into various statistical analysis tools (Matlab, R, Python). Wu et al. (2007) utilized the Empirical Mode Decomposition (EMD) method to determine an intrinsic trend in the GSTA dataset that is adaptive to nonstationary and nonlinear processes and compared this to the straight-line trend fit. Data was detrended for both trend fit approaches to calculate a residual and illustrate the differences in variances. The results showed that the EMD approach defined the trend in the data with a narrow variance around the trend line (i.e., the fit was robust) and revealed intrinsic properties of the data such as multidecadal fluctuation patterns and acceleration of warming. In comparison, the linear trend approach showed a greater variance around the trend line.

Ultimately, the trends in datasets analyzed for this study (naturalized flow, precipitation, temperature, groundwater elevation) were fit and detrended with either a linear or exponential regression. Wu et al.

(2007) indicated that other trend analysis techniques can be used to fit data with less variability (e.g., nonlinear regression, moving mean, Fourier-based filtering, EMD, etc.); however, these techniques are more complex and may not significantly improve the fit of the data analyzed in this study.

1.2.2 Literature-Based Approach for Trends Analysis

The literature review provides a broad range of approaches to address changing conditions in a river basin. Our focus is on changes in hydrology and how these changes can be incorporated into the Brazos WAM. The WAMs use naturalized flows as input. The current study analyzed trends in naturalized flows and extrapolated significant trends for input into the Brazos WAM. The study team determined the approach for adjusting the WAM hydrology for these trends with input from TWDB, and ***Section 1.3*** of Chapter 1 discusses the approach for this study. If there are trends in naturalized streamflow, they were incorporated into the assessments of future water availability discussed in Chapters 2 and 3.

The trends were assessed using the same starting year as the Brazos WAM. This is because a very wet period prior to the period of analysis for the Brazos WAM might indicate a decreasing trend despite stationary hydrology during the period of record for the Brazos. The period of record of the original Brazos WAM is 1940 through 1997. The Brazos River Authority (BRA) Drought Study extended the hydrology through 2015, but only adjusted for the major diversions and return flows. TCEQ is currently working to fully extend the Brazos WAM hydrology through 2018, but those flows were not available in time to use for this study.

The basic approach for the trends analysis used the same techniques as Harwell et al. (2020), namely Kendall's tau and p-value significance, to evaluate trends in naturalized streamflow, precipitation, and temperature from 1940 to the most recent year with complete data (which is 2015 for naturalized streamflow, and 2019 for precipitation and temperature).

This current TWDB study essentially started with the trends identified by Harwell et al. (2020) but recomputed them using naturalized flows instead of gaged historical flows. Next, similar to Zhu and Fernando (2017), those trends were extrapolated forward and used to adjust WAM input hydrology. In the current study, the approach taken to adjust naturalized flows and reservoir net evaporation rates for future hydrology is conceptually similar to Wurbs et al. (2005). Where Wurbs et al. (2005) used a GCM to predict future conditions, this study extrapolated a trend found in historical data to project future conditions. The methods and findings of the other cited studies inform the methodology and expected outcomes of the current study.

1.3 TREND ASSESSMENT AND WAM ADJUSTMENT METHODOLOGY

1.3.1 Introduction

Drawing on the literature review, the applied methodology adjusted naturalized flows (FLO file) and net reservoir evaporation (EVA file), which are inputs to the WAM. Efforts as part of Task 2 assessed trends and adjusted WAM inputs based on identified trends for the Brazos WAM. Then, the monthly WAM was executed to assess potential impacts of the observed trends on surface water supply availability within the Brazos Basin in Regional Water Planning Areas G and H. Task 3 utilized the adjusted monthly hydrology developed in Task 2 to assess changes in the attainment of environmental flow metrics in the middle and lower basins, defined as Lake Possum Kingdom and below.

1.3.2 Adjusting Historical WAM Hydrology for Trends in 2050 and 2070

A primary focus of this study is to adjust the historical WAM hydrology for trends in naturalized flow (FLO file) and net evaporation (i.e., gross reservoir evaporation minus precipitation) (EVA file) to represent potential conditions in 2050 and 2070. Adjustments to the FLO file and the EVA file follow the same general approach for converting a historical time series into one that is representative of future conditions based on observed trends. The procedure for this general approach is as follows:

1. Extrapolate significant trend(s) in a data subset to a future condition (2050 or 2070). A “subset” may include, as an example, all summer months during dry conditions. This step provides an estimate of what the average value of the data subset will be for a given year in the future. Identification of which trends in a data subset are considered significant is discussed in ***Section 1.3.3***.

2. Remove the observed trend from the time series of the data subset to develop a series of deviations from the trend. This series, which will have zero slope, represents the variability in observed values that has occurred over the period of record. The deviations of the observed data from a well-fit least-squares regression trendline, whether linear or exponential, will have an average value of approximately zero. Assuming a linear trend, a detrended time series is represented by the equation:

$$deviation(t) = Y_{observed}(t) - Y_{trend}(t)$$ Equation 1-2

Where $deviation$ is the detrended time series at time step t, $Y_{observed}$ is the observed time series, and Y_{trend} is the trend-predicted time series (usually a best-fit regression line). Other similar methods will be applied when a trend is more complex (e.g., exponential). We used the time series of deviations when adjusting data for future conditions (2050 or 2070) so that no trend is present in the adjusted data (i.e., zero slope).

3. Add the series of deviations in Step 2 (Equation 1-2) to the trend-predicted average future condition calculated in Step 1 to determine an adjusted future dataset that replicates historical variability given a new average condition.

The method of using deviations from the observed trend, rather than the original observed values, was applied to produce an adjusted time series of 76 years of hydrology representing conditions in the selected future year (e.g. 2070). An alternative approach that does not remove the trend from observations would produce a 76-year time series centered around the selected future year; for example, when adjusting based on extrapolation to 2070, the adjusted series would reflect conditions from 2033 to 2108 due to the inherent trend in the observed data. As a result, if the drought of record had occurred early in the observed period of record, the modeled drought of record based on the adjusted 2033-2108 time series might represent conditions in the 2040s rather than in 2070, thus underestimating the impact of long-term trends.

Figure 1-1 illustrates a step-by-step example of the general procedure for adjusting the historical WAM hydrology for trends in 2070. The following sections (***Section 1.3.4*** and ***Section 1.3.5***) describe this general approach applied specifically to determining the WAM adjustments for the FLO and EVA files, respectively. More information on the use of a detrended time series is provided in **Appendix 1-B**.

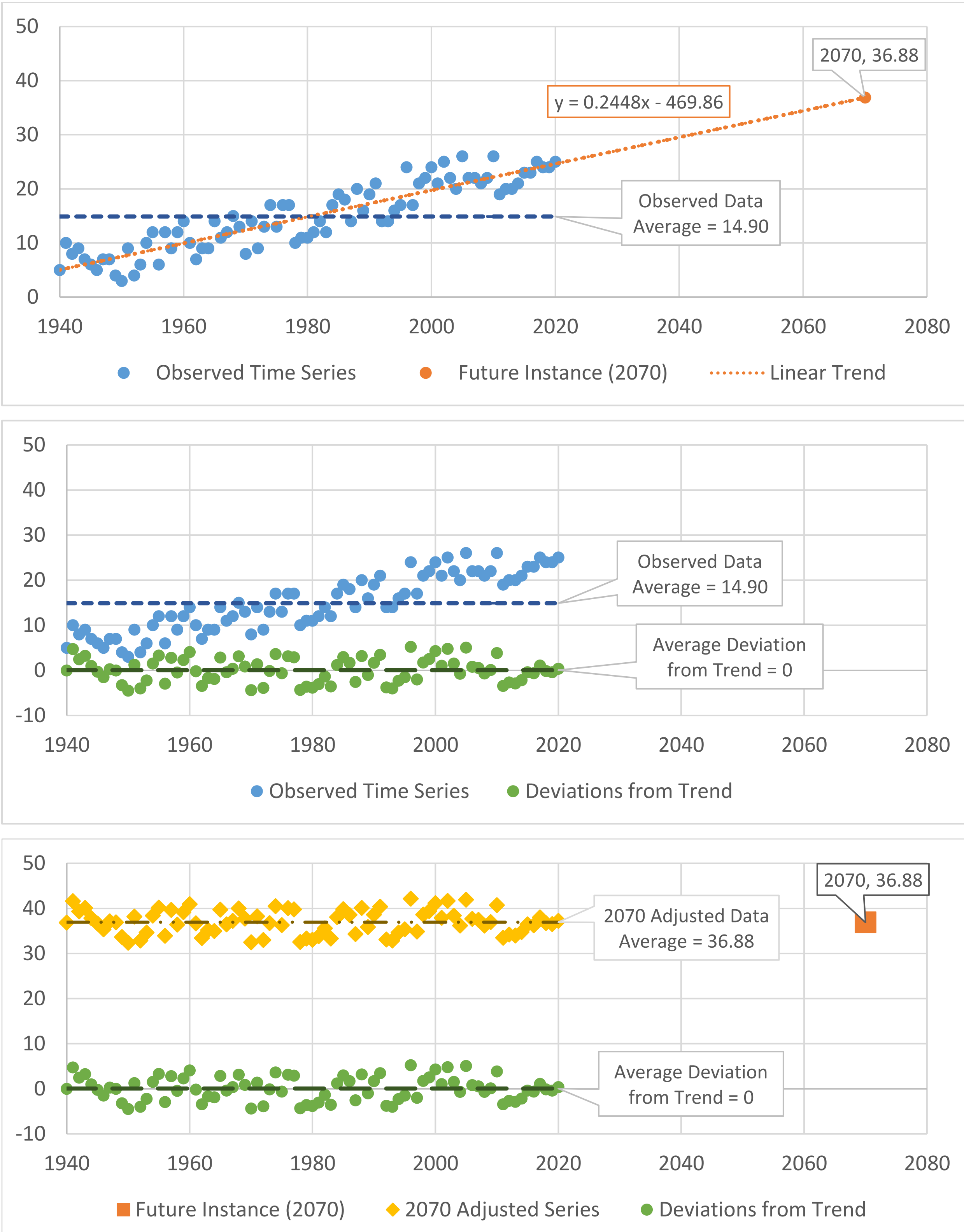


Figure 1-1 – Example of the Approach for Adjusting WAM Hydrology for Trends in 2070

1.3.3 Trend Analysis Methodology

Kendall's Tau

The literature review identified the use of Kendall's tau (τ) as a useful statistic for assessing the presence and strength of a monotonic trend (Harwell et al. (2020), Mishra et al. (2011), Wurbs et al. (2005)). As noted in Helsel et al. (2020), Kendall's tau is "resistant to the effects of outliers" since it is based on the ranks of values rather than the values themselves. Additionally, tau can provide a meaningful analysis for datasets with as few as 10 data points.

Tau varies from values of -1 to 1, and an absolute value for tau of 1 indicates a perfectly monotonic trend. A monotonic function is one that always increases without ever decreasing (or vice versa). Values of +1 indicate that Y always increases when X increases; conversely, a tau value of -1 indicates that Y always decreases when X increases. The absolute value of tau decreases as the strength of the trend decreases, and a tau value of zero indicates no monotonic trend is present. Tau is calculated based on the identification of the number of concordant (C) and discordant (D) pairs. An adjusted formulation, τ_B, accounts for the presence of tied values in either X or Y (Equation 1-3). In this analysis, there will be no ties in the X variable because X is time. However, there could be ties in the Y variable (e.g., two months with the same average temperature). When no ties are present, τ_B simplifies to τ, as shown in Equation 1-4.

$$\tau_B = \frac{(C-D)}{\sqrt{(C+D+X_0)(C+D+Y_0)}}$$

Equation 1-3

C = # concordant pairs (Y increases as X increases)

D = # discordant pairs (Y decreases as X increases)

X_0= # pairs with tied X but not Y

Y_0= # pairs with tied Y but not X

X = date or year

Y = variable assessed (P, Q/P, $Temp$, etc.)

$$\tau = \tau_B = \frac{C - D}{C + D}$$ Equation 1-4

The statistical significance of a trend indicated by τ can be determined by finding the test statistic Z and its associated probability. Z is an approximately normally distributed scaled version of the test statistic S, with a mean of zero and standard deviation σ_S. The formulation of S, σ_S, and Z shown in Equation 1-5 through Equation 1-7 is provided in Helsel et al. (2020).

$$S = C - D$$ Equation 1-5

$$\sigma_S = \frac{1}{3}\sqrt{\left(\frac{n(n-1)}{2}\right) * (2n+5)}$$ Equation 1-6

$$Z = \begin{cases} \dfrac{S-1}{\sigma_S} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \dfrac{S+1}{\sigma_S} \; if \; S < 0 \end{cases}$$ Equation 1-7

As Z depends on the number of concordant and discordant pairs (C and D, respectively), a critical Z value to achieve a significant p-value can be determined for a given sample size n. The total number of possible pairs is $n(n-1)/2$. If no ties are present, $D = \frac{n(n-1)}{2} - C$, so Z becomes a function of n and C. By solving for a critical C value for various sample sizes n, Figure 1-2 demonstrates that the minimum absolute value of τ required to achieve a significant p-value decreases as sample size increases. In other words, if two data series have equal τ values but different sample sizes, the trend in the larger series is more significant because it is based on more data points.

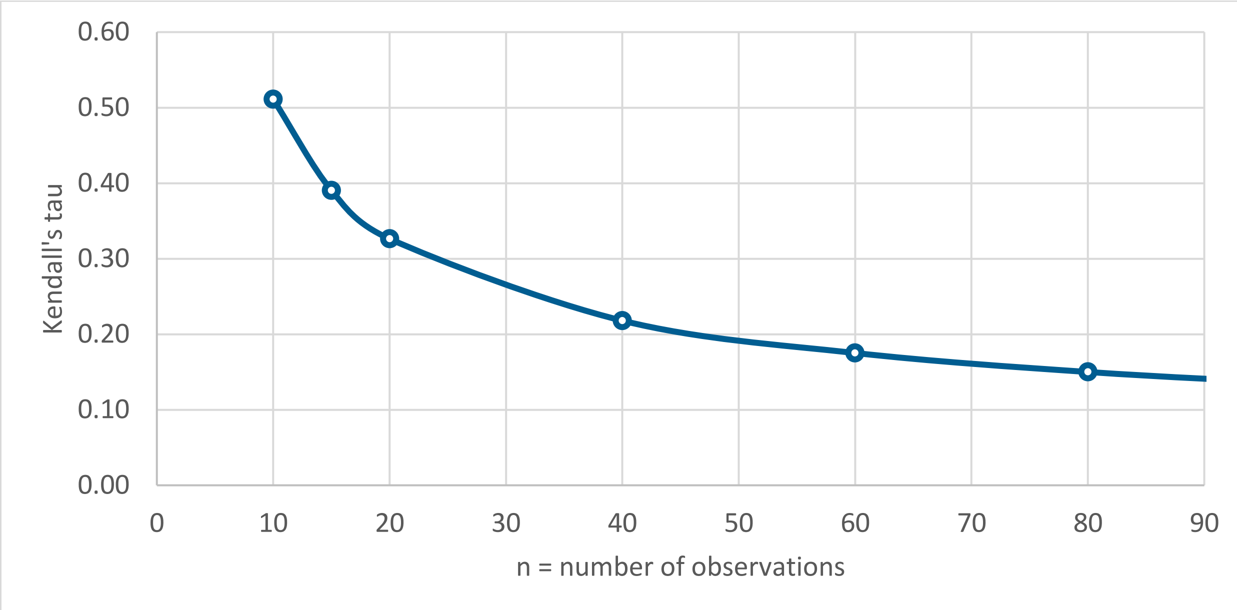


Figure 1-2 – Minimum Absolute Value of Kendall's Tau to Achieve Significance (p ≤0.05) for a Given Number of Observations

Determination of Starting Year

Trendline slopes and goodness of fit vary depending on the window of analysis. Trends may exist for various subsets of the period of record, but some subset "trends" may only reflect cyclic variability rather than a long-term trend. Wurbs et al. (2005) identified patterns in annual naturalized flow variability on 3.8-, 5-, 7-, and 24-year cycles even though no long-term trends were identified. In an analysis of annual rainfall in Harris County, Gooch and Albright (2011) did not find any long-term trends but identified short-term trends over periods of approximately 20 years. For the purpose of estimating future conditions, we were interested in identifying persistent long-term trends if they exist. These trends may begin in 1940 (i.e., the beginning of the period of analysis) or they may begin later, but the long-term trends of interest to this study are those that persist through the end of the period of analysis. In other words, trends present from 1960 to 2010 but disappearing after 2010 will not be used to adjust WAM inputs for future conditions.

Nielsen-Gammon et al. (2020) found that the starting year for a trend can greatly impact the slope of that trend, particularly for temperature trends. To identify the most appropriate starting year from which to define the trend, we tested trend strength from various starting points. Trends with higher absolute values of Kendall's tau are considered to be stronger trends. This approach assumes that the strongest significant trend (out of 1950 – 2015, 1960 – 2015, etc.) is the trend that will continue into the future. For example, in Figure 1-3, the red trend in the series beginning in 1975 (tau = 0.55) would be applied to future estimates rather than the green trend beginning in 1940 (tau = 0.39).

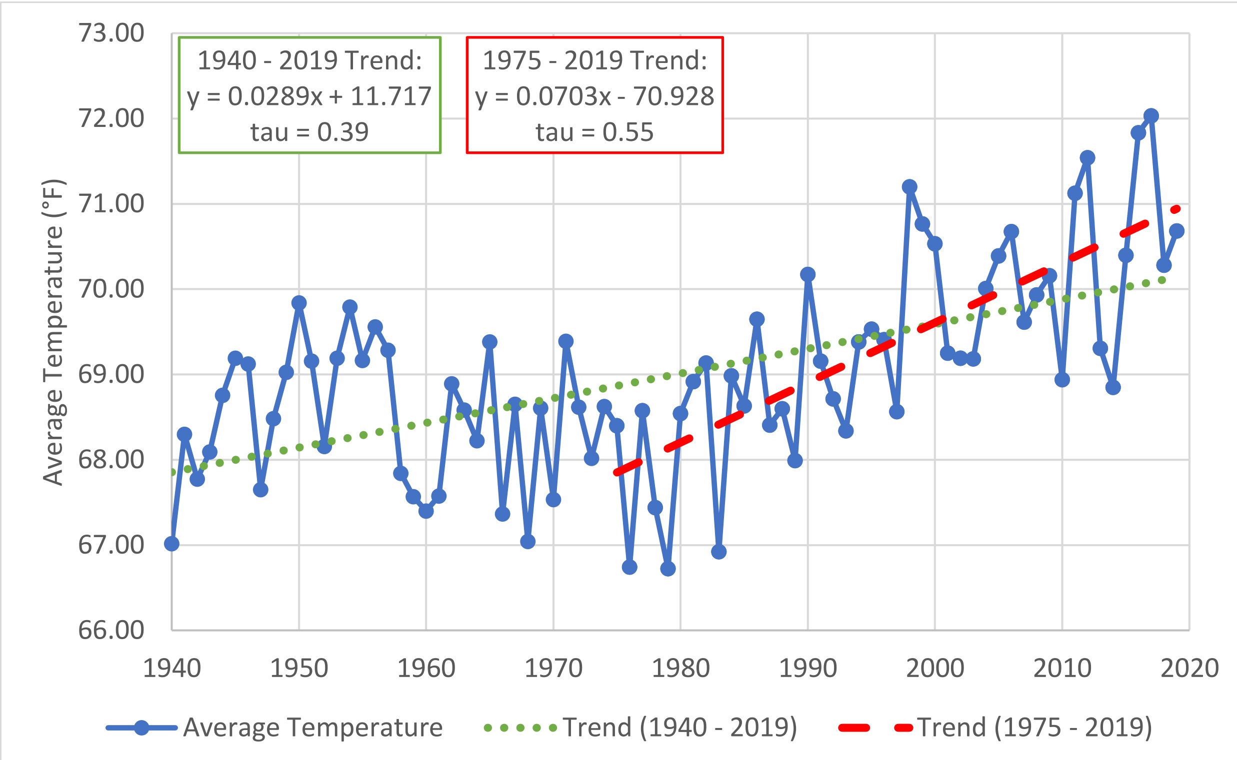


Figure 1-3 – Annual Average Temperature in Climate Division 4108 (Texas Upper Coast)

We determined Kendall's tau for each annual time series beginning with all possible starting years and ending with the last year of data available to identify the optimal starting year for which Kendall's tau is maximized, ignoring data prior to that starting year. We considered only trends that are significant (p-value≤0.05). We required the minimum period of record to be 50 years to avoid defining a long-term trend based on recent short-term variability, such as those identified by Wurbs et al. (2005) and Gooch and Albright (2011). In other words, 1966 was the latest allowable starting year for analysis of trends in naturalized flows, as flow data ends in 2015 (discussed in ***Section 1.3.4***). Similarly, 1970 was the latest allowable starting year for analysis of trends in precipitation and temperature, as data was analyzed through 2019. We chose 50 years as the minimum because it is over twice as long as the longest cycle identified in Wurbs et al. (2005). This study shows what would happen if trends identified as significant by the Kendall's tau methodology and persisting for at least 50 years continued at least until 2070. Furthermore, the slope of the strongest trend, as characterized by Kendall's tau, was applied in this study, but it should be noted that this slope is not necessarily the most accurate slope for the projection into the future. These assumptions should be treated as limitations to the results of this study, as trend attribution and the assessment of climate projections to determine future trends were beyond the scope of this project.

If we identified a starting year that produced a significant trend with greater strength (larger absolute tau value) than the full period of record, that start year was used for analysis of that variable at all timescales (annual, seasonal, and seasonal grouped by hydrologic condition). If no significant annual trends were found with greater trend strength than the full period of record, then the period of analysis for all timescales included all years in the period of record.

The application of this approach to determine a start year other than 1940 was subject to review of the results. This approach is intended to identify the trendline with the strongest tau value amongst various potential trendlines, which depend on an arbitrary period of analysis. However, if a significant annual trend was only found for a particular start year, whereas no trend was identified if the start year was anything else, we assumed that there is in fact no significant annual trend in that dataset, and the start year remained 1940 (beginning of data period). **Appendix 1-C** provides examples of the application of this approach.

Trend Characterization

Kendall's tau is useful for identifying the presence of a monotonically increasing or decreasing trend, but it does not describe that trend. Monotonic trends may resemble linear, exponential, or other functions. Zhu et al. (2021) fit an exponential trend to historical streamflow in the Canadian River Basin in northern Texas. Fitting an exponential equation to a decreasing trend in streamflow has the desirable property of never reaching zero.

For each time series with a significant trend, as identified using Kendall's tau, we used least squares regression to estimate both a linear and an exponential trend line. We estimated exponential trends using least squares regression to determine the slope and intercept for log-transformed variables as shown below. Equation 1-8 is the standard form of an exponential equation, in which A and B are the constants to be determined by regression. Taking the natural logarithm of both sides of this equation produces Equation 1-9, which takes the form of a linear equation. Then, linear regression can be used to find slope B and intercept $\ln(A)$.

$$Y = A * e^{BX}$$ Equation 1-8

$$\ln(Y) = \ln(A) + B * X$$ Equation 1-9

For simplicity, the linear trend equation was preferred unless the coefficient of determination (R-squared) was at least 0.10 greater for the exponential trendline than the linear trendline. For simplicity of discussion, linear trendlines are used as examples throughout the remainder of this chapter.

Treatment of Outliers

Kendall's tau is resistant to effects of outliers when identifying trends in a paired dataset such as a time series. For example, the tau value is the same for the two series shown in Figure 1-4 because the Y values at X=4, X=10, and X=17 have the same rank relative the other values in the series. However, although the more extreme values in Series B do not change the tau value, they do change the slope of a linear trendline.

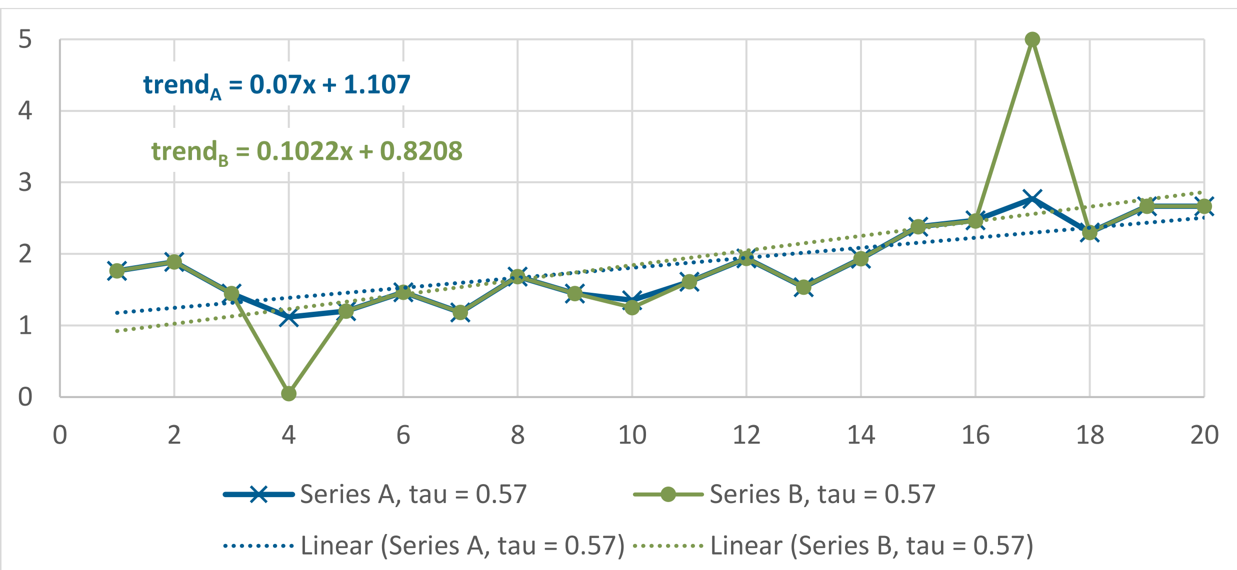


Figure 1-4 – Example of the Impact of Outliers on Trends and on Tau

We applied the following approach to mitigate the impact of outlier values on the slope of trend lines that were extrapolated for use in adjusting the WAM.

1. Upper and lower thresholds were calculated on the given data series, using the following formulation for the upper fence (UF) and lower fence (LF): UF=Q3+1.5(IQR) and LF=Q1-1.5(IQR), where Q1 is the value exceeded 75 percent of the time, Q3 is exceeded 25 percent of the time, and IQR is the interquartile range (difference between Q1 and Q3). This is the same definition of outliers used by Microsoft Excel's box-and-whiskers plots.

2. Large outlier values were replaced with the calculated upper fence and small outliers with the lower fence as illustrated in Figure 1-5.

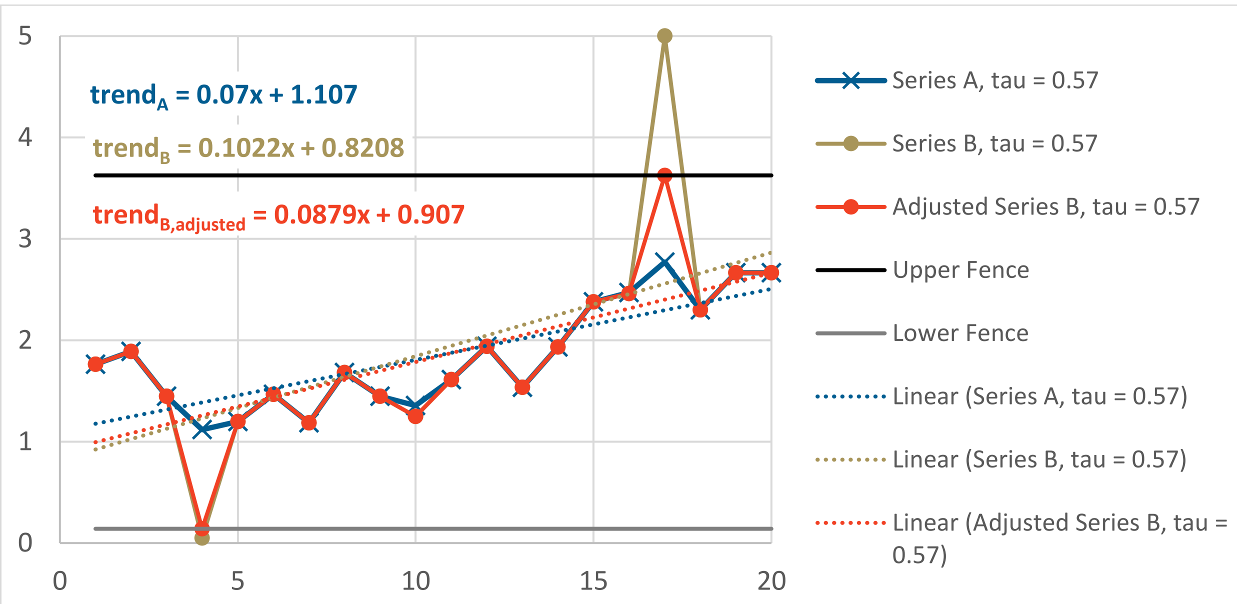


Figure 1-5 – Example of Replacing Outlier Values in order to Calculate Trends

1.3.4 WAM Adjustment – Naturalized Flows (FLO File)

Overview

This project calls for adjustments to naturalized flows that are input into the Brazos WAM. The difference between historical flows and naturalized flows is that naturalized flows are developed by adjusting historical flows to remove the impacts of reservoirs, water use and return flows. Harwell et al. (2020) conducted a trend analysis on historical gaged flows, so it is likely that the decreasing trends they identified are at least partially attributable to increasing surface water use and reservoir evaporation. The trends used to project forward and adjust input into the Brazos WAM should be based on naturalized flows. The naturalized flows in the FLO input file to the Brazos WAM were adjusted based on observed trends in historical naturalized flows.

Primary control points are locations, typically streamflow gage locations, where naturalized flow data are input into the WAM. Naturalized flows (Q) were developed for each primary control point based on stream gage measurements and other historical data and were distributed within the WAM to other control points. The original Brazos WAM uses hydrology (i.e., naturalized flows and net evaporation rates) on a monthly timestep covering a period from 1940 through 1997. A version of the Brazos WAM developed in 2017 for the BRA Drought Study (Freese and Nichols, 2017) extended the period of record through 2015, so that monthly naturalized flows are available from 1940 through 2015. The flows from 1998 through 2015 are considered "semi-naturalized" because the flows have only been corrected for diversions by water rights authorized for more than 1,000 acre-feet per year (as opposed to all water rights), reservoirs with current capacity of 10,000 acre-feet or more (as opposed to all reservoirs included in the original WAM), and return flows greater than 2 MGD. The current study used the original Brazos WAM and BRA Drought Study hydrology and covered a period from 1940 through 2015.

Trends were assessed for each primary control point. When a primary control point was downstream of another primary control point (i.e., the drainage area of the downstream control point includes the drainage area of the upstream control point), trends for the downstream control point were assessed based on the naturalized runoff from the incremental watershed between the two points rather than total naturalized flows, where incremental runoff is the difference in upstream flow less channel losses and downstream flow. For other control points, the incremental flow is equivalent to the total flow. When there was a control point upstream, $NAT_{incremental}$ was used so that any trends are independent of the trend already accounted for in $NAT_{upstream}$.

The adjustments to the naturalized flows for each control point were developed using the following procedure.

1. Prepare data subsets of time series for trend assessment.
2. Use Kendall's tau to identify the presence or absence of significant monotonic trends.
3. Select the trend or trends to use for adjusting incremental naturalized flows.
4. Calculate the flow adjustment factor ΔQ for each data subset based on observed trends in incremental naturalized flows.

5. Add adjustment factor ΔQ, which varies by time series subset, to incremental naturalized flows.

6. Reconstruct time series of adjusted total naturalized flows from subsets of incremental flows.

Each step is described in more detail below.

Step 1 – Preparing the time series

1. Using naturalized flows in the FLO file, monthly incremental naturalized flow (Q) was calculated using Equation 1-10.

$$Q_{CP} = NAT_{CP} - \Sigma\left(NAT_{upstream} * \left(1 - Loss_{upstream-to-CP}\right)\right) \quad \text{Equation 1-10}$$

Q_{CP} = incremental naturalized flow at selected control point

NAT_{CP} = total naturalized flow at selected control point

$NAT_{upstream}$= total naturalized flow at each upstream control point

$Loss_{upstream-to-CP}$ = loss factor, expressed as a fraction, between upstream control point and selected control point

2. Monthly Q was aggregated into seasonal totals and annual totals, then divided by the number of months (4 and 12 respectively) to obtain average monthly flows on a seasonal and annual basis. Seasons were defined as four-month periods based on the Environmental Flow Standards for the Brazos River Basin as shown in Table 1-1, which were developed by the Brazos River Basin and Bay Expert Science Team (BBEST, 2012).

Table 1-1 – Seasons in Brazos River Basin

Winter	November, December, January, February
Spring	March, April, May, June
Summer	July, August, September, October

3. Seasonal average flows (spring, summer, and winter) were grouped by hydrologic condition (dry, average, and wet) to create nine subsets of the seasonal time series as shown in Figure 1-6. The

hydrologic condition of a season was determined based on the average Palmer Hydrological Drought Index (PHDI) during that season. NOAA reports historical PHDI values for each climate division on a monthly basis. The monthly PHDI values were averaged to develop seasonal PHDI values in each climate division. The hydrologic condition of each season was classified based on the thresholds shown in Table 1-2 for the climate division that overlapped the greatest portion of the drainage area of the selected control point. The PHDI dataset and the development of hydrologic condition threshold values are discussed in **Appendix 1-D**.

Seasonal Analysis Year	Winter	Spring	Summer
1940	dry	dry	wet
1941	wet	wet	wet
1942	wet	wet	wet
1943	wet	average	dry
1944	dry	average	average
1945	average	wet	wet
1946	wet	average	average
1947	average	average	average
1948	average	average	dry
1949	dry	average	average
1950	average	average	wet
1951	dry	dry	dry
1952	dry	dry	dry
1953	dry	dry	dry

Dry Spring: 1940, 1951, 1952, 1953, 1954, 1955, 1956, ...
Dry Summer: 1951, 1952, 1953, 1954, 1955, 1956, 1963, ...
Dry Winter: 1944, 1948, 1949, 1952, 1953, 1955, 1956, ...
Average Spring: 1943, 1944, 1945, 1947, 1948, 1949, 1950, ...
Average Summer: 1940, 1943, 1944, 1947, 1948, 1949, 1950, ...
Average Winter: 1941, 1945, 1947, 1950, 1951, 1954, 1960, ...
Wet Spring: 1941, 1942, 1946, 1958, 1960, 1961, 1968, ...
Wet Summer: 1941, 1942, 1945, 1946, 1957, 1958, 1968, ...
Wet Winter: 1942, 1943, 1946, 1958, 1959, 1969, 1974, ...

Figure 1-6 – Example Classification of Seasons by Hydrologic Condition

Table 1-2 – Classification of Seasons by Hydrologic Condition Based on PHDI

Climate Division	Dry	Average	Wet
4101, High Plains	Less than -1.43	-1.43 to 1.51	Greater than 1.51
4102, Low Rolling Plains	Less than -1.44	-1.44 to 1.53	Greater than 1.53
4103, North Central	Less than -1.13	-1.13 to 1.92	Greater than 1.92
4104, East Texas	Less than -1.07	-1.07 to 1.93	Greater than 1.93
4106, Edwards Plateau	Less than -1.50	-1.50 to 1.49	Greater than 1.49
4107, South Central	Less than -1.45	-1.45 to 1.80	Greater than 1.80
4108, Upper Coast	Less than -0.91	-0.91 to 1.81	Greater than 1.81

Step 2 – Assessing the presence and significance of monotonic trends

1. Kendall's tau and associated p-value were calculated for each subset of Q following the approach described in ***Section 1.3.2***, including treatment of outliers and starting year analyses. Note that the number of data pairs in each time series subset varied, as there may be more years with an average condition than a dry or wet condition. Trends in precipitation volume (PV) and the ratio of streamflow to precipitation (Q/P) were also assessed to provide additional context for trends observed in Q. More information on the assessment of PV and Q/P is provided in **Appendix 1-E**.

2. Subsets were identified in which a significant trend (p-value $\leq$ 0.05) was present in Q.

3. An equation was developed predicting monthly incremental naturalized flow as a function of time (Q_{trend}) as described in ***Section 1.3.2***.

Step 3 – Selecting trends to apply based on Kendall's tau

If significant trends were identified at multiple timescales, we used the timescale with the strongest trend (based on tau). Only significant trends (p-value $\leq$ 0.05) were considered. Months with no significant trends remained unchanged (i.e., adjustment factors equal to 0). When a smaller timescale included trends both stronger and weaker than a longer timescale, preference was given to the more detailed subset of data. This process for the selection of which trend to apply to each month of the naturalized flow series is summarized in Figure 1-7.

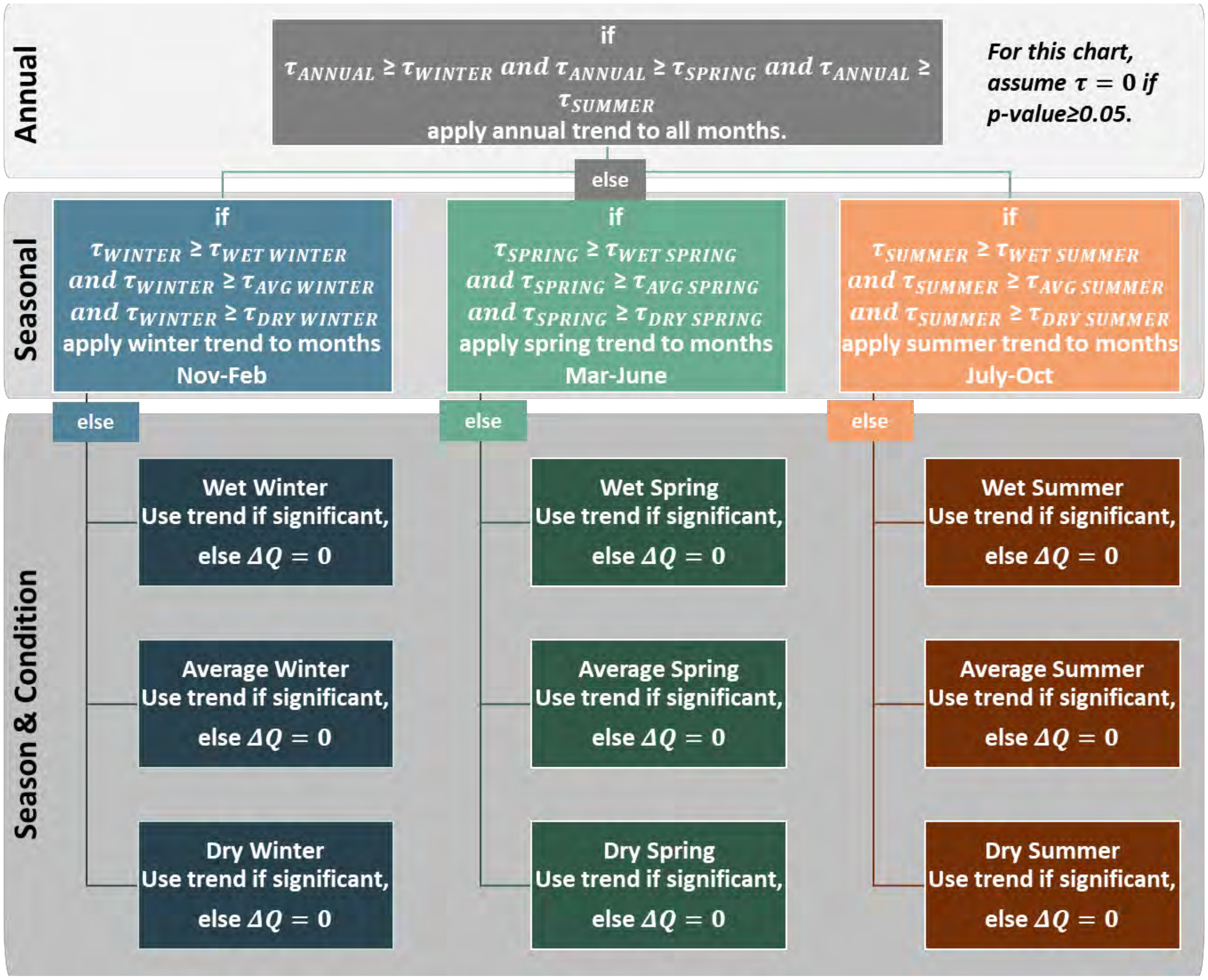


Figure 1-7 – Selection of Trend to Apply

Step 4 – Calculating flow adjustment factors

The adjustment factor for naturalized flows is defined as the expected average value of Q in the future year of interest (based on the observed trend) minus the trend-predicted value of Q for a given timestep, as shown in Equation 1-11.

$$\Delta Q(t) = Q_{trend}(2070) - Q_{trend}(t)$$

Equation 1-11

The adjustment factor was determined for each subset selected in Step 3 according to the following procedure:

1. The trend in monthly incremental naturalized flow was extrapolated to 2070 to obtain the expected average value of Q in 2070: $Q_{trend}(2070)$. If the extrapolation of a decreasing trend

resulted in an estimate of negative flows, the estimate was replaced with zero. A decreasing exponential trend will not reach zero.

2. Adjustment factors, $\Delta Q(t)$, were computed based on Equation 1-11. Because trends were analyzed based on the average monthly flow within a season or year, ΔQ was equal for each month within a year or season.

3. This procedure was repeated for end year 2050 (in place of 2070).

For trends in which a Start Year later than 1940 were identified using the process outlined in ***Section 1.3.3***, Equation 1-11 was modified to Equation 1-12. Using Equation 1-12, the same adjustment factor for a given subset (such as dry summers) was applied to all months within that subset in years prior to the Start Year to avoid over-adjusting values from a period when the identified trend was not yet present. Additional information on this approach is provided in **Appendix 1-F**.

$$if\ t < StartYear, then\ \Delta Q(t) = Q_{trend}(2070) - Q_{trend}(StartYear) \qquad \text{Equation 1-12}$$

Step 5 - Adjusting incremental naturalized flows

The selected adjustment factor was applied for each month as shown in Equation 1-13 to calculate the adjusted monthly incremental naturalized flow values.

$$\begin{array}{lll} \text{if } \Delta Q = 0, & \text{then } Q_{incremental,adjusted} = Q_{incremental} & \\ \text{else} & Q_{incremental,adjusted} = \max(0, Q_{incremental} + \Delta Q) & \end{array} \qquad \text{Equation 1-13}$$

The ΔQ term in Equation 1-11 is positive for an increasing trend and negative for a decreasing trend. If the adjustment to incremental flow produced a negative incremental flow, $Q_{incremental,adjusted}$ was set to zero. However, if no adjustment was applied to a given timestep (due to the lack of a significant trend), $Q_{incremental}$ was not changed and may be positive or negative depending on the original value. Figure 1-8 demonstrates this concept in summer seasons at a hypothetical control point.

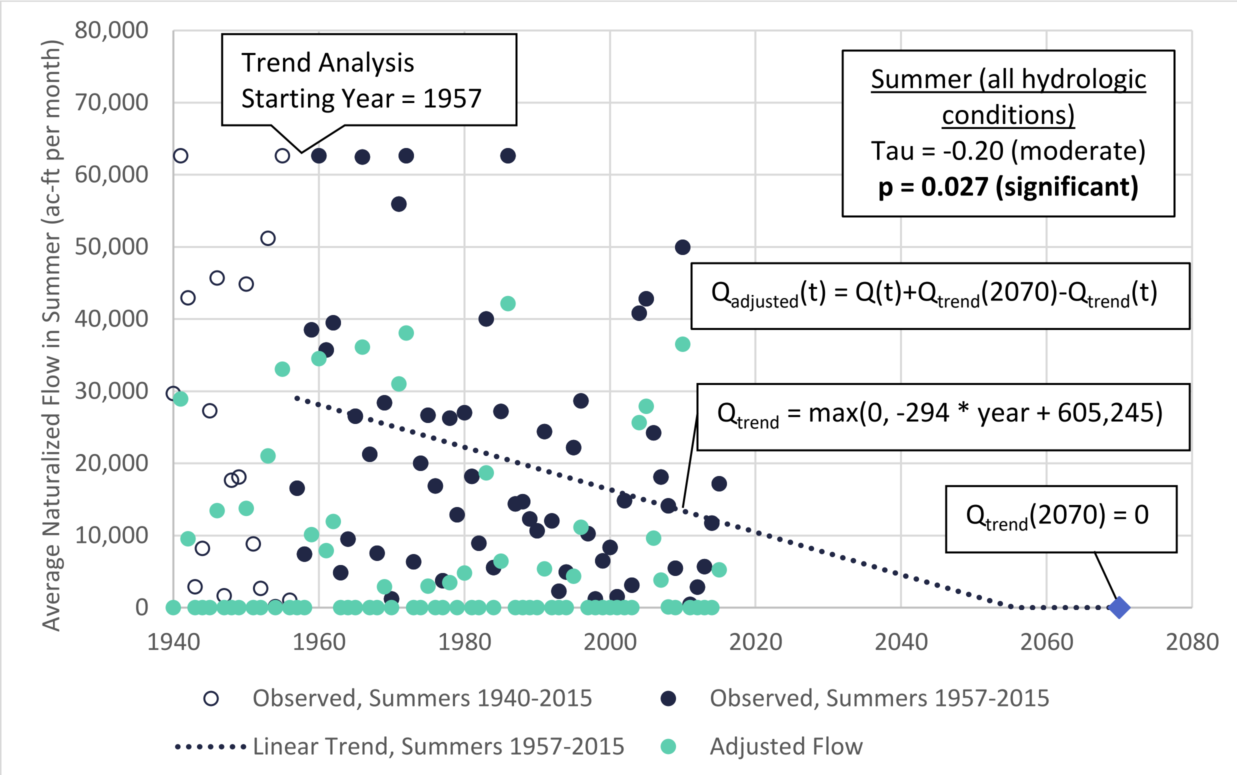


Figure 1-8 – Example of Derivation of Adjusted Flow for Summer Season at Hypothetical Control Point

Step 6 – Reconstructing total adjusted naturalized flow time series

For control points downstream of other gaged control points, the adjusted incremental flows were added to the adjusted flows from upstream points, accounting for losses, to generate the adjusted total naturalized flow value by rearranging Equation 1-10 as shown in Equation 1-14.

$$NAT_{CP,adjusted} = Q_{CP,adjusted} + \left[\Sigma\left(NAT_{upstream,adjusted} * \left(1 - Loss_{upstream-to-CP}\right)\right)\right] \quad \text{Equation 1-14}$$

NAT_{CP} = total naturalized flow at selected control point

Q_{CP} = incremental naturalized flow at selected control point

$NAT_{upstream}$= total naturalized flow at each upstream control point

$Loss_{upstream-to-CP}$ = loss factor, expressed as a fraction, between upstream control point and selected control point

1.3.5 WAM Adjustment – Net Reservoir Evaporation (EVA File)

Overview

The current study calls for adjustments to the net reservoir evaporation rates at control points entered in the EVA file for the Brazos WAM. Control points in the Brazos WAM EVA file are located at either: (1) reservoirs in the Brazos Basin or (2) one degree latitude by longitude quadrangles intersecting the Brazos Basin, for which non-reservoir control points in the WAM are assigned net evaporation rate data. Evaporation data are entered into the EVA file as "net" evaporation, where:

$$Net\ Evaporation = Gross\ Reservoir\ Evaporation - Precipitation \quad \text{Equation 1-15}$$

Gross reservoir evaporation (E) and precipitation (P) rates are determined on a monthly time step in dimensions of depth per month (in this study, inches per month). In this study, we only considered adjustments to gross reservoir evaporation and precipitation since that is the information entered in the EV records of the EVA file. According to the WRAP Reference Manual (2019), the monthly SIM simulation model includes an option to adjust net evaporation to account for runoff that would have occurred from the land area inundated by the reservoir. This option is used by the Brazos WAM, so the WRAP program will calculate the runoff from the area inundated by the reservoir using the adjusted flows. The naturalized flows for the Brazos WAM include an adjustment to the historical gaged data for the amount of rainfall that would have become runoff in the absence of the reservoir.

Wurbs et al. (2005) applied an additive factor to net evaporation records in the WAM, based on differences in a baseline and potential future scenario, which were estimated using a watershed model. For this analysis, we also adjusted net evaporation records using additive factors. However, we adjusted net evaporation in the EVA input file to the WAM based on observed historical trends in two climate variables: (1) average air temperature (T), which was used to estimate an adjustment to gross reservoir evaporation (E), and (2) precipitation (P).

Gross reservoir evaporation data, computed based on pan evaporation and pan-to-lake coefficients, are available from TWDB in one-degree quadrangles, gridded one-degree latitude by one-degree longitude, that cover Texas. Data is available from 1954 through 2019, which was used as the analysis time period for determining relationships between E and T. An area-weighted average approach was applied to scale E from the one-degree quadrangles to climate divisions. Figure 1-9 illustrates climate divisions and one-degree quadrangles across Texas and the Brazos River Basin.

In this analysis, we used trends observed in air temperature (T) to estimate the adjustment to gross reservoir evaporation (E), rather than directly using trends in E, because datasets of T are generally more complete and consistent than datasets of E. McVicar et al. (2012) highlighted how trends in evaporative demand are driven by four meteorologic variables: air temperature, wind speed, atmospheric humidity, and radiation. Air temperature was selected for this analysis, rather than the other variables influential to E (e.g., wind speed, humidity, radiation), due to its widespread availability and relationship with E. Zhao and Gao (2019) found correlations between reservoir evaporation rate changes and air temperature that support the use of T. TWDB quadrangle data are commonly used to estimate the gross reservoir evaporation component of net evaporation in the WAMs. Although we used trends in T to estimate the adjustment factor for E, we also considered trends in TWDB quadrangle gross reservoir evaporation data due to its relevance to the WAMs. Trend analyses of TWDB quadrangle data were scaled up to the climate division level, rather than the quadrangle-level data itself, to maintain a consistent analysis scale with the other climate variables being analyzed.

We used the NOAA U.S. Climate Divisional Dataset to analyze trends in historical T and P. The Climate Divisional Dataset is a long-term temporally and spatially complete dataset (1895 – Present) that can be used to generate historical climate analyses throughout the contiguous U.S. (Vose et al., 2014). The dataset is available on a monthly time step at various spatial scales, including (from smallest to largest) the NOAA climate division, state, regional, and national scale. The PRISM Climate Group also provides a set of monthly gridded temperature and precipitation data; however, according to PRISM documentation, the "dataset should not be used to calculate multi-decadal trends" because the PRISM grids contain "non-climatic variations due to station equipment and location changes, station openings and closings and varying observation times." Thus, the NOAA U.S. Climate Divisional Dataset was deemed more appropriate for this study.

For this analysis, we used data at the NOAA climate division scale. We analyzed the seven climate divisions that intersect the Brazos River Basin: 01 – High Plains, 02 – Low Rolling Plains, 03 – North Central, 04 – East Texas, 06 – Edwards Plateau, 07 – South Central, and 08 – Upper Coast. The period of analysis for T and P is from 1940, when the WAM data begin, to 2019 (i.e., the last complete year with data at the time of this study).

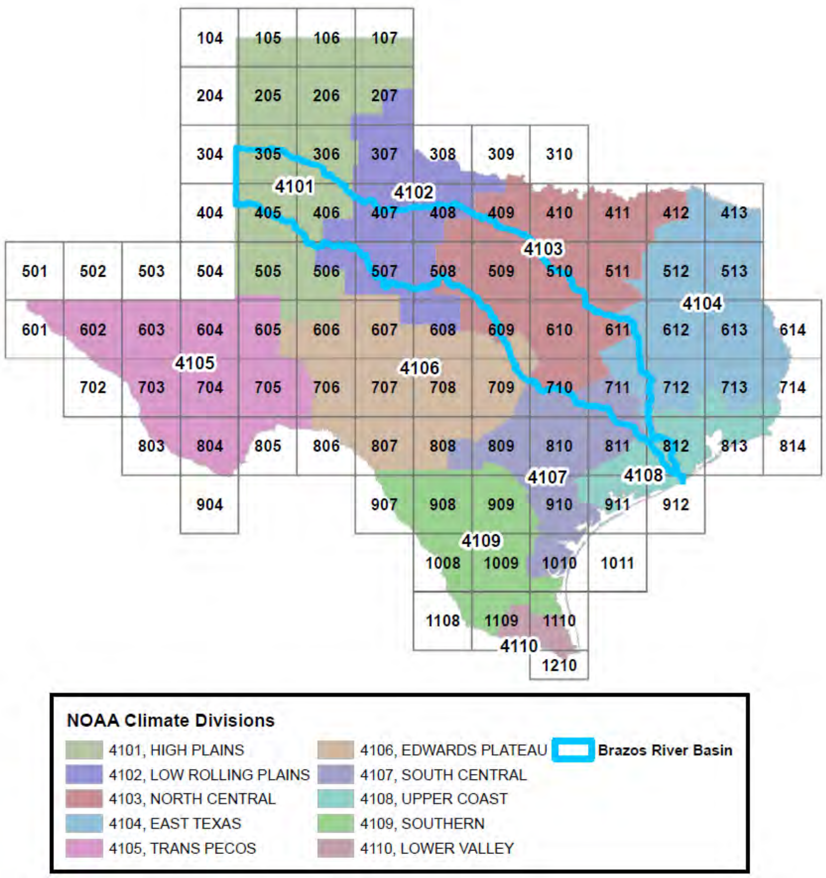


Figure 1-9 – Texas Climate Divisions and One-Degree Quadrangles

We computed adjustment factors separately for each subset of E and P data (e.g., seasonal/hydrologic condition, seasonal, annual), based on the presence of significant trends identified in a particular subset. We used this approach to adjustment factors to develop WAM inputs that are representative of 2050 and 2070 conditions. We developed E and P adjustments for each climate division, and adjustments from one climate division were applied to each control point in the EVA file, based on the climate division that the control point predominantly intersects. For the reservoir control points, the predominant climate division was selected based on which climate division the majority of the reservoir surface area is located within. For example, the surface area of Lake Limestone intersects both climate division 4103 (North Central) and 4104 (East Texas), but the majority of the reservoir surface area is located in climate division 4103; thus, the EVA control point associated with Lake Limestone was assigned the E and P adjustment factors determined for climate division 4103. The control points in the EVA file that represent one-degree quadrangle data were assigned to the climate division that had the majority of WAM control points using that quadrangle for net evaporation data.

Adjustments for both E and P follow the same general procedure (outlined below). The following sections describe the adjustment procedure for each component in more detail.

1. Prepare data subsets of time series for trend assessment.
2. Use Kendall's tau to identify the presence or absence of significant monotonic trends.
3. Select the strongest trend(s) to apply for adjusting variables.
4. Calculate adjustment factors (gross evaporation factor and precipitation factor) for each climate division, for each subset of data, based on the significant trends.
5. Add adjustment factors to each time series subset for all control points.

Step 1 – Preparing time series

1. Monthly datasets were compiled for historical temperature (T), precipitation (P), and gross reservoir evaporation (E) for each climate division located in the Brazos River Basin.
    a. E datasets were scaled from one-degree quadrangles to climate divisions using an area-weighted approach.
2. T, P, and E were aggregated monthly into seasonal and annual average totals, then divided by number of months (4 and 12 respectively) to obtain average monthly totals on a seasonal and annual basis, respectively. In this analysis, seasons are defined as four-month periods based on the environmental flow standards for the Brazos River Basin, which were developed by the BBEST (2012). These are shown in Table 1-1.
3. Seasonal average totals (spring, summer, and winter) were grouped by hydrologic condition (dry, average, and wet) to create nine subsets of the seasonal time series of T and P for each climate

division, as shown in Figure 1-6. The hydrologic condition of a season was determined based on the average Palmer Hydrological Drought Index (PHDI) during that season. NOAA reports historical PHDI values for each climate division on a monthly basis. The monthly PHDI values were averaged to develop seasonal PHDI values in each climate division. The hydrologic condition of each season was classified based on the thresholds shown in Table 1-2. The PHDI dataset and the development of hydrologic condition threshold values are discussed in **Appendix 1-D**.

Step 2 – Assessing presence and significance of monotonic trends

1. Kendall's tau and associated p-value were calculated for each subset of T and P following the approach described in ***Section 1.3.3***.
2. Subsets were identified in which a significant trend (p-value $\leq$ 0.05) was present in T, P, or both.
3. An equation was developed predicting monthly average T and P as a function of time ($T_{trend}(t)$ and $P_{trend}(t)$, respectively), as described in ***Section 1.3.2***.

Step 3 – Selecting trends to apply

When a significant trend (p-value $\leq$ 0.05) was identified in a data subset at any timescale (seasonal, annual), we calculated additive adjustment factors for E and P. If there was no significant trend identified in T of a given subset, the E adjustment factor (ΔE) equaled zero so that no change to net evaporation was applied based on gross reservoir evaporation. Likewise, if there was no significant trend identified in P of a given subset, the P adjustment factor (ΔP) was set equal to zero. In cases where trends were identified at multiple timescales for the same data subset, we selected which adjustment factors to use based on the same hierarchy of timescales discussed in *Step 3* of ***Section 1.3.4***. The selection of which trend to apply is summarized in Figure 1-7.

Step 4 – Calculating adjustment factors

Evaporation

Based on trends in historical average temperature selected in *Step 3* above, we determined a monthly gross reservoir evaporation adjustment factor (ΔE) for each climate division intersecting the Brazos River Basin. The procedure we used to determine ΔE is described below.

1. Significant trend(s) were extrapolated to obtain the predicted value of T in 2070, $T_{trend}(2070)$. Figure 1-10 demonstrates this concept for trends in the spring season for a hypothetical climate division.

Figure 1-10 – Example Spring Season Trend of Average Monthly Temperatures (°F) in a Hypothetical Climate Division

2. The trend-predicted average monthly temperature, $T_{trend}(t)$, was calculated for each time step in the historical time series (1940 to 2019).

3. An equation was developed to estimate E as a function of T. We developed this equation based on relationships determined between E and T during the historical period of record of these data (1954 to 2019). We assessed relationships for each analysis time scale (e.g., seasonal, annual). The T to E equation was used to determine the E adjustment factor. Figure 1-11 demonstrates the development of the equation relating T to E for the spring season in the hypothetical climate division.

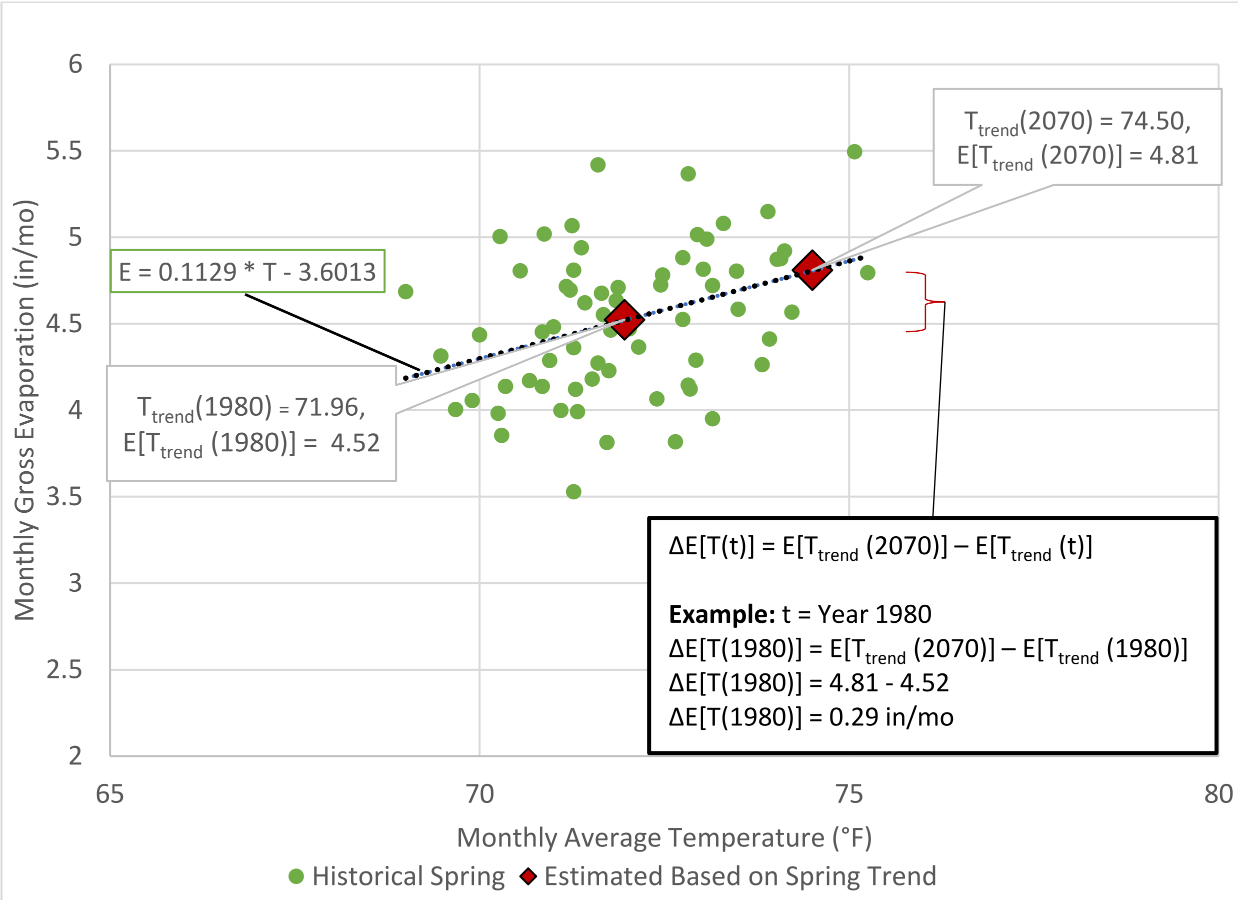


Figure 1-11 – Example Derivation of the ΔE Adjustment Factor for Spring Seasons in a Hypothetical Climate Division, based on Relationship between Monthly Gross Reservoir Evaporation (in) and Average Temperature (°F)

The relationship between T and E shown in Figure 1-11 is linear. We also considered exponential relationships between T and E, although conducting the analysis for each of the three seasons removes much of the non-linearity.

4. The equation that relates T to E was used to calculate an E for trend-predicted future conditions in 2070, $E[T_{trend}(2070)]$, and a trend-predicted E at each time step throughout the historical time series, $E[T_{trend}(t)]$. Figure 1-11 shows an example of the values calculated for $E[T_{trend}(2070)]$ and $E[T_{trend}(t)]$ in the year 1980 for the spring season in the hypothetical climate division.

5. An additive adjustment factor for E (ΔE) was calculated at each time step throughout the historical time series, $\Delta E[T(t)]$, based on the equation:

$$\Delta E[T(t)] = E[T_{trend}(2070)] - E[T_{trend}(t)]$$ Equation 1-16

Figure 1-11 demonstrates an example of the calculation for $\Delta E[T(t)]$ in the year 1980 for the spring season in a climate division. Because trends were analyzed based on average values within a season or year, ΔE is equal for each month within a year or season.

6. This procedure was repeated for end year 2050 (in place of 2070).

For trends in which a Start Year later than 1940 were identified using the process outlined in ***Section 1.3.3***, Equation 1-16 was modified to Equation 1-17. Using Equation 1-17, the same adjustment factor for a given subset (such as dry summers) was applied to all months within that subset in years prior to the Start Year to avoid over-adjusting values from a period when the identified trend was not yet present. Additional information on this approach is provided in **Appendix 1-F**.

$$if\ t < StartYear, then\ \Delta E[T(t)] = E[T_{trend}(2070)] - E[T_{trend}(StartYear)]$$ Equation 1-17

Precipitation

We determined a precipitation adjustment factor (ΔP) for each climate division intersecting the Brazos River Basin based on the trends in historical precipitation selected in Step 3 above. The procedure we used to determine ΔP is described below.

1. Significant trend(s) were extrapolated to obtain the predicted value of P in 2070, $P_{trend}(2070)$. Figure 1-12 shows this concept for trends in the wet spring season for a hypothetical climate division.

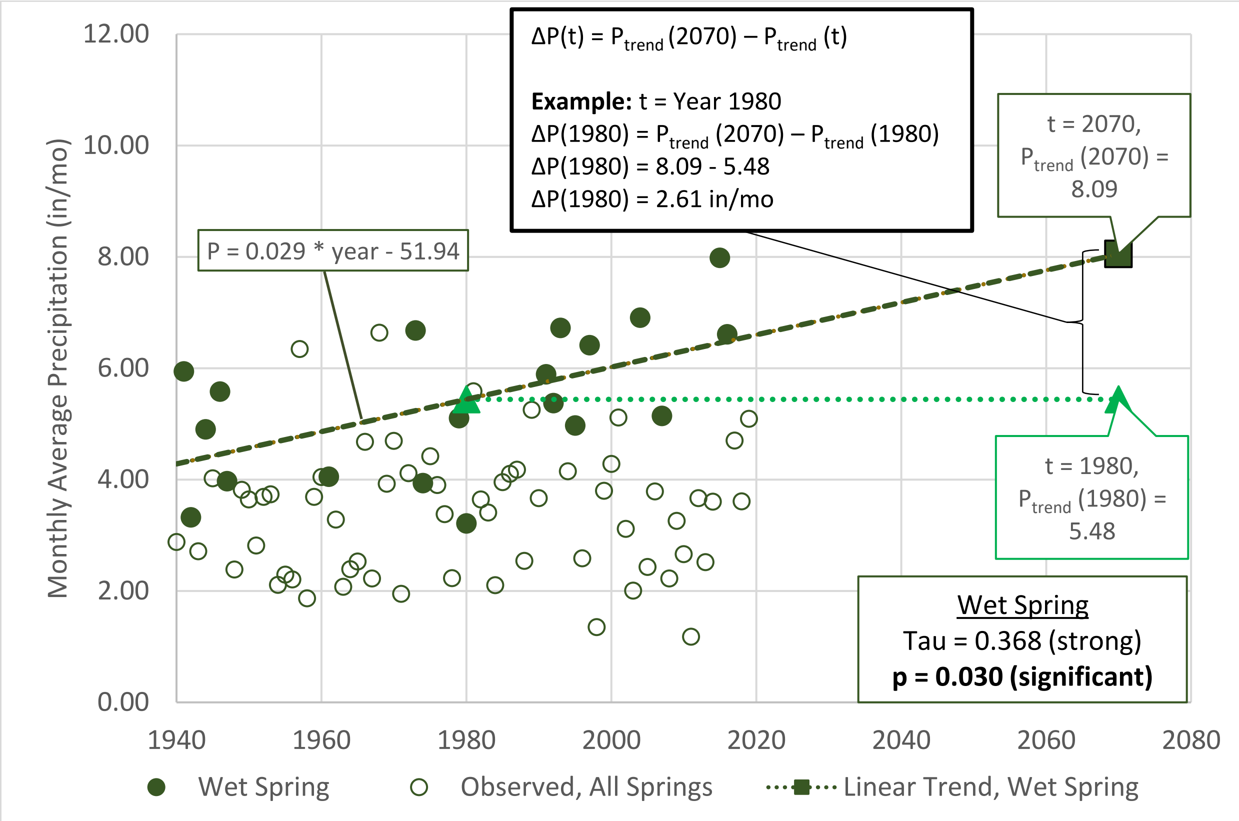


Figure 1-12 – Example Derivation of ΔP Adjustment Factor for Wet Spring Seasons in a Hypothetical Climate Division

2. The trend-predicted average monthly precipitation, $P_{trend}(t)$, was calculated for each time step in the historical time series (1940 to 2019).

3. An additive adjustment factor for P (ΔP) was calculated at each time step throughout the historical time series, $\Delta P(t)$, based on the equation:

$$\Delta P(t) = P_{trend}(2070) - P_{trend}(t)$$

Equation 1-18

Figure 1-12 demonstrates an example of the calculation for $\Delta P(t)$ in the year 1980 for the wet spring season in the hypothetical climate division. Because trends are analyzed based on average values within a season or year, ΔP is equal for each month within a year or season.

4. This procedure was repeated for end year 2050 (in place of 2070).

For trends in which a Start Year later than 1940 was identified using the process outlined in ***Section 1.3.3***, Equation 1-18 was modified to Equation 1-19. Using Equation 1-19, the same adjustment factor for a given subset (such as dry summers) was applied to all months within that subset in years prior to the Start Year to avoid over-adjusting values from a period when the identified trend was not yet present. Additional information on this approach is provided in **Appendix 1-F**.

$$if\ t < StartYear, then\ \Delta P(t) = P_{trend}(2070) - P_{trend}(StartYear)$$

Equation 1-19

Step 5 – Adjust monthly time series of net evaporation

We used the climate division adjustment factors developed in *Step 4* above to adjust the monthly net evaporation (i.e., gross reservoir evaporation minus precipitation) time series in the EVA input file. We applied adjustments to all control points in the EVA file, based on their corresponding climate division (i.e., net evaporation adjustment factors developed for a climate division were applied to all control points with reservoirs located within that climate division). When there were significant trends for temperature, and thus gross evaporation, during an analysis period subset (e.g., seasonal, annual), we added ΔE to the gross reservoir evaporation time series from 1940 to 2015 based on the trends assessed. Likewise, when there were significant trends for precipitation during an analysis period subset (e.g., seasonal/hydrologic condition, seasonal, annual), we added ΔP to the precipitation time series from 1940 to 2015 based on the trends assessed. If there were no significant trends identified for either E or P during the analysis period, their respective adjustment factors were set to zero ($\Delta E = 0$ or $\Delta P = 0$).

Figure 1-13 demonstrates the net evaporation time series for a hypothetical control point from 1940 to 2015, which is located in the hypothetical climate division shown in previous steps, adjusted by the factors for ΔE and ΔP determined for that climate division in *Step 4*. This figure illustrates instances in the monthly time series where a positive adjustment to P exceeded a positive adjustment to E, which resulted in a negative adjustment to net evaporation, and vice versa.

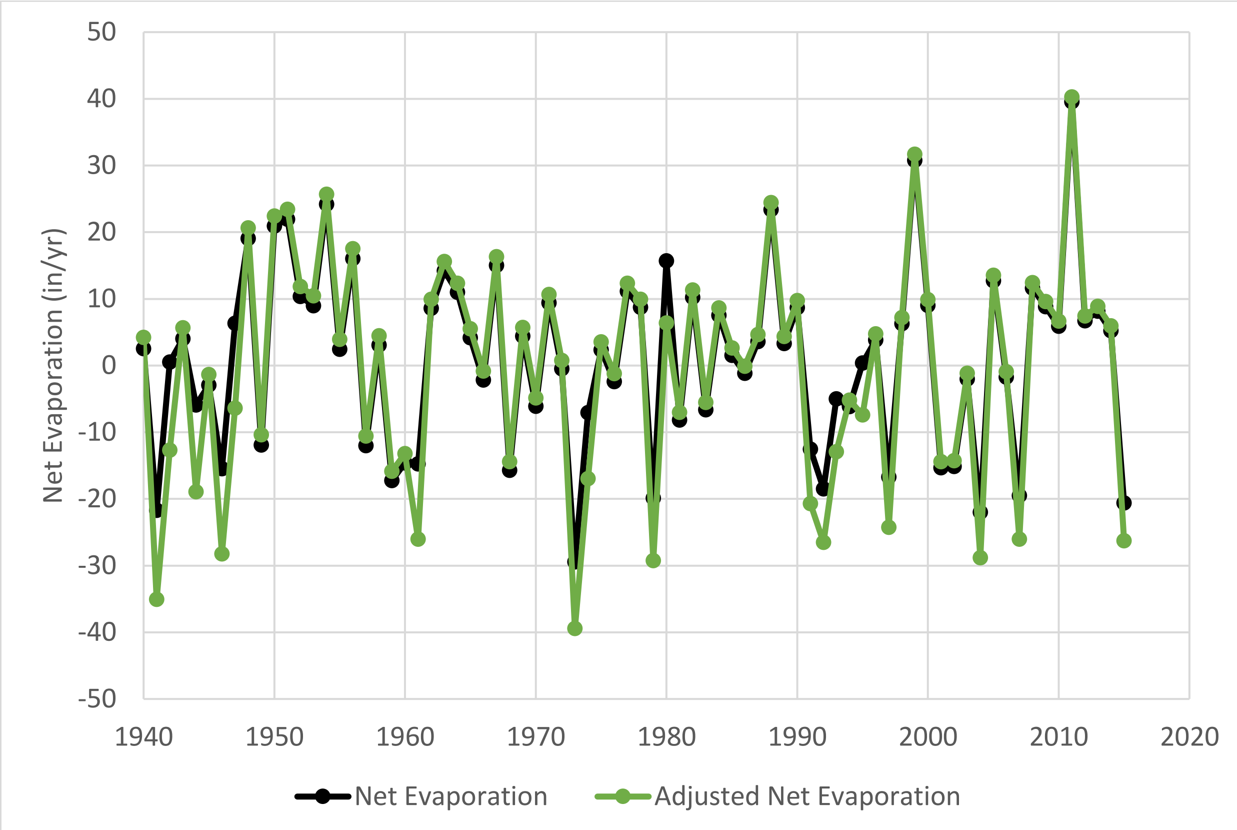


Figure 1-13 – Example Net Evaporation Time Series for a Hypothetical Reservoir from 1940 - 2015, Adjusted by ΔE and ΔP Factors determined for a Hypothetical Climate Division

1.3.6 Trends in Groundwater Elevations

Potential causes of trends in naturalized flows include trends in groundwater elevations (which impact baseflow) or in land use (which impact runoff from rainfall events). This study includes an assessment of trends in groundwater elevations in the Brazos River Basin, which is discussed below. **Appendix 1-E** includes a brief description of a potential approach to analyzing trends in land use, which could be applied in future studies. The assessment of trends in groundwater elevations was not applied directly in the adjustment of WAM inputs, but findings may provide insight on the causes of trends in Q and inform how to extend the trends into the future.

Groundwater in the Brazos River Basin

Groundwater in deep aquifers does not usually directly interact with streamflow. However, in much of the middle and lower Brazos River Basin, the stream is directly connected to the shallow Brazos River Alluvium Aquifer. The Alluvium Aquifer in turn may have exchanges with deeper aquifers, including the Carrizo-Wilcox, Yegua-Jackson, and others. Turco et al. (2007) identified various gaining and losing reaches of the Brazos River within the extent of the Alluvium Aquifer in an analysis of measurements from March and August 2006 that was updated by Ewing et al. (2016). A gaining reach occurs when streamflow is increasing as a result of groundwater discharge to the stream. A losing reach means the stream is losing water to the aquifer. Both studies identified gaining reaches during March 2006 in areas where the river intersected the outcrop of the Carrizo-Wilcox and Yegua-Jackson Aquifers. August 2006 data indicated persistence of gains in areas overlying these aquifers, as well as the appearance of gaining reaches intersecting the outcrops of the Queen City and Sparta Aquifers. Turco et al. (2007) noted that these findings were consistent with potentiometric surface maps in Garza et al. (1987) and with qualitative descriptions in a Texas Board of Water Engineers study (TBWE, 1960). Results of the analyses in areas overlying the Gulf Coast Aquifer were inconsistent between seasons and between Turco et al. (2007) and Ewing et al. (2016).

The presence of gaining reaches suggests that the river may gain streamflow directly from groundwater contributions in these areas. As a result, it is important to assess long-term trends in groundwater elevations in these aquifers to gain a better understanding of changes in the overall volume of water in the river. Additionally, if there are long-term declining trends in the aquifers and those trends correlate to trends in streamflow, there may be a time in the future when the aquifers no longer contribute to the river's baseflow, at which point the stream would become a losing stream.

Groundwater Elevation Trend Analysis Methodology

The trend analysis of groundwater elevations focused on measurements of groundwater elevations within and adjacent to the Brazos River Basin. The following procedure was used:

1. Groundwater elevation measurements were gathered from USGS Water Services and the TWDB Groundwater Database. Measurements are typically limited to wells within 5 miles of the Brazos River Basin. However, if observed well data is sparse for some aquifers, this buffer may be extended beyond 5 miles to obtain data outside the basin boundaries so that estimates of groundwater elevations are of reasonable quality across the basin. We compiled data from the last 30 years (1991 to 2020), but the period of analysis was truncated in some cases based on data availability within each aquifer.

2. Data was filtered to maintain consistency in year-to-year comparisons:

    a. Records with questionable data were filtered out.

   b. For each aquifer, records were limited to observations made at the same time of year to maintain consistency in developing the annual water level surfaces. (For example, well levels in the Gulf Coast Aquifer in Brazoria County are recorded by USGS in December, January, or February each year, so August measurements were excluded in this area.)

   c. For wells with multiple observations each year, only the measurement recorded closest to the center of the typical measurement season was used (for example, January 1 for Gulf Coast Aquifer in Brazoria County).

   d. Measurements from wells which are screened in multiple aquifer formations were excluded.

3. Spatial interpolation techniques were applied to the individual water level observations to develop an approximate groundwater piezometric surface for each aquifer. The interpolated surfaces were extracted for each aquifer (including subcrops and outcrops) so that we had one piezometric surface for each aquifer, for each year during the period of available data.

4. The average elevation of the piezometric surface was calculated for each year in a given aquifer.

5. The Kendall's tau methodology was applied to analyze average groundwater elevations for temporal trends.

The number of well observations may vary year-to-year for a given aquifer. We discarded data from years with a low number of well observations.

1.3.7 WAM Execution for Task 2

Whereas Task 1 aimed to develop a methodology for converting trends in naturalized flow, precipitation, and temperature to changes in the naturalized flow (FLO) and reservoir net evaporation (EVA) datasets, Task 2 aims to implement that methodology. The objective of Task 2 is to assess the impacts of the observed trends on availability of surface water supplies identified in the Region G and Region H 2021 Regional Water Plans.

The updated FLO and EVA datasets are used to evaluate impacts to run-of-river and reservoir firm yields for the water supply sources in Region G and Region H using the monthly WAM. The monthly WAM is the preferred approach because it is the WAM used for Regional Water Planning. Modifications to the WAM for Regional Water Planning purposes were also used in this project where appropriate. We completed Task 2 in consultation with TWDB, the U.S. Army Corps of Engineers, and the Brazos River Authority.

The reliability of surface water supplies is typically assessed based on reservoir firm yields and run-of-river supplies. Firm yield is the maximum annual water supply diversion that can be achieved without incurring any shortages. A reservoir diverting its firm yield will have close to no water during the driest part of the simulation. The Washita Basin Project by the Bureau of Reclamation (2018), Zhu and Fernando (2017), and Zhu et al. (2021) analyzed the impact of adjusted hydrology on reservoir firm yield. If a reservoir or reservoir system has a firm yield greater than its permitted diversion, a hypothetical junior water right needs to be added to the WAM in order to calculate the additional firm yield in excess of the permitted amount (note that adding a junior water right would be considered a water management strategy in the Region G Water Plan, and therefore is not counted as part of the existing supply in the Regional Water Plan). In Regions G and H, the supply from run-of-river rights is defined as the minimum annual diversion during the simulation. The firm yields and run-of-river availability statistics computed based on the adjusted hydrology were compared to the WAM results using unadjusted hydrology.

Figure 1-14 summarizes the existing surface water supply sources within the Brazos River Basin for Regions G and H. Task 2 aims to evaluate how Figure 1-14 is likely to change in the future if there are trends in Brazos River Basin hydrology. Nearly 99% of the reliable (firm) water currently originating in Region G comes from within the Brazos River Basin. Of that, 54% comes from surface water sources and the remainder comes from groundwater (41%) and reuse (5%). The majority of surface water availability in Region G (73%) is associated with the BRA reservoir system, another 19% comes from non-BRA reservoirs and 3% from run-of-river rights. In 2020, 17% of the reliable water originating in Region H comes from within the Brazos River Basin. Of that, 81% comes from surface water and the remainder comes from groundwater (19%) and reuse (<1%). The Brazos River Basin surface water originating in Region H is from run-of-river rights with only limited operational storage. Entities in Region H also receive substantial contractual supply from the upstream BRA reservoir system in Region G.

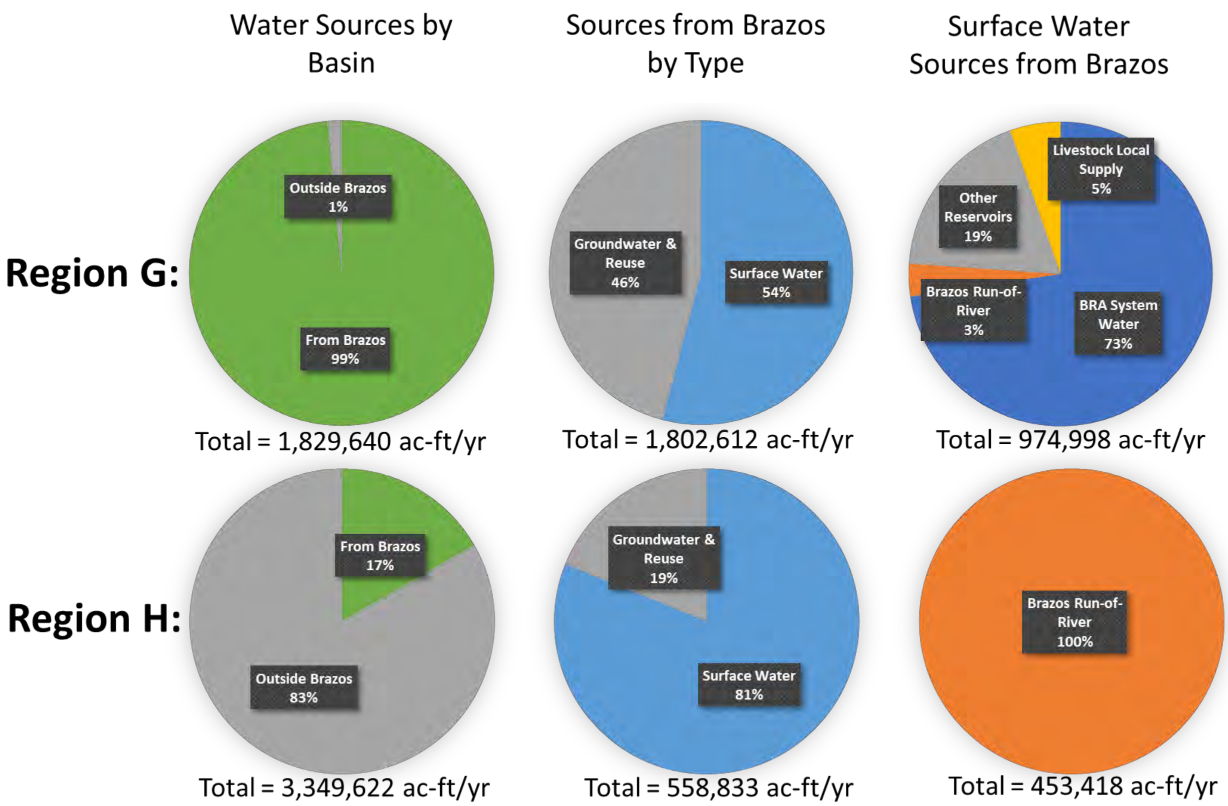


Figure 1-14 – Summary of Existing Surface Water Availability from the Brazos River Basin for Region G and Region H in 2020

1.3.8 WAM Execution for Task 3

The objective of Task 3 is to assess the frequency of attainment of environmental flow standards in the Brazos River Basin under changed hydrological conditions and the future water use (full utilization of permitted diversions). TWDB performed Task 3 using the flow scenarios developed by FNI in Task 2. Whereas Task 2 uses the monthly WAM to assess the impact of trends in streamflow and groundwater elevations on water supply sources, Task 3 uses the daily WAM to assess the impact on the attainment of environmental flow standards.

To date, the daily WAMs have been used primarily as a research tool and have not been routinely used for regional water planning or water rights applications. The existing daily WAM for the Brazos River Basin requires some modifications prior to use in this study. The daily WAM available from Texas A&M does not include the BRA System Operation Permit, which is an existing supply that influences the way many of the reservoirs in the basin are operated. The System Operation Permit was added to the daily WAM by incorporating the modeling techniques used to simulate the Permit at the monthly timescale. The water management strategies scheduled to come online by 2050 according to the Regional Water Plans for Regions G and H were also added to the daily WAM model.

In addition to the baseline full authorized diversions scenario (i.e. Run 3), the following future use scenarios were developed for analysis in Task 3:

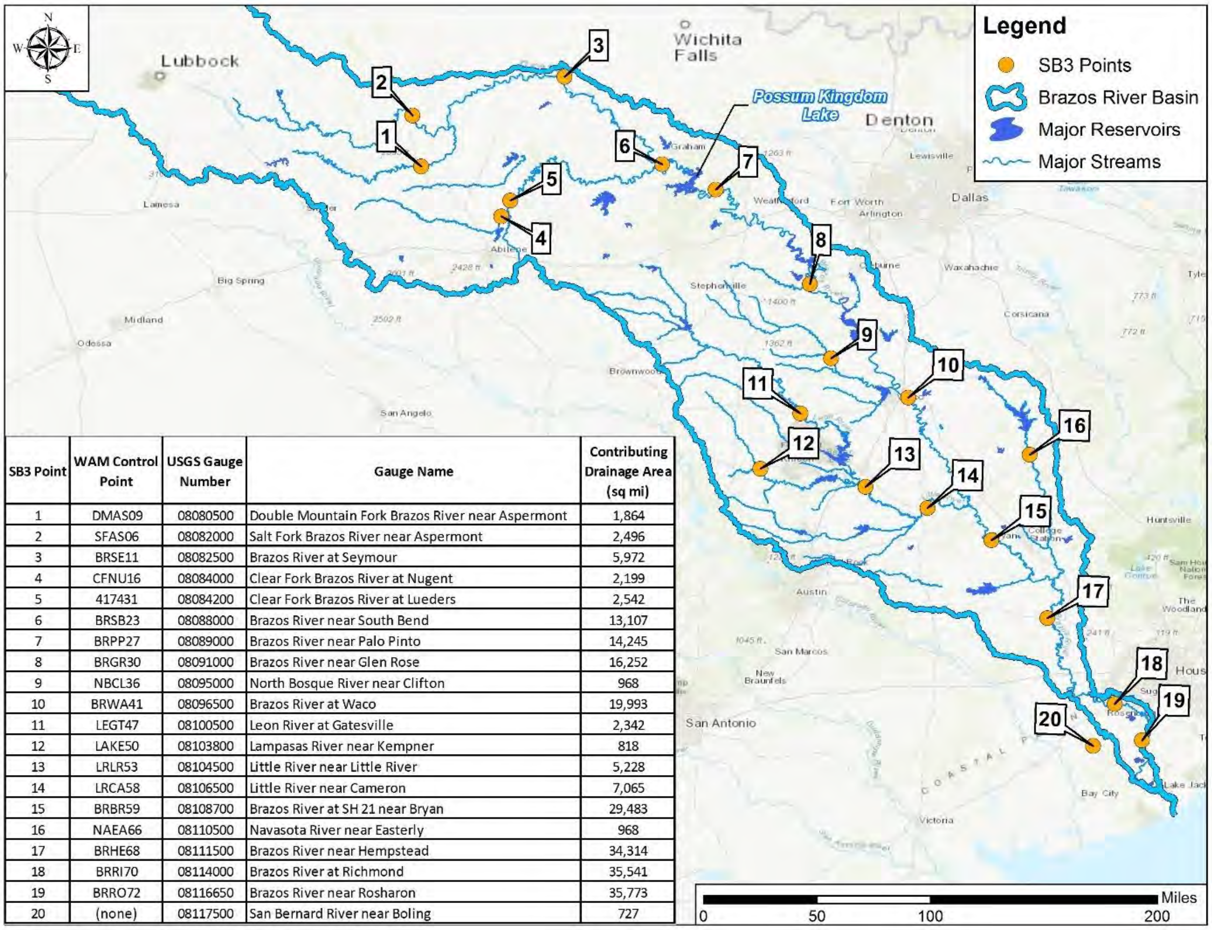
- Full authorized diversions of existing water rights (Run 3) plus the water management strategies scheduled to come online in 2040, plus the water management strategies scheduled to come online in 2050.

The attainment frequency of environmental flow standards was evaluated for each flow scenario based on the metrics listed in Pauls and Wurbs (2016), which were developed specifically for daily simulations. The metrics were evaluated by season (i.e. winter, spring, and summer as defined by statute), flow type (i.e. subsistence, base, or pulse flows), and hydrologic condition (i.e. dry, average, or wet).

The WAMs allocate water in a date-based priority system in which senior (earlier) water rights have priority. Within the daily WAM, the environmental flow standards have a priority date of 3/1/2012. The future water management strategies are not expected to impact the attainment frequency of environmental flow standards over baseline conditions (full use of existing water rights) because future water management strategies will be added to the WAM as junior water rights. We do not expect future surface water projects to increase the frequency of occurrence of flows below subsistence, but they will decrease the frequency of exceedance of seasonal base and pulse flow thresholds when compared to a without future projects baseline. If hydrological trends decrease streamflow availability, the yields of those strategies may be affected and water rights senior to the environmental flows could negatively impact attainment frequencies.

There may also be considerable value in comparing the attainment frequencies based on the daily WAM to the frequencies calculated using the monthly WAMs. Within the monthly WAM, the environmental flow standards can be modeled as they are currently modeled in the official TCEQ WAM. The standards can also be modeled in the monthly WAM by setting hard-wired environmental flow targets (using TS records within WRAP) that were calculated within the daily WAMs.

Figure 1-15 is a map of the WAM control points for which environmental flow standards have been adopted by rule for the Brazos River Basin (i.e. SB3 Points). Primary control points are those points for which naturalized flow is input into the WAM. The SB3 Points correspond to primary WAM control points, except for SB3 Point 5 (Clear Fork of the Brazos River at Lueders) which was added for the proposed Cedar Ridge Reservoir. SB3 Point 20 is listed in the Texas Administrative Code (§298.480) but is in the coastal basin and does not correspond to a control point in the Brazos WAM. Possum Kingdom Lake is generally regarded as the divider between the upper-basin upstream and the mid- and lower-basin downstream.



SB3 Point	WAM Control Point	USGS Gauge Number	Gauge Name	Contributing Drainage Area (sq mi)
1	DMAS09	08080500	Double Mountain Fork Brazos River near Aspermont	1,864
2	SFAS06	08082000	Salt Fork Brazos River near Aspermont	2,496
3	BRSE11	08082500	Brazos River at Seymour	5,972
4	CFNU16	08084000	Clear Fork Brazos River at Nugent	2,199
5	417431	08084200	Clear Fork Brazos River at Lueders	2,542
6	BRSB23	08088000	Brazos River near South Bend	13,107
7	BRPP27	08089000	Brazos River near Palo Pinto	14,245
8	BRGR30	08091000	Brazos River near Glen Rose	16,252
9	NBCL36	08095000	North Bosque River near Clifton	968
10	BRWA41	08096500	Brazos River at Waco	19,993
11	LEGT47	08100500	Leon River at Gatesville	2,342
12	LAKE50	08103800	Lampasas River near Kempner	818
13	LRLR53	08104500	Little River near Little River	5,228
14	LRCA58	08106500	Little River near Cameron	7,065
15	BRBR59	08108700	Brazos River at SH 21 near Bryan	29,483
16	NAEA66	08110500	Navasota River near Easterly	968
17	BRHE68	08111500	Brazos River near Hempstead	34,314
18	BRRI70	08114000	Brazos River at Richmond	35,541
19	BRRO72	08116650	Brazos River near Rosharon	35,773
20	(none)	08117500	San Bernard River near Boling	727

Figure 1-15 – Map of SB3 Points in the Brazos (i.e. WAM Control Points for which Environmental Flow Standards Have Been Developed)

1.4 LIMITATIONS

1.4.1 Interpretation of Results

The results of this study provide an assessment of on-going trends within a study area. The study does not directly provide the cause for the trends nor does it assess whether the trends will increase or decrease beyond the analysis period (i.e., it is a current snapshot of the trends). As expected, some trends will diminish or stabilize over time as the root cause of the impact to streamflow slows or stops. This approach also does not address future changes that may be accelerated over time, such as climate change. It is important to remember that trends are dynamic and perpetual extension of trends into the future may not be reasonable. Updating the analysis every few years as new data become available would help ameliorate this issue.

1.4.2 Applicability to Other Basins in Texas

The approach in this study was developed with the intention that it could be applied to other river basins in Texas. However, it is important to recognize that available data and primary factors affecting streamflows could vary significantly between basins and/or subbasins. Some river basins have greater groundwater influence, which could be a driving factor for the noted trends. Other basins may be subject to increased temperatures and evaporative losses, or distinct trends in precipitation. While each of these factors are considered in the trend analysis methodology, it was tested on the Brazos River Basin. Adjustments to the methodology may be warranted for river basins with very different hydrological conditions.

1.4.3 Uncertainty in Trend Slopes

The slopes of the trends identified are subject to uncertainty embedded in the assessment approach, including start and end dates, temporal scale, and major one-time events (2011 drought, Hurricane Harvey flooding). The study methodology mitigates some of these issues by considering trends on a seasonal timescale, adjusting for outliers, and identifying an optimal starting year. However, caution is needed when assuming that these observed trends can be carried forward as a projection of future conditions.

The starting year for a trend analysis can impact results considerably. Even if we assume that future trends through 2070 will resemble observed historical trends (which may not be the case), we cannot say with certainty whether the 2020-2070 trend will look more like observed trends from 1940 through 2015 or observed trends from 1960 through 2015. The study methodology attempts to address this limitation by assuming that the trend most likely to continue in the future is the strongest observed trend of significance continuing through the present day.

1.4.4 Reliance on Historical Data

In this study, adjustments to historical hydrology are based on observed trends rather than using modeled future trends. This is an important limitation because future conditions may not follow the pattern of observed trends. Others in the literature have extrapolated observed trends (Zhu and Fernando (2017), Zhu et al. (2021), and Nielsen-Gammon et al. (2020)), but projections based on downscaled GCMs are more common.

Other studies that used GCMs for forward projection have found that the models predict trends that have not yet been realized in the observed record. For example, in a previous trend study in the Brazos River Basin, “no significant long-term trends or stepwise trends were detected in the series of naturalized streamflow selected for analysis,” but forward projections based on the Canadian Center for Climate Modeling and Analysis (CCCMA) GCM produced substantial changes in streamflow (Wurbs et al. (2005)).

1.4.5 Single Scenario

This methodology applies adjustment factors to each value in the naturalized flow and net evaporation time series from the Brazos WAM. However, no resampling or reordering of these values is applied, so the pattern of month-to-month variability remains largely the same. It is important to demonstrate that the single scenario approach reasonably adjusts the historical hydrologic sequences to account for trends prior to introducing complex synthetic hydrology approaches.

A multi-scenario approach would provide an ensemble of potential future hydrology time series, which could provide insight on changes that cannot be achieved by directly adjusting the historical hydrology. For example, a combined Monte Carlo Markov Chain approach could be applied to resample historical hydrology, such as the analyses done by Prairie et al (2008), USBR (2018), and Zhu et al. (2021). Alternatively, projected climate variables from multiple GCMs could provide a range of potential climate conditions on which naturalized flows could be modeled.

1.4.6 Other Considerations

1. Potential changes in the frequency of seasonal hydrologic conditions (e.g., dry summers or wet winters) are difficult to characterize with less than 100 years of data. The approach in this study does not account for the fact that a given hydrologic condition may occur more or less frequently in the future.

2. Adjusting FLO and EVA independently of each other is a simplifying assumption. In reality, trends in temperature, evaporation and precipitation will interact with and influence trends in antecedent moisture conditions and streamflow. Similar to Kiem et al. (2020), this study is based

on the observed historical relationship between flow, temperature, and precipitation, and so may not account for potential changes in the way the variables respond as the trends move outside the observed range.

3. TCEQ is currently developing fully naturalized flows for the Brazos River Basin from 1940 through 2018. However, those flows were not available in time for this study. Instead, "semi-naturalized" flows were used to extend the period of record for the original WAM from 1997 through 2015. This creates a minor inconsistency between the 1940-1997 data and the 1998-2015 data. We do not expect this difference in data to appreciably influence trend detection; to the contrary, the additional 18 years of semi-naturalized data is valuable for identification of trends continuing through the present day.

4. Sedimentation reduces the capacity of reservoirs over time. To model future sedimentation conditions of reservoirs, area-capacity curves in the WAM are typically adjusted each decade based on historical sedimentation rates. Where trends are present in streamflows, sedimentation rates may also be changing. An assessment of the potential changes to sedimentation rates is outside the scope of this study. However, such changes are expected to have a small impact on overall water availability and can be addressed through future sedimentation surveys.

5. Adjustments to flow and evaporation are made similarly to all years (or all springs, all summers, or all winters) except when the selected trend for adjustment is based on seasons of a specific hydrologic condition. Trends that continue into the future will likely not impact all years equally.

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Zhu, J., Fernando, N., and Guthrie, C. (2021). Estimate of Long-Term Water Availability for a Reservoir in Texas Using a Markov Chain Monte Carlo Method with Paleo Drought and Trend Consideration. Selected Papers from the *Proceedings of the World Environmental and Water Resources Congress 2021*, June 21 – 25, 2021 (accepted).

Zhu, J. and N. Fernando. (2017). Forecasting Long-term Water Supply Using Stochastic Methods with Trend Consideration: A Study on Lake Meredith in the Canadian River Basin in Texas. *Science and Technology Infusion Climate Bulletin, 42nd NOAA Annual Climate Diagnostics and Prediction Workshop*, Norman, OK, 23-26 October 2017.

APPENDIX 1-A: RESPONSE TO TWDB COMMENTS ON DRAFT CHAPTER 1

The first draft of the Brazos Trends Study Chapter 1 (Literature Review and Assessment Methodology) was submitted to the TWDB for review on February 4, 2021. TWDB reviewed Draft Chapter 1 and provided a list of major and minor comments on March 9, 2021. The following appendix contains formal responses to the comments from TWDB and descriptions of accompanying updates incorporated into Draft Chapter 1 Revision #1.

Major Comments and Responses (shown in *italics*)

1. Section 1.2.1, page 1-4, Section summarizing Harwell et al., 2020: Consider adding a point that describes how trends in other basins vary from those for the Brazos.

   Response: *A description of general trends in the other Texas river basins analyzed in Harwell et al. (2020) was incorporated in Section 1.2.1, page 1-4, second paragraph of the Harwell et al. (2020) section: "Harwell et al. (2020) also studied several other basins (Colorado, Big Cypress, Guadalupe, Neches, Sulphur, and Trinity). Their findings in those basins indicate the types of trends that exist in other basins, which vary from their findings in the Brazos River Basin. For these other basins, results of precipitation trend analyses on an annual time step in basin sections were primarily upward trends (lower Guadalupe, Neches Sulphur, Trinity) or no trend was found (Colorado, Big Cypress). Despite upward trends in precipitation in sections of these other basins, trends in annual streamflow varied. Upward trends in annual streamflow were indicated in the upper Trinity basin and one station in the upper Big Cypress and upper Guadalupe basins, whereas downward trends were found in the upper Colorado basin and one station in the upper Big Cypress and Sulphur basins, and no trends were found in the lower Colorado, lower Big Cypress, lower Guadalupe, Neches, and lower Trinity basins."*

2. Section 1.2.1, page 1-4, Section summarizing Zhu and Fernando, 2017: Consider adding a brief clarifying point describing what the reconstructed PDSI data were used for in the study.

   Response: *A clarifying statement was added to Section 1.2.1, page 1-5, second paragraph of the Zhu and Fernando (2017) section to describe the purpose of the reconstructed PDSI data in the Zhu et al. (2021) study: "Reconstructed PDSI provided a means to assess regional* *drought variability over an extended time period. Drought duration in the study was defined as the number of years where the summer PDSI is continuously below zero."*

3. Section 1.2.1, page -1-9, Section summarizing Nielsen-Gammon et al., 2020, first sentence: Consider adding a clarification that the projection was done using climate model output.

   Response: *A statement was added to Section 1.2.1, page 1-10, first paragraph of the Nielsen-Gammon et al. (2020) section to clarify that the projections from Nielsen-Gammon et al. (2020) were done using a climate model output: "…and then projected trends forward to 2036 using a climate model output."*

4. Section 1.2.1, page 1-9, Section summarizing Nielsen-Gammon et al., 2020, last sentence:

   a. Nielsen-Gammon et al. (2020) state that precipitation intensity is projected to increase. Summertime rainfall is projected to decrease but there is no model consensus on whether there will be an overall increase in rainfall over Texas. Drought projections for West Texas and East Texas indicate shifts towards drier conditions.

   b. Please consider revising the existing sentence to reflect points covered in a.

   Response: *A statement was added to Section 1.2.1, page 1-11, first paragraph of the Nielsen-Gammon et al. (2020) section to reflect the points mentioned in Comment 4.a: "…the tendency for increasing precipitation in Texas is not consistent with other global climate models, which on average show a slightly decreasing trend in precipitation per century across Texas, indicating that there is not a model consensus. The majority of influential factors on drought (temperature, carbon dioxide, evapotranspiration, runoff) indicate that drought severity will increase in Texas, but it is impossible to make a quantitative statewide projection. Ultimately, multidecadal variability in precipitation and drought severity are so large across Texas that they are likely to have a greater impact than any underlying long-term trends."*

5. Section 1.3.2, page 1-16, point 2: Detrending the time series

   a. Typically, detrending of a time series is done to identify cycles (i.e., oscillations or variability) in a time series.

Response: *This comment was addressed in a memo sent to the TWDB from the consultant team on March 26, 2021, which is included in Appendix 1-B.*

b. In this study, we are interested in incorporating the trend over time. Therefore, it is unclear why the data are being detrended here. Please provide the rationale for detrending the data.

Response: *This comment was addressed in a memo sent to the TWDB from the consultant team on March 26, 2021, which is included in Appendix 1-B.*

c. Did any of the articles reviewed for the literature review propose detrending of datasets prior to further analysis? If so, please include a mention of this methodology under the relevant literature summary.

Response: *This comment was addressed in a memo sent to the TWDB from the consultant team on March 26, 2021, which is included in Appendix 1-B.*

d. If none of the articles proposed detrending of datasets prior to further analysis, it is unclear how the literature review informed the selection of this particular portion of the methodology. [Further clarification may be needed via a phone call].

Response: *This comment was addressed in a memo sent to the TWDB from the consultant team on March 26, 2021, which is included in Appendix 1-B.*

e. If we take Possum Kingdom's yield without detrending, the existing baseline yield is 100,000 ac-ft/y and the future yield may be 90,000 ac-ft/y in 2070 due to decreasing trends in flow. After detrending, the existing baseline yield may increase to 110,000 ac- ft/y, and the future yield may be 99,000 ac-ft/y in 2070. If the method of detrending is retained it may be necessary to simulate current firm yield under two scenarios: i.e., existing data and detrended data. [This is a point to consider, further discussion may be needed; no action required to address comment at this point.]

Response: *This comment was addressed in a memo sent to the TWDB from the consultant team on March 26, 2021, which is included in Appendix 1-B.*

6. Section 1.3.2, page 1-16, point 2, page 1-17: Please consider explaining why there is a need to

not have a trend in the adjusted data.

Response: *This comment was addressed in a memo sent to the TWDB from the consultant team on March 26, 2021, which is included in Appendix 1-B.*

7. Section 1.3.2, Figure 1-1, second panel: The plot of the detrended data series looks more like normalized data where the mean has been removed. In such a time series, it is clear that the average would be zero. Is it always the case though that if a trend is removed in a time series its mean would still be zero?

   Response: *This comment was addressed in a memo sent to the TWDB from the consultant team on March 26, 2021, which is included in Appendix 1-B.*

8. Section 1.3.3, page 1-21, first paragraph: Please consider clarifying how trends that continue beyond the present are going to be identified.

   Response: *The phrase "trends of interest to this study should continue up to and beyond the present" was revised in Section 1.3.3, page 1-24, first paragraph of the "Determination of Starting Year" section, as no data is available to identify trends beyond the present: "long-term trends of interest are those that persist through the end of the period of analysis. In other words, trends present from 1960 to 2010 but disappearing after 2010 will not be used to adjust WAM inputs for future conditions."*

   Additional language was added to Section 1.3.3, page 1-25, third paragraph of the "Determination of Starting Year" section to highlight the limitations of this assumption: "This study assumes that trends identified as significant by the Kendall's tau methodology and persisting for at least 50 years will continue into the future at least until 2070. Furthermore, the slope of the strongest trend, as characterized by Kendall's tau, will be applied in this study, but it should be noted that this slope is not necessarily the most accurate slope for the projection into the future. These assumptions should be treated as limitations to the results of this study, as trend attribution and the assessment of climate projections to determine future trends were beyond the scope of this project."

9. Section 1.3.3, page 1-21, second paragraph: Please consider using wording to state that the study identified stronger trends for projection into the future.

a. Whether or not the stronger trend is the "accurate trend slope" is debatable.

__Response:__ The assertion that the strongest trend would "identify a more accurate trend slope" has been removed from Section 1.3.3, page 1-24, second paragraph of the "Determination of Starting Year" section.

b. Therefore, please include wording that speaks to the assumption that stronger trends were assumed to continue into the future but are not necessarily "a more accurate trend slope".

__Response:__ Additional language was added to Section 1.3.3, page 1-25, third paragraph of the "Determination of Starting Year" section to highlight the limitations of this assumption: "This study assumes that trends identified as significant by the Kendall's tau methodology and persisting for at least 50 years will continue into the future at least until 2070. Furthermore, the slope of the strongest trend, as characterized by Kendall's tau, will be applied in this study, but it should be noted that this slope is not necessarily the most accurate slope for the projection into the future. These assumptions should be treated as limitations to the results of this study, as trend attribution and the assessment of climate projections to determine future trends were beyond the scope of this project."

10. Section 1.3.4, page 1-29, Step 4: Please consider clarifying how the expected average value of Q in the future is obtained.

__Response:__ The language in Section 1.3.4, page 1-36, item 1 of Step 4 (Calculate flow adjustment factors) was revised to clarify that this sub-step describes the calculation of the expected future average value of Q: "1. Extrapolate the trend in monthly incremental flow to 2070 to obtain the expected average value of Q in 2070 $Q_{trend}(2070)$*."*

11. Section 1.3.4, page 1-32, last sentence: Are the TWDB quadrangle data not always used to estimate gross reservoir evaporation?

__Response:__ In the development of the EVA input file for the Brazos WAM, local reservoir evaporation data from the U.S. Army Corps of Engineers (USACE) Fort Worth District is used to estimate gross reservoir evaporation for some reservoirs (BRA Drought Study, *Freese & Nichols (2017)). In most cases, local data from USACE is not available and TWDB quadrangle data is used to estimate gross reservoir evaporation.*

12. Section 1.3.5, page 1-33, first paragraph, last sentence:

    a. Is there a citation to back the statement that the PRISM data are not homogenized? If so, please include. If not, please remove this statement. The PRISM dataset is considered to be of a very high quality.

    Response: *Yes. There is a citation found in the "Descriptions of PRISM Spatial Climate Datasets for the Coterminous United States" documentation available on the PRISM website (revised in October 2019). In this document, it states that the PRISM grids contain "non-climatic variations due to station equipment and location changes, station openings and closings and varying observation times", i.e., it is not homogenized.*

    b. By homogenized, was the intended meaning that the data are not available as spatially averaged datasets for different boundaries? If so, please consider rewording this statement to convey this meaning and omit use of the term "homogenized".

    Response: *The following information was added to Section 1.3.5, page 1-36, third paragraph to clarify the use of the term "homogenized": "PRISM grids contain 'non-climatic variations due to station equipment and location changes, station openings and closings and varying observation times.' "*

13. Section 1.3.7, page 1-43: Please add "and Region H".

Response: *"Region H" was added to Section 1.3.7, page 1-47, first paragraph: "The objective of Task 2 is to assess the impacts of the observed trends on availability of surface water supplies identified in the Region G and Region H 2021 Regional Water Plans…"*

14. Section 1.5, references, page 1-53: reference for PRISM

    a. Was the PRISM data used for analysis?

Response: *The PRISM data was not used for this analysis because, according to the PRISM supporting documentation "Descriptions of PRISM Spatial Climate Datasets for the Coterminous United States", "the dataset is currently not suitable for calculating multi-decadal trends." Thus, the NOAA U.S. Climate Divisional Dataset was deemed more appropriate for this analysis. Additional language was added to Section 1.3.5, page 1-36, third paragraph to reflect this: "The PRISM Climate Group also provides a set of monthly gridded temperature and precipitation data; however, according to PRISM documentation, the 'dataset should not be used to calculate multi-decadal trends' because the PRISM grids contain 'non-climatic variations due to station equipment and location changes, station openings and closings and varying observation times.' Thus, the NOAA U.S. Climate Divisional Dataset was deemed more appropriate for this study."*

b. If not, if the citation is for the PRISM dataset in general, please use one of the Daly citations.

Response: *The citation for PRISM primarily refers to the "Descriptions of PRISM Spatial Climate Datasets for the Coterminous United States" documentation available on the PRISM website (revised in October 2019). A citation to this document was added Citations to Section 1.5, References, page 1-58. Citations to Daly et al. (2008, 2015) were also added to reference the general PRISM dataset in Section 1.5, References, Page 1-55.*

Minor Comments and Responses (shown in *italics*)

1. Report introduction: add "in the upper basin of the Brazos River basin" in the sentence citing Harwell et al. (2020).

   Response: *The phrase "in the upper basin of the Brazos River basin" was added to the Report Introduction section, first paragraph, line 5.*

2. Report introduction, line 5, delete one use of "in the".

   Response: *The one repeated use of "in the" was deleted from to the Report Introduction section, first paragraph, line 5.*

3. Section 1.2.1, page 1-13, Section summarizing Albright, 2014: Should BRAA be BRA?

Response: *In this instance, "BRAA" refers to the Brazos River Alluvium Aquifer as defined in the previous section [Turco et al. (2007), Ewing et al. (2016)].*

4. Section 1.2.1, page 1-9, first paragraph, last sentence: add "e" after "us" for land use.

   Response: *An "e" was added after "us" for the term "land use" in Section 1.2.1, page 1-9, first paragraph of Rodgers et al. (2020) section.*

5. Section 1.3.4, page 1-32, last paragraph: add a comma after "wind speed"

   Response: *A comma was added after the term "wind speed" in Section 1.3.5, page 1-36, second paragraph.*

APPENDIX 1-B: RESPONSE TO COMMENTS ON DRAFT CHAPTER 1 REGARDING DETRENDING

The following memorandum was submitted by e-mail to TWDB on March 26, 2021, in response to Comments 5, 6, and 7 on the February 4 version of Draft Chapter 1.

RESPONSE TO COMMENTS

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TO:	Nelun Fernando (TWDB)
FROM:	Spencer Schnier and Courtney Corso (FNI)
SUBJECT:	Response to Comments Regarding Detrending on Draft Chapter 1
PROJECT:	Brazos Trends Study
DATE:	March 26, 2021

The Texas Water Development Board (TWDB) provided comments to Freese and Nichols (FNI) on the draft of Chapter 1 of the Brazos Trends Study on March 9, 2021. FNI will formally address these comments as part of the final report. However, at this time we would like to respond to Comments 5, 6, and 7, which address the approach of detrending data series before extrapolating trends. Comments 5, 6, and 7 are reproduced below in **bold**, and FNI responses follow.

TWDB Comment 5. Section 1.3.2, page 1-16, point 2: Detrending the time series

a. **Typically, detrending of a time series is done to identify cycles (i.e., oscillations or variability) in a time series.**

The reviewers are correct that detrending time series is typically done to identify seasonal cycles or variability in a time series. The proposed approach uses the detrending procedure for the same purpose, namely to extract the natural hydrologic variability through time, independent of the trend in observed streamflow, temperature, or precipitation data.

b. **In this study, we are interested in incorporating the trend over time. Therefore, it is unclear why the data are being detrended here. Please provide the rationale for detrending the data.**

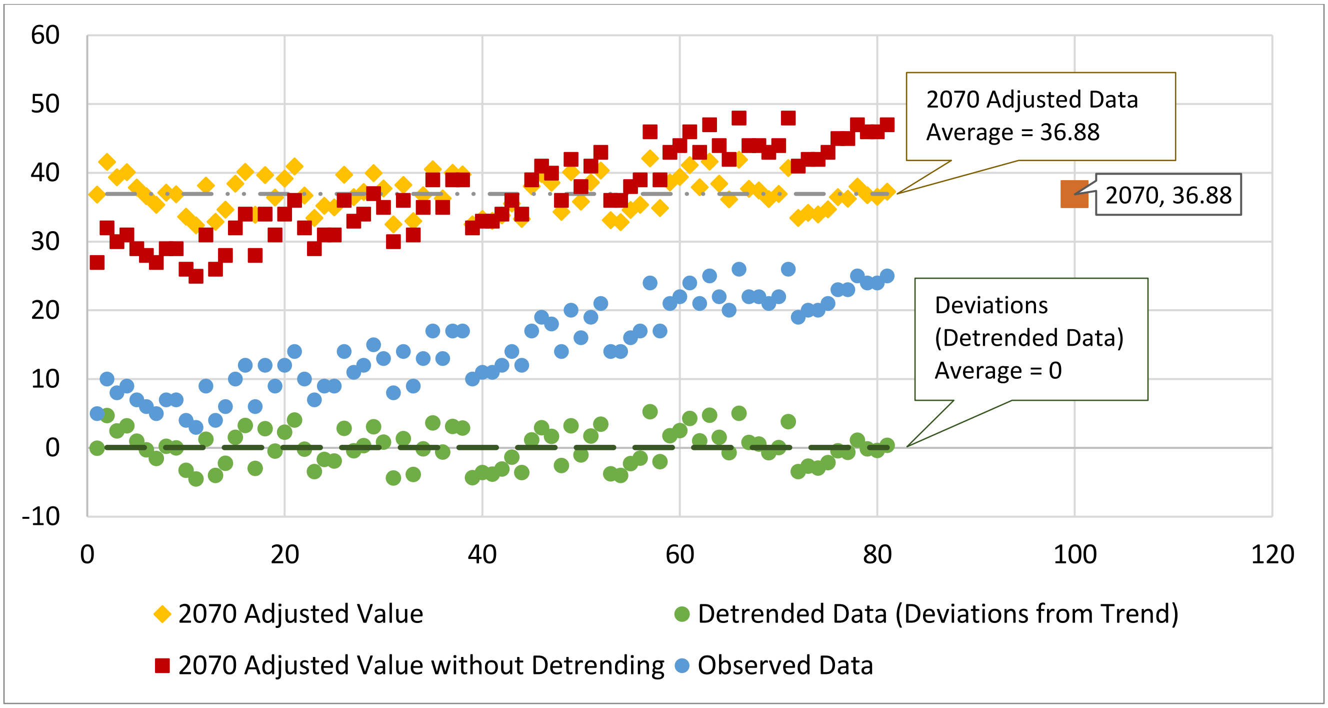
This is a key question, the answer to which will be better elucidated in the revised Chapter 1. Sam Vaugh at HDR made the following comment on an early iteration of the methodology that speaks to the rationale for detrending the data: "If an historical trend is sufficiently significant to extrapolate it into the future, then adjustments early in the historical record should be greater than adjustments late in the historical record in order to obtain a complete historical data set representative of current or some future condition. This could be particularly significant if the drought of record was in the 1950s." He went on to say, "bottom line, if a trend-removed historical record has been successfully derived, then a regression line based on the resulting… values for [the] period of record should have no slope and pass through the projected future condition". The approach proposed in Chapter 1 extrapolates the observed trend in streamflow or net evaporation to come up with a projected future *average* value. Then, the historical values are detrended, such that new average of that time series is zero, which is then added to the projected future average value to restore the natural hydrologic variability to the time series.

The intent of the overall approach is to carry forward significant trends observed in the historical series to produce a new time series of hydrology (streamflows and net evaporation) that would represent future conditions in the model. However, as Mr. Vaugh pointed out, if the observed trends are indeed significant, this implies that the hydrologic input data for the WAM already contain a trend. The step outlined in Section 1.3.2, described there as "detrending," develops a sequence of deviations from the trend for that series. Thus, the series of deviations ("detrended data" in Draft Chapter 1) represents the variability in streamflows or net evaporation that has occurred over the observed period of record. Then, those deviations are applied to the trend-projected average at some future time.

The figure below illustrates two alternative future time series (using example data), one which is based on the original historical data and the other being based on detrended historical data. The red series shows that directly adjusting historical observations maintains the presence of a trend in the future time series. The yellow series shows a potential future series based on the observed deviations from the trend, or detrended data. Ultimately, the detrending approach was selected for the Brazos Trends Study because it represents a 76-year time series of potential 2070 hydrology. Alternatively, choosing not to remove the trend from the projections produces a time series that could be considered 2033-2108 hydrology: 76 years that are centered around 2070 but which reflect conditions from years 2033 to 2108 due to the ongoing impact of the trend over time.

If instead of 76 years of 2070 hydrology, we desired a time series representing 2033-2108 hydrology, then we could not say we are determining firm yields for 2070 conditions. For example, if the firm yield of a given reservoir is determined by the 2011-2015 drought, then under the alternative approach that uses

2033-2108 hydrology, the new firm yield would actually be determined by conditions in years 2104-2108 (not conditions in year 2070).



c. Did any of the articles reviewed for the literature review propose detrending of datasets prior to further analysis? If so, please include a mention of this methodology under the relevant literature summary.

The literature review in the draft of Chapter 1 does not directly address detrending of datasets prior to further analysis. We agree that it would be beneficial to include citations and discussion of detrending in the literature review. For example, Wu et al. (2007) state that "the most common detrending process usually consists of removing a straight line best fit, yielding a zero-mean residue"[1]. As part of the final report, we plan to revise the relevant literature review sections to include citations and discussion of detrending to illustrate its application to this study.

[1] Wu, Z., N. E. Huang, S. R. Long, and C.-K. Peng (2007). On the trend, detrending, and variability of nonlinear and nonstationary time series. Proceedings of the National Academy of Sciences (PNAS), 104(38): 14889-14894.

d. If none of the articles proposed detrending of datasets prior to further analysis, it is unclear how the literature review informed the selection of this particular portion of the methodology. *[Further clarification may be needed via a phone call]*.

The rationale for detrending the data is provided in response to TWDB Comment 5b above. Our response to Comment 5c above acknowledged that the literature review needs to be more robust regarding detrending data. A discussion of how the literature review informed the selection of this particular portion of the methodology is included here.

Zhu and Fernando (2017) and Zhu et al. (2021) extrapolated historical trends in streamflow to project future streamflow conditions. Most of the other studies cited in the literature review that projected future streamflow conditions used modeled projections of future climate from Global Circulation Models (GCMs) or stochastically resampled historical hydrology. In the present study, the approach for extrapolating trends forward in time was inspired by Zhu and Fernando (2017) and evolved through discussions with the project advisory team. The project advisory team includes TWDB, the U.S. Army Corps of Engineers, the Brazos River Authority, HDR Engineering, and senior FNI staff. While the proposed methodology differs from that in Zhu and Fernando (2017) and Zhu et al. (2021), the removal of a trend was inherent in Zhu et al.'s approach as well. Zhu and Fernando (2017) and Zhu et al. (2021) applied a variable multiplicative factor that took the historical trend-predicted value V_{t_1} as the denominator, which has a similar effect of scaling the trend for the projected future series.

e. If we take Possum Kingdom's yield without detrending, the existing baseline yield is 100,000 ac-ft/y and the future yield may be 90,000 ac-ft/y in 2070 due to decreasing trends in flow. After detrending, the existing baseline yield may increase to 110,000 ac-ft/y, and the future yield may be 99,000 ac-ft/y in 2070. If the method of detrending is retained it may be necessary to simulate current firm yield under two scenarios: i.e., existing data and detrended data. *[This is a point to consider, further discussion may be needed; no action required to address comment at this point.]*

The point made by the TWDB reviewers is well taken. As previously mentioned, if the observed trends in naturalized streamflows and/or net evaporation are significant, then the hydrologic inputs for the existing

WAM already contain a trend. In this case, to determine a firm yield for “current” (e.g., 2020) conditions would require a procedure similar to the one described in the draft Chapter 1 for 2070 conditions.

With regard to the Possum Kingdom example, assuming a decreasing trend in streamflow, and further assuming that the firm yield calculated using the existing WAM is 100,000 ac-ft/yr, the firm yield for 2070 conditions may be estimated to be 90,000 ac-ft/yr using the procedure outlined in the draft Chapter 1, while the firm yield for 2020 conditions may be estimated to be around 97,000 ac-ft/yr.

TWDB Comment 6. Section 1.3.2, page 1-16, point 2, page 1-17: Please consider explaining why there is a need to not have a trend in the adjusted data.

Please refer to our response to TWDB Comment 5a above. To briefly summarize, there is a need to not have a trend in the adjusted data because it represents 76 years of 2070 hydrology. An alternative would be to not remove the trend from the projections, but that would produce a time series that could be considered 2033-2108 hydrology: 76 years that are centered around 2070 but which reflect conditions from years 2033 to 2108 due to the ongoing impact of the trend over time.

If the drought of record for a given reservoir is from 2011-2015, then if we followed this alternative 2033-2108 approach, the 2070 firm yield of that reservoir would be determined by 2104-2108 conditions. In other words, the ‘true’ 2070 firm yield would be underestimated (assuming a decreasing trend in streamflow). Conversely, if the drought of record is the 1950s drought, then under this alternative 2033-2108 approach the firm yield for “2070” conditions would be determined by hydrology in the late 2040s, which would overestimate the ‘true’ firm yield.

Given that one of the goals of the Brazos Trends Study is to determine how water availability and environmental flow attainment metrics are likely to change under *2070* conditions, having firm yields determined by conditions in either 2040 or 2100 would be undesirable.

TWDB Comment 7. Section 1.3.2, Figure 1-1, second panel: The plot of the detrended data series looks more like normalized data where the mean has been removed. In such a time series, it is clear that the average would be zero. Is it always the case though that if a trend is removed in a time series its mean would still be zero?

Throughout the draft of Chapter 1, the term "detrending" is used to describe the calculation shown in Equation 1-2:

$$Y_{detrended}(t) = Y_{observed}(t) - Y_{trend}(t)$$ *Equation 1-2*

For clarity, we propose that $Y_{detrended}(t)$ be renamed $Deviation(t)$ throughout the chapter. The deviations (i.e., $Y_{observed}(t) - Y_{trend}(t)$) of the observed data from a well-fit least-squares regression trendline, whether linear or exponential, will have an average value of approximately zero. This "detrended" time series represents the variability present in the observed data that is not due to the presence of a trend. In the current study, this time series of deviations from the trend (with an average of approximately zero) is added to the average streamflow projected for the decade of interest (e.g., 2070) to reconstruct a realistic hydrologic time series that replicates historical variability given a new average condition.

APPENDIX 1-C: EXAMPLES OF START YEAR DETERMINATION METHODOLOGY

Example 1. Selection of Start Year Based on Greatest Tau Value

When assessing trends in annual temperature in Climate Division 4108, the Kendall's tau value generally increased in magnitude with later start years, as shown in Figure 1-C-1. The slope of the trendline also increased with later start years. The methodology identifies the start year for which absolute value of Tau is the greatest, so the selected start year for trend analysis is 1968.

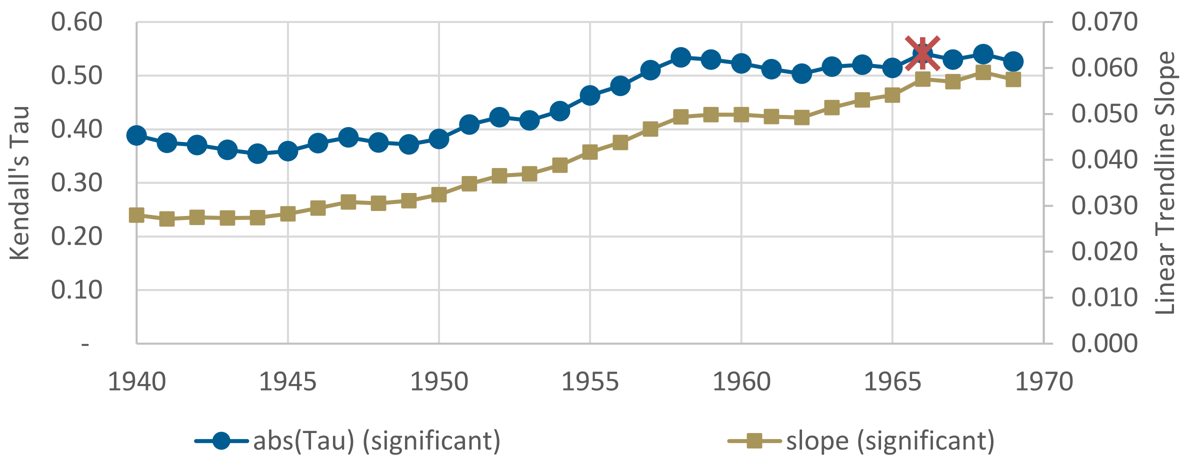


Figure 1-C-1 – Average Annual Temperature in Climate Division 4108

Example 2. Exception to Start Year Selection Based on Review

An assessment of trends in annual precipitation in Climate Division 4108 initially identified 1950 as the best start year for trend analysis. However, upon examination of the trends from various start years, it was found that trends in precipitation were only significant if the period of analysis began between 1945 and 1952, a historically dry period (Figure 1-C-2). Beginning the analysis in drier years skewed the time series so that precipitation appeared to be increasing over time, but that trend was a result of the start year selection rather than a true long-term trend. Based on this review, the identified start years were discarded and 1940 was used instead as the beginning of the analysis period for seasonal and seasonal conditional trends in precipitation in this climate division.

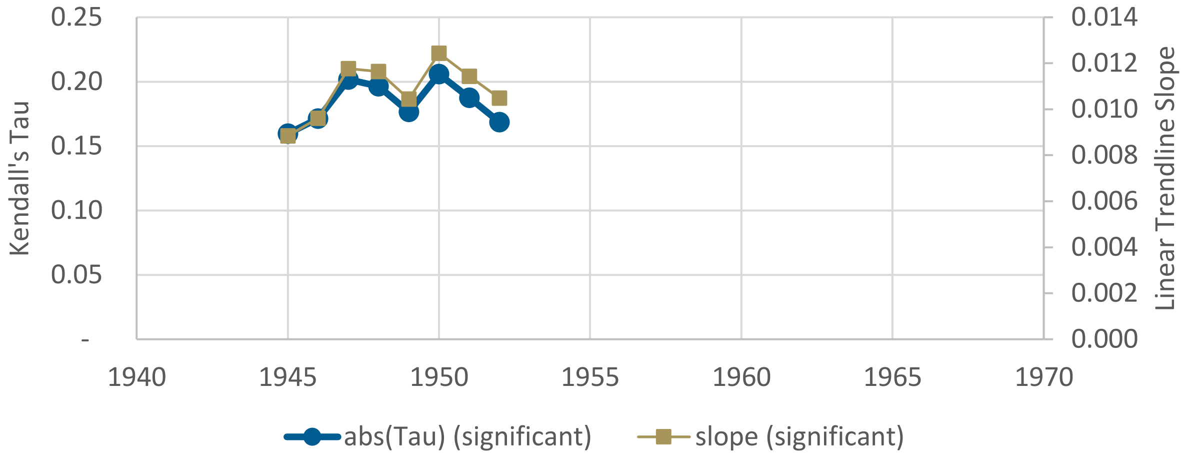


Figure 1-C-2 – Annual Precipitation in Climate Division 4108

APPENDIX 1-D: PALMER HYDROLOGICAL DROUGHT INDEX AND CLASSIFICATION OF SEASONS BY HYDROLOGIC CONDITION

The Palmer Hydrological Drought Index (PHDI) "measures hydrological impacts of drought (e.g., reservoir levels, groundwater levels, etc.) that take longer to develop and longer to recover from [than other climatic conditions]" (NOAA NCEI, 2021). In comparison to the Palmer Drought Severity Index (PDSI), which is another common drought index used to measure the duration and intensity of long-term drought-inducing circulation patterns, PHDI responds more slowly to changing conditions.

Monthly PHDI data from 1940 through 2019 was downloaded from the NOAA National Data Center (NNDC) Climate Data Online (CDO) in December 2020 for each of the climate divisions located in the Brazos River Basin. For each climate division, monthly PHDI values were averaged for each four-month season (Table 1-1) and hydrologic conditions were assigned based on the seasonal PHDI averages. Hydrologic conditions (dry, average, wet) were classified for each climate division by apportioning respective seasonal PHDI data from the study period (1940 to 2019) into three equal quantiles (i.e., terciles), where:

- The lower tercile of seasonal PHDI is a dry condition;
- The middle tercile of seasonal PHDI is an average condition;
- The upper tercile of seasonal PHDI is a wet condition.

Table 1-D-1 shows the thresholds for dry, wet, and average hydrologic conditions determined for each climate division in the Brazos River Basin.

Table 1-D-1 – Classification of Seasons by Hydrologic Condition Based on PHDI

Climate Division	Dry	Average	Wet
4101, High Plains	Less than -1.43	-1.43 to 1.51	Greater than 1.51
4102, Low Rolling Plains	Less than -1.44	-1.44 to 1.53	Greater than 1.53
4103, North Central	Less than -1.13	-1.13 to 1.92	Greater than 1.92
4104, East Texas	Less than -1.07	-1.07 to 1.93	Greater than 1.93
4106, Edwards Plateau	Less than -1.50	-1.50 to 1.49	Greater than 1.49
4107, South Central	Less than -1.45	-1.45 to 1.80	Greater than 1.80
4108, Upper Coast	Less than -0.91	-0.91 to 1.81	Greater than 1.81

The Brazos BBEST used PHDI to define hydrologic conditions for each season in the Upper, Middle, and Lower Brazos Basin (30 Tex. Admin. Code §298.470(c)) for environmental flow standard compliance purposes. Ultimately, the hydrologic conditions specified in the Texas Administrative Code (TAC) were not used, and instead, hydrologic conditions were defined specifically for this study. Reasons for this include:

- The PHDI data used to calculate the hydrologic conditions in the TAC are from an obsolete PHDI dataset from NOAA that covered a period from 1940 to 1998. NOAA has since updated the PHDI calculation methodology from the time that dataset was used, and more recent PHDI data is available. The most recently available PHDI dataset from NOAA, covering 1940 to 2019, was used for this study.

- The hydrologic conditions thresholds defined in the TAC are for the three sections of the Brazos Basin (Upper, Middle, Lower), whereas the thresholds defined in this study are at the climate division level to be consistent with data scale in the trend analysis approach.

- The hydrologic conditions in the TAC are determined based on the PHDI value present on the last day of the month of the preceding season ((30 TAC §298.470(a)). This approach was used because the hydrologic condition needs to be known at the beginning of a season in real time to set environmental flow targets in the WAM. This approach was deemed inapplicable for this study. Instead, seasonal average PHDI was used to determine hydrologic conditions in order to represent the PHDI across an entire seasonal period.

- The TAC assigns a season one of three hydrologic conditions (dry, average, or wet) based on thresholds that represent the first and third quartiles of the historical data (25th and 75th percentile). For this study, terciles (approximately the 33rd and 67th percentile) were used to define thresholds instead so that the number of seasons in each category from each historical time series would be approximately equal, maintaining a similar number of data points for each trend analysis of seasonal, conditional subsets of the data.

For reference, Table 1-D-2 contains the monthly PHDI from 1940 to 2019 for each climate division in the study area (downloaded from the NOAA NNDC CDO in December 2020).

Table 1-D-2 – PHDI Data by Climate Division

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Nov 1939	Winter 1940	-2.45	-3.38	-2.67	-2.80	-1.91	-3.59	-2.70
Dec 1939	Winter 1940	-2.04	-3.21	-2.90	-2.65	-1.76	-3.69	-2.94
Jan 1940	Winter 1940	-1.83	-3.21	-3.09	-2.82	-1.70	-3.84	-3.33
Feb 1940	Winter 1940	-1.47	-2.44	-2.77	-2.21	-1.14	-3.55	-3.13
Mar 1940	Spring 1940	-1.70	-2.80	-3.22	-2.63	-1.16	-3.46	-3.16
Apr 1940	Spring 1940	-1.54	-2.42	-2.35	-1.88	-0.69	-3.46	-2.87
May 1940	Spring 1940	-1.73	-2.67	-2.01	-1.74	1.06	-3.52	-3.05
Jun 1940	Spring 1940	-1.88	-2.43	1.78	-0.83	2.32	-1.94	-2.50
Jul 1940	Summer 1940	-2.94	-3.06	2.53	1.58	2.36	-1.43	-2.38
Aug 1940	Summer 1940	-2.66	-2.09	3.32	2.66	2.50	-1.44	-2.38
Sep 1940	Summer 1940	-3.13	-2.39	2.54	2.10	1.52	-1.87	-2.70
Oct 1940	Summer 1940	-3.22	-2.69	1.82	1.67	1.24	-1.45	-2.09
Nov 1940	Winter 1941	-1.65	-1.48	3.60	4.01	2.08	2.19	1.85
Dec 1940	Winter 1941	-1.65	-1.48	4.29	4.71	2.37	3.21	2.76
Jan 1941	Winter 1941	-1.42	-1.27	3.85	3.92	2.33	3.00	2.22
Feb 1941	Winter 1941	-1.08	1.27	4.42	3.78	2.58	3.47	2.13
Mar 1941	Spring 1941	2.02	1.78	4.21	3.81	3.60	4.18	2.80
Apr 1941	Spring 1941	2.86	3.03	4.41	3.46	4.48	4.93	3.29
May 1941	Spring 1941	5.58	4.42	3.93	3.19	4.30	5.02	3.56
Jun 1941	Spring 1941	6.98	5.86	4.93	3.96	4.70	5.56	3.78
Jul 1941	Summer 1941	8.51	6.96	5.49	4.54	5.13	6.11	4.30
Aug 1941	Summer 1941	9.04	7.89	6.60	4.57	4.85	6.02	4.11
Sep 1941	Summer 1941	9.36	7.43	5.56	4.62	4.82	5.25	4.69
Oct 1941	Summer 1941	11.13	8.57	5.90	5.11	4.86	5.07	5.38
Nov 1941	Winter 1942	10.01	7.66	5.09	4.56	4.16	4.28	4.72
Dec 1941	Winter 1942	9.22	7.19	4.57	3.97	3.49	3.67	4.06
Jan 1942	Winter 1942	8.28	6.38	3.77	3.07	2.69	2.73	3.21
Feb 1942	Winter 1942	7.50	5.58	2.97	2.21	2.09	2.28	3.10
Mar 1942	Spring 1942	6.96	4.92	2.23	1.69	1.49	1.71	2.80
Apr 1942	Spring 1942	8.06	5.76	4.18	2.65	1.78	1.87	3.05
May 1942	Spring 1942	6.99	4.96	3.81	2.31	1.14	1.11	2.07
Jun 1942	Spring 1942	7.30	4.75	3.90	2.55	-1.87	-1.70	1.91
Jul 1942	Summer 1942	6.88	4.30	3.54	2.48	-2.05	1.45	3.21
Aug 1942	Summer 1942	7.33	4.64	3.47	3.55	1.64	2.08	3.69
Sep 1942	Summer 1942	7.19	4.71	3.70	3.43	1.72	2.26	3.47
Oct 1942	Summer 1942	7.80	5.01	4.05	2.71	1.95	2.16	2.78
Nov 1942	Winter 1943	6.70	4.17	3.35	1.77	1.40	1.64	2.25

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Dec 1942	Winter 1943	6.79	4.23	3.12	1.35	1.17	1.00	1.85
Jan 1943	Winter 1943	5.89	3.49	2.34	0.87	0.72	0.68	1.81
Feb 1943	Winter 1943	4.87	2.58	1.35	-2.24	-1.36	-1.58	1.21
Mar 1943	Spring 1943	4.10	2.49	1.60	-2.01	-1.10	-1.23	1.57
Apr 1943	Spring 1943	3.34	1.91	0.87	-2.53	-1.76	-1.94	0.82
May 1943	Spring 1943	2.95	1.91	0.82	-2.18	-1.72	-1.88	-1.03
Jun 1943	Spring 1943	2.28	1.39	0.55	-2.33	-1.97	-2.30	-1.52
Jul 1943	Summer 1943	2.25	0.71	-1.52	-1.85	-2.08	-1.97	1.24
Aug 1943	Summer 1943	0.88	-2.37	-2.56	-2.28	-2.93	-2.68	0.73
Sep 1943	Summer 1943	-2.32	-2.54	-2.29	-2.02	-2.05	-2.28	0.55
Oct 1943	Summer 1943	-2.68	-2.79	-2.44	-1.98	-2.31	-2.55	-0.95
Nov 1943	Winter 1944	-2.44	-2.61	-2.82	-2.25	-1.93	-2.04	0.95
Dec 1943	Winter 1944	-0.90	-1.71	-2.41	-2.22	-1.25	-1.71	1.37
Jan 1944	Winter 1944	1.80	-0.99	-1.77	-1.28	1.33	-0.75	2.80
Feb 1944	Winter 1944	1.94	1.59	-0.80	-0.71	1.66	-0.75	2.01
Mar 1944	Spring 1944	1.61	1.35	-0.73	1.31	1.71	1.54	3.16
Apr 1944	Spring 1944	1.90	1.08	-0.66	1.49	1.44	0.95	2.27
May 1944	Spring 1944	1.96	0.82	1.67	2.86	2.13	1.75	3.41
Jun 1944	Spring 1944	1.99	0.60	0.99	2.07	2.09	1.44	2.51
Jul 1944	Summer 1944	2.44	0.86	0.62	0.96	1.26	0.89	1.39
Aug 1944	Summer 1944	2.17	0.92	0.97	1.46	1.97	1.63	1.52
Sep 1944	Summer 1944	2.29	0.61	-0.65	0.79	1.92	1.08	1.34
Oct 1944	Summer 1944	1.78	0.01	-0.89	-1.76	1.47	-0.99	-1.43
Nov 1944	Winter 1945	1.79	0.33	0.46	-0.89	1.69	0.78	-1.10
Dec 1944	Winter 1945	2.32	0.89	1.06	1.77	2.01	1.24	0.68
Jan 1945	Winter 1945	2.38	1.05	1.19	1.73	2.08	1.33	0.54
Feb 1945	Winter 1945	1.99	1.10	2.15	2.03	2.04	1.44	0.50
Mar 1945	Spring 1945	1.54	1.09	3.07	2.95	2.32	1.70	0.37
Apr 1945	Spring 1945	1.40	1.29	3.21	2.93	2.39	1.96	1.09
May 1945	Spring 1945	-1.48	-0.95	2.19	2.41	1.59	1.23	0.77
Jun 1945	Spring 1945	-2.21	-1.00	2.39	2.62	1.27	1.26	0.76
Jul 1945	Summer 1945	-1.79	0.83	3.00	3.38	1.39	1.00	0.56
Aug 1945	Summer 1945	-1.75	0.80	3.25	4.24	0.93	1.23	2.44
Sep 1945	Summer 1945	-1.42	-0.02	3.11	3.80	0.55	0.56	1.79
Oct 1945	Summer 1945	-1.31	0.00	2.93	4.11	0.88	0.63	1.91
Nov 1945	Winter 1946	-1.74	-0.56	2.16	3.19	-0.77	-1.12	1.11
Dec 1945	Winter 1946	-1.79	-0.87	1.59	2.89	-0.83	-1.16	1.83
Jan 1946	Winter 1946	-1.27	-0.36	1.94	3.67	-0.20	-0.58	2.49
Feb 1946	Winter 1946	-1.41	-0.59	1.99	3.85	-0.46	0.47	2.41

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Mar 1946	Spring 1946	-1.57	-0.85	1.87	3.84	-0.68	0.95	2.23
Apr 1946	Spring 1946	-2.26	-1.61	1.43	3.20	-0.79	1.06	1.89
May 1946	Spring 1946	-2.69	-1.97	1.97	4.11	-0.88	1.20	2.87
Jun 1946	Spring 1946	-3.11	-2.38	1.62	3.94	-0.94	1.75	3.36
Jul 1946	Summer 1946	-3.86	-3.21	1.10	3.65	-1.63	1.82	3.66
Aug 1946	Summer 1946	-3.31	-3.15	1.26	3.74	-2.13	2.80	3.90
Sep 1946	Summer 1946	-2.55	-2.49	1.30	3.08	-1.74	3.18	4.04
Oct 1946	Summer 1946	-0.79	-2.17	0.61	2.55	-1.70	3.16	3.88
Nov 1946	Winter 1947	2.18	-1.85	1.58	3.99	-1.68	3.31	5.24
Dec 1946	Winter 1947	2.11	-1.34	1.78	3.27	-1.45	2.84	4.39
Jan 1947	Winter 1947	2.11	-1.16	1.95	3.28	0.98	3.00	4.28
Feb 1947	Winter 1947	1.75	-1.35	1.38	2.43	0.57	2.34	3.29
Mar 1947	Spring 1947	1.93	-0.95	1.63	2.78	0.99	2.48	3.29
Apr 1947	Spring 1947	2.27	-0.65	1.51	2.06	0.82	2.22	2.61
May 1947	Spring 1947	3.49	2.01	1.36	2.32	0.81	2.29	3.18
Jun 1947	Spring 1947	3.33	1.95	1.10	1.86	-0.07	1.74	2.67
Jul 1947	Summer 1947	2.94	1.45	-0.58	1.01	-0.77	1.06	1.91
Aug 1947	Summer 1947	1.71	-1.24	-0.59	0.64	-0.84	1.45	2.05
Sep 1947	Summer 1947	-2.04	-2.07	-1.11	-1.50	-1.58	-1.15	0.88
Oct 1947	Summer 1947	-2.62	-2.42	-1.52	-2.12	-2.34	-1.96	-1.68
Nov 1947	Winter 1948	-1.97	-1.65	-1.30	-1.62	-1.91	-1.67	-1.24
Dec 1947	Winter 1948	-1.47	-1.20	-0.63	-1.20	-1.68	-1.42	-0.89
Jan 1948	Winter 1948	-1.28	-1.26	-0.56	-0.91	-1.80	-1.46	0.77
Feb 1948	Winter 1948	1.39	-0.61	0.93	-0.58	-1.57	-1.11	0.96
Mar 1948	Spring 1948	1.45	0.92	-0.18	-0.78	-1.63	-1.14	-0.20
Apr 1948	Spring 1948	1.03	-0.57	-0.78	-0.96	-1.73	-1.35	-0.52
May 1948	Spring 1948	0.84	-0.91	-0.81	-0.76	-2.25	-1.43	-0.64
Jun 1948	Spring 1948	0.78	-1.00	-0.82	-1.32	-2.36	-1.77	-1.21
Jul 1948	Summer 1948	0.79	-0.62	-0.85	-1.73	-2.02	-2.11	-1.85
Aug 1948	Summer 1948	0.98	-1.01	-1.40	-2.30	-2.39	-2.19	-2.22
Sep 1948	Summer 1948	-0.68	-1.79	-2.03	-2.91	-2.29	-2.30	-2.47
Oct 1948	Summer 1948	-0.85	-1.76	-2.32	-3.20	-2.50	-2.52	-2.96
Nov 1948	Winter 1949	-0.57	-1.98	-2.72	-2.76	-2.61	-2.67	-2.64
Dec 1948	Winter 1949	-0.90	-2.34	-3.13	-3.14	-2.76	-3.26	-3.43
Jan 1949	Winter 1949	1.35	-0.79	-1.89	-1.83	-1.72	-2.70	-3.27
Feb 1949	Winter 1949	1.34	-0.72	-1.46	-1.60	-0.82	-2.09	-2.32
Mar 1949	Spring 1949	1.26	-0.58	-1.23	-1.18	-0.72	-1.82	-1.57
Apr 1949	Spring 1949	1.85	1.60	-0.85	-0.69	2.37	2.03	2.18
May 1949	Spring 1949	2.93	2.19	-0.68	-1.41	2.30	1.16	1.26

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Jun 1949	Spring 1949	3.79	2.64	1.37	-1.43	2.66	0.94	0.57
Jul 1949	Summer 1949	4.32	2.60	1.32	-0.96	2.50	1.06	0.74
Aug 1949	Summer 1949	4.26	2.43	1.09	-0.88	2.63	0.80	-0.99
Sep 1949	Summer 1949	4.14	2.36	0.75	-0.87	2.31	-0.96	-1.32
Oct 1949	Summer 1949	3.68	2.33	1.38	2.18	2.46	0.97	2.91
Nov 1949	Winter 1950	2.61	1.41	-0.75	1.16	1.65	-0.68	1.94
Dec 1949	Winter 1950	2.27	1.18	-0.84	1.40	1.73	-0.19	2.89
Jan 1950	Winter 1950	1.67	0.80	-0.61	1.54	1.16	-0.69	2.15
Feb 1950	Winter 1950	0.91	-1.18	-0.22	2.18	0.88	-0.59	2.29
Mar 1950	Spring 1950	-2.00	-1.64	-0.79	1.61	-1.11	-0.91	1.68
Apr 1950	Spring 1950	-2.14	-1.65	0.38	1.83	-1.07	-0.35	2.12
May 1950	Spring 1950	-2.24	-1.28	0.59	2.11	-1.06	-0.61	1.44
Jun 1950	Spring 1950	-2.19	-1.47	0.64	2.19	-1.48	-0.37	1.57
Jul 1950	Summer 1950	2.24	0.85	1.96	2.54	-1.13	-0.47	1.31
Aug 1950	Summer 1950	2.77	1.07	2.96	2.28	-1.00	-0.84	0.61
Sep 1950	Summer 1950	3.82	1.80	3.20	2.67	-0.62	-1.04	-1.25
Oct 1950	Summer 1950	2.87	0.77	2.11	1.73	-1.46	-1.84	-1.98
Nov 1950	Winter 1951	2.06	-1.39	1.12	0.77	-1.96	-2.45	-2.59
Dec 1950	Winter 1951	1.43	-1.78	-2.20	-2.44	-2.33	-3.01	-3.25
Jan 1951	Winter 1951	1.19	-2.06	-2.71	-2.61	-2.66	-3.50	-3.24
Feb 1951	Winter 1951	1.16	-2.20	-2.86	-2.68	-2.71	-3.70	-3.86
Mar 1951	Spring 1951	1.02	-2.19	-3.03	-2.38	-2.35	-3.12	-3.27
Apr 1951	Spring 1951	0.60	-2.44	-3.26	-2.69	-2.66	-3.53	-3.46
May 1951	Spring 1951	1.72	-2.31	-3.37	-3.05	-2.90	-3.48	-3.44
Jun 1951	Spring 1951	1.60	-2.25	-2.71	-2.88	-3.13	-3.43	-3.51
Jul 1951	Summer 1951	1.13	-2.58	-2.98	-3.10	-3.74	-4.12	-3.81
Aug 1951	Summer 1951	0.59	-2.68	-3.55	-3.84	-4.00	-4.65	-4.37
Sep 1951	Summer 1951	-1.22	-2.84	-3.51	-2.66	-4.28	-3.62	-3.11
Oct 1951	Summer 1951	-1.38	-3.04	-3.52	-2.92	-4.57	-3.75	-3.31
Nov 1951	Winter 1952	-1.46	-3.08	-3.69	-3.07	-4.59	-3.56	-3.45
Dec 1951	Winter 1952	-1.65	-3.36	-4.25	-3.30	-4.67	-3.92	-3.77
Jan 1952	Winter 1952	-1.80	-3.48	-4.91	-3.63	-4.93	-4.51	-4.48
Feb 1952	Winter 1952	-2.10	-3.75	-5.36	-3.17	-4.95	-4.53	-3.55
Mar 1952	Spring 1952	-2.19	-3.66	-4.92	-2.86	-4.49	-4.17	-3.20
Apr 1952	Spring 1952	-1.42	-3.03	-3.87	-1.61	-3.90	-3.58	-1.93
May 1952	Spring 1952	-2.05	-3.28	-3.41	-1.13	-3.54	-3.11	-1.47
Jun 1952	Spring 1952	-3.13	-4.64	-4.03	-1.78	-4.21	-3.49	-1.76
Jul 1952	Summer 1952	-2.98	-4.69	-4.44	-1.82	-4.46	-3.43	-1.52
Aug 1952	Summer 1952	-3.55	-5.26	-5.11	-2.59	-5.10	-4.11	-2.17

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Sep 1952	Summer 1952	-3.85	-5.10	-5.29	-3.31	-4.41	-3.28	-2.35
Oct 1952	Summer 1952	-4.23	-5.38	-5.52	-3.72	-4.73	-3.58	-2.80
Nov 1952	Winter 1953	-3.55	-4.52	-3.88	-2.67	-3.87	-2.20	-1.75
Dec 1952	Winter 1953	-3.25	-4.06	-3.01	-2.00	-3.07	-1.50	-1.23
Jan 1953	Winter 1953	-3.27	-4.22	-3.12	-2.23	-3.30	-1.79	-1.75
Feb 1953	Winter 1953	-3.17	-4.09	-3.07	-1.93	-3.35	-1.55	-1.27
Mar 1953	Spring 1953	-3.25	-3.76	-2.73	-1.68	-3.01	-1.99	-2.03
Apr 1953	Spring 1953	-3.37	-3.64	-2.24	-0.76	-3.16	-1.71	-2.21
May 1953	Spring 1953	-3.99	-4.29	-1.97	2.08	-3.57	-1.66	-1.19
Jun 1953	Spring 1953	-5.33	-5.40	-2.45	1.40	-4.46	-2.03	-1.07
Jul 1953	Summer 1953	-4.98	-4.90	-2.47	1.33	-4.63	-2.58	-1.33
Aug 1953	Summer 1953	-4.58	-4.16	-2.16	1.31	-3.91	-1.42	1.72
Sep 1953	Summer 1953	-5.15	-4.70	-2.52	0.58	-3.99	-1.65	0.76
Oct 1953	Summer 1953	-3.82	-3.34	-1.80	-1.01	-3.38	-1.06	0.55
Nov 1953	Winter 1954	-3.51	-3.08	-1.66	-1.27	-3.53	-1.38	0.60
Dec 1953	Winter 1954	-3.28	-3.09	-1.50	-0.80	-3.43	-1.10	0.89
Jan 1954	Winter 1954	-3.27	-3.06	-1.39	-0.92	-3.53	-1.49	-0.65
Feb 1954	Winter 1954	-3.67	-3.52	-2.01	-1.84	-4.01	-2.33	-1.53
Mar 1954	Spring 1954	-3.88	-3.73	-2.44	-2.45	-4.20	-2.82	-1.95
Apr 1954	Spring 1954	-3.69	-3.18	-2.41	-2.56	-3.80	-2.79	-1.90
May 1954	Spring 1954	-2.57	-1.71	-2.12	-1.76	-3.78	-2.97	-1.97
Jun 1954	Spring 1954	-3.09	-2.05	-2.58	-2.36	-3.71	-3.56	-2.48
Jul 1954	Summer 1954	-3.90	-2.82	-3.25	-2.91	-4.27	-3.99	-2.76
Aug 1954	Summer 1954	-3.65	-3.25	-3.81	-3.62	-4.67	-4.36	-3.20
Sep 1954	Summer 1954	-4.46	-4.09	-4.29	-4.28	-5.09	-4.76	-3.74
Oct 1954	Summer 1954	-4.09	-4.24	-3.91	-3.09	-4.87	-4.56	-3.17
Nov 1954	Winter 1955	-4.24	-4.12	-3.70	-2.94	-4.77	-4.59	-3.38
Dec 1954	Winter 1955	-4.20	-3.87	-3.86	-3.12	-4.92	-4.87	-3.89
Jan 1955	Winter 1955	-3.89	-3.49	-3.81	-2.92	-4.44	-4.82	-3.66
Feb 1955	Winter 1955	-3.80	-3.28	-3.60	-2.15	-4.12	-4.16	-3.00
Mar 1955	Spring 1955	-4.00	-3.14	-3.57	-2.49	-4.08	-4.36	-3.46
Apr 1955	Spring 1955	-4.13	-3.77	-3.70	-2.19	-4.79	-4.81	-3.37
May 1955	Spring 1955	-3.31	-2.96	-3.37	-2.28	-4.63	-4.68	-3.35
Jun 1955	Spring 1955	-3.43	-2.24	-2.83	-2.35	-4.53	-4.78	-3.46
Jul 1955	Summer 1955	-3.22	-2.25	-2.61	-2.19	-3.92	-4.95	-3.45
Aug 1955	Summer 1955	-3.85	-2.76	-2.32	-0.93	-3.50	-4.48	-2.66
Sep 1955	Summer 1955	-3.64	-2.33	-2.02	-1.28	-3.28	-4.45	-2.60
Oct 1955	Summer 1955	-3.29	-1.85	-2.47	-1.66	-3.64	-4.63	-2.92
Nov 1955	Winter 1956	-3.36	-2.09	-3.07	-2.42	-3.57	-4.60	-3.35

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Dec 1955	Winter 1956	-3.54	-2.43	-3.47	-3.18	-3.65	-4.60	-3.75
Jan 1956	Winter 1956	-3.62	-2.56	-3.50	-3.40	-3.55	-4.65	-3.82
Feb 1956	Winter 1956	-3.09	-2.56	-3.45	-3.05	-3.59	-4.78	-3.99
Mar 1956	Spring 1956	-3.34	-3.04	-3.96	-3.28	-3.97	-4.86	-4.10
Apr 1956	Spring 1956	-3.69	-3.43	-4.18	-3.27	-4.18	-4.97	-3.91
May 1956	Spring 1956	-3.88	-3.67	-4.48	-3.39	-4.84	-5.32	-4.18
Jun 1956	Spring 1956	-4.47	-4.85	-5.29	-3.42	-5.60	-5.98	-4.28
Jul 1956	Summer 1956	-4.46	-5.25	-6.02	-4.06	-5.76	-6.36	-4.81
Aug 1956	Summer 1956	-4.93	-5.77	-6.30	-4.34	-5.86	-6.35	-5.17
Sep 1956	Summer 1956	-5.62	-6.25	-6.82	-4.97	-6.16	-6.68	-5.72
Oct 1956	Summer 1956	-5.52	-5.90	-6.55	-5.09	-5.87	-6.46	-5.56
Nov 1956	Winter 1957	-5.40	-5.72	-5.87	-4.77	-5.57	-6.21	-5.58
Dec 1956	Winter 1957	-5.25	-5.31	-5.37	-5.03	-5.25	-5.67	-5.14
Jan 1957	Winter 1957	-4.93	-5.02	-5.07	-4.92	-5.10	-5.81	-5.54
Feb 1957	Winter 1957	-4.56	-4.36	-4.63	-4.68	-4.70	-5.61	-5.64
Mar 1957	Spring 1957	-3.48	-3.74	-3.68	-3.32	-3.95	-4.04	-3.51
Apr 1957	Spring 1957	-2.06	-1.56	-0.66	-0.95	-1.92	-2.08	-1.80
May 1957	Spring 1957	-0.63	3.91	4.50	-1.02	3.70	-1.27	-1.82
Jun 1957	Spring 1957	2.97	4.50	4.09	2.79	3.82	-0.73	-1.19
Jul 1957	Summer 1957	2.24	4.56	3.44	2.44	3.11	-0.79	-1.58
Aug 1957	Summer 1957	1.77	3.42	2.22	2.16	1.88	-1.40	-2.02
Sep 1957	Summer 1957	1.00	2.65	2.32	2.60	1.79	2.51	-1.22
Oct 1957	Summer 1957	1.77	2.99	2.94	3.75	2.80	3.15	2.02
Nov 1957	Winter 1958	2.22	3.85	4.09	4.71	3.57	3.95	2.67
Dec 1957	Winter 1958	1.61	3.17	3.66	3.89	3.05	3.41	1.95
Jan 1958	Winter 1958	2.06	3.24	3.66	3.73	3.64	4.32	2.45
Feb 1958	Winter 1958	2.00	3.14	3.45	3.10	4.23	5.17	2.60
Mar 1958	Spring 1958	2.95	3.62	3.52	2.59	4.37	4.68	2.14
Apr 1958	Spring 1958	3.52	3.98	3.82	2.95	3.92	4.01	1.70
May 1958	Spring 1958	3.43	3.98	3.20	2.19	3.84	3.58	0.99
Jun 1958	Spring 1958	3.32	3.81	2.80	2.03	4.31	2.96	-1.59
Jul 1958	Summer 1958	4.11	4.14	2.68	1.73	3.65	2.45	-2.12
Aug 1958	Summer 1958	3.37	3.47	2.59	1.90	3.44	1.53	-2.41
Sep 1958	Summer 1958	3.29	3.21	2.68	3.48	3.99	2.62	-0.59
Oct 1958	Summer 1958	2.65	2.49	2.07	2.98	4.20	3.35	1.55
Nov 1958	Winter 1959	2.28	1.92	1.49	2.43	3.72	2.88	1.06
Dec 1958	Winter 1959	1.77	1.28	0.87	1.53	3.12	2.75	0.99
Jan 1959	Winter 1959	1.37	0.65	-1.80	0.72	2.41	2.25	0.65
Feb 1959	Winter 1959	0.89	-1.85	-2.10	1.13	2.19	2.88	2.45

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Mar 1959	Spring 1959	-1.36	-2.22	-2.47	0.58	1.60	2.18	1.76
Apr 1959	Spring 1959	-1.44	-2.36	-2.50	1.24	1.61	2.78	2.35
May 1959	Spring 1959	-1.16	-2.35	-2.93	1.15	1.28	2.49	2.12
Jun 1959	Spring 1959	-1.08	-1.77	-2.09	1.26	1.98	2.56	1.92
Jul 1959	Summer 1959	0.54	-0.93	-1.41	2.39	2.57	2.37	2.60
Aug 1959	Summer 1959	-0.31	-1.40	-1.07	2.96	2.02	2.66	3.42
Sep 1959	Summer 1959	-0.88	-1.94	-1.30	2.39	1.32	1.98	2.83
Oct 1959	Summer 1959	0.54	-0.97	1.89	2.47	2.37	2.51	3.23
Nov 1959	Winter 1960	0.34	-0.92	1.73	1.94	2.37	2.42	2.74
Dec 1959	Winter 1960	1.55	1.64	2.31	2.22	2.72	2.35	2.88
Jan 1960	Winter 1960	1.94	2.06	2.72	2.17	2.80	2.12	2.40
Feb 1960	Winter 1960	2.32	2.23	2.61	2.35	2.78	2.29	2.61
Mar 1960	Spring 1960	2.25	2.05	2.14	1.79	2.69	2.17	2.12
Apr 1960	Spring 1960	1.96	1.53	1.51	1.14	2.15	2.09	1.71
May 1960	Spring 1960	1.25	1.20	0.79	-1.41	1.37	1.46	0.86
Jun 1960	Spring 1960	1.83	1.15	-1.23	-0.60	-1.58	2.13	2.17
Jul 1960	Summer 1960	4.06	2.24	-0.97	0.74	-0.84	2.30	2.15
Aug 1960	Summer 1960	3.84	2.10	-0.63	1.45	0.89	3.10	3.28
Sep 1960	Summer 1960	3.60	1.42	-0.86	1.40	-0.81	2.16	2.33
Oct 1960	Summer 1960	4.74	2.46	-0.01	1.82	0.45	3.93	3.37
Nov 1960	Winter 1961	3.99	1.81	-0.55	1.81	0.20	4.04	3.27
Dec 1960	Winter 1961	4.27	2.46	1.05	3.06	1.09	4.90	4.28
Jan 1961	Winter 1961	4.05	2.73	1.97	3.32	1.61	4.61	4.29
Feb 1961	Winter 1961	3.91	2.86	2.21	3.34	1.78	4.69	4.43
Mar 1961	Spring 1961	4.47	3.00	2.05	3.25	1.32	3.67	3.39
Apr 1961	Spring 1961	3.86	2.22	1.09	2.33	0.63	3.07	2.98
May 1961	Spring 1961	3.21	1.66	-1.41	1.42	-1.45	1.95	2.09
Jun 1961	Spring 1961	3.65	2.71	0.91	2.20	1.22	2.59	3.21
Jul 1961	Summer 1961	4.54	4.06	1.58	2.94	2.05	3.12	3.96
Aug 1961	Summer 1961	4.18	3.75	1.43	3.13	1.52	2.64	4.05
Sep 1961	Summer 1961	3.54	3.36	1.61	3.74	1.11	2.74	4.79
Oct 1961	Summer 1961	2.83	2.71	1.36	3.03	0.94	2.22	3.69
Nov 1961	Winter 1962	3.39	3.38	1.58	3.02	1.03	2.40	4.40
Dec 1961	Winter 1962	2.95	2.94	1.41	3.23	0.61	1.77	3.75
Jan 1962	Winter 1962	2.74	2.49	0.97	3.05	-0.89	1.30	3.00
Feb 1962	Winter 1962	2.04	1.62	-0.80	2.17	-1.47	-1.38	1.88
Mar 1962	Spring 1962	1.63	1.22	-0.94	1.48	-1.61	-1.55	1.28
Apr 1962	Spring 1962	1.26	1.21	-0.60	1.50	-1.36	-1.22	1.50
May 1962	Spring 1962	-1.96	-2.15	-1.60	-1.43	-2.52	-1.91	0.81

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Jun 1962	Spring 1962	-1.10	-1.00	-0.69	-0.78	-2.50	-1.69	1.03
Jul 1962	Summer 1962	1.49	-0.66	1.24	-0.95	-2.97	-2.42	-1.59
Aug 1962	Summer 1962	0.77	-1.20	0.94	-1.48	-3.37	-2.99	-2.16
Sep 1962	Summer 1962	1.34	1.57	1.88	-0.94	-3.21	-2.51	-2.28
Oct 1962	Summer 1962	1.05	1.51	1.87	-0.98	-3.16	-2.72	-2.28
Nov 1962	Winter 1963	0.71	1.39	1.96	-0.89	-3.01	-2.63	-2.10
Dec 1962	Winter 1963	-0.50	1.20	1.62	-1.06	-2.82	-2.06	-1.69
Jan 1963	Winter 1963	-0.77	0.74	1.06	-1.39	-2.96	-2.27	-1.68
Feb 1963	Winter 1963	-0.77	-0.64	-1.03	-1.64	-2.66	-1.99	-1.52
Mar 1963	Spring 1963	-1.31	-0.96	-1.61	-2.26	-2.98	-2.51	-2.11
Apr 1963	Spring 1963	-1.99	-1.48	-1.64	-2.38	-3.32	-2.92	-2.77
May 1963	Spring 1963	-1.81	-1.44	-1.88	-2.87	-3.03	-3.55	-3.41
Jun 1963	Spring 1963	-1.31	-1.34	-2.25	-2.88	-3.29	-3.71	-3.20
Jul 1963	Summer 1963	-1.57	-1.92	-2.67	-2.78	-3.96	-4.14	-3.55
Aug 1963	Summer 1963	-1.35	-2.02	-3.08	-3.15	-3.93	-4.48	-3.97
Sep 1963	Summer 1963	-1.76	-2.29	-3.43	-3.11	-3.99	-4.64	-3.72
Oct 1963	Summer 1963	-2.38	-2.91	-3.95	-3.77	-4.29	-4.80	-4.16
Nov 1963	Winter 1964	-2.26	-2.20	-3.48	-3.50	-3.37	-4.09	-3.51
Dec 1963	Winter 1964	-2.16	-2.04	-3.41	-3.44	-3.13	-3.66	-3.11
Jan 1964	Winter 1964	-2.20	-1.78	-2.84	-3.32	-2.47	-3.21	-2.71
Feb 1964	Winter 1964	-1.55	-1.14	-2.64	-3.15	-2.09	-2.76	-2.14
Mar 1964	Spring 1964	-1.57	-1.08	-2.13	-2.69	-1.58	-2.21	-1.79
Apr 1964	Spring 1964	-2.18	-1.45	-2.03	-2.29	-1.50	-2.33	-2.08
May 1964	Spring 1964	-2.70	-1.95	-2.31	-2.54	-1.92	-2.45	-2.37
Jun 1964	Spring 1964	-2.86	-1.96	-2.37	-2.84	-2.47	-2.47	-2.66
Jul 1964	Summer 1964	-3.70	-2.63	-2.97	-3.52	-2.92	-2.61	-2.84
Aug 1964	Summer 1964	-3.99	-2.48	-2.29	-3.18	-2.69	-2.56	-2.76
Sep 1964	Summer 1964	-3.42	-2.02	-0.91	-2.48	-0.92	-1.99	-2.23
Oct 1964	Summer 1964	-3.75	-2.40	-1.21	-2.81	-0.91	-2.08	-2.36
Nov 1964	Winter 1965	-2.90	-1.85	1.48	-2.97	-0.78	-2.24	-2.50
Dec 1964	Winter 1965	-2.50	-1.83	0.99	-3.35	-0.98	-2.26	-2.26
Jan 1965	Winter 1965	-2.59	-1.85	1.23	-3.40	-0.96	-2.05	-2.55
Feb 1965	Winter 1965	-2.32	-1.71	1.93	-2.20	1.58	-0.67	-2.23
Mar 1965	Spring 1965	-2.04	-1.68	1.61	-1.74	1.44	-0.57	-2.15
Apr 1965	Spring 1965	-2.19	-1.65	0.91	-2.55	1.15	-0.77	-2.64
May 1965	Spring 1965	-2.28	-1.32	2.03	-1.74	2.15	1.59	-2.52
Jun 1965	Spring 1965	-0.58	-1.18	1.64	-1.79	2.41	1.45	-2.62
Jul 1965	Summer 1965	-1.06	-1.89	0.99	-2.17	1.90	0.99	-2.98
Aug 1965	Summer 1965	-0.95	-1.71	0.66	-2.26	1.34	0.61	-3.02

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Sep 1965	Summer 1965	-0.92	-1.48	0.79	-1.76	0.87	-0.85	-3.09
Oct 1965	Summer 1965	-0.98	-1.08	0.55	-2.11	0.68	0.31	-2.92
Nov 1965	Winter 1966	-1.62	-1.50	-0.86	-2.58	-1.22	0.43	-2.71
Dec 1965	Winter 1966	-1.65	-1.63	-1.07	-2.32	-0.95	1.26	-1.93
Jan 1966	Winter 1966	-1.44	-1.39	-1.23	-2.00	-0.88	1.40	-1.14
Feb 1966	Winter 1966	-1.29	-1.40	-1.10	-1.30	-0.70	1.81	1.64
Mar 1966	Spring 1966	-1.61	-1.71	-1.47	-1.88	-0.79	1.40	1.13
Apr 1966	Spring 1966	-1.30	-0.67	1.79	1.54	0.74	1.69	1.79
May 1966	Spring 1966	-2.24	-1.58	1.11	1.31	-0.12	2.09	2.43
Jun 1966	Spring 1966	-2.14	-1.90	0.86	0.65	-0.41	1.98	2.28
Jul 1966	Summer 1966	-2.58	-2.44	-0.90	-1.08	-1.15	1.79	1.99
Aug 1966	Summer 1966	-0.56	1.86	1.38	0.97	1.26	2.13	2.66
Sep 1966	Summer 1966	1.61	2.18	1.94	1.06	1.62	1.81	1.94
Oct 1966	Summer 1966	0.85	1.51	1.31	0.93	1.11	1.20	1.77
Nov 1966	Winter 1967	-1.19	0.59	-1.36	-0.96	-1.15	-1.41	1.02
Dec 1966	Winter 1967	-1.38	-1.54	-1.82	-1.38	-1.55	-1.77	-1.35
Jan 1967	Winter 1967	-1.79	-2.04	-2.65	-2.19	-1.96	-2.18	-1.70
Feb 1967	Winter 1967	-2.04	-2.41	-3.37	-2.74	-2.17	-2.53	-1.97
Mar 1967	Spring 1967	-2.57	-2.78	-3.76	-3.34	-2.67	-2.94	-2.35
Apr 1967	Spring 1967	-2.91	-3.00	-3.89	-3.14	-3.15	-3.56	-2.48
May 1967	Spring 1967	-3.32	-3.42	-3.65	-2.32	-3.46	-3.57	-2.35
Jun 1967	Spring 1967	-2.41	-3.39	-4.35	-2.61	-4.11	-4.59	-2.99
Jul 1967	Summer 1967	-1.60	-2.87	-4.31	-2.40	-3.91	-4.73	-2.88
Aug 1967	Summer 1967	-1.88	-3.25	-4.61	-2.50	-3.70	-4.00	-2.59
Sep 1967	Summer 1967	-1.77	-2.54	-3.12	-2.05	-2.39	-1.23	-1.78
Oct 1967	Summer 1967	-2.20	-2.61	-2.44	-1.82	-1.99	2.96	-1.41
Nov 1967	Winter 1968	-2.28	-2.44	-2.10	-2.47	-1.12	2.82	-1.97
Dec 1967	Winter 1968	-2.10	-2.24	-1.61	-2.05	-0.92	2.61	-1.78
Jan 1968	Winter 1968	-1.32	-0.73	2.83	-1.25	2.72	3.90	-0.81
Feb 1968	Winter 1968	-0.98	1.64	2.73	-1.34	2.76	3.71	-0.81
Mar 1968	Spring 1968	1.05	2.19	3.25	-1.19	3.25	3.48	-0.69
Apr 1968	Spring 1968	1.05	2.25	3.03	1.03	3.59	3.29	-0.57
May 1968	Spring 1968	1.30	2.34	3.23	1.73	3.66	3.81	1.48
Jun 1968	Spring 1968	1.04	2.56	3.35	2.67	3.70	4.80	3.33
Jul 1968	Summer 1968	1.35	3.17	3.99	2.92	3.94	5.13	3.31
Aug 1968	Summer 1968	1.75	3.47	3.99	2.67	3.18	4.67	2.70
Sep 1968	Summer 1968	0.96	2.59	3.82	3.34	2.95	4.87	2.65
Oct 1968	Summer 1968	0.55	1.74	2.87	2.83	1.87	4.16	2.30
Nov 1968	Winter 1969	1.01	2.60	3.20	3.13	2.50	4.26	2.10

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Dec 1968	Winter 1969	0.70	2.19	2.73	3.10	2.02	3.83	1.65
Jan 1969	Winter 1969	-0.87	1.60	2.22	2.24	1.36	3.13	0.91
Feb 1969	Winter 1969	0.27	1.64	2.20	2.51	1.20	3.52	1.68
Mar 1969	Spring 1969	0.83	2.18	2.88	3.34	1.47	3.83	1.95
Apr 1969	Spring 1969	0.86	2.01	2.81	3.37	2.26	3.97	2.32
May 1969	Spring 1969	1.51	2.61	3.00	3.41	2.32	3.82	2.42
Jun 1969	Spring 1969	1.50	2.63	2.53	2.48	2.11	3.32	1.79
Jul 1969	Summer 1969	1.05	2.08	1.81	1.49	1.32	2.53	1.22
Aug 1969	Summer 1969	0.86	2.12	1.66	0.59	1.70	2.40	0.85
Sep 1969	Summer 1969	1.64	2.69	1.52	-2.11	1.40	1.82	-1.25
Oct 1969	Summer 1969	2.69	3.20	2.00	-1.76	2.81	1.90	-1.23
Nov 1969	Winter 1970	2.54	3.02	1.61	-1.80	3.29	1.95	-1.57
Dec 1969	Winter 1970	2.32	3.08	1.98	-1.46	3.33	1.92	-1.39
Jan 1970	Winter 1970	1.84	2.52	1.57	-1.83	2.86	1.81	-1.54
Feb 1970	Winter 1970	1.38	2.27	2.32	-1.37	3.07	1.98	-1.54
Mar 1970	Spring 1970	2.00	3.10	2.72	-0.92	3.43	2.46	0.88
Apr 1970	Spring 1970	2.03	2.89	2.49	-0.96	2.86	1.96	0.62
May 1970	Spring 1970	0.99	2.35	2.01	-1.12	3.11	2.84	1.63
Jun 1970	Spring 1970	-1.13	1.74	1.30	-1.39	2.88	2.50	1.29
Jul 1970	Summer 1970	-1.72	0.67	-1.43	-1.75	1.90	2.18	1.03
Aug 1970	Summer 1970	-2.07	-1.85	-1.82	-2.04	1.35	1.74	0.60
Sep 1970	Summer 1970	-1.96	-1.77	1.13	-1.48	1.76	1.97	1.25
Oct 1970	Summer 1970	-1.85	-1.77	1.21	1.39	1.17	1.97	2.63
Nov 1970	Winter 1971	-2.05	-2.09	-0.54	0.82	-1.22	1.15	2.00
Dec 1970	Winter 1971	-2.43	-2.49	-1.20	-1.12	-1.80	-1.45	1.04
Jan 1971	Winter 1971	-2.63	-2.85	-1.95	-1.95	-2.33	-2.39	-1.89
Feb 1971	Winter 1971	-2.33	-2.90	-2.36	-2.00	-2.46	-2.86	-1.99
Mar 1971	Spring 1971	-2.64	-3.32	-2.93	-2.56	-2.95	-3.48	-2.28
Apr 1971	Spring 1971	-2.67	-3.48	-3.24	-2.92	-2.71	-3.73	-2.36
May 1971	Spring 1971	-2.97	-3.57	-3.59	-2.79	-3.46	-4.16	-2.48
Jun 1971	Spring 1971	-3.33	-4.14	-4.40	-3.11	-3.17	-4.45	-2.77
Jul 1971	Summer 1971	-3.21	-4.18	-3.89	-2.77	-2.66	-5.01	-3.27
Aug 1971	Summer 1971	-1.95	-1.58	-2.56	-2.24	2.88	-3.20	-2.38
Sep 1971	Summer 1971	-0.60	3.01	-2.20	-2.08	3.06	-1.74	-1.09
Oct 1971	Summer 1971	2.10	3.24	-1.26	-1.90	3.63	-1.13	-0.98
Nov 1971	Winter 1972	2.51	2.82	-1.26	-2.00	3.04	-1.16	-1.24
Dec 1971	Winter 1972	2.42	2.87	2.25	-1.20	2.75	-0.65	1.42
Jan 1972	Winter 1972	1.90	2.31	2.03	-0.76	2.29	2.08	1.49
Feb 1972	Winter 1972	1.28	1.67	1.26	-1.67	1.57	1.60	0.86

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Mar 1972	Spring 1972	-1.36	0.83	-1.37	-1.88	0.86	1.02	0.57
Apr 1972	Spring 1972	-2.14	-1.67	-1.58	-2.10	-1.61	-1.02	-0.88
May 1972	Spring 1972	-1.80	-1.55	-1.88	-2.29	-0.90	1.26	0.93
Jun 1972	Spring 1972	-1.58	-1.65	-2.13	-2.07	-0.88	1.47	0.79
Jul 1972	Summer 1972	-0.95	-1.62	-2.28	-1.55	-1.09	1.93	0.94
Aug 1972	Summer 1972	1.36	1.54	-2.02	-1.30	1.55	2.39	0.85
Sep 1972	Summer 1972	1.46	1.52	-1.99	-1.00	1.52	2.03	1.03
Oct 1972	Summer 1972	1.54	2.13	-1.11	1.14	1.28	1.69	0.82
Nov 1972	Winter 1973	1.99	2.31	-0.66	1.41	1.03	1.77	1.38
Dec 1972	Winter 1973	1.69	1.85	-0.79	1.32	-0.61	1.19	0.98
Jan 1973	Winter 1973	1.98	2.62	1.44	1.65	0.43	1.51	1.27
Feb 1973	Winter 1973	2.19	2.81	1.53	1.36	0.85	1.71	1.46
Mar 1973	Spring 1973	3.65	3.80	1.64	2.19	0.97	1.77	1.79
Apr 1973	Spring 1973	4.26	4.17	2.23	3.07	1.15	2.47	3.13
May 1973	Spring 1973	3.75	3.28	1.54	2.43	-0.60	1.83	2.57
Jun 1973	Spring 1973	3.24	3.12	2.24	3.57	0.56	3.61	4.01
Jul 1973	Summer 1973	3.79	3.51	3.47	3.94	1.66	4.20	3.95
Aug 1973	Summer 1973	2.85	2.75	3.27	4.11	0.99	4.64	4.51
Sep 1973	Summer 1973	2.56	3.38	3.82	5.25	1.14	5.07	5.42
Oct 1973	Summer 1973	1.85	2.94	4.36	6.07	2.09	6.20	6.13
Nov 1973	Winter 1974	1.07	2.07	3.85	5.53	1.38	5.18	4.94
Dec 1973	Winter 1974	0.68	1.28	3.18	5.25	0.73	4.36	4.21
Jan 1974	Winter 1974	-1.53	0.68	2.86	5.77	-1.15	4.49	4.63
Feb 1974	Winter 1974	-1.86	-1.99	2.23	4.46	-1.63	3.47	3.59
Mar 1974	Spring 1974	-2.06	-2.39	1.25	3.28	-2.07	2.95	3.33
Apr 1974	Spring 1974	-2.46	-2.39	0.88	2.73	-2.14	2.27	2.74
May 1974	Spring 1974	-3.38	-3.11	-2.01	2.13	-2.05	2.27	3.18
Jun 1974	Spring 1974	-3.75	-3.49	-2.08	1.99	-2.61	1.84	2.59
Jul 1974	Summer 1974	-4.43	-4.20	-2.44	1.60	-3.09	1.25	2.00
Aug 1974	Summer 1974	-2.04	-2.97	-0.64	2.65	2.47	2.59	2.30
Sep 1974	Summer 1974	3.14	-0.88	2.92	4.19	3.72	3.15	2.34
Oct 1974	Summer 1974	4.27	3.42	3.64	4.15	4.45	2.93	1.95
Nov 1974	Winter 1975	3.93	3.21	3.94	4.85	4.41	3.46	2.78
Dec 1974	Winter 1975	3.68	3.22	3.84	4.42	4.38	3.19	2.70
Jan 1975	Winter 1975	3.45	3.15	3.46	3.68	3.77	2.69	2.17
Feb 1975	Winter 1975	3.81	3.57	3.67	3.74	3.89	2.50	1.51
Mar 1975	Spring 1975	3.36	3.10	3.23	3.38	3.21	1.89	1.05
Apr 1975	Spring 1975	3.24	2.73	2.92	3.24	3.10	1.92	0.95
May 1975	Spring 1975	3.32	3.13	3.37	3.55	4.05	2.79	1.60

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Jun 1975	Spring 1975	3.53	3.19	3.16	3.63	4.27	3.03	1.87
Jul 1975	Summer 1975	4.58	4.46	3.53	3.68	5.02	3.44	1.92
Aug 1975	Summer 1975	4.14	4.76	3.52	3.57	4.77	3.74	2.39
Sep 1975	Summer 1975	3.77	4.70	2.98	2.88	4.18	3.28	1.87
Oct 1975	Summer 1975	2.64	3.70	2.06	2.60	3.58	2.90	1.82
Nov 1975	Winter 1976	2.72	3.84	1.36	1.87	3.19	2.10	1.37
Dec 1975	Winter 1976	2.20	3.47	0.78	1.04	2.60	1.71	1.26
Jan 1976	Winter 1976	1.60	2.70	-2.26	-1.76	1.85	0.97	0.65
Feb 1976	Winter 1976	0.64	1.63	-3.30	-2.45	0.76	-2.09	-1.60
Mar 1976	Spring 1976	-1.87	1.05	-3.25	-1.76	-1.98	-2.24	-1.76
Apr 1976	Spring 1976	-1.30	1.76	-2.20	-1.46	-1.20	-0.81	-1.35
May 1976	Spring 1976	-1.57	1.11	-1.71	-0.79	-0.99	1.63	-1.22
Jun 1976	Spring 1976	-2.19	-1.55	-1.51	1.57	-1.29	1.46	-0.56
Jul 1976	Summer 1976	-1.64	-0.72	1.81	2.38	2.26	2.62	1.53
Aug 1976	Summer 1976	-1.98	-0.85	2.01	2.39	2.36	2.54	1.41
Sep 1976	Summer 1976	-1.26	0.78	2.40	2.81	2.69	2.67	1.55
Oct 1976	Summer 1976	-1.09	1.70	3.02	2.94	3.56	3.98	1.98
Nov 1976	Winter 1977	-1.05	1.48	2.60	2.39	3.33	4.25	2.35
Dec 1976	Winter 1977	-1.37	1.03	2.52	2.49	3.12	4.89	3.20
Jan 1977	Winter 1977	-1.32	1.11	2.73	2.21	3.08	4.90	2.99
Feb 1977	Winter 1977	-1.41	0.93	2.44	1.88	2.58	4.50	2.37
Mar 1977	Spring 1977	-1.56	0.91	3.08	2.04	2.70	3.84	1.85
Apr 1977	Spring 1977	-0.69	1.86	3.24	2.05	3.97	4.71	2.11
May 1977	Spring 1977	0.79	2.04	2.11	0.94	3.47	4.04	1.45
Jun 1977	Spring 1977	-0.71	1.96	1.37	0.62	3.26	3.69	1.39
Jul 1977	Summer 1977	-1.40	1.63	-1.86	-1.60	2.23	2.83	0.81
Aug 1977	Summer 1977	0.72	1.92	-1.79	-1.38	1.27	1.79	-0.88
Sep 1977	Summer 1977	-0.96	0.66	-2.49	-1.57	-2.29	1.03	-1.02
Oct 1977	Summer 1977	-1.41	-1.47	-2.83	-2.04	-2.22	0.62	-1.21
Nov 1977	Winter 1978	-1.72	-1.82	-2.85	-1.86	-1.96	0.77	-0.57
Dec 1977	Winter 1978	-2.03	-2.26	-3.42	-2.33	-2.32	-1.93	-1.07
Jan 1978	Winter 1978	-1.86	-2.25	-3.50	-1.66	-2.32	-1.72	0.82
Feb 1978	Winter 1978	-1.21	-1.65	-3.06	-1.51	-1.91	-1.45	1.01
Mar 1978	Spring 1978	-1.39	-1.84	-2.86	-1.64	-2.02	-1.59	-0.49
Apr 1978	Spring 1978	-2.11	-2.63	-3.21	-2.34	-2.44	-1.74	-0.88
May 1978	Spring 1978	-1.16	-2.11	-3.21	-2.84	-2.78	-2.23	-1.72
Jun 1978	Spring 1978	-0.83	-2.35	-3.59	-3.03	-2.67	-1.91	-1.55
Jul 1978	Summer 1978	-1.68	-3.01	-4.25	-3.48	-3.05	-2.19	-1.80
Aug 1978	Summer 1978	-1.91	-2.21	-3.67	-3.59	-1.78	-2.09	-2.13

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Sep 1978	Summer 1978	-1.20	-1.34	-3.73	-3.18	-1.18	-0.95	-1.55
Oct 1978	Summer 1978	-1.53	-1.72	-3.98	-3.46	-1.51	-1.25	-2.08
Nov 1978	Winter 1979	-0.89	-1.52	-3.00	-2.74	-0.68	0.98	-1.48
Dec 1978	Winter 1979	-0.99	-1.72	-3.00	-2.60	-0.76	0.98	-1.64
Jan 1979	Winter 1979	-0.67	-1.44	-2.24	-1.25	-0.64	1.85	1.13
Feb 1979	Winter 1979	-0.67	-1.39	-1.72	-0.71	1.13	1.94	1.36
Mar 1979	Spring 1979	0.79	0.91	1.81	2.02	1.80	2.23	1.74
Apr 1979	Spring 1979	0.80	0.74	1.57	2.49	1.81	2.79	2.75
May 1979	Spring 1979	0.91	0.68	2.33	2.90	1.57	3.06	2.84
Jun 1979	Spring 1979	1.66	1.27	2.09	2.51	2.29	3.18	2.52
Jul 1979	Summer 1979	2.11	1.89	2.35	3.54	2.58	4.17	3.99
Aug 1979	Summer 1979	2.37	2.44	3.04	3.84	2.73	4.20	3.96
Sep 1979	Summer 1979	1.32	1.31	2.31	4.75	1.56	4.18	5.73
Oct 1979	Summer 1979	0.79	-1.52	1.69	4.30	-1.68	3.12	5.01
Nov 1979	Winter 1980	-1.18	-1.53	0.94	3.76	-1.81	2.48	4.23
Dec 1979	Winter 1980	-1.04	-1.10	1.02	3.51	-1.29	2.25	3.79
Jan 1980	Winter 1980	-0.79	-0.98	0.82	3.28	-1.34	1.98	3.98
Feb 1980	Winter 1980	-0.77	-1.06	-1.16	2.59	-1.49	1.49	3.31
Mar 1980	Spring 1980	0.26	-1.06	-1.28	2.68	-1.39	1.33	3.63
Apr 1980	Spring 1980	0.59	-1.34	-1.44	2.52	-1.72	0.79	2.84
May 1980	Spring 1980	1.05	-0.56	-1.02	2.50	-1.25	1.11	2.86
Jun 1980	Spring 1980	-0.81	-1.04	-1.43	1.68	-1.88	-1.36	1.93
Jul 1980	Summer 1980	-2.09	-2.06	-2.25	0.62	-2.70	-2.01	1.00
Aug 1980	Summer 1980	-2.35	-2.55	-3.06	-2.24	-2.46	-1.47	-1.86
Sep 1980	Summer 1980	-1.43	-0.78	-1.70	-2.07	-0.82	-1.07	-1.09
Oct 1980	Summer 1980	-1.84	-1.05	-1.81	-2.02	-1.05	-1.35	-0.95
Nov 1980	Winter 1981	-1.41	-0.76	-1.80	-2.13	1.39	-0.90	-1.10
Dec 1980	Winter 1981	-1.34	1.20	-1.81	-2.98	1.34	-1.31	-1.69
Jan 1981	Winter 1981	-1.48	0.84	-2.20	-3.48	1.19	-1.32	-1.77
Feb 1981	Winter 1981	-1.58	0.81	-2.51	-3.89	0.82	-1.56	-1.80
Mar 1981	Spring 1981	-1.19	1.06	-1.84	-3.68	1.70	-1.29	-1.82
Apr 1981	Spring 1981	-0.98	1.53	-2.08	-4.12	2.60	-1.44	-2.02
May 1981	Spring 1981	-1.30	1.48	-1.64	-3.06	2.80	-0.77	-1.16
Jun 1981	Spring 1981	-1.99	1.56	1.33	-1.50	4.13	1.91	2.21
Jul 1981	Summer 1981	-1.79	1.28	1.81	-0.68	4.38	2.52	2.76
Aug 1981	Summer 1981	1.32	1.33	1.81	2.31	4.12	3.55	3.36
Sep 1981	Summer 1981	1.35	0.64	1.54	2.23	3.30	2.86	2.89
Oct 1981	Summer 1981	1.98	1.49	3.45	3.00	4.23	3.64	3.33
Nov 1981	Winter 1982	1.98	1.21	3.24	2.42	3.50	3.14	2.97

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Dec 1981	Winter 1982	1.40	0.71	2.62	1.42	2.65	2.50	2.61
Jan 1982	Winter 1982	1.01	0.65	2.54	0.98	2.12	1.85	1.88
Feb 1982	Winter 1982	0.83	-0.51	2.33	0.60	2.23	2.09	2.16
Mar 1982	Spring 1982	0.60	-0.59	1.87	-1.67	1.68	1.51	1.57
Apr 1982	Spring 1982	-0.94	-0.91	1.52	-1.07	1.37	1.27	1.43
May 1982	Spring 1982	0.41	1.56	2.78	-0.87	1.80	1.70	1.98
Jun 1982	Spring 1982	1.03	3.29	3.46	0.86	1.93	1.26	1.52
Jul 1982	Summer 1982	1.56	4.03	3.79	0.82	1.35	-0.84	0.72
Aug 1982	Summer 1982	-0.98	3.61	3.36	-0.42	0.71	-1.37	-1.39
Sep 1982	Summer 1982	-1.46	2.67	2.24	-1.06	-1.46	-1.94	-2.11
Oct 1982	Summer 1982	-1.82	1.73	1.70	-0.65	-1.92	-1.60	-1.95
Nov 1982	Winter 1983	-1.52	1.78	1.95	1.03	-1.32	-0.87	-0.66
Dec 1982	Winter 1983	-0.87	1.77	2.04	2.17	-0.97	-0.92	1.61
Jan 1983	Winter 1983	1.33	2.28	1.73	1.42	-0.61	-0.92	1.45
Feb 1983	Winter 1983	1.57	2.04	1.80	2.02	0.79	0.67	2.08
Mar 1983	Spring 1983	1.52	2.13	2.08	2.25	1.19	1.70	2.39
Apr 1983	Spring 1983	1.48	1.92	1.25	1.29	0.68	0.97	1.55
May 1983	Spring 1983	1.29	1.72	1.53	2.05	-0.42	1.06	1.49
Jun 1983	Spring 1983	1.18	1.69	1.60	2.09	0.57	1.07	1.49
Jul 1983	Summer 1983	-0.83	1.18	1.75	2.07	-0.24	1.77	2.30
Aug 1983	Summer 1983	-2.11	-1.32	1.76	2.69	-0.65	1.92	3.23
Sep 1983	Summer 1983	-2.84	-2.07	0.83	2.45	-1.37	1.95	4.10
Oct 1983	Summer 1983	-1.47	1.56	0.67	1.77	-0.88	1.83	3.54
Nov 1983	Winter 1984	-1.06	1.71	-0.89	1.39	-0.58	1.52	3.26
Dec 1983	Winter 1984	-0.88	1.61	-1.23	1.41	-0.84	1.00	2.98
Jan 1984	Winter 1984	-0.86	1.49	-1.54	0.99	-0.03	1.09	3.01
Feb 1984	Winter 1984	-1.02	1.28	-1.79	1.16	-0.48	0.58	2.54
Mar 1984	Spring 1984	-0.75	1.13	-1.29	1.11	-0.77	-0.81	1.93
Apr 1984	Spring 1984	-0.58	0.68	-1.85	-0.94	-1.51	-1.57	0.96
May 1984	Spring 1984	-1.39	-1.41	-2.51	-1.16	-2.38	-2.03	0.80
Jun 1984	Spring 1984	-0.98	-1.87	-2.84	-1.29	-2.84	-2.55	-1.64
Jul 1984	Summer 1984	-1.42	-2.25	-3.20	-1.50	-2.91	-2.82	-1.83
Aug 1984	Summer 1984	-0.70	-1.90	-3.27	-1.72	-3.33	-3.11	-1.92
Sep 1984	Summer 1984	-1.14	-2.12	-3.39	-1.74	-3.30	-3.36	-1.80
Oct 1984	Summer 1984	0.72	-1.58	-1.66	2.02	-2.02	-1.82	1.79
Nov 1984	Winter 1985	1.28	-0.65	-1.06	2.06	-1.37	-1.69	1.66
Dec 1984	Winter 1985	1.78	2.23	2.71	1.55	2.37	-1.30	1.13
Jan 1985	Winter 1985	1.74	2.06	2.49	1.28	2.40	-0.78	1.19
Feb 1985	Winter 1985	1.97	2.40	2.53	1.60	2.32	1.65	1.65

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Mar 1985	Spring 1985	2.53	2.94	2.69	1.39	2.43	1.82	2.27
Apr 1985	Spring 1985	2.73	3.17	2.39	0.93	2.12	2.01	2.07
May 1985	Spring 1985	2.52	2.69	1.78	-0.72	1.91	1.62	1.33
Jun 1985	Spring 1985	3.45	3.77	1.96	-1.00	2.18	1.89	1.23
Jul 1985	Summer 1985	3.46	4.31	1.93	-0.98	2.12	1.87	0.92
Aug 1985	Summer 1985	2.69	3.67	1.07	-1.59	1.09	1.04	-0.95
Sep 1985	Summer 1985	3.83	3.47	0.92	-1.46	1.25	1.24	-0.83
Oct 1985	Summer 1985	4.88	3.86	1.49	1.12	1.34	1.38	-0.37
Nov 1985	Winter 1986	4.38	3.44	1.64	1.73	1.03	2.06	-0.34
Dec 1985	Winter 1986	3.81	2.80	1.46	1.60	0.58	1.66	-0.50
Jan 1986	Winter 1986	3.02	1.97	0.68	0.57	-1.00	1.20	-1.01
Feb 1986	Winter 1986	2.81	1.65	0.87	-1.02	-1.14	0.76	-1.42
Mar 1986	Spring 1986	1.97	0.86	-0.91	-1.86	-1.68	-1.12	-1.72
Apr 1986	Spring 1986	1.25	-1.76	-0.93	-1.64	-2.52	-1.69	-2.11
May 1986	Spring 1986	1.10	-1.62	0.53	-0.92	-1.89	-1.10	-1.67
Jun 1986	Spring 1986	1.88	-1.24	1.49	1.43	-1.23	-0.62	-0.73
Jul 1986	Summer 1986	1.32	-1.27	1.84	1.04	-1.84	-1.16	-1.16
Aug 1986	Summer 1986	2.39	0.89	1.88	0.95	-1.24	-1.31	-1.26
Sep 1986	Summer 1986	2.88	1.55	2.14	1.07	-0.94	-1.33	-1.24
Oct 1986	Summer 1986	3.57	3.10	2.55	1.41	2.30	0.87	0.99
Nov 1986	Winter 1987	4.33	3.52	2.91	1.99	2.61	1.01	1.90
Dec 1986	Winter 1987	4.59	3.76	3.27	2.29	3.59	2.23	2.68
Jan 1987	Winter 1987	4.42	3.75	3.04	1.66	3.05	2.01	2.52
Feb 1987	Winter 1987	4.65	4.44	3.54	2.18	3.55	2.75	2.88
Mar 1987	Spring 1987	4.62	4.29	3.08	1.69	3.57	2.32	2.10
Apr 1987	Spring 1987	4.14	3.55	2.01	0.56	3.37	1.62	1.13
May 1987	Spring 1987	5.37	4.77	2.39	-1.29	4.52	2.10	1.12
Jun 1987	Spring 1987	5.92	5.13	2.97	0.65	5.98	3.93	2.24
Jul 1987	Summer 1987	5.95	5.52	3.24	0.88	6.78	4.27	2.62
Aug 1987	Summer 1987	6.11	5.38	2.99	0.59	6.73	4.00	2.38
Sep 1987	Summer 1987	6.13	4.83	2.76	0.58	6.08	3.28	1.98
Oct 1987	Summer 1987	5.00	3.60	1.88	0.17	4.72	2.33	1.11
Nov 1987	Winter 1988	4.19	2.77	2.04	1.00	4.22	2.36	1.37
Dec 1987	Winter 1988	4.26	3.03	2.44	1.99	3.95	2.12	1.29
Jan 1988	Winter 1988	3.76	2.56	1.88	1.28	3.15	1.42	0.81
Feb 1988	Winter 1988	3.17	1.95	1.47	0.79	2.41	0.76	-0.95
Mar 1988	Spring 1988	3.17	1.83	1.22	1.00	1.86	0.63	-0.36
Apr 1988	Spring 1988	3.59	1.75	0.68	-0.89	1.06	-1.46	-0.46
May 1988	Spring 1988	3.64	0.78	-1.57	-1.74	0.75	-1.73	-1.05

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Jun 1988	Spring 1988	3.41	0.64	-1.27	-2.20	-1.77	-2.02	-1.38
Jul 1988	Summer 1988	3.96	0.83	-0.88	-2.19	-0.96	-1.99	-1.51
Aug 1988	Summer 1988	3.17	-1.34	-1.17	-2.15	-1.32	-2.41	-1.92
Sep 1988	Summer 1988	3.91	0.90	-0.83	-2.50	-1.04	-2.62	-2.04
Oct 1988	Summer 1988	2.89	-0.56	-1.13	-2.29	-1.65	-2.89	-2.43
Nov 1988	Winter 1989	2.07	-1.12	-1.44	-2.32	-2.23	-3.52	-3.22
Dec 1988	Winter 1989	1.59	-1.26	-1.50	-2.15	-2.27	-3.70	-3.54
Jan 1989	Winter 1989	1.12	-1.39	-1.39	-1.36	-1.85	-2.91	-2.89
Feb 1989	Winter 1989	1.22	-0.79	-0.73	-1.23	-0.93	-3.14	-3.22
Mar 1989	Spring 1989	0.79	-0.92	0.67	1.14	-0.67	-2.83	-2.91
Apr 1989	Spring 1989	-2.12	-1.63	-0.63	-0.61	-1.08	-2.78	-3.01
May 1989	Spring 1989	-2.38	-1.79	0.94	0.80	-1.45	-3.08	-2.44
Jun 1989	Spring 1989	-1.21	-0.82	2.35	2.40	-1.49	-2.92	-0.62
Jul 1989	Summer 1989	-1.63	-1.41	2.91	2.96	-2.11	-3.24	1.92
Aug 1989	Summer 1989	-0.88	-1.17	3.51	3.06	-2.30	-3.40	2.07
Sep 1989	Summer 1989	1.03	-0.64	3.31	2.40	-2.50	-3.77	1.25
Oct 1989	Summer 1989	-0.78	-1.31	2.51	1.91	-2.35	-3.60	0.91
Nov 1989	Winter 1990	-1.30	-1.89	1.45	0.85	-2.41	-3.59	-1.08
Dec 1989	Winter 1990	-1.26	-2.00	0.61	-2.08	-2.44	-3.65	-1.71
Jan 1990	Winter 1990	-0.99	-1.81	0.65	-1.14	-2.58	-3.86	-1.54
Feb 1990	Winter 1990	0.64	-1.13	0.93	-0.93	-1.96	-3.66	-1.37
Mar 1990	Spring 1990	0.93	1.06	1.92	1.53	-1.23	-2.80	-0.59
Apr 1990	Spring 1990	1.34	2.07	3.02	1.46	1.33	-2.29	0.93
May 1990	Spring 1990	0.62	1.86	3.17	1.85	1.29	-2.63	-0.14
Jun 1990	Spring 1990	-1.98	1.50	2.48	1.47	-0.94	-3.40	-0.71
Jul 1990	Summer 1990	-1.68	2.00	2.49	1.34	1.64	-2.33	-0.54
Aug 1990	Summer 1990	-1.60	2.07	2.39	0.76	1.44	-2.80	-1.30
Sep 1990	Summer 1990	-1.30	1.98	2.14	0.72	1.95	-2.76	-1.41
Oct 1990	Summer 1990	-1.61	1.44	1.79	0.85	1.86	-2.67	-1.41
Nov 1990	Winter 1991	-1.44	1.61	1.92	0.90	1.81	-2.71	-1.70
Dec 1990	Winter 1991	-1.41	1.38	1.49	0.77	1.24	-3.02	-2.15
Jan 1991	Winter 1991	-0.88	1.95	2.05	2.12	1.73	-1.60	1.60
Feb 1991	Winter 1991	-1.33	1.18	1.68	2.27	1.28	-1.25	1.98
Mar 1991	Spring 1991	-1.61	-1.11	0.98	1.60	0.72	-1.27	1.69
Apr 1991	Spring 1991	-2.42	-1.76	0.71	2.56	-0.86	1.49	2.91
May 1991	Spring 1991	-2.59	-1.67	0.57	2.55	-1.30	1.34	2.87
Jun 1991	Spring 1991	-2.15	1.13	1.07	2.52	-0.77	1.80	3.27
Jul 1991	Summer 1991	-1.10	1.53	1.55	2.52	-0.61	1.97	3.12
Aug 1991	Summer 1991	-0.82	2.15	2.65	3.25	0.40	1.79	2.82

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Sep 1991	Summer 1991	2.05	3.34	2.87	3.30	1.56	2.02	2.72
Oct 1991	Summer 1991	1.53	3.24	3.54	2.97	1.23	1.55	2.14
Nov 1991	Winter 1992	1.86	2.96	3.25	2.75	1.03	1.06	2.06
Dec 1991	Winter 1992	3.16	4.45	5.45	3.51	3.00	3.16	3.06
Jan 1992	Winter 1992	3.34	4.82	5.65	3.63	3.52	4.10	4.05
Feb 1992	Winter 1992	3.34	5.52	5.94	4.18	4.70	5.35	5.04
Mar 1992	Spring 1992	3.14	4.97	5.41	4.07	4.75	5.53	4.85
Apr 1992	Spring 1992	3.16	4.74	4.37	3.37	4.42	5.58	5.11
May 1992	Spring 1992	4.06	4.96	4.44	2.98	4.97	6.28	5.28
Jun 1992	Spring 1992	5.56	6.61	4.86	2.97	5.83	6.21	5.04
Jul 1992	Summer 1992	6.06	7.36	5.28	3.13	6.35	6.00	4.76
Aug 1992	Summer 1992	6.34	7.17	5.23	2.75	5.79	5.46	4.03
Sep 1992	Summer 1992	4.99	6.00	4.73	2.47	4.46	4.32	3.08
Oct 1992	Summer 1992	3.66	4.55	3.68	2.04	3.22	3.34	2.28
Nov 1992	Winter 1993	3.77	5.09	3.95	2.28	3.35	3.86	2.92
Dec 1992	Winter 1993	3.56	4.76	4.12	2.70	3.12	3.55	2.75
Jan 1993	Winter 1993	3.73	4.62	4.10	2.94	2.83	3.43	3.28
Feb 1993	Winter 1993	3.56	4.74	4.44	2.37	2.56	3.37	3.09
Mar 1993	Spring 1993	3.54	4.56	4.30	2.69	2.53	3.79	3.78
Apr 1993	Spring 1993	3.44	4.47	4.06	2.70	2.50	3.65	3.98
May 1993	Spring 1993	2.89	4.19	3.37	2.60	2.20	4.45	4.48
Jun 1993	Spring 1993	2.77	4.14	3.38	3.46	2.18	5.42	5.10
Jul 1993	Summer 1993	2.96	3.86	2.57	2.60	1.47	4.91	4.11
Aug 1993	Summer 1993	2.72	3.52	1.59	1.76	0.97	3.72	2.98
Sep 1993	Summer 1993	2.03	2.81	1.58	1.19	0.86	2.51	1.84
Oct 1993	Summer 1993	1.56	2.54	2.36	1.89	-0.95	2.35	2.01
Nov 1993	Winter 1994	1.29	2.03	2.16	1.82	-1.20	1.84	2.03
Dec 1993	Winter 1994	0.93	1.68	2.09	1.48	-1.33	1.42	1.68
Jan 1994	Winter 1994	0.76	1.40	1.85	1.24	-0.96	0.81	1.43
Feb 1994	Winter 1994	-1.08	1.21	1.93	1.61	-0.99	-2.00	0.94
Mar 1994	Spring 1994	-1.24	0.83	1.42	1.24	-0.89	-1.48	0.90
Apr 1994	Spring 1994	-1.07	0.69	1.11	0.69	-1.07	-1.38	0.75
May 1994	Spring 1994	-0.80	0.98	1.82	1.19	-0.76	-0.81	1.06
Jun 1994	Spring 1994	-2.00	-1.56	1.21	0.85	-1.41	-0.91	1.26
Jul 1994	Summer 1994	-1.79	-1.90	1.29	0.84	-1.74	-1.49	0.71
Aug 1994	Summer 1994	-2.09	-2.49	1.13	1.32	-2.00	-1.15	0.99
Sep 1994	Summer 1994	-2.28	-2.22	1.10	0.90	-1.83	-1.07	0.57
Oct 1994	Summer 1994	-2.34	-2.02	1.83	3.10	-1.47	1.70	2.63
Nov 1994	Winter 1995	-2.08	-1.44	2.57	2.53	-1.09	1.06	1.69

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Dec 1994	Winter 1995	-2.20	-1.44	3.09	3.26	0.95	1.75	2.12
Jan 1995	Winter 1995	-2.12	-1.44	2.94	3.55	0.54	1.49	2.27
Feb 1995	Winter 1995	-2.49	-1.69	2.21	2.65	0.32	1.21	1.79
Mar 1995	Spring 1995	-2.61	-1.45	2.49	2.59	0.62	1.61	2.27
Apr 1995	Spring 1995	-2.65	-1.27	2.59	2.80	0.73	1.50	2.37
May 1995	Spring 1995	-1.68	1.18	3.02	2.49	1.40	1.82	2.56
Jun 1995	Spring 1995	-1.38	1.91	2.97	2.22	1.54	1.96	2.56
Jul 1995	Summer 1995	-1.51	2.11	3.44	2.46	1.07	1.82	2.38
Aug 1995	Summer 1995	-1.85	3.43	4.23	2.36	0.61	1.92	2.36
Sep 1995	Summer 1995	-0.62	3.89	4.13	2.09	0.79	1.42	1.48
Oct 1995	Summer 1995	-0.98	3.11	3.06	1.40	-0.96	0.93	1.22
Nov 1995	Winter 1996	-1.48	2.43	2.30	0.64	-0.74	0.81	1.06
Dec 1995	Winter 1996	-1.42	1.92	1.63	-1.11	-1.05	-0.73	1.62
Jan 1996	Winter 1996	-1.63	1.38	0.84	-1.65	-1.48	-1.47	1.07
Feb 1996	Winter 1996	-2.08	-1.73	-2.81	-2.63	-2.04	-2.28	-1.08
Mar 1996	Spring 1996	-2.39	-1.77	-2.75	-2.96	-2.17	-2.42	-1.43
Apr 1996	Spring 1996	-2.93	-2.22	-2.82	-2.80	-2.27	-2.77	-1.63
May 1996	Spring 1996	-3.83	-3.39	-3.95	-3.63	-3.21	-3.90	-2.52
Jun 1996	Spring 1996	-3.63	-3.58	-4.28	-3.44	-3.73	-3.97	-2.01
Jul 1996	Summer 1996	-2.33	-3.33	-4.21	-3.17	-3.88	-4.51	-2.59
Aug 1996	Summer 1996	-0.90	-1.72	-2.04	-1.50	-2.34	-3.13	-1.36
Sep 1996	Summer 1996	2.17	-1.02	-1.24	2.02	-1.71	-2.67	-0.61
Oct 1996	Summer 1996	1.48	-1.24	-1.11	1.68	-1.46	-2.98	-0.80
Nov 1996	Winter 1997	1.51	1.72	2.81	1.77	-0.68	-2.80	-1.02
Dec 1996	Winter 1997	0.98	1.03	2.31	1.44	-0.83	-2.78	-1.17
Jan 1997	Winter 1997	0.76	0.62	1.89	1.30	-0.92	-2.63	-0.72
Feb 1997	Winter 1997	1.12	1.90	3.62	2.67	2.31	-2.25	0.98
Mar 1997	Spring 1997	-0.70	1.26	3.32	2.56	2.78	-1.31	2.36
Apr 1997	Spring 1997	2.48	3.14	4.01	3.24	3.57	1.82	3.56
May 1997	Spring 1997	2.62	3.15	3.61	2.74	3.57	2.20	3.79
Jun 1997	Spring 1997	3.15	4.46	4.02	2.88	5.18	3.20	3.36
Jul 1997	Summer 1997	3.29	5.23	4.01	2.56	5.46	3.07	2.55
Aug 1997	Summer 1997	3.54	5.46	3.90	2.78	4.39	2.46	1.65
Sep 1997	Summer 1997	3.02	4.62	2.62	2.18	3.21	1.83	1.97
Oct 1997	Summer 1997	2.44	3.98	2.62	2.36	2.65	2.81	2.70
Nov 1997	Winter 1998	2.15	3.42	2.32	2.28	2.36	2.99	2.64
Dec 1997	Winter 1998	2.86	3.91	3.31	2.61	2.50	2.99	2.73
Jan 1998	Winter 1998	2.27	3.48	3.82	3.20	2.13	2.70	3.03
Feb 1998	Winter 1998	2.41	3.49	3.93	3.44	2.17	3.40	3.39

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Mar 1998	Spring 1998	3.07	4.10	4.24	2.94	2.66	3.27	2.98
Apr 1998	Spring 1998	2.73	3.36	3.27	2.03	1.87	2.52	2.13
May 1998	Spring 1998	1.45	2.10	1.69	-2.04	-1.66	1.22	0.74
Jun 1998	Spring 1998	-2.28	0.88	-2.58	-3.12	-2.29	-2.36	-2.52
Jul 1998	Summer 1998	-2.58	-2.81	-3.40	-4.23	-2.87	-3.02	-3.39
Aug 1998	Summer 1998	-2.37	-3.00	-3.45	-3.82	-0.56	-1.74	-2.73
Sep 1998	Summer 1998	-3.37	-3.90	-3.44	-2.14	-1.08	-1.11	-0.96
Oct 1998	Summer 1998	-1.82	-3.55	-2.57	-0.78	-0.75	3.46	2.59
Nov 1998	Winter 1999	-1.23	-3.21	-1.80	3.00	1.63	4.27	3.24
Dec 1998	Winter 1999	-1.21	-3.20	-1.04	3.11	1.38	3.93	2.92
Jan 1999	Winter 1999	-0.58	-2.59	-0.70	3.49	0.77	3.18	2.30
Feb 1999	Winter 1999	-1.11	-3.12	-1.45	1.88	-1.33	2.15	1.32
Mar 1999	Spring 1999	1.30	-2.21	-0.82	1.86	0.66	2.45	1.40
Apr 1999	Spring 1999	2.33	-1.72	-1.00	1.36	-0.16	1.71	-1.37
May 1999	Spring 1999	3.02	-1.29	-0.75	1.32	-0.51	1.45	-1.31
Jun 1999	Spring 1999	3.75	1.51	-0.11	1.53	-0.24	1.67	-0.93
Jul 1999	Summer 1999	3.45	0.79	-0.06	1.55	-0.44	1.71	-0.73
Aug 1999	Summer 1999	2.58	-1.18	-0.94	0.56	-1.26	1.30	-1.50
Sep 1999	Summer 1999	2.28	-1.55	-1.49	-1.38	-2.11	-1.07	-1.84
Oct 1999	Summer 1999	1.50	-1.85	-1.63	-1.51	-2.28	-1.47	-2.19
Nov 1999	Winter 2000	0.55	-2.59	-2.50	-2.51	-2.90	-2.23	-2.91
Dec 1999	Winter 2000	-1.54	-2.69	-2.55	-2.88	-3.01	-2.66	-3.26
Jan 2000	Winter 2000	-1.77	-2.92	-2.73	-3.40	-3.27	-2.64	-3.82
Feb 2000	Winter 2000	-2.40	-3.30	-3.21	-4.35	-3.39	-3.12	-4.75
Mar 2000	Spring 2000	-1.27	-2.11	-3.06	-4.01	-3.64	-2.98	-5.17
Apr 2000	Spring 2000	-1.12	-2.04	-2.96	-3.48	-3.99	-3.18	-4.56
May 2000	Spring 2000	-2.23	-3.14	-3.26	-2.56	-4.67	-2.96	-3.81
Jun 2000	Spring 2000	-0.80	-1.74	-2.10	-1.69	-3.58	-2.79	-3.72
Jul 2000	Summer 2000	-1.52	-2.25	-2.37	-1.85	-4.15	-3.53	-4.22
Aug 2000	Summer 2000	-2.88	-3.25	-3.31	-2.68	-4.73	-4.04	-4.63
Sep 2000	Summer 2000	-3.87	-3.97	-3.76	-2.80	-4.78	-4.39	-4.79
Oct 2000	Summer 2000	-2.36	-2.83	-3.02	-2.88	-3.17	-3.57	-4.43
Nov 2000	Winter 2001	-1.54	-1.40	-0.87	2.27	-0.68	-1.33	-2.43
Dec 2000	Winter 2001	-1.11	-1.10	2.67	2.56	2.98	-0.79	-2.22
Jan 2001	Winter 2001	2.15	2.15	3.15	2.76	3.22	2.71	-1.42
Feb 2001	Winter 2001	2.26	2.51	4.00	2.81	2.91	2.05	-2.11
Mar 2001	Spring 2001	3.08	3.02	4.44	4.04	3.29	2.89	-0.77
Apr 2001	Spring 2001	2.58	2.29	3.27	2.63	2.69	2.07	-1.36
May 2001	Spring 2001	2.97	2.30	2.62	1.93	2.34	1.64	-1.55

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Jun 2001	Spring 2001	2.35	1.47	1.90	3.08	1.32	1.12	1.51
Jul 2001	Summer 2001	0.97	-1.77	0.86	2.65	-1.79	-1.51	1.38
Aug 2001	Summer 2001	0.68	-1.51	1.13	2.95	-1.20	1.42	2.63
Sep 2001	Summer 2001	-1.74	-1.49	1.17	3.75	-1.20	1.61	3.10
Oct 2001	Summer 2001	-2.37	-1.99	0.91	3.89	-1.46	1.42	3.28
Nov 2001	Winter 2002	-1.50	-0.66	0.86	3.68	1.22	1.85	3.31
Dec 2001	Winter 2002	-1.65	-0.83	1.09	4.17	1.02	2.24	3.50
Jan 2002	Winter 2002	-1.36	-0.83	0.90	3.30	0.61	1.63	2.67
Feb 2002	Winter 2002	-1.30	-0.72	0.67	2.62	-0.46	1.06	1.90
Mar 2002	Spring 2002	-0.75	1.22	1.41	2.64	-0.28	0.63	1.45
Apr 2002	Spring 2002	-0.79	1.30	1.03	1.88	-0.74	-1.29	1.25
May 2002	Spring 2002	-1.76	0.61	0.81	1.19	-1.61	-1.93	0.59
Jun 2002	Spring 2002	-2.40	-0.63	0.75	0.96	-2.03	-1.96	0.58
Jul 2002	Summer 2002	-2.42	1.13	1.75	1.23	1.49	1.22	0.77
Aug 2002	Summer 2002	-2.25	0.71	1.66	1.07	0.56	0.93	1.37
Sep 2002	Summer 2002	-2.46	-0.76	1.11	0.71	-0.86	1.45	1.96
Oct 2002	Summer 2002	-0.88	1.20	2.09	1.92	1.52	2.90	3.77
Nov 2002	Winter 2003	-0.75	1.10	1.75	2.14	1.44	3.51	3.96
Dec 2002	Winter 2003	1.66	1.68	2.55	3.23	1.55	4.29	4.63
Jan 2003	Winter 2003	1.18	1.28	1.99	2.14	1.18	3.94	3.95
Feb 2003	Winter 2003	0.94	1.10	2.33	2.95	1.49	4.16	3.72
Mar 2003	Spring 2003	0.74	0.82	1.64	2.10	1.42	3.67	3.10
Apr 2003	Spring 2003	-0.87	0.58	0.77	1.08	0.69	2.65	2.19
May 2003	Spring 2003	-1.53	-1.10	-1.69	-2.14	-1.32	1.27	0.74
Jun 2003	Spring 2003	1.24	1.28	-0.92	-1.63	-0.81	0.89	-2.01
Jul 2003	Summer 2003	-1.10	0.70	-1.17	-1.52	-0.59	1.26	-1.60
Aug 2003	Summer 2003	-1.70	-0.67	-1.20	-1.45	-0.56	0.73	-1.50
Sep 2003	Summer 2003	-1.81	-0.98	-0.81	-0.82	0.70	1.56	1.00
Oct 2003	Summer 2003	-2.17	-1.44	-1.01	-0.90	0.96	1.49	1.15
Nov 2003	Winter 2004	-2.23	-1.55	-1.30	-0.94	-0.27	0.94	1.24
Dec 2003	Winter 2004	-2.51	-2.07	-1.94	-1.37	-0.84	-1.03	1.18
Jan 2004	Winter 2004	-2.14	-1.64	-2.07	-1.16	0.11	-0.81	1.51
Feb 2004	Winter 2004	-1.32	-0.72	-1.28	1.16	0.34	0.41	2.03
Mar 2004	Spring 2004	-0.71	1.25	-1.55	0.72	0.88	0.22	1.45
Apr 2004	Spring 2004	2.13	1.73	-0.94	0.67	1.87	1.27	1.75
May 2004	Spring 2004	0.75	-1.08	-1.44	0.74	1.25	1.36	2.54
Jun 2004	Spring 2004	1.48	0.98	1.73	2.35	2.54	3.15	4.20
Jul 2004	Summer 2004	1.59	1.67	2.64	2.18	2.70	3.38	3.74
Aug 2004	Summer 2004	1.89	2.41	3.99	2.37	3.33	3.40	3.09

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Sep 2004	Summer 2004	2.83	1.65	3.09	1.55	2.82	2.63	1.95
Oct 2004	Summer 2004	3.29	1.98	3.25	1.60	3.16	2.75	1.74
Nov 2004	Winter 2005	5.38	4.44	4.94	2.89	5.11	4.52	3.71
Dec 2004	Winter 2005	4.89	4.04	4.33	2.30	4.39	3.75	3.03
Jan 2005	Winter 2005	5.11	4.08	4.37	1.97	4.01	3.64	2.36
Feb 2005	Winter 2005	5.04	4.09	4.13	2.15	4.18	3.75	2.76
Mar 2005	Spring 2005	4.94	3.92	3.61	1.61	4.22	3.97	2.74
Apr 2005	Spring 2005	4.56	3.16	2.45	0.90	3.33	3.09	1.98
May 2005	Spring 2005	4.45	2.81	1.82	-1.40	3.57	2.77	1.71
Jun 2005	Spring 2005	4.43	2.54	0.89	-2.22	2.89	1.89	0.72
Jul 2005	Summer 2005	4.16	2.65	-1.88	-2.23	2.73	1.76	0.73
Aug 2005	Summer 2005	4.72	4.30	-0.75	-2.11	3.30	1.16	-1.53
Sep 2005	Summer 2005	3.30	3.19	-1.62	-2.14	1.81	-1.88	-2.03
Oct 2005	Summer 2005	3.04	2.81	-1.99	-2.70	1.88	-1.92	-2.15
Nov 2005	Winter 2006	2.15	1.76	-2.69	-3.25	1.07	-2.38	-2.22
Dec 2005	Winter 2006	1.50	1.04	-3.35	-4.06	-1.70	-2.79	-2.57
Jan 2006	Winter 2006	0.64	-2.34	-3.70	-4.16	-2.07	-3.37	-3.13
Feb 2006	Winter 2006	-2.37	-2.60	-3.81	-4.00	-2.35	-3.83	-3.70
Mar 2006	Spring 2006	-2.16	-2.32	-3.12	-3.53	-2.33	-4.10	-4.05
Apr 2006	Spring 2006	-2.83	-2.81	-3.36	-3.76	-2.69	-4.81	-4.32
May 2006	Spring 2006	-3.59	-3.20	-3.89	-4.08	-3.41	-5.09	-4.04
Jun 2006	Spring 2006	-4.27	-4.15	-4.28	-4.01	-3.82	-5.23	-3.41
Jul 2006	Summer 2006	-4.56	-4.80	-4.85	-3.62	-4.14	-4.75	-1.77
Aug 2006	Summer 2006	-3.08	-4.26	-4.93	-3.77	-3.92	-5.20	-1.62
Sep 2006	Summer 2006	-2.22	-3.49	-4.59	-3.68	-3.60	-4.44	-1.50
Oct 2006	Summer 2006	-1.70	-2.52	-3.96	-1.72	-3.31	-3.87	2.80
Nov 2006	Winter 2007	-2.06	-2.54	-3.89	-1.82	-3.80	-4.29	1.91
Dec 2006	Winter 2007	-0.81	-1.78	-3.46	-1.19	-3.50	-3.69	1.88
Jan 2007	Winter 2007	2.13	-1.16	-2.39	2.51	-2.46	-2.12	2.89
Feb 2007	Winter 2007	1.73	-1.33	-2.59	1.57	-2.65	-2.47	2.02
Mar 2007	Spring 2007	3.34	2.31	-0.98	1.28	-0.60	2.26	2.52
Apr 2007	Spring 2007	3.61	2.54	-1.00	0.95	2.11	2.22	2.74
May 2007	Spring 2007	4.37	3.17	2.38	1.25	3.58	2.44	2.84
Jun 2007	Spring 2007	5.03	4.74	4.39	1.74	5.17	2.88	2.77
Jul 2007	Summer 2007	5.18	5.65	5.47	3.67	7.52	5.67	4.67
Aug 2007	Summer 2007	4.82	7.05	6.19	4.04	9.19	6.66	4.98
Sep 2007	Summer 2007	4.35	6.11	5.70	3.34	8.27	5.83	4.42
Oct 2007	Summer 2007	3.09	4.75	4.75	2.72	6.83	4.93	3.74
Nov 2007	Winter 2008	2.36	3.85	3.80	2.03	5.83	4.30	3.35

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Dec 2007	Winter 2008	2.49	3.59	3.04	1.40	4.80	3.32	2.41
Jan 2008	Winter 2008	1.88	2.77	2.00	0.89	3.84	2.75	2.66
Feb 2008	Winter 2008	1.45	2.11	1.15	0.92	2.68	1.76	2.15
Mar 2008	Spring 2008	0.83	2.02	2.10	1.32	2.59	1.46	1.84
Apr 2008	Spring 2008	-1.80	1.87	2.13	0.92	1.89	0.99	1.31
May 2008	Spring 2008	-2.03	1.23	1.49	0.70	0.65	-2.62	-1.37
Jun 2008	Spring 2008	-2.41	0.56	0.93	-0.89	-3.28	-3.60	-1.90
Jul 2008	Summer 2008	-2.24	-2.22	-1.89	-1.51	-3.50	-3.41	-2.15
Aug 2008	Summer 2008	-1.11	-1.18	-0.82	1.17	-2.26	-2.78	-1.38
Sep 2008	Summer 2008	-0.69	-0.77	-1.07	1.53	-2.40	-3.32	-1.10
Oct 2008	Summer 2008	2.03	1.17	-1.19	1.23	-2.48	-3.44	-1.17
Nov 2008	Winter 2009	1.56	-0.54	-1.65	0.93	-2.92	-3.79	-1.17
Dec 2008	Winter 2009	1.01	-1.08	-2.34	-0.97	-3.17	-4.12	-1.87
Jan 2009	Winter 2009	-1.06	-1.54	-2.98	-1.64	-3.40	-4.64	-2.85
Feb 2009	Winter 2009	-1.42	-2.08	-3.88	-2.43	-3.82	-5.38	-3.93
Mar 2009	Spring 2009	-1.77	-2.43	-3.37	-1.53	-3.17	-5.11	-3.96
Apr 2009	Spring 2009	-1.51	-2.13	-2.66	-0.70	-2.47	-4.46	-2.53
May 2009	Spring 2009	-2.23	-2.73	-2.75	-0.81	-2.94	-4.90	-2.89
Jun 2009	Spring 2009	-2.24	-2.97	-3.07	-1.45	-3.32	-5.81	-3.54
Jul 2009	Summer 2009	-1.27	-2.28	-2.64	-1.01	-3.05	-6.25	-3.97
Aug 2009	Summer 2009	-1.45	-2.56	-2.64	-1.04	-3.40	-6.36	-4.23
Sep 2009	Summer 2009	-1.69	-2.00	-1.14	1.10	-2.54	-5.08	-3.92
Oct 2009	Summer 2009	-1.34	-1.62	3.02	3.73	-1.73	-3.26	-2.12
Nov 2009	Winter 2010	-1.80	-2.08	2.62	2.94	-1.57	-2.27	-1.94
Dec 2009	Winter 2010	-1.48	-1.63	2.72	3.02	-1.15	-1.27	-0.84
Jan 2010	Winter 2010	-0.76	-0.90	3.23	2.53	1.82	3.18	-0.74
Feb 2010	Winter 2010	1.57	1.38	3.48	2.55	2.39	3.66	2.01
Mar 2010	Spring 2010	2.05	1.55	3.50	2.25	2.60	3.52	1.78
Apr 2010	Spring 2010	3.06	2.86	3.04	1.18	3.04	3.14	1.00
May 2010	Spring 2010	2.80	2.47	2.05	-1.90	2.71	2.65	-0.92
Jun 2010	Spring 2010	2.82	2.58	1.53	-1.98	2.26	2.48	-1.15
Jul 2010	Summer 2010	3.89	4.15	1.65	-1.76	2.84	3.16	1.29
Aug 2010	Summer 2010	3.47	3.60	0.85	-2.37	1.87	2.27	0.87
Sep 2010	Summer 2010	2.62	3.47	1.90	-2.51	1.78	3.18	1.26
Oct 2010	Summer 2010	2.01	2.70	1.31	-2.79	0.80	2.20	-0.79
Nov 2010	Winter 2011	1.75	1.93	0.62	-2.91	-1.89	1.54	-0.88
Dec 2010	Winter 2011	1.13	1.30	-1.27	-3.67	-2.02	0.81	-1.19
Jan 2011	Winter 2011	0.60	0.67	-1.38	-3.39	-2.03	0.96	-1.10
Feb 2011	Winter 2011	-1.47	-1.79	-1.77	-3.71	-2.29	-1.67	-1.69

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Mar 2011	Spring 2011	-2.17	-2.54	-2.65	-4.43	-3.06	-2.43	-2.16
Apr 2011	Spring 2011	-3.05	-3.57	-3.21	-4.87	-3.98	-3.42	-3.00
May 2011	Spring 2011	-4.17	-4.50	-3.41	-5.05	-4.79	-4.02	-3.78
Jun 2011	Spring 2011	-5.61	-5.86	-4.36	-5.45	-5.57	-4.60	-4.32
Jul 2011	Summer 2011	-6.32	-6.55	-5.42	-6.18	-6.02	-5.28	-4.62
Aug 2011	Summer 2011	-6.98	-6.94	-5.81	-6.85	-6.18	-5.85	-5.30
Sep 2011	Summer 2011	-6.84	-6.99	-5.99	-6.86	-6.39	-6.21	-5.70
Oct 2011	Summer 2011	-6.39	-6.08	-5.06	-6.55	-5.66	-5.89	-5.39
Nov 2011	Winter 2012	-6.05	-5.57	-4.75	-6.19	-5.46	-5.74	-5.38
Dec 2011	Winter 2012	-4.66	-4.63	-3.56	-5.13	-4.46	-4.89	-5.08
Jan 2012	Winter 2012	-4.44	-4.06	-2.03	-4.36	-3.74	-4.37	-4.72
Feb 2012	Winter 2012	-3.96	-3.66	-1.63	-3.47	-3.00	-3.58	-3.54
Mar 2012	Spring 2012	-3.77	-3.46	-0.77	-2.27	-2.32	-2.58	-2.68
Apr 2012	Spring 2012	-3.82	-3.82	-1.53	-2.64	-2.65	-2.91	-2.57
May 2012	Spring 2012	-4.29	-4.39	-2.23	-3.19	-2.03	-2.67	-2.61
Jun 2012	Spring 2012	-4.52	-4.51	-2.59	-3.22	-2.60	-3.05	-2.71
Jul 2012	Summer 2012	-5.00	-4.75	-2.99	-2.51	-2.52	-2.55	-1.65
Aug 2012	Summer 2012	-5.12	-4.54	-2.61	-2.48	-2.68	-2.82	-1.61
Sep 2012	Summer 2012	-4.39	-3.60	-2.22	-1.59	-1.90	-2.41	-1.62
Oct 2012	Summer 2012	-4.50	-3.93	-2.59	-1.88	-2.43	-2.75	-2.13
Nov 2012	Winter 2013	-4.76	-4.35	-3.38	-2.71	-3.01	-3.34	-2.82
Dec 2012	Winter 2013	-4.47	-4.42	-3.70	-3.06	-3.32	-3.78	-3.15
Jan 2013	Winter 2013	-3.86	-3.90	-3.22	-2.63	-2.74	-3.47	-2.89
Feb 2013	Winter 2013	-2.99	-3.35	-3.43	-2.66	-3.05	-3.81	-3.15
Mar 2013	Spring 2013	-3.00	-3.56	-3.39	-2.94	-3.24	-4.03	-3.48
Apr 2013	Spring 2013	-3.35	-3.63	-3.21	-2.80	-3.34	-3.59	-2.62
May 2013	Spring 2013	-4.15	-4.26	-3.22	-2.69	-3.12	-3.69	-2.69
Jun 2013	Spring 2013	-4.14	-4.16	-3.41	-2.64	-3.40	-4.22	-2.87
Jul 2013	Summer 2013	-3.42	-3.25	-2.75	-2.38	-2.85	-4.28	-2.93
Aug 2013	Summer 2013	-3.32	-3.02	-2.97	-2.85	-3.17	-4.47	-2.98
Sep 2013	Summer 2013	-3.29	-2.97	-2.68	-1.69	-2.53	-3.69	-2.70
Oct 2013	Summer 2013	-3.33	-3.15	-2.03	1.93	-2.02	-2.79	-2.03
Nov 2013	Winter 2014	-3.05	-3.08	-1.74	2.21	-1.58	-2.53	-1.58
Dec 2013	Winter 2014	-2.71	-2.59	-1.40	1.81	-1.46	-2.73	-2.10
Jan 2014	Winter 2014	-2.82	-2.82	-1.77	1.04	-1.78	-2.95	-2.49
Feb 2014	Winter 2014	-2.78	-2.76	-2.16	0.60	-2.12	-3.30	-2.45
Mar 2014	Spring 2014	-3.00	-2.82	-2.32	-0.99	-2.38	-2.86	-2.10
Apr 2014	Spring 2014	-3.45	-3.28	-2.55	-1.33	-2.94	-3.28	-2.46
May 2014	Spring 2014	-3.28	-3.30	-2.37	-0.56	-2.37	-2.34	-1.58

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Jun 2014	Spring 2014	-2.89	-3.10	-1.91	0.81	-2.52	-2.42	-1.46
Jul 2014	Summer 2014	-2.39	-2.70	-1.25	1.49	-2.78	-2.59	-1.33
Aug 2014	Summer 2014	-2.85	-2.72	-1.12	1.43	-2.58	-3.08	-1.51
Sep 2014	Summer 2014	-1.45	-2.19	-1.57	1.05	-2.30	-2.93	-1.32
Oct 2014	Summer 2014	-1.79	-2.64	-1.62	1.05	-2.76	-3.17	-1.55
Nov 2014	Winter 2015	-1.34	-1.79	-1.15	1.08	-1.67	-2.14	-1.23
Dec 2014	Winter 2015	-1.48	-1.96	-1.47	0.61	-1.86	-2.08	-1.08
Jan 2015	Winter 2015	-0.70	-1.33	-0.94	1.30	-1.25	-1.47	0.58
Feb 2015	Winter 2015	-0.59	-1.31	-0.74	0.84	-1.46	-1.64	-0.59
Mar 2015	Spring 2015	-0.64	-1.14	0.79	2.14	1.12	2.03	1.38
Apr 2015	Spring 2015	1.29	1.11	1.30	2.67	1.15	2.68	2.29
May 2015	Spring 2015	3.61	3.70	4.07	4.14	3.23	4.32	3.38
Jun 2015	Spring 2015	4.35	4.22	4.23	4.04	3.97	4.52	3.78
Jul 2015	Summer 2015	5.55	5.33	4.19	3.10	3.85	4.12	3.01
Aug 2015	Summer 2015	5.45	4.88	3.24	2.10	2.71	3.20	2.76
Sep 2015	Summer 2015	4.19	3.38	1.99	1.00	1.43	2.19	2.53
Oct 2015	Summer 2015	5.33	3.43	3.45	1.93	2.31	3.12	3.30
Nov 2015	Winter 2016	5.47	4.30	5.25	2.95	3.06	2.99	3.20
Dec 2015	Winter 2016	5.42	4.36	5.64	3.60	2.97	2.74	2.70
Jan 2016	Winter 2016	4.79	3.76	4.79	2.81	2.45	2.39	2.34
Feb 2016	Winter 2016	3.98	3.14	4.13	1.98	1.98	1.90	1.58
Mar 2016	Spring 2016	3.11	2.55	4.07	3.00	2.46	2.34	1.78
Apr 2016	Spring 2016	3.28	3.10	4.90	4.00	3.10	2.80	2.91
May 2016	Spring 2016	3.11	3.71	5.26	4.07	3.77	3.55	3.34
Jun 2016	Spring 2016	2.91	4.01	5.04	3.89	4.40	3.47	3.59
Jul 2016	Summer 2016	1.99	4.05	4.63	3.15	3.94	3.08	3.24
Aug 2016	Summer 2016	3.06	4.46	5.63	4.28	4.61	4.17	4.15
Sep 2016	Summer 2016	2.77	4.49	4.98	3.15	4.53	3.27	3.45
Oct 2016	Summer 2016	1.61	3.34	3.89	1.95	3.10	2.03	2.24
Nov 2016	Winter 2017	1.58	3.53	3.66	1.14	3.17	1.50	1.37
Dec 2016	Winter 2017	1.29	3.33	2.84	0.74	3.17	1.80	1.24
Jan 2017	Winter 2017	2.01	3.42	2.67	0.79	2.98	1.57	1.10
Feb 2017	Winter 2017	1.55	3.16	2.17	-2.13	2.75	1.19	0.58
Mar 2017	Spring 2017	1.37	2.80	1.33	-2.41	2.20	1.24	0.87
Apr 2017	Spring 2017	1.73	2.56	1.33	-1.96	2.06	0.95	0.81
May 2017	Spring 2017	0.82	1.71	0.65	-1.38	1.61	-1.11	0.61
Jun 2017	Spring 2017	-1.12	1.14	1.20	-0.93	1.16	-1.16	1.16
Jul 2017	Summer 2017	-1.10	1.05	1.66	1.27	0.81	-1.75	0.98
Aug 2017	Summer 2017	1.51	1.91	3.18	5.41	1.24	3.11	7.46

Month	Season	Climate Division						
		4101	4102	4103	4104	4106	4107	4108
Sep 2017	Summer 2017	1.84	2.06	2.58	4.43	0.99	2.67	6.19
Oct 2017	Summer 2017	1.64	1.29	1.90	3.67	-0.93	2.05	5.14
Nov 2017	Winter 2018	0.80	-1.11	0.99	2.55	-1.49	1.04	3.81
Dec 2017	Winter 2018	-1.03	-1.44	0.79	2.28	-1.11	1.33	3.30
Jan 2018	Winter 2018	-1.40	-1.84	-1.84	1.78	-1.44	0.79	2.88
Feb 2018	Winter 2018	-1.75	-1.94	-0.90	3.13	-1.41	-1.15	2.69
Mar 2018	Spring 2018	-2.37	-2.25	-0.79	3.31	-1.67	-0.79	2.29
Apr 2018	Spring 2018	-2.67	-2.74	-1.20	2.91	-2.30	-1.03	1.93
May 2018	Spring 2018	-3.66	-3.45	-1.86	1.61	-2.87	-1.64	1.14
Jun 2018	Spring 2018	-3.83	-4.03	-2.65	0.79	-3.68	-1.73	1.36
Jul 2018	Summer 2018	-3.85	-4.33	-3.30	-1.87	-3.69	-1.79	1.27
Aug 2018	Summer 2018	-3.45	-4.07	-2.79	-2.15	-3.15	-2.23	0.77
Sep 2018	Summer 2018	-2.84	-2.67	-1.13	1.41	-1.24	-0.68	2.09
Oct 2018	Summer 2018	-0.93	3.20	3.61	2.73	4.30	2.26	2.44
Nov 2018	Winter 2019	-0.85	3.13	3.58	3.29	3.85	2.50	2.65
Dec 2018	Winter 2019	1.79	3.60	4.48	4.55	4.31	3.15	3.38
Jan 2019	Winter 2019	1.40	3.28	4.19	4.39	3.72	3.13	3.33
Feb 2019	Winter 2019	1.06	2.70	3.52	3.72	2.85	2.49	2.78
Mar 2019	Spring 2019	1.48	2.73	3.01	2.85	2.52	1.80	1.90
Apr 2019	Spring 2019	1.88	3.82	3.59	3.25	2.93	2.08	1.56
May 2019	Spring 2019	2.61	4.65	4.30	4.09	3.31	2.10	1.99
Jun 2019	Spring 2019	2.77	5.03	4.62	4.70	4.08	2.47	2.99
Jul 2019	Summer 2019	2.38	5.06	4.50	4.26	3.82	2.19	2.53
Aug 2019	Summer 2019	1.40	3.92	3.96	3.64	2.73	1.16	2.13
Sep 2019	Summer 2019	1.12	3.16	2.51	2.96	1.36	-1.62	3.16
Oct 2019	Summer 2019	1.64	2.21	2.38	3.31	0.81	-1.43	3.22
Nov 2019	Winter 2020	2.03	2.55	2.13	2.31	-1.93	-1.62	2.62
Dec 2019	Winter 2020	1.88	2.01	1.39	1.18	-2.10	-2.10	1.71

APPENDIX 1-E: METHODOLOGY TO ASSESS AND APPLY TRENDS IN PRECIPITATION AND FLOW-TO-PRECIPITATION RATIO

Assessment of Trends in Precipitation and the Flow-to-Precipitation Ratio

Flows in the Brazos River Basin are adjusted based on trends in incremental naturalized flows (Q), but trends in precipitation volume within a watershed (PV) and the ratio of flow volume to precipitation volume (Q/P) are also assessed to provide context for the observed trends in Q.

Precipitation Data

As described in ***Section 1.3.4***, precipitation data has been collected from the NOAA U.S. Climate Divisional Dataset. In the Climate Divisional Dataset, precipitation (P) is provided in terms of depth (inches). However, in the context of trends in naturalized flows, the volume rather than depth of precipitation is considered. For each control point, the area-weighted average precipitation depth over the incremental drainage area is multiplied by the incremental drainage area of the associated stream gage to obtain estimates of historical precipitation volumes (PV) within the watershed, as shown in Equation 1-E-1. The incremental drainage area is defined as only the area which directly contributes runoff to the gage of interest without first draining to an upstream gage.

$$PV = Precipitation\ Depth * Drainage\ Area_{incremental} \qquad \text{Equation 1-E-1}$$

As with Q, PV is calculated for each month in the WAM period of record and is aggregated to seasons and years and also grouped by season and condition.

Flow to Precipitation Ratio

The variable Q/P is calculated as the ratio of incremental naturalized flow at a control point to the volume of precipitation falling on the incremental watershed draining to that control point (Equation 1-E-2). This ratio is calculated for each aggregated time series.

$$\frac{Q}{P} = Q\ /\ PV\ = \frac{NAT_{incremental}}{Precipitation\ Depth * Drainage\ Area_{incremental}} \qquad \text{Equation 1-E-2}$$

Alternative Flow Adjustment Method

Section 1.3.3 describes a method to adjust incremental naturalized flows (Q) based on observed trends in Q. This method is applied for flows throughout the Brazos River Basin. During development of this methodology, an alternative approach was considered which would adjust flows based on observed trends in precipitation volume within a watershed (PV) and the ratio of flow volume to precipitation volume (Q/P). Ultimately, the direct application of trends in Q was recommended for adjustments to the Brazos WAM. However, the alternative approach may be useful in other watersheds where separate trends in PV and Q/P may be of importance. For example, many watersheds within the San Jacinto River Basin in the greater Houston area are highly developed. Gooch and Albright (2011) assessed changes in runoff and the runoff-to-rainfall ratio in Harris County and found increasing trends in runoff, independent of trends in precipitation, in some watersheds. Those watersheds with the most clear increasing trends are in primarily urban areas. Gooch and Albright (2011) also discussed several mechanisms by which urbanization may increase runoff:

- Removal of natural prairie vegetation,
- Increased antecedent soil moisture due to landscape irrigation,
- Drainage improvements that improve conveyance efficiency, and
- Reduced channel losses due to channels having greater baseflows supported by wastewater return flows.

For watersheds which experienced significant development over the past several decades but are now mostly developed, observed increasing trends in Q/P may be expected to flatten out in the near future. In this case, it would be advantageous to separate flows into PV and Q/P and apply adjustment factors based on trends in each. This would allow trends in Q/P to only be extrapolated for as many years as development is expected to continue, rather than continuously to 2070. Then, flows can still be adjusted for any separate trend that may be identified in precipitation, which is independent of land use changes.

To adjust flows based on trends in PV and Q/P, the flow adjustment factor f_Q is replaced with two factors for each primary control point: a watershed factor based on Q/P ($f_{\frac{Q}{P}}$) and a precipitation factor based on PV (f_P). These factors are calculated following the same approach described in ***Section 1.3.3*** for determining f_Q from trends in Q. These factors are applied as shown in Equation 1-E-3 to calculate the adjusted monthly incremental naturalized flow values.

$$NAT_{incr,adjusted} = NAT_{incr} * f_{\frac{Q}{P}} * f_P$$ Equation 1-E-3

The hierarchy described in ***Section 1.3.3*** to select the best timescale for trend extrapolation is applied separately for P and Q/P. For example, if trends in PV are strongest (have the highest significant tau value) on a seasonal basis but trends in Q/P are strongest on an annual basis, the control point will have three f_P factors (one for each season) and a single $f_{\frac{Q}{P}}$ factor. In this case, each monthly flow value is multiplied by f_P for the associated season and by the constant (annual) $f_{\frac{Q}{P}}$. Months with no significant trends remain unchanged (i.e., adjustment factors are equal to 1).

Land Use

The process of developing naturalized flows from historical gage measurements accounts for many anthropogenic impacts on flows. However, no adjustments are made for changes in land use, as its impact on streamflow is more difficult to quantify. In addition to an assessment of groundwater elevations, trends in land use change within the Brazos River Basin may also provide insight into observed trends in the Q/P ratio. As discussed previously, Gooch and Albright (2011) found increasing trends in runoff and the runoff-to-rainfall ratio in Harris County to be most apparent in primarily urban areas. In a separate study on rainfall and runoff trends in the Upper Colorado River Basin, Furnans et al. (2019) assessed trends in an area-weighted curve number, which relates to the fraction of rainfall which becomes runoff. The curve number was weighted based on different land use categories, so it served as an indicator of potential changes in Q/P as well as a proxy for changes in land use. Furnans et al. (2019) also attributed some trends in streamflow to an increase in small ponds within the Upper Colorado River Basin.

Because urbanization and other changes in land use and land cover are not accounted for in the development of naturalized flows, these changes may contribute to trends in Q/P. In watersheds that are primarily urban or are experiencing significant urban development, analysis of trends in land use may provide insight into trends in Q or Q/P.

In order to determine whether a watershed has experienced significant development and may benefit from use of the two-factor approach based on PV and Q/P, an analysis of land use data may be beneficial. We propose using data from the National Land Cover Database (NLCD), which is developed and distributed by the Multi-Resolution Land Characteristics Consortium (MRLC), to analyze trends over time in the percentage of area that is developed or is impervious. Trends should be assessed for land cover within each incremental drainage area considered in the Q/P analysis.

APPENDIX 1-F: ADJUSTMENTS TO OBSERVATIONS IN YEARS PRIOR TO SELECTED START YEAR

The approach outlined in Section 1.3.3 for Determination of Start Year describes the selection of a modified period of analysis for trend identification, starting at a later year than 1940. When a start year later than 1940 is identified using this approach, the adjustment factors that are subsequently developed based on the trend analysis reflect a trend only present in observations occurring during or after that start year. This implies that data prior to the start year did not contain the trend being used for adjustment. The modification to Equation 1-F-1 shown in Equation 1-F-2 avoids over-adjusting earlier flow or evaporation data with a trend not present in data before the start year.

Equation 1-F-1

$$\Delta Y(t) = Y_{trend}(2070) - Y_{trend}(t)$$

Equation 1-F-2

$$\begin{cases} \boldsymbol{if}\ t \geq StartYear,\ \ \boldsymbol{then} \quad \Delta Y(t) = Y_{trend}(2070) - Y_{trend}(t) \\ \boldsymbol{if}\ t < StartYear,\ \ \boldsymbol{then} \quad \Delta Y(t) = Y_{trend}(2070) - Y_{trend}(StartYear) \end{cases}$$

Figure 1-F-1 through 1-F-3 illustrate this approach using annual incremental flow data from control point CFEL22. Figure 1-F-1 illustrates incremental naturalized flow from 1940 to 2015 in green. The trend analysis start year for this dataset was determined to be 1957, and outlier-adjusted values from 1957 to 2015 are shown in blue. The linear trendline fit to the 1957-2015 data and extended through 2070 is shown in orange. Figure 1-F-2 illustrates the extended trend line and the adjustment that would be applied to an early value based only on Equation 1-F-1. The modification provided by Equation 1-F-2, in which the trend is not extrapolated prior to 1957, is shown in Figure 1-F-3.

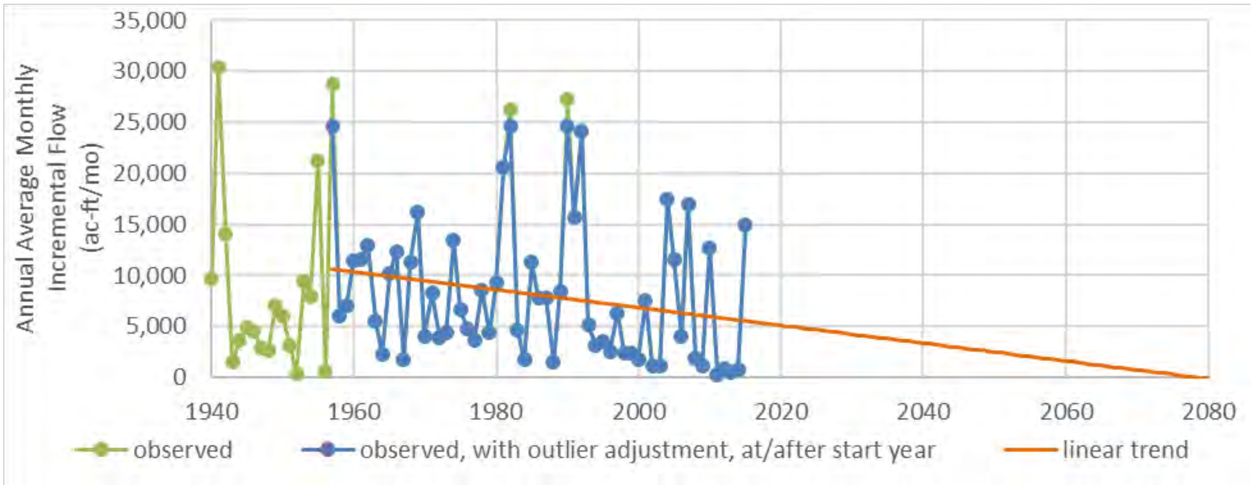


Figure 1-F-1 – Trend with Start Year

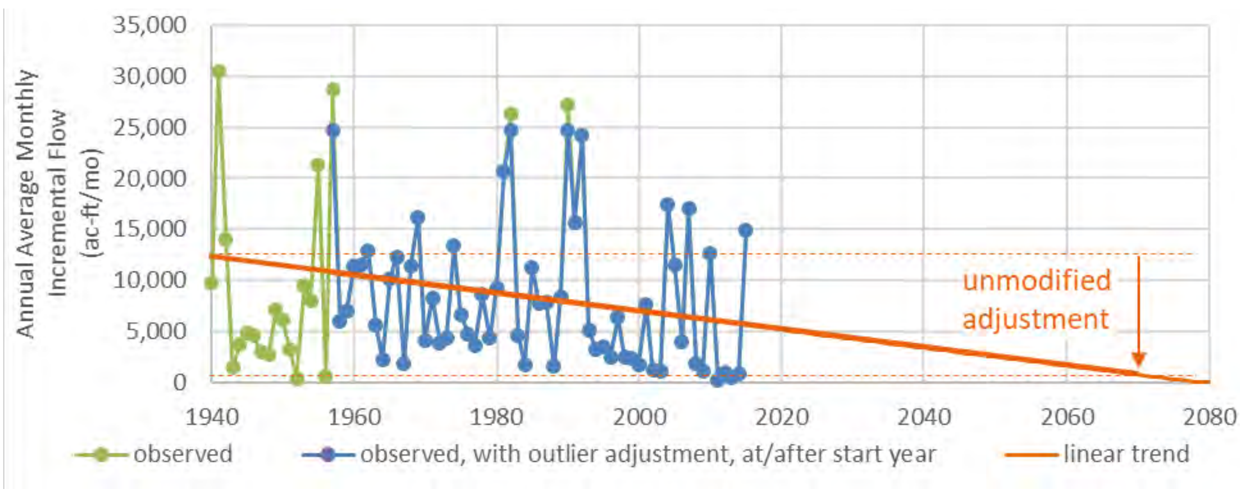


Figure 1-F-2 – Adjustment to Data Based on Extrapolated Trend

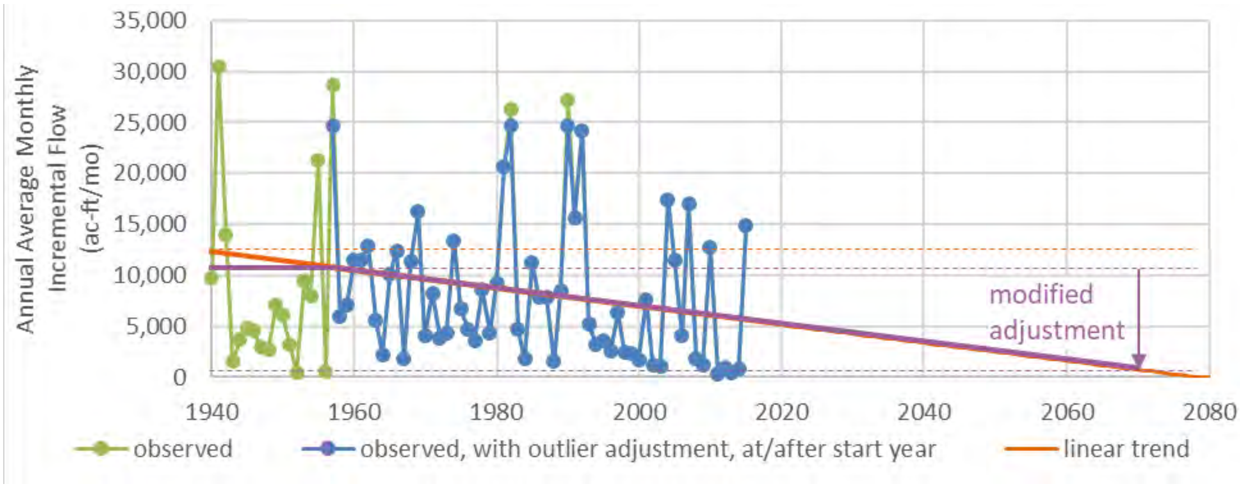


Figure 1-F-3 – Adjustment to Data Based on Forward Extrapolation Only
(No Extrapolation Prior to 1957 Start Year)

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Outstanding service

CHAPTER 2

Trend Analysis Results and Impacts of Observed Trends on Surface Water Supply Sources in Regions G and H

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2.0 TREND ANALYSIS RESULTS AND IMPACTS OF OBSERVED TRENDS ON SURFACE WATER SUPPLY SOURCES IN REGIONS G AND H

2.1 TRENDS IN INCREMENTAL NATURALIZED FLOWS

The FNI team evaluated historical monthly incremental naturalized flows for trends based on multiple time series subsets (annual, seasonal, and seasonal split by hydrologic condition). We evaluated trends for all primary control points in the Brazos WAM. Where significant trends were present, we fit both linear and exponential functions to the historical data. However, we found no exponential trend to be substantially better than a linear trend for any control point ($R^2_{exponential} - R^2_{linear}$ was not greater than or equal to 0.1 for any trend), and thus we selected linear best-fit equations for all detected trends to determine adjustment factors for all control points. We developed additive adjustment factors (which could be zero) for each primary control point to adjust for future flow averages expected under 2050 and 2070 conditions. This section focuses on describing the trends in incremental flow across the Brazos Basin (which are the basis for both the 2050 and 2070 adjustments) and adjustments for 2070 conditions unless otherwise noted. We also assessed trends in precipitation volume and the ratio of streamflow to precipitation (Q/P) to provide additional context for trends in observed incremental naturalized flows. **Appendix 2-C** includes graphs and data for the analysis.

We computed Kendall's tau for the multiple time-series subsets of the incremental naturalized flow for all primary control points to identify persistent long-term trends during the period of record (1940-2015). The strength of Kendall's tau and the p-value threshold for significance ($p \leq 0.05$) guided which subset(s) to use for adjusting the incremental flows. When multiple significant trends were found, we used the criteria previously presented in Figure 1-7 to select which trends to apply. We conducted a start year analysis for all primary control points to identify significant trends beginning with the full period of record (1940-2015) and analyzing through a minimum period of 50 years (1966-2015). The year between 1940 and 1966 (inclusive) that maximized Kendall's tau for significant annual trends was the start year used for the trend analysis and development of adjustment factors.

We did not adjust incremental flows for a control point when no significant trends were detected for any time series subsets of that control point. Table 2-1 lists the 26 primary control points with no trends in incremental flow detected in their incremental drainage area. We found all other primary control points to have a significant trend in one or multiple subsets of their incremental flow time series and adjusted flows for those points according to the process described in ***Section 1.3.4***. For all control points, the magnitude of adjustments to naturalized flows was greatest in the beginning of the time series and declined to zero by the selected future year (e.g., 2050 or 2070). In other words, the beginning of the time series is furthest from the 2050 or 2070 conditions and therefore requires the largest adjustments to shift it to the future conditions, whereas subsequent years need progressively less adjustments to shift to the future conditions. As described in Section 1.3.2, the purpose of this approach is to produce an adjusted time series of 76 years of hydrology representing conditions in the selected future year (e.g., 2050 or 2070).

We used the time series of adjusted incremental flows to reconstruct adjusted total naturalized flows at each control point based on Equation 1-14. Entries in the FLO file for control points that had no significant trends in incremental flows may still have adjustments if these control points have adjustments for upstream trends. Trends in incremental flow in the drainage area between the Rosharon gage (BRRO72) and the Gulf of Mexico (BRGM73) were not assessed due to uncertainty in the naturalized flow data at BRGM73, but total naturalized flows at BRGM73 were updated based on upstream adjustments. Figure 2-2 and Table 2-2 show overall changes to naturalized flows.

In the following subsections, we discuss significant extrapolated trends for individual subbasins in an upstream to downstream order (Table 2-1).

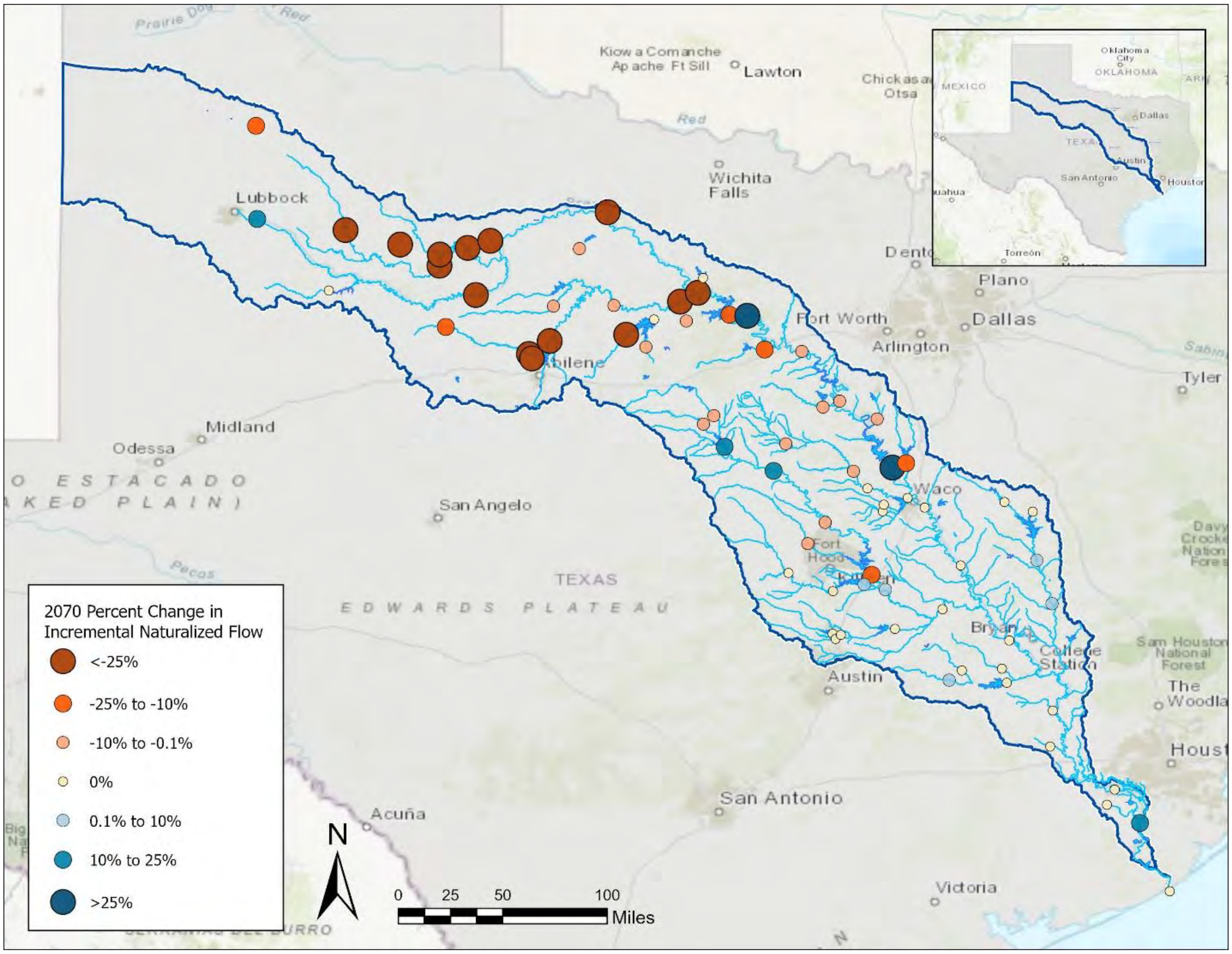


Figure 2-1 – Net Percent Changes in Total Naturalized Flows over the 1940-2015 Model Period (2050)

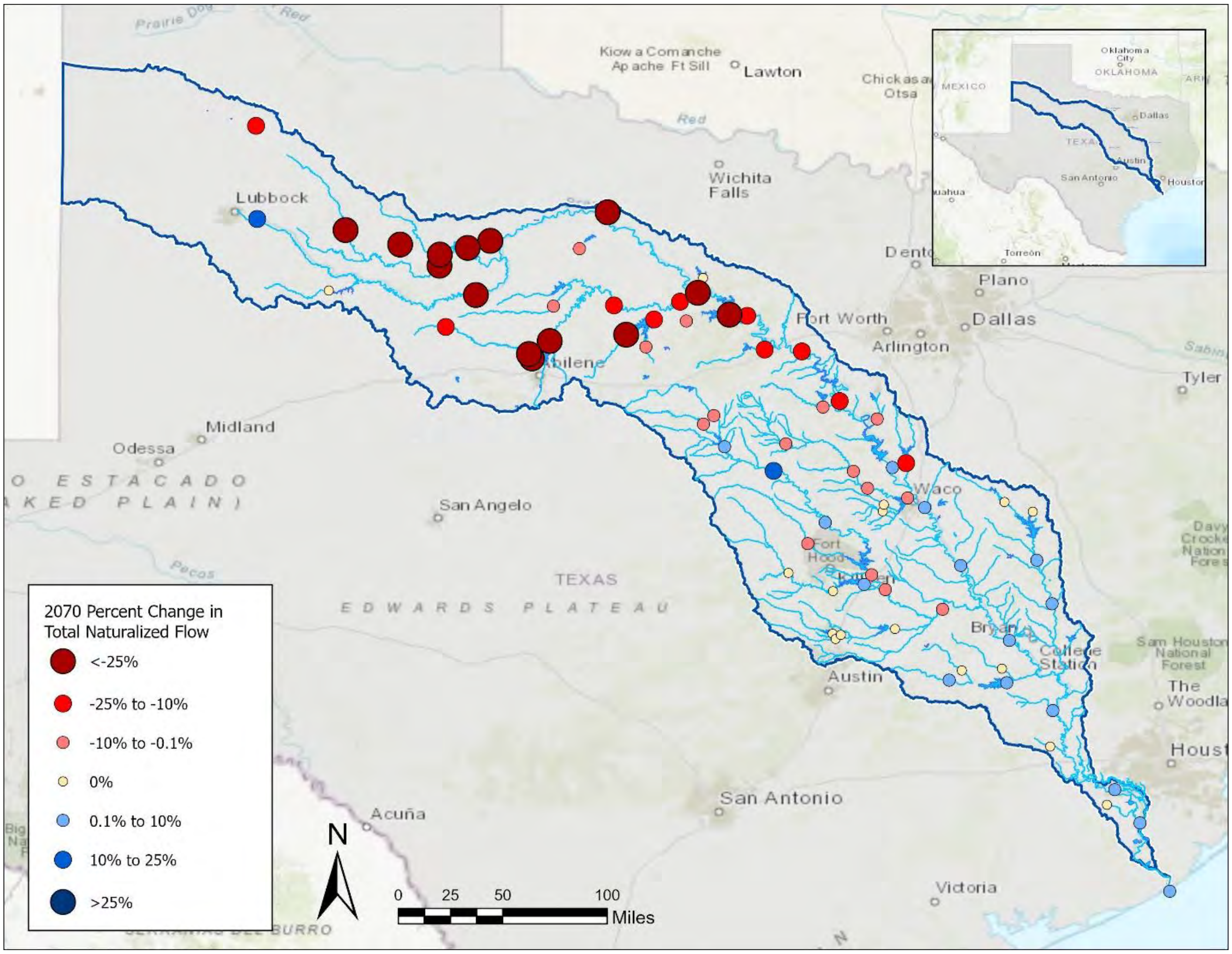


Figure 2-2 – Net Percent Changes in Total Naturalized Flows over the 1940-2015 Model Period (2070)

Table 2-1 – Brazos River Basin Primary Control Points

Control Point ID	Control Point Name	USGS Gage Number	Discussed in Subbasin	Trend Detected in Incremental Flow
RWPL01	Running Water Draw at Plainview	08080700	BRSE11	Yes
WRSP02	White River Reservoir near Spur	08080910	BRSE11	Yes
DUGI03	Duck Creek near Girard	08080950	BRSE11	Yes
SFPE04	Salt Fork Brazos River near Peacock	08081000	BRSE11	Yes
CRJA05	Croton Creek near Jayton	08081200	BRSE11	Yes
SFAS06	Salt Fork Brazos River near Aspermont	08082000	BRSE11	Yes
BSLU07	Buffalo Springs Lake near Lubbock	08079550	BRSE11	Yes
DMJU08	Double Mountain Fork Brazos River at Justiceburg	08079600	BRSE11	No
DMAS09	Double Mountain Fork Brazos River near Aspermont	08080500	BRSE11	Yes
NCKN10	North Croton Creek near Knox City	08082180	BRSE11	Yes
BRSE11	Brazos River at Seymour	08082500	BRSE11	Yes
MSMN12	Millers Creek near Munday	08082700	SHGR26	Yes
CFRO13	Clear Fork Brazos River near Roby	08083100	CFEL22	Yes
CFHA14	Clear Fork Brazos River at Hawley	08083240	CFEL22	Yes
MUHA15	Mulberry Creek near Hawley	08083245	CFEL22	Yes
CFNU16	Clear Fork Brazos River at Nugent	08084000	CFEL22	Yes
CAST17	California Creek near Stamford	08084800	CFEL22	Yes
CFFG18	Clear Fork Brazos River at Fort Griffin	08085500	CFEL22	Yes
HCAL19	Hubbard Creek below Albany	08086212	CFEL22	Yes
BSBR20	Big Sandy Creek above Breckenridge	08086290	CFEL22	Yes
HCBR21	Hubbard Creek near Breckenridge	08086500	CFEL22	No
CFEL22	Clear Fork Brazos River at Eliasville	08087300	CFEL22	Yes
BRSB23	Brazos River near South Bend	08088000	SHGR26	Yes
GHGH24	Lake Graham near Graham	08088400	SHGR26	No
CCIV25	Big Cedar Creek near Ivan	08088450	SHGR26	Yes
SHGR26	Brazos River at Morris Sheppard Dam near Graford	08088600	SHGR26	Yes
BRPP27	Brazos River near Palo Pinto	08089000	BRAQ33	Yes
PPSA28	Palo Pinto Creek near Santo	08090500	BRAQ33	Yes
BRDE29	Brazos River near Dennis	08090800	BRAQ33	Yes
BRGR30	Brazos River near Glen Rose	08091000	BRAQ33	Yes
PAGR31	Paluxy River at Glen Rose	08091500	BRAQ33	Yes
NRBL32	Nolan River at Blum	08092000	BRAQ33	Yes
BRAQ33	Brazos River near Aquilla	08093100	BRAQ33	Yes
AQAQ34	Aquilla Creek near Aquilla	08093500	BRBR59	Yes
NBHI35	North Bosque River at Hico	08094800	BOWA40	Yes
NBCL36	North Bosque River near Clifton	08095000	BOWA40	Yes

Control Point ID	Control Point Name	USGS Gage Number	Discussed in Subbasin	Trend Detected in Incremental Flow
NBVM37	North Bosque River at Valley Mills	08095200	BOWA40	No
MBMG38	Middle Bosque River near McGregor	08095300	BOWA40	No
HGCR39	Hog Creek near Crawford	08095400	BOWA40	No
BOWA40	Bosque River near Waco	08095600	BOWA40	No
BRWA41	Brazos River at Waco	08096500	BRBR59	No
BRHB42	Brazos River near Highbank	08098290	BRBR59	No
LEDL43	Leon River near De Leon	08099100	LRCA58	Yes
SADL44	Sabana River near De Leon	08099300	LRCA58	Yes
LEHS45	Leon River near Hasse	08099500	LRCA58	Yes
LEHM46	Leon River near Hamilton	08100000	LRCA58	Yes
LEGT47	Leon River at Gatesville	08100500	LRCA58	Yes
COPI48	Cowhouse Creek at Pidcoke	08101000	LRCA58	Yes
LEBE49	Leon River near Belton	08102500	LRCA58	Yes
LAKE50	Lampasas River near Kempner	08103800	LRCA58	No
LAYO51	Lampasas River at Youngsport	08104000	LRCA58	No
LABE52	Lampasas River near Belton	08104100	LRCA58	Yes
LRLR53	Little River near Little River	08104500	LRCA58	Yes
NGGE54	North Fork San Gabriel River near Georgetown	08104700	LRCA58	No
SGGE55	South Fork San Gabriel River at Georgetown	08104900	LRCA58	No
GAGE56	San Gabriel River at Georgetown	08105000	LRCA58	No
GALA57	San Gabriel River at Laneport	08105700	LRCA58	No
LRCA58	Little River near Cameron	08106500	LRCA58	No
BRBR59	Brazos River near Bryan	08109000	BRBR59	No
MYDB60	Middle Yegua Creek near Dime Box	08109700	BRRO72	Yes
EYDB61	East Yegua Creek near Dime Box	08109800	BRRO72	No
YCSO62	Yegua Creek near Somerville	08110000	BRRO72	No
DCLY63	Davidson Creek near Lyons	08110100	BRRO72	No
NAGR64	Navasota River above Groesbeck	08110325	NABR67	No
BGFR65	Big Creek near Freestone	08110430	NABR67	No
NAEA66	Navasota River near Easterly	08110500	NABR67	Yes
NABR67	Navasota River near Bryan	08111000	NABR67	Yes
BRHE68	Brazos River near Hempstead	08111500	BRRO72	No
MCBL69	Mill Creek near Bellville	08111700	BRRO72	No
BRRI70	Brazos River at Richmond	08114000	BRRO72	No
BGNE71	Big Creek near Needville	08115000	BRRO72	No
BRRO72	Brazos River at Rosharon	08116650	BRRO72	Yes
BRGM73	Brazos River at Gulf of Mexico			No

Table 2-2 – Changes in Annual Average Incremental and Total Naturalized Flows Due to Adjustments for 2070 Conditions During Period of Record (1940-2015)

Control Point ID	Average Change in Incremental Naturalized Flow (ac-ft/yr)	Percent Change in Incremental Naturalized Flow	Average Change in Total Naturalized Flow (ac-ft/yr)	Percent Change in Total Naturalized Flow	Trend(s) in Incremental Flow Applied
RWPL01	-474	-24%	-474	-24%	Annual
WRSP02	-4,646	-34%	-4,670	-34%	Annual
DUGI03	-2,907	-33%	-2,907	-33%	Annual
SFPE04	-10,449	-34%	-15,662	-34%	Annual
CRJA05	-3,715	-35%	-3,715	-35%	Annual
SFAS06	-6,274	-35%	-22,826	-34%	Annual
BSLU07	3,720	20%	3,719	20%	Wet Spring
DMJU08	0	0%	0	0%	None
DMAS09	-32,550	-40%	-31,338	-31%	Annual
NCKN10	-3,649	-33%	-3,649	-33%	Annual
BRSE11	-48,455	-37%	-78,816	-35%	Annual
MSMN12	-139	-2%	-139	-2%	Winter, Dry Spring
CFRO13	-826	-14%	-827	-14%	Average Winter, Dry Winter, Wet Spring, Average Summer
CFHA14	-15,532	-45%	-16,080	-42%	Annual
MUHA15	-2,699	-41%	-2,700	-41%	Annual
CFNU16	-17,946	-43%	-34,524	-43%	Annual
CAST17	-710	-3%	-710	-3%	Dry Spring
CFFG18	-1,670	-2%	-21,024	-14%	Dry Spring
HCAL19	-14,159	-29%	-14,159	-29%	Annual
BSBR20	-686	-3%	-686	-3%	Dry Spring
HCBR21	0	0%	-12,427	-15%	None
CFEL22	-36,176	-37%	-61,106	-22%	Annual
BRSB23	-68,012	-34%	-169,481	-29%	Annual
GHGH24	0	0%	0	0%	None
CCIV25	-334	-3%	-334	-3%	Average Summer
SHGR26	-15,818	-21%	-182,643	-26%	Annual
BRPP27	57,072	183%	-124,374	-17%	Wet Winter, Dry Winter, Wet Spring, Average Spring
PPSA28	-6,015	-10%	-6,016	-10%	Dry Spring, Summer
BRDE29	-5,083	-4%	-131,594	-15%	Average Winter
BRGR30	-414	-0.3%	-129,058	-13%	Dry Summer
PAGR31	-3,864	-7%	-3,864	-7%	Average Winter, Dry Spring
NRBL32	-532	-1%	-532	-1%	Average Winter, Dry Winter
BRAQ33	202,643	118%	72,120	6%	Annual
AQAQ34	-9,879	-11%	-9,879	-11%	Wet Spring
NBHI35	-1,757	-4%	-1,757	-4%	Average Winter, Dry Spring
NBCL36	-3,926	-3%	-5,312	-3%	Average Winter

Control Point ID	Average Change in Incremental Naturalized Flow (ac-ft/yr)	Percent Change in Incremental Naturalized Flow	Average Change in Total Naturalized Flow (ac-ft/yr)	Percent Change in Total Naturalized Flow	Trend(s) in Incremental Flow Applied
NBVM37	0	0%	-4,974	-2%	None
MBMG38	0	0%	0	0%	None
HGCR39	0	0%	0	0%	None
BOWA40	0	0%	-4,264	-1%	None
BRWA41	0	0%	57,199	3%	None
BRHB42	0	0%	56,409	3%	None
LEDL43	-2,430	-5%	-2,430	-5%	Average Winter, Dry Spring
SADL44	-1,272	-4%	-1,272	-4%	Dry Spring, Average Summer
LEHS45	8,133	16%	5,129	4%	Average Winter, Dry Winter, Dry Spring, Wet Summer, Average Summer
LEHM46	18,893	22%	22,126	14%	Wet Summer
LEGT47	-3,061	-3%	18,523	7%	Average Winter
COPI48	-2,423	-3%	-2,423	-3%	Average Winter
LEBE49	-31,976	-18%	-16,376	-3%	Wet Spring
LAKE50	0	0%	0	0%	None
LAYO51	0	0%	0	0%	None
LABE52	575	2%	575	0%	Dry Winter
LRLR53	5,956	5%	-9,748	-1%	Dry Winter
NGGE54	0	0%	0	0%	None
SGGE55	0	0%	0	0%	None
GAGE56	0	0%	0	0%	None
GALA57	0	0%	0	0%	None
LRCA58	0	0%	-9,537	-1%	None
BRBR59	0	0%	46,100	1%	None
MYDB60	3,723	9%	3,723	9%	Average Spring, Summer
EYDB61	0	0%	0	0%	None
YCSO62	0	0%	3,640	2%	None
DCLY63	0	0%	0	0%	None
NAGR64	0	0%	0	0%	None
BGFR65	0	0%	0	0%	None
NAEA66	3,365	2%	3,365	1%	Dry Summer
NABR67	933	1%	4,265	1%	Dry Summer
BRHE68	0	0%	52,501	1%	None
MCBL69	0	0%	0	0%	None
BRRI70	0	0%	50,952	1%	None
BGNE71	0	0%	0	0%	None
BRRO72	63,494	22%	113,920	2%	Average Summer
BRGM73	0	0%	112,034	2%	None

2.1.1 BRSE11 – Brazos River at Seymour

Ten control points upstream of the Brazos River at Seymour (BRSE11) gage contribute naturalized flow to BRSE11 (Figure 2-3) in addition to the flow contributed from the incremental drainage area for BRSE11. Nine of those control points (including BRSE11 itself) had decreasing annual trends in incremental flows. One control point had an increasing wet spring trend (BSLU07), and one control point had no trend (DMJU08) in incremental flows (Table 2-3). Start years for trends ranged from 1940 to 1959. Incremental flow trends in spring and summer seasons were prevalent for primary control points in this portion of the upper basin, whereas there were no trends in the winter season. The Kendall's tau values for these seasonal subsets were not as strong as the annual incremental flow trends, and thus, annual trends were predominantly selected for adjustments to incremental flows.

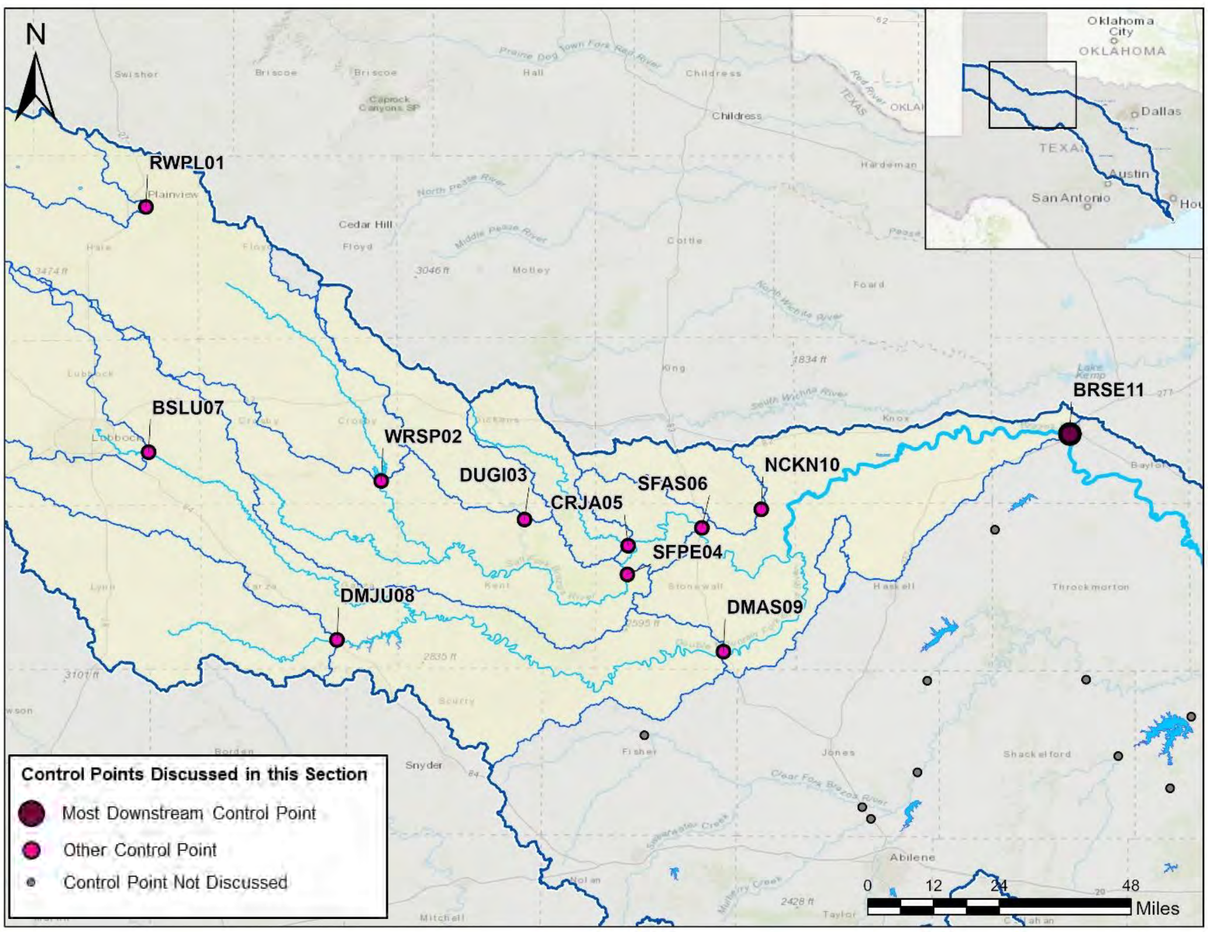


Figure 2-3 – Drainage Area of BRSE11 and Control Points RWPL01 through BRSE11

Table 2-3 - Trend Results for Incremental Flow in the Upper Brazos River Basin: Control Points RWPL01 through BRSE11

	RWPL01		WRSP02		DUGI03		SFPE04		CRJA05		SFAS06	
Start Year	1959		1945		1940		1945		1946		1945	
	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	**-0.42**	**0.00**	**-0.36**	**0.00**	**-0.22**	**0.01**	**-0.26**	**0.00**	**-0.31**	**0.00**	**-0.30**	**0.00**
Winter	0.09	0.32	-0.04	0.62	-0.07	0.38	-0.01	0.91	0.00	0.99	-0.09	0.29
Spring	-0.35	0.00	-0.29	0.00	-0.13	0.09	-0.18	0.02	-0.23	0.01	-0.18	0.03
Summer	-0.38	0.00	-0.27	0.00	-0.21	0.01	-0.15	0.06	-0.20	0.02	-0.23	0.01
Dry Winter	0.19	0.35	0.15	0.35	-0.17	0.26	-0.13	0.39	-0.09	0.54	-0.18	0.22
Average Winter	-0.06	0.69	-0.19	0.16	0.03	0.85	0.01	0.93	0.07	0.63	-0.08	0.57
Wet Winter	0.31	0.08	0.05	0.76	-0.10	0.52	-0.05	0.80	0.02	0.95	-0.16	0.33
Dry Spring	-0.59	0.00	-0.34	0.02	-0.24	0.10	-0.26	0.08	-0.33	0.03	-0.31	0.04
Average Spring	-0.55	0.00	-0.37	0.01	-0.09	0.52	-0.16	0.26	-0.27	0.06	-0.20	0.17
Wet Spring	0.10	0.59	-0.20	0.23	-0.04	0.78	-0.14	0.40	-0.13	0.43	-0.01	0.95
Dry Summer	-0.35	0.03	-0.23	0.10	-0.20	0.14	-0.14	0.33	-0.18	0.23	-0.18	0.21
Average Summer	-0.27	0.13	-0.18	0.26	-0.21	0.16	-0.15	0.34	-0.19	0.24	-0.25	0.10
Wet Summer	-0.42	0.01	-0.29	0.05	-0.24	0.10	-0.10	0.53	-0.15	0.34	-0.19	0.22

	BSLU07		DMJU08		DMAS09		NCKN10		BRSE11	
Start Year	1940		1940		1957		1945		1957	
	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	0.13	0.10	0.00	0.96	**-0.27**	**0.00**	**-0.26**	**0.00**	**-0.20**	**0.03**
Winter	0.03	0.71	-0.02	0.85	0.00	0.99	-0.04	0.67	-0.09	0.30
Spring	0.03	0.69	-0.06	0.44	-0.17	0.06	-0.17	0.04	-0.14	0.12
Summer	0.09	0.24	0.02	0.83	-0.23	0.01	-0.19	0.02	-0.20	0.03
Dry Winter	0.08	0.62	0.01	0.98	0.11	0.56	-0.15	0.31	-0.25	0.17
Average Winter	0.04	0.80	0.13	0.34	0.25	0.11	0.00	1.00	0.02	0.93
Wet Winter	0.20	0.18	0.01	0.96	-0.13	0.46	-0.07	0.70	-0.06	0.75
Dry Spring	-0.20	0.15	-0.28	0.05	-0.33	0.08	-0.31	0.04	-0.43	0.02
Average Spring	-0.07	0.61	-0.12	0.39	-0.06	0.74	-0.16	0.27	-0.02	0.93
Wet Spring	**0.33**	**0.02**	0.19	0.21	-0.08	0.65	0.03	0.88	0.02	0.90
Dry Summer	0.08	0.55	-0.01	0.95	-0.18	0.32	-0.21	0.15	-0.27	0.13
Average Summer	0.19	0.23	0.15	0.34	-0.32	0.06	-0.18	0.25	-0.22	0.21
Wet Summer	0.06	0.71	-0.04	0.81	-0.07	0.65	-0.11	0.46	0.15	0.34

Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

At RWPL01, the Kendall's tau for the spring (-0.35) incremental flow trend is not as strong as the Kendall's tau values for dry spring (-0.59) and average spring (-0.55) trends (Table 2-3). A possible explanation may be the increasing trend in precipitation volume discovered for wet spring seasons at RWPL01, which influences the overall seasonal spring trend (Table 2-C-3). Control points DMAS09 and BRSE11 historically have the highest average monthly incremental flows in this part of the basin. The annual decreasing trends for these two control points create the greatest adjustments to the total naturalized flows due to these large flows. Control point DMAS09 (slope of -109 ac-ft/mo/yr) has a greater decreasing slope than BRSE11 (slope of -95 ac-ft/mo/yr) (Figures C-16 and C-20). This means that the extrapolated average incremental flow for DMAS09 decreases to 0 ac-ft/yr by 2044 (Figure 2-C-16). By contrast, the average incremental flow at BRSE11 decreases to about 28,000 ac-ft/yr by 2070 (Figure 2-C-20; note units). In terms of percent change in incremental naturalized flow, the largest change is a decrease by 40% for control point DMAS09 (Table 2-2).

Trends in the ratio of monthly naturalized flow to monthly precipitation (Q/P) for control points upstream of and at BRSE11 mostly follow the same trends and direction as incremental flow (**Appendix 2-C**). Increasing precipitation volume trends for wet spring, wet winter, or average summer do not match any hydrologic trends for incremental flow. Except for watersheds BSLU07 and DMJU08, the remaining watersheds are generating less streamflow given the same amount of precipitation during these seasonal and hydrologic conditions.

One explanation for the increasing trend in wet spring for control point BSLU07 may be the contribution of playa lake stormwater. In 2003 and 2008, the City of Lubbock completed construction of the South-Central and South Playa Lake Drainage Systems, respectively (City of Lubbock, 2013). The City of Lubbock created the drainage system to reduce flooding, and supplement natural flows in the Brazos River by discharging the stormwater into a tributary of the North Fork. The proposed Jim Bertram Lake 7 is anticipated to eventually capture the stormwater from the Playa Lake Drainage Systems. The most recent wet spring years in the analysis are 2005, 2007, 2010, and 2015. These four years produce a steep increasing slope on the tail end of the data which contribute to the increasing trend detected. This may be correlated with the playa lake stormwater discharging into the North Fork. While a step change assessment may have been more appropriate, a linear increasing trendline was applied.

No trends in precipitation volume were detected for SFAS06 (Table 2-C-8). We found no trends in flow at DMJU08 (Table 2-3). We found a decreasing trend in Q/P (dry spring) and an increasing trend in precipitation volume (wet winter) (Table 2-C-10). We detected no trends in precipitation volume at control point DMAS09, and the decreasing Q/P trend in annual, spring, and summer for this study corroborate the findings in Harwell et al. (2020) (Table 2-C-11).

We calculated a time series of total adjusted naturalized flow at BRSE11 from the upstream adjusted incremental flows multiplied by delivery factors plus the adjusted runoff from the incremental drainage area of BRSE11 (Figure 2-4).

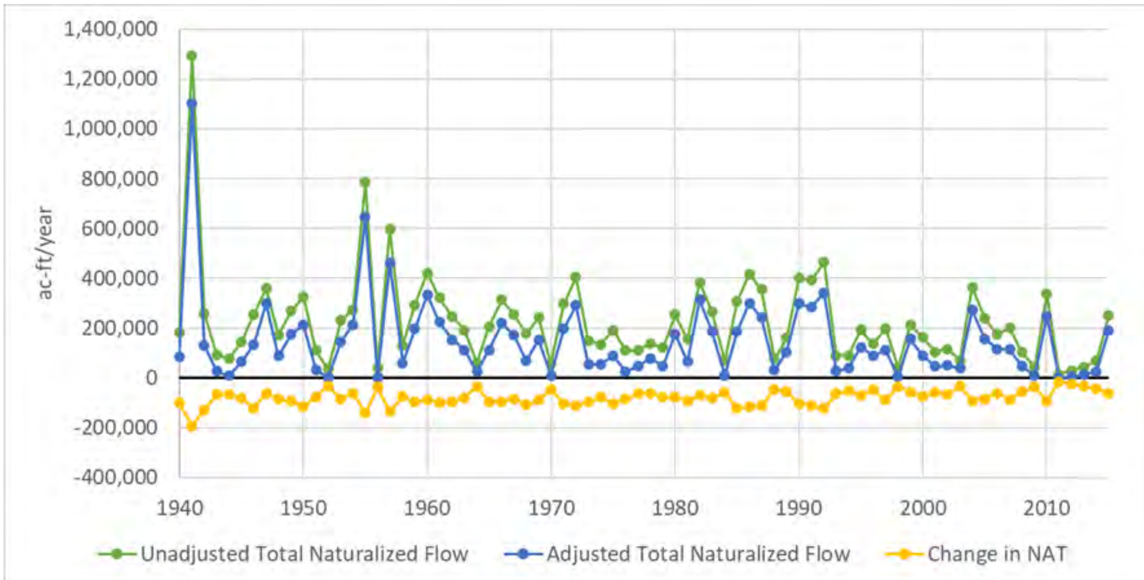


Figure 2-4 – Original and Adjusted Naturalized Flow Time Series for BRSE11 for 2070 Conditions

2.1.2 CFEL22 – Clear Fork of the Brazos River at Eliasville

There are nine control points upstream of the Clear Fork at Eliasville (CFEL22) gage that contribute naturalized flow to CFEL22 (Figure 2-5), plus the flow contributed from the incremental drainage area for CFEL22. This part of the basin, called the Clear Fork watershed, experienced more seasonal and hydrologic condition trends (Table 2-4) than the watersheds upstream of BRSE11. We found decreasing annual trends in incremental flow at five upstream control points (CFRO13, CFHA14, MUHA15, CFNU16, HCAL19) plus the CFEL22 control point itself, and one control point had no significant trends in incremental flow (HCBR21). We found dry spring trends for three control points (CAST17, CFFG18, and BSBR20). For the incremental flows at CFRO13, we detected decreasing trends for four time series subsets (dry winter, average winter, wet spring, and average summer).

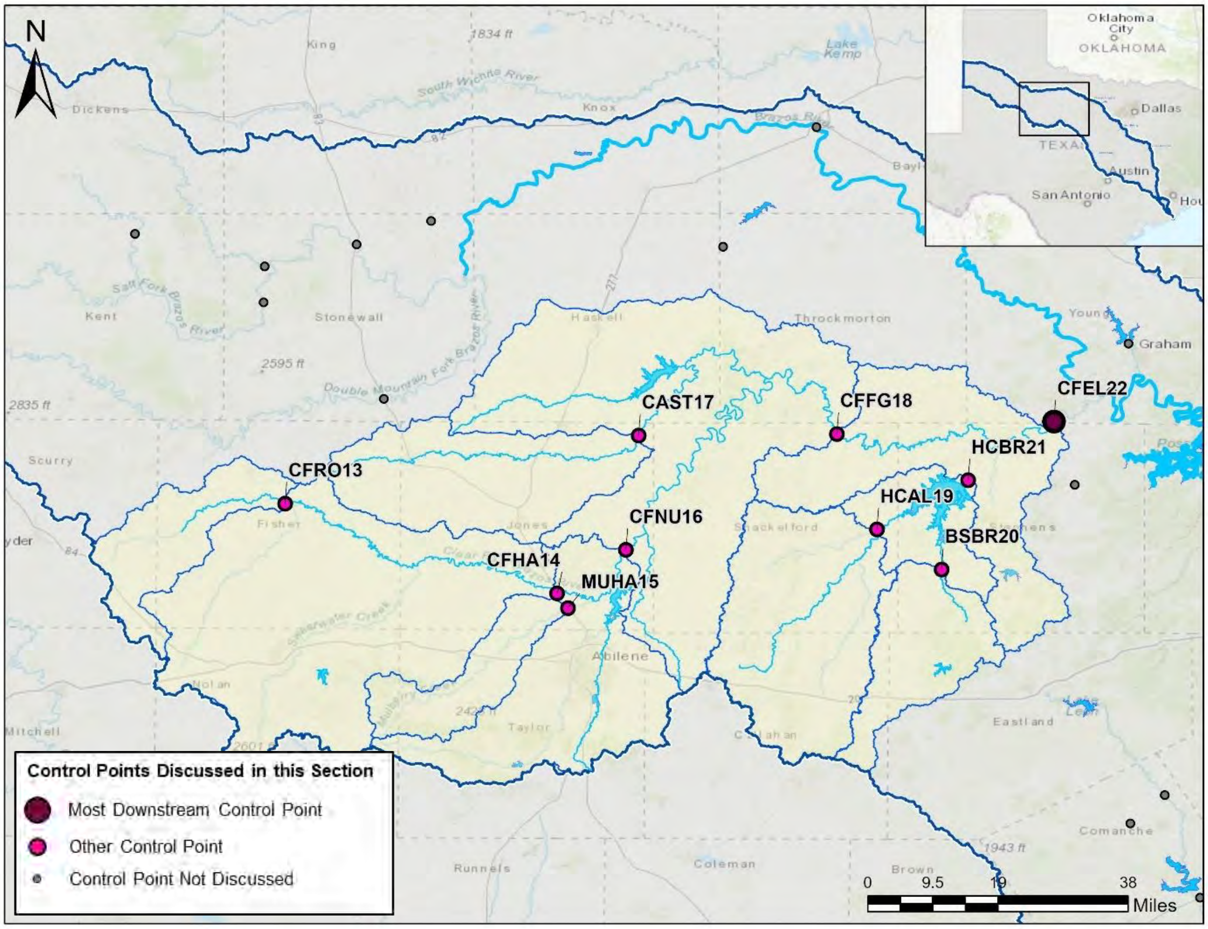


Figure 2-5 – Clear Fork Subbasin and Control Points CFRO13 through CFEL22

Table 2-4 – Trend Results for Incremental Flow in the Clear Fork of the Brazos River Basin: Control Points CFRO13 through CFEL22

	CFRO13		CFHA14		MUHA15		CFNU16		CAST17	
Start Year	1957		1965		1965		1965		1940	
	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	-0.40	0.00	**-0.28**	**0.00**	**-0.28**	**0.00**	**-0.29**	**0.00**	-0.04	0.66
Winter	-0.37	0.00	-0.21	0.03	0.00	0.97	-0.17	0.08	0.00	0.96
Spring	-0.29	0.00	-0.26	0.01	-0.23	0.02	-0.26	0.01	-0.03	0.72
Summer	-0.41	0.00	-0.16	0.10	-0.19	0.06	-0.12	0.24	-0.10	0.22
Dry Winter	**-0.59**	**0.00**	-0.37	0.06	0.05	0.84	-0.14	0.49	-0.03	0.86
Average Winter	**-0.32**	**0.04**	-0.11	0.55	0.05	0.78	-0.08	0.65	0.08	0.54
Wet Winter	-0.16	0.33	-0.04	0.87	0.20	0.28	0.01	1.00	0.01	0.98
Dry Spring	-0.36	0.06	-0.65	0.00	-0.54	0.01	-0.49	0.02	**-0.30**	**0.04**
Average Spring	-0.20	0.21	0.00	1.00	0.03	0.88	-0.02	0.94	0.08	0.57
Wet Spring	**-0.36**	**0.02**	-0.09	0.62	-0.14	0.42	-0.25	0.14	0.12	0.44
Dry Summer	-0.34	0.05	-0.30	0.12	-0.40	0.03	-0.42	0.03	-0.14	0.32
Average Summer	**-0.55**	**0.00**	-0.13	0.51	-0.26	0.16	-0.15	0.43	-0.19	0.21
Wet Summer	-0.25	0.11	0.07	0.70	0.20	0.27	0.28	0.11	0.10	0.50

	CFFG18		HCAL19		BSBR20		HCBR21		CFEL22	
Start Year	1940		1953		1940		1940		1957	
	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	-0.11	0.16	**-0.27**	**0.00**	-0.06	0.46	-0.04	0.63	**-0.26**	**0.00**
Winter	0.04	0.60	-0.25	0.00	-0.08	0.34	0.11	0.17	-0.16	0.07
Spring	-0.10	0.22	-0.26	0.00	-0.16	0.05	-0.08	0.30	-0.18	0.04
Summer	-0.11	0.16	-0.24	0.01	-0.12	0.14	-0.07	0.40	-0.21	0.02
Dry Winter	0.03	0.88	-0.53	0.00	-0.06	0.71	0.05	0.76	-0.18	0.32
Average Winter	0.13	0.33	-0.31	0.05	-0.12	0.43	0.17	0.23	-0.28	0.08
Wet Winter	0.23	0.15	0.02	0.95	0.02	0.92	0.06	0.69	-0.04	0.85
Dry Spring	**-0.31**	**0.03**	-0.69	0.00	**-0.51**	**0.00**	-0.25	0.08	-0.39	0.03
Average Spring	-0.09	0.52	0.03	0.89	0.12	0.38	0.09	0.49	-0.31	0.05
Wet Spring	0.03	0.86	-0.25	0.14	-0.13	0.43	-0.22	0.17	0.01	1.00
Dry Summer	-0.13	0.35	-0.22	0.15	0.05	0.74	0.17	0.22	-0.17	0.33
Average Summer	-0.16	0.28	-0.43	0.01	-0.29	0.06	-0.28	0.06	-0.44	0.01
Wet Summer	0.03	0.85	0.06	0.74	-0.07	0.63	-0.10	0.49	0.05	0.76

Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

Trends in Q/P for control points in this subbasin mostly followed the same trends and direction as incremental flow (**Appendix 2-C**). We did not detect trends in precipitation volume in any of these watersheds (Tables C-15 to C-24).

Figure 2-6 shows total adjusted naturalized flows at CFEL22. The control points upstream of CFEL22 with the largest percent change to total naturalized flows are CFNU16 (-43%) and CFHA14 (-42%) (Table 2-2). The largest changes in total naturalized flows at CFEL22 are due to adjustments at CFNU16 (responsible for 11 percent of the decrease at CFEL22), HCAL19 (responsible for 17 percent of the decrease at CFEL22) and CFEL22 itself (responsible for 59 percent of the decrease at CFEL22). The extrapolated linear trend for CFNU16 shows average incremental flows reaching 0 ac-ft/yr by 2046 (Figure 2-C-34), and the linear trend for HCAL19 has average incremental flows reaching 0 ac-ft/yr by 2053 (Figure 2-C-40). The linear trend for CFEL22 is not projected to reach 0 ac-ft/yr by 2070 (Figure 2-C-45).

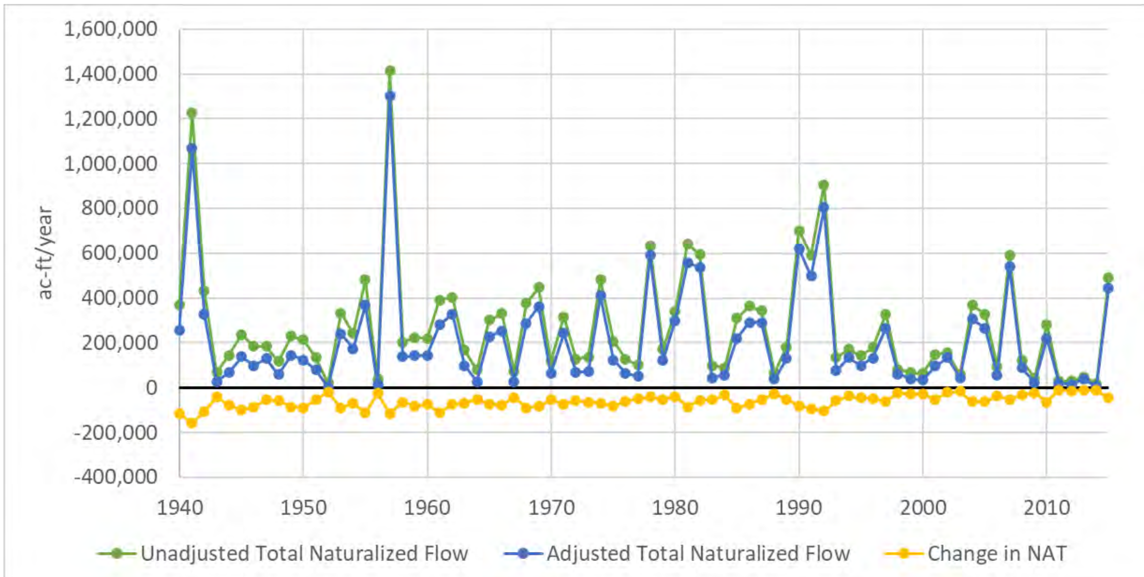


Figure 2-6 – Original and Adjusted Naturalized Flow Time Series for CFEL22 for 2070 Conditions

2.1.3 SHGR26 – Brazos River at Morris Sheppard Dam near Graford

Possum Kingdom Lake is typically regarded as the boundary between the upper basin upstream and the middle and lower basin downstream (Figure 2-7). Control point GHGH24 is on a tributary upstream of SHGR26 and had no trends detected in incremental flow. The total naturalized flow at GHGH24 is also unchanged (Table 2-2) because there are no primary control points upstream of it (i.e., incremental flow is total flow). Control point CCIV25 is on a different tributary upstream of SHGR26, with no other control points upstream of it. Total and incremental flows at CCIV25 were adjusted based on the trend found in average summers (Table 2-5).

Twenty-six incremental drainage areas (i.e., control points) contribute to the total flow at SHGR26, a point on the main stem of the Brazos River just downstream of Possum Kingdom Lake. The trends applied within those 26 individual drainage areas vary and collectively reduced the total flows at SHGR26 by 26 percent

(Table 2-2). For example, MSMN12 indicated decreasing trends in incremental flow for winter and dry spring (Table 2-C-2). Figure 2-8 shows the original and adjusted total naturalized flows at SHGR26.

We did not detect trends in precipitation volume in any of these watersheds. Trends in Q/P for control points in this subbasin mostly followed the same trends and direction as incremental flow (**Appendix 2-C**). For BRSB23, this study found decreasing incremental flow in annual, winter, spring, summer, dry spring, and average summer (Table 2-5).

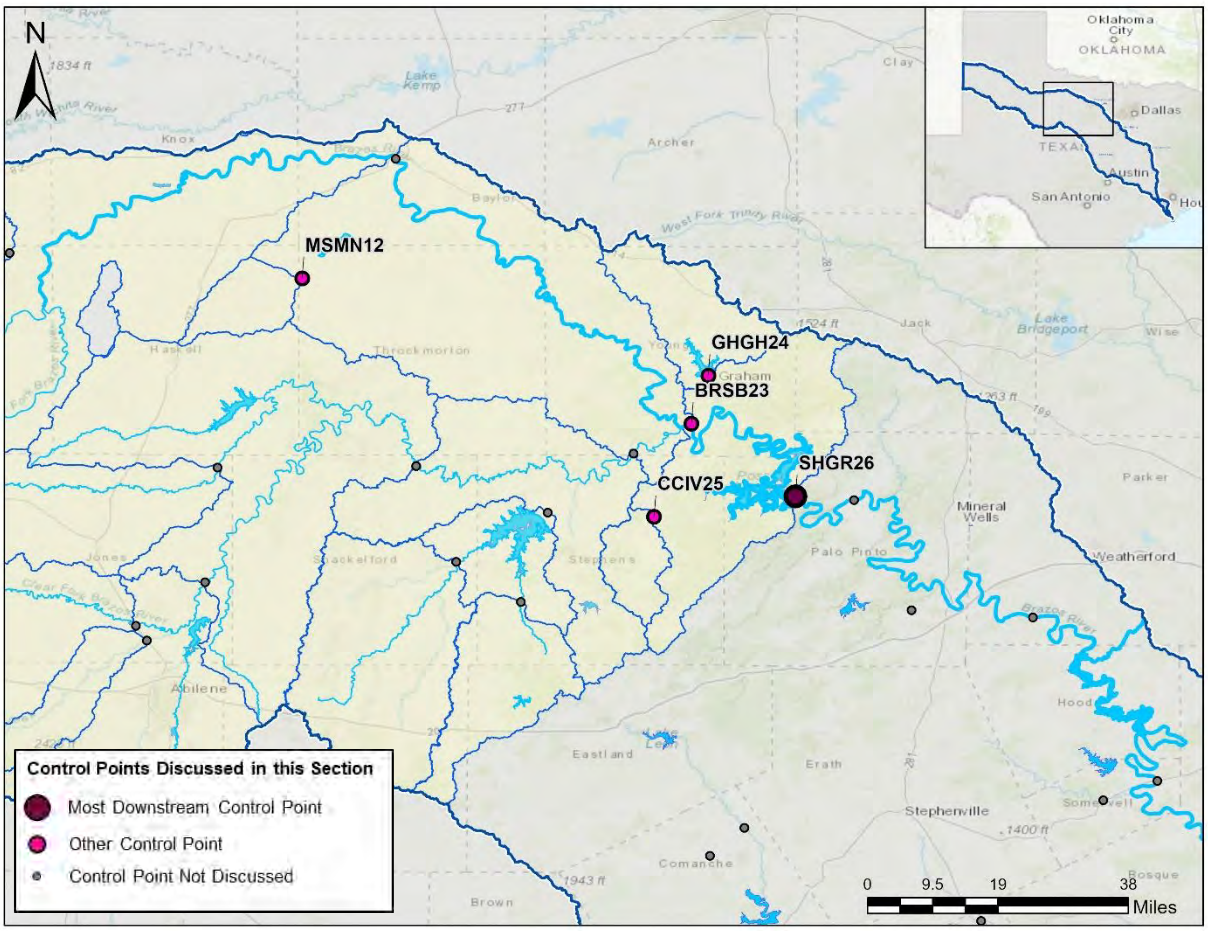


Figure 2-7 – Drainage Area of SHGR26 and Control Points MSMN12 and BRSB23 through SHGR26

Table 2-5 – Trend Results for Incremental Flow near Possum Kingdom of the Brazos River Basin: Control Points MSMN12 and BRSB23 through SHGR26

	MSMN12		BRSB23		GHGH24		CCIV25		SHGR26	
Start Year	1940		1957		1940		1940		1965	
	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	-0.10	0.20	**-0.23**	**0.01**	0.03	0.75	-0.12	0.11	**-0.34**	**0.00**
Winter	**-0.17**	**0.05**	-0.18	0.05	0.00	0.99	-0.04	0.64	-0.13	0.17
Spring	-0.12	0.14	-0.18	0.04	0.00	1.00	-0.08	0.32	-0.30	0.00
Summer	-0.14	0.07	-0.21	0.02	-0.11	0.18	-0.23	0.00	-0.19	0.05
Dry Winter	-0.02	0.90	-0.31	0.08	-0.11	0.44	0.10	0.51	0.07	0.75
Average Winter	-0.18	0.21	-0.17	0.30	-0.06	0.67	-0.20	0.17	-0.18	0.34
Wet Winter	-0.20	0.20	0.06	0.75	0.19	0.21	-0.04	0.80	-0.18	0.31
Dry Spring	**-0.33**	**0.02**	-0.58	0.00	-0.23	0.11	-0.28	0.06	-0.14	0.49
Average Spring	-0.12	0.40	-0.11	0.48	0.14	0.31	0.02	0.87	-0.34	0.05
Wet Spring	0.07	0.64	0.02	0.94	0.13	0.41	-0.01	0.96	-0.49	0.01
Dry Summer	-0.04	0.79	-0.25	0.14	-0.07	0.63	-0.23	0.10	-0.19	0.30
Average Summer	-0.29	0.06	-0.39	0.02	-0.20	0.19	**-0.35**	**0.02**	-0.18	0.37
Wet Summer	-0.19	0.19	0.15	0.35	-0.03	0.84	-0.19	0.18	-0.15	0.40

Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

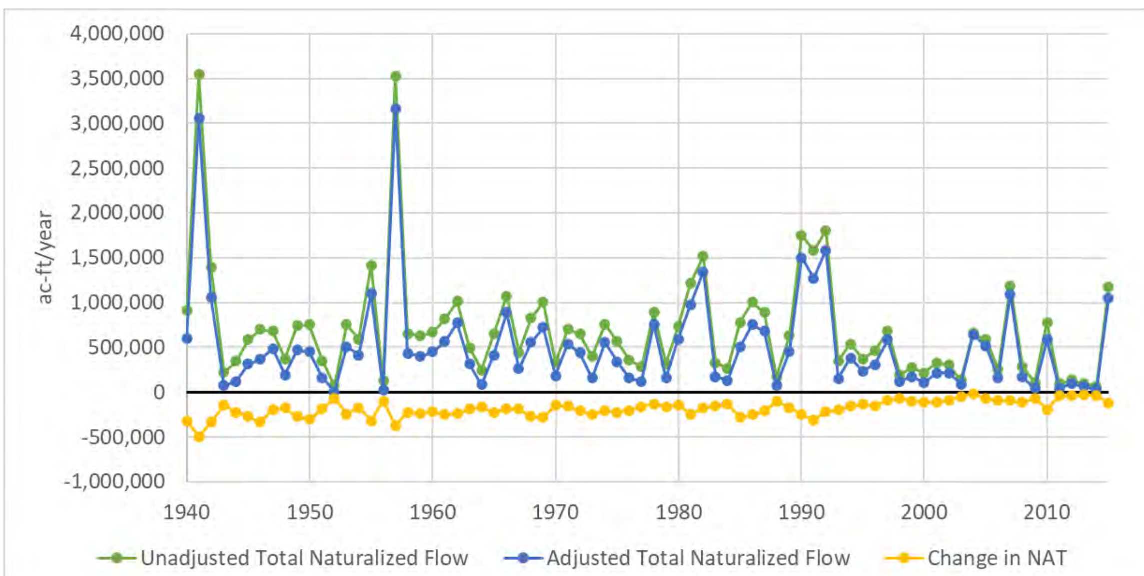


Figure 2-8 – Original and Adjusted Naturalized Flow Time Series for SHGR26 for 2070 Conditions

2.1.4 BRAQ33 – Brazos River near Aquilla

Thirty-three incremental drainage areas (i.e., control points) contribute to the total flow at the Brazos River near Aquilla (BRAQ33) gage, a point on the main stem of the Brazos River just below Lake Whitney

(Figure 2-9). In contrast to many other upstream points, trends show that the total flow at BRAQ33 would increase by 2070 (Table 2-2). The incremental drainage area of BRAQ33 experienced an increasing annual trend in incremental flow (Table 2-6). The total naturalized flow at control point BRAQ33 (Figure 2-10) was influenced by trends in seasons and hydrologic conditions at upstream control points BRPP27 through NRBL32 (Table 2-6). Of these, BRPP27 and NRBL32 experienced increasing trends in incremental flow. We found decreasing average winter trends in the incremental flows of three different upstream control points (BRDE29, PAGR31 and NRBL32). We applied increasing trends during dry winters to two control points (BRPP27 and NRBL32) and decreasing dry spring trends to two control points (PPSA28 and PAGR31). Control point BRPP27 had the most trends applied from hydrologic conditions (dry winter, wet winter, average spring, and wet spring), all of which were increasing trends in incremental flow. We found both increasing and decreasing flow trends for control point NRBL32. The increasing incremental flow trends, especially at BRAQ33, caused greater positive adjustments to the total adjusted naturalized flows at BRAQ33 than decreasing adjustments from upstream decreasing incremental flow trends. **Appendix 2-A** describes the increases in flow at BRAQ33 in more detail, including contributions from upstream control points and impacts on downstream control points.

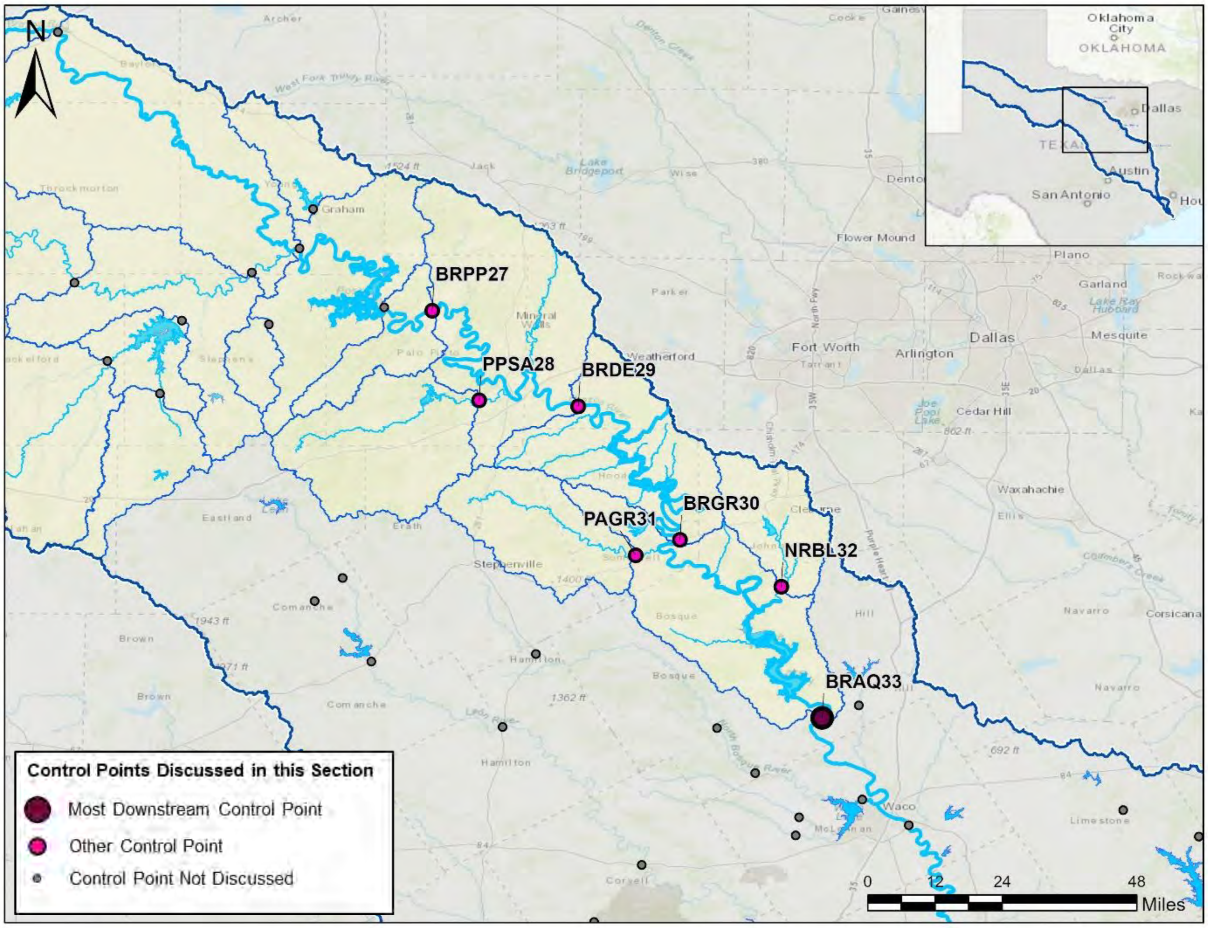


Figure 2-9 – Drainage Area of BRAQ33 and Control Points BRPP27 to BRAQ33

Table 2-6 – Trend Results for Incremental Flow near Lake Whitney of the Brazos River Basin: Control Points BRPP27 through BRAQ33

	BRPP27		PPSA28		BRDE29		BRGR30		PAGR31		NRBL32		BRAQ33	
Start Year	1943		1940		1940		1940		1940		1940		1948	
	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	0.31	0.00	-0.12	0.12	-0.08	0.29	-0.05	0.56	-0.03	0.72	0.04	0.60	**0.21**	**0.01**
Winter	0.33	0.00	-0.10	0.22	-0.25	0.00	0.03	0.66	-0.10	0.19	0.03	0.71	0.07	0.39
Spring	0.21	0.01	-0.10	0.22	0.00	0.95	-0.03	0.70	-0.04	0.58	-0.01	0.92	0.15	0.07
Summer	0.10	0.24	**-0.18**	**0.02**	-0.04	0.64	-0.27	0.00	-0.09	0.26	0.02	0.85	0.19	0.02
Dry Winter	**0.39**	**0.01**	-0.07	0.64	-0.20	0.15	0.20	0.15	-0.24	0.09	**0.29**	**0.04**	0.24	0.09
Average Winter	0.18	0.21	-0.23	0.12	**-0.48**	**0.00**	-0.22	0.12	**-0.41**	**0.00**	**-0.39**	**0.01**	-0.28	0.07
Wet Winter	**0.40**	**0.01**	-0.05	0.77	-0.29	0.05	0.12	0.43	0.08	0.62	0.12	0.41	-0.02	0.92
Dry Spring	-0.05	0.75	**-0.32**	**0.02**	-0.07	0.64	-0.27	0.06	**-0.29**	**0.04**	0.01	0.98	0.09	0.54
Average Spring	**0.28**	**0.03**	0.04	0.75	-0.02	0.87	0.13	0.33	0.03	0.84	0.05	0.71	0.20	0.17
Wet Spring	**0.45**	**0.01**	-0.21	0.18	-0.17	0.27	-0.13	0.40	0.00	1.00	-0.09	0.57	0.01	1.00
Dry Summer	0.07	0.60	-0.27	0.06	0.03	0.82	**-0.32**	**0.02**	-0.22	0.12	-0.06	0.66	0.21	0.14
Average Summer	-0.04	0.83	-0.16	0.30	-0.10	0.51	-0.26	0.09	-0.13	0.41	0.14	0.37	0.21	0.21
Wet Summer	0.25	0.10	-0.08	0.60	0.00	1.00	-0.24	0.09	0.17	0.23	0.09	0.54	0.19	0.25

Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

Trends in Q/P for control points in this subbasin mostly followed the same trends and direction as incremental flow (**Appendix 2-C**). We did not detect trends in precipitation volume in any of these sub-watersheds.

NRBL32 has an increasing trend in incremental flow and Q/P for dry winters (Table 2-C-34). Average winters for this same sub-watershed have decreasing trends for incremental flow and Q/P. There are no trends in incremental flow for wet winters or precipitation volume in any of the winter subsets. The increasing trend in dry winters, combined with a decreasing trend in average winters, resulted in a 1 percent decrease in projected total flows at NRBL32 by 2070 (Table 2-2).

In this study, we did not identify any significant trends in precipitation volume in the incremental watershed of BRDE29 (Table 2-C-31). This analysis found decreasing trends in incremental flow and Q/P for winter and average winter. In this study, the total flow at BRDE29 is projected to decrease by 15 percent by 2070 (Table 2-2). We detected decreasing trends in incremental flow and Q/P during dry summer and summers for BRGR30. We did not find any significant trends in precipitation volume in this incremental watershed (Table 2-C-32).

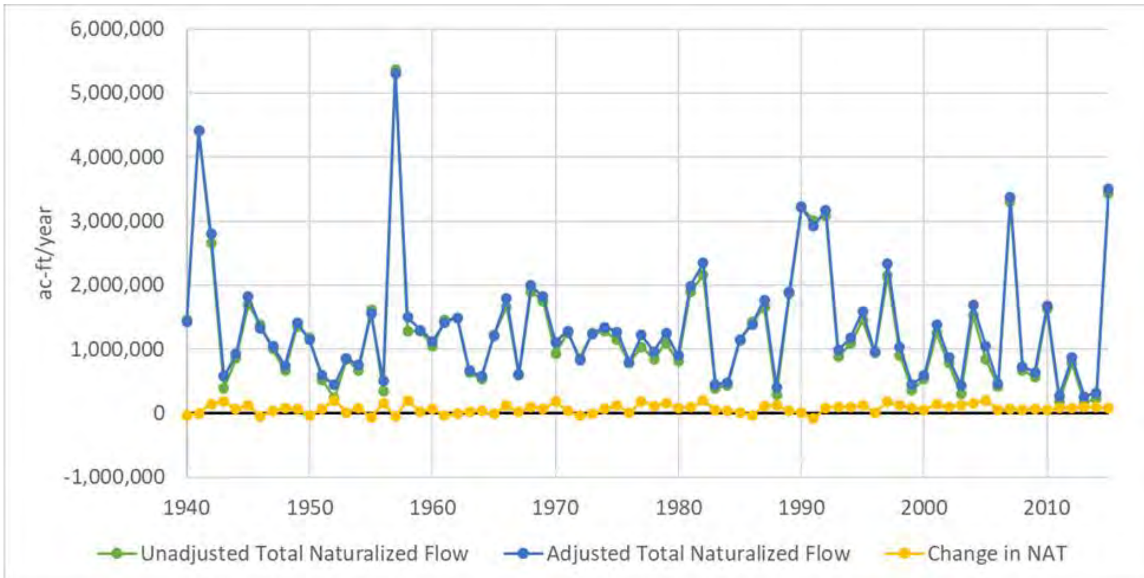


Figure 2-10 – Original and Adjusted Naturalized Flow Time Series for BRAQ33 for 2070 Conditions

2.1.5 BOWA40 – Bosque River near Waco

There are six primary control points in the Bosque River watershed, a tributary to the Brazos River, that drain through control point BOWA40 (Figure 2-11). For this watershed, the start year analysis set the start years for all six control points to 1940 (Table 2-7). We applied decreasing flow trends for average winters to the incremental flows of NBHI35 and NBCL36 and decreasing trends in dry springs at NBHI35. Application of these trends resulted in a decrease of 4 percent at NBHI35 (the most upstream control point in the Bosque River watershed) and a 3 percent decrease in total naturalized flows at NBCL36 (downstream of NBHI35) (Table 2-2). The trends in Q/P for NBHI35 and NBCL36 are consistent with the decreasing direction of trends in incremental flow (**Appendix 2-C**). The adjustments at NBHI35 and NBCL36 translated to a 2 percent decrease in total naturalized flows at NBVM37, downstream of those two points, although there are no trends in the incremental flows associated with NBVM37. MBMG38 and HGCR39 both have no points upstream of them, and we did not find significant trends at either point, so no adjustments were made to the naturalized flows at those points (Table 2-2). Furthermore, there are no significant trends in precipitation volume in any of these incremental drainage areas (**Appendix 2-C**). Adjustments to total naturalized flows at control point BOWA40 were minimal (Figure 2-12).

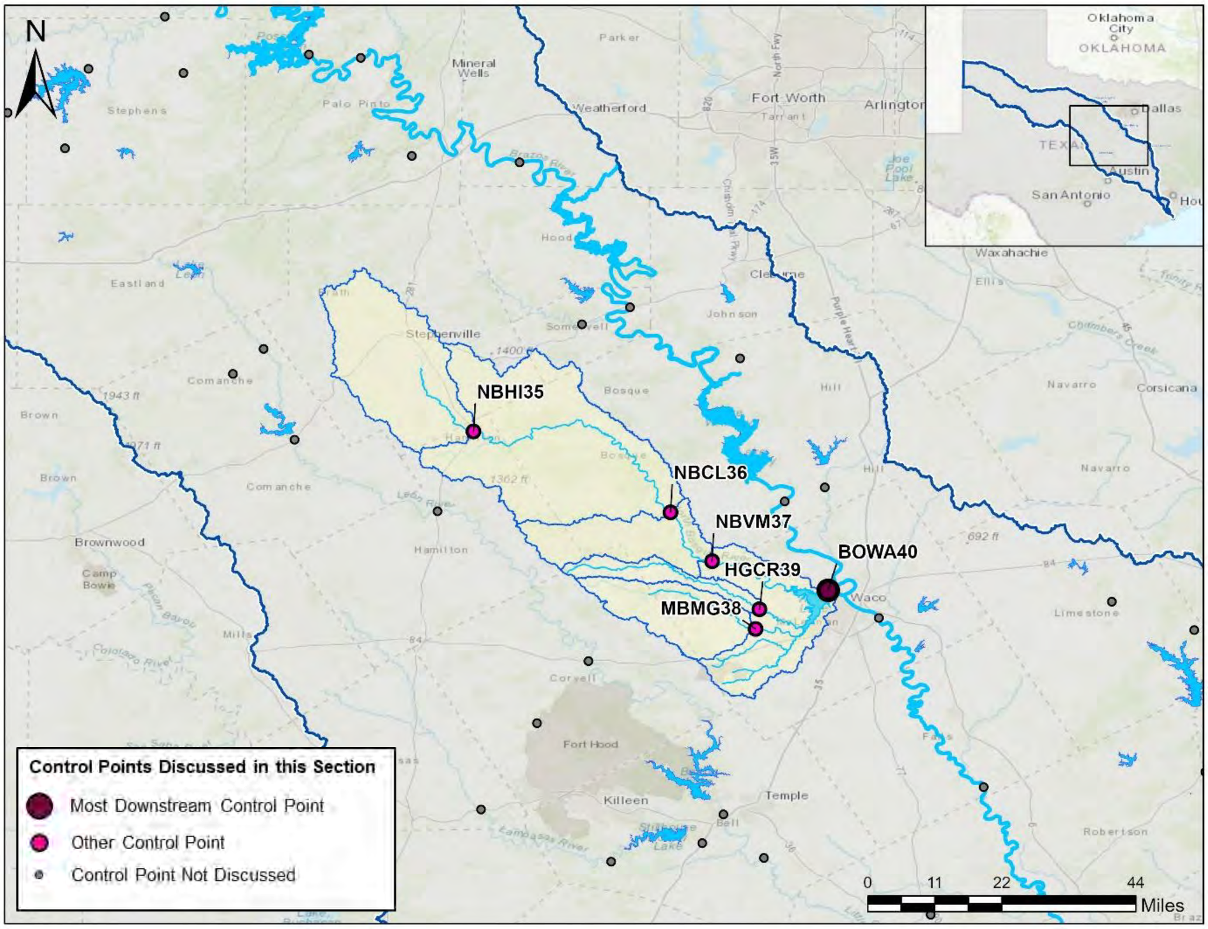


Figure 2-11 – Bosque River Subbasin and Control Points NBHI35 through BOWA40

Table 2-7 – Trend Results for Incremental Flow in the Bosque River of the Brazos River Basin: Control Points NBHI35 through BOWA40

	NBHI35		NBCL36		NBVM37		MBMG38		HGCR39		BOWA40	
Start Year	1940		1940		1940		1940		1940		1940	
	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	0.01	0.86	0.00	1.00	0.07	0.37	0.04	0.59	0.00	1.00	0.01	0.87
Winter	-0.04	0.58	-0.07	0.39	0.03	0.73	0.06	0.45	0.01	0.88	0.10	0.19
Spring	-0.01	0.88	-0.03	0.69	0.02	0.78	-0.05	0.56	-0.05	0.52	-0.11	0.16
Summer	0.00	0.97	-0.05	0.50	0.09	0.26	0.00	1.00	-0.06	0.44	0.01	0.86
Dry Winter	-0.01	0.96	-0.04	0.77	0.19	0.18	0.13	0.35	-0.04	0.79	0.06	0.69
Average Winter	**-0.29**	**0.05**	**-0.35**	**0.01**	-0.27	0.06	-0.02	0.93	-0.20	0.17	-0.02	0.91
Wet Winter	0.11	0.46	0.08	0.59	0.20	0.19	0.12	0.41	0.20	0.19	0.26	0.08
Dry Spring	**-0.29**	**0.04**	-0.28	0.06	-0.09	0.56	-0.10	0.50	-0.24	0.10	-0.17	0.25
Average Spring	0.12	0.37	0.10	0.48	0.03	0.81	-0.02	0.88	0.04	0.79	-0.08	0.55
Wet Spring	-0.16	0.31	-0.24	0.13	-0.02	0.93	-0.19	0.24	-0.15	0.34	-0.21	0.18
Dry Summer	-0.10	0.47	-0.15	0.27	0.17	0.23	-0.03	0.82	-0.25	0.07	-0.09	0.55
Average Summer	0.06	0.69	0.12	0.44	0.12	0.43	0.21	0.18	0.19	0.22	0.09	0.56
Wet Summer	0.18	0.20	-0.16	0.26	0.17	0.24	-0.11	0.44	-0.14	0.33	-0.02	0.93

Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

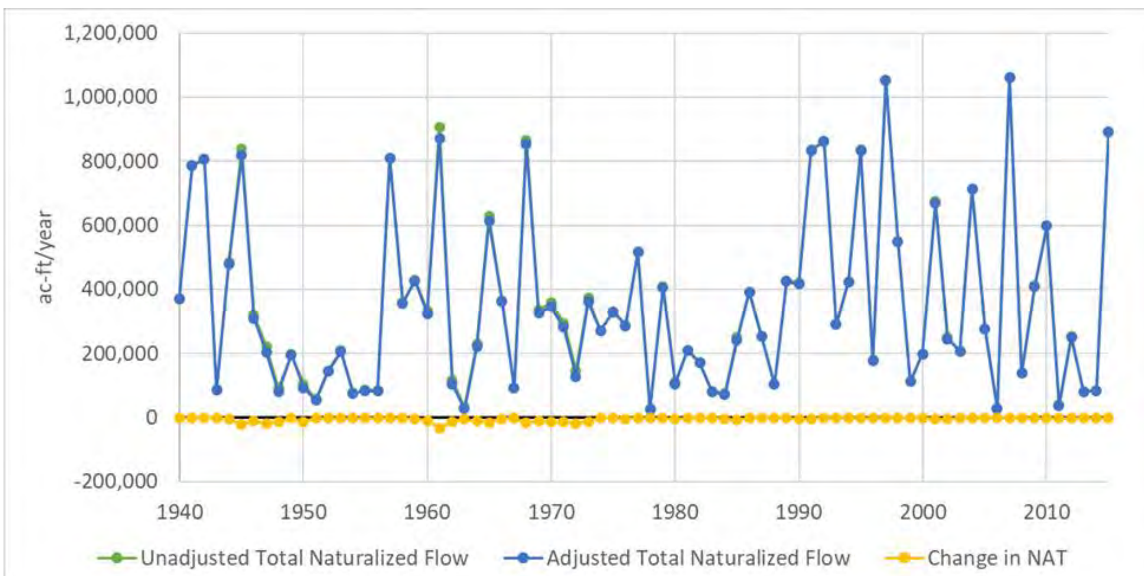


Figure 2-12 – Original and Adjusted Naturalized Flow Time Series for BOWA40 for 2070 Conditions

2.1.6 LRCA58 – Little River at Cameron

The Little River at Cameron control point (LRCA58) is the most downstream control point within the Little River watershed before it drains into the Brazos River. The watershed that drains through control point

LRCA58 (Figure 2-13) has seven control points with no significant trends in incremental flow (LAKE50, LAYO51, NGGE54, SGGE55, GAGE56, GALA57, and LRCA58). At the nine other control points in the Little River watershed, significant trends in incremental flows are all based on subsets classified by both season and hydrologic condition (Table 2-8). Control points around Lakes Leon and Proctor (LEDL43, SADL44, LEHS45) have decreasing trends in incremental flows primarily driven by dry springs, average winters, and average summers. There are also decreasing trends in average winters further downstream at LEGT47 and COPI48. LRLR53, which is downstream of both Lakes Belton and Stillhouse Hollow, showed a significant increasing trend in incremental flows during dry winters. Increasing trends during wet summers were found for control points LEHS45 and LEHM46 only. The increasing trends in incremental flows at LEHS45 and LEHM46 do not correspond to trends in precipitation volume (Tables C-47 and C-48). LEDL43 and the next downstream control point, LEHS45, could be responding to a change in watershed characteristics along the Leon River.

Missing naturalized flow data for LEHM46 are filled in using a relationship with LEHS45 naturalized flow from 1940-1950 and using a relationship with LEHS45 and LEGT47 from 1951-1960 and 1998-2007. Data specific to LEHM46 from 2008-2015 has only one large data point for wet summer (2015) which creates an increasing slope at the tail end of the trendline (Figure 2-C-99). The increasing wet summer trend in incremental flows is likely strengthened by the lack of variability in the beginning of the period due to filled in missing data using an upstream gage combined with large values later in the period (summer 2015).

LAYO51, NGGE54, SGGE55, GAGE56, and GALA57 are upstream of LRCA58 (Figure 2-13). We found no trends for incremental flow, precipitation volume, or Q/P for LAYO51, NGGE54, GAGE56, and GALA57 (**Appendix 2-C**). SGGE55 has a decreasing dry summer trend for Q/P (Table 2-C-57).

Overall, trends in Q/P at control points in this subbasin mostly followed the same trends and direction as incremental flow (**Appendix 2-C**). We did not detect any trends in precipitation volume in these sub-watersheds.

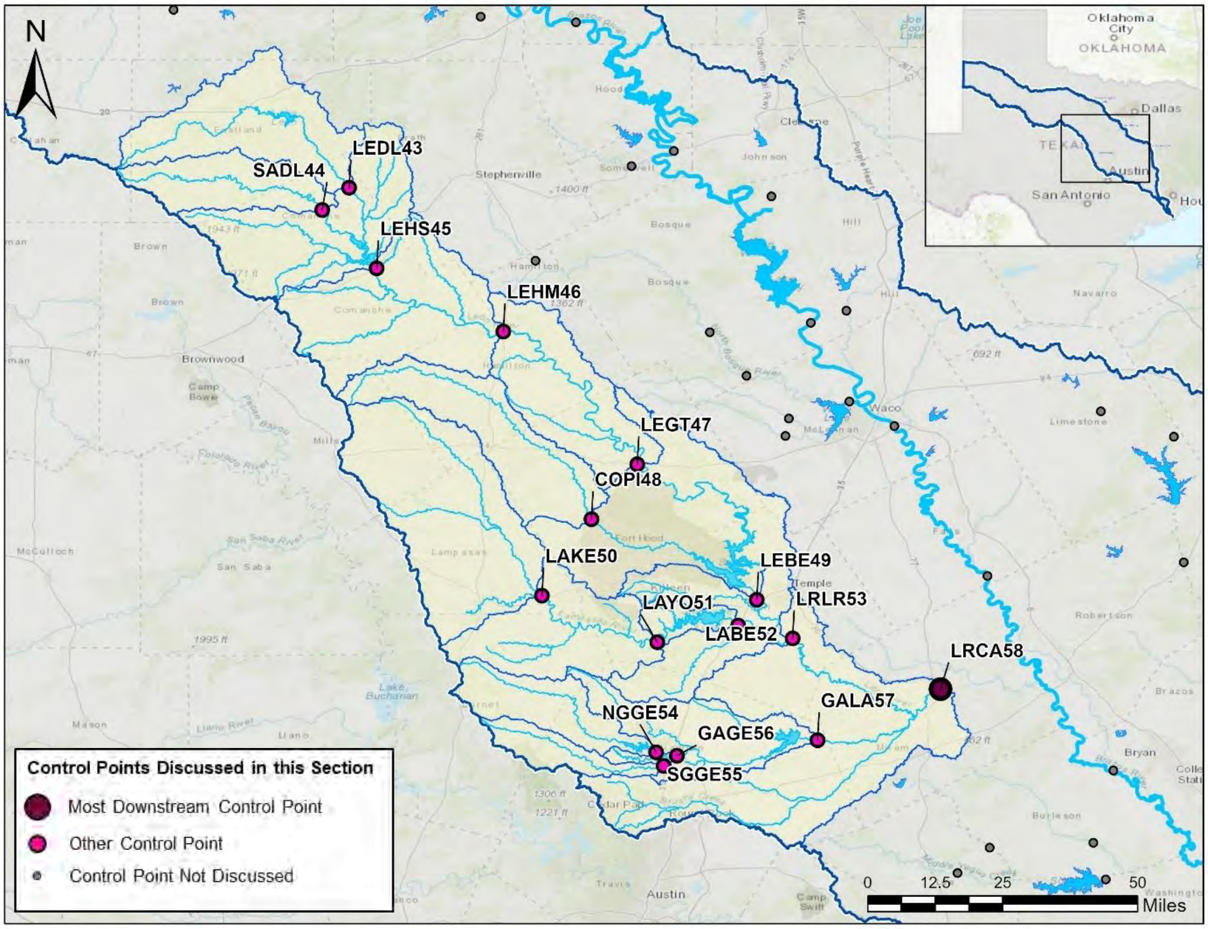


Figure 2-13 – Little River Subbasin and Control Points LEDL43 through LRCA58

Table 2-8 – Trend Results for Incremental Flow in the Little River of the Brazos River Basin: Control Points LEDL43 through LRCA58

	LEDL43		SADL44		LEHS45		LEHM46		LEGT47	
Start Year	1940		1940		1940		1940		1940	
	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	-0.08	0.30	-0.09	0.23	-0.11	0.15	0.07	0.39	-0.03	0.71
Winter	-0.13	0.09	-0.13	0.11	-0.23	0.00	-0.04	0.63	-0.02	0.81
Spring	-0.11	0.17	-0.10	0.20	-0.13	0.10	0.03	0.72	-0.06	0.47
Summer	-0.06	0.45	-0.09	0.25	-0.09	0.25	0.09	0.24	0.04	0.65
Dry Winter	-0.23	0.11	-0.28	0.05	**-0.28**	**0.05**	-0.06	0.69	0.22	0.12
Average Winter	**-0.30**	**0.04**	-0.28	0.06	**-0.39**	**0.01**	-0.24	0.10	**-0.34**	**0.02**
Wet Winter	0.01	0.96	0.03	0.84	-0.11	0.46	0.19	0.20	0.07	0.66
Dry Spring	**-0.38**	**0.01**	**-0.33**	**0.02**	**-0.47**	**0.00**	-0.23	0.12	-0.08	0.59
Average Spring	0.01	0.97	0.03	0.82	0.04	0.79	0.11	0.41	-0.08	0.56
Wet Spring	-0.16	0.31	-0.19	0.21	-0.18	0.26	0.05	0.78	-0.17	0.27
Dry Summer	-0.18	0.20	-0.14	0.33	-0.21	0.14	0.07	0.65	0.00	1.00
Average Summer	-0.23	0.13	**-0.30**	**0.05**	**-0.39**	**0.01**	-0.11	0.46	0.17	0.26
Wet Summer	0.27	0.06	0.23	0.10	**0.38**	**0.01**	**0.40**	**0.00**	0.02	0.89

	COPI48		LEBE49		LABE52		LRLR53		LRCA58	
Start Year	1940		1940		1940		1940		1940	
	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	-0.05	0.51	-0.01	0.93	0.10	0.22	0.07	0.34	0.04	0.57
Winter	-0.08	0.29	0.04	0.60	-0.08	0.29	0.11	0.16	0.05	0.52
Spring	-0.07	0.38	-0.05	0.52	0.02	0.79	-0.01	0.92	0.01	0.88
Summer	-0.05	0.54	0.03	0.71	0.05	0.54	0.08	0.29	0.03	0.68
Dry Winter	-0.03	0.86	0.23	0.10	**-0.28**	**0.04**	**0.43**	**0.00**	0.13	0.35
Average Winter	**-0.40**	**0.01**	-0.16	0.26	-0.05	0.76	-0.03	0.87	-0.12	0.43
Wet Winter	0.04	0.82	0.07	0.67	0.13	0.40	0.06	0.71	0.10	0.50
Dry Spring	-0.17	0.25	0.03	0.83	-0.10	0.51	0.02	0.93	-0.01	0.96
Average Spring	-0.08	0.56	-0.03	0.84	0.04	0.75	0.01	0.94	-0.09	0.51
Wet Spring	-0.16	0.31	**-0.34**	**0.03**	0.06	0.74	-0.11	0.50	0.17	0.28
Dry Summer	-0.01	0.97	0.06	0.66	0.08	0.59	0.23	0.09	0.26	0.06
Average Summer	0.01	0.96	0.15	0.33	-0.11	0.48	0.20	0.19	-0.01	0.98
Wet Summer	-0.09	0.55	-0.11	0.45	0.21	0.13	-0.05	0.72	-0.22	0.13

LAKE50, LAYO51, NGGE54, SGGE55, GAGE56, and GALA57 all contribute flow to LRCA58 but no significant trends in incremental flow were detected for those control points and so they were omitted here due to space considerations. Results at those points are reported in Table 2-C-2 of Appendix 2-C.
Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

Figure 2-14 shows the total adjusted naturalized flow at LRCA58. Figure 2-15 and Figure 2-16 show the total naturalized flows for LEHS45 and LEHM46. Control point LEHS45 contains smaller positive adjustments than LEHM46 because four decreasing trends in its incremental watershed, all based on season and hydrologic condition, impact its incremental naturalized flow.

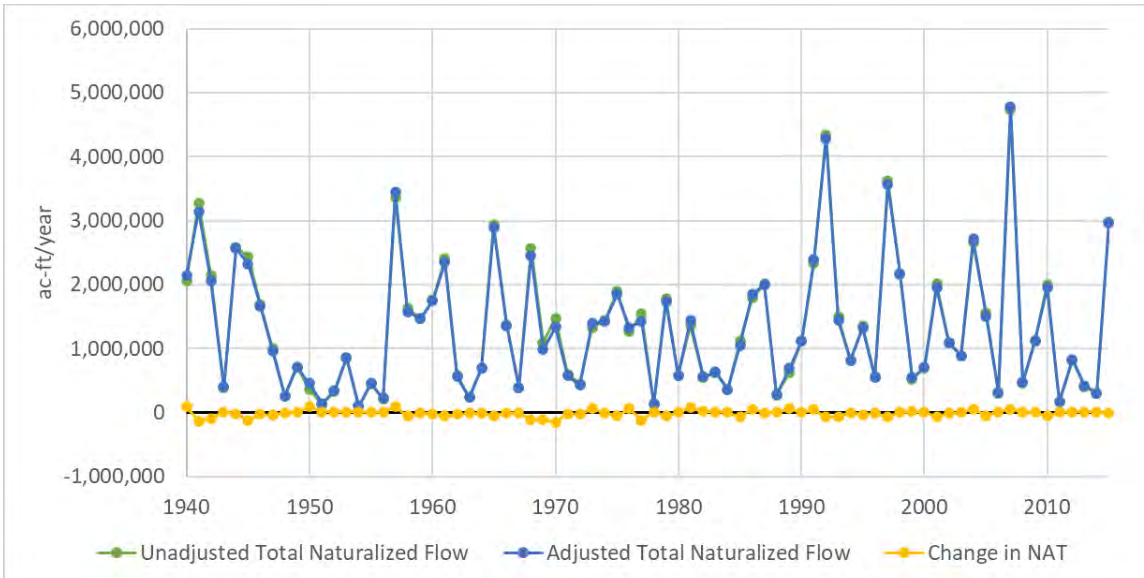


Figure 2-14 – Original and Adjusted Naturalized Flow Time Series for LRCA58 for 2070 Conditions

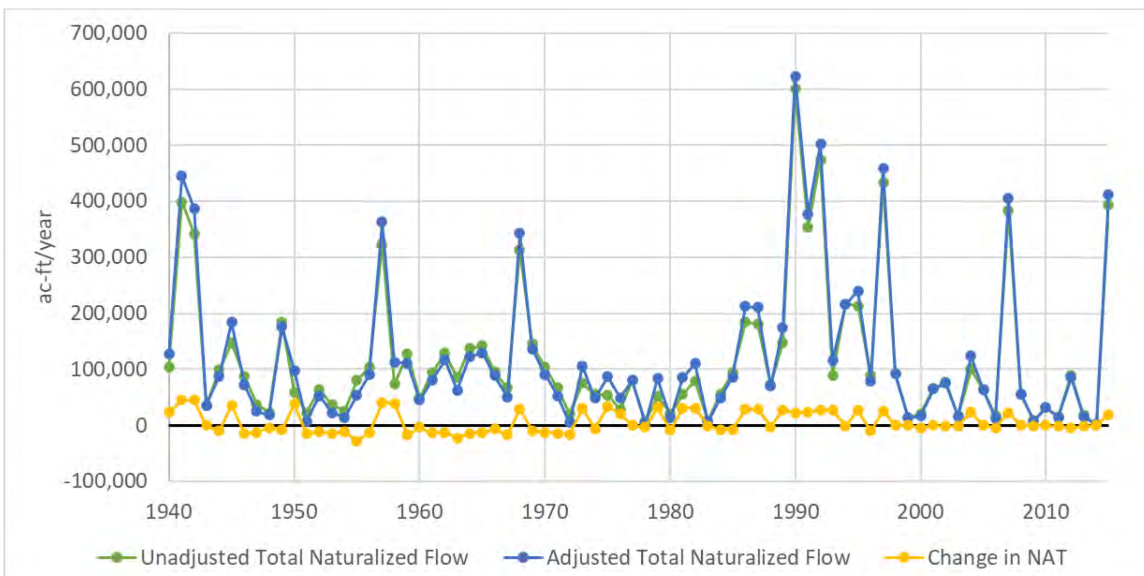


Figure 2-15 – Original and Adjusted Naturalized Flow Time Series for LEHS45 for 2070 Conditions

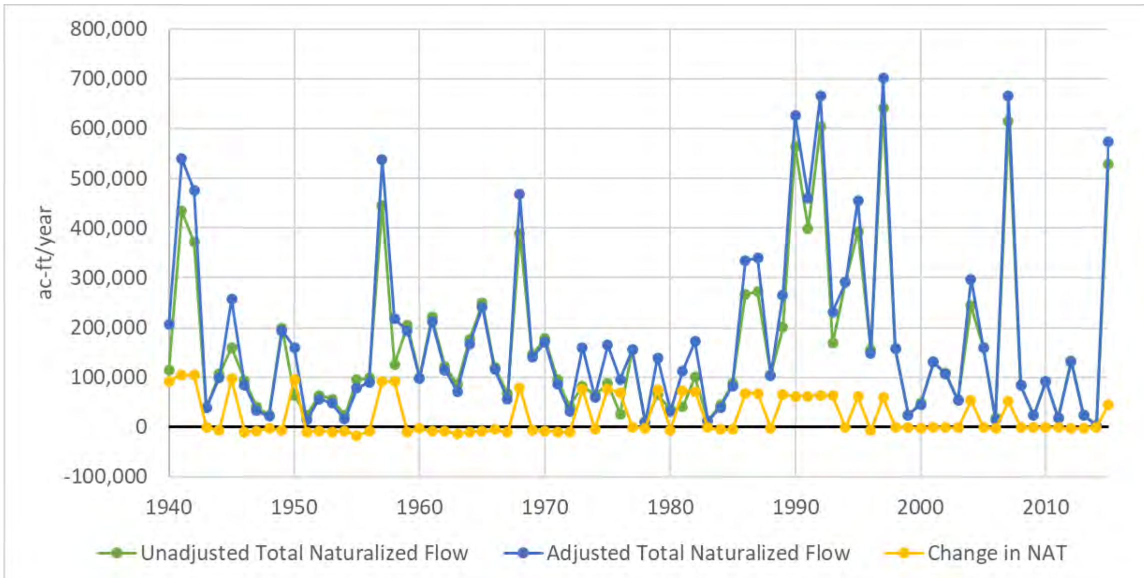


Figure 2-16 – Original and Adjusted Naturalized Flow Time Series for LEHM46 for 2070 Conditions

This study found decreasing trends in both incremental flow and Q/P in average winters at LEGT47 (Table 2-C-49). We did not find trends in flow, Q/P, or precipitation volume at LAKE50 (Table 2-C-52) or LRCA58 (Table 2-C-60).

2.1.7 BRBR59 – Brazos River near Bryan

The Brazos River near Bryan control point (BRBR59) is on the main stem of the Brazos River just downstream of where the Little River drains into the Brazos River (Figure 2-17). There are no significant trends in incremental flow at this control point, and adjustments to total naturalized flows at BRBR59 are small, around +1 percent (Table 2-2, Figure 2-18). Stronger trends present in the upper and middle basins do not have a large impact on naturalized flows near Bryan. No trend in Q/P was found for this control point, but there is an increasing trend in precipitation volume in dry summers (Table 2-C-61). This increase in dry summer precipitation volume does not translate to an increasing trend in incremental flow at BRBR59 during the same season and hydrologic condition.

AQAQ34, BRWA41, and BRHB42 are upstream of BRBR59 (Figure 2-17). Table 2-9 summarizes trends in flow at these points. The only significant trend at AQAQ34 is a downward trend in wet springs for incremental flow (Table 2-C-36).

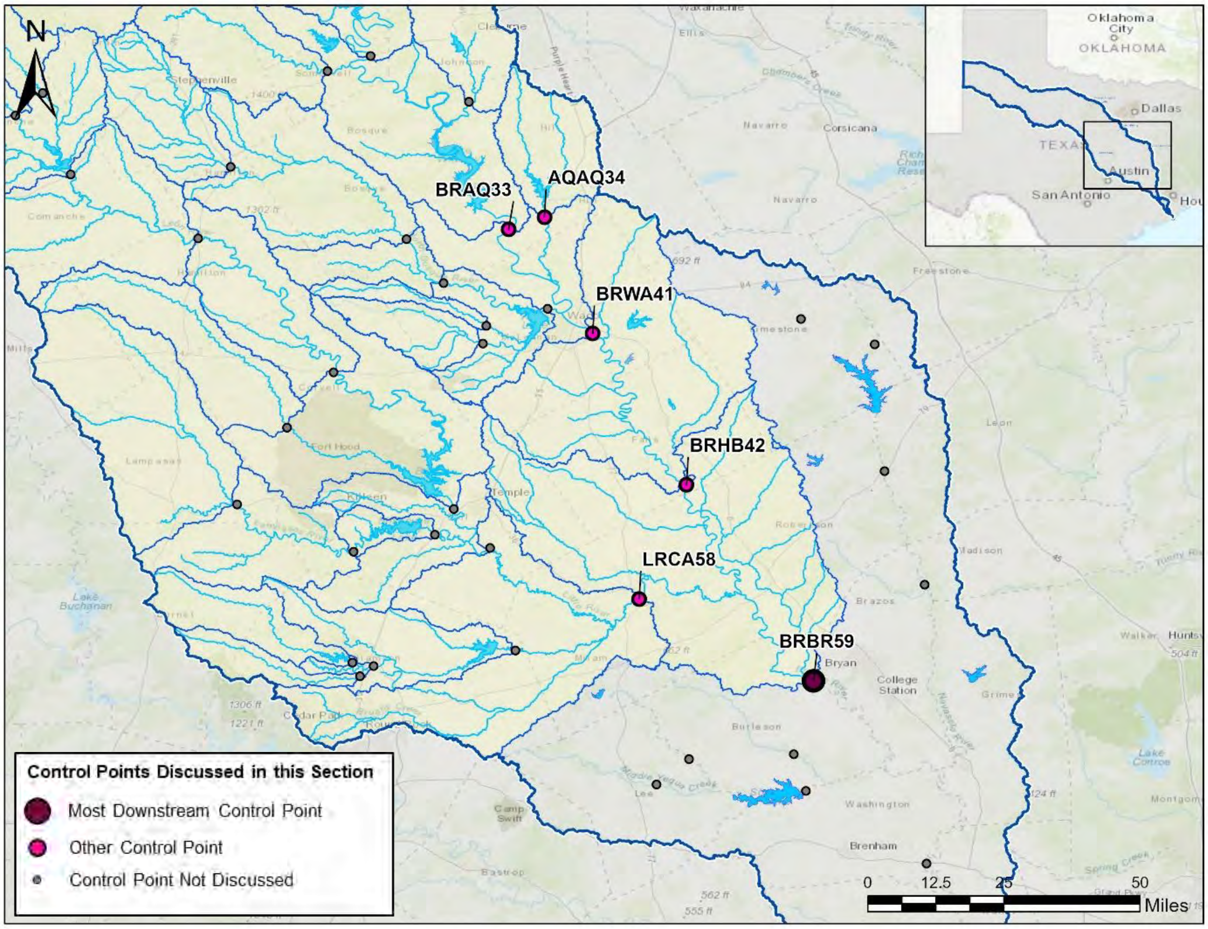


Figure 2-17 – Drainage Area of BRBR59 and Control Points Between BRAQ33 and BRBR5959

Table 2-9 - Trend Results for Incremental Flow in the Middle Brazos River Basin: Control Points AQAQ34, BRWA41, BRHB42, and BRBR59

	AQAQ34		BRWA41		BRHB42		BRBR59	
Start Year	1940		1940		1940		1940	
	τ	p	τ	p	τ	p	τ	p
Annual	0.03	0.70	0.01	0.86	0.02	0.76	0.05	0.49
Winter	0.08	0.32	0.04	0.65	0.05	0.52	0.03	0.71
Spring	-0.11	0.15	-0.04	0.64	-0.05	0.56	0.01	0.91
Summer	0.04	0.63	-0.08	0.31	0.04	0.61	0.07	0.34
Dry Winter	0.11	0.43	0.18	0.22	0.24	0.09	0.17	0.23
Average Winter	-0.14	0.34	-0.02	0.91	-0.02	0.91	-0.06	0.69
Wet Winter	0.23	0.12	0.04	0.82	0.05	0.77	0.04	0.78
Dry Spring	-0.18	0.22	0.02	0.91	-0.09	0.53	0.14	0.35
Average Spring	-0.07	0.59	0.03	0.81	-0.08	0.54	-0.08	0.54
Wet Spring	**-0.31**	**0.05**	-0.30	0.06	-0.08	0.61	0.08	0.63
Dry Summer	-0.08	0.57	-0.17	0.23	0.16	0.26	0.11	0.43
Average Summer	0.25	0.10	0.01	0.98	-0.02	0.89	0.09	0.58
Wet Summer	0.06	0.69	-0.06	0.68	-0.05	0.76	-0.04	0.77

Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

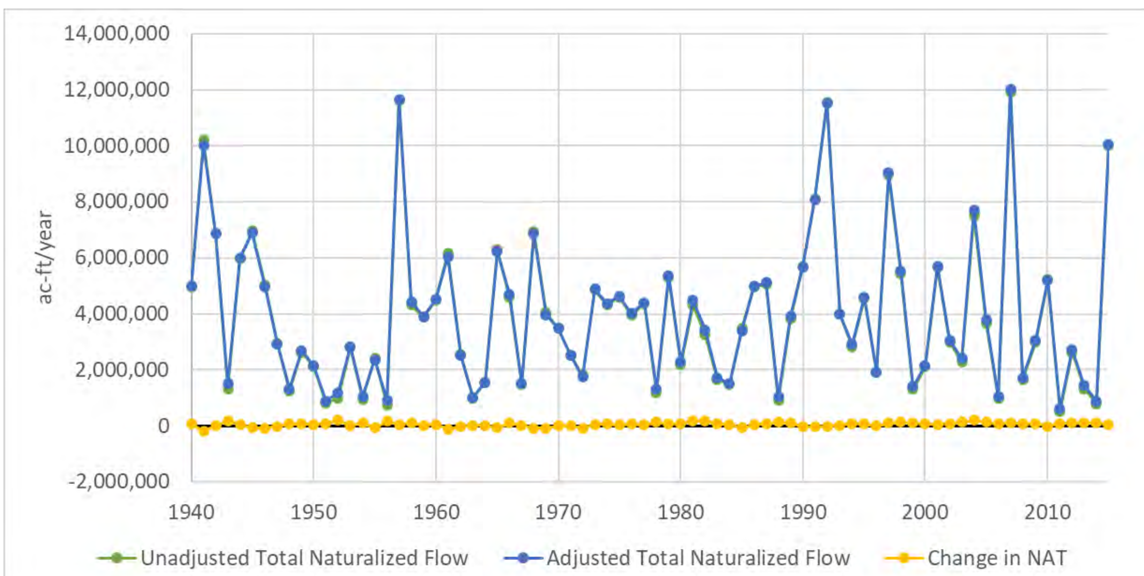


Figure 2-18 – Original and Adjusted Naturalized Flow Time Series for BRBR59 for 2070 Conditions

2.1.8 NABR67 – Navasota River near Bryan

The Navasota River near Bryan control point (NABR67) is the most downstream control point in the Navasota River watershed before it drains into the Brazos River. In the Navasota River watershed, which is east of Bryan, Texas (Figure 2-19), the absence of annual trends allowed the full period of record from 1940 – 2015 to be used to determine trends in incremental flow. We applied increasing dry summer flow trends to NAEA66 and NABR67 (Table 2-10). The impact of the adjustments is minor (Figure 2-20).

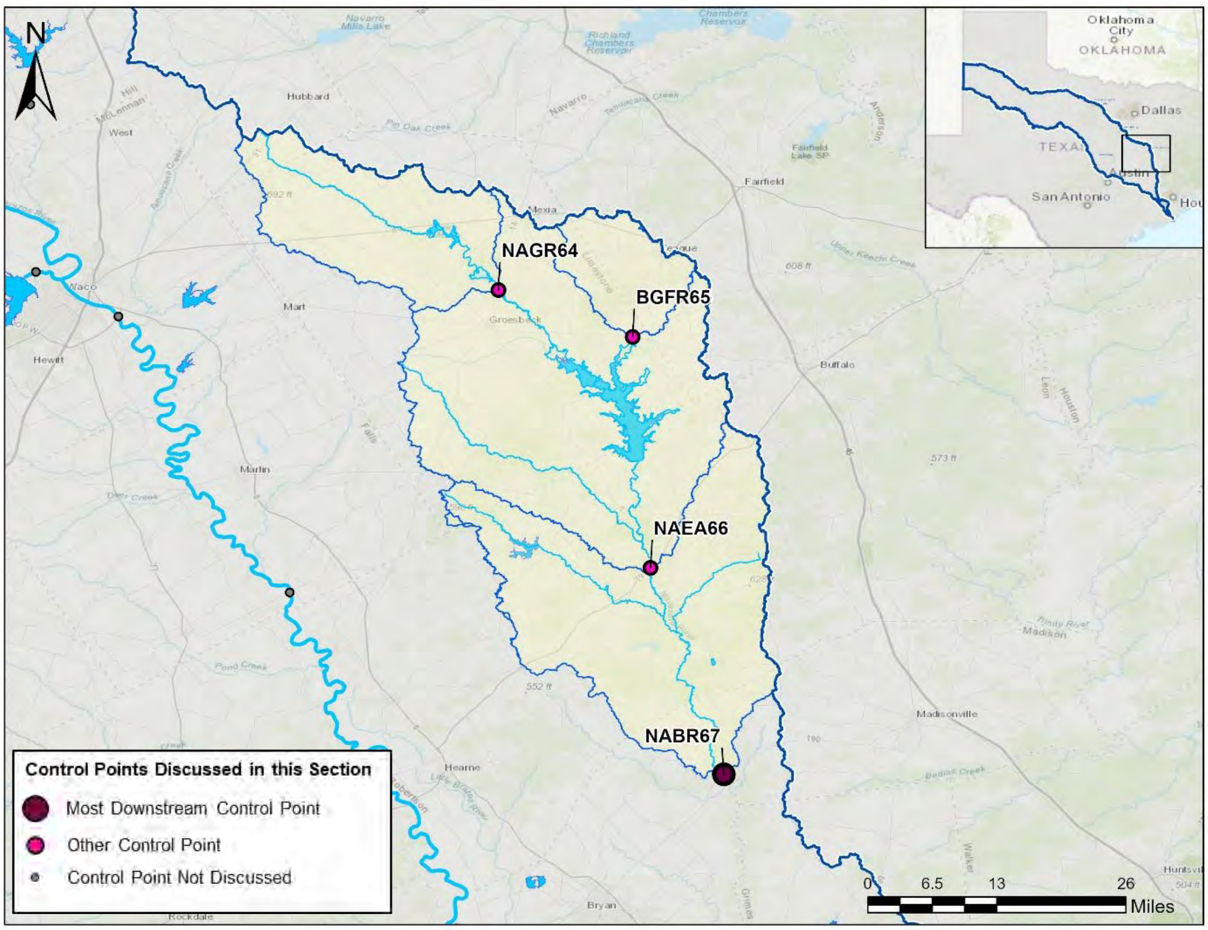


Figure 2-19 – Navasota River Subbasin and Control Points NAGR64 through NABR67

Table 2-10 –Trend Results for Incremental Flow in the Navasota River of the Brazos River Basin: Control Points NAGR64 through NABR67

	NAGR64		BGFR65		NAEA66		NABR67	
Start Year	1940		1940		1940		1940	
	τ	p	τ	p	τ	p	τ	p
Annual	0.07	0.41	0.10	0.21	0.07	0.41	0.02	0.82
Winter	0.05	0.51	0.07	0.38	0.10	0.22	0.03	0.70
Spring	0.00	0.99	0.01	0.89	0.00	0.97	-0.01	0.89
Summer	0.04	0.64	0.00	0.99	0.07	0.35	0.05	0.50
Dry Winter	0.04	0.77	-0.11	0.42	0.22	0.13	-0.10	0.46
Average Winter	-0.06	0.67	-0.01	0.96	-0.03	0.83	-0.07	0.65
Wet Winter	0.12	0.41	0.17	0.24	0.11	0.47	0.03	0.88
Dry Spring	0.02	0.91	0.04	0.80	-0.01	0.98	0.06	0.69
Average Spring	-0.10	0.44	-0.14	0.27	-0.03	0.84	-0.24	0.07
Wet Spring	0.05	0.78	0.09	0.57	-0.01	0.96	0.15	0.34
Dry Summer	0.16	0.24	0.03	0.84	**0.38**	**0.01**	**0.28**	**0.05**
Average Summer	0.04	0.81	-0.03	0.83	0.09	0.58	0.04	0.82
Wet Summer	0.00	1.00	-0.09	0.56	-0.14	0.34	-0.04	0.80

Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

In this study, NAEA66 has strong increasing trends in dry summer for incremental flow and Q/P only (Table 2-C-68). The only significant trend for precipitation volume in this subbasin is an increasing trend in dry summers for BGFR65 (Table 2-C-67). This increase in dry summer precipitation volume does not translate to an increasing trend in incremental flow at BGFR65 during the same hydrologic condition.

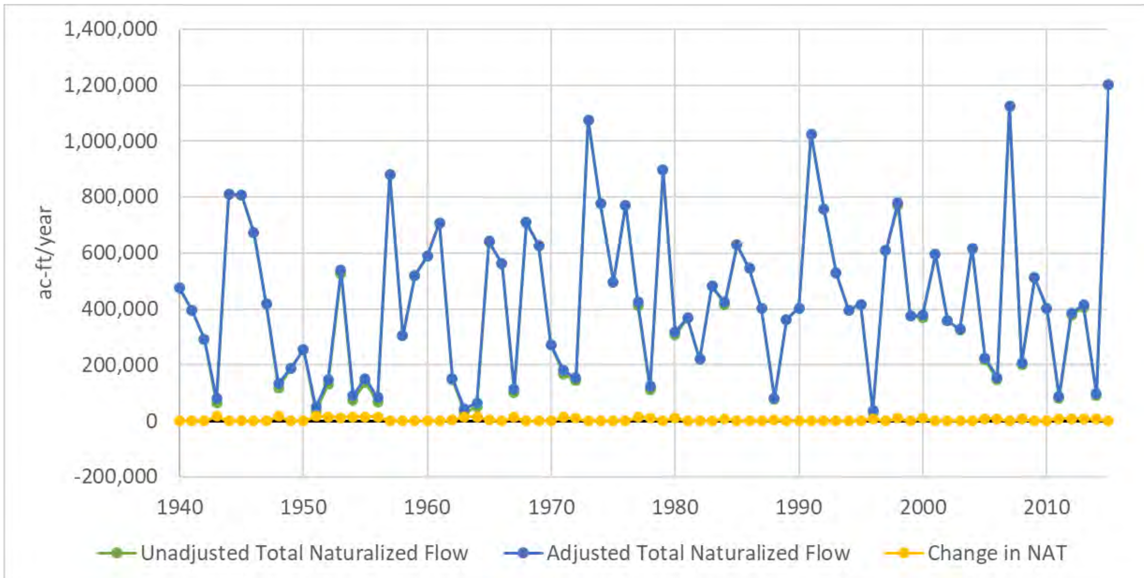


Figure 2-20 – Original and Adjusted Naturalized Flow Time Series for NABR67 for 2070 Conditions

2.1.9 BRRO72 – Brazos River at Rosharon

There are 72 incremental drainage areas that drain into the control point at the Brazos River at Rosharon gage (BRRO72) (Figure 2-21). BRRO72 is the most downstream control point in the Brazos Basin before reaching the Gulf of Mexico. The incremental flows for the BRRO72 control point itself experienced an increasing average summer trend (Table 2-11). Given the variety of strong increasing and decreasing trends upstream of BRRO72, these results show that the effects of upstream trends on naturalized flows can diminish as the flows move downstream and the percent contribution of flow from the incremental drainage areas with trends decreases (Figure 2-22).

Control points BRHE68 through BRRO72 in this subbasin have trends in precipitation volume during certain hydrologic conditions – a decreasing trend in wet summers at MCBL69 and BRRI70, increasing trends in wet spring at BGNE71 and BRRO72, and an increasing trend in dry summer at BRHE68 (Tables C-70 to C-74). BRRI70 has no trends in incremental flow. In the incremental drainage area of BRRI70, the precipitation volume trend is decreasing and Q/P trend is increasing, but there is no effect on incremental flow (Table 2-C-72). The projected change in total flow at BRRO72 is minor, only a 2 percent increase (Table 2-2).

The Yegua Creek and Davidson Creek watersheds, which include control points MYDB60, EYDB61, YCSO62 and DCLY63, also contribute flow to BRRO72 (Figure 2-21). We found no trends in incremental flow, precipitation volume or Q/P at EYDB61 and DCLY63 (Tables C-63 and C-65). We identified increasing trends in incremental flow and Q/P in summer and decreasing trends in incremental streamflow and Q/P in average springs at MYDB60 (Table 2-C-62). YCSO62 has a decreasing trend for precipitation volume in wet summer (Table 2-C-64).

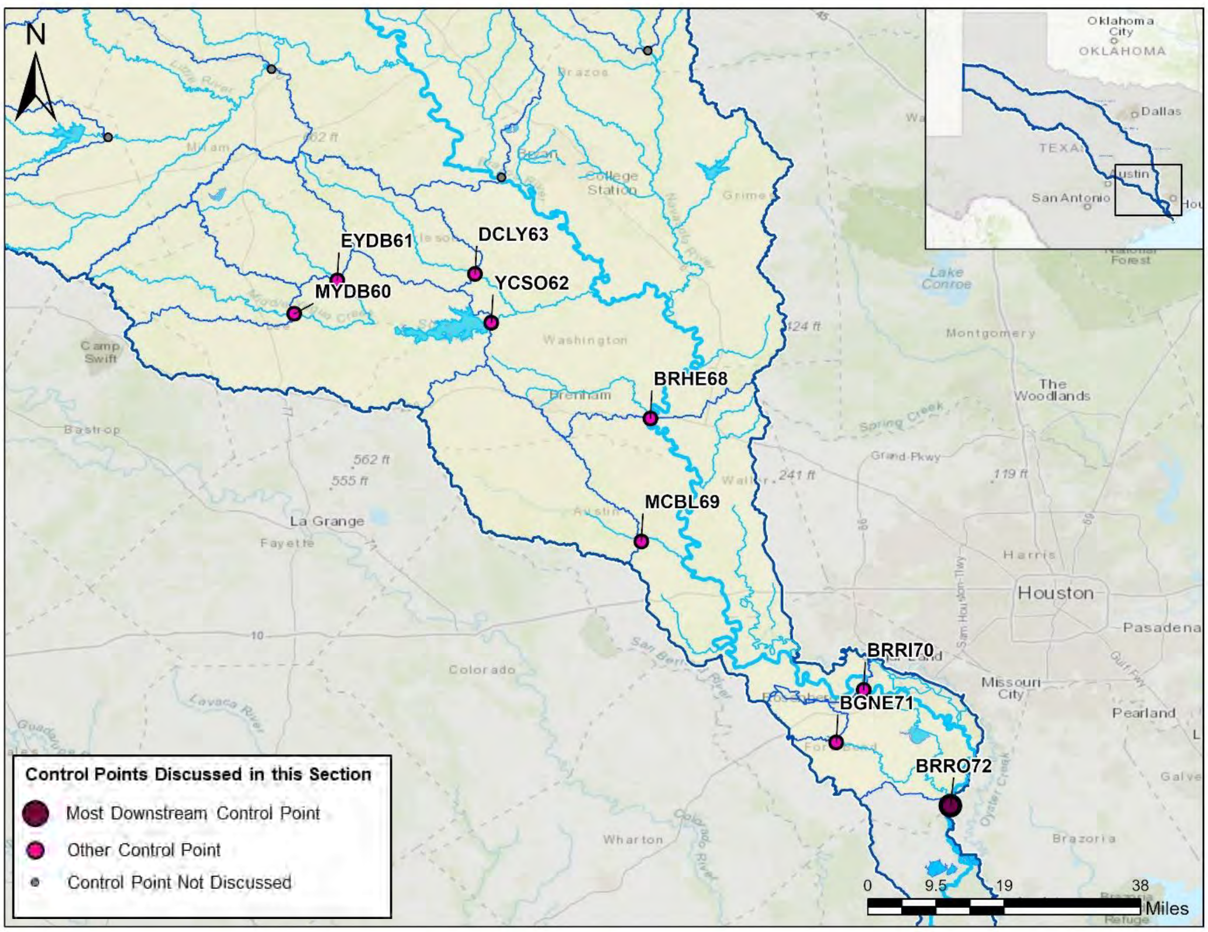


Figure 2-21 – Drainage Area of BRRO72 and Control Points Downstream of BRBR59 and NABR67

Table 2-11– Trend Results for Incremental Flow near Rosharon of the Brazos River Basin: Control Points BRHE68 through BRRO72

	BRHE68		MCBL69		BRRI70		BGNE71		BRRO72	
Start Year	1940		1940		1940		1940		1940	
	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	-0.02	0.85	-0.04	0.60	0.00	0.95	0.00	1.00	0.02	0.83
Winter	0.02	0.82	0.01	0.85	-0.02	0.80	-0.04	0.59	0.05	0.50
Spring	-0.07	0.40	-0.04	0.58	0.03	0.71	0.01	0.92	-0.05	0.50
Summer	0.06	0.46	-0.06	0.44	0.07	0.34	0.02	0.76	0.18	0.02
Dry Winter	-0.13	0.33	0.10	0.50	0.24	0.11	-0.04	0.80	0.23	0.11
Average Winter	0.00	1.00	-0.08	0.58	-0.06	0.66	0.00	1.00	0.22	0.14
Wet Winter	0.09	0.54	0.22	0.15	-0.13	0.40	-0.08	0.57	-0.09	0.55
Dry Spring	0.07	0.66	-0.09	0.52	0.09	0.55	0.06	0.69	0.02	0.93
Average Spring	-0.15	0.24	-0.06	0.69	-0.12	0.41	-0.09	0.49	-0.12	0.38
Wet Spring	-0.08	0.61	-0.05	0.76	0.06	0.69	0.21	0.20	0.04	0.83
Dry Summer	0.12	0.41	0.01	0.94	-0.03	0.82	0.19	0.16	0.07	0.59
Average Summer	0.08	0.58	-0.03	0.87	0.07	0.67	0.15	0.34	**0.52**	**0.00**
Wet Summer	0.01	0.94	-0.14	0.31	0.22	0.12	-0.13	0.39	0.16	0.28

MYDB60, EYDB61, YCSO62, and DCLY63 also contribute flow to BRRO72 but were omitted here due to space considerations. Results at those points are reported in Table 2-C-2 of Appendix 2-C.
Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

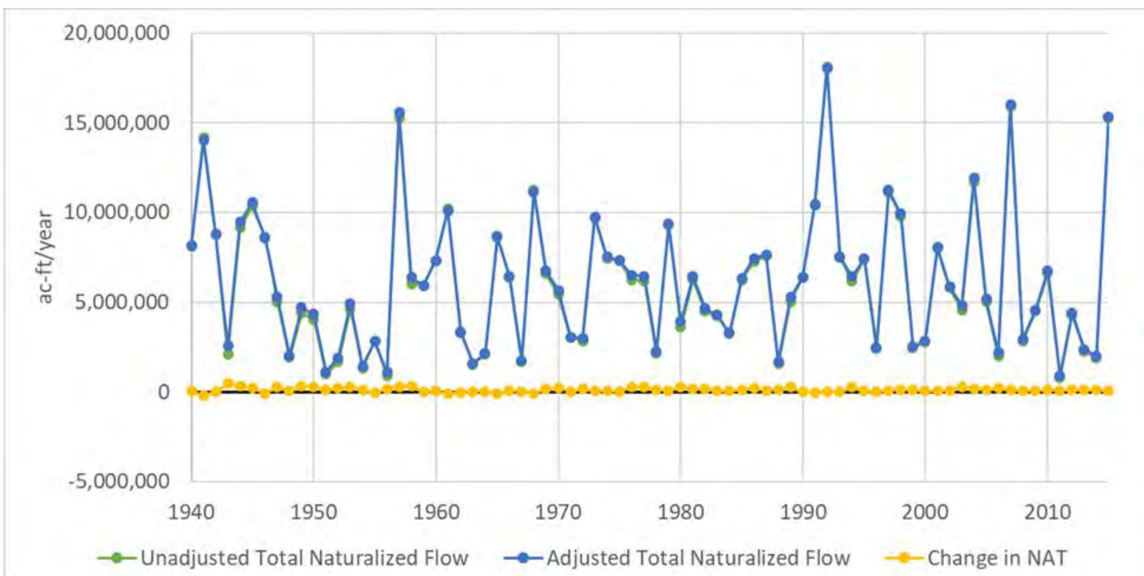


Figure 2-22 – Original and Adjusted Naturalized Flow Time Series for BRRO72 for 2070 Conditions

2.1.10 Assessment of Start Years for FLO Analysis

The start year of the period with the maximum value of Kendall's tau for significant annual trends between 1940 and 1966 was the start year used for the trend analysis. In some cases, we discarded the start year identified by this method and used the full period of record (1940-2015) for trend analysis. **Appendix 1-C** (**Chapter 1**) describes this approach in more detail, and **Appendix 2-C** to this chapter lists control points for which the selected start year was replaced with 1940 (Table 2-C-1).

2.2 TRENDS IN AVERAGE AIR TEMPERATURE AND PRECIPITATION

We calculated adjustments to net reservoir evaporation at the U.S. climate division scale by evaluating trends in average air temperature (T) and precipitation (P) and determining a relationship between T and gross evaporation (E[T]). We assigned the control points that require input in the Brazos WAM's EVA file to the climate division within which they are located, as described in ***Section 1.3.5***. Control points in the EVA file are different from control points in the FLO file. We made net evaporation adjustments at the climate division scale, so that all the control points within a given climate division have the same adjustments. As with incremental flow, we conducted a start year analysis for each climate division to identify significant trends, beginning with the full period of record (1940-2019) and analyzing through a minimum period of record of 50 years (1970-2019). We used a start year between 1940 and 1970 that maximized Kendall's tau for significant annual trends as the start year for the trend analysis and to develop the adjustment factors. We followed the same criteria as the FLO analysis ($R^2_{exponential}$–R^2_{linear}≥0.1) to evaluate linear and exponential trends for precipitation, temperature, and the relationship between temperature and gross evaporation (E[T]). We did not find any exponential trend to be better than a linear trend. Thus, we selected linear best-fit equations for all detected trends to determine adjustment factors. We developed additive adjustment factors for evaporation control points to adjust for future net evaporation averages expected under 2050 and 2070 conditions. This section describes the trends in precipitation and temperature across the Brazos Basin (which are the basis for both the 2050 and 2070 EVA adjustments) and adjustments for 2070 conditions unless otherwise noted. Table 2-12 shows a summary of the start years and trends selected to adjust each climate division for future 2070 conditions. **Appendix 2-D** includes graphs and data for the analysis.

The net evaporation rates used in most of the Brazos WAM EVA control points are based on TWDB estimates of gross reservoir evaporation and precipitation at the one-degree quadrangle scale. We also assessed trends in TWDB quadrangle gross reservoir evaporation, scaled to the climate division level, for comparison with trends in air temperature.

Table 2-12 – Summary of Climate Division Trends and Adjustments

Climate Division	Precipitation		Temperature		Average Annual Change in Net Reservoir Evaporation for 2050 Conditions (ft/yr)	Average Annual Change in Net Reservoir Evaporation for 2070 Conditions (ft/yr)
	Trend(s) Applied and Direction [a]	Start Year	Trend(s) Applied and Direction [a]	Start Year		
4101[b]	Wet winter (+) Average summer (+)	1940 1940	Annual (+)	1968 1968	0.78	1.01
4102	Dry summer (+)	1940	Annual (+)	1968	0.92	1.19
4103	none	1940	Annual (+)	1968	0.66	0.86
4104	none	1940	Annual (+)	1966	0.49	0.63
4106[c]	none	1940	Annual (+)	1968	None	None
4107	Wet summer (-)	1940	Annual (+)	1968	0.59	0.76
4108	Wet spring (+)	1940	Annual (+)	1966	0.21	0.28

a) *+/- signs indicate decreasing or increasing trend direction*
b) *Multiple trends for this climate division*
c) *There are no control points in the EVA file assigned to this climate division.*

The temperature trends analysis consistently identified start years in the late 1960s for each climate division (Table 2-12). This means that temperature trends starting in 1966 or 1968 had the highest absolute tau that was significant. In terms of adjustments to net evaporation rates, we set adjustments prior to 1966 (or 1968) equal to the adjustments being made under 1966 (or 1968) conditions to avoid over-adjusting values from a period when the identified trend was not yet present (**Appendix 1-F**). We found few significant annual precipitation trends for the climate divisions. Significant annual trends in precipitation that were detected had intermittent start years that occurred in the late 1940s and early 1950s, a historically dry period, but not for other start years. We set the start year for the precipitation trend analysis in these climate divisions to 1940. The start years for seasonal analysis in all other climate divisions that did not have trends in annual precipitation defaulted to 1940.

We found significant precipitation trends in seasonal hydrologic conditions for some climate divisions (Table 2-12). We found increasing wet winter and average summer precipitation trends in climate division 4101 (High Plains). Approximately sixty-five percent of the upper basin is in climate division 4102 (Low Rolling Plains), which has an increasing precipitation trend in dry summers. The middle basin is solely within climate division 4103 (North Central), which has no significant trends in precipitation. The lower basin is split among five climate divisions; of these, only climate divisions 4107 (South Central) and 4108 (Upper Coast) have significant precipitation trends. Precipitation trends in climate divisions 4107 and 4108, located along the Gulf Coast, both take place during wet conditions but occur during different seasons and have opposing trend directions, e.g., the precipitation trend is decreasing during wet summers in climate division 4107; whereas, the precipitation trend is increasing during wet springs in climate division 4108.

We used the additive adjustment factors for precipitation and gross evaporation (based on temperature) determined for each climate division to adjust net reservoir evaporation at each EVA control point in the Brazos WAM (Table 2-D-3). Figure 2-23 illustrates the average change in net reservoir evaporation at each control point in the original EVA file and the new adjusted EVA file for 2070 conditions. The adjustments determined from the trend analysis cause increases in net reservoir evaporation at all control points across the Brazos River Basin. The greatest changes in net evaporation are in the upper basin (climate divisions 4101 and 4102), and the smallest changes in net evaporation are in the most downstream part of the basin (climate division 4108). The greater adjustment factors in climate divisions 4101 and 4102 are caused by greater increasing trends in temperature, and thus greater adjustments to gross evaporation, which reduce the impact of slight increasing trends in precipitation during certain seasonal and hydrologic conditions (Tables D-1 and D-2). Even though climate divisions 4103 and 4104 further downstream have no trends in precipitation, adjustments in these divisions are comparatively smaller due to smaller increasing trends in temperature and smaller adjustments to gross evaporation. No EVA control points are assigned trends from climate division 4106. Compared to climate divisions further upstream, increasing trends in temperature and adjustments to gross evaporation are even smaller in climate divisions 4107 and 4108. However, climate division 4107 has a decreasing trend in precipitation during wet summers resulting in midrange changes to its net reservoir evaporation. In contrast, climate division 4108 has an increasing trend in precipitation during wet springs that offsets increasing trends in temperature and adjustments to gross evaporation to a greater extent compared to other climate divisions, resulting in the smallest adjustment to net evaporation.

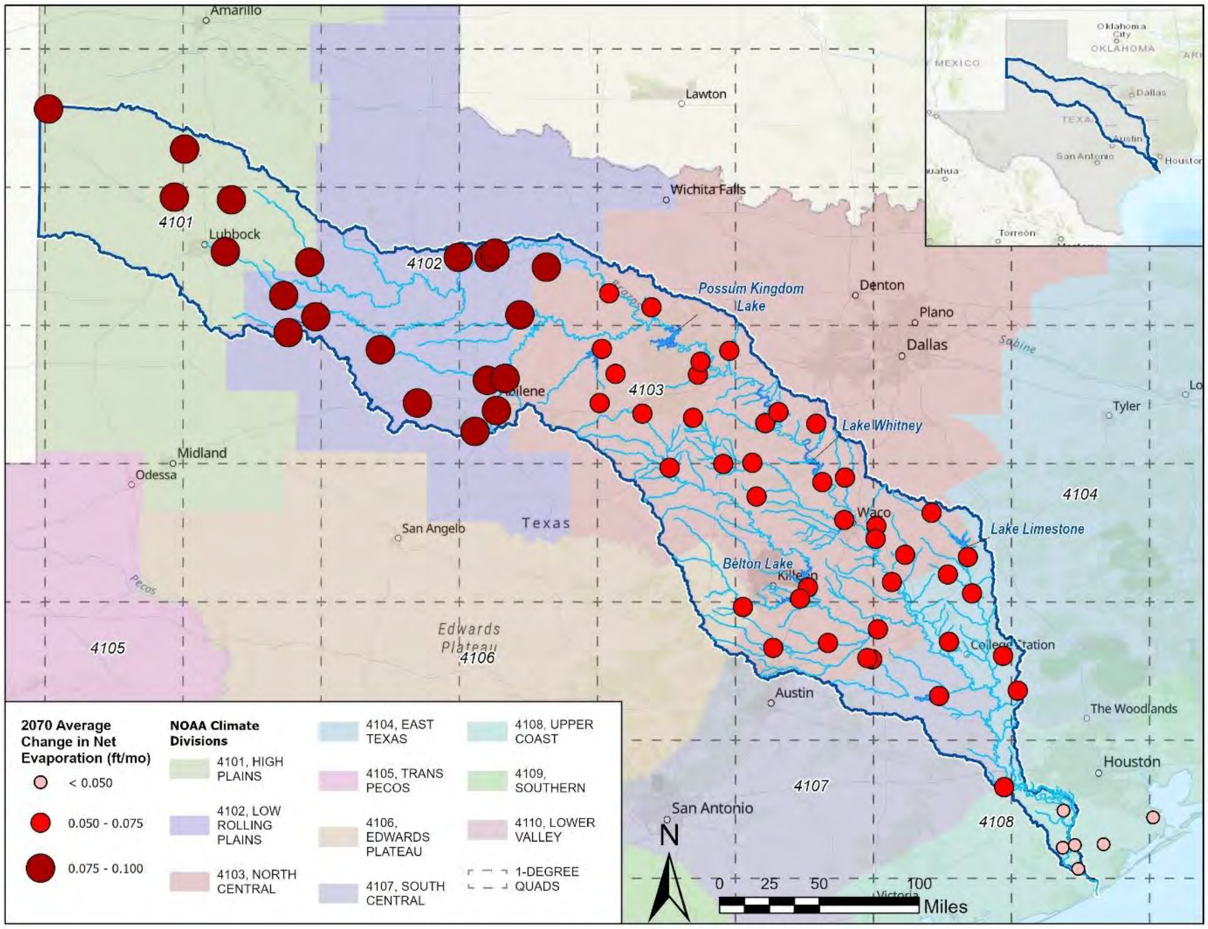


Figure 2-23 – Average Change in Net Reservoir Evaporation over the 1940-2015 Model Period (2070) for EVA Control Points

2.2.1 Climate Division 4101 – High Plains

Six EVA control points are in climate division 4101 in the uppermost part of the Brazos River Basin (Table 2-D-1). We detected significant increasing precipitation trends for average summer and wet winter conditions (Table 2-D-7). The trend in average summers was slightly greater than in wet winter conditions and resulted in negative net reservoir evaporation when added to gross evaporation during those hydrologic conditions. There was an increasing trend for average annual temperature starting in the year 1968. Trends in TWDB quadrangle gross evaporation in this climate division generally correlated with E[T] trends (Table 2-D-5).

Comparisons between the original and adjusted net evaporation for the two reservoirs within climate division 4101, Buffalo Springs Lake and White River Lake, are shown in Figure 2-24 and Figure 2-25. The increase in adjusted net evaporation is primarily influenced by the increasing gross evaporation (0.014 inches per month per year), based on trends in increasing temperature, versus the precipitation adjustments based on season and condition (0.006 inches per month per year for wet winters and -0.003 inches per month per year for average summers) as seen in Table 2-D-6. Net evaporation for these two reservoirs is driven by continued increasing temperatures for 2050 and 2070 conditions.

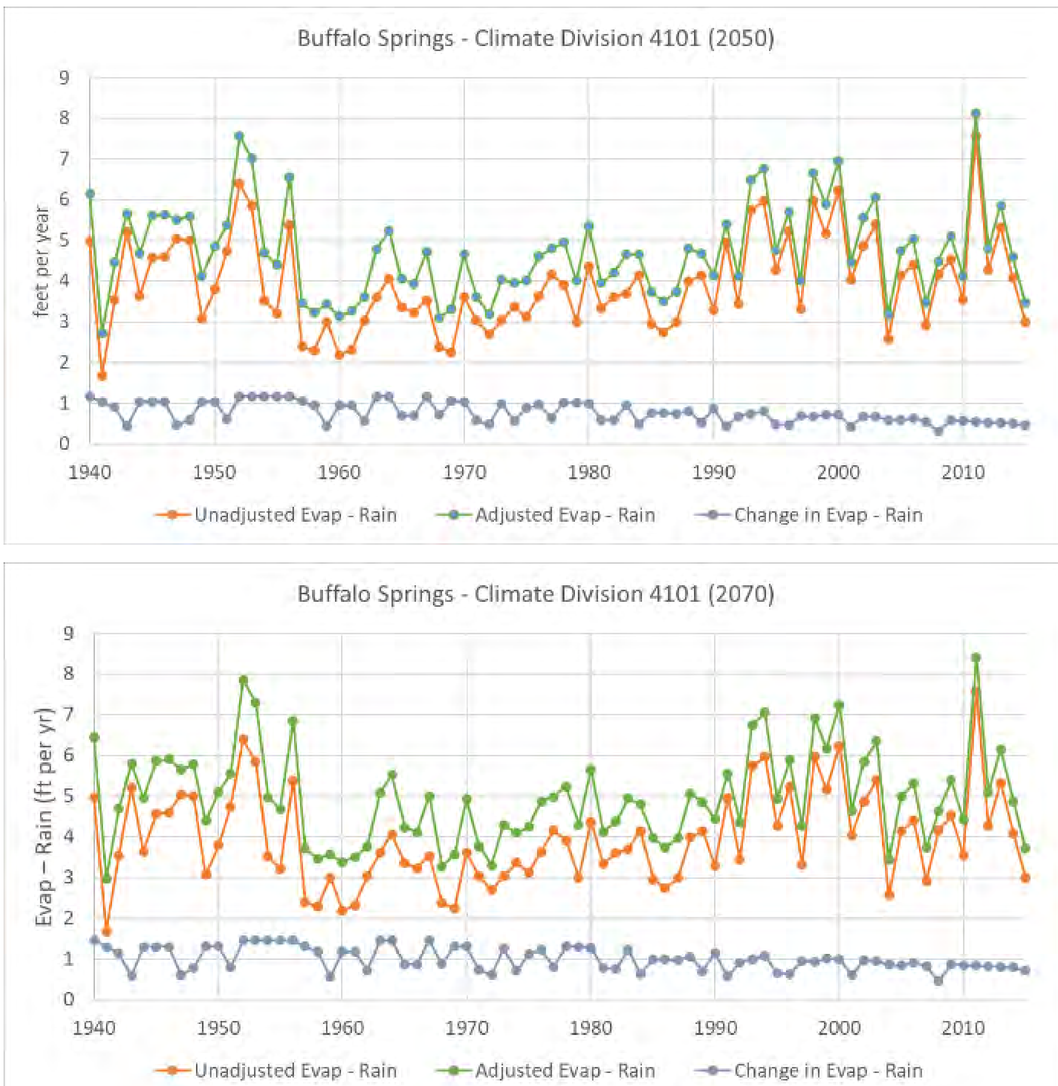
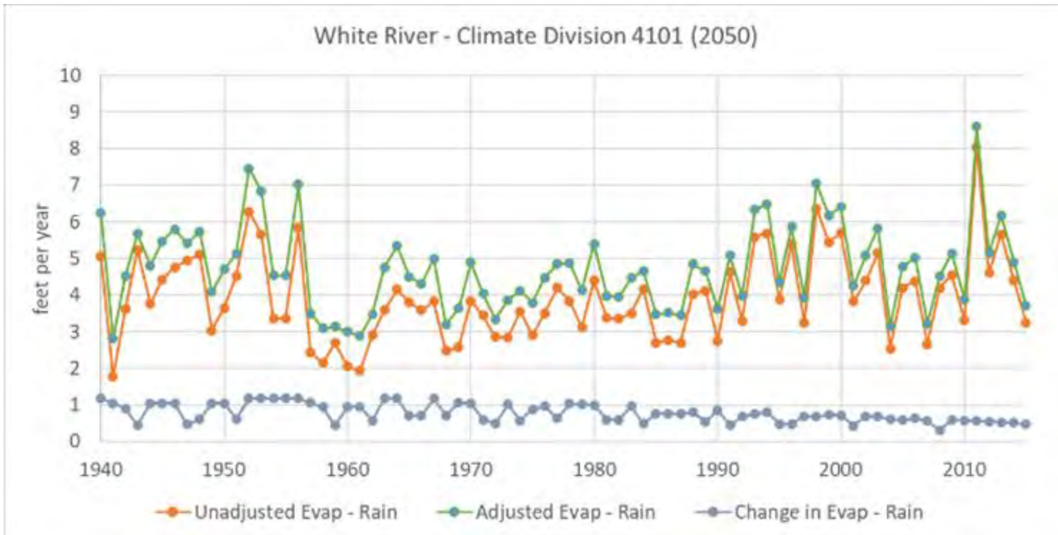


Figure 2-24 – Original and Adjusted Naturalized Net Reservoir Evaporation for Buffalo Springs Lake with 2050 and 2070 Conditions



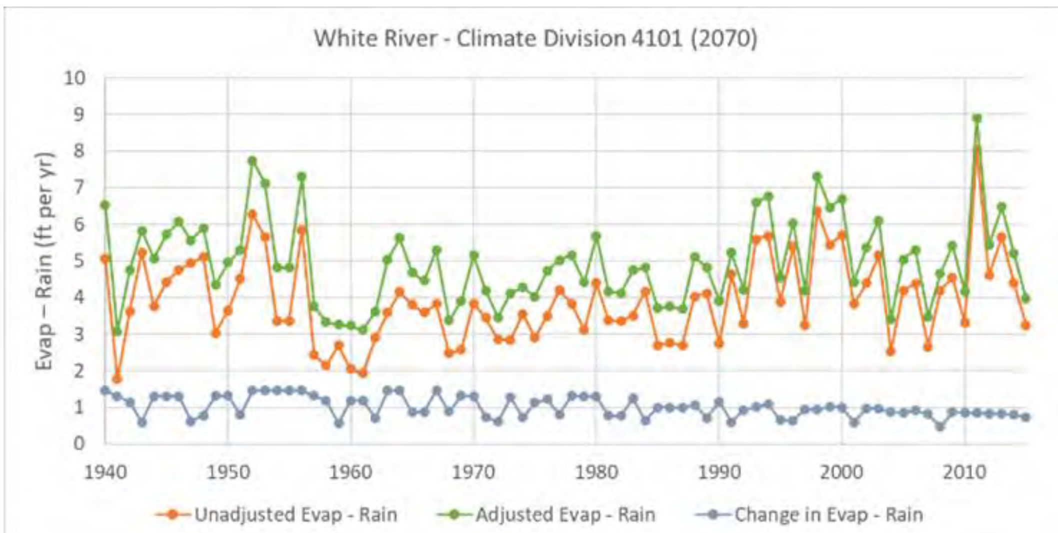


Figure 2-25 – Original and Adjusted Naturalized Net Reservoir Evaporation for White River Lake with 2050 and 2070 Conditions

2.2.2 Climate Division 4102 – Low Rolling Plains

Within climate division 4102, there was a significant increasing trend in precipitation during dry summers (Table 2-D-8). We adjusted the 14 control points in this climate division based on this seasonal condition. All other months without this condition had no adjustment for precipitation. Average monthly temperature exhibited an increasing annual trend, with the greatest Kendall's tau showing a start year of 1968 (Table 2-D-1). Similar to climate division 4101, we used adjustment factors based on Equations 1-16 and 1-17 to create an adjusted EVA dataset. Lake Alan Henry net evaporation increased given the projected increase in average annual temperature (Figure 2-26). Additional net evaporation graphs for all reservoirs in climate division 4102 can be found in **Appendix 2-D**. The primary trend influencing the increased net evaporation is increasing gross evaporation (0.015 inches per month per year), based on increasing trends in temperature, which works against an increasing trend in precipitation during wet summers (0.003 inches per month per year) (Table 2-D-6). Increasing trends in E[T] generally showed positive associations with trends in TWDB quadrangle gross evaporation in this climate division (Table 2-D-5).

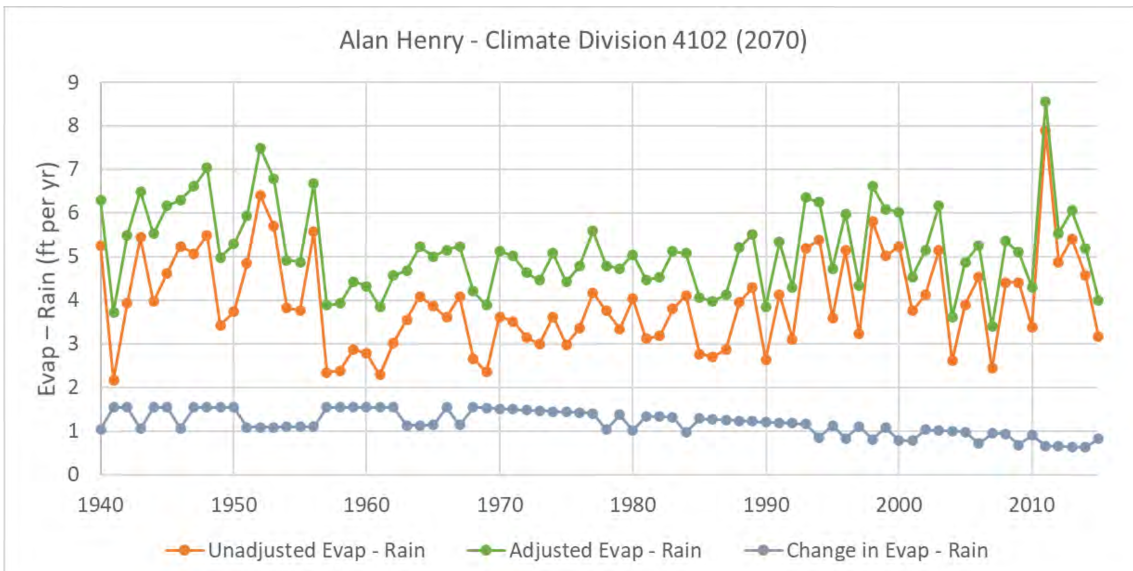


Figure 2-26 – Original and Adjusted Naturalized Net Reservoir Evaporation for Lake Alan Henry with 2070 Conditions

2.2.3 Climate Division 4103 – North Central

Climate division 4103 encompasses 32 Brazos River Basin control points, which is more than any other climate division. We found no significant precipitation trends (Table 2-D-9). We found the strongest Kendall's tau for an increasing annual trend for average monthly temperature starting in 1968 and used 1968 as the start year the trend analysis. The annual trend in temperature had the greatest tau, so this trend was used to adjust gross evaporation (Figure 2-27). In contrast to the trends detected for E[T], a significant trend in TWDB quadrangle gross evaporation was only found during the winter season in climate division 4103, but showed the same trend direction (Table 2-D-5)

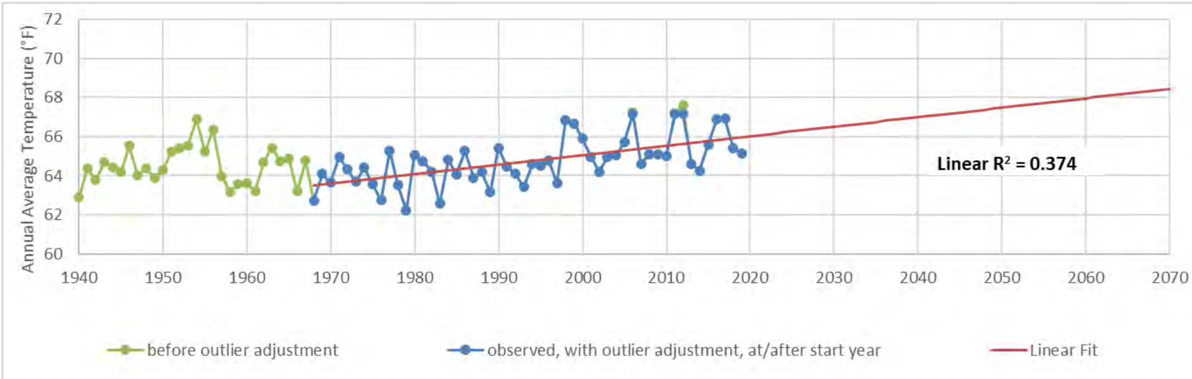


Figure 2-27 – Annual Trend for Temperature for Climate Division 4103 in 2070 Conditions

Figure 2-28 shows a comparison between the original and adjusted net evaporation for Possum Kingdom Lake, located within climate division 4103. The increase in adjusted net evaporation for Possum Kingdom is caused by the increasing temperature trend because we detected no significant precipitation trends in climate division 4103. In fact, we project all reservoirs in climate division 4103 to experience increasing reservoir net evaporation due to this temperature trend. The gray line at the bottom of Figure 2-28 is the adjustment added to the original net evaporation time series to develop the adjusted net evaporation time series. 1968 was selected as the start year for the temperature trend analysis, so the value of the adjustment prior to that is equal to the value in 1968 (i.e., the adjustment is a flat line between 1940 and 1968). After 1968, the adjustment slopes down linearly until finally reaching 0 feet per year in 2070. The underlying concept is that years in the beginning of the period of record need to be increased more than later years to account for the increasing trend in temperature and to generate an adjusted time series that represents 76 years of 2070 hydrology. Additional graphs of net evaporation for all reservoirs in climate division 4103 can be found in **Appendix 2-D**.

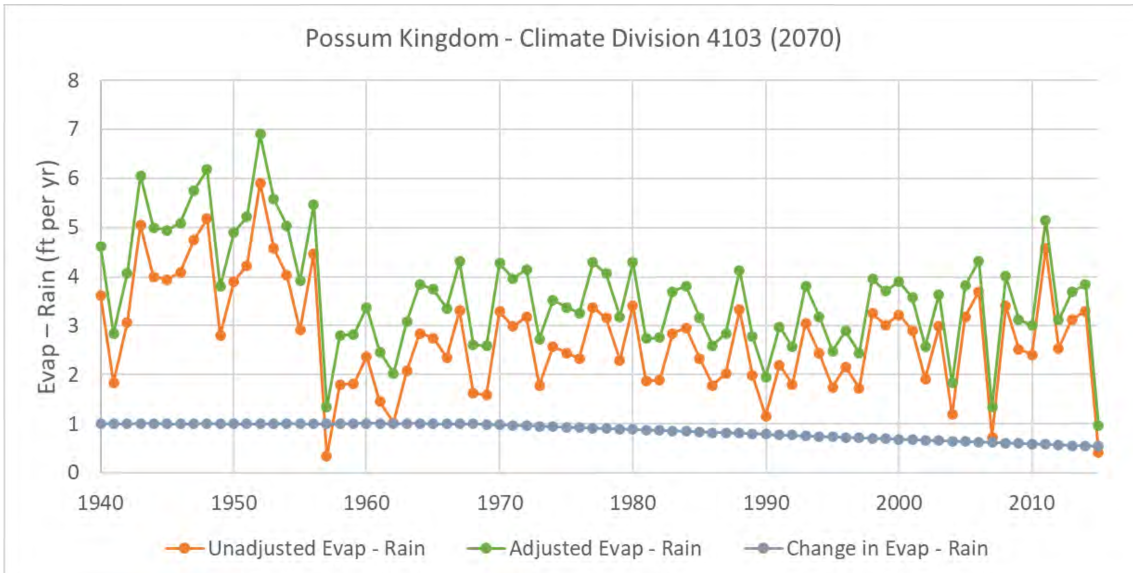


Figure 2-28 – Original and Adjusted Naturalized Net Reservoir Evaporation for Possum Kingdom Lake with 2070 Conditions

2.2.4 Climate Division 4104 – East Texas

A small portion of climate division 4104 overlaps the Brazos River Basin with seven control points assigned in the EVA file. We did not detect any significant precipitation trends for climate division 4104 (Table 2-D-10), which means that the adjustments to net evaporation come solely from trends in gross evaporation as a function of temperature. The comparison of TWDB quadrangle gross evaporation to E[T] in climate division 4104 shows a positive association (Table 2-D-5). Average monthly temperature beginning in 1966 exhibits an increasing annual trend with the strongest Kendall's tau (Figure 2-29).

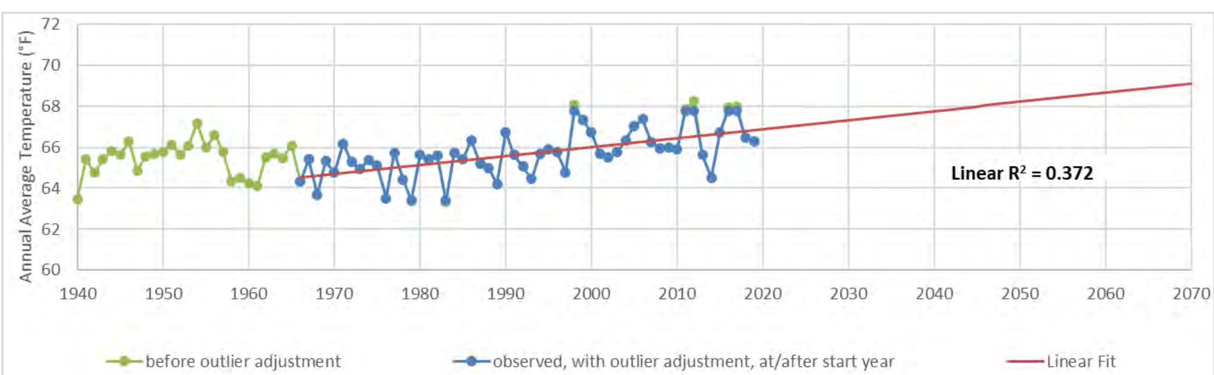


Figure 2-29 – Annual Trend for Temperature for Climate Division 4104 in 2070 Conditions

Figure 2-30 shows the predicted net evaporation for Gibbons Creek Lake. In this climate division, the adjustments for Gibbons Creek Lake and three other reservoirs resulted in a 40 to 72 percent increase in net evaporation by 2070 relative to the historical time series from 1940-2015 (Table 2-D-3). The net evaporation graphs for the three other reservoirs in climate division 4104 can be found in **Appendix 2-D**.

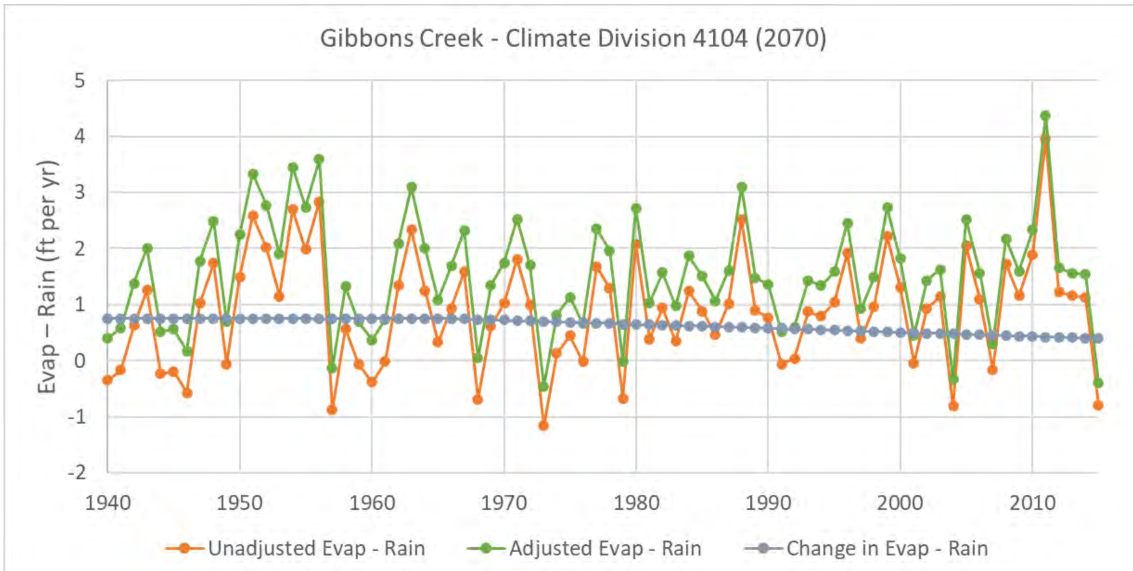


Figure 2-30 – Original and Adjusted Naturalized Net Reservoir Evaporation for Gibbons Creek Lake with 2070 Conditions

2.2.5 Climate Division 4106 – Edwards Plateau

There are no EVA file control points for the Brazos River WAM within climate division 4106. Figure 2-23 shows one control point (in quadrangle 710) in this climate division; however, most EVA control points within this quadrangle are assigned to climate division 4103, so we adjusted quadrangle 710 (and consequently that control point) using climate division 4103. We still investigated precipitation and temperature trends because this climate division intersects the Brazos Basin, but result tables will show no adjustments. We did not find any significant annual trends for precipitation. There is an increasing annual trend for average monthly temperature (Figure 2-D-71). TWDB quadrangle gross evaporation only shows a trend during average winters in this climate division, where it exhibits the same trend direction as E[T] (Table 2-D-5). Overall, since no EVA file control points are in climate division 4106, we did not adjust any net evaporation datasets based on the trends in this climate division.

2.2.6 Climate Division 4107 – South Central

The part of the Brazos Basin that overlaps climate division 4107 includes two EVA file control points associated with reservoirs (Somerville Lake and the proposed Allens Creek Reservoir). We detected a significant decreasing precipitation trend for wet summers in climate division 4107 (Figure 2-D-73). Average monthly temperature exhibited a strong increasing annual trend, with the strongest Kendall's tau for a start year of 1968 (Figure 2-D-74). Trends in E[T] and the TWDB quadrangle gross evaporation did not correspond in this climate division. We found positive trends for E[T] for multiple subsets (annual, seasonal, seasonal and hydrologic), with the annual subset exhibiting the strongest Kendall's tau. Conversely, a negative trend in TWDB quadrangle gross evaporation during average summers was the only trend detected in this climate division and there was no trend in E[T] during average summers. (Table 2-D-5).

Figure 2-31 and Figure 2-32 show the adjusted net evaporation for the control points in this climate division for 2070 conditions. As shown in Table 2-D-6 in **Appendix 2-D**, the annual decrease in wet summer precipitation (0.020 inches per month per year) is greater than the annual change in gross evaporation (0.006 inches per month per year), based on an increasing trend in temperature. Since the adjustment factors are additive, this suggests that decreasing precipitation in climate division 4107 for traditionally wet summer periods will cause greater increases to reservoir net evaporation during periods where a wet summer occurs compared to other periods. In other words, rainfall in wet summer months may be decreasing thereby causing the loss of reservoir storage.

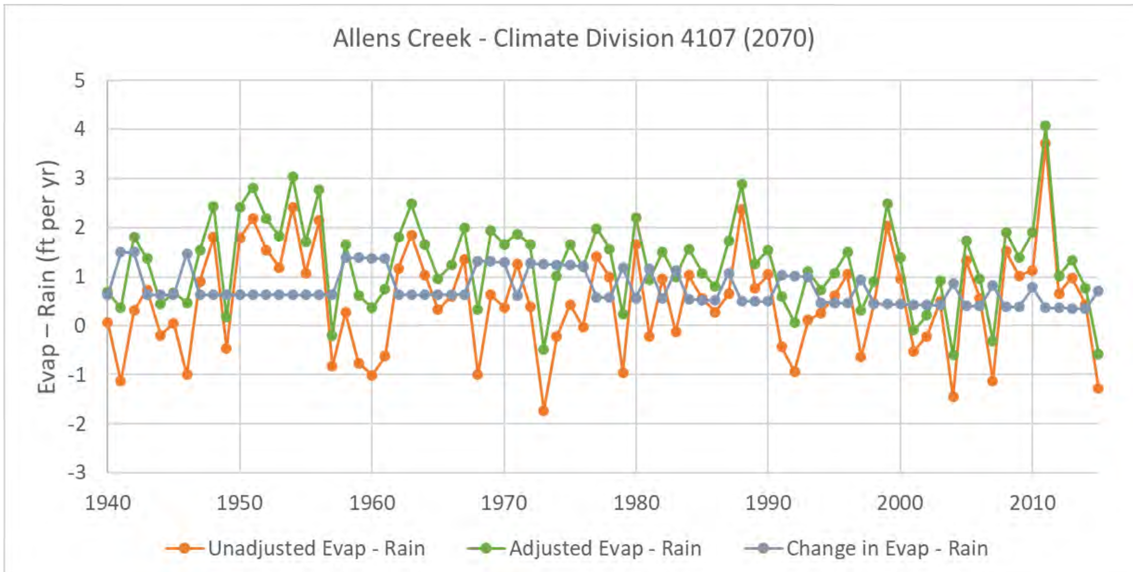


Figure 2-31 – Original and Adjusted Naturalized Net Reservoir Evaporation for Allens Creek Lake with 2070 Conditions

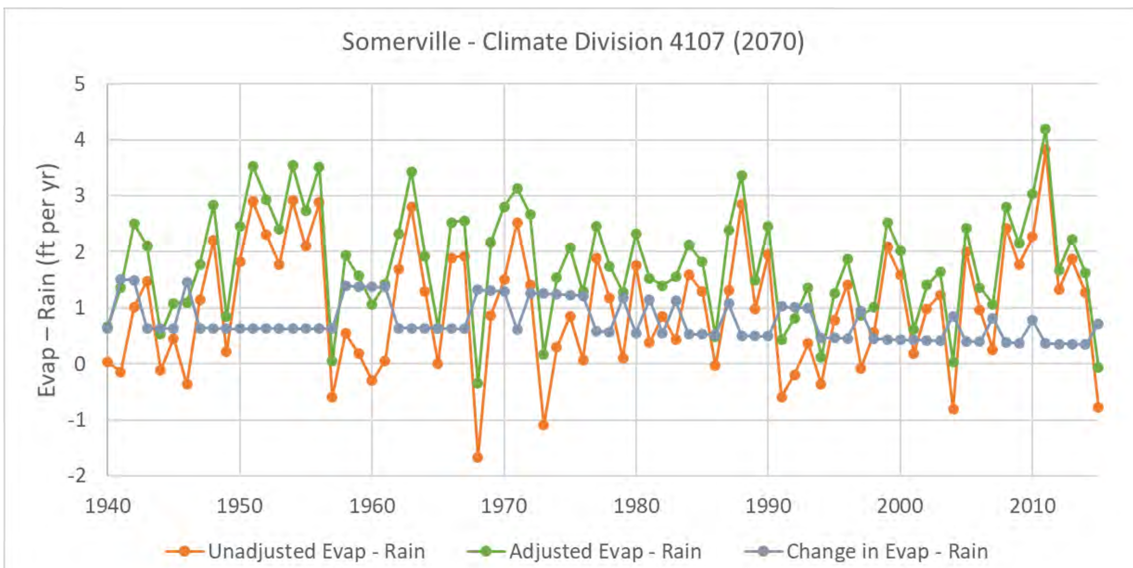


Figure 2-32 – Original and Adjusted Naturalized Net Reservoir Evaporation for Lake Somerville with 2070 Conditions

2.2.7 Climate Division 4108 – Upper Coast

Six control points are in climate division 4108 in the lowermost part of the Brazos River Basin. An increasing precipitation trend for wet springs was detected for this climate division (Table 2-D-13). This precipitation trend results in negative adjustments to net reservoir evaporation during wet springs as it is larger than the gross evaporation adjustment. An increasing annual trend was found for the historical average monthly temperature (Figure 2-D-79). No trends were found in TWDB quadrangle gross evaporation, which does not correspond to the increasing trends shown for E[T] (Table 2-D-5).

The net evaporation rate at Smithers Lake is projected to decrease during years with wet springs and increase during all other periods (Figure 2-33). Net evaporation graphs for all reservoirs in climate division 4108 are included in **Appendix 2-D**.

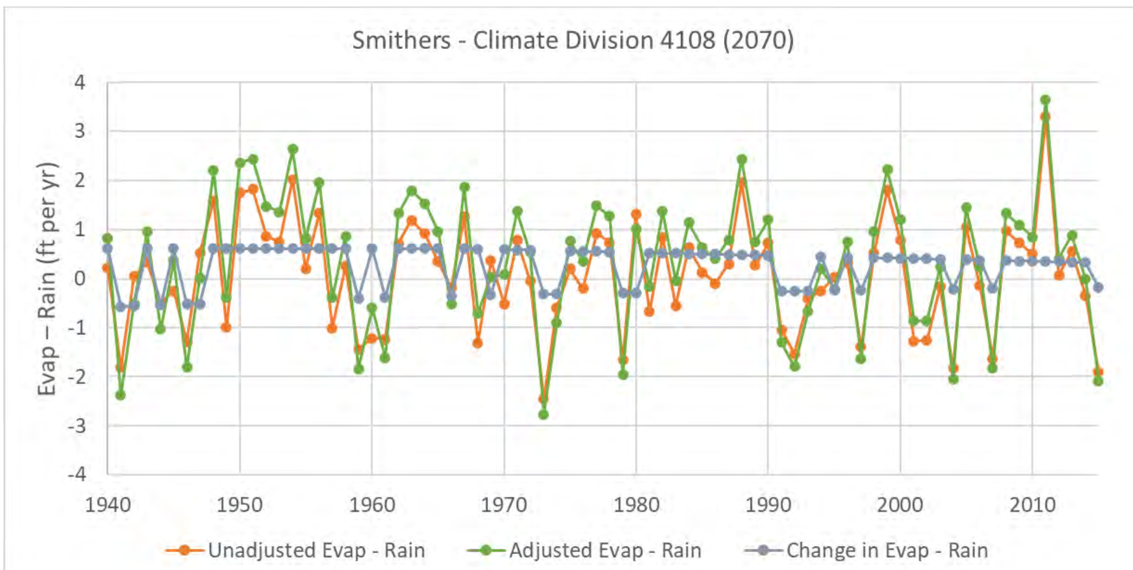


Figure 2-33 – Original and Adjusted Naturalized Net Reservoir Evaporation for Smithers Lake with 2070 Conditions

2.2.8 Assessment of Start Years for EVA Analysis

Significant annual trends in average air temperature were identified for every start year evaluated for trends (1940-2019 through 1970-2019) for each climate division. In other words, significant temperature trends were detected regardless of the selected start year. The maximum Kendall's tau for trends in temperature were consistently identified for start years in the late 1960s. Conversely, significant annual trends in precipitation were detected intermittently for start years occurring in the late 1940s and early

1950s, a historically dry period, but not for other start years elsewhere from 1940 to 1970. Start years for precipitation analyses for climate divisions 4103, 4104, and 4108 were manually set to 1940 due to the inconsistency of the trends detected in the start year analysis period (1940-1970). These intermittent trends shown may be artificially created during the analysis of start years for trends, rather than indicating a true long-term trend. Further discussion of the manual reset of start years to 1940 is discussed in **Appendix 1-C**. **Appendix 2-D** shows a list of climate divisions where the start year for the precipitation analysis was set to 1940.

2.3 TRENDS IN GROUNDWATER LEVELS

2.3.1 Overview

The assessment of the impacts of trends in hydrologic variables on water supplies and environmental flows in the Brazos Basin included an analysis of trends in groundwater elevation across the basin at the aquifer level. The analysis of groundwater elevation trends was not used to update the WAM inputs. However, groundwater trends may provide insight into the causes of trends in streamflow as the Brazos Basin contains gaining stream reaches that are fed by groundwater and are therefore impacted by groundwater elevation (Turco et al. 2007).

In order to assess trends in groundwater levels, groundwater elevation measurements (feet above sea level) were gathered for aquifers that intersect the Brazos Basin. Major and minor aquifers that intersect the basin are depicted in Figure 2-34. Figure 2-34 also indicates the percent change in incremental flow predicted for 2070 at primary control points in the Brazos Basin (calculated as the percent change in the sum of incremental flows over the 76-year model period). Subbasins with the greatest negative predicted change in incremental flow (decreases of 25% or more) overlie the Blaine, Cross Timbers, and Seymour Aquifers in the Upper Brazos Basin. Drainage areas of control points with a predicted increase in incremental flow occur primarily in the Middle and Lower Brazos Basin and overlie portions of the Queen City, Sparta, Carrizo, Trinity, Ogallala, Cross Timbers, and Gulf Coast Aquifers.

Groundwater elevation measurements (feet above sea level) were obtained from the USGS National Water Information System (NWIS) and TWDB Groundwater Database for the years 1991 through 2020. This period of analysis was selected to provide a consistent analysis period across aquifers that is longer than the short-term cycles identified in other studies (see ***Section 1.3.3***) without assessing a large number of years with very few water level observations. Figure 2-B-1 in **Appendix 2-B** summarizes the number of groundwater elevation measurements available over time in each of the aquifers that were analyzed. Due to limited availability of USGS data within the river basin, TWDB data were used for the analysis for each aquifer. The dataset was filtered to create uniformity and remove low quality measurements. This involved removing groundwater elevation measurements reported as null or N/A by TWDB, and removing measurements from wells screened in multiple aquifers to only include wells in counties that intersect the Brazos Basin. The data was also filtered to include measurements recorded closest to January 1, in order to select measurements taken around a similar time of year, as the bulk of observations were recorded during winter months. Some wells had multiple groundwater elevation measurements reported for one year, of which the measurement closest to January 1 was selected. This provided one observation per well per year that was included in the analysis.

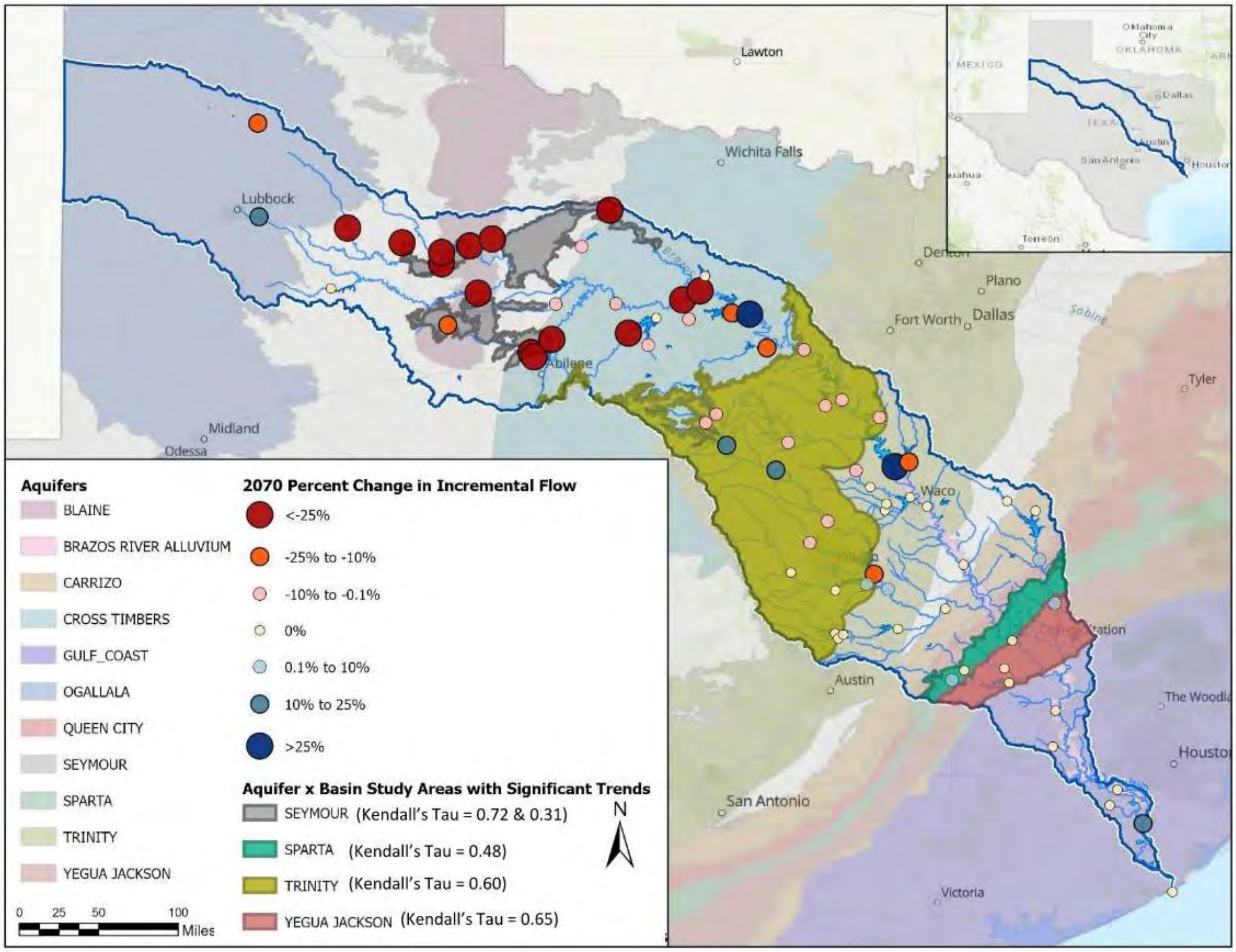


Figure 2-34 – Percent Change in Incremental Flow (2070) at Primary Control Points, Overlaid on Major and Minor Aquifers that Intersect the Brazos River Basin

Trends in water levels were not analyzed in the Ogallala, Carrizo, and Gulf Coast Aquifers. The Ogallala Aquifer underlies only the uppermost part of the Brazos Basin. Much of this portion of the basin does not contribute to streamflow, so water levels in the Ogallala were not expected to be closely related to streamflow trends. The Gulf Coast Aquifer intersects only a narrow portion of the Lower Brazos Basin, and runoff from incremental drainage areas in most of the intersected area did not have any significant trends, so the various formations in the Gulf Coast Aquifer also were not analyzed. Finally, the Carrizo Aquifer had limited water level data available within the extent of the Brazos Basin and was not analyzed.

The groundwater elevation measurements were spatially interpolated across each aquifer for each year. In some cases, a buffer was applied to the interpolation region to capture well observations just outside the boundaries of the Brazos Basin. For each aquifer, the interpolated surface was then clipped to constrain the study area to the portion of the aquifer that overlaps the Brazos Basin. From the interpolated surfaces, the average elevation of the piezometric surface for each year was determined for each portion of the aquifer located within the Brazos Basin. In each aquifer, years with a low number of well observations relative to other years for that aquifer (defined as less than the lower threshold for outliers[1]) were excluded from the trend analysis to maintain a more consistent comparison between years. Kendall's tau was used to analyze the average annual groundwater elevations for temporal trends.

2.3.2 Blaine Aquifer

The Blaine Aquifer is a minor aquifer located in north Texas. Due to the limited number of measurements in the aquifer, not enough data were available to create an interpolated piezometric surface across the area of the Blaine Aquifer that intersects the Brazos Basin. Instead, an individual trend analysis was performed on each of two wells which had data available for most of the study period: state well number 2915501 in Fisher County (Figure 2-35) and state well number 2238301 in King County (Figure 2-36). Figure 2-B-2 shows the location of these wells. No significant trend was identified in the groundwater levels in either well.

[1] Threshold for small outliers defined as the first quartile less 1.5 times the interquartile range, as shown in Section 1.3.3 of Chapter 1.

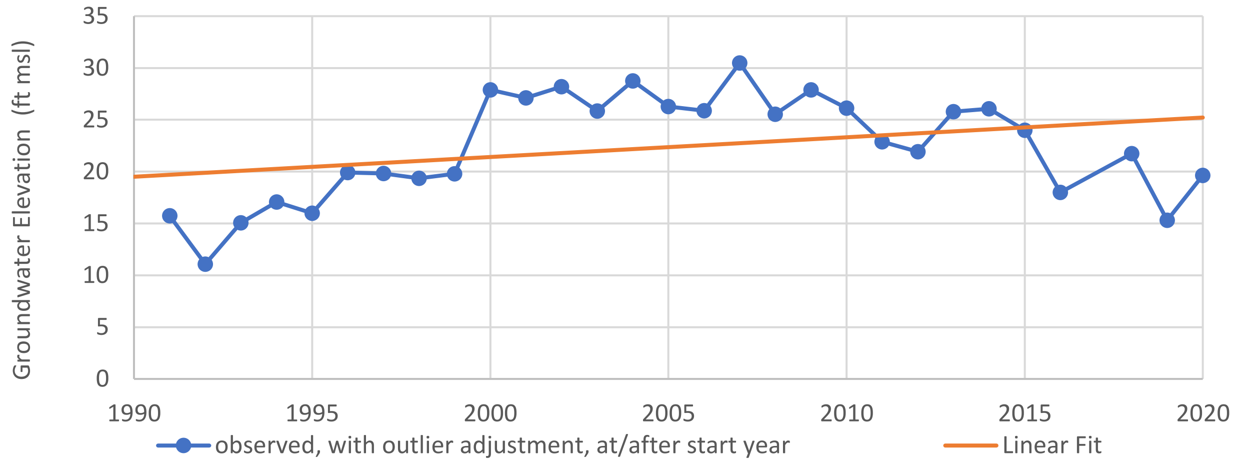


Figure 2-35 – Groundwater Level Elevation in Fisher County Well 2915501

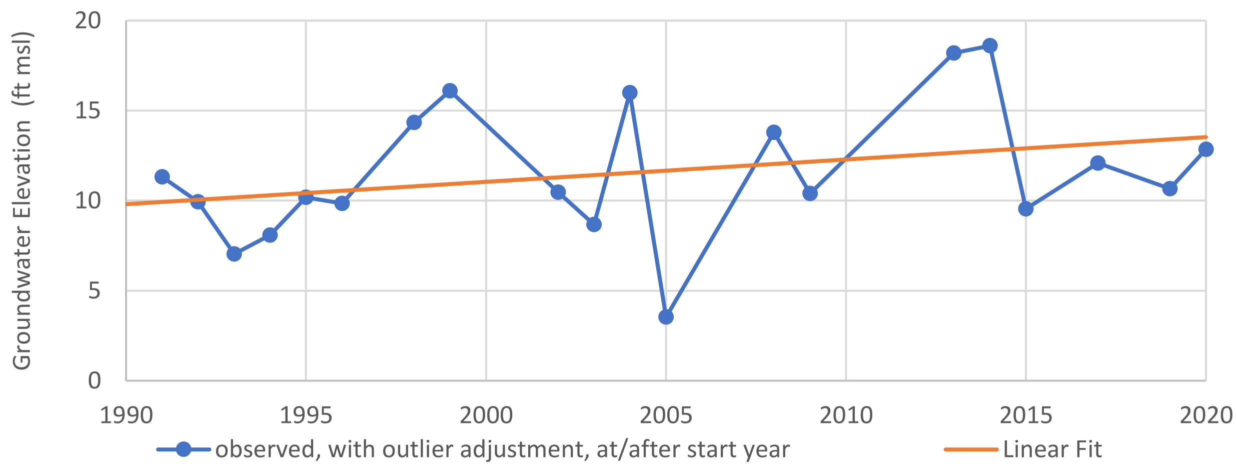


Figure 2-36 – Groundwater Level Elevation in King County Well 2238301

2.3.3 Seymour Aquifer

The Seymour Aquifer is a major aquifer located in north central Texas. This aquifer is unique as it exists as a series of isolated "pods" of water-bearing alluvial sediments. Fifteen (15) distinct pods are defined and numbered in the Groundwater Availability Model (GAM) Report for the Seymour Aquifer (Ewing et al. 2004). Only Pods 7 and 13 had adequate well observation data to develop interpolated piezometric surfaces. Water levels were interpolated separately within Pod 7 and Pod 13. Pod 7 of the Seymour Aquifer included wells screened in the following formations: Alluvium, Alluvium and Fluviatile Terrace Deposits, Alluvium and High Terrace Plain Deposits, Seymour Formation and Quaternary Alluvium. Wells in Pod 7 were tagged as being screened in either Quaternary Alluvium or the Seymour Formation. Both Pod 7 (Figure 2-37) and Pod 13 (Figure 2-38) showed a significant positive increasing trend in average annual groundwater elevation (feet above sea level). Pod 7 had a Kendall's tau value of 0.72 and Pod 13 had a Kendall's tau equal to 0.31 (p value ≤ 0.05 for both). Pods 9 and 11 did not have sufficient water level measurements to develop interpolated piezometric surfaces. Instead, state well numbers 2252107 and 2252110 in Kent County were assessed in Pod 9 (Figure 2-39 and Figure 2-40), and state well number 2923606 in Jones County was assessed for Pod 11 (Figure 2-41). There were no significant trends found in these wells. Figure 2-B-3 shows the locations of wells with groundwater elevation data used in the trend analysis for each pod.

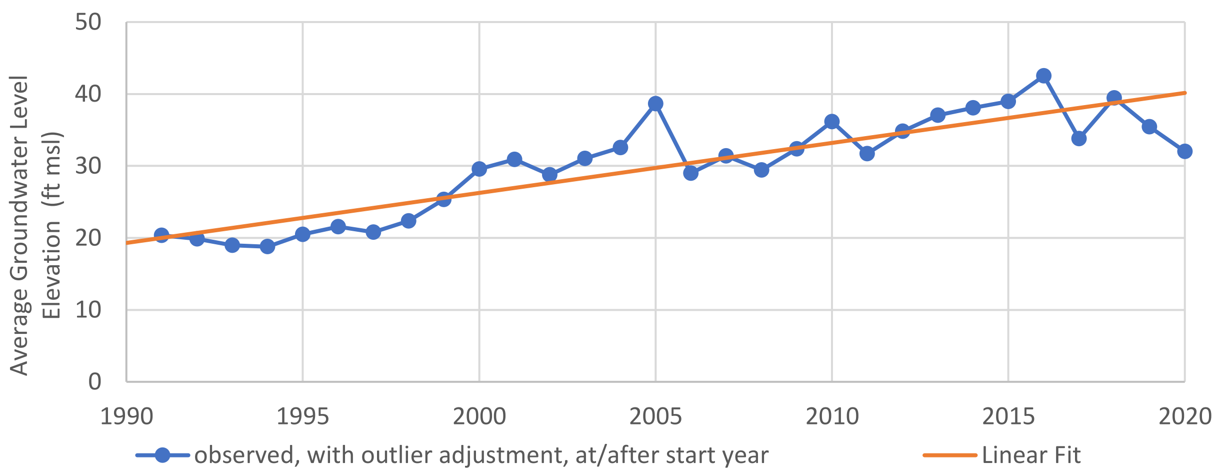


Figure 2-37 – Annual Average Groundwater Level Elevation in the Seymour Aquifer, Pod 7

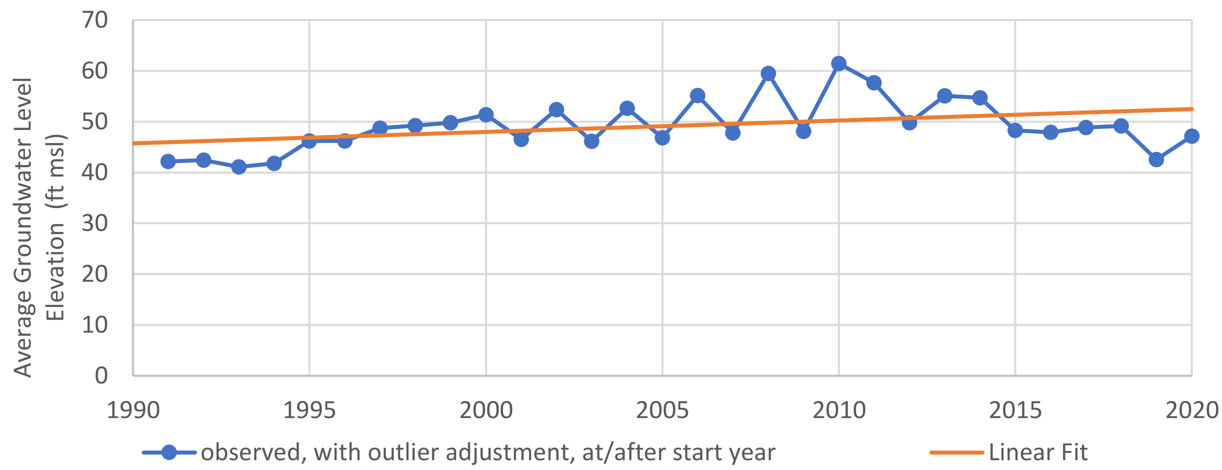


Figure 2-38 – Annual Average Groundwater Level Elevation in the Seymour Aquifer, Pod 13

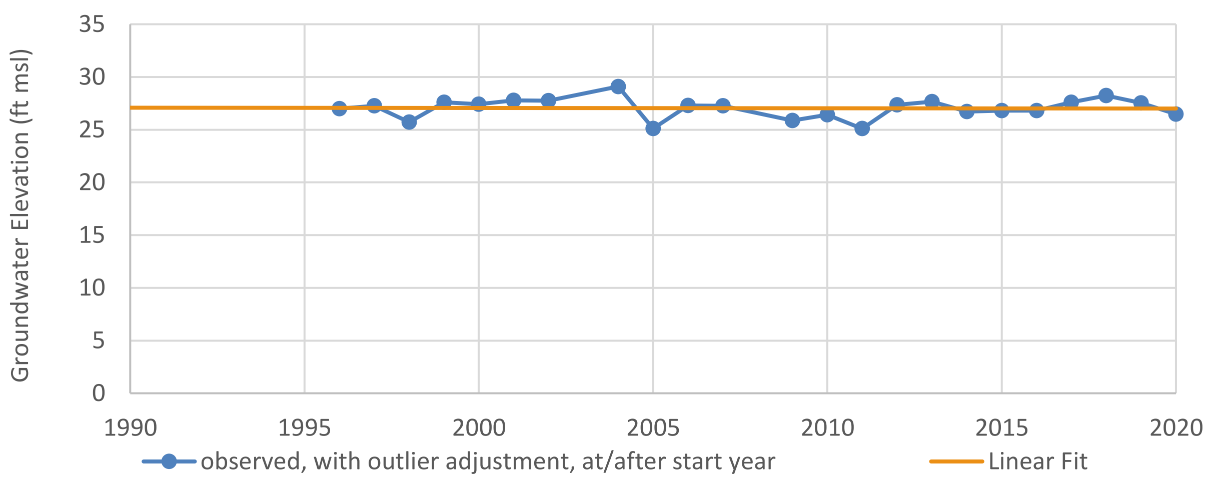


Figure 2-39. Groundwater Level Elevation in Pod 9 Well 2252107

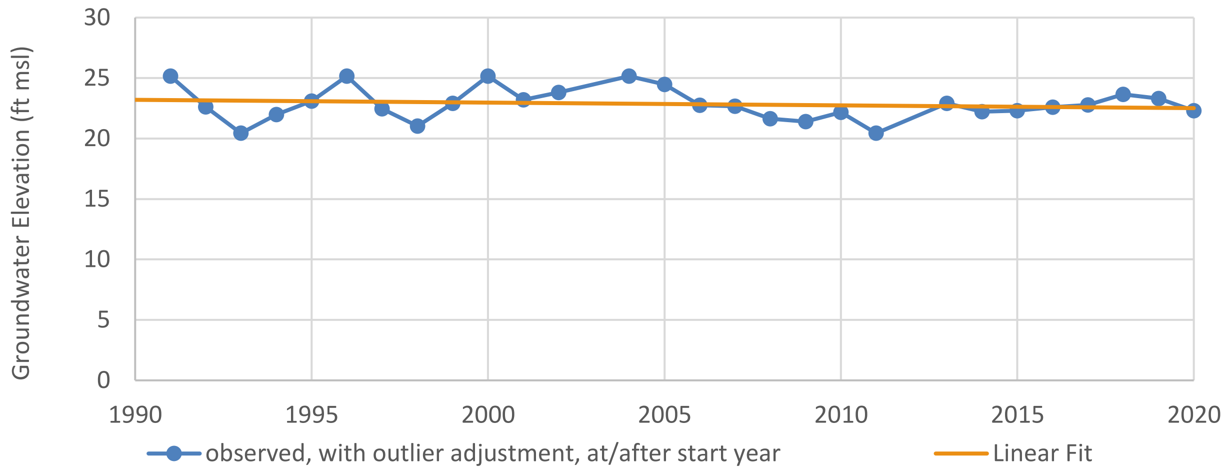


Figure 2-40. Groundwater Level Elevation in Pod 9 Well 2252110

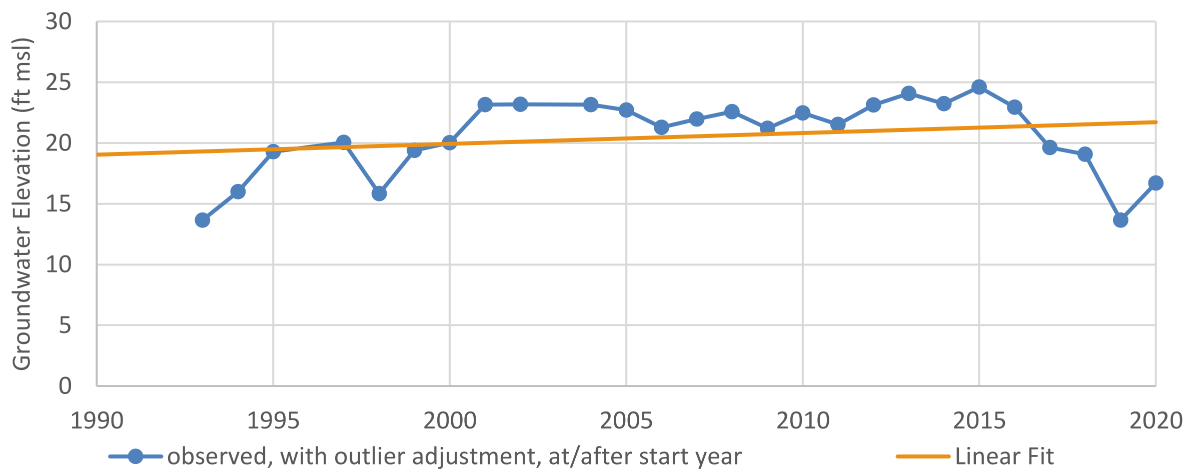


Figure 2-41. Groundwater Level Elevation in Pod 11 Well 2923606

2.3.4 Cross Timbers Aquifer

The Cross Timbers Aquifer is a minor aquifer in north-central Texas, located in the central area of the Brazos Basin. A buffer was used around the northeast edge of the Cross Timbers Aquifer to capture two wells that lie just outside of the Brazos Basin boundary for a more comprehensive interpolation at this edge (Figure 2-B-4). One well within the study area was removed from the analysis because it was substantially deeper than the other wells analyzed (state well number 2130802, well depth = 1,538 ft). The aquifer formations included in this analysis were: Brazos River Conglomerate Member, Belle Plains Formation, Cisco Group, Colony Creek Shale, Graham Formation, Lueders Limestone, Mineral Wells Formation, Palo Pinto Limestone, Strawn Group, Thrifty Formation, Wichita Formation or Group, and Wolf Mountain Shale. The Cross Timbers Aquifer shows no significant trend over time in the average groundwater elevation, as seen in Figure 2-42.

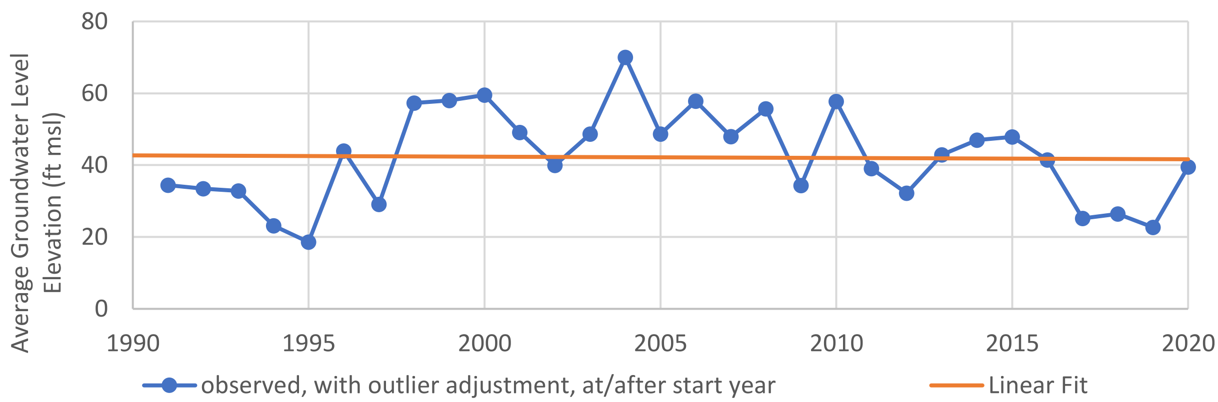


Figure 2-42 – Annual Average Groundwater Level Elevation in the Cross Timbers Aquifer

2.3.5 Trinity Aquifer

The Trinity Aquifer is a major aquifer extending through the central/northeastern part of Texas and covering the central area of the Brazos Basin. A 10-mile buffer was used around the aquifer outcrop, as delineated in TWDB shapefiles, to capture wells in the shallower portion of the aquifer (Figure 2-B-5). The study area was restricted to the mid-western and upper portion of the Trinity Aquifer within the Brazos Basin in order to represent water levels in the shallow portions of the aquifer that might more likely interact with surface water. Numerous water-bearing formations are classified as part of the Trinity Aquifer. This analysis focused on shallower formations of primarily sandy material and was limited to observations in or near the outcrop of the aquifer, where interactions with surface runoff and streamflow were more likely. Water level observations in the Trinity Aquifer were classified by screened formation and location, and two groups of observations were identified for trend analysis. The Paluxy Sand is the shallowest sandy formation in the Trinity Aquifer and is distinct from other sandy layers (Kelley et al., 2014). Wells screened in the Paluxy Sand were treated as one distinct group for water level interpolation and trend analysis. The second group comprises wells in the Twin Mountains, Travis Peak, Hensell, and Antlers Formations and was generally considered to represent the Twin Mountains Aquifer for this analysis. These wells were grouped together because the GAM Report for the Northern Trinity and Woodbine Aquifers (Kelley et al., 2014) indicated that these formations are hydraulically connected, and the various formation names partially reflect regional naming conventions rather than separate aquifers.

Water levels in the Paluxy Sand did not display a significant trend (Figure 2-43), but a strong increasing trend in groundwater level was identified in the Trinity Twin Mountains Aquifer (Figure 2-44), with a Kendall's tau value of 0.60 (p value ≤ 0.05).

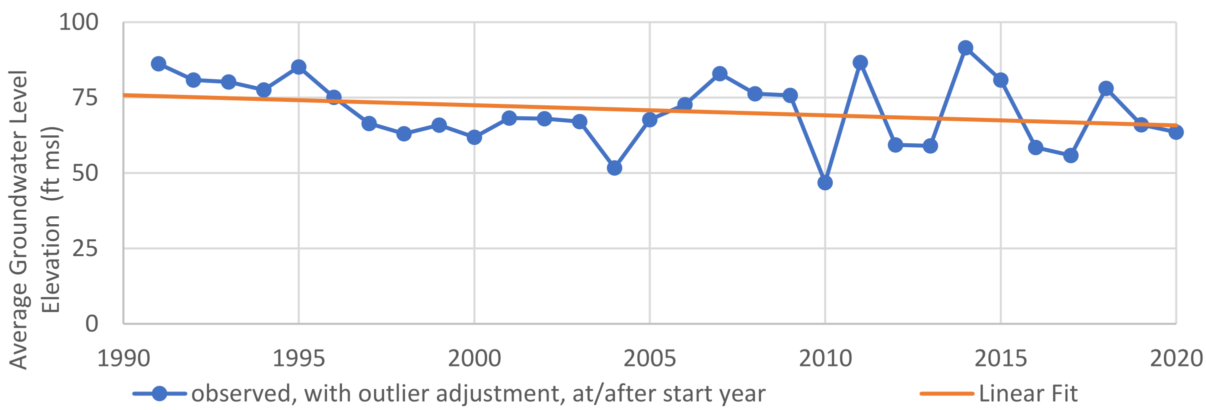


Figure 2-43 – Annual Average Groundwater Level Elevation in the Paluxy Sand Aquifer

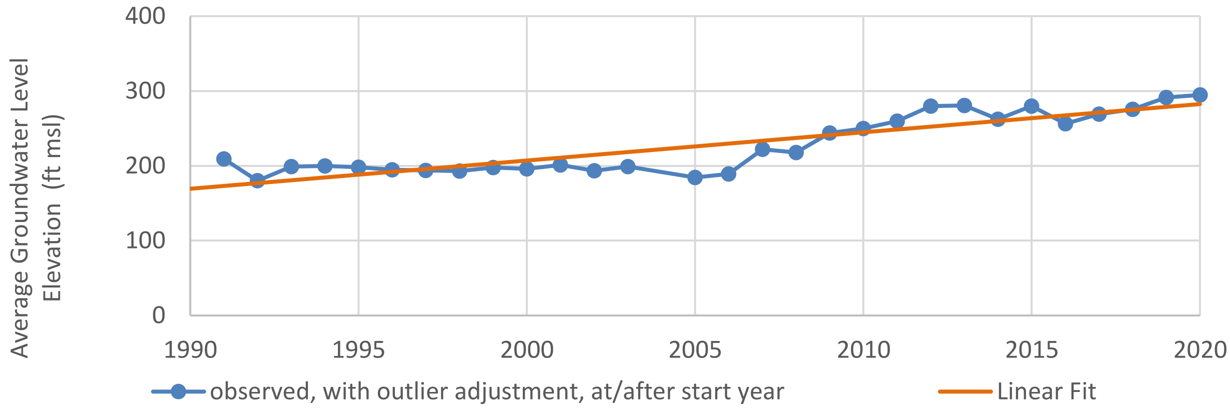


Figure 2-44 – Annual Average Groundwater Level Elevation in the Twin Mountains Aquifer

2.3.6 Brazos River Alluvium Aquifer

The Brazos River Alluvium Aquifer is a shallow aquifer that runs southeast throughout the bottom half of the Brazos Basin. Numerous studies have suggested a strong hydraulic connection between the alluvial aquifer and the Brazos River (Ewing et al. 2016; Turco et al. 2007). The study area for this aquifer was restricted to the portion of the aquifer north of Highway 290 because the southern section of the aquifer did not have sufficient data available (see Figure 2-B-6). Figure 2-45 shows the average groundwater level elevation within the study area in feet for each year since 1991. This graph shows some variation occurred in groundwater levels from year to year, but no significant annual groundwater elevation trend was identified in the Brazos Alluvium Aquifer.

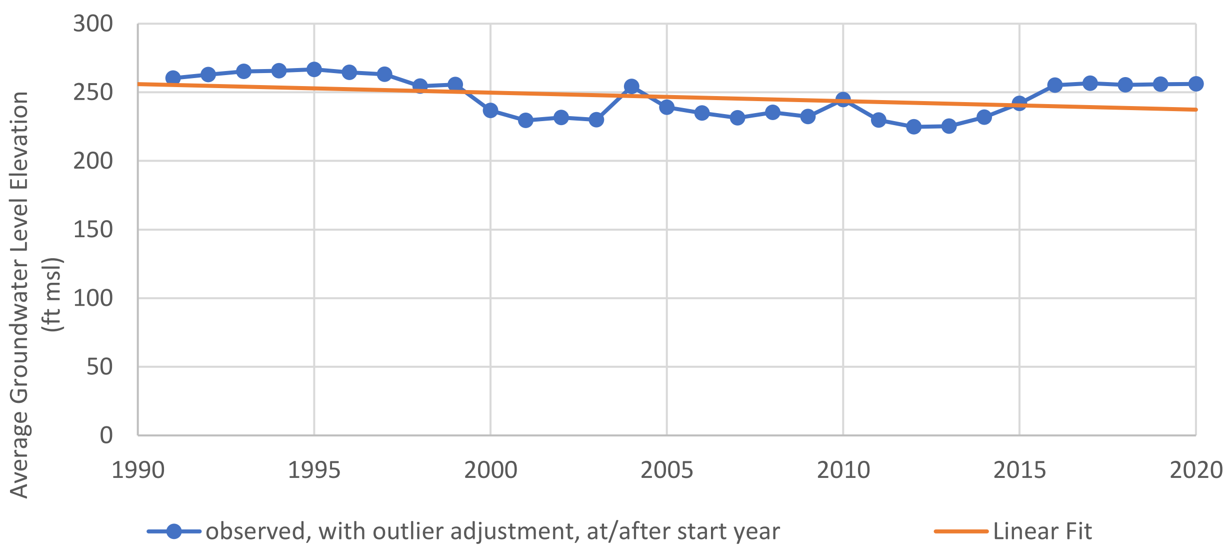


Figure 2-45 – Annual Average Groundwater Level Elevation in the Brazos River Alluvium Aquifer

2.3.7 Queen City Aquifer

The Queen City Aquifer is a minor aquifer spanning northeast through a narrow section of the Brazos Basin, underlying sections of the Sparta Aquifer. Wells outside the Brazos Basin were used in the spatial interpolation of water levels to interpolate water levels more accurately near the edge of the study area within the basin (Figure 2-B-7). The aquifer formation used in the Queen City Aquifer analysis was the Queen City Sand of Claiborne group. The Queen City Aquifer trend analysis did not identify a significant trend in the average annual groundwater elevation (Figure 2-46).

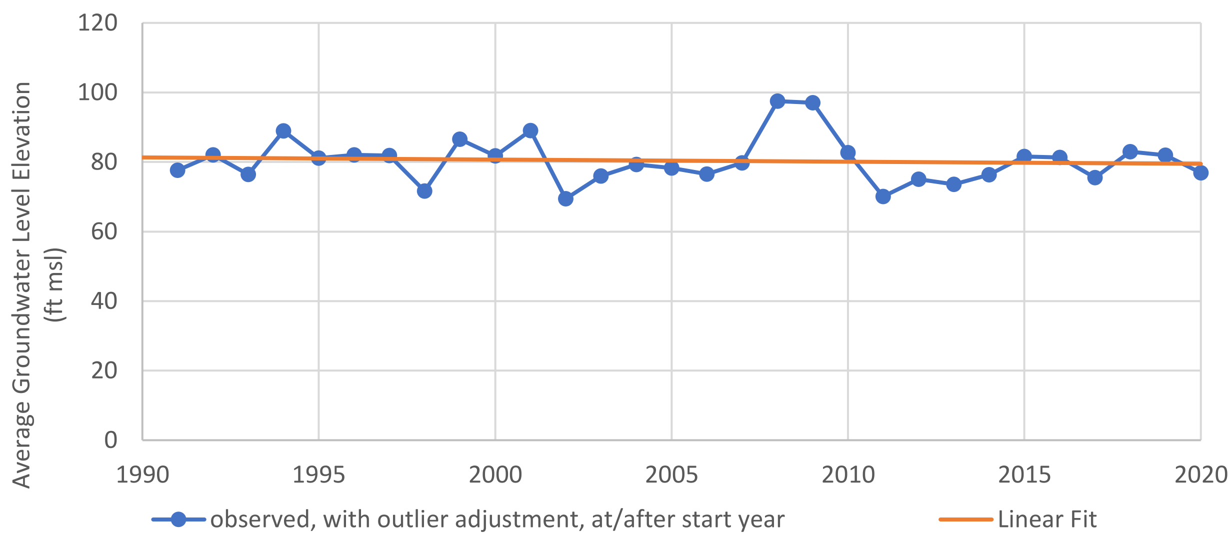


Figure 2-46 – Annual Average Groundwater Level Elevation in the Queen City Aquifer

2.3.8 Sparta Aquifer

The Sparta Aquifer is a minor aquifer located in the southeast end of the Brazos Basin, underlying the Yegua-Jackson Aquifer. Wells outside the Brazos Basin were used in the spatial interpolation of water levels to interpolate water levels more accurately near the edge of the study area within the basin (Figure 2-B-8). The Sparta Sand Aquifer formation was the only formation used in the analysis. Similar to the Yegua-Jackson Aquifer, the average annual groundwater elevation also showed a significant positive trend (p value ≤ 0.05), as seen in Figure 2-47, with a strong Kendall's tau value of 0.48.

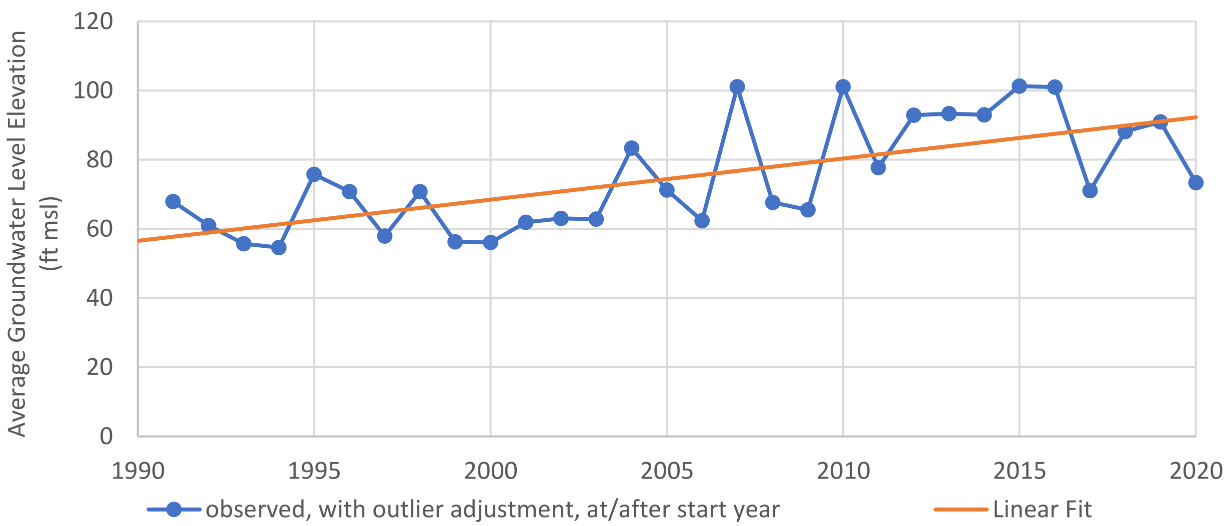


Figure 2-47 – Annual Average Groundwater Level Elevation in the Sparta Aquifer

2.3.9 Yegua-Jackson Aquifer

The Yegua-Jackson Aquifer is a minor aquifer that overlaps a portion of the southeast region of the Brazos Basin. Wells outside the Brazos Basin were used in the spatial interpolation of water levels to interpolate water levels more accurately near the edge of the study area within the basin (Figure 2-B-9). These were used to get a more accurate spatial interpolation for the outer edges of the Yegua-Jackson/Brazos Basin boundary. The two aquifer formations used in the analysis were the Jackson Group and Yegua formations. From the spatial interpolation and the Kendall's tau analysis, a significant positive trend of the average annual groundwater elevation was determined, with a strong Kendall's tau value of 0.65 (p-value ≤ 0.05), as seen in Figure 2-48.

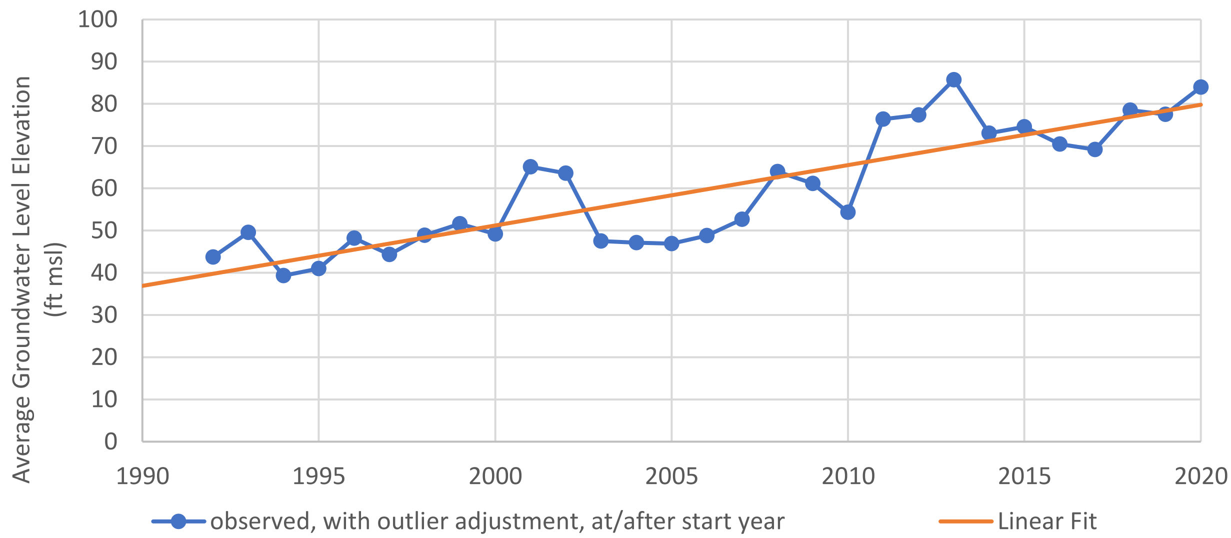


Figure 2-48 – Annual Average Groundwater Level Elevation in the Yegua-Jackson Aquifer

2.3.10 Summary of Groundwater Trends

We assessed eight aquifers that intersect the Brazos Basin for trends in groundwater levels in order to provide further insight into trends in streamflow in the Brazos Basin. We split two of the eight aquifers into separate aquifer groups to provide a more accurate analysis, and we did not assess the Blaine Aquifer at the aquifer-wide scale due to lack of data. We split the Trinity Aquifer into the Paluxy Sand and the Twin Mountains Aquifers. We analyzed two pods of the Seymour Aquifer, based on data availability. Of the nine aquifer study areas, five showed significant trends in groundwater levels, as depicted in Table 2-13. We also analyzed two well sites in the Blaine Aquifer (Table 2-14) and three well sites in the Seymour Aquifer (Table 2-15) individually.

We found significant increasing trends in groundwater levels in Pods 7 and 13 of the Seymour Aquifer, which are surficial aquifer formations in the drainage areas of control points in the Upper Brazos Basin. Of the other aquifers analyzed in the Upper Basin, Cross Timbers did not demonstrate significant trends in groundwater levels, nor did either well assessed in the Blaine Aquifer. Based on these findings, decreases in total flow in the Upper Basin do not appear to be the result of falling groundwater levels.

We also identified a significant increasing trend in water level in wells screened in formations within the Twin Mountains group of the Trinity Aquifer. These wells are located within the Middle and Lower Brazos Basin. Most control points demonstrated a small decreasing trend in runoff in this area, also showing no correlation to the groundwater level trend. In the Lower Basin, we identified significant increasing trends in the Sparta Aquifer and the Yegua-Jackson Aquifer. Control points with drainage areas overlying the outcrop of the Yegua-Jackson Aquifer generally had no significant trend in incremental runoff. Although two control points (MYDB60 and NABR67) with drainage areas overlapping the Sparta Aquifer outcrop had slight increasing trends in incremental runoff, it is unlikely that this increase could be attributed to changing groundwater levels, as the outcrop of the aquifer is relatively narrow and only interacts with a small portion of these incremental watersheds.

Table 2-13 – Summary of Trends in Average Annual Groundwater Levels

Aquifer	Kendall's Tau	P Value	Number of Water Level Observations Included in Analysis*
Seymour Pod 7	**0.72**	**0.000**	602
Seymour Pod 13	**0.13**	**0.017**	202
Cross Timbers	-0.09	0.498	903
Paluxy (Trinity)	-0.21	0.108	822
Twin Mountains (Trinity)	**0.60**	**0.000**	1,500
Brazos River Alluvium	-0.24	0.064	516
Queen City	-0.07	0.592	2,667
Sparta	**0.48**	**0.000**	726
Yegua-Jackson	**0.65**	**0.000**	510

* Note: The number of water level observations refers to the number of observations and not the number of wells, which have multiple observations each, over time.

Table 2-14 – Summary of Trends in Wells in the Blaine Aquifer

State Well Number	Kendall's Tau	P Value	County
2238301	0.24	0.144	King
2915501	0.14	1.050	Fisher

Table 2-15 – Summary of Trends in Wells in the Seymour Aquifer

State Well Number	Kendall's Tau	P Value	County	Pod Number
2252107	0.00	1.000	Kent	9
2252110	-0.07	0.607	Kent	9
2923606	0.18	0.201	Jones	11

2.4 IMPACTS OF OBSERVED TRENDS ON SURFACE WATER SUPPLY SOURCES IN REGIONS G AND H

Another objective of Task 2, in addition to assessing trends in the Brazos Basin, is to evaluate the potential impacts of those trends on the reliability of surface water supplies in the Brazos G and Region H Regional Water Planning Areas, specifically in 2050, 2060, and 2070. Inputs to the Brazos G WAM were replaced with the trend-adjusted naturalized flow and net reservoir evaporation data.

2.4.1 Surface Water Supply Sources in Regional Water Planning Areas G and H

As discussed in **Chapter 1**, surface water supplies from the Brazos Basin comprise the majority of water supply in Region G and a substantial portion of supply (>13% of total supplies) in Region H. In Region G, 92% of surface water availability comes from reservoirs. Of these reservoirs, 38 have an authorized diversion amount greater than 1,000 acre-feet per year; these are listed in Table 2-E-1 of **Appendix 2-E**. Both Region G and Region H supplies include a large number of run-of-river rights, 36 of which have an authorized annual diversion of more than 1,000 acre-feet per year (Table 2-E-2 in **Appendix 2-E**).

2.4.2 Methodology to Assess Surface Water Supply Availability in the 2021 Regional Water Plans

We used the Brazos G WAM to determine the reliability of surface water supply sources in the 2021 Brazos G and Region H Regional Water Plans (RWPs) under current (2020) and future (2070) conditions. The Brazos G WAM includes the following modifications from the TCEQ Brazos River Basin WAM used for permitting evaluations (Run 3).

- Utilization of naturalized flow and net evaporation data developed by the Brazos River Authority (BRA) for its adopted management plan, which includes a period of record of 1940 through2015.
- Inclusion of a certain level of current and future return flows by entities located throughout the basin. These return flows are based on historical monthly return flow information as well as projected future rates assuming an aggressive plan for future reuse. More information on how the projected return flows are derived is provided in Section 2.4.3 below and in the Brazos G Regional Water Plan.
- Inclusion of BRA current contractual demand amounts and locations as provided by the BRA consistent with the BRA adopted management plan.

- Incorporation of reservoir system operations rules provided by the BRA to more accurately reflect current operations of BRA reservoirs to meet contract demands.
- The Brazos G WAM uses Year 2020, or the most up to date reservoir survey available, and estimated Year 2070 area-capacity information for all reservoirs authorized for greater than 5,000 acre-feet (ac-ft) storage capacity.
- The Brazos G WAM includes five subordination agreements:
  - Possum Kingdom Reservoir is subordinated to Lake Alan Henry,
  - Possum Kingdom Reservoir is subordinated to the Fort Phantom Hill Reservoir Scalping water right located on the Clear Fork of the Brazos River,
  - Possum Kingdom Reservoir is subordinated to Hubbard Creek Reservoir,
  - Possum Kingdom Reservoir is subordinated to the City of Stamford's California Creek pump-back operation into Lake Stamford, and
  - Lake Waco is subordinated to the City of Clifton's 1996 priority date water right.
- The Brazos G WAM excludes the following permitted, but not constructed, reservoirs:
  - Allens Creek Reservoir
  - Post Reservoir
  - Turkey Peak Reservoir (Lake Palo Pinto expansion)

As part of the 2021 Brazos G RWP, HDR developed an alternate version of the Brazos G WAM without the BRA System Operations permit to determine the stand-alone yields of the BRA's reservoirs. The alternate version of the Brazos G WAM was also applied in this study to evaluate the stand-alone yields of the BRA reservoirs.

2.4.3 Detailed Description of Methodology to Assess Changes to Surface Water Supply Availability

HDR used the following procedures to assess the potential impacts on surface water supplies in Brazos G and Region H for 2050, 2060, and 2070 conditions considering the observed trends.

- 2070 conditions with trends were evaluated using the 2070 Brazos G WAM and the 2070 trends adjusted net evaporation and naturalized flow datasets provided by FNI. No modifications were made to the WAM input file (.DAT file).

- The following modifications were made to the 2020 Brazos G WAM to create a 2050 version for use in assessing surface water supplies considering observed trends under 2050 conditions.

    - Return flows included in the Brazos G WAM were linearly interpolated from 2020 and 2070 levels included in the existing 2020 and 2070 Brazos G WAMs to estimate 2050 return flow levels.

    - A reservoir sediment distribution analysis was completed to estimate 2050 storage-surface area relationships for the reservoirs included in Table 2-16. The analysis applied the most recent Texas Water Development Board (TWDB) reservoir surveys and published sedimentation rates. Storage Volume (SV Records) and Surface Area (SA Records) for the selected reservoirs in the 2050 Brazos G WAM were updated with results of the sediment distribution analysis.

Table 2-16 – Sedimentation Rates of Selected Reservoirs

Reservoir Name	Date of TWDB Survey	Sediment Rate (ac-ft/yr)
Aquilla	2014	209
Granbury	2015	278
Limestone	2012	481
Somerville	2012	379
Possum Kingdom Reservoir	2016	298
Whitney	2005	910

- Conservation storage capacities for all other reservoirs not included in the sediment distribution analysis were estimated for 2050 sediment conditions by linear interpolation from conservation storage capacities included in the 2020 and 2070 Brazos G WAMs. Reservoir storages (WS Records) were updated with the estimated 2050 authorized conservation capacities. The 2020 SV and SA Records were included in the 2050 versions of the Brazos G WAM.

- Reliabilities of surface water supply sources for 2060 conditions with trend adjustments were estimated by linearly interpolating reservoir firm yields and run-of-river minimum annual diversions determined for 2050 and 2070. In the 2050 and 2070 versions of the Brazos G WAMs, the minimum annual diversions were defined as the smallest volume of water diverted by a run-of-river water right during a single calendar year throughout the WAM period of record.

- Reliabilities of surface water supply sources for 2050 and 2060 conditions without trend adjustments were interpolated from 2020 and 2070 results included in the Brazos G and Region H RWPs.

- Reservoir firm yields were computed using the developed 2050 Brazos G WAM and the existing 2070 Brazos G WAM for reservoirs with authorized diversions greater than 1,000 acre-feet per year (ac-ft/yr). If a reservoir or reservoir system has a firm yield greater than its authorized diversion, a hypothetical junior water right with a uniform use pattern was added to calculate the additional firm yield in excess of the authorized diversion amount[2].

- The availability of supplies from run-of-river water rights was assumed to be the minimum annual diversion throughout the Brazos G WAM period of record. This approach is consistent with the approach used in the 2021 Brazos G and Region H RWP assessments.

2.4.4 Changes to Reservoir Yield Based on Observed Trends

Appendix 2-E includes a detailed summary in Table 2-E-1 of the calculated firm yields for all reservoirs located in the Brazos G planning area with an authorized diversion amount greater than 1,000 ac-ft/year. The table compares the firm yields calculated considering the trend adjustments to those calculated in the 2021 Brazos G RWP with no trend adjustments. No existing reservoirs were included in the 2021 Region H RWP in the Brazos Basin.

Review of the reservoir yield comparisons for scenarios with and without trend adjustments to naturalized flow and net evaporation shows the following.

[2] Reservoir yields evaluated in the 2021 Brazos G water plan were capped at the authorized diversion amount.

- Of the BRA reservoirs, Possum Kingdom Reservoir, Lake Proctor, and Lake Limestone have reductions of more than 10 percent in firm yield by both 2050 and 2070 when trends are considered. All other BRA reservoirs show increases or decreases in future firm yield of less than 10 percent when trends are considered.

- The incremental yield of the BRA System Operations Permit increases by 19 percent of reliable yield in the 2070 scenario when trends are considered. This increase is likely a result of increased availability of run-of-river flows in the middle and lower basin from increasing trends in naturalized flow in these regions of the basin. The incremental yield refers to the additional yield available from the reservoirs as a result of operating as a system and is calculated as the difference between the sum of firm yields of all reservoirs in the system when modeled with system operations versus without. **Appendix 2-G** includes the Brazos G WAM .DAT input files for scenarios with and without system operations.

- Reservoirs located in the upper basin (including Possum Kingdom and non-BRA reservoirs) all show decreases in firm yield. The combined firm yield of these reservoirs decreases by 31 percent in 2070 when trends are considered. These reductions in yield are expected as the trend adjustments in the upper basin have the greatest reduction in streamflows and increases in net evaporation.

- Reservoirs located in the middle basin (downstream of Possum Kingdom Reservoir, including BRA and non-BRA reservoirs) show varied impacts on firm yield from the trend adjustments with some reservoirs increasing and some decreasing. The combined firm yield of these reservoirs decreases by less than 1 percent in 2070 when trends are considered.

- Several middle basin reservoirs show an increase in yield with trends in 2050 compared to 2020 followed by a reduction in yield in 2070 with trends, (e.g., Stillhouse Hollow). This trend in firm yield is present in locations where flows and net evaporation are increasing. In 2050, the increase in water availability from increasing trends in streamflow is greater than the increased storage loss from evaporation. By 2070, the increasing losses in evaporation have overcome the yield benefits from increased streamflow, resulting in a slight reduction in yield from that in 2050.

- Additionally, review of model output indicates some reservoirs (e.g., Lake Granbury) in the middle basin benefit from the increase in streamflow in the lower basin through a reduction in priority calls to pass water at upstream locations for downstream senior water rights.

- Squaw Creek Reservoir shows an increase in yield of over 100 percent even though observed trends in the Paluxy River watershed and on the Brazos River below Granbury are decreasing. Review of WAM naturalized and available streamflows calculated at the Squaw Creek Reservoir control point show substantial increases in naturalized and available streamflow greater than 300 percent during the critical drought period occurring in the 1950s when trends are considered. These increases are assumed to be an artifact of the model calculations that use upstream control points (Brazos River near Glen Rose, Paluxy River at Glen Rose, and Nolan River at Blum) with decreasing trends in flow and a downstream control point (Brazos River at Aquilla) with an increasing trend in flow. The Brazos G WAM model uses the incremental flow originating between the control points to calculate naturalized flow at the Squaw Creek Reservoir control point. It is believed that the decreasing trends in the upstream control points coupled with the increasing trends in the downstream control point causes overestimation of the naturalized streamflow originating in the incremental watershed, resulting in overestimation of naturalized and available streamflow at the Squaw Creek Reservoir. HDR performed supplemental model simulations using only naturalized flows at the Paluxy River at Glen Rose control point to compute naturalized flow at the Squaw Creek Reservoir control point by adjusting for differences in contributing drainage areas. Results of the supplemental model simulations show a 34 percent reduction of firm yield in 2070 when trends are considered and suggest that the existing methods for calculating naturalized flow at Squaw Creek Reservoir are not appropriate when considering the trend adjustments.

- Pat Cleburne Reservoir shows an increase in firm yield from the trend adjustments. An increasing trend in net evaporation was identified in Climate Division 4103 and was applied to the reservoir. The control point used to calculate natural and available streamflow at the reservoir is NRBL32 (Nolan River at Blum). The only significant trends identified in the incremental naturalized flow at NRBL32 watershed were increasing flows in dry winters and decreasing flows in average winters. No other primary control points are upstream of NRBL32, so the adjustments to naturalized flows were based only on these trends in the runoff from the NRBL32 drainage area. The increasing flow trend in dry winters caused an increase in streamflow during the critical drought period. The decreases applied to flow in average winters were greater than the increases applied to dry winters, so the average winter trend caused the total change in streamflow (over the full model period) to decrease by approximately 1%, as shown in Figure 2-2. As a result, naturalized flows calculated at the reservoir control point show decreasing naturalized flow during some periods, but an increase in naturalized flow during the critical drought period occurring in the 1950s, resulting in an increase in modeled firm yield.

It may be noted that several of the control points for which net evaporation data are included in the Brazos G WAM, for example Lake Granbury (CP416131), show a shift in magnitude in the mid-1950s that is likely the result of the change from the "old" TWDB evaporation data to the "new" data beginning in 1954. The trend analysis that was used to determine adjustments to the net evaporation data in the Brazos G WAM was not affected by the shift in net evaporation data in the mid-1950s because the assessment was based on trends in NOAA's average air temperature (T) and precipitation (P) data at the climate division-level, rather than the TWDB gross evaporation (E) at the one-degree quadrangle level. Relationships between E and T were determined from 1954 to 2019 based on the "new" E data from the TWDB (scaled up from the quadrangle to the climate division level) to calculate an adjustment factor for E. However, the net evaporation data that was ultimately adjusted was obtained from the Brazos G WAM, so the shift from the "old" to "new" TWDB data in the 1950's is still reflected in the net evaporation time series.

2.4.5 Changes to Run-of-River Supply Availability Based on Observed Trends

Appendix 2-E includes a detailed summary in Table 2-E-2 of the minimum annual diversions of all run-of-river water rights in the Brazos G and Region H water planning areas with authorized diversions greater than 1,000 ac-ft/yr. The table includes water right identification numbers, current owners, stream location of diversions, and comparisons to the values included in the 2021 Brazos G and Region H water plans with no trend adjustments.

Review of the run-of-river reliability comparisons for scenarios with and without trend adjustments of naturalized flow and net evaporation shows that:

- All upper basin water rights have a minimum annual diversion of zero with and without trends. However, average annual diversion amounts show significant reductions which range from 40 to 70 percent when trends are considered for these water rights located in the upper basin.

- Water rights in the middle basin located on the Brazos River all show increasing minimum annual diversions because of increasing trends in streamflows. Several water rights which are located on tributary rivers to the Brazos show decreases in minimum annual diversion.

- All lower basin water rights included in the Region H planning area show increased minimum annual diversions unless already capped at the authorized diversion amount.

2.5 REFERENCES

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APPENDIX 2-A: IMPACT OF UPSTREAM TRENDS ON DOWNSTREAM FLOW

As discussed in ***Section 2.1***, trends in incremental flows in the Upper Brazos Basin were primarily decreasing, while trends in the Middle and Lower Basin varied. Once total adjusted naturalized flows were reconstructed from upstream flows and incremental runoff at each control point, total flows on the main stem of the Brazos River in the Lower Basin were typically increasing. This appendix presents a detailed analysis of the adjusted naturalized flow at control point BRAQ33 (Brazos River near Aquilla), which is the most upstream control point on the main stem of the river at which total adjusted flows increased when all flows at all directly upstream primary control points were decreased by the trend adjustment.

BRAQ33 is directly downstream of three primary control points: PAGR31 and NRBL32 on tributaries and BRGR30 on the main stem (Figure 2-A-1). The incremental drainage area of BRAQ33 downstream of these three points has an area of 733 square miles, which includes Lake Whitney. Equation 2-A-1 describes the contribution of upstream flows and runoff; the coefficients shown are delivery factors (i.e., $1 - channel\ loss\ factor$).

$$NAT_{BRAQ33} = Q_{BRAQ33} + 0.97801NAT_{BRGR30} + 0.9777NAT_{PAGR31} + 0.98776NAT_{NRBL32}$$

Equation 2-A-1

NAT = total naturalized flow $\qquad$ Q = incremental naturalized flow

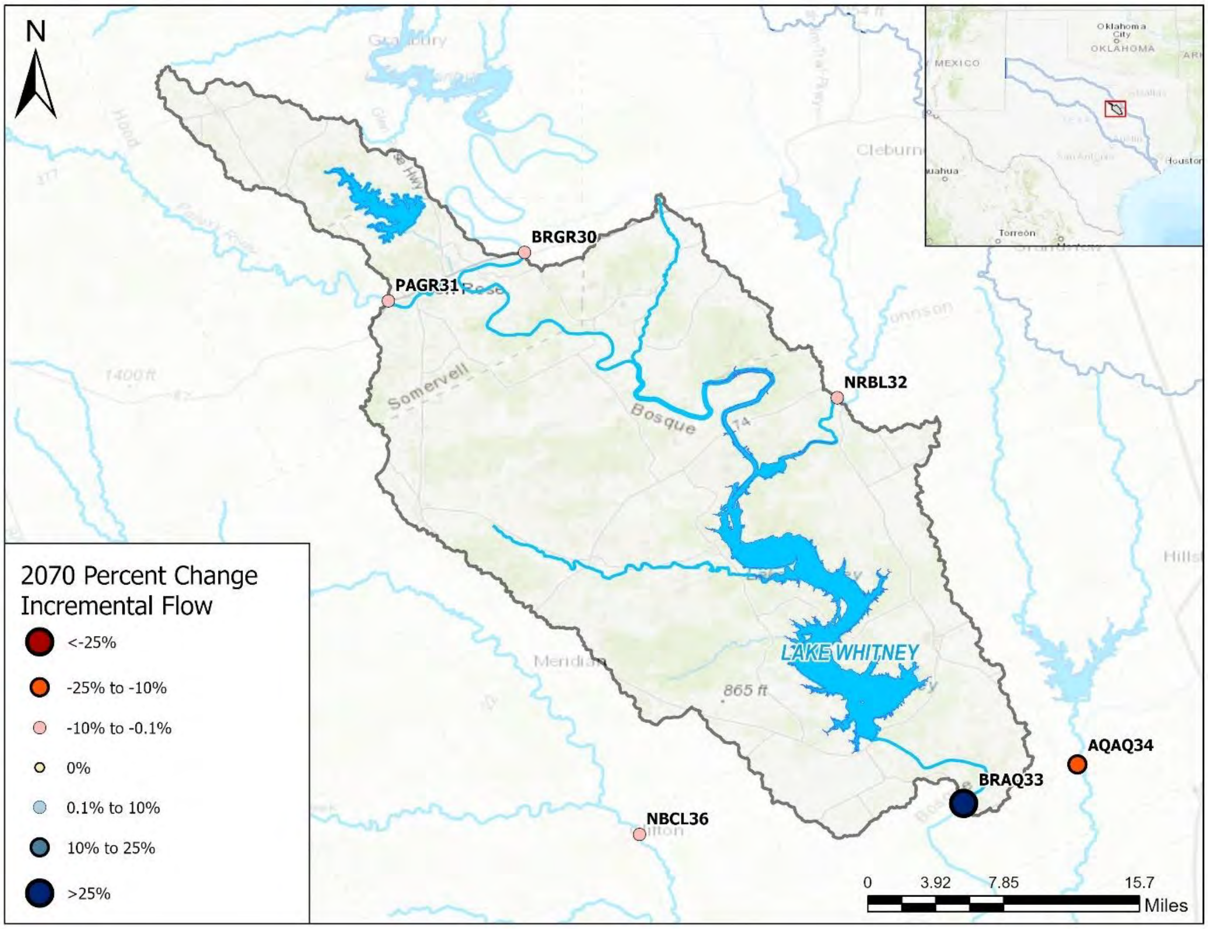


Figure 2-A-1. Incremental Drainage Area of Control Point BRAQ33 and Adjustments to Incremental Flow

After adjusting for identified trends in incremental naturalized flows, the sum of incremental flow at BRAQ33 over the 76-year model period increased by +118%. The adjustment was based on an **annual** trend. Factors contributing to this increase included:

1. **Determination of Start Year:** The applied methodology selected a start year of 1948 based on trends in annual incremental flow at BRAQ33.

    a. As a result, flows were increased based on the trend identified from 1948 through 2015, which impacted all downstream points. If start year had been left at the default year of 1940 (beginning of our period of record), no significant annual trend would have been found, and flows would instead have been adjusted based on an increasing summer trend and a decreasing average winter trend.

   b. This example demonstrates the sensitivity of the trend analysis and flow adjustment methodology to the selection of the period of analysis. **This sensitivity should be considered as an important limitation in the application of historical trends to predict potential future changes in hydrology.**

2. **Avoidance of Negative Adjusted Incremental Flows:** The approach to adjusting negative incremental flows likely over-adjusted incremental flow, increasing flows in negative-incremental-flow months by too much.

   a. 16.3% of months had incremental flow at BRAQ33 < 0 before adjustment. All of these were adjusted to non-negative values. Some were adjusted by a greater amount than ΔQ to bring the adjusted flow up to at least zero.

3. **Uniform Monthly Distribution of Annual Flow Adjustment:** The same adjustment value (ΔQ) was applied to every month within a year (or season if applicable). As a result, very dry months, even those with negative unadjusted incremental runoff, are increased by as much as wet months in the same year.

4. **Lake Whitney:** Within the WAM hydrology, there are some large negative incremental flows downstream of Lake Whitney that occur during periods of flood control releases, which is related to #2 above.

Other factors that do not appear to have contributed to the increasing trend at this control point include:

1. **Source Data for Naturalized Flow:** The source data used in developing naturalized flow at BRAQ33 did not contain fill data, so the observed trend in incremental flow is not as likely to be a result of erroneous source data as if gap-filled data had been used to develop flows. The source data for naturalized flows at the tributaries (PAGR31 and NRBL32) include some fill data, which have a small impact on the calculated incremental flow at BRAQ33 and thus do not affect the observed trend much.

2. **Trends in Precipitation:** No significant trends were identified in the precipitation volume falling on the incremental drainage area. Trends in Q/P (ratio of incremental runoff to precipitation on incremental drainage area) were similar to trends in Q, as expected.

3. **Groundwater-Surface Water Interactions:** The incremental drainage area does not overlie any aquifers except the downdip of the Trinity Aquifer. This formation is relatively deep, so increases in incremental runoff are not likely to be related to any changes in groundwater levels.

Flow adjustments based on observed trends altered the proportional contribution of each component of flow at BRAQ33 by decreasing flows from all upstream reaches and increasing runoff from the incremental watershed above BRAQ33. The percent contribution of each watershed (PAGR31, BRGR30, NRBL32, and the incremental drainage area of BRAQ33) to total flow at BRAQ33 is illustrated in Figure 2-A-2, which shows flow contributions in the original WAM, and Figure 2-A-3, which shows percent contributions after trend adjustment.

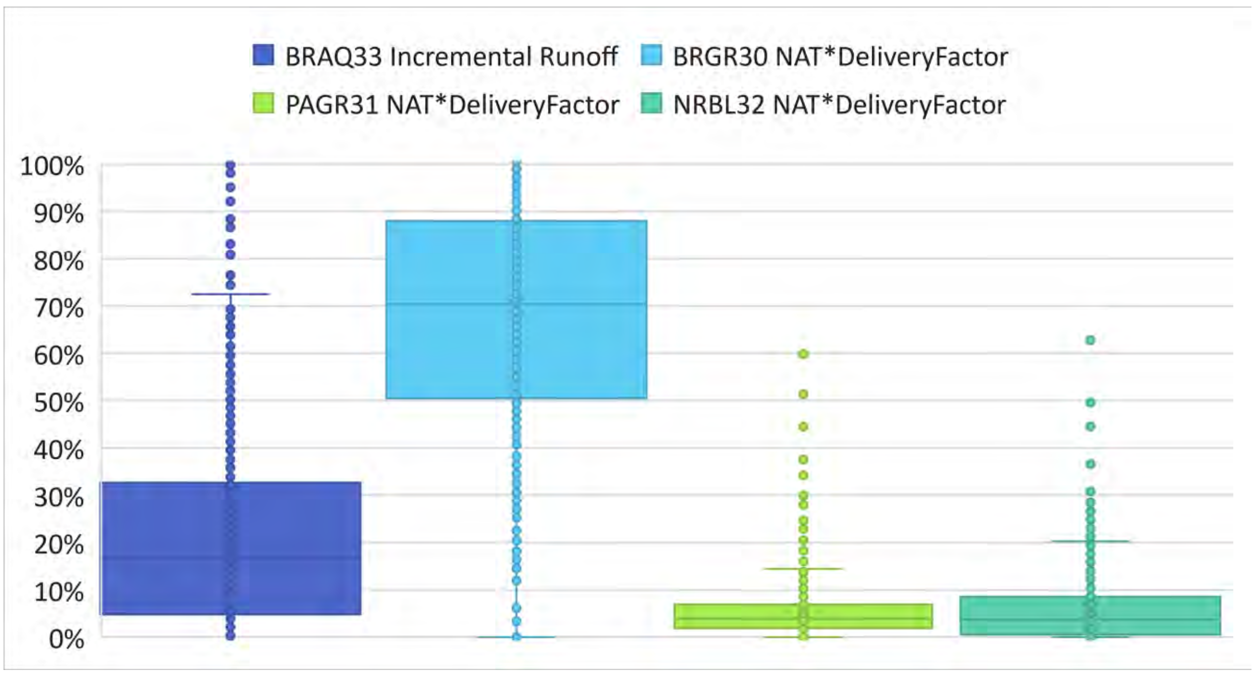


Figure 2-A-2. Percent Contribution from Drainage Areas to Original Total Naturalized Flow at BRAQ33

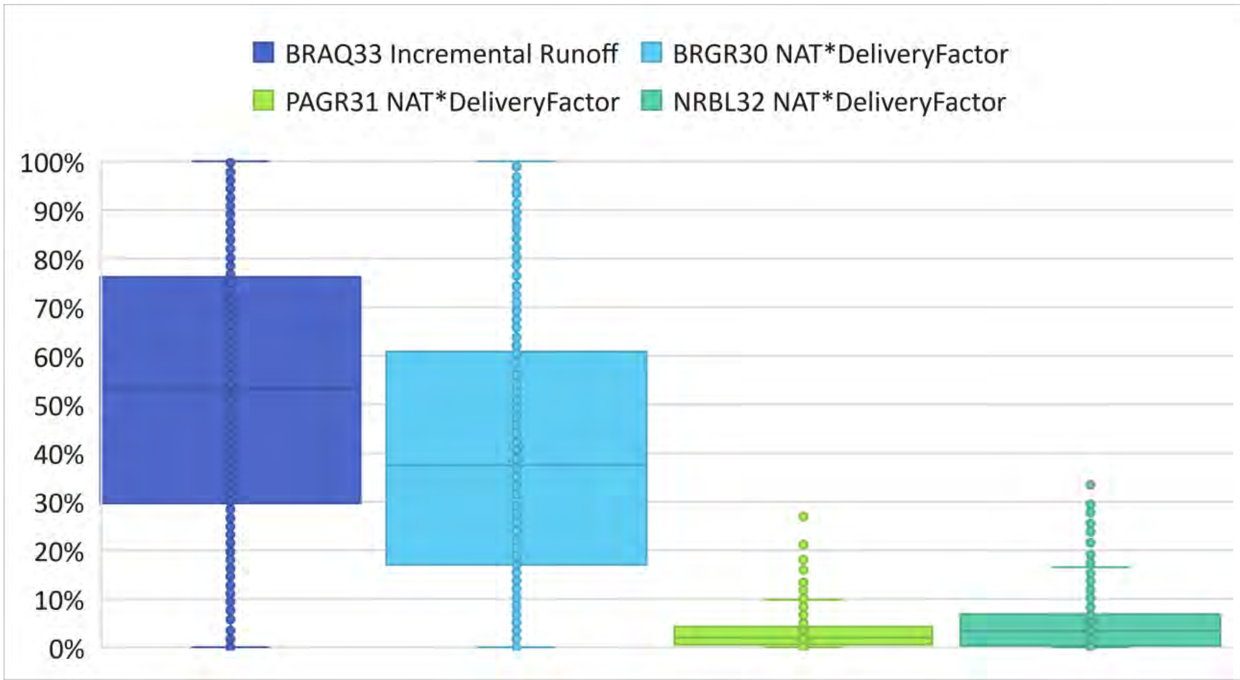


Figure 2-A-3. Percent Contribution from Drainage Areas to Adjusted Total Naturalized Flow at BRAQ33

The increase in flow from the incremental drainage area was large enough to overcome the loss of upstream flows, resulting in an overall increase in naturalized flow at BRAQ33. However, Figure 2-A-4 shows that the increase in incremental flow (ΔQ_{BRAQ33}) still only accounts for a small portion of the total flow at this control point. In other words, the increase in flow caused by the trend adjustment methodology did not dramatically alter the flow regime at this location on the main stem of the Brazos River.

Increases at downstream points BRWA41, BRHB42, and BRBR59 can mostly be attributed to the increasing trend in the incremental runoff at BRAQ33, although seasonal increases in flows in the Little River Subbasin also contribute to some downstream increases at BRBR59 (Table 2-8).

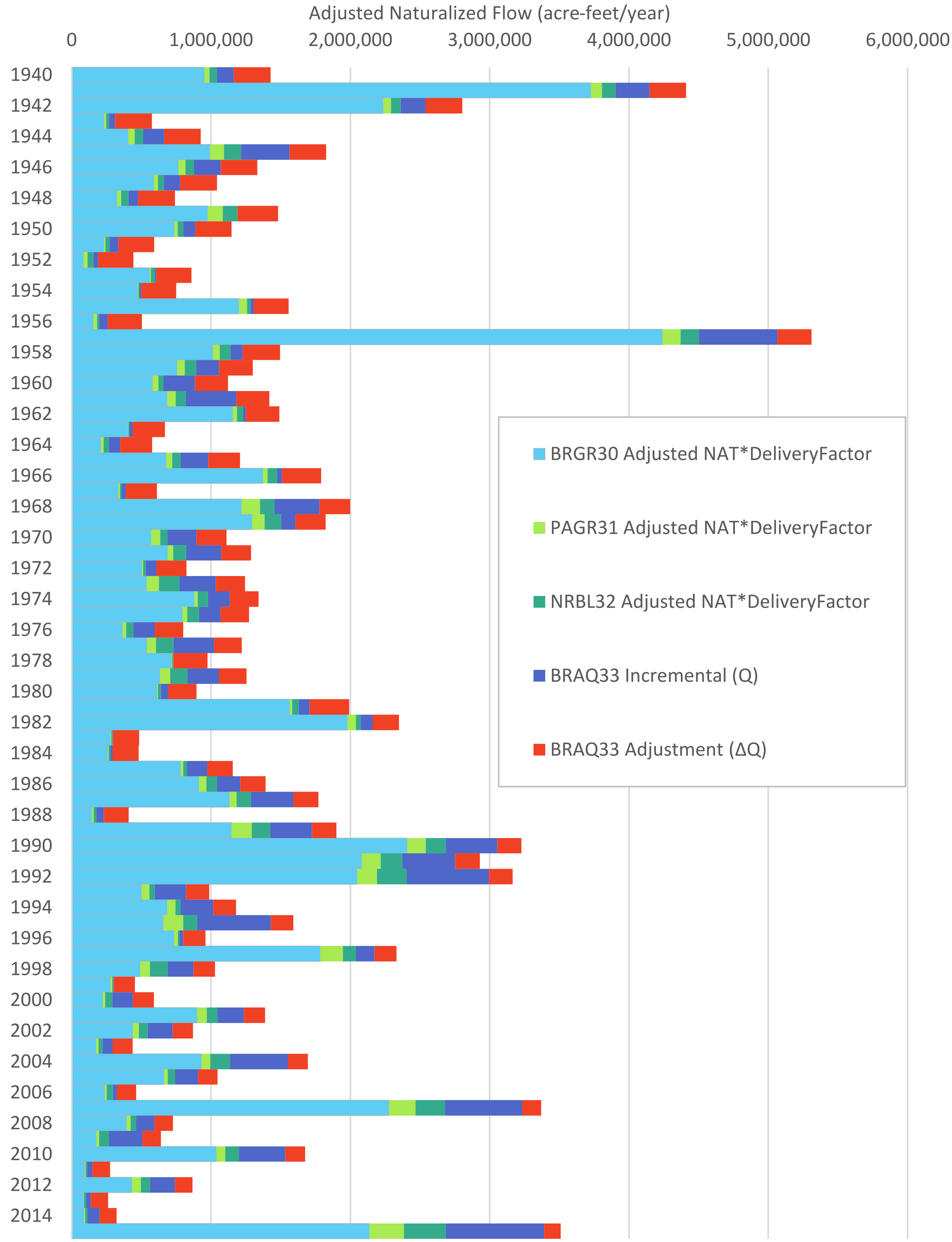


Figure 2-A-4 – Annual Adjusted Naturalized Flow at BRAQ33 by Flow Component

APPENDIX 2-B: GROUNDWATER TREND ANALYSIS: DATA AVAILABILITY AND STUDY AREAS

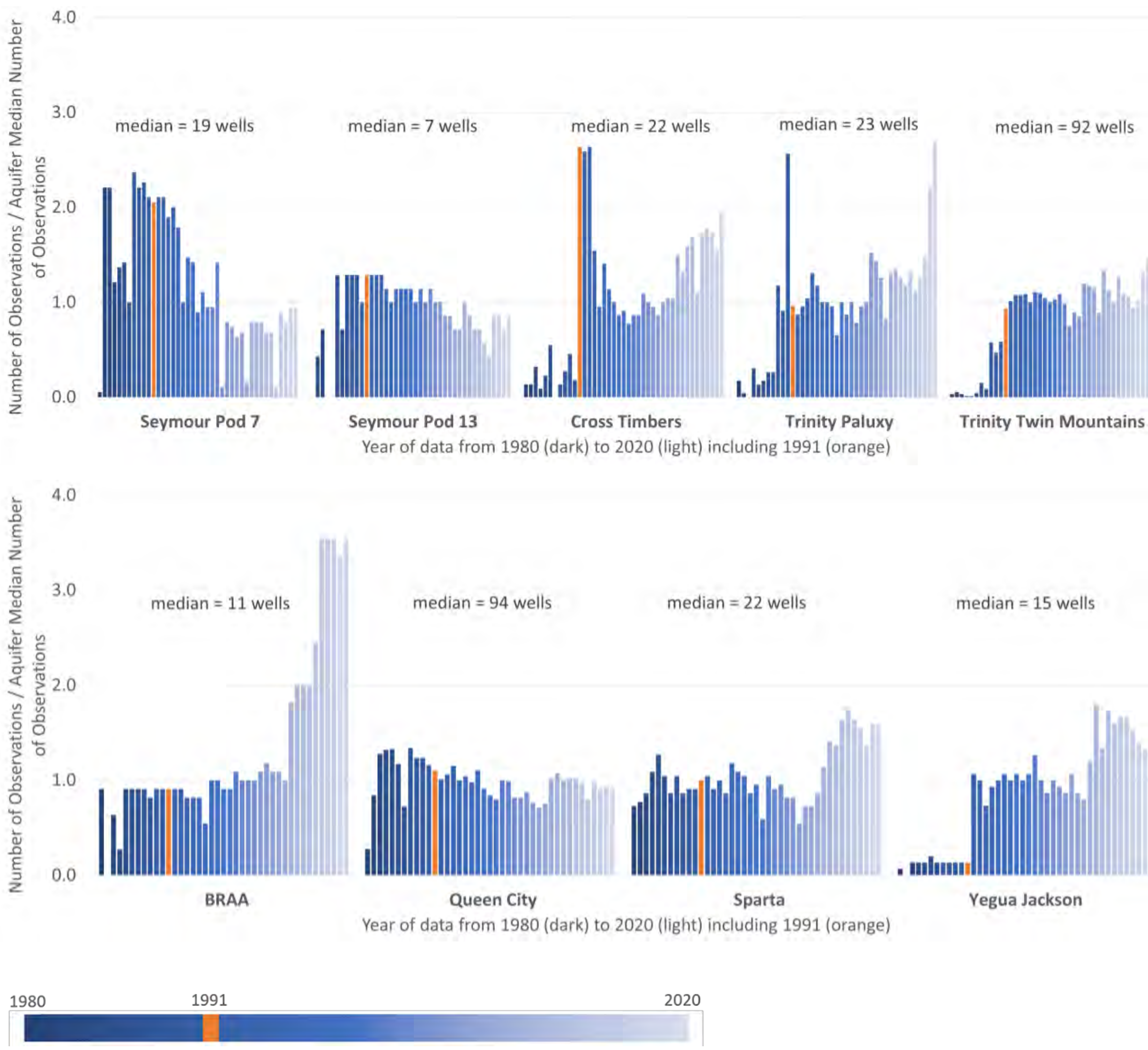


Figure 2-B-1. Number of Wells with Water Level Observations per Year

(1980-2020 within downloaded area, normalized to median to facilitate comparison between aquifers)

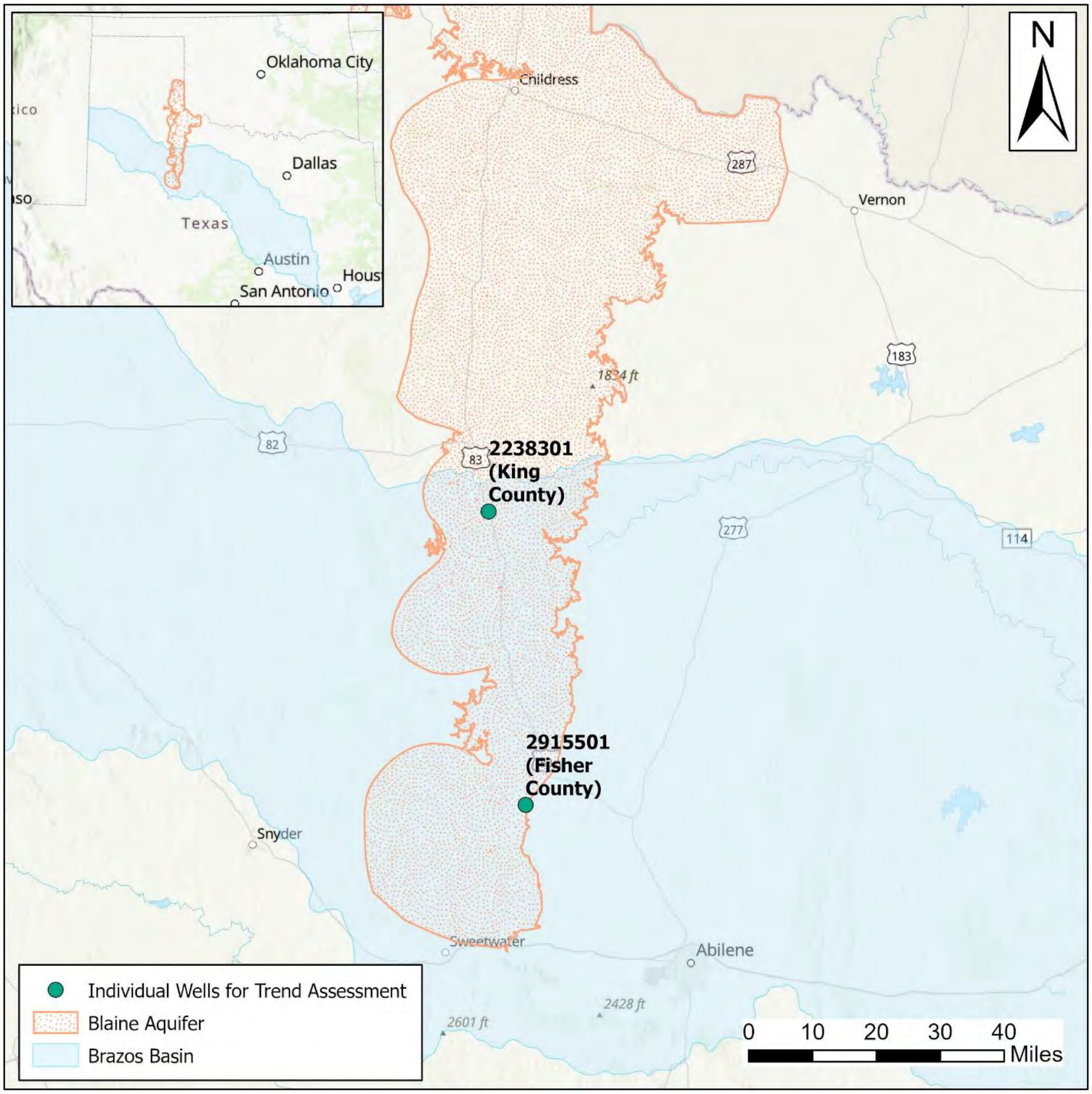


Figure 2-B-2. Wells with Water Level Data in the Blaine Aquifer

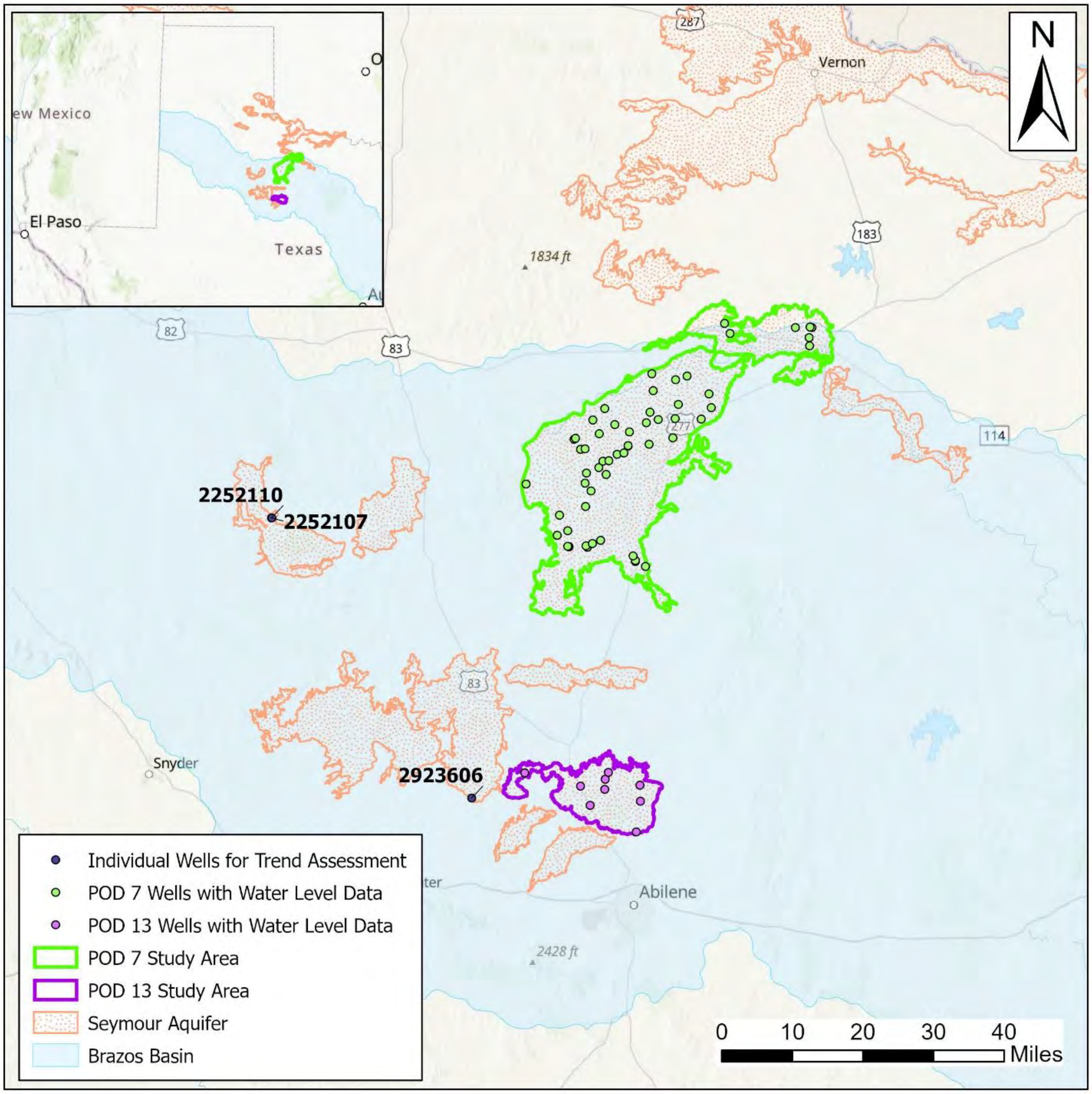


Figure 2-B-3. Wells with Water Level Data in the Seymour Aquifer

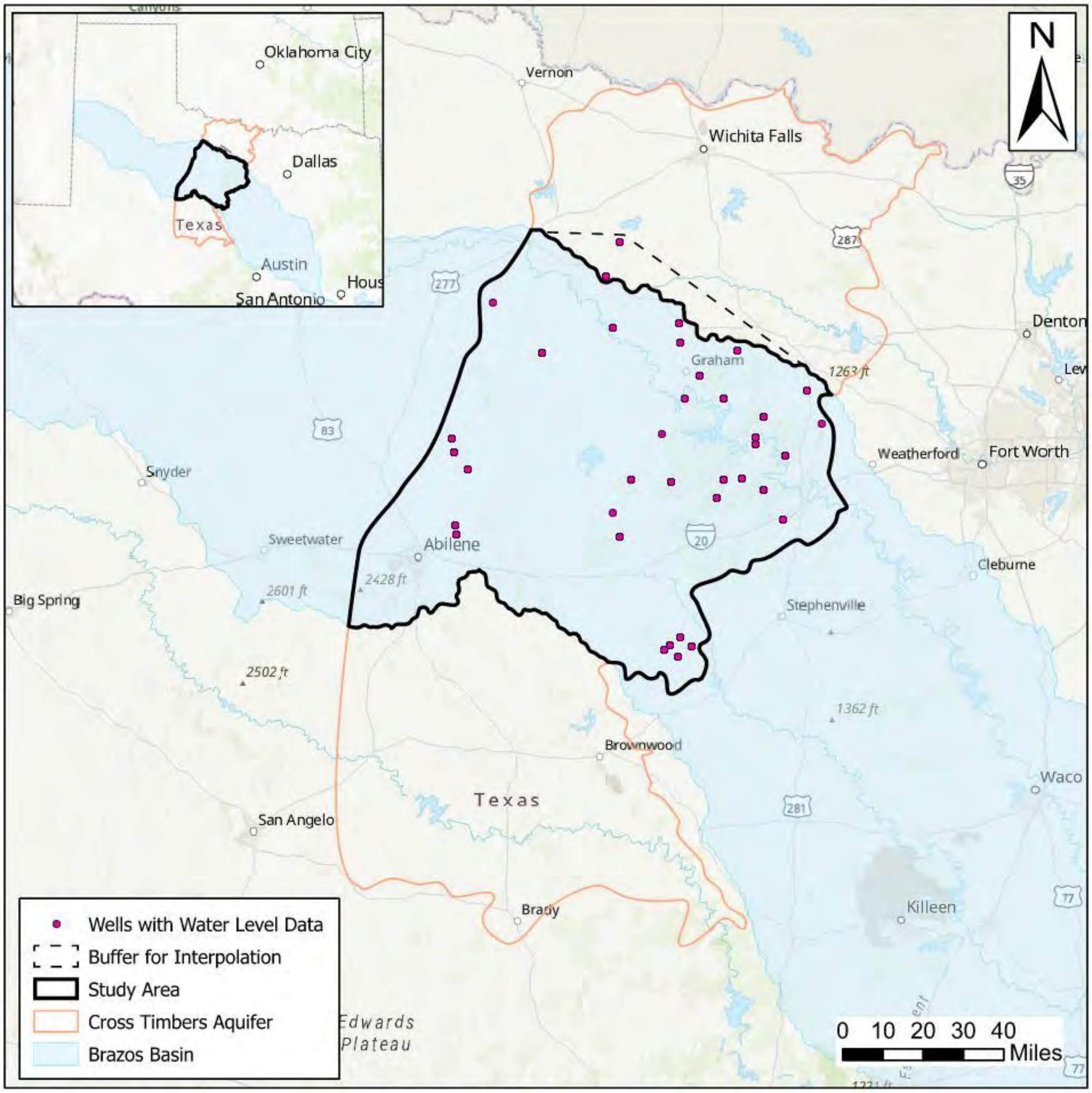


Figure 2-B-4. Wells with Water Level Data in the Cross Timbers Aquifer

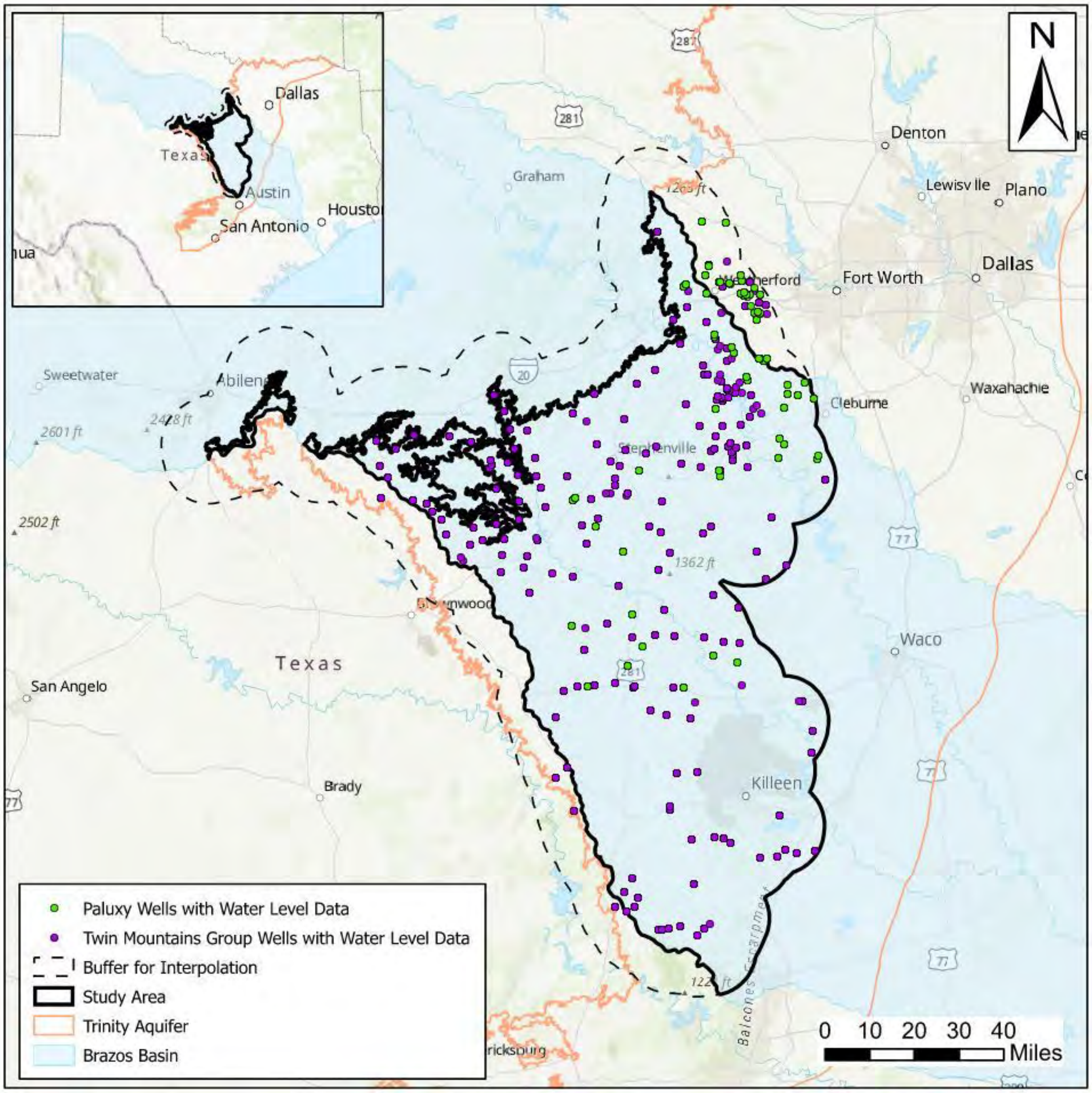


Figure 2-B-5. Wells with Water Level Data in the Trinity Aquifer

Figure 2-B-6. Wells with Water Level Data in the Brazos River Alluvium Aquifer

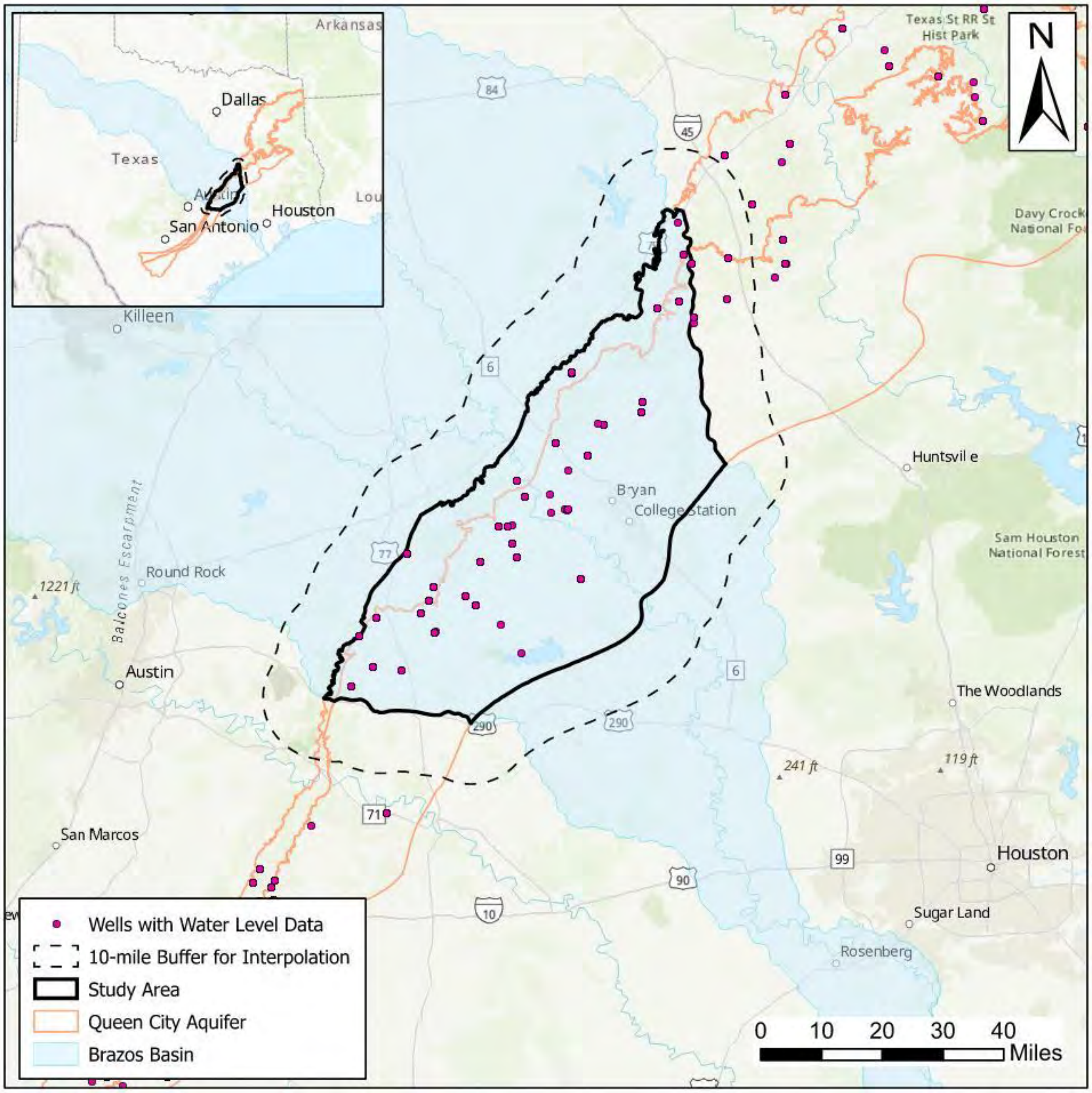


Figure 2-B-7. Wells with Water Level Data in the Queen City Aquifer

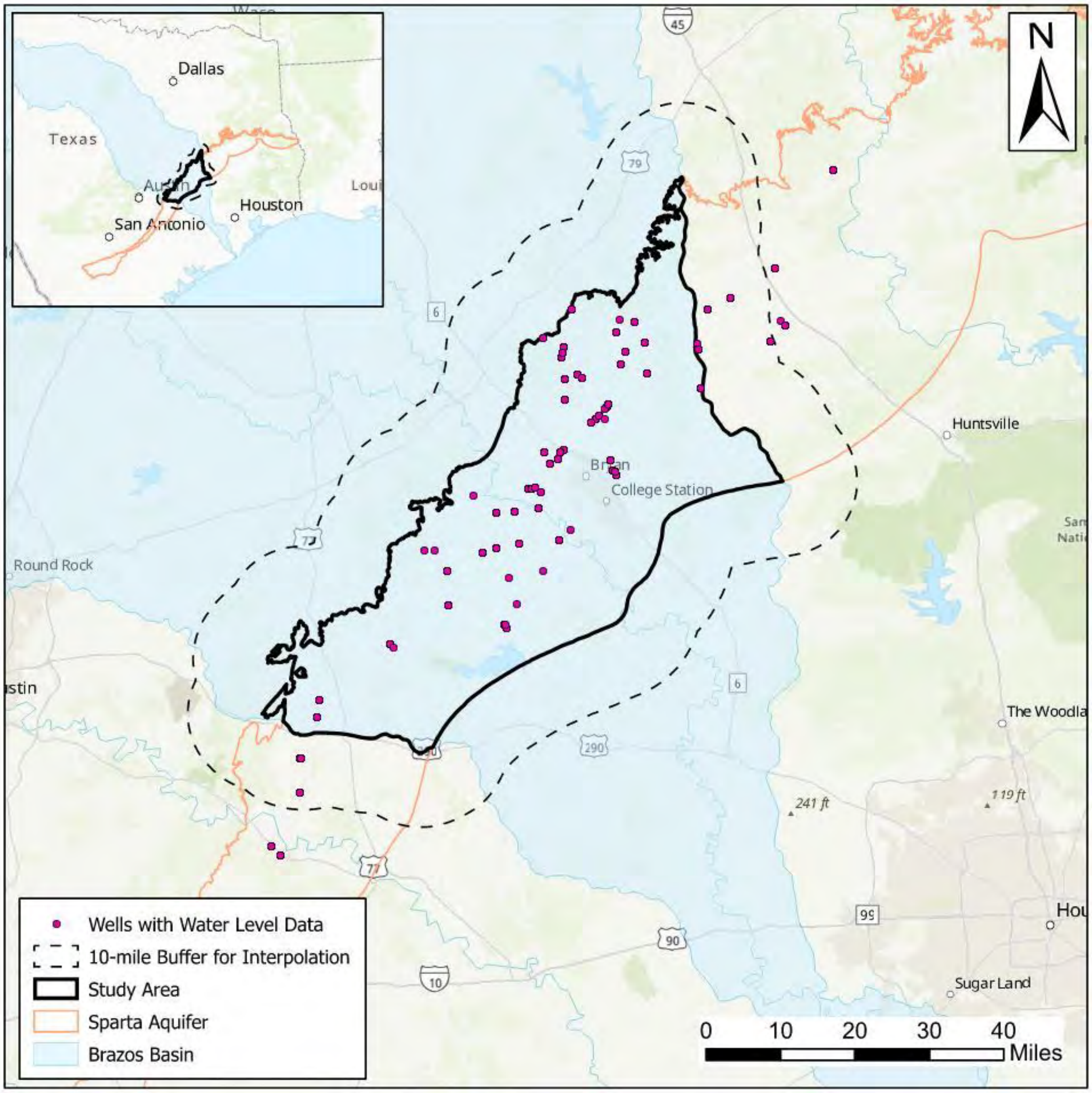


Figure 2-B-8. Wells with Water Level Data in the Sparta Aquifer

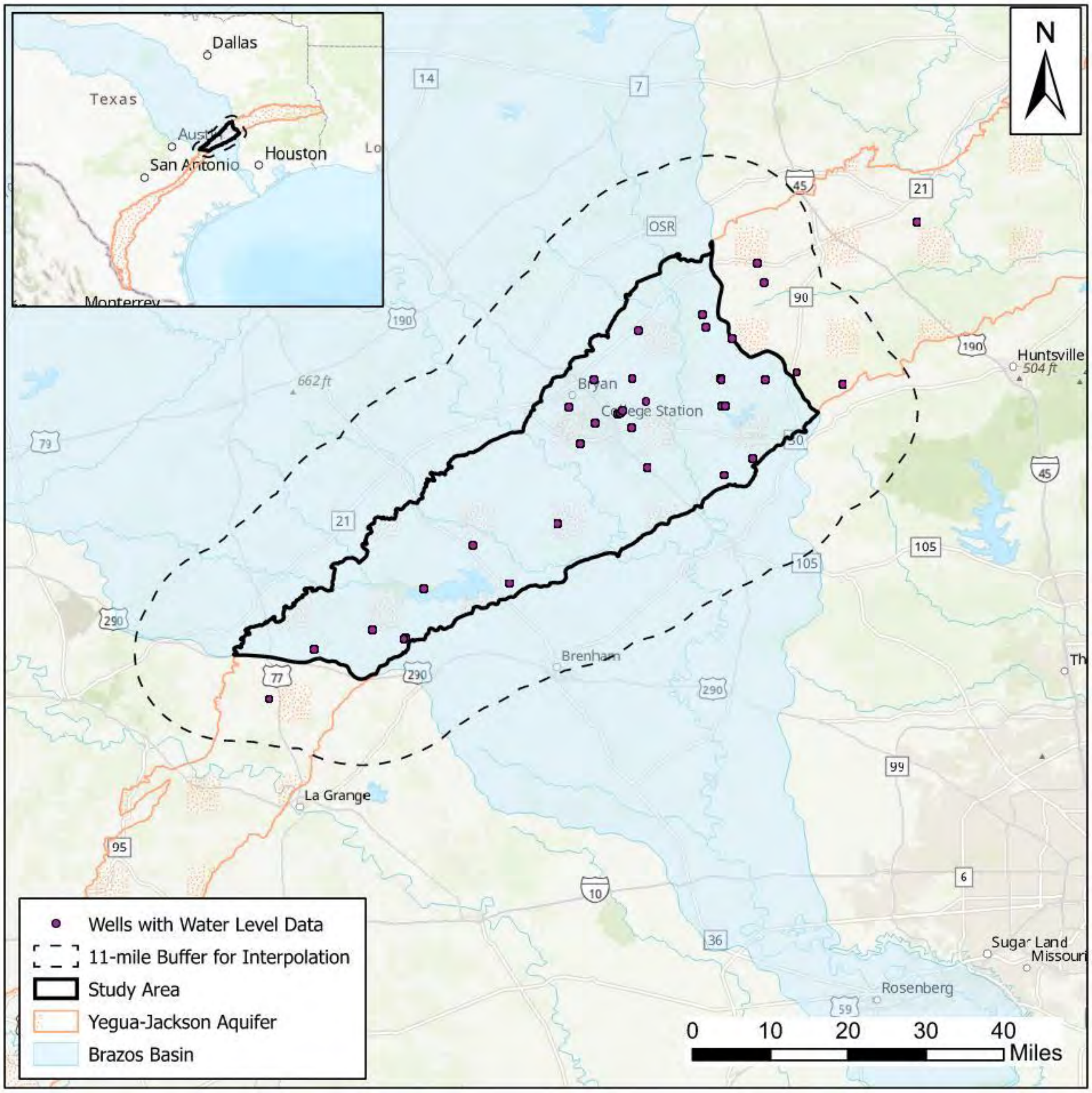


Figure 2-B-9. Wells with Water Level Data in the Yegua-Jackson Aquifer

APPENDIX 2-C: SUMMARY OF RESULTS OF STREAMFLOW TREND ANALYSIS

Table 2-C-1 – Primary control points with start years based on annual flow trends

Control Point	Start year		Control Point	Start year		Control Point	Start year
RWPL01	1959		SHGR26	1965		LAYO51	1940
WRSP02	1945		BRPP27	1943		LABE52	1940*
DUGI03	1940		PPSA28	1940		LRLR53	1940*
SFPE04	1945		BRDE29	1940		NGGE54	1940
CRJA05	1946		BRGR30	1940		SGGE55	1940
SFAS06	1945		PAGR31	1940		GAGE56	1940
BSLU07	1940		NRBL32	1940		GALA57	1940*
DMJU08	1940		BRAQ33	1948		LRCA58	1940
DMAS09	1957		AQAQ34	1940		BRBR59	1940*
NCKN10	1945		NBHI35	1940		MYDB60	1940
BRSE11	1957		NBCL36	1940		EYDB61	1940
MSMN12	1940		NBVM37	1940		YCSO62	1940
CFRO13	1957		MBMG38	1940		DCLY63	1940
CFHA14	1965		HGCR39	1940		NAGR64	1940
MUHA15	1965		BOWA40	1940		BGFR65	1940*
CFNU16	1965		BRWA41	1940		NAEA66	1940
CAST17	1940		BRHB42	1940		NABR67	1940
CFFG18	1940		LEDL43	1940		BRHE68	1940
HCAL19	1953		SADL44	1940		MCBL69	1940*
BSBR20	1940		LEHS45	1940		BRRI70	1940
HCBR21	1940		LEHM46	1940		BGNE71	1940
CFEL22	1957		LEGT47	1940		BRRO72	1940
BRSB23	1957		COPI48	1940		BRGM73	1940
GHGH24	1940*		LEBE49	1940			
CCIV25	1940		LAKE50	1940			

*Start year manually set to 1940.

Table 2-C-2 – Trend Results of Control Points Not in a Specific Subbasin

	MSMN12		AQAQ34		BRWA41		BRHB42		LAKE50		LAYO51		NGGE54		SGGE55		GAGE56		GALA57		MYDB60		EYDB61		YCSO62		DCLY63	
Start Year	1940		1940		1940		1940		1940		1940		1940		1940		1940		1940		1940		1940		1940		1940	
	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p	τ	p
Annual	-0.10	0.20	0.03	0.70	0.01	0.86	0.02	0.76	-0.04	0.62	-0.06	0.44	-0.04	0.63	-0.03	0.74	0.04	0.60	0.08	0.29	0.00	1.00	0.07	0.39	-0.02	0.83	0.04	0.58
Winter	**-0.17**	**0.05**	0.08	0.32	0.04	0.65	0.05	0.52	-0.05	0.50	-0.03	0.72	-0.09	0.25	-0.03	0.67	-0.02	0.82	0.12	0.14	0.05	0.63	0.06	0.43	0.02	0.81	0.07	0.37
Spring	-0.12	0.14	-0.11	0.15	-0.04	0.64	-0.05	0.56	-0.02	0.82	-0.06	0.46	-0.07	0.34	-0.09	0.28	-0.01	0.90	0.01	0.91	-0.12	0.22	0.04	0.57	-0.04	0.60	0.01	0.94
Summer	-0.14	0.07	0.04	0.63	-0.08	0.31	0.04	0.61	-0.02	0.82	-0.02	0.84	-0.06	0.42	-0.04	0.64	0.01	0.94	0.07	0.35	**0.20**	**0.04**	0.12	0.14	-0.04	0.66	-0.05	0.50
Dry Winter	-0.02	0.90	0.11	0.43	0.18	0.22	0.24	0.09	0.01	0.98	0.11	0.46	-0.24	0.11	-0.07	0.63	-0.03	0.83	0.23	0.10	0.16	0.44	0.22	0.14	0.13	0.40	0.14	0.35
Average Winter	-0.18	0.21	-0.14	0.34	-0.02	0.91	-0.02	0.91	-0.07	0.60	-0.12	0.38	-0.05	0.72	-0.15	0.30	-0.09	0.53	0.00	1.00	0.23	0.15	0.03	0.86	-0.01	0.98	0.05	0.71
Wet Winter	-0.20	0.20	0.23	0.12	0.04	0.82	0.05	0.77	-0.01	0.96	0.05	0.78	-0.02	0.91	0.08	0.59	0.08	0.60	0.13	0.39	0.09	0.65	0.14	0.36	0.06	0.71	0.24	0.12
Dry Spring	**-0.33**	**0.02**	-0.18	0.22	0.02	0.91	-0.09	0.53	0.00	1.00	-0.02	0.88	-0.16	0.25	-0.28	0.06	-0.14	0.34	-0.04	0.80	0.34	0.10	0.08	0.58	0.02	0.88	-0.05	0.74
Average Spring	-0.12	0.40	-0.07	0.59	0.03	0.81	-0.08	0.54	-0.11	0.49	-0.13	0.40	-0.24	0.11	-0.06	0.67	0.04	0.76	0.04	0.78	**-0.37**	**0.03**	-0.01	0.94	-0.14	0.34	-0.09	0.56
Wet Spring	0.07	0.64	**-0.31**	**0.05**	-0.30	0.06	-0.08	0.61	-0.05	0.76	-0.13	0.35	-0.01	0.96	-0.13	0.40	0.02	0.91	0.04	0.82	0.09	0.62	0.17	0.23	-0.07	0.66	0.03	0.87
Dry Summer	-0.04	0.79	-0.08	0.57	-0.17	0.23	0.16	0.26	0.07	0.62	0.01	0.97	-0.07	0.61	-0.05	0.71	0.03	0.85	0.13	0.34	0.28	0.13	0.22	0.10	-0.09	0.49	-0.09	0.54
Average Summer	-0.29	0.06	0.25	0.10	0.01	0.98	-0.02	0.89	-0.09	0.54	-0.13	0.39	-0.12	0.43	0.03	0.87	0.10	0.53	0.09	0.58	0.25	0.23	0.16	0.35	-0.03	0.90	-0.03	0.90
Wet Summer	-0.19	0.19	0.06	0.69	-0.06	0.68	-0.05	0.76	0.02	0.92	0.05	0.77	0.05	0.75	-0.15	0.30	-0.10	0.48	0.04	0.81	0.17	0.31	0.06	0.68	-0.05	0.72	-0.12	0.39

Bold text indicates which trend was applied to adjust hydrology.
Green indicates significance (P-value≤0.05).
Light blue indicates moderate to strong Kendall's tau (|τ|≥0.10) when trend is significant.

RWPL01 - Running Water Draw at Plainview

Table 2-C-3 –Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.42	0.09	-0.35	-0.38	0.19	-0.06	0.31	-0.59	-0.55	0.10	-0.35	-0.27	-0.42
	P	0.000	0.325	0.000	0.000	0.347	0.691	0.075	0.001	0.000	0.592	0.032	0.130	0.014
P	τ	-0.03	0.06	0.02	-0.04	0.10	0.07	0.24	-0.19	-0.16	0.37	0.11	0.06	-0.06
	P	0.741	0.522	0.853	0.665	0.621	0.673	0.173	0.289	0.310	0.044	0.538	0.762	0.726
Q/P	τ	-0.45	0.08	-0.39	-0.41	0.10	-0.05	0.25	-0.58	-0.58	0.04	-0.40	-0.25	-0.47
	P	0.000	0.397	0.000	0.000	0.621	0.747	0.161	0.001	0.000	0.837	0.016	0.150	0.006
Period of Record (1940:2015)		76	75	76	76	23	28	24	26	26	24	28	22	26
Period of Analysis (Start Year: 1959)		57	57	57	57	15	24	18	18	22	17	20	18	19

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

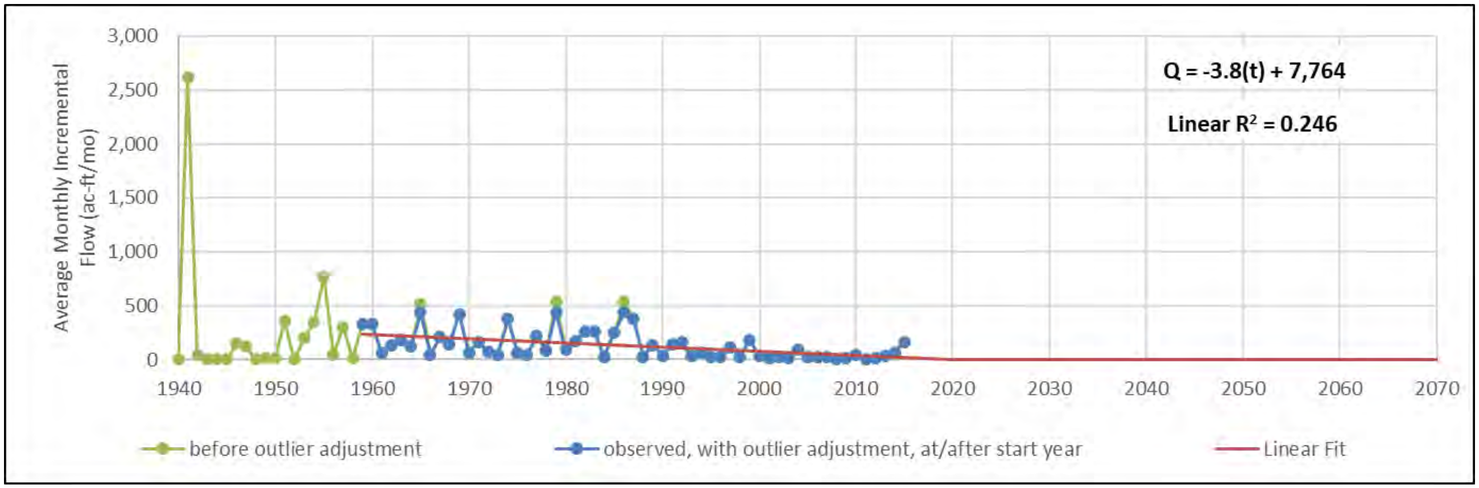


Figure 2-C-1 –Annual Trend for Average Monthly Incremental Flow

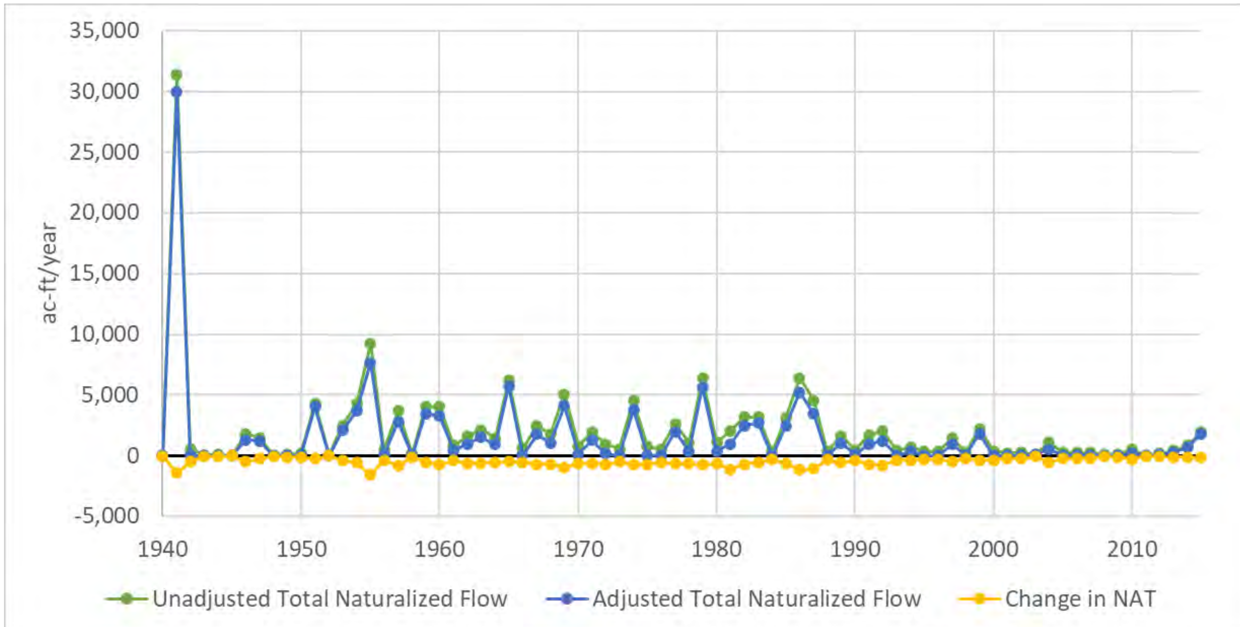


Figure 2-C-2 – Original and Adjusted Naturalized Flow Time Series for RWP01 for 2070 Conditions

WRSP02- White River Reservoir near Spur

Table 2-C-4 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.36	-0.04	-0.29	-0.27	0.15	-0.19	0.05	-0.34	-0.37	-0.20	-0.23	-0.18	-0.29
	P	0.000	0.620	0.000	0.001	0.352	0.162	0.756	0.020	0.009	0.230	0.095	0.264	0.054
P	τ	0.08	0.10	0.07	0.04	0.28	-0.04	0.21	0.00	-0.09	0.21	0.08	0.25	-0.11
	P	0.348	0.202	0.421	0.627	0.071	0.770	0.176	1.000	0.537	0.206	0.588	0.124	0.460
Q/P	τ	-0.40	-0.09	-0.34	-0.29	-0.04	-0.13	-0.05	-0.34	-0.40	-0.27	-0.28	-0.24	-0.32
	P	0.000	0.290	0.000	0.000	0.800	0.359	0.778	0.017	0.005	0.098	0.045	0.139	0.032
Period of Record (1940:2015)		76	75	76	76	23	28	24	26	26	24	28	22	26
Period of Analysis (Start Year: 1945)		71	71	71	71	22	27	22	25	26	20	27	21	23

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

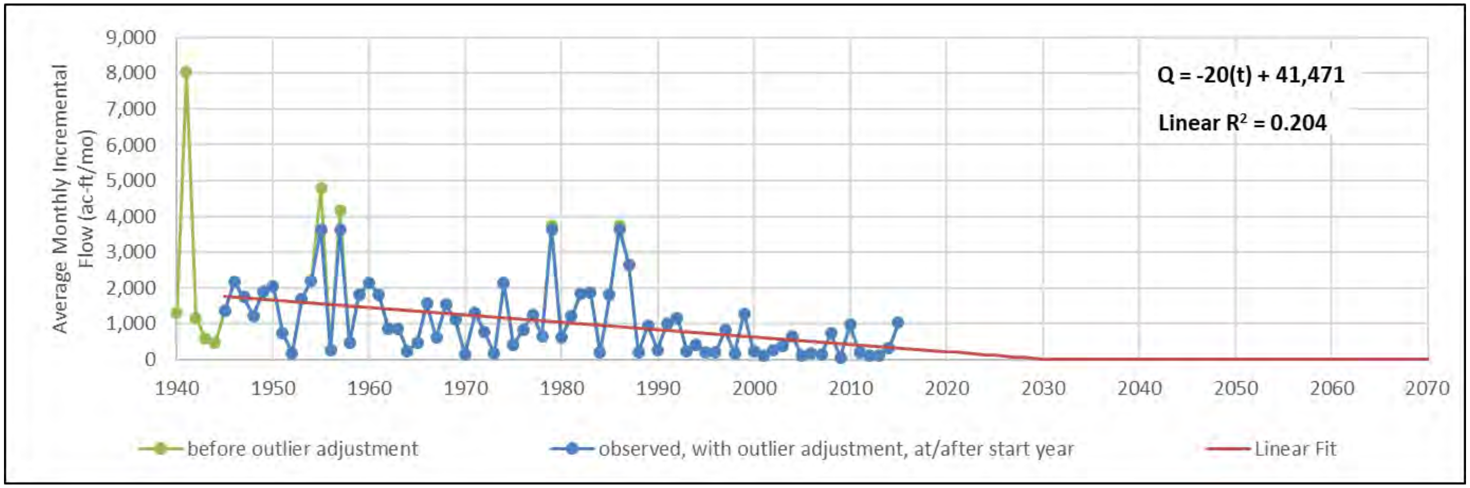


Figure 2-C-3 – Annual Trend for Average Monthly Incremental Flow

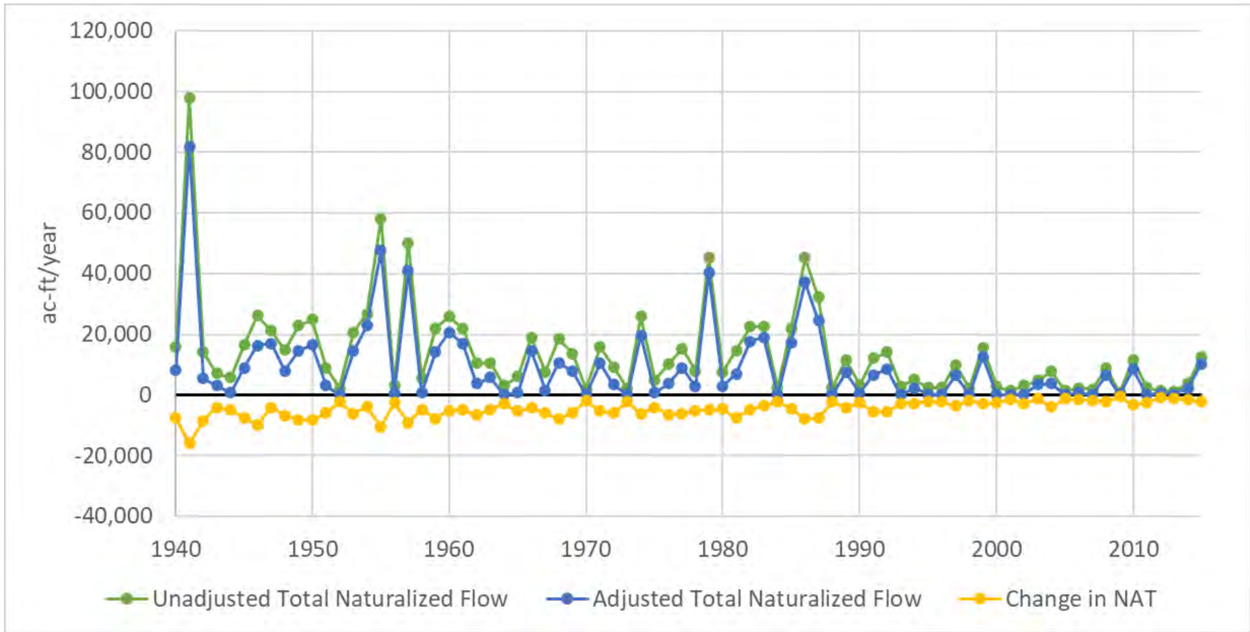


Figure 2-C-4 – Original and Adjusted Naturalized Flow Time Series for WRSP02 for 2070 Conditions

DUGI03 - Duck Creek near Girard

Table 2-C-5 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.22	-0.07	-0.13	-0.21	-0.17	0.03	-0.10	-0.24	-0.09	-0.04	-0.20	-0.21	-0.24
	P	0.005	0.380	0.089	0.008	0.264	0.851	0.517	0.097	0.518	0.785	0.144	0.165	0.102
P	τ	0.08	0.06	0.05	0.01	0.24	-0.16	0.22	-0.08	0.16	0.07	0.18	-0.01	-0.08
	P	0.322	0.484	0.533	0.897	0.107	0.223	0.159	0.591	0.260	0.655	0.196	0.980	0.591
Q/P	τ	-0.28	-0.09	-0.17	-0.24	-0.23	0.11	-0.12	-0.24	-0.15	-0.11	-0.26	-0.23	-0.22
	P	0.000	0.282	0.029	0.002	0.124	0.431	0.463	0.093	0.278	0.457	0.061	0.124	0.129
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1940)		76	75	76	76	24	29	22	25	27	24	27	24	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

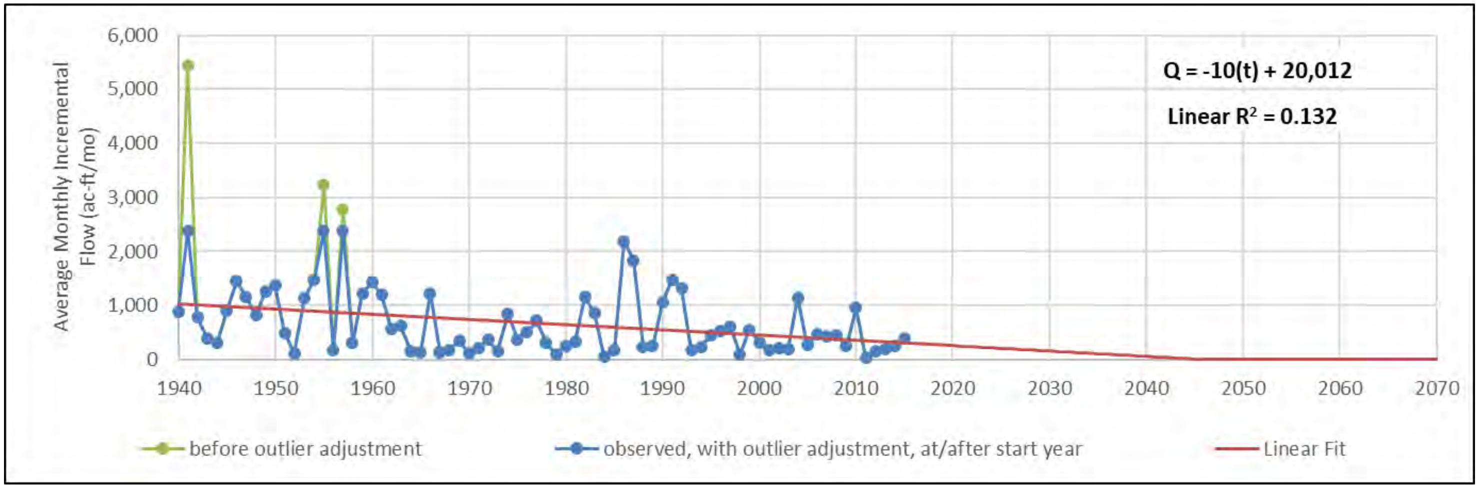


Figure 2-C-5 – Annual Trend for Average Monthly Incremental Flow

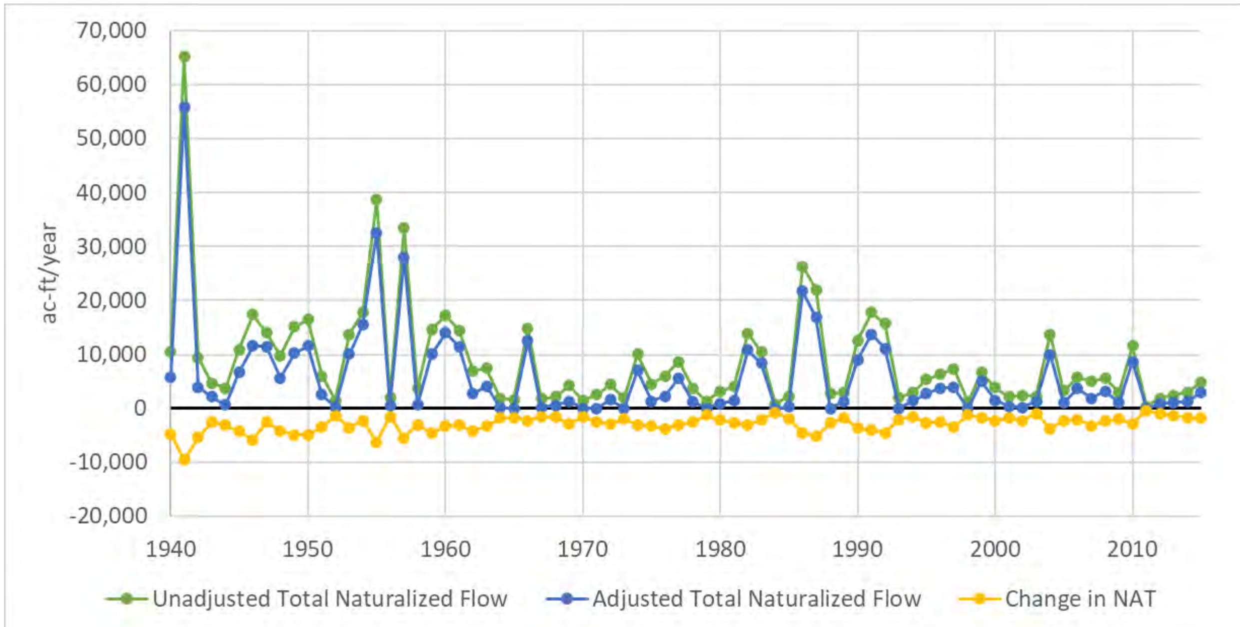


Figure 2-C-6 – Original and Adjusted Naturalized Flow Time Series for DUGI03 for 2070 Conditions

SFPE04 - Salt Fork Brazos River near Peacock

Table 2-C-6 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	T	-0.26	-0.01	-0.18	-0.15	-0.13	0.01	-0.05	-0.26	-0.16	-0.14	-0.14	-0.15	-0.10
	P	0.002	0.905	0.024	0.059	0.385	0.934	0.795	0.083	0.261	0.398	0.327	0.342	0.526
P	T	0.11	0.07	0.06	0.02	0.25	-0.07	0.05	-0.09	0.12	0.17	0.11	-0.05	0.09
	P	0.177	0.372	0.454	0.789	0.087	0.617	0.770	0.535	0.402	0.291	0.469	0.751	0.561
Q/P	T	-0.33	-0.02	-0.24	-0.20	-0.17	0.12	-0.06	-0.31	-0.25	-0.24	-0.22	-0.19	-0.13
	P	0.000	0.843	0.003	0.013	0.254	0.381	0.721	0.040	0.074	0.139	0.135	0.224	0.398
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1945)		71	71	71	71	24	27	20	24	26	21	25	23	23

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

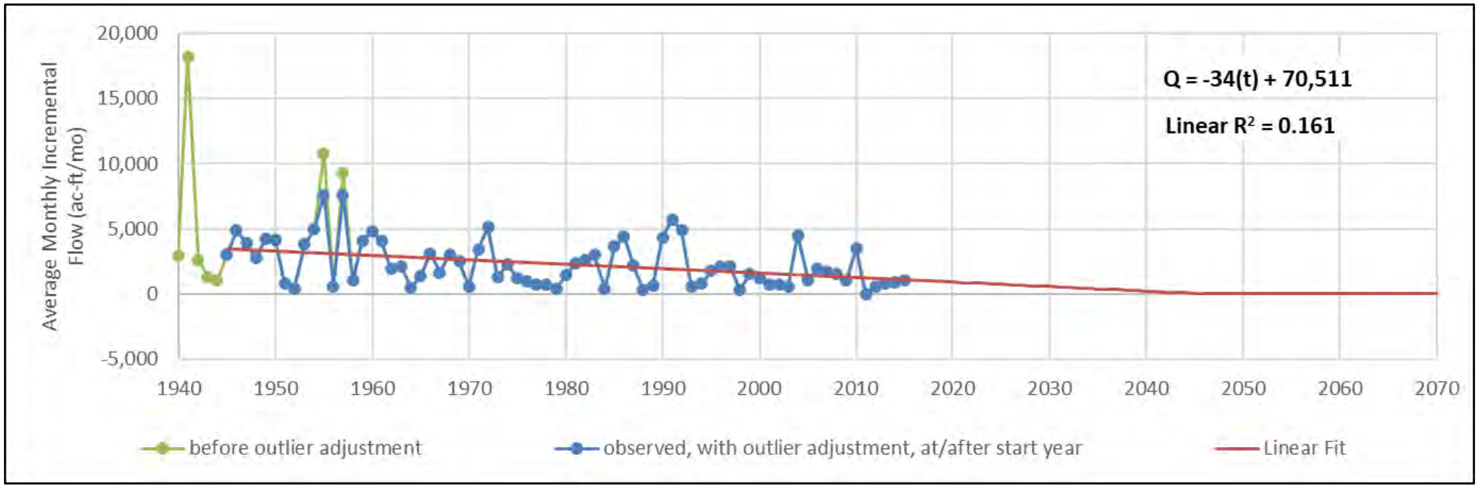


Figure 2-C-7 – Annual Trend for Average Monthly Incremental Flow

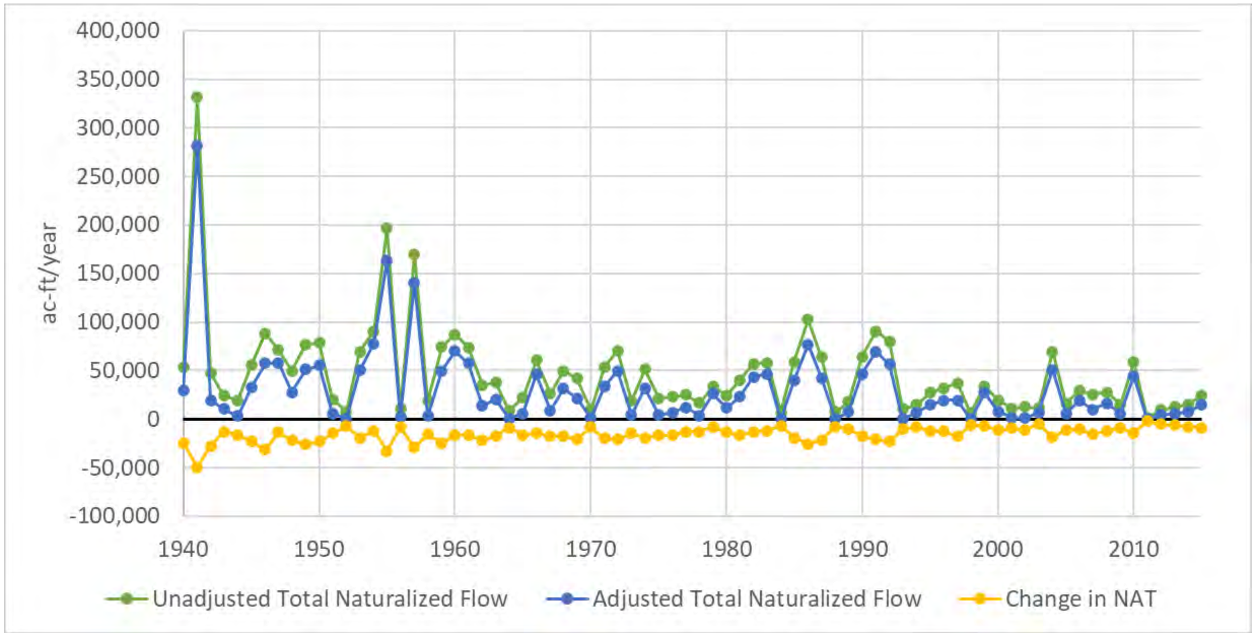


Figure 2-C-8 – Original and Adjusted Naturalized Flow Time Series for SFPE04 for 2070 Conditions

CRJA05 - Croton Creek near Jayton

Table 2-C-7 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.31	0.00	-0.23	-0.20	-0.09	0.07	0.02	-0.33	-0.27	-0.13	-0.18	-0.19	-0.15
	P	0.000	0.992	0.005	0.016	0.535	0.628	0.948	0.026	0.059	0.432	0.234	0.236	0.342
P	τ	0.10	0.09	0.04	0.05	0.24	-0.02	0.06	-0.12	0.08	0.15	0.15	-0.04	0.08
	P	0.236	0.260	0.602	0.574	0.102	0.930	0.721	0.413	0.591	0.365	0.293	0.822	0.635
Q/P	τ	-0.37	-0.05	-0.29	-0.23	-0.19	0.10	-0.03	-0.37	-0.30	-0.13	-0.24	-0.26	-0.16
	P	0.000	0.530	0.000	0.004	0.215	0.494	0.871	0.012	0.038	0.415	0.107	0.102	0.291
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1946)		70	70	70	70	24	26	20	24	25	21	25	22	23

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

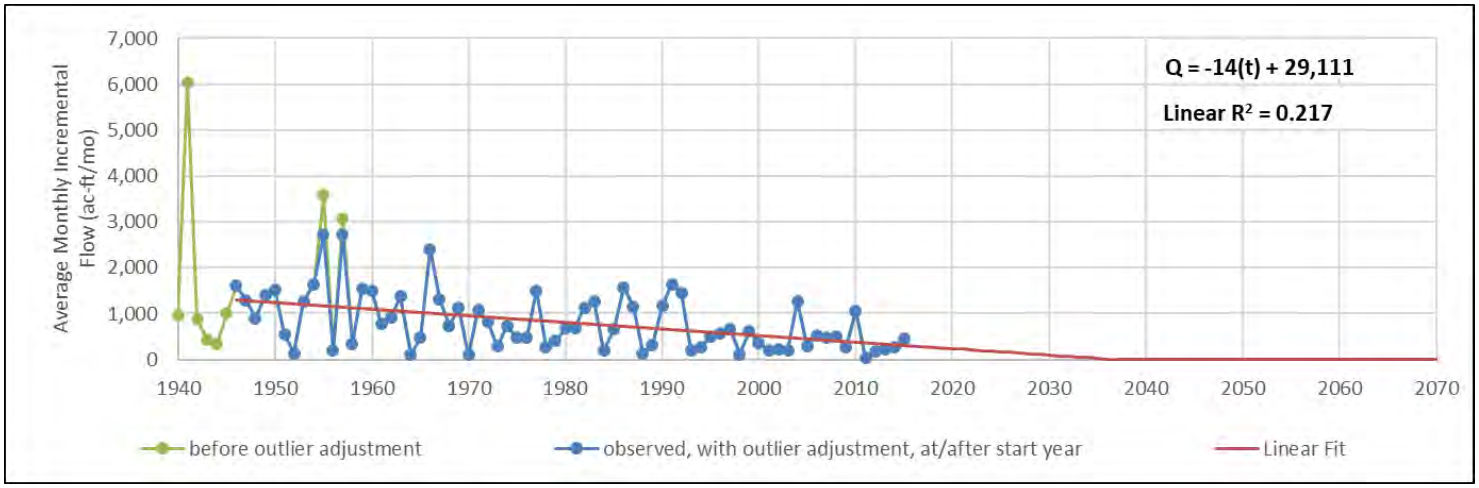


Figure 2-C-9 – Annual Trend for Average Monthly Incremental Flow

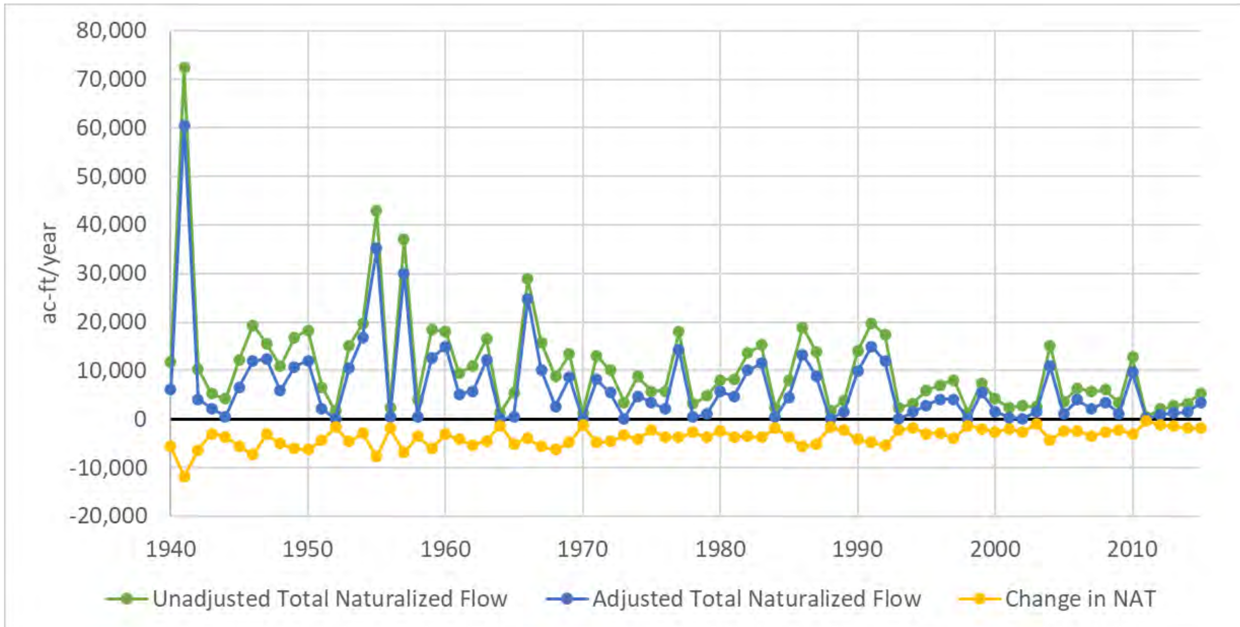


Figure 2-C-10 – Original and Adjusted Naturalized Flow Time Series for CRJA05 for 2070 Conditions

SFAS06 - Salt Fork Brazos River near Aspermont

Table 2-C-8 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.30	-0.09	-0.18	-0.23	-0.18	-0.08	-0.16	-0.31	-0.20	-0.01	-0.18	-0.25	-0.19
	P	0.000	0.295	0.032	0.006	0.224	0.574	0.330	0.040	0.172	0.952	0.207	0.096	0.224
P	τ	0.10	0.07	0.06	0.03	0.24	-0.07	0.06	-0.12	0.14	0.15	0.15	-0.04	0.08
	P	0.211	0.407	0.460	0.702	0.102	0.646	0.721	0.413	0.332	0.365	0.293	0.792	0.635
Q/P	τ	-0.35	-0.09	-0.25	-0.25	-0.27	0.11	-0.15	-0.35	-0.28	-0.14	-0.23	-0.30	-0.15
	P	0.000	0.250	0.002	0.002	0.074	0.428	0.381	0.018	0.050	0.398	0.112	0.045	0.316
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1945)		71	71	71	71	24	27	20	24	26	21	25	23	23

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

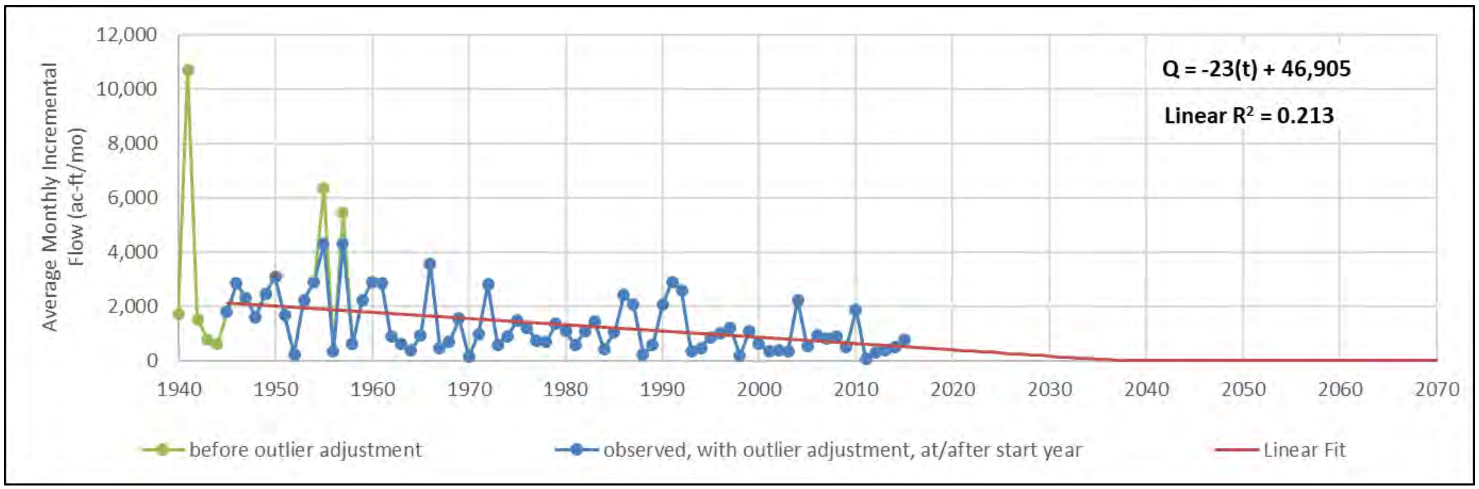


Figure 2-C-11 – Annual Trend for Average Monthly Incremental Flow

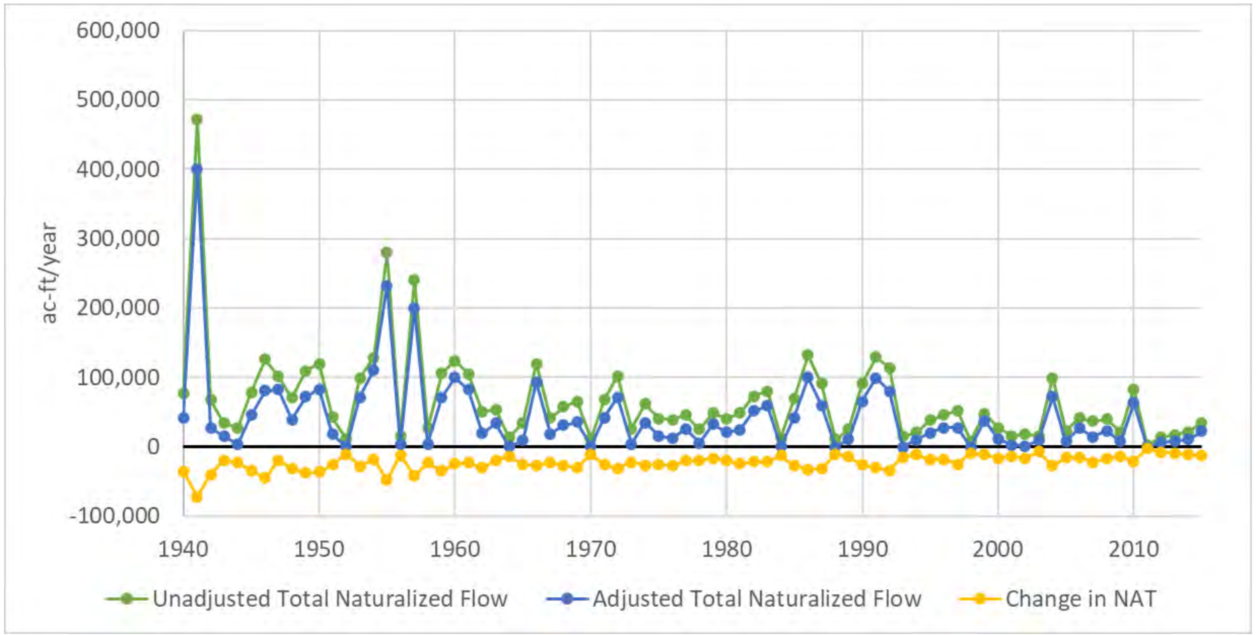


Figure 2-C-12 – Original and Adjusted Naturalized Flow Time Series for SFAS06 for 2070 Conditions

BSLU07 - Buffalo Springs Lake near Lubbock

Table 2-C-9 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.13	0.03	0.03	0.09	0.08	0.04	0.20	-0.20	-0.07	0.33	0.08	0.19	0.06
	P	0.098	0.711	0.693	0.236	0.616	0.797	0.180	0.152	0.612	0.024	0.553	0.225	0.708
P	τ	0.06	0.07	0.05	0.05	0.15	-0.12	0.30	-0.03	-0.11	0.20	0.11	0.32	-0.21
	P	0.440	0.372	0.557	0.542	0.342	0.396	0.045	0.860	0.427	0.189	0.441	0.037	0.134
Q/P	τ	0.14	0.01	0.01	0.12	0.07	0.08	0.06	-0.27	-0.03	0.31	0.06	0.19	0.12
	P	0.082	0.880	0.854	0.130	0.653	0.567	0.691	0.061	0.843	0.035	0.678	0.225	0.390
Period of Record (1940:2015)		76	75	76	76	23	28	24	26	26	24	28	22	26
Period of Analysis (Start Year: 1940)		76	75	76	76	23	28	24	26	26	24	28	22	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

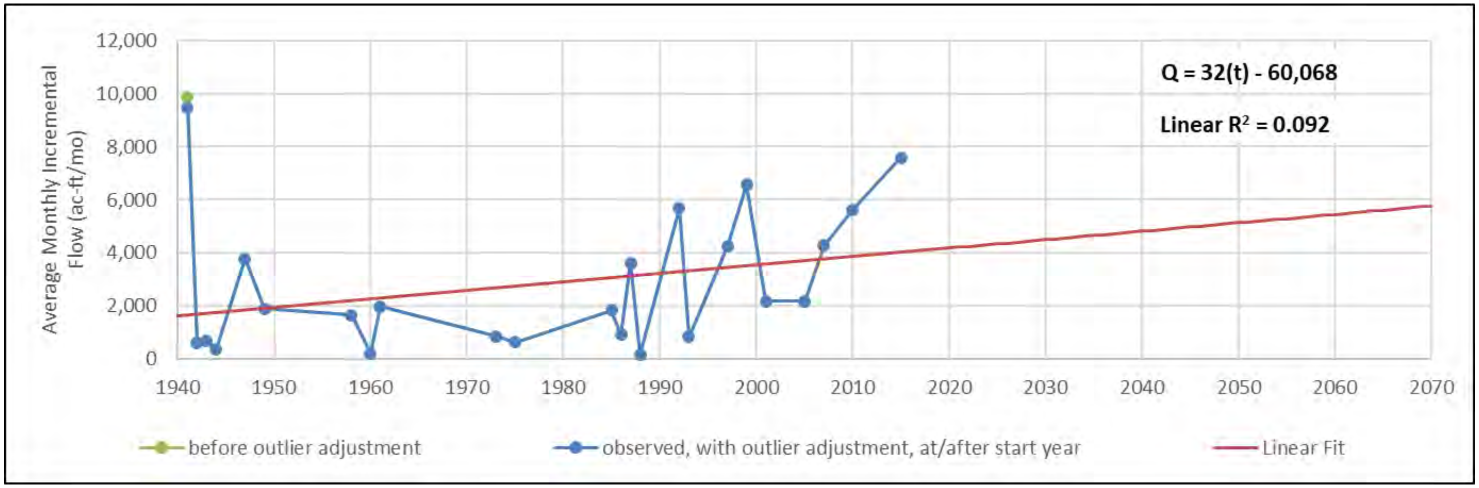


Figure 2-C-13 – Wet Spring Trend for Average Monthly Incremental Flow

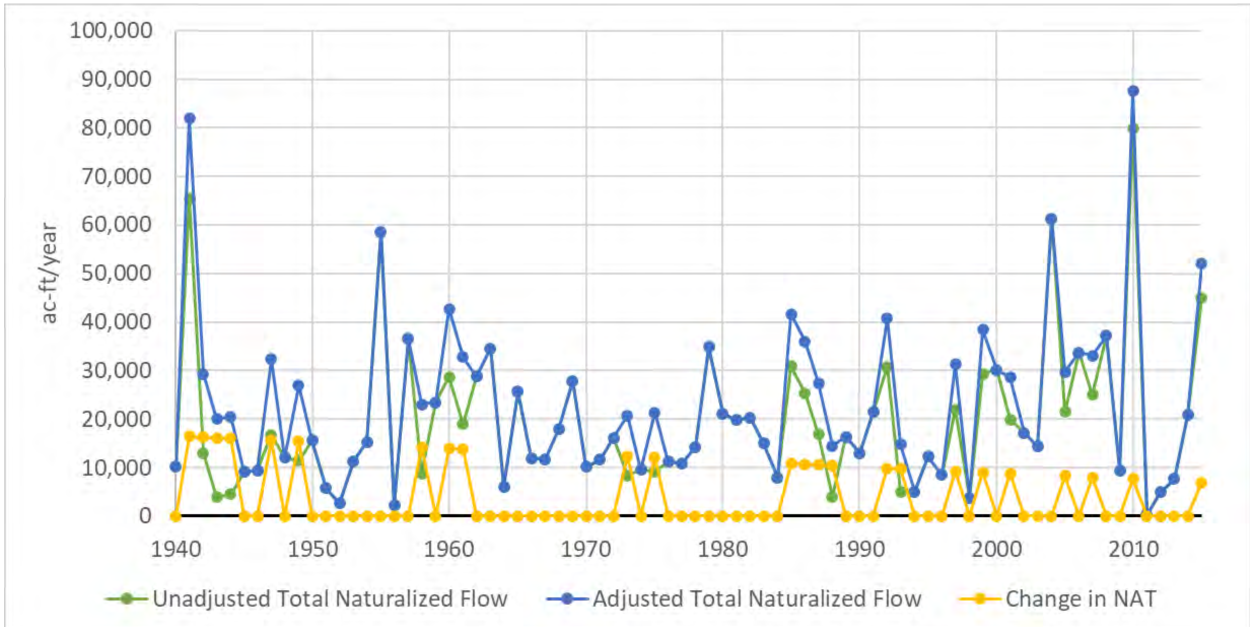


Figure 2-C-14 – Original and Adjusted Naturalized Flow Time Series for BSLU07 for 2070 Conditions

DMJU08 - Double Mountain Fork Brazos River at Justiceburg

Table 2-C-10 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.00	-0.02	-0.06	0.02	0.01	0.13	0.01	-0.28	-0.12	0.19	-0.01	0.15	-0.04
	P	0.961	0.848	0.440	0.830	0.979	0.343	0.960	0.052	0.390	0.206	0.953	0.338	0.808
P	τ	0.05	0.06	0.04	0.02	0.14	-0.07	0.30	-0.02	-0.07	0.17	0.11	0.26	-0.24
	P	0.518	0.418	0.622	0.833	0.369	0.594	0.045	0.930	0.628	0.244	0.441	0.091	0.094
Q/P	τ	-0.03	-0.03	-0.09	0.02	0.00	0.18	-0.08	-0.33	-0.16	0.20	-0.03	0.12	0.01
	P	0.720	0.711	0.253	0.837	1.000	0.179	0.620	0.021	0.261	0.172	0.859	0.463	0.965
Period of Record (1940:2015)		76	75	76	76	23	28	24	26	26	24	28	22	26
Period of Analysis (Start Year: 1940)		76	75	76	76	23	28	24	26	26	24	28	22	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

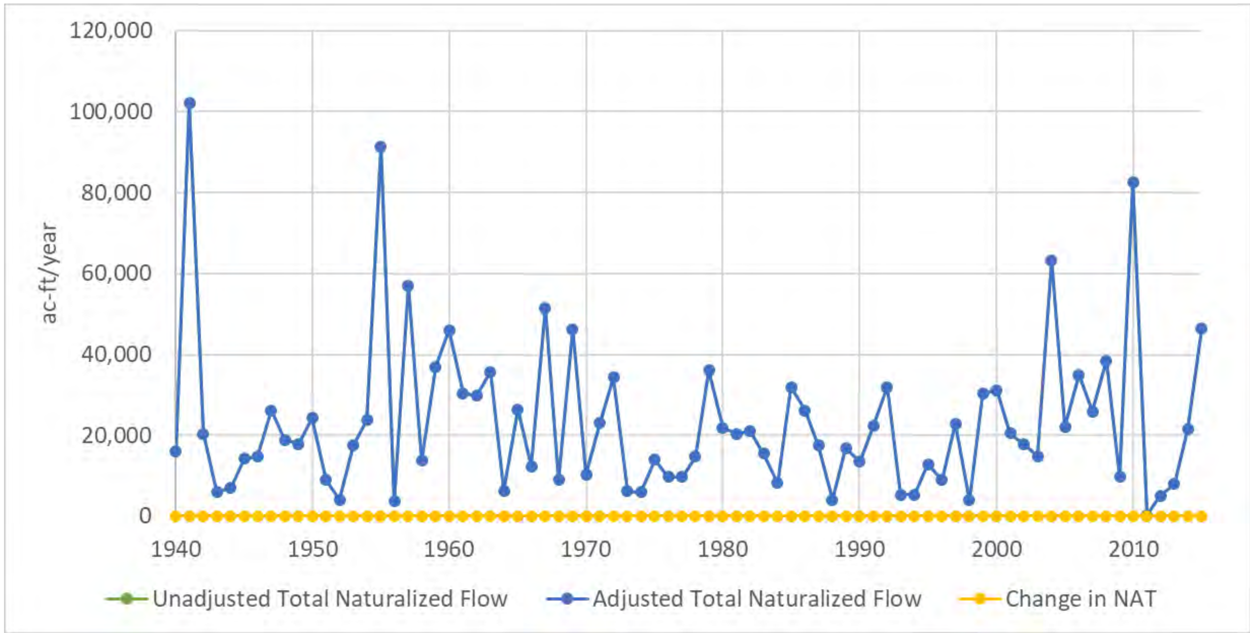


Figure 2-C-15 – Original and Adjusted Naturalized Flow Time Series for DMJU08 for 2070 Conditions

DMAS09 - Double Mountain Fork Brazos River near Aspermont

Table 2-C-11 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.27	0.00	-0.17	-0.23	0.11	0.25	-0.13	-0.33	-0.06	-0.08	-0.18	-0.32	-0.07
	P	0.002	0.990	0.056	0.012	0.564	0.114	0.456	0.079	0.735	0.651	0.325	0.064	0.652
P	τ	-0.05	0.04	-0.01	-0.08	0.12	0.03	0.07	-0.20	0.08	0.13	0.08	-0.15	0.09
	P	0.543	0.690	0.911	0.381	0.537	0.866	0.673	0.300	0.612	0.415	0.649	0.401	0.573
Q/P	τ	-0.33	0.00	-0.20	-0.24	0.03	0.23	-0.09	-0.30	-0.10	-0.16	-0.19	-0.31	-0.08
	P	0.000	0.990	0.029	0.007	0.902	0.135	0.581	0.115	0.535	0.319	0.289	0.069	0.612
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1957)		59	59	59	59	17	22	20	16	22	21	18	19	22

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

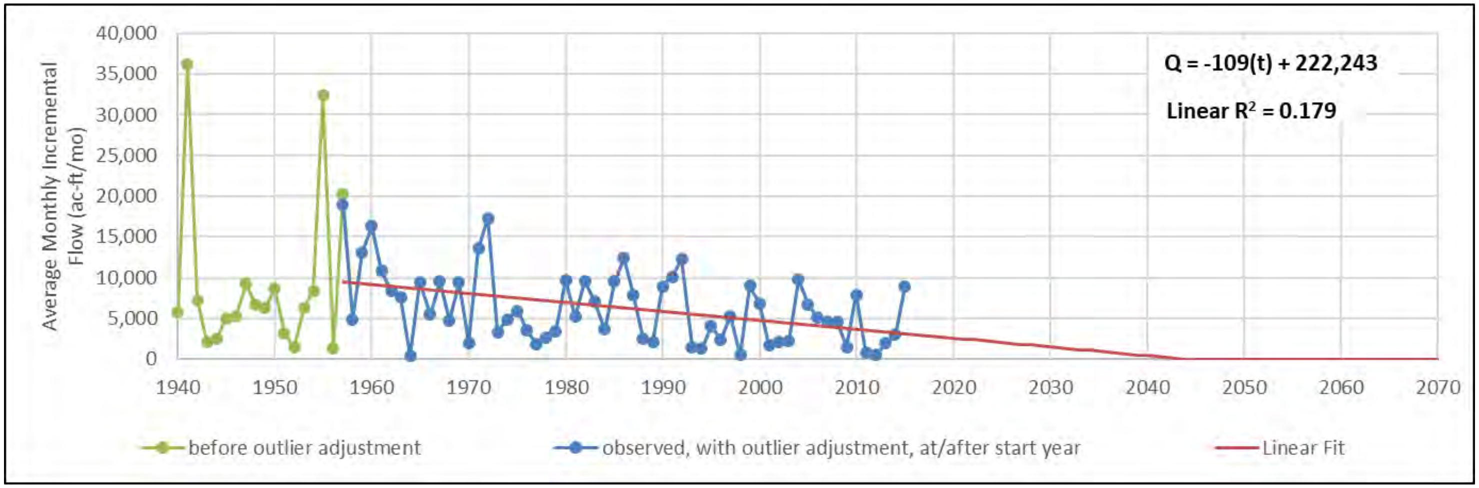


Figure 2-C-16 – Annual Trend for Average Monthly Incremental Flow

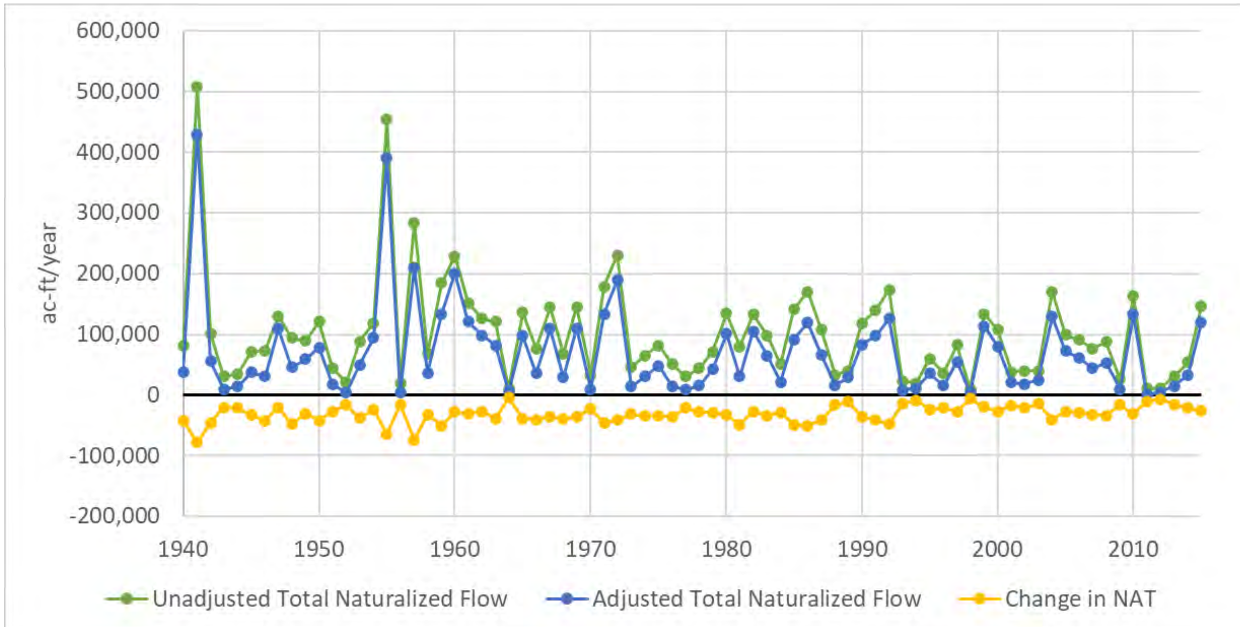


Figure 2-C-17 – Original and Adjusted Naturalized Flow Time Series for DMAS09 for 2070 Conditions

NCKN10 - North Croton Creek near Knox City

Table 2-C-12 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.26	-0.04	-0.17	-0.19	-0.15	0.00	-0.07	-0.31	-0.16	0.03	-0.21	-0.18	-0.11
	P	0.001	0.669	0.040	0.022	0.309	1.000	0.697	0.040	0.270	0.880	0.148	0.245	0.460
P	τ	0.10	0.07	0.06	0.03	0.24	-0.07	0.06	-0.12	0.14	0.15	0.15	-0.04	0.08
	P	0.211	0.404	0.460	0.702	0.102	0.646	0.721	0.413	0.332	0.365	0.293	0.792	0.635
Q/P	τ	-0.33	-0.04	-0.23	-0.23	-0.21	0.12	-0.03	-0.35	-0.25	-0.11	-0.26	-0.25	-0.11
	P	0.000	0.588	0.004	0.005	0.172	0.393	0.871	0.018	0.078	0.487	0.076	0.107	0.492
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1945)		71	71	71	71	24	27	20	24	26	21	25	23	23

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

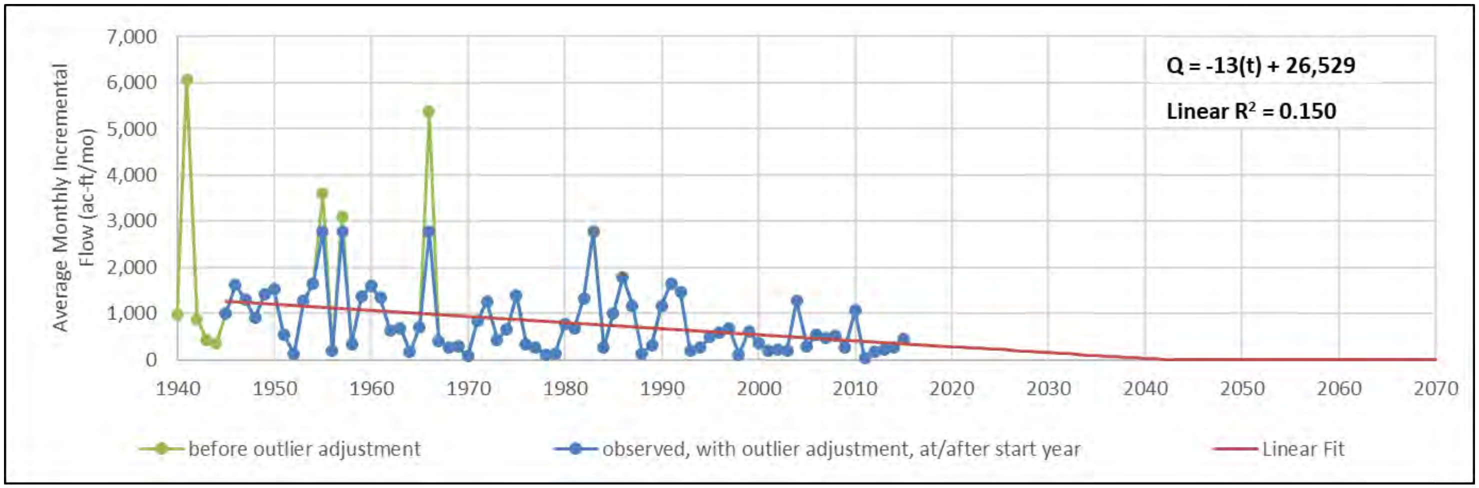


Figure 2-C-18 – Annual Trend for Average Monthly Incremental Flow

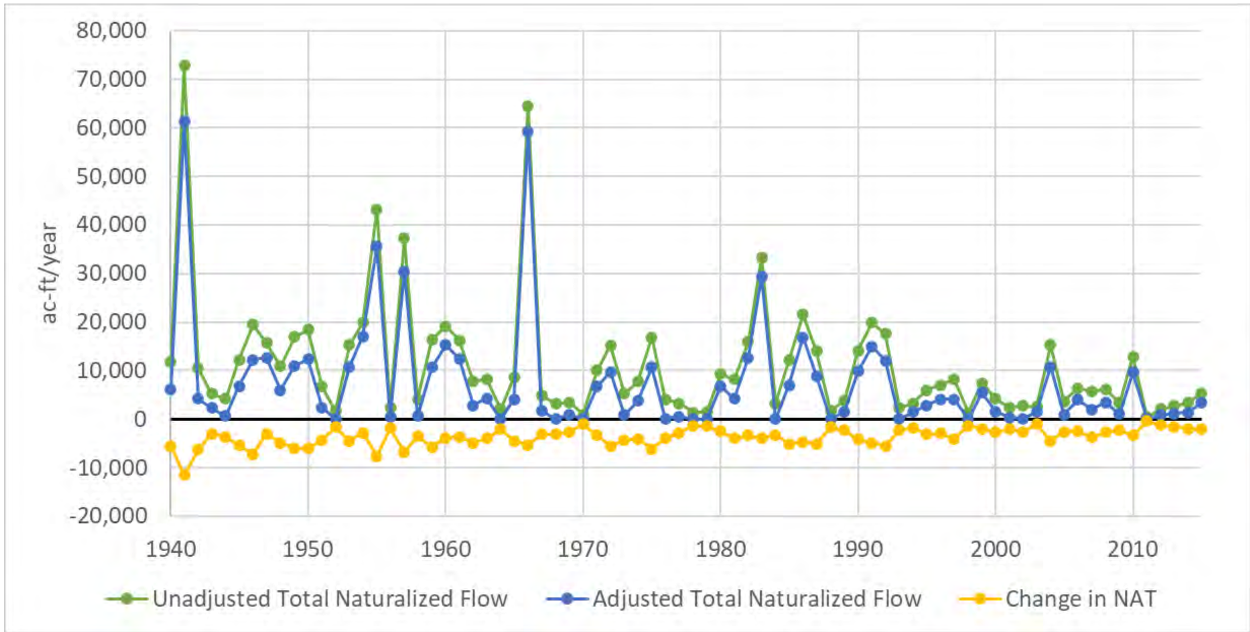


Figure 2-C-19 – Original and Adjusted Naturalized Flow Time Series for NCKN10 for 2070 Conditions

BRSE11 - Brazos River at Seymour

Table 2-C-13 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.20	-0.09	-0.14	-0.20	-0.25	0.02	-0.06	-0.43	-0.02	0.02	-0.27	-0.22	0.15
	P	0.026	0.295	0.123	0.028	0.174	0.933	0.746	0.022	0.933	0.904	0.130	0.208	0.338
P	τ	-0.05	0.02	0.01	-0.08	0.08	0.02	0.06	-0.27	0.14	0.15	0.08	-0.20	0.08
	P	0.561	0.860	0.932	0.399	0.680	0.910	0.721	0.163	0.367	0.365	0.649	0.234	0.612
Q/P	τ	-0.24	-0.06	-0.17	-0.21	-0.26	0.14	-0.03	-0.38	-0.05	-0.13	-0.37	-0.20	0.13
	P	0.008	0.530	0.054	0.021	0.149	0.367	0.871	0.043	0.778	0.432	0.034	0.234	0.398
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1957)		59	59	59	59	17	22	20	16	22	21	18	19	22

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

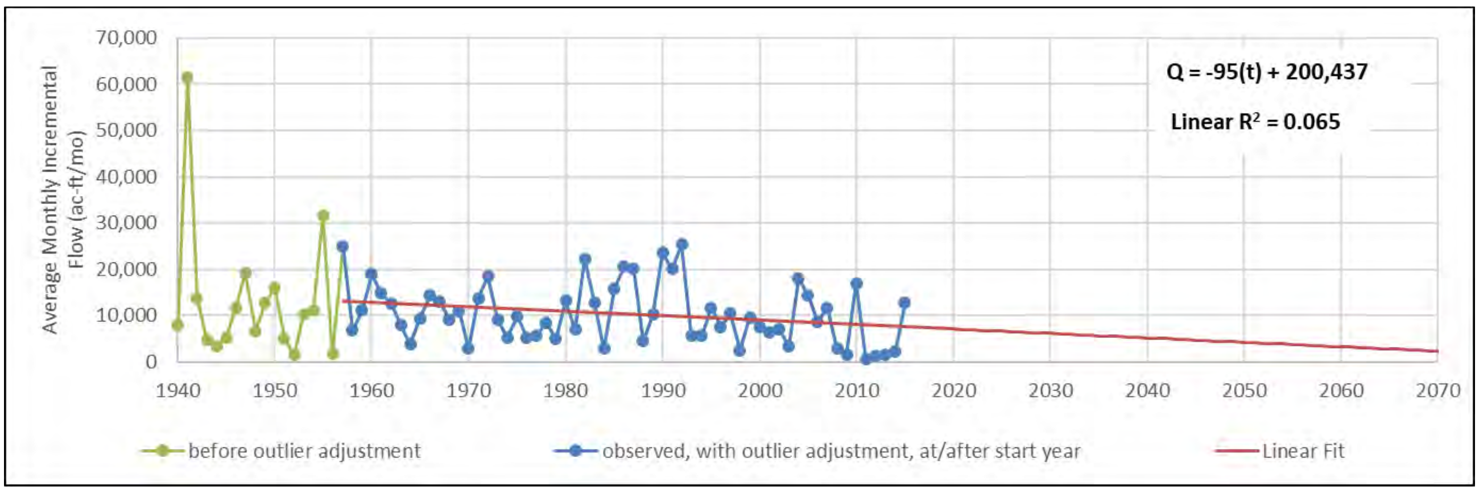


Figure 2-C-20 – Annual Trend for Average Monthly Incremental Flow

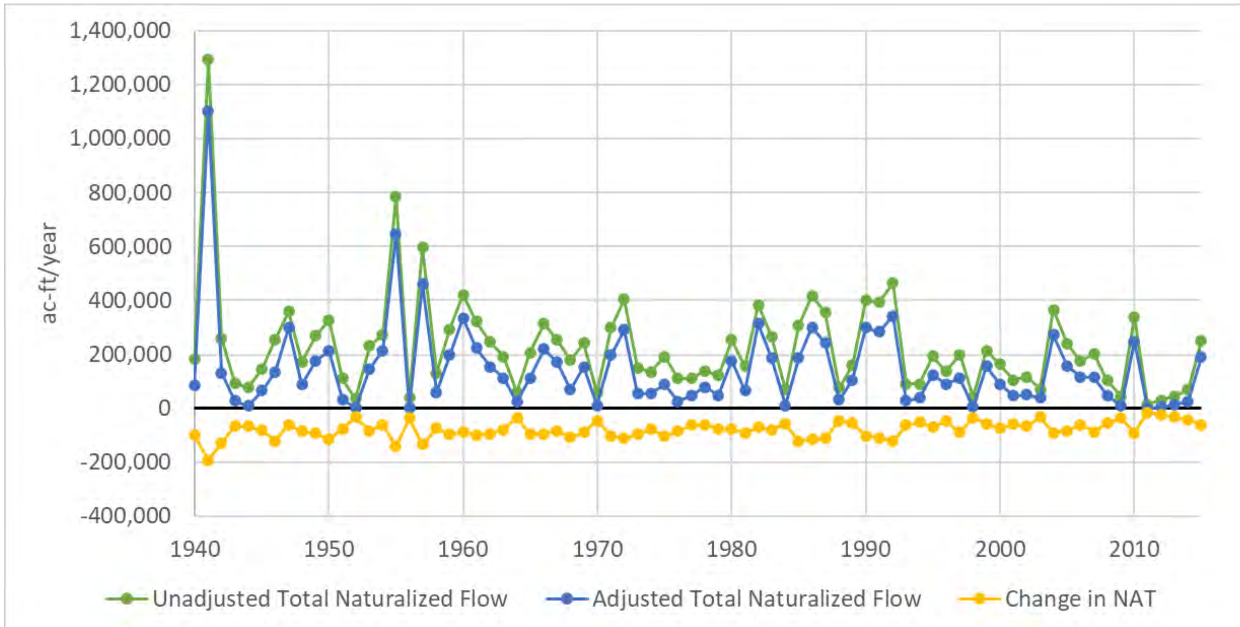


Figure 2-C-21 – Original and Adjusted Naturalized Flow Time Series for BRSE11 for 2070 Conditions

MSMN12 - Millers Creek near Munday

Table 2-C-14 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.10	-0.17	-0.12	-0.14	-0.02	-0.18	-0.20	-0.33	-0.12	0.07	-0.04	-0.29	-0.19
	P	0.200	0.048	0.138	0.069	0.901	0.209	0.204	0.022	0.404	0.637	0.786	0.056	0.191
P	τ	0.08	0.05	0.05	0.01	0.23	-0.17	0.22	-0.13	0.19	0.08	0.21	-0.03	-0.08
	P	0.335	0.564	0.515	0.854	0.118	0.209	0.159	0.388	0.169	0.585	0.123	0.862	0.591
Q/P	τ	-0.13	-0.16	-0.13	-0.16	-0.04	-0.14	-0.23	-0.32	-0.14	0.06	-0.03	-0.29	-0.20
	P	0.097	0.062	0.103	0.048	0.823	0.339	0.150	0.027	0.317	0.710	0.819	0.050	0.183
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1940)		76	75	76	76	24	29	22	25	27	24	27	24	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

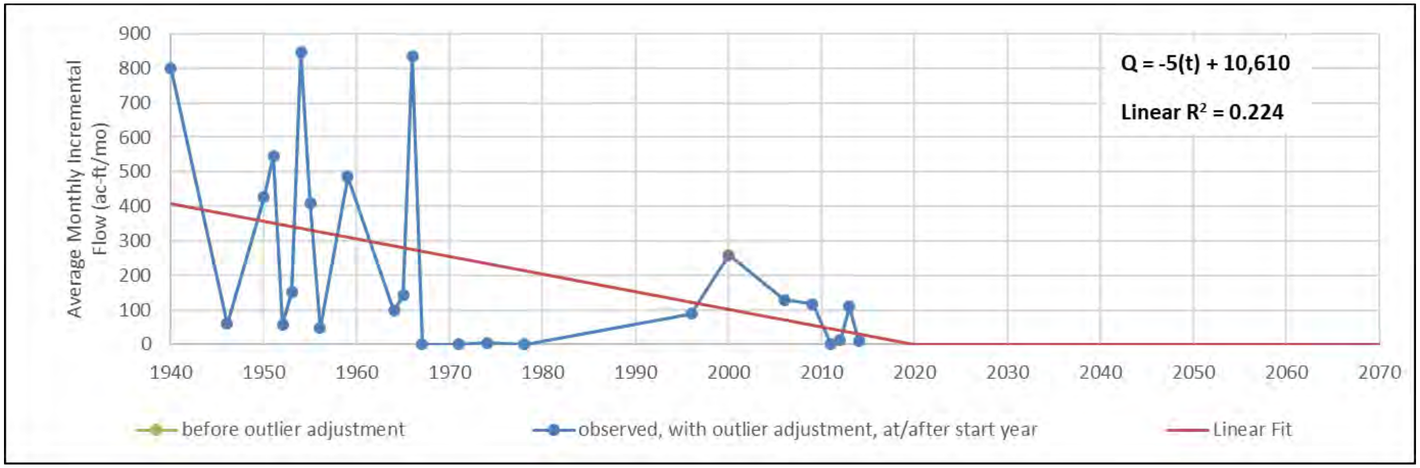


Figure 2-C-22 – Dry Spring Trend for Average Monthly Incremental Flow

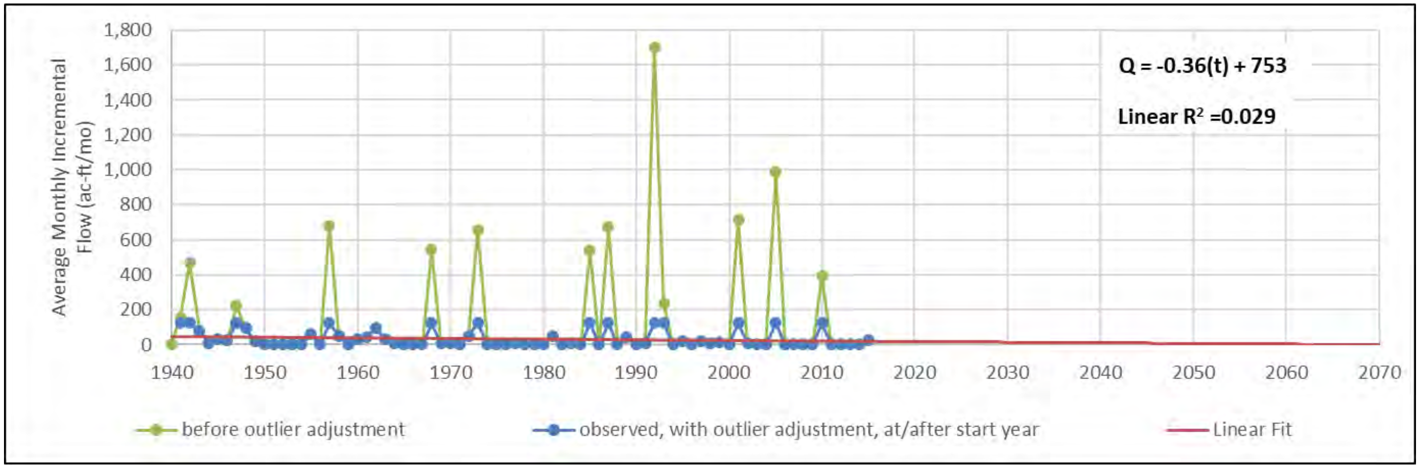


Figure 2-C-23 – Winter Trend for Average Monthly Incremental Flow

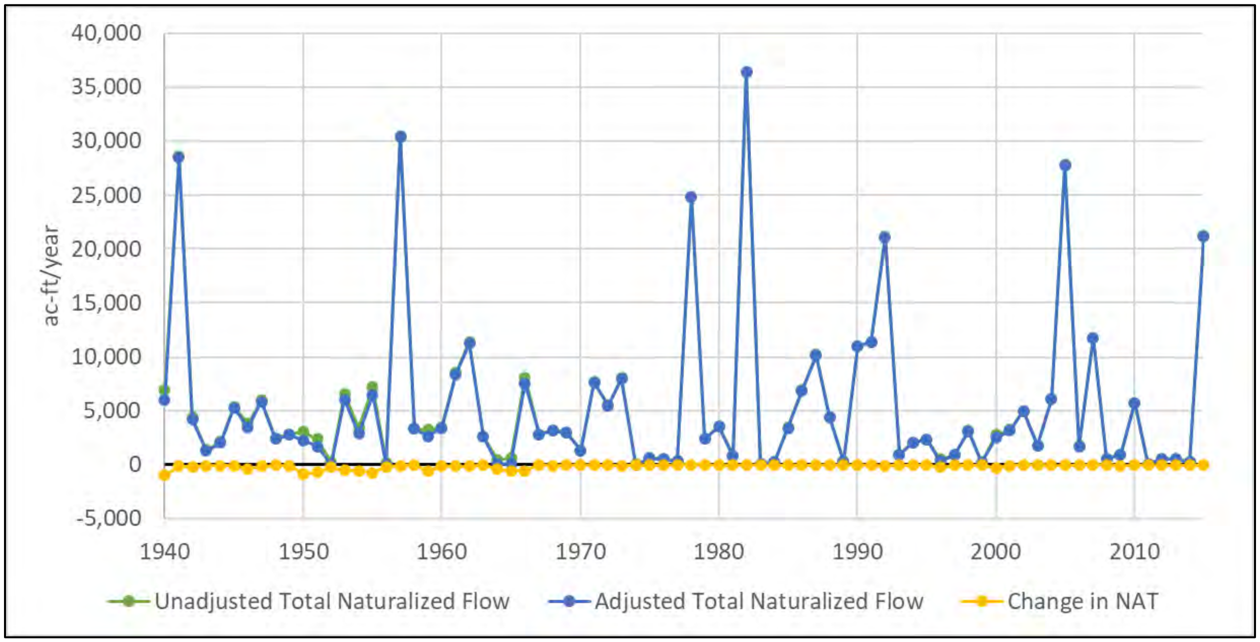


Figure 2-C-24 – Original and Adjusted Naturalized Flow Time Series for MSMN12 for 2070 Conditions

CFRO13 - Clear Fork Brazos River near Roby

Table 2-C-15 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.40	-0.37	-0.29	-0.41	-0.59	-0.32	-0.16	-0.36	-0.20	-0.36	-0.34	-0.55	-0.25
	P	0.000	0.000	0.001	0.000	0.002	0.042	0.330	0.059	0.215	0.024	0.053	0.001	0.108
P	τ	-0.05	0.02	0.01	-0.08	0.08	0.02	0.06	-0.27	0.14	0.15	0.08	-0.20	0.08
	P	0.561	0.865	0.932	0.399	0.680	0.910	0.721	0.163	0.367	0.365	0.649	0.234	0.612
Q/P	τ	-0.39	-0.37	-0.31	-0.41	-0.57	-0.34	-0.10	-0.28	-0.23	-0.47	-0.39	-0.47	-0.30
	P	0.000	0.000	0.001	0.000	0.002	0.030	0.559	0.150	0.143	0.003	0.025	0.006	0.059
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1957)		59	59	59	59	17	22	20	16	22	21	18	19	22

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

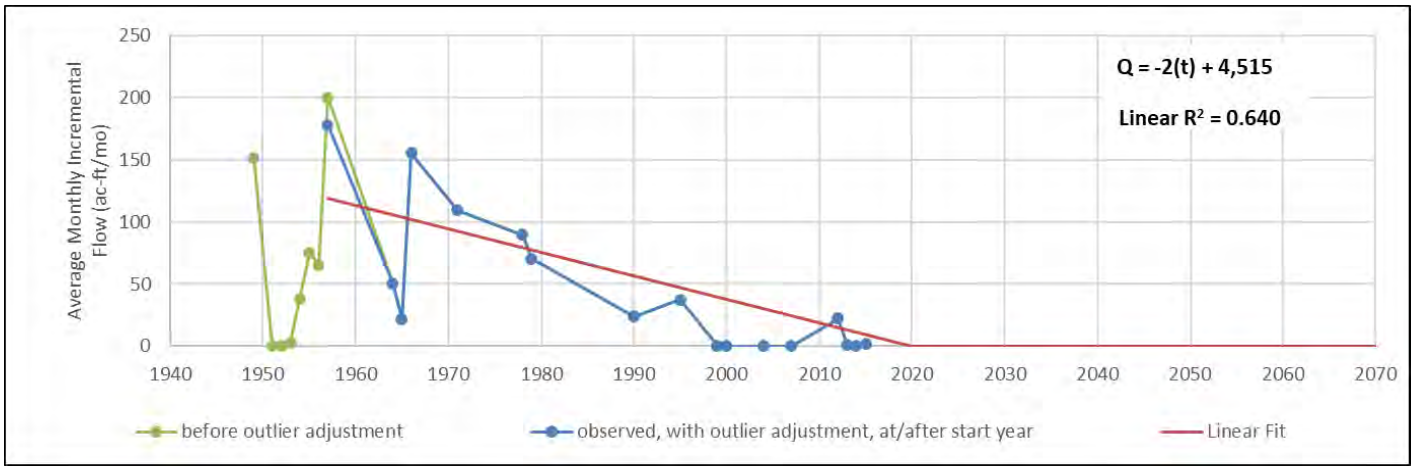


Figure 2-C-25 – Dry Winter Trend for Average Monthly Incremental Flow

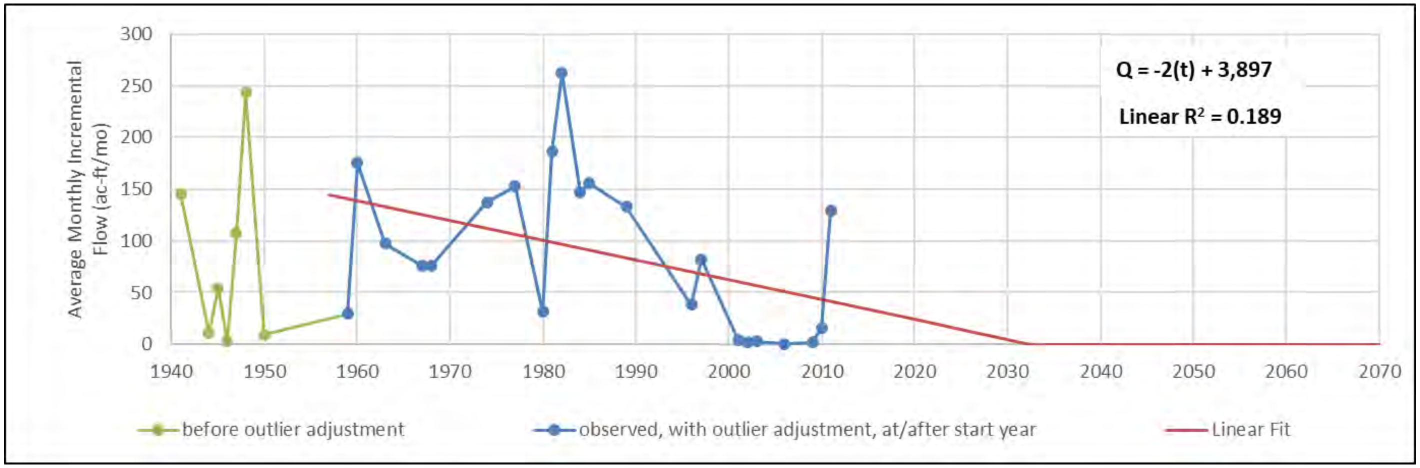


Figure 2-C-26 – Average Winter Trend for Average Monthly Incremental Flow

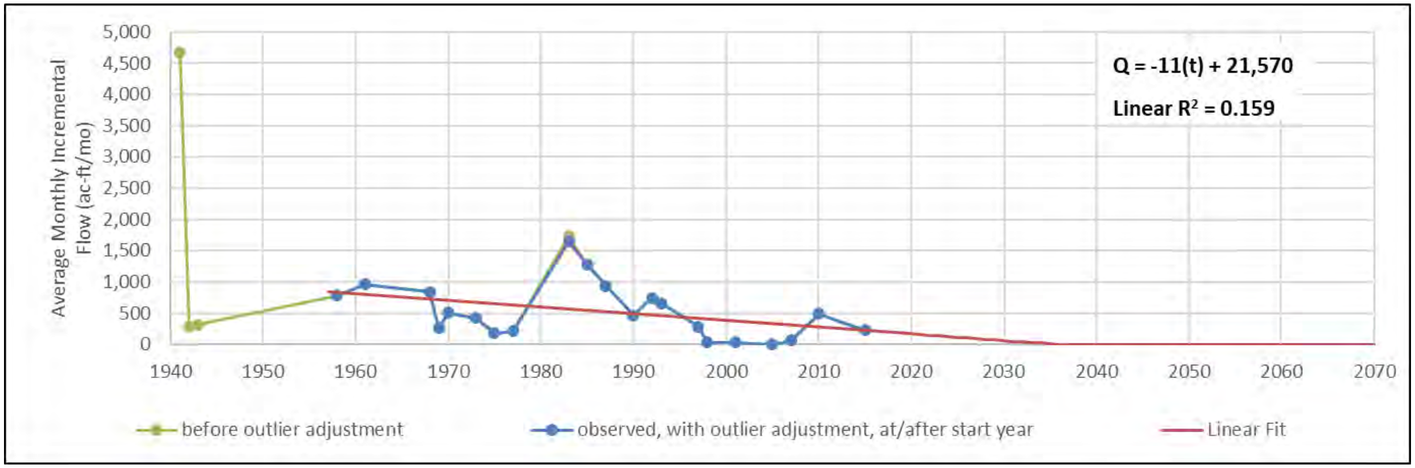


Figure 2-C-27 – Wet Spring Trend for Average Monthly Incremental Flow

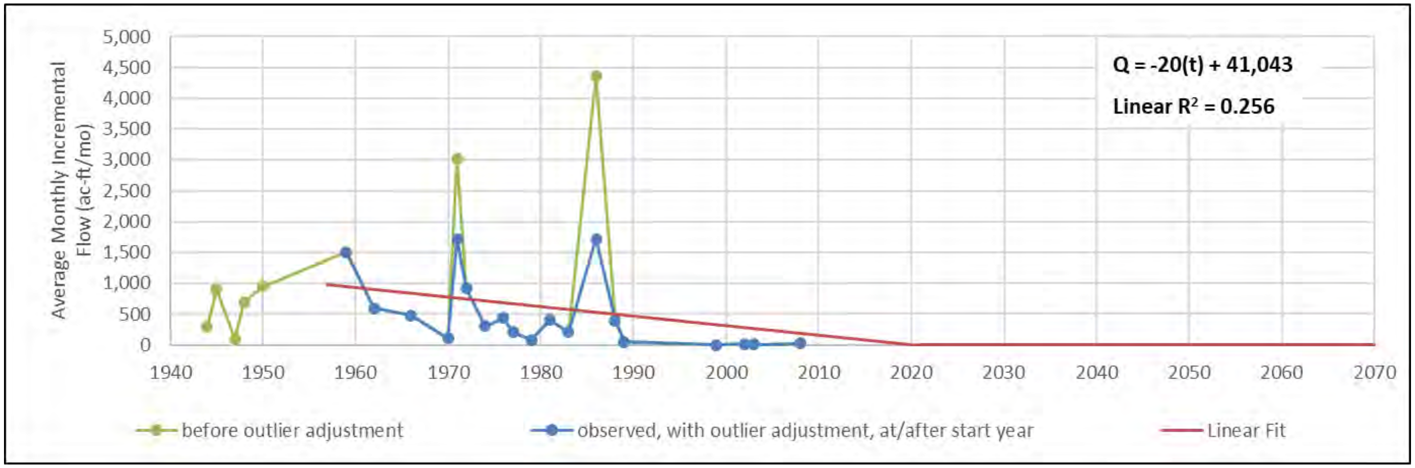


Figure 2-C-28 – Average Summer Trend for Average Monthly Incremental Flow

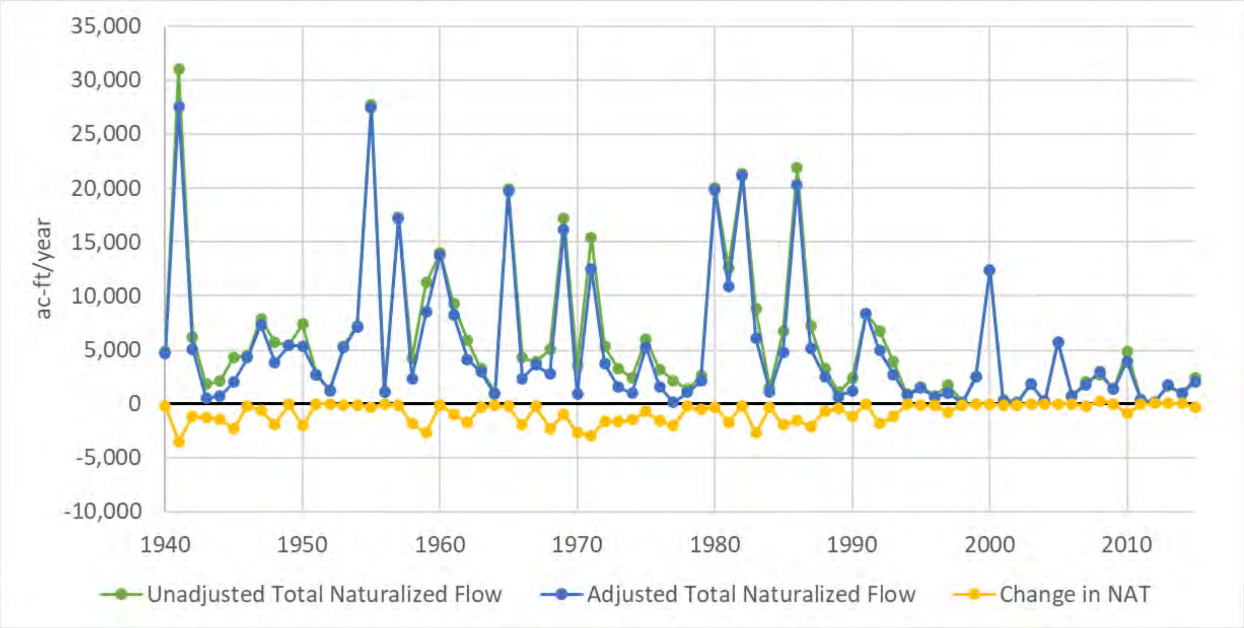


Figure 2-C-29 – Original and Adjusted Naturalized Flow Time Series for CFRO13 for 2070 Conditions

CFHA14 - Clear Fork Brazos River at Hawley

Table 2-C-16 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.28	-0.21	-0.26	-0.16	-0.37	-0.11	-0.04	-0.65	0.00	-0.09	-0.30	-0.13	0.07
	P	0.004	0.031	0.007	0.099	0.060	0.552	0.869	0.001	1.000	0.624	0.115	0.510	0.705
P	τ	-0.03	0.06	0.03	-0.11	0.23	0.01	0.15	-0.27	0.19	0.16	-0.07	-0.22	0.10
	P	0.751	0.570	0.739	0.280	0.255	1.000	0.434	0.189	0.289	0.345	0.753	0.232	0.596
Q/P	τ	-0.33	-0.29	-0.29	-0.16	-0.52	-0.23	-0.26	-0.53	-0.08	-0.26	-0.28	-0.18	-0.01
	P	0.001	0.003	0.003	0.093	0.008	0.184	0.161	0.010	0.649	0.124	0.150	0.343	1.000
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1965)		51	51	51	51	15	19	17	14	18	19	16	17	18

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

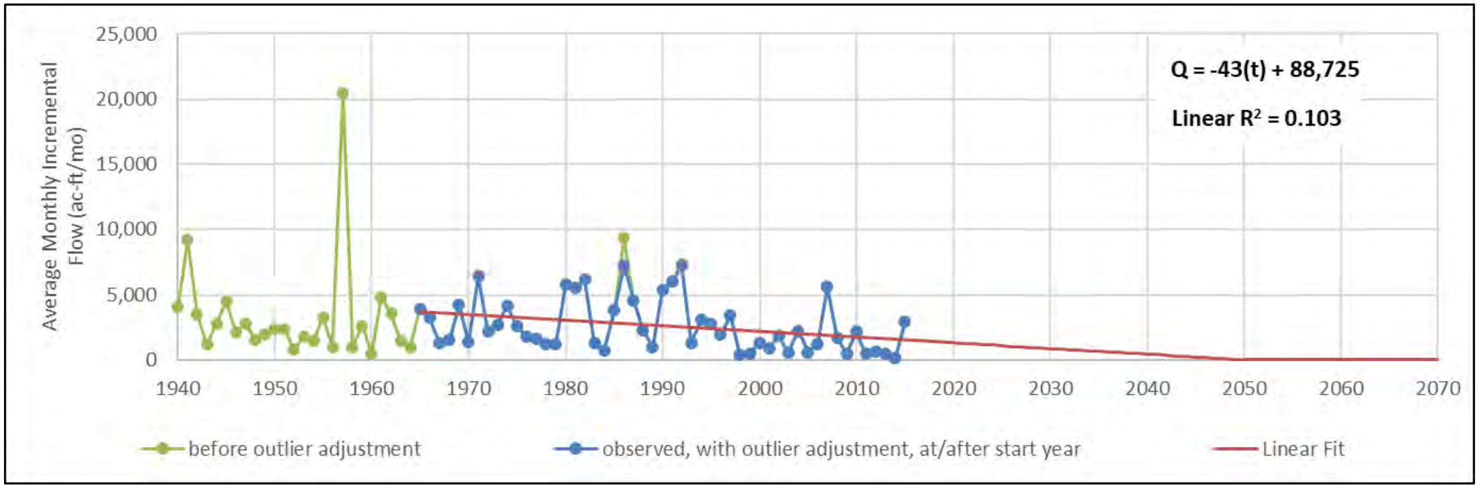


Figure 2-C-30 – Annual Trend for Average Monthly Incremental Flow

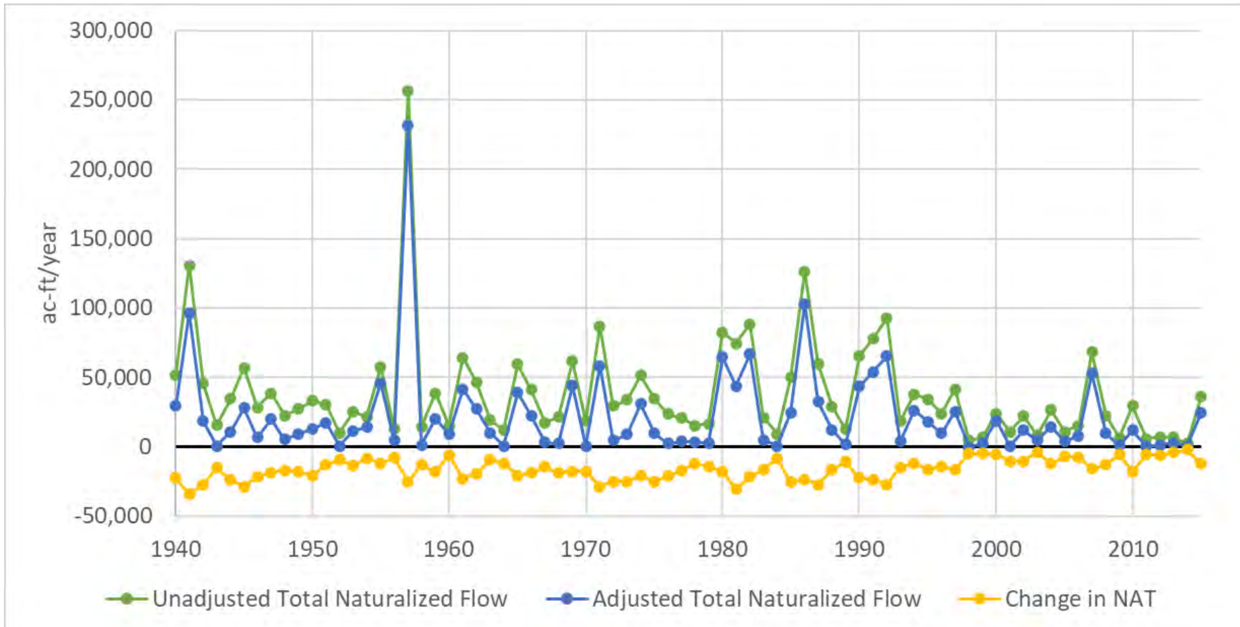


Figure 2-C-31 – Original and Adjusted Naturalized Flow Time Series for CFHA14 for 2070 Conditions

MUHA15 - Mulberry Creek near Hawley

Table 2-C-17 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.28	0.00	-0.23	-0.19	0.05	0.05	0.20	-0.54	0.03	-0.14	-0.40	-0.26	0.20
	P	0.004	0.974	0.019	0.055	0.843	0.780	0.284	0.009	0.880	0.421	0.034	0.161	0.272
P	τ	-0.03	0.06	0.03	-0.11	0.23	0.01	0.15	-0.27	0.19	0.16	-0.07	-0.22	0.10
	P	0.751	0.570	0.739	0.280	0.255	1.000	0.434	0.189	0.289	0.345	0.753	0.232	0.596
Q/P	τ	-0.32	0.02	-0.27	-0.16	-0.03	0.08	0.16	-0.54	0.01	-0.28	-0.35	-0.24	0.22
	P	0.001	0.826	0.005	0.090	0.921	0.649	0.410	0.009	1.000	0.100	0.065	0.202	0.211
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1965)		51	51	51	51	15	19	17	14	18	19	16	17	18

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

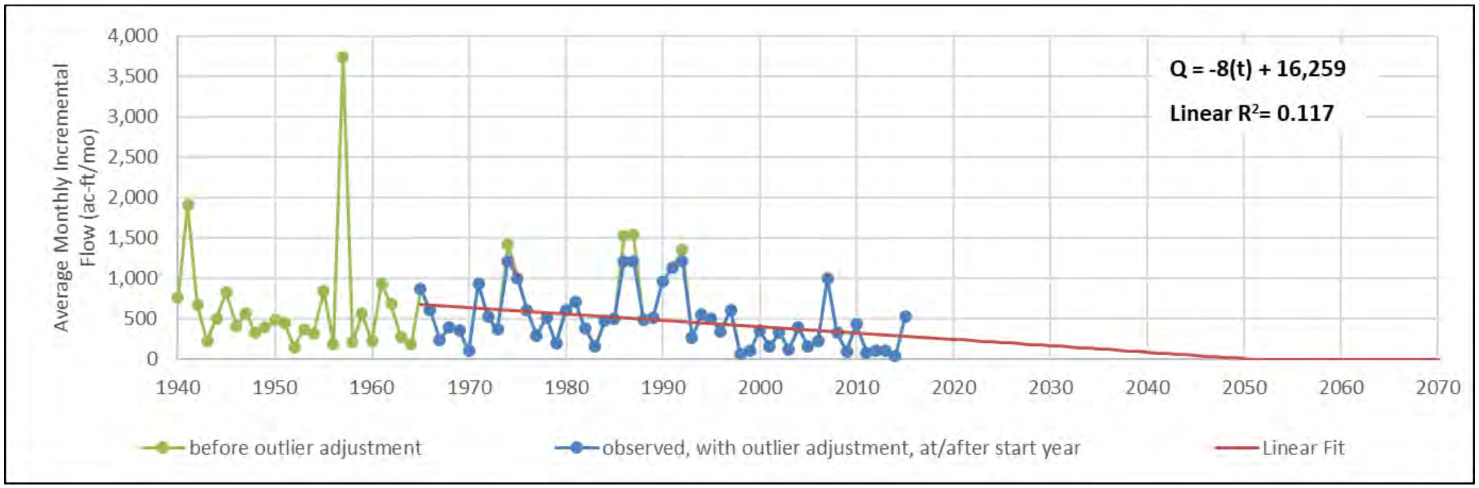


Figure 2-C-32 – Annual Trend for Average Monthly Incremental Flow

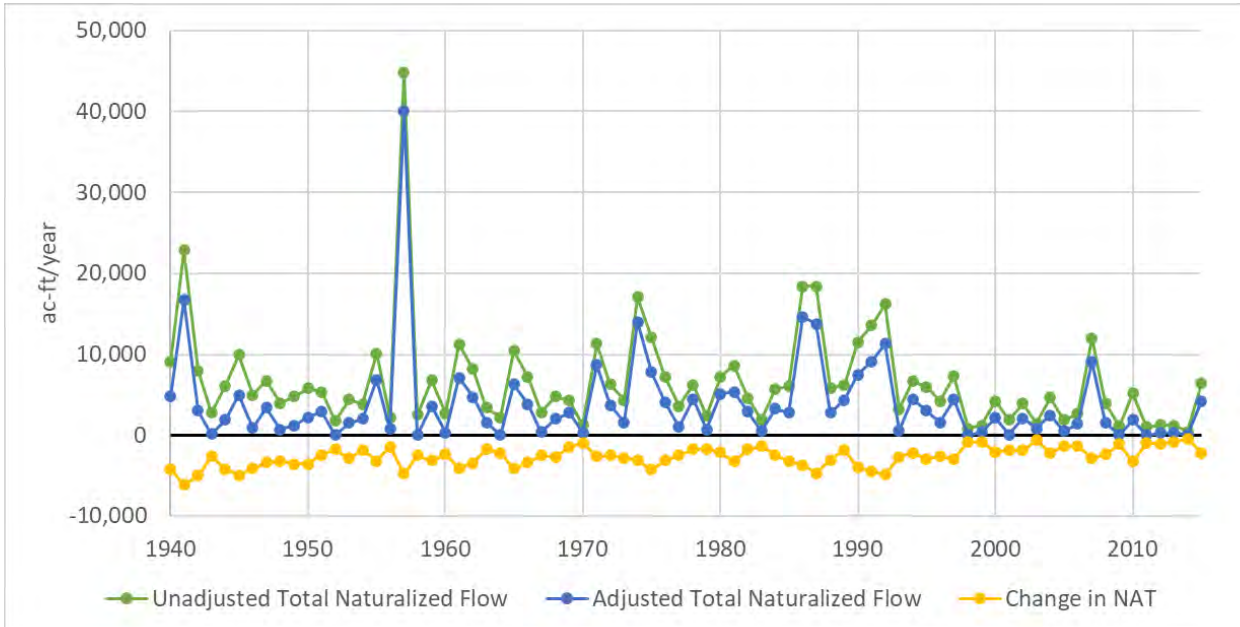


Figure 2-C-33 – Original and Adjusted Naturalized Flow Time Series for MUHA15 for 2070 Conditions

CFNU16 - Clear Fork Brazos River at Nugent

Table 2-C-18 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.29	-0.17	-0.26	-0.12	-0.14	-0.08	0.01	-0.49	-0.02	-0.25	-0.42	-0.15	0.28
	P	0.003	0.077	0.007	0.236	0.488	0.649	1.000	0.016	0.940	0.142	0.027	0.434	0.112
P	τ	-0.05	0.06	0.04	-0.11	0.20	-0.01	0.18	-0.23	0.18	0.16	-0.08	-0.22	0.10
	P	0.643	0.559	0.703	0.262	0.322	1.000	0.343	0.274	0.325	0.345	0.685	0.232	0.596
Q/P	τ	-0.35	-0.21	-0.32	-0.10	-0.33	-0.16	-0.14	-0.49	-0.03	-0.39	-0.37	-0.12	0.25
	P	0.000	0.031	0.001	0.295	0.092	0.363	0.458	0.016	0.880	0.021	0.053	0.537	0.150
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1965)		51	51	51	51	15	19	17	14	18	19	16	17	18

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

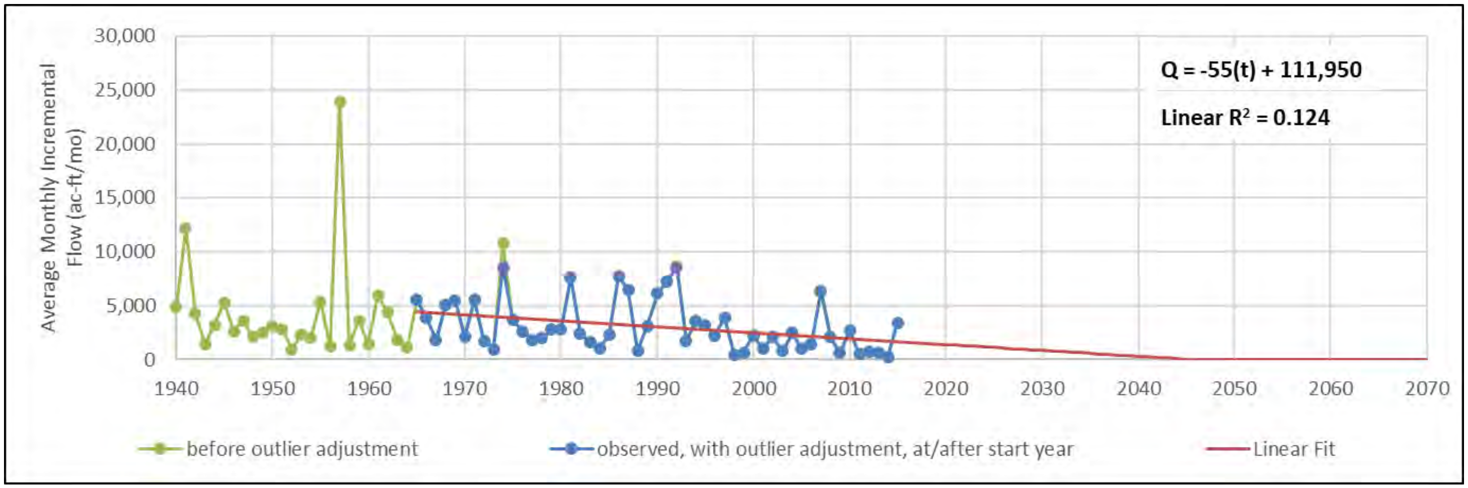


Figure 2-C-34 – Annual Trend for Average Monthly Incremental Flow

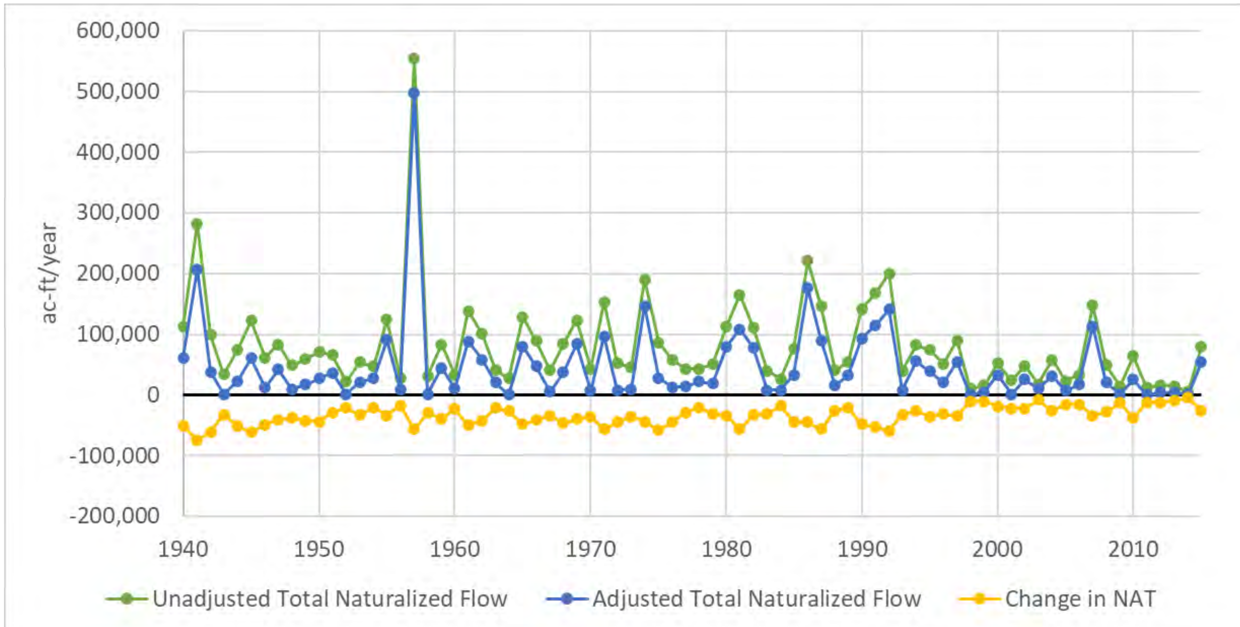


Figure 2-C-35 – Original and Adjusted Naturalized Flow Time Series for CFNU16 for 2070 Conditions

CAST17 - California Creek near Stamford

Table 2-C-19 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.04	0.00	-0.03	-0.10	-0.03	0.08	0.01	-0.30	0.08	0.12	-0.14	-0.19	0.10
	P	0.657	0.956	0.720	0.216	0.862	0.536	0.978	0.038	0.574	0.442	0.317	0.215	0.498
P	τ	0.08	0.05	0.05	0.02	0.24	-0.17	0.22	-0.12	0.19	0.08	0.21	-0.03	-0.08
	P	0.317	0.552	0.515	0.833	0.107	0.209	0.159	0.414	0.182	0.585	0.123	0.862	0.591
Q/P	τ	-0.07	0.02	-0.05	-0.10	-0.17	0.26	-0.06	-0.28	0.04	0.09	-0.16	-0.23	0.12
	P	0.389	0.848	0.495	0.184	0.244	0.047	0.714	0.053	0.802	0.568	0.260	0.118	0.427
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1940)		76	75	76	76	24	29	22	25	27	24	27	24	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

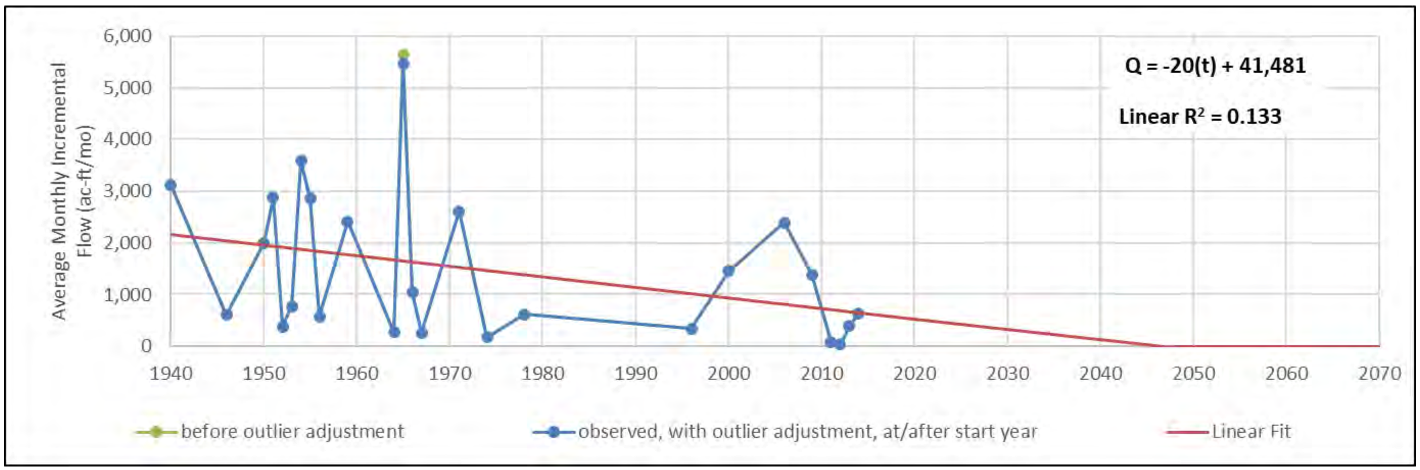


Figure 2-C-36 – Dry Spring Trend for Average Monthly Incremental Flow

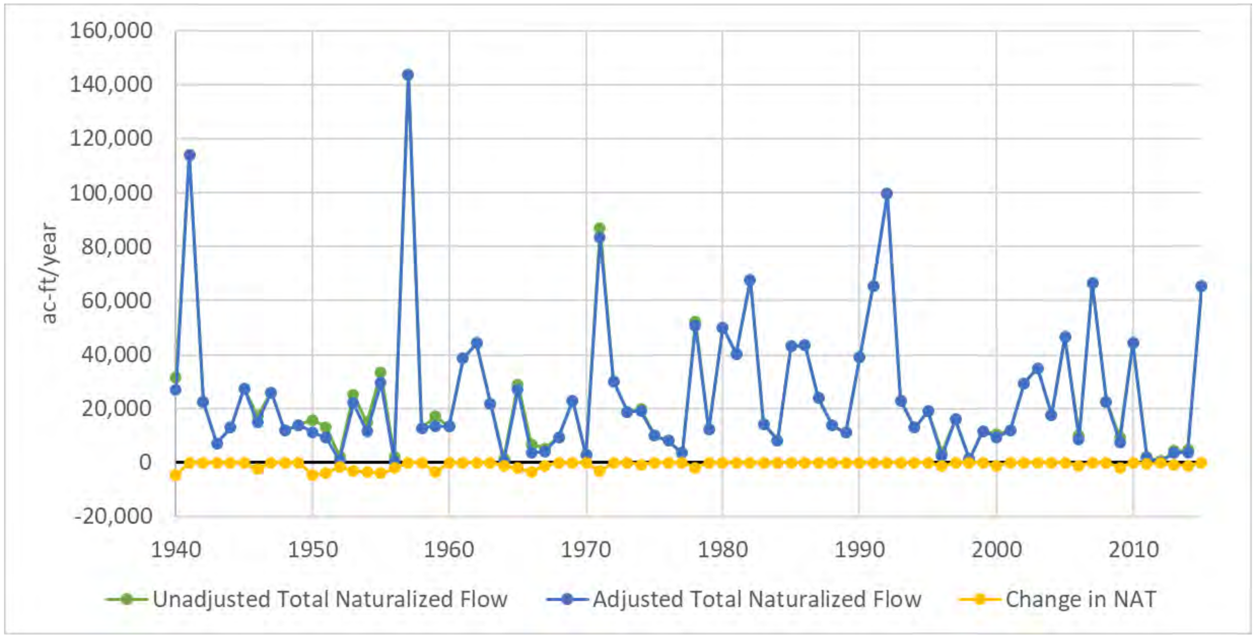


Figure 2-C-37 – Original and Adjusted Naturalized Flow Time Series for CAST17 for 2070 Conditions

CFFG18 - Clear Fork Brazos River at Fort Griffin

Table 2-C-20 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.11	0.04	-0.10	-0.11	0.03	0.13	0.23	-0.31	-0.09	0.03	-0.13	-0.16	0.03
	P	0.155	0.602	0.219	0.156	0.882	0.329	0.150	0.030	0.518	0.862	0.348	0.275	0.852
P	τ	0.05	0.04	0.01	0.05	0.20	-0.18	0.26	-0.24	0.14	-0.01	0.26	-0.02	-0.08
	P	0.530	0.583	0.900	0.545	0.172	0.171	0.091	0.097	0.317	0.960	0.055	0.901	0.591
Q/P	τ	-0.16	0.07	-0.12	-0.12	0.08	0.21	0.15	-0.33	-0.11	0.06	-0.10	-0.23	0.05
	P	0.040	0.370	0.139	0.126	0.620	0.115	0.352	0.023	0.416	0.691	0.491	0.124	0.726
Period of Record (1940:2015)		76	75	76	76	24	29	22	25	27	24	27	24	25
Period of Analysis (Start Year: 1940)		76	75	76	76	24	29	22	25	27	24	27	24	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

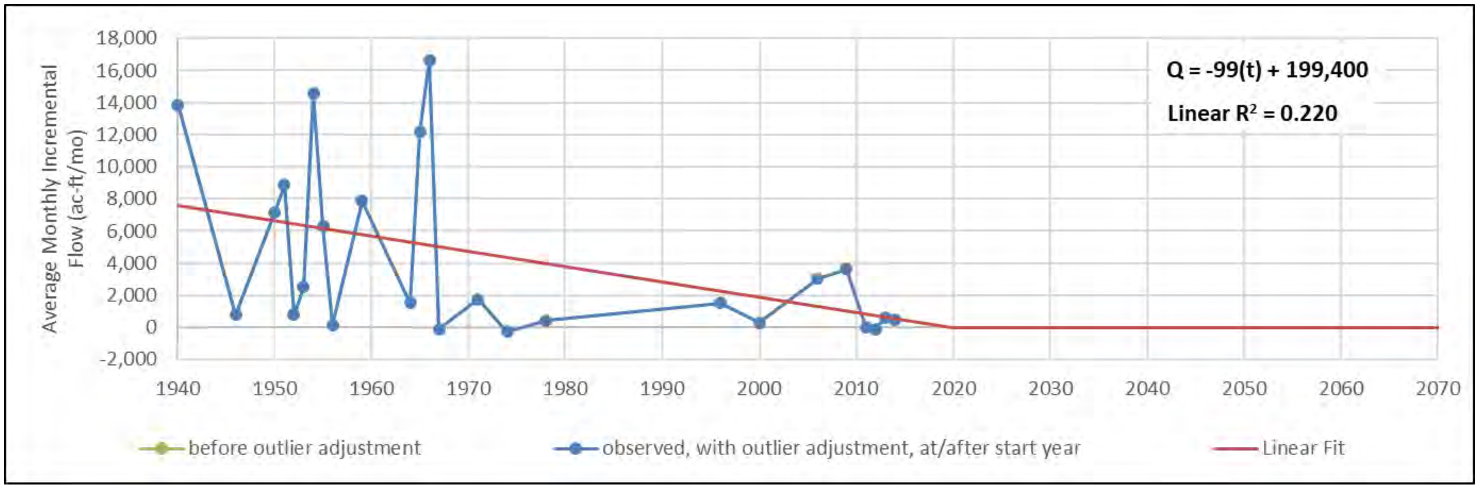


Figure 2-C-38 – Dry Spring Trend for Average Monthly Incremental Flow

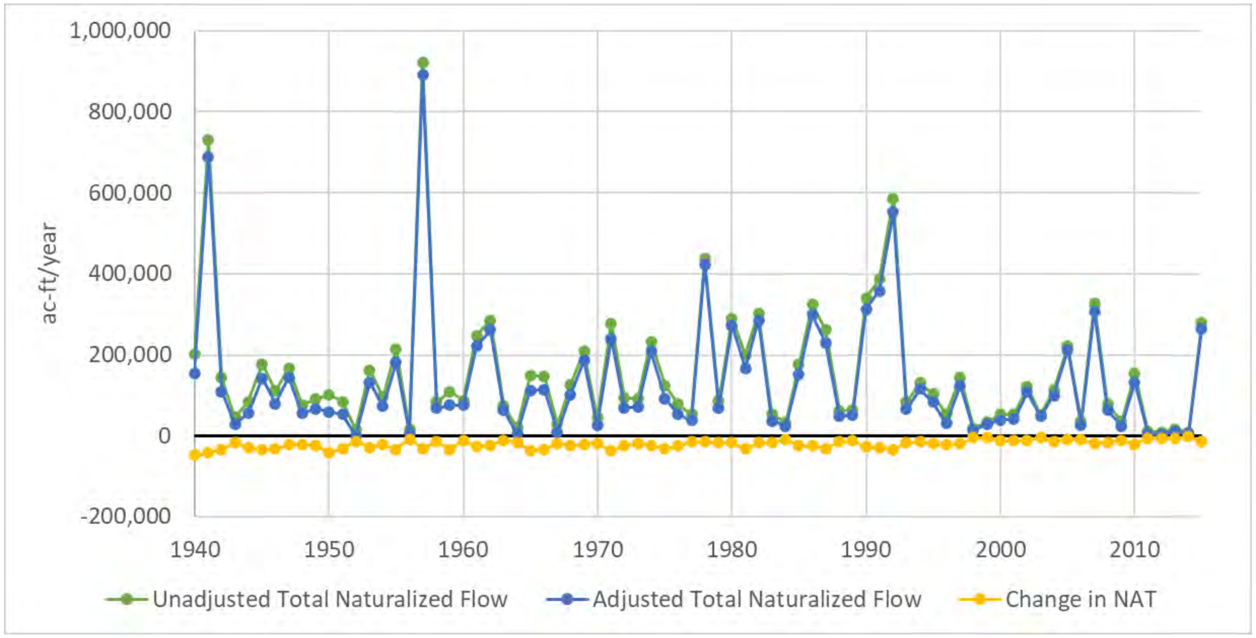


Figure 2-C-39 – Original and Adjusted Naturalized Flow Time Series for CFFG18 for 2070 Conditions

HCAL19 - Hubbard Creek below Albany

Table 2-C-21 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.27	-0.25	-0.26	-0.24	-0.53	-0.31	0.02	-0.69	0.03	-0.25	-0.22	-0.43	0.06
	P	0.002	0.004	0.003	0.006	0.001	0.053	0.948	0.000	0.888	0.142	0.154	0.012	0.740
P	τ	0.09	0.07	0.06	-0.01	-0.03	-0.05	0.12	0.00	0.13	-0.04	0.08	-0.09	0.03
	P	0.313	0.448	0.488	0.943	0.866	0.786	0.496	1.000	0.430	0.834	0.635	0.624	0.880
Q/P	τ	-0.31	-0.29	-0.29	-0.25	-0.59	-0.36	-0.04	-0.64	-0.04	-0.27	-0.21	-0.42	0.07
	P	0.000	0.001	0.001	0.004	0.000	0.024	0.846	0.000	0.822	0.108	0.170	0.014	0.695
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1953)		63	63	63	63	22	21	20	22	22	19	23	19	21

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

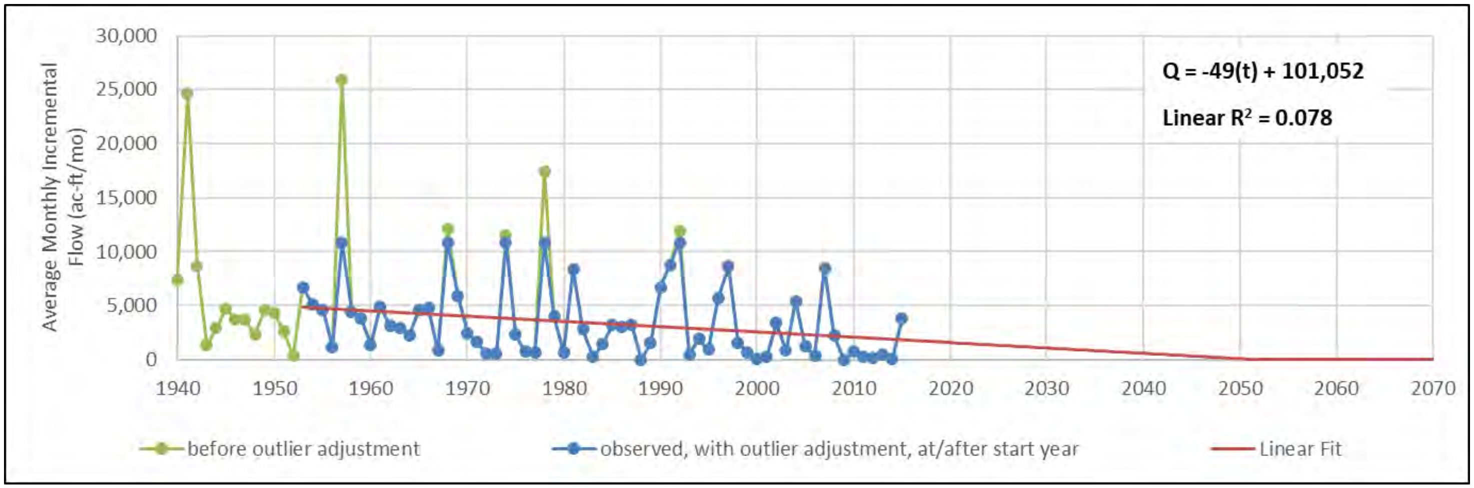


Figure 2-C-40 – Annual Trend for Average Monthly Incremental Flow

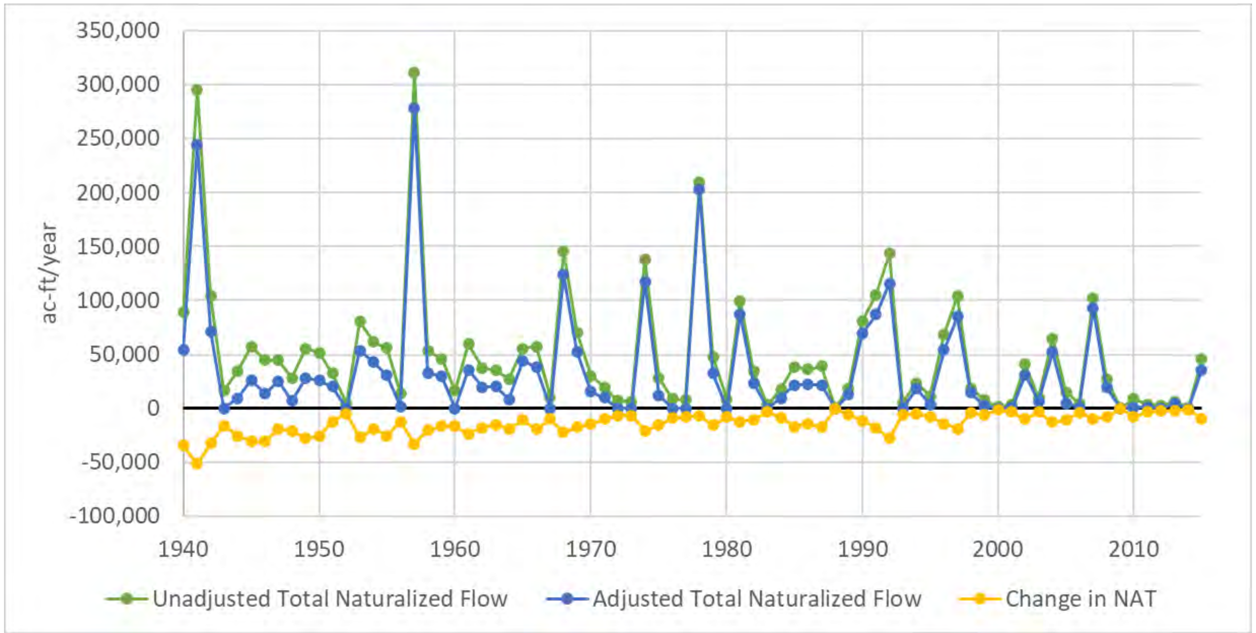


Figure 2-C-41 – Original and Adjusted Naturalized Flow Time Series for HCAL19 for 2070 Conditions

BSBR20 - Big Sandy Creek above Breckenridge

Table 2-C-22 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.06	-0.08	-0.16	-0.12	-0.06	-0.12	0.02	-0.51	0.12	-0.13	0.05	-0.29	-0.07
	P	0.465	0.337	0.046	0.140	0.708	0.427	0.921	0.000	0.378	0.430	0.739	0.061	0.628
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.435	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.08	-0.10	-0.16	-0.15	-0.09	-0.10	-0.08	-0.50	0.07	-0.06	0.00	-0.38	-0.05
	P	0.304	0.224	0.046	0.054	0.567	0.513	0.620	0.001	0.586	0.714	1.000	0.011	0.724
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

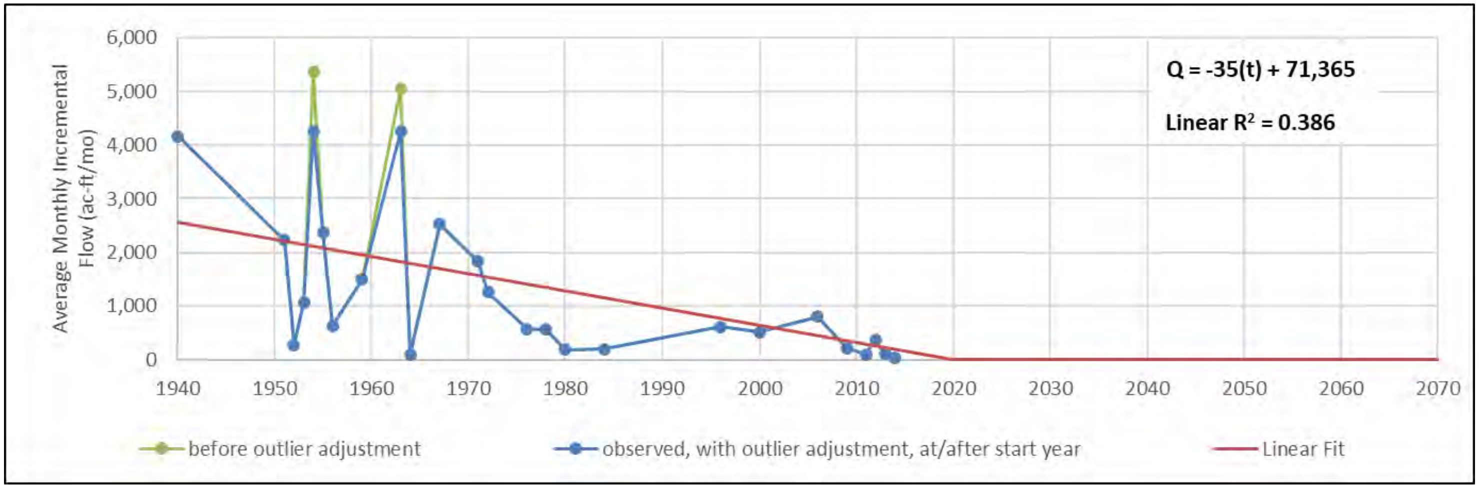


Figure 2-C-42 – Dry Spring Trend for Average Monthly Incremental Flow

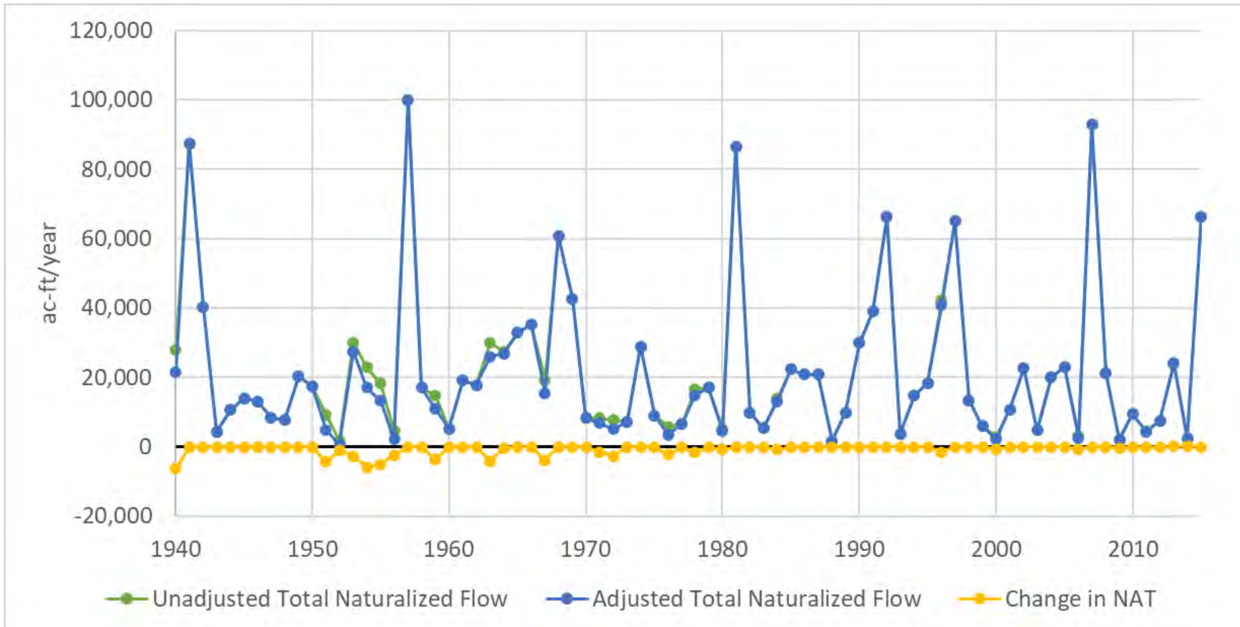


Figure 2-C-43 – Original and Adjusted Naturalized Flow Time Series for BSBR20 for 2070 Conditions

HCBR21 - Hubbard Creek near Breckenridge

Table 2-C-23 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.04	0.11	-0.08	-0.07	0.05	0.17	0.06	-0.25	0.09	-0.22	0.17	-0.28	-0.10
	P	0.635	0.170	0.298	0.399	0.758	0.234	0.691	0.084	0.488	0.167	0.219	0.064	0.494
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.435	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.06	0.09	-0.09	-0.07	0.05	0.27	-0.01	-0.19	0.07	-0.19	0.16	-0.32	-0.06
	P	0.457	0.236	0.240	0.363	0.741	0.065	0.980	0.199	0.613	0.236	0.243	0.035	0.675
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

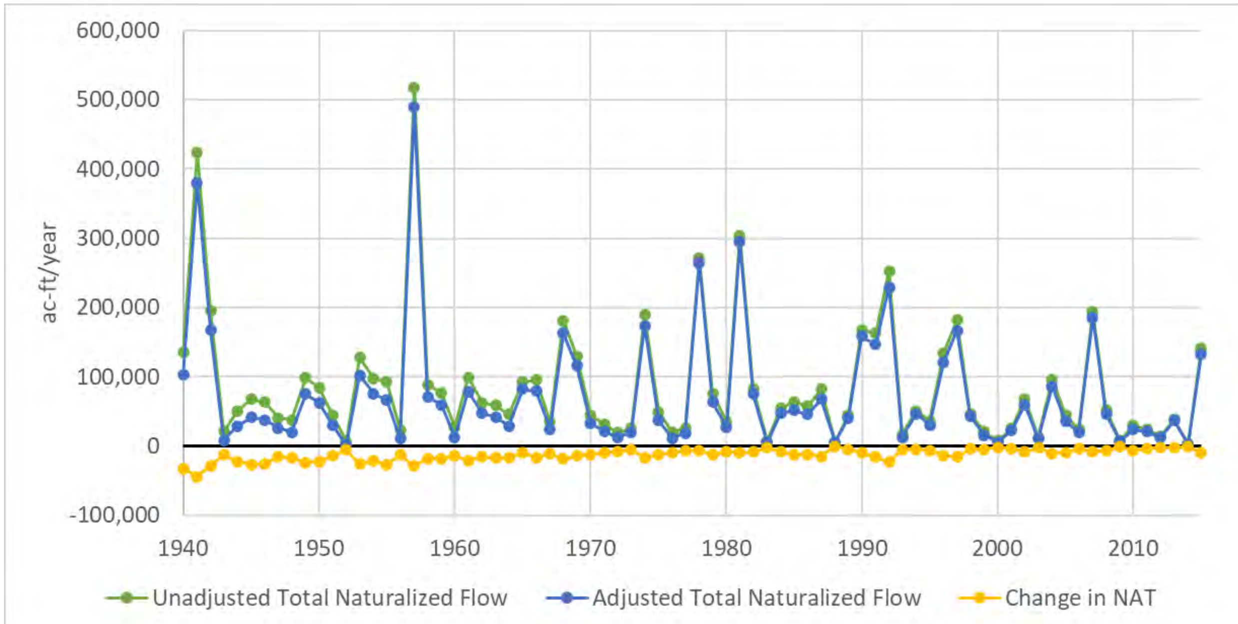


Figure 2-C-44 – Original and Adjusted Naturalized Flow Time Series for HCBR21 for 2070 Conditions

CFEL22 - Clear Fork Brazos River at Eliasville

Table 2-C-24 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.26	-0.16	-0.18	-0.21	-0.18	-0.28	-0.04	-0.39	-0.31	0.01	-0.17	-0.44	0.05
	P	0.004	0.069	0.041	0.022	0.325	0.080	0.846	0.028	0.048	1.000	0.327	0.010	0.763
P	τ	-0.01	0.03	0.01	-0.08	-0.03	-0.05	0.12	0.01	0.13	-0.04	-0.06	-0.09	0.03
	P	0.958	0.704	0.958	0.360	0.880	0.786	0.496	1.000	0.430	0.834	0.726	0.624	0.880
Q/P	τ	-0.27	-0.20	-0.20	-0.19	-0.23	-0.28	-0.12	-0.45	-0.32	-0.04	-0.20	-0.50	0.10
	P	0.003	0.027	0.024	0.031	0.198	0.080	0.475	0.010	0.037	0.834	0.248	0.003	0.566
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1957)		59	59	59	59	18	21	20	18	22	19	19	19	21

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

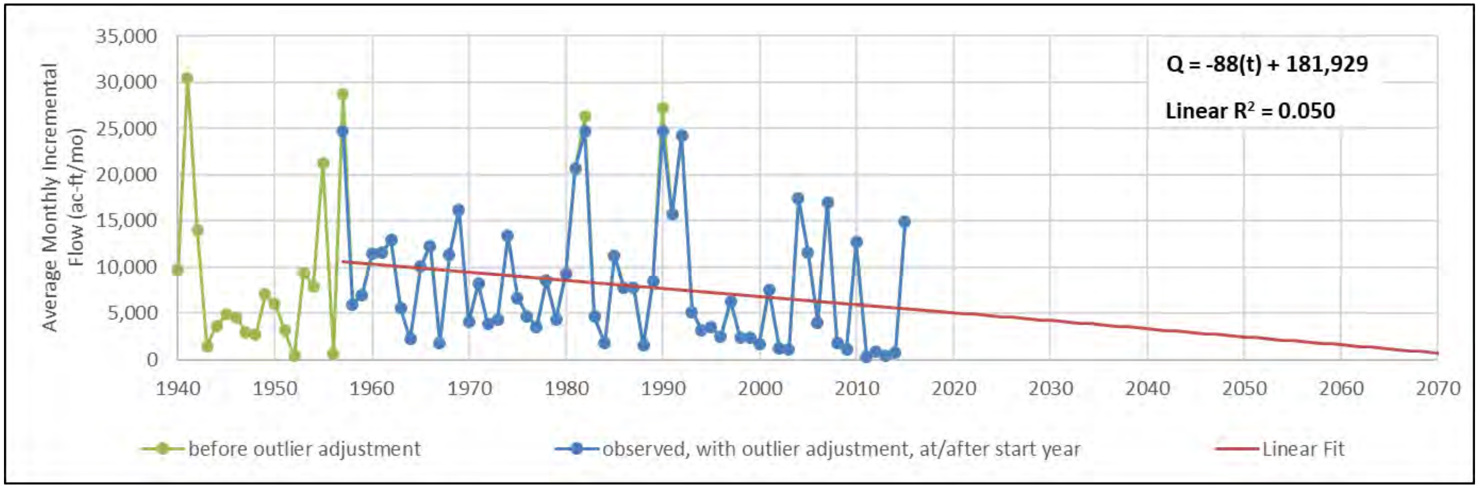


Figure 2-C-45 – Annual Trend for Average Monthly Incremental Flow

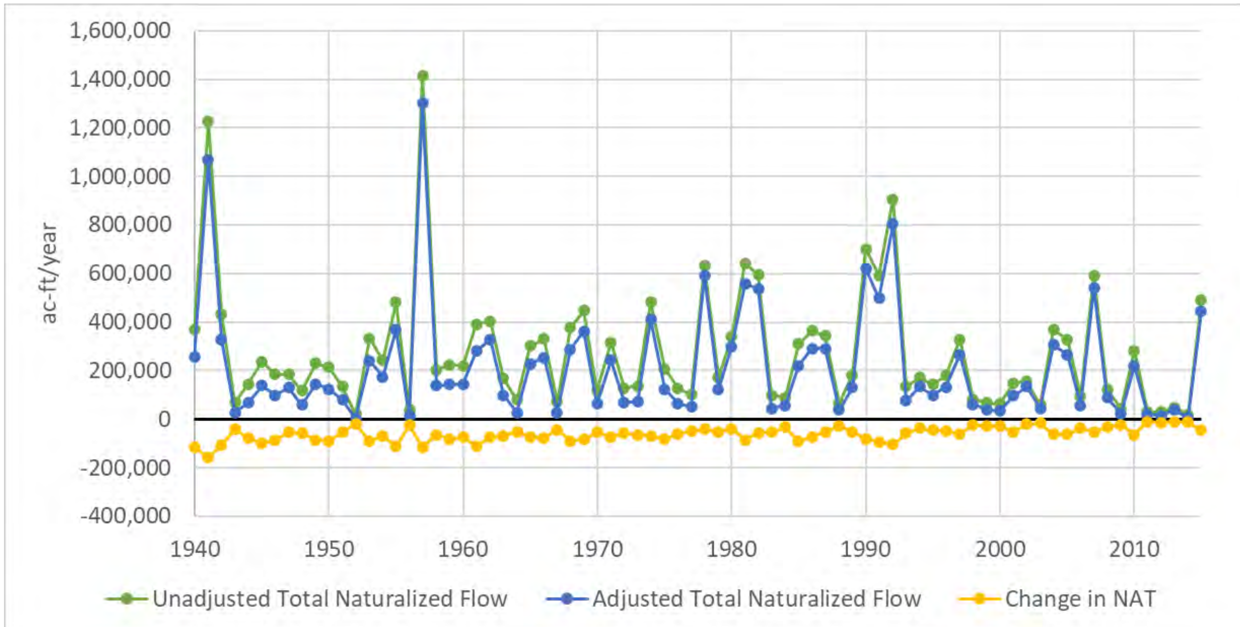


Figure 2-C-46 – Original and Adjusted Naturalized Flow Time Series for CFEL22 for 2070 Conditions

BRSB23 - Brazos River near South Bend

Table 2-C-25 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.23	-0.18	-0.18	-0.21	-0.31	-0.17	0.06	-0.58	-0.11	0.02	-0.25	-0.39	0.15
	P	0.009	0.048	0.043	0.017	0.081	0.305	0.746	0.001	0.481	0.944	0.142	0.021	0.349
P	τ	-0.02	0.03	0.00	-0.09	-0.02	-0.04	0.15	-0.02	0.11	0.01	-0.05	-0.16	0.02
	P	0.865	0.714	0.974	0.320	0.940	0.833	0.381	0.940	0.481	1.000	0.780	0.363	0.928
Q/P	τ	-0.27	-0.19	-0.20	-0.24	-0.39	-0.11	0.03	-0.57	-0.11	0.08	-0.25	-0.40	0.14
	P	0.003	0.037	0.023	0.007	0.028	0.506	0.897	0.001	0.499	0.675	0.142	0.019	0.381
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1957)		59	59	59	59	18	21	20	18	22	19	19	19	21

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

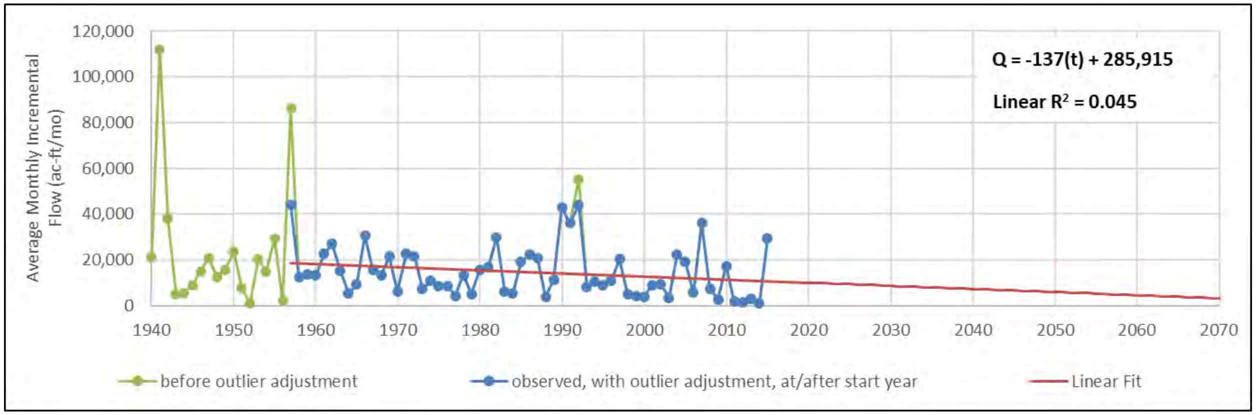


Figure 2-C-47 – Annual Trend for Average Monthly Incremental Flow

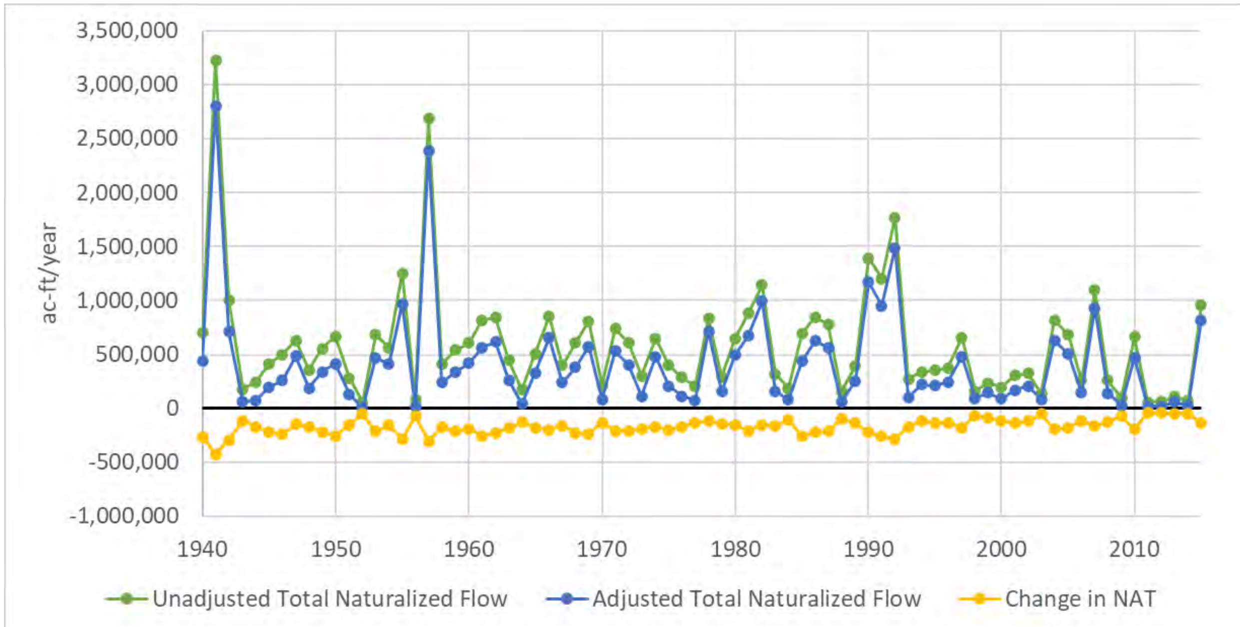


Figure 2-C-48 – Original and Adjusted Naturalized Flow Time Series for BRSB23 for 2070 Conditions

GHGH24 - Lake Graham near Graham

Table 2-C-26 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.03	0.00	0.00	-0.11	-0.11	-0.06	0.19	-0.23	0.14	0.13	-0.07	-0.20	-0.03
	P	0.750	0.985	1.000	0.178	0.440	0.674	0.215	0.112	0.311	0.414	0.632	0.187	0.843
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.01	0.01	-0.01	-0.13	-0.10	0.01	0.16	-0.24	0.10	0.13	-0.11	-0.25	-0.02
	P	0.907	0.902	0.932	0.097	0.494	0.981	0.275	0.097	0.476	0.414	0.416	0.102	0.877
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

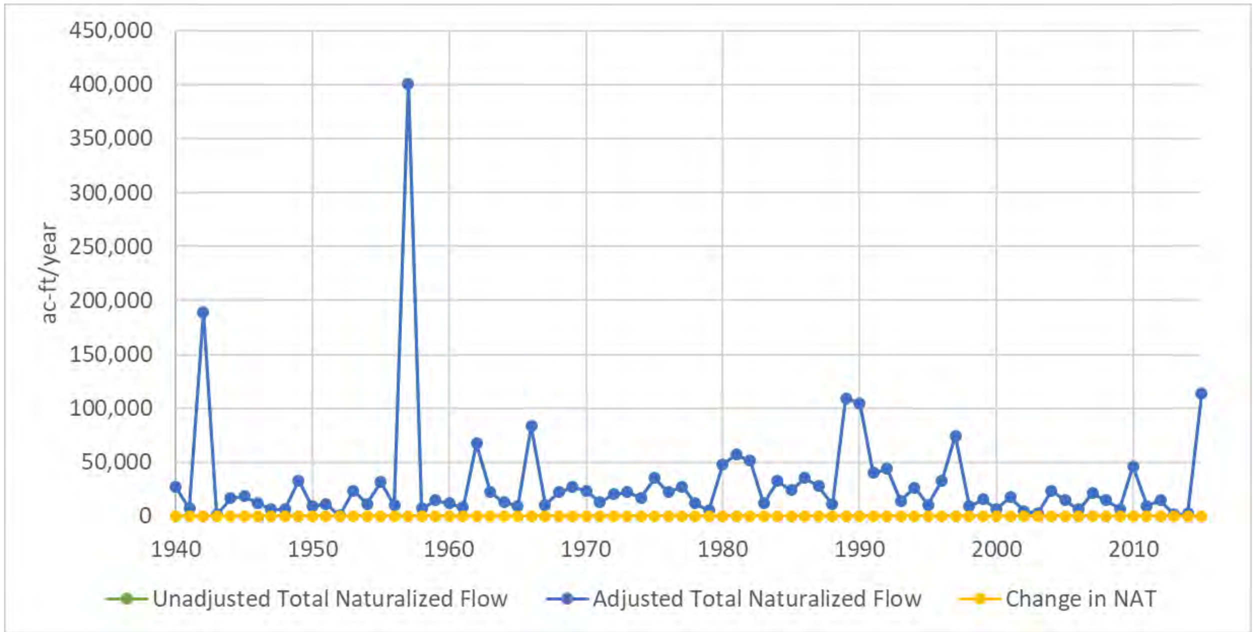


Figure 2-C-49 – Original and Adjusted Naturalized Flow Time Series for GHGH24 for 2070 Conditions

CCIV25 - Big Cedar Creek near Ivan

Table 2-C-27 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.12	-0.04	-0.08	-0.23	0.10	-0.20	-0.04	-0.28	0.02	-0.01	-0.23	-0.35	-0.19
	P	0.114	0.638	0.317	0.004	0.508	0.168	0.804	0.055	0.866	0.955	0.104	0.022	0.179
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.710	0.438	0.826	0.168	0.189	0.293	0.294	0.236	0.080	0.342	0.537
Q/P	τ	-0.14	-0.04	-0.08	-0.27	0.14	-0.13	-0.12	-0.25	-0.02	-0.02	-0.30	-0.40	-0.21
	P	0.077	0.612	0.317	0.000	0.332	0.375	0.442	0.080	0.896	0.910	0.030	0.008	0.134
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

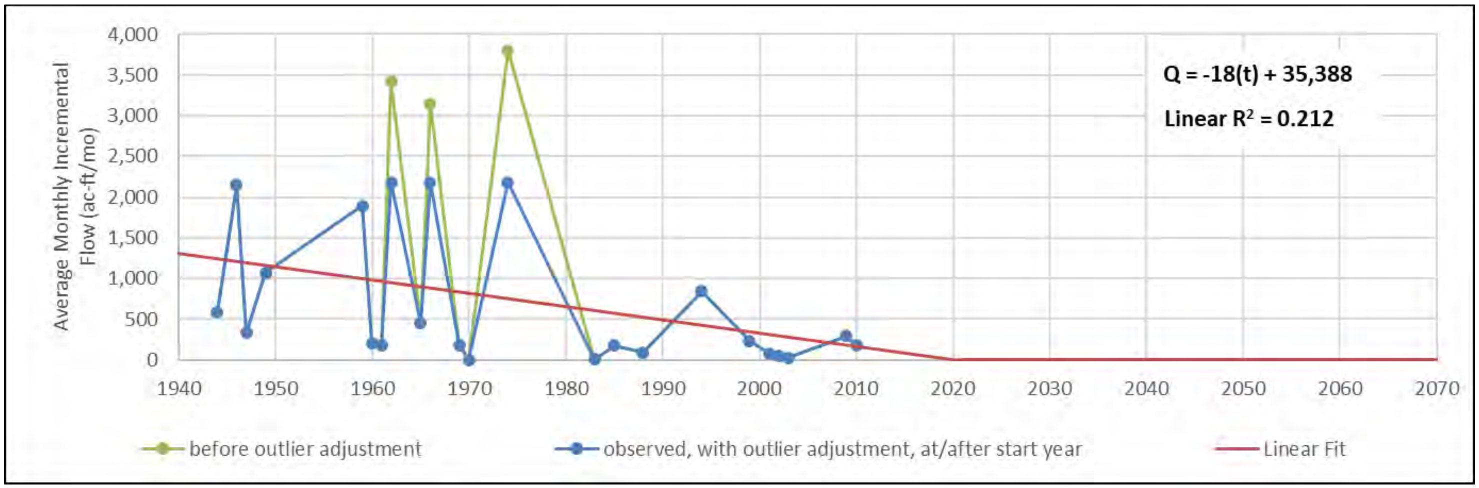


Figure 2-C-50 – Average Summer Trend for Average Monthly Incremental Flow

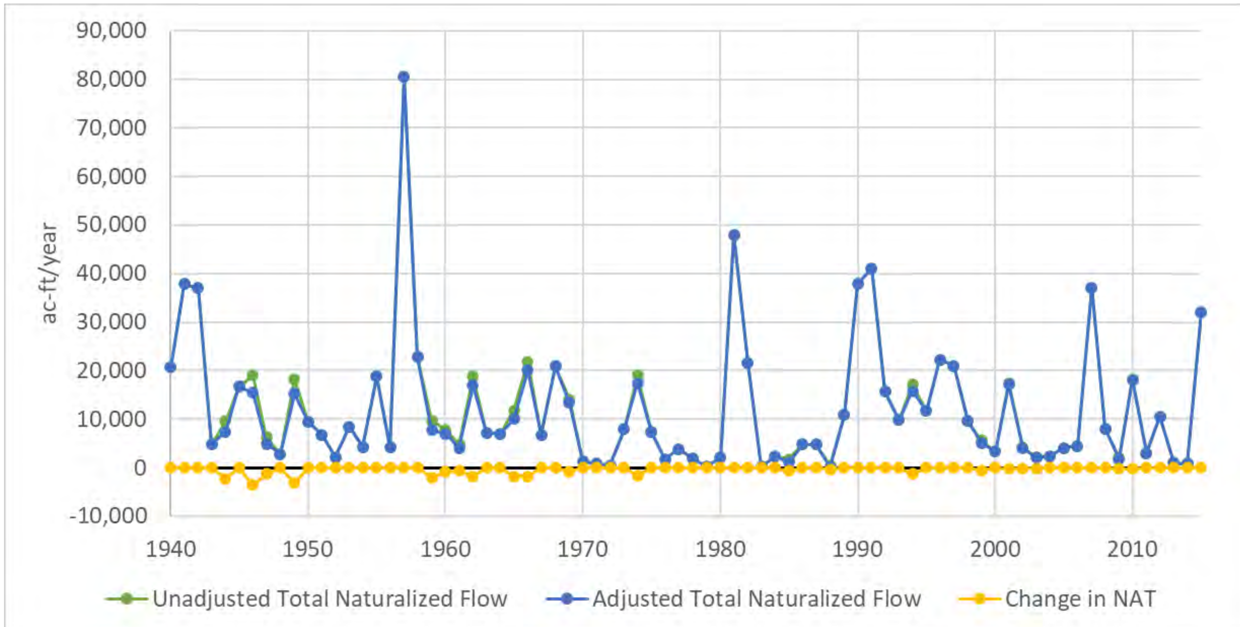


Figure 2-C-51 – Original and Adjusted Naturalized Flow Time Series for CCIV25 for 2070 Conditions

SHGR26 - Brazos River at Morris Sheppard Dam near Graford

Table 2-C-28 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.34	-0.13	-0.30	-0.19	0.07	-0.18	-0.18	-0.14	-0.34	-0.49	-0.19	-0.18	-0.15
	P	0.000	0.172	0.002	0.047	0.753	0.343	0.306	0.488	0.053	0.005	0.303	0.373	0.401
P	τ	-0.01	0.03	-0.03	-0.06	0.05	-0.22	0.18	0.10	0.09	-0.08	-0.18	0.09	0.08
	P	0.922	0.758	0.733	0.542	0.822	0.232	0.325	0.621	0.649	0.649	0.343	0.692	0.675
Q/P	τ	-0.36	-0.18	-0.32	-0.20	0.05	-0.22	-0.28	-0.14	-0.46	-0.48	-0.21	-0.20	-0.18
	P	0.000	0.065	0.001	0.035	0.822	0.249	0.112	0.488	0.010	0.006	0.266	0.322	0.294
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1965)		51	51	51	51	16	17	18	15	18	18	17	15	19

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

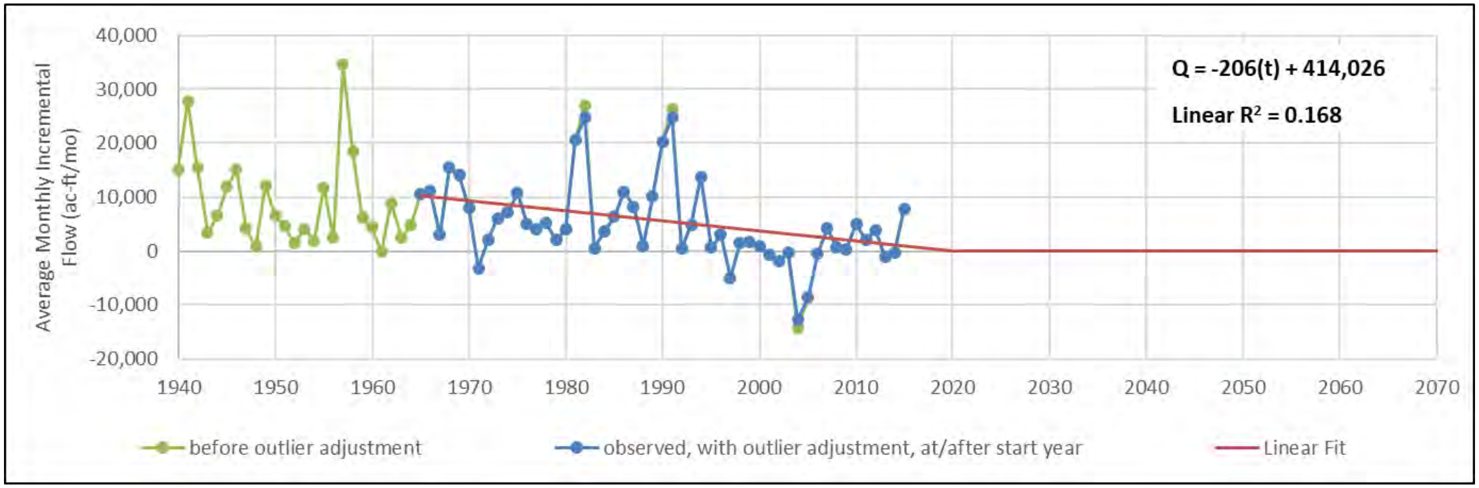


Figure 2-C-52 – Annual Trend for Average Monthly Incremental Flow

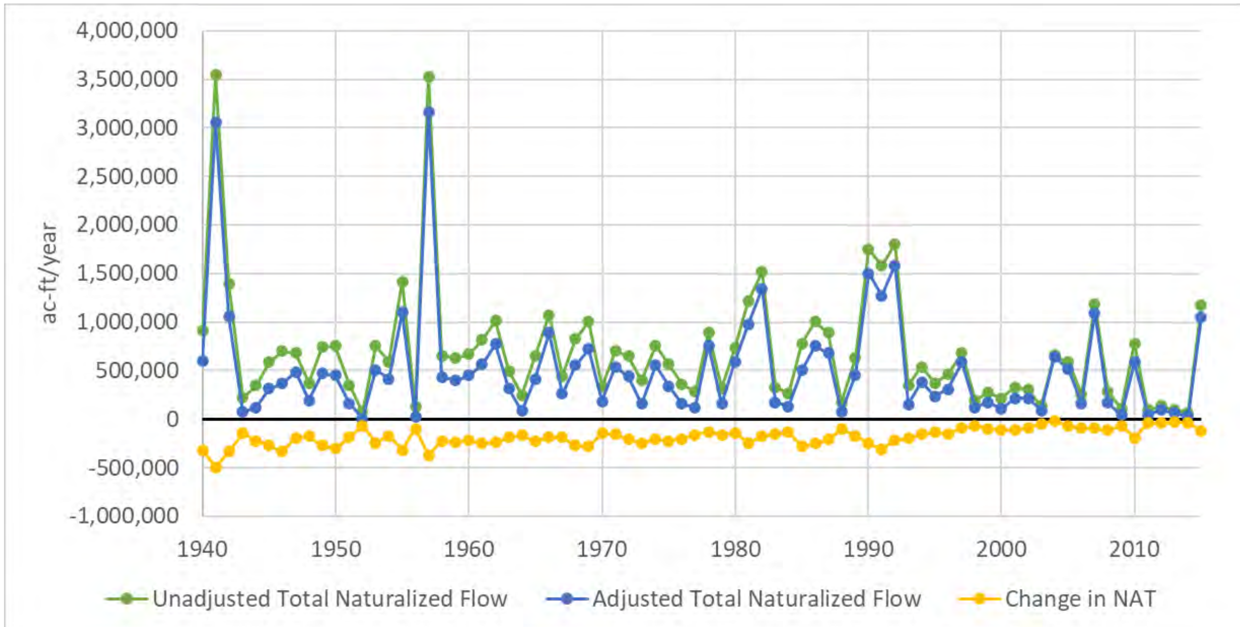


Figure 2-C-53 – Original and Adjusted Naturalized Flow Time Series for SHGR26 for 2070 Conditions

BRPP27 - Brazos River near Palo Pinto

Table 2-C-29 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.31	0.33	0.21	0.10	0.39	0.18	0.40	-0.05	0.28	0.45	0.07	-0.04	0.25
	P	0.000	0.000	0.008	0.236	0.005	0.207	0.011	0.747	0.034	0.006	0.602	0.833	0.096
P	τ	0.11	0.03	0.03	0.09	-0.03	-0.20	0.22	-0.08	0.14	-0.06	0.24	0.15	-0.06
	P	0.184	0.682	0.675	0.253	0.826	0.168	0.159	0.602	0.294	0.721	0.080	0.342	0.712
Q/P	τ	0.30	0.36	0.23	0.08	0.46	0.25	0.36	-0.07	0.31	0.50	0.05	-0.11	0.27
	P	0.000	0.000	0.005	0.320	0.001	0.084	0.019	0.655	0.018	0.002	0.707	0.492	0.077
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1943)		73	73	73	73	26	25	22	24	29	20	27	23	23

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

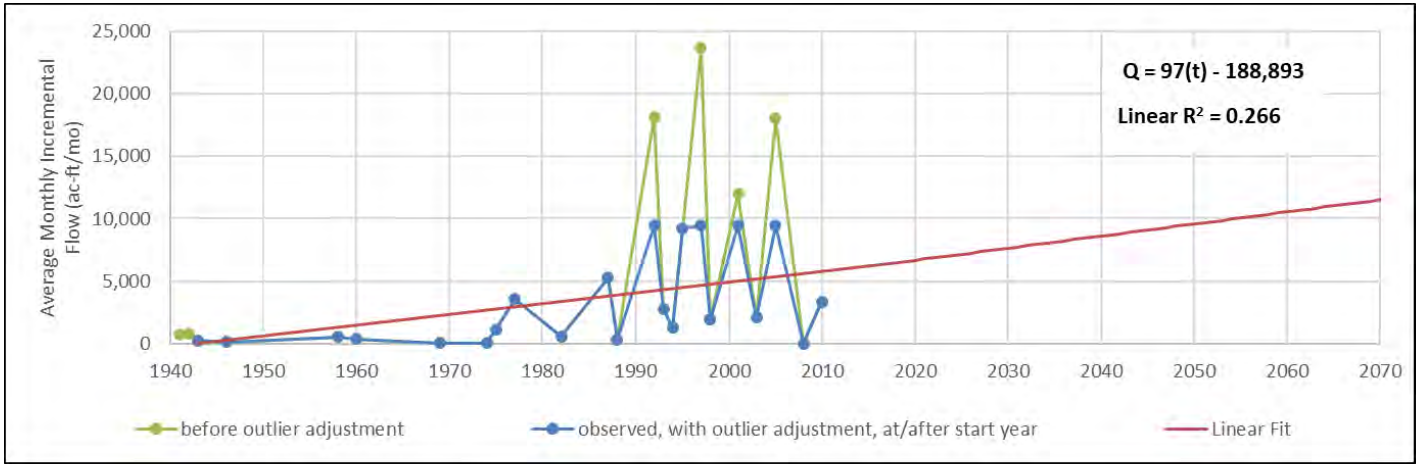


Figure 2-C-54 – Wet Winter Trend for Average Monthly Incremental Flow

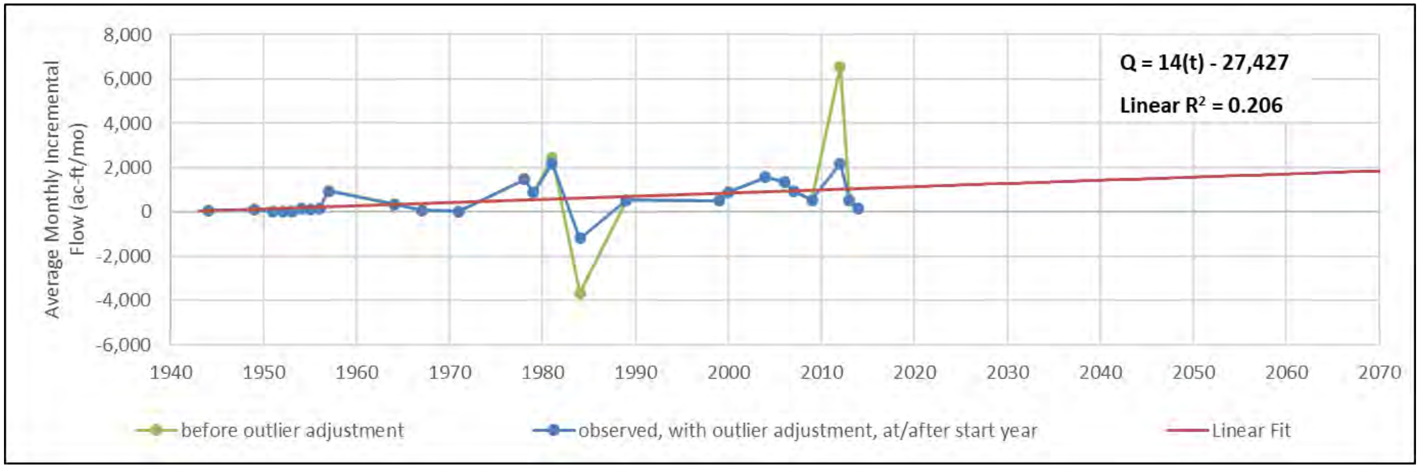


Figure 2-C-55 – Dry Winter Trend for Average Monthly Incremental Flow

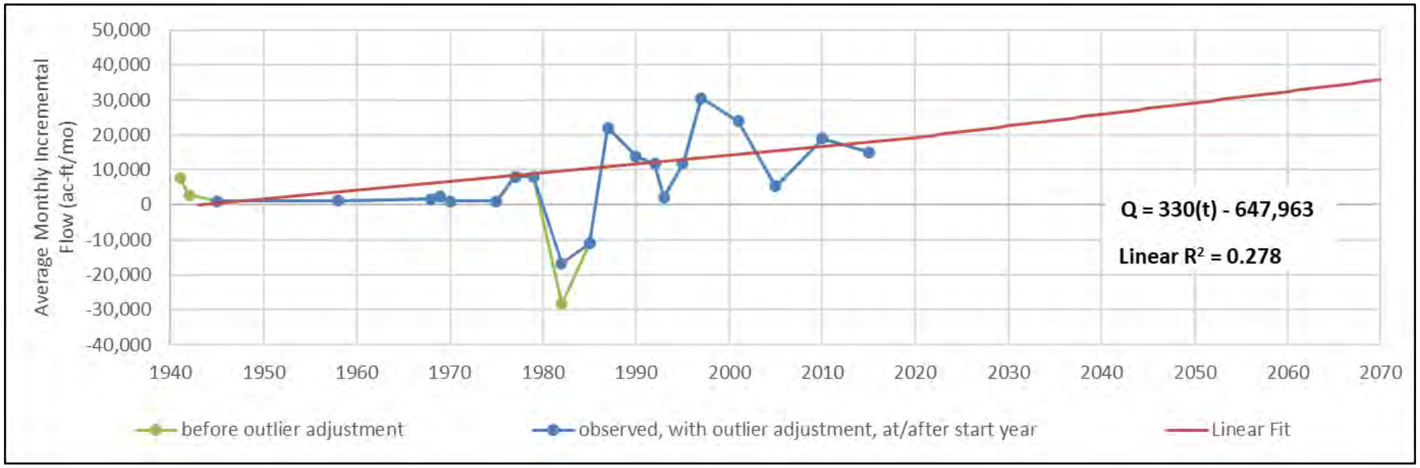


Figure 2-C-56 – Wet Spring Trend for Average Monthly Incremental Flow

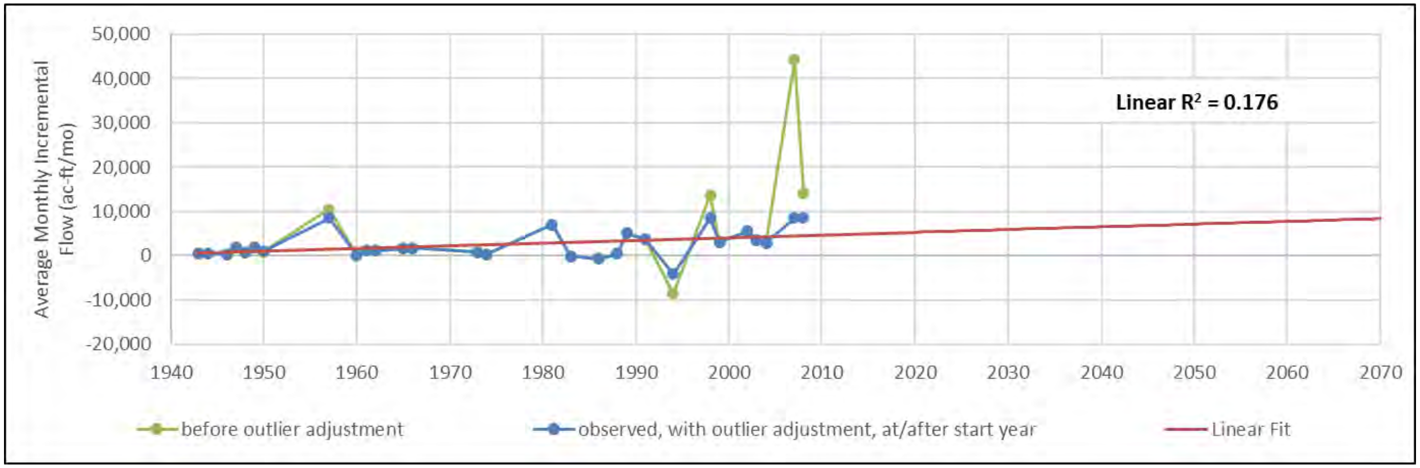


Figure 2-C-57 – Average Spring Trend for Average Monthly Incremental Flow

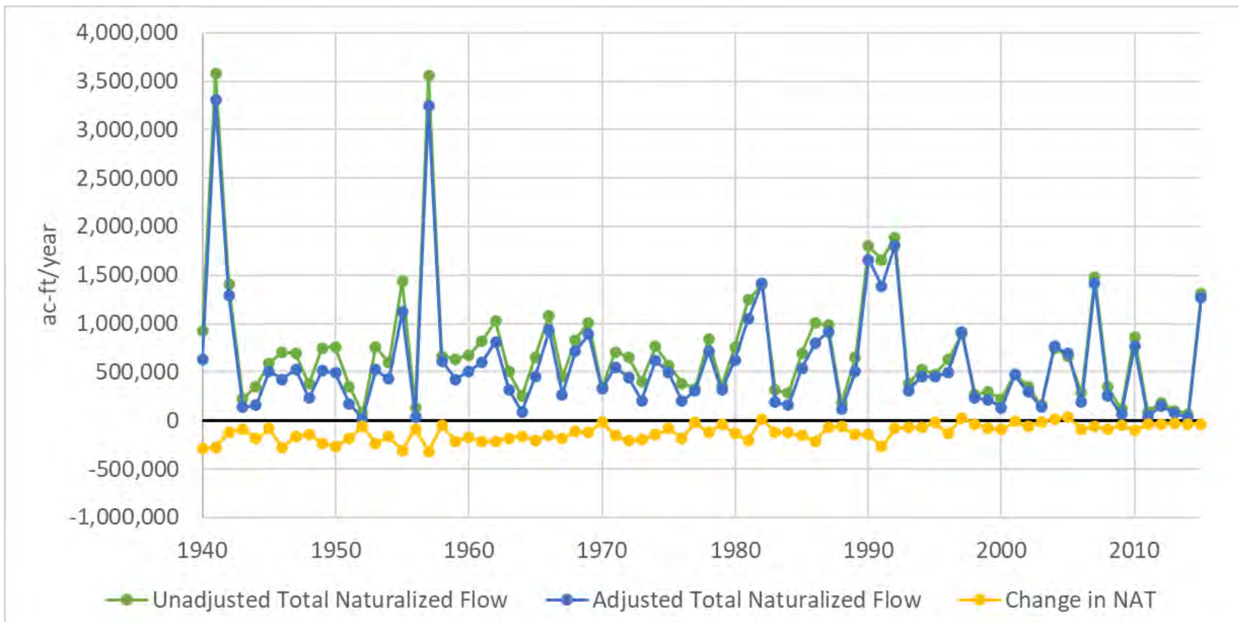


Figure 2-C-58 – Original and Adjusted Naturalized Flow Time Series for BRPP27 for 2070 Conditions

PPSA28 - Palo Pinto Creek near Santo

Table 2-C-30 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.12	-0.10	-0.10	-0.18	-0.07	-0.23	-0.05	-0.32	0.04	-0.21	-0.27	-0.16	-0.08
	P	0.115	0.217	0.223	0.019	0.643	0.118	0.766	0.025	0.750	0.176	0.055	0.303	0.597
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.17	-0.11	-0.11	-0.22	-0.03	-0.23	-0.14	-0.28	-0.04	-0.20	-0.31	-0.29	-0.08
	P	0.034	0.179	0.164	0.005	0.843	0.107	0.346	0.055	0.793	0.195	0.023	0.061	0.582
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

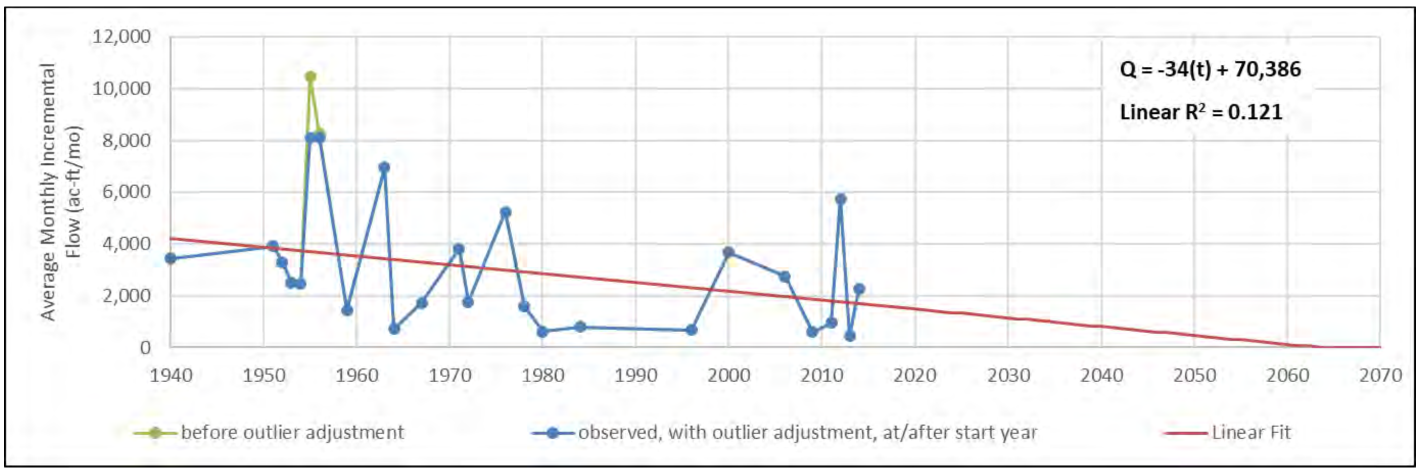


Figure 2-C-59 – Dry Spring Trend for Average Monthly Incremental Flow

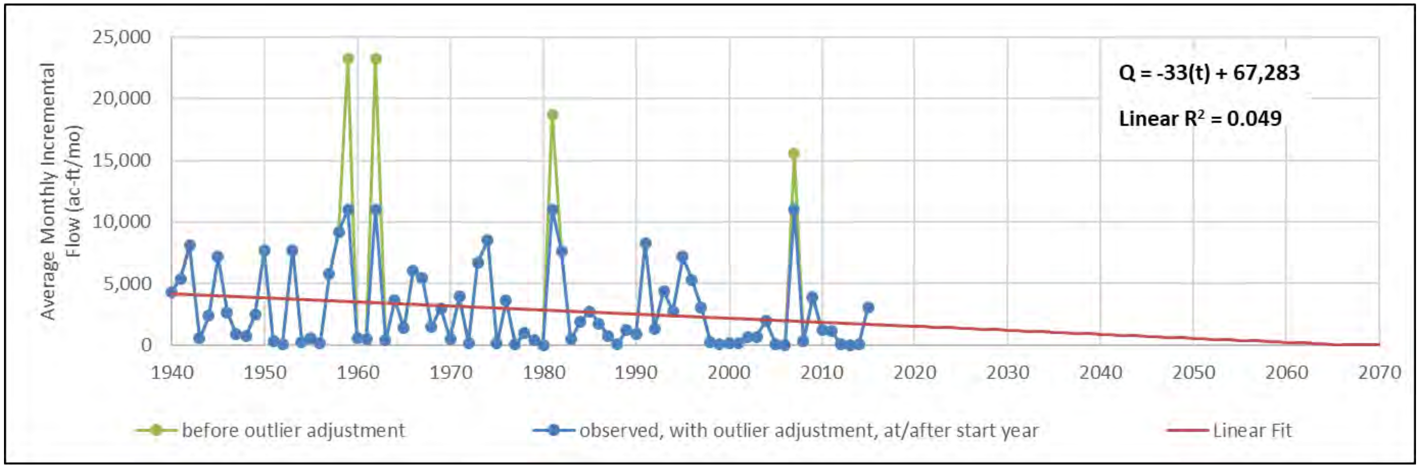


Figure 2-C-60 – Summer Trend for Average Monthly Incremental Flow

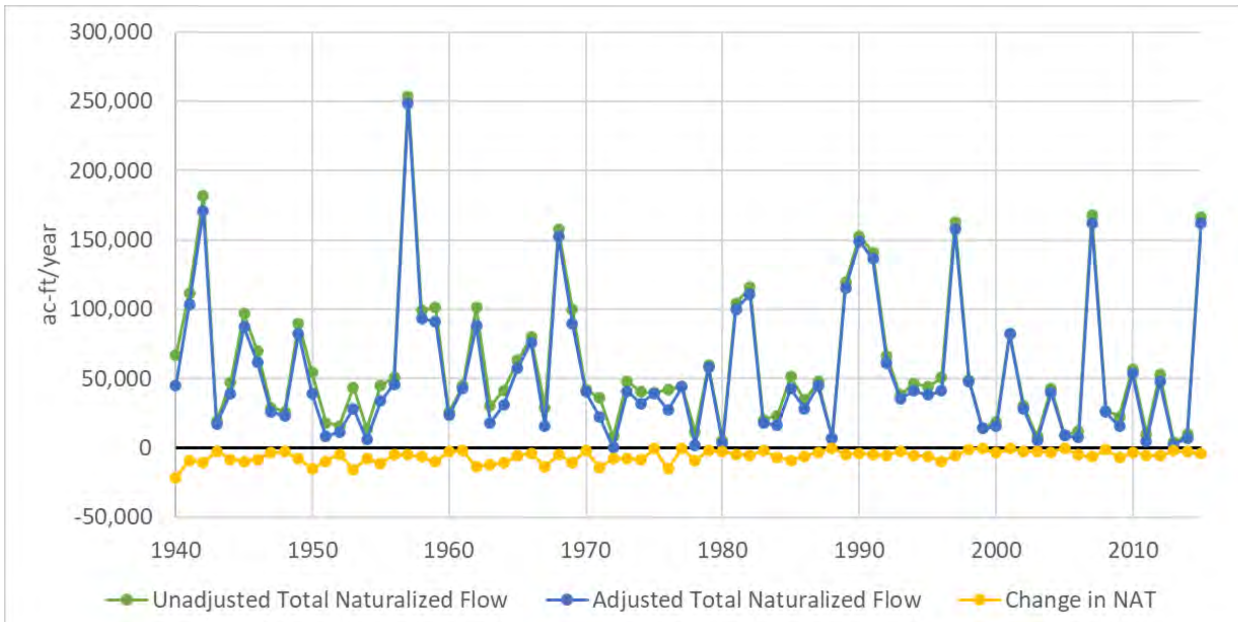


Figure 2-C-61 – Original and Adjusted Naturalized Flow Time Series for PPSA28 for 2070 Conditions

BRDE29 - Brazos River near Dennis

Table 2-C-31 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.08	-0.25	0.00	-0.04	-0.20	-0.48	-0.29	-0.07	-0.02	-0.17	0.03	-0.10	0.00
	P	0.294	0.001	0.954	0.638	0.152	0.001	0.050	0.640	0.866	0.271	0.819	0.509	1.000
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.742	0.713	0.440	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.09	-0.30	-0.01	-0.06	-0.19	-0.48	-0.38	-0.03	-0.07	-0.16	-0.01	-0.15	0.01
	P	0.244	0.000	0.868	0.438	0.186	0.001	0.010	0.852	0.626	0.310	0.950	0.328	0.982
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

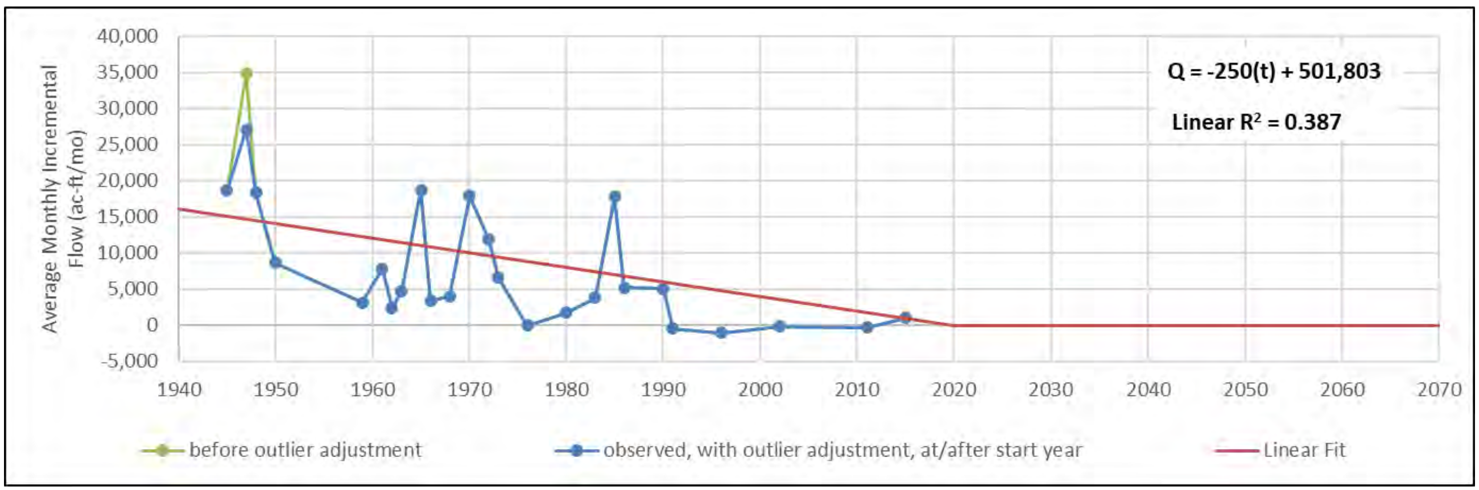


Figure 2-C-62 – Average Winter Trend for Average Monthly Incremental Flow

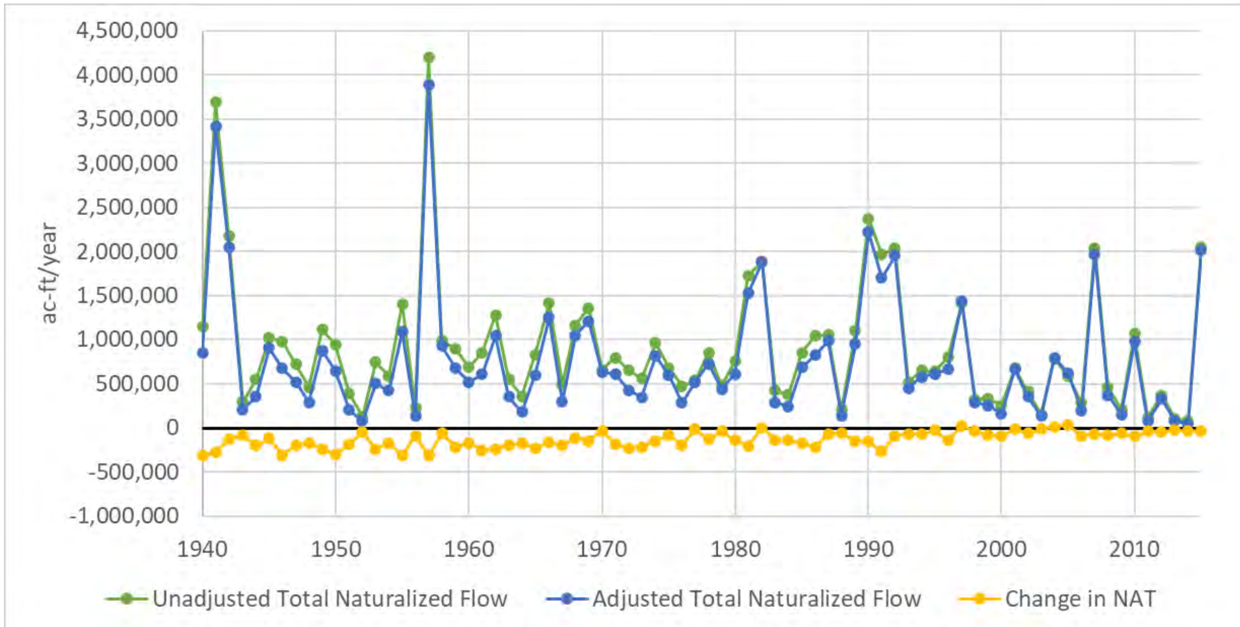


Figure 2-C-63 – Original and Adjusted Naturalized Flow Time Series for BRDE29 for 2070 Conditions

BRGR30 - Brazos River near Glen Rose

Table 2-C-32 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.05	0.03	-0.03	-0.27	0.20	-0.22	0.12	-0.27	0.13	-0.13	-0.32	-0.26	-0.24
	P	0.557	0.664	0.703	0.001	0.152	0.123	0.427	0.059	0.329	0.398	0.021	0.086	0.090
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.728	0.713	0.433	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.08	0.05	-0.03	-0.32	0.22	-0.13	0.07	-0.21	0.11	-0.07	-0.41	-0.32	-0.24
	P	0.322	0.546	0.737	0.000	0.118	0.375	0.655	0.141	0.409	0.652	0.003	0.035	0.086
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

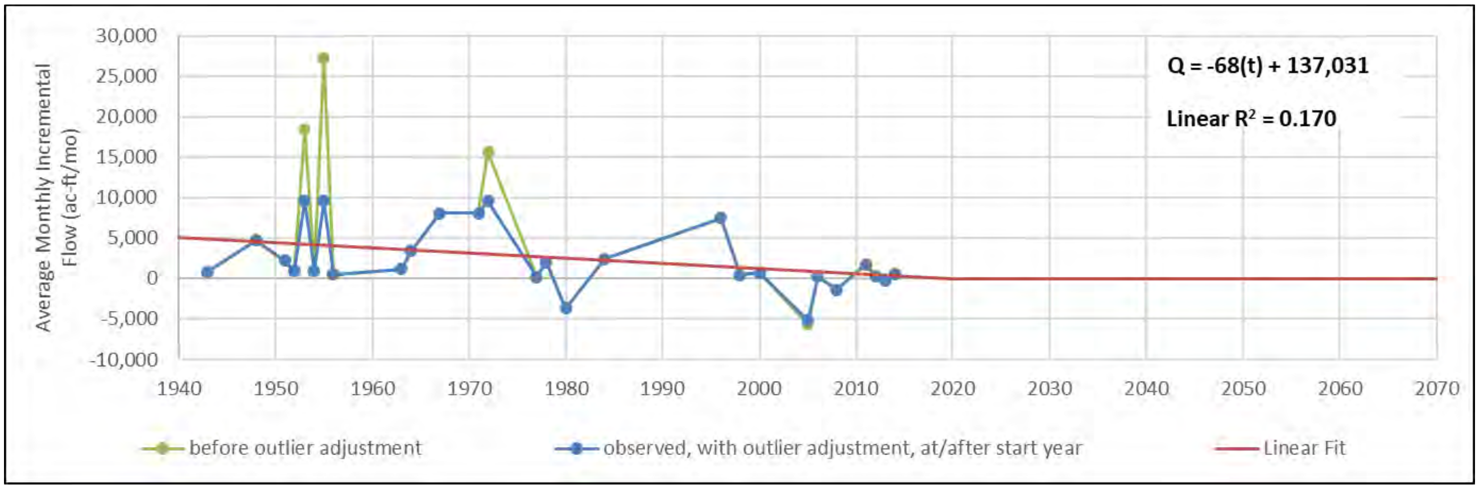


Figure 2-C-64 – Dry Summer Trend for Average Monthly Incremental Flow

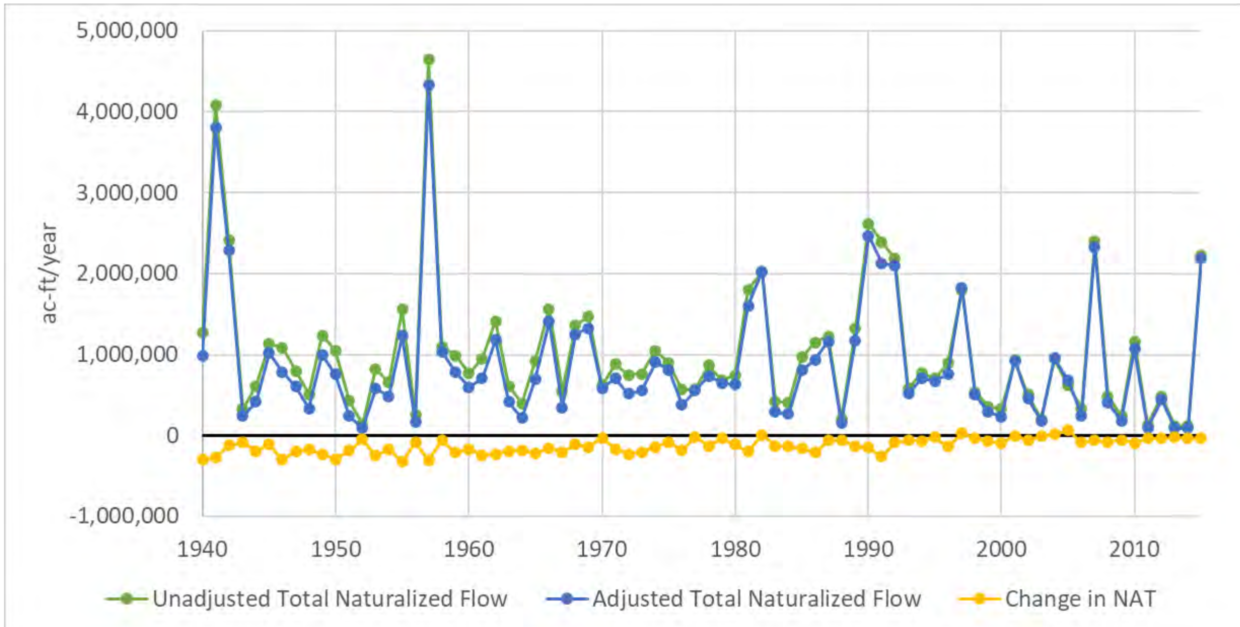


Figure 2-C-65 – Original and Adjusted Naturalized Flow Time Series for BRGR30 for 2070 Conditions

PAGR31 - Paluxy River at Glen Rose

Table 2-C-33 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.03	-0.10	-0.04	-0.09	-0.24	-0.41	0.08	-0.29	0.03	0.00	-0.22	-0.13	0.17
	P	0.723	0.191	0.575	0.257	0.090	0.004	0.620	0.045	0.837	1.000	0.118	0.413	0.225
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.05	-0.14	-0.02	-0.16	-0.19	-0.40	-0.05	-0.24	0.01	0.09	-0.36	-0.18	0.20
	P	0.551	0.075	0.816	0.047	0.193	0.005	0.728	0.107	0.940	0.573	0.010	0.235	0.152
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

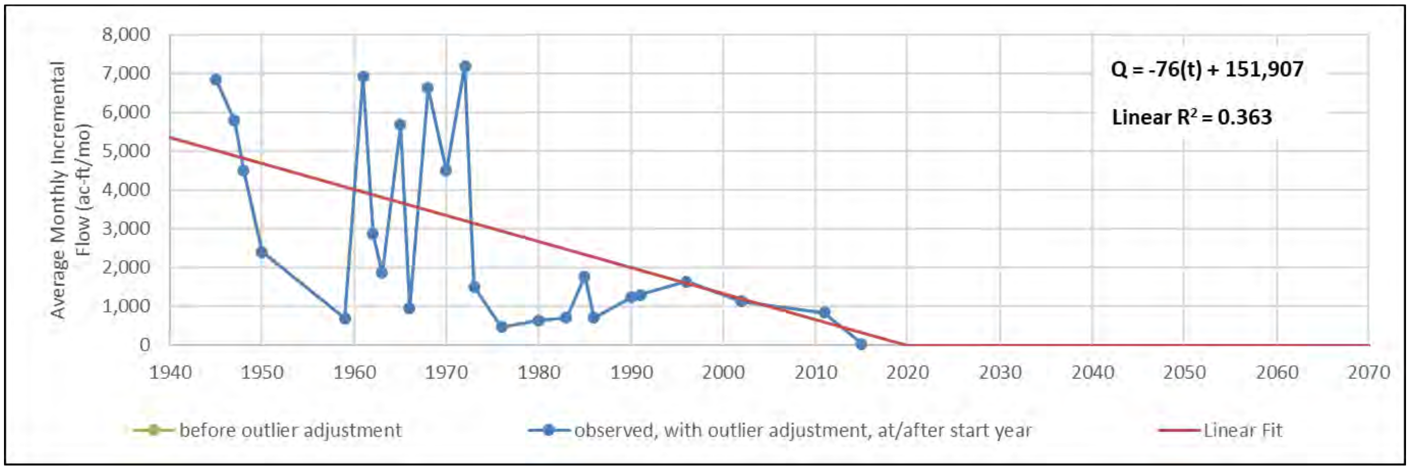


Figure 2-C-66 – Average Winter Trend for Average Monthly Incremental Flow

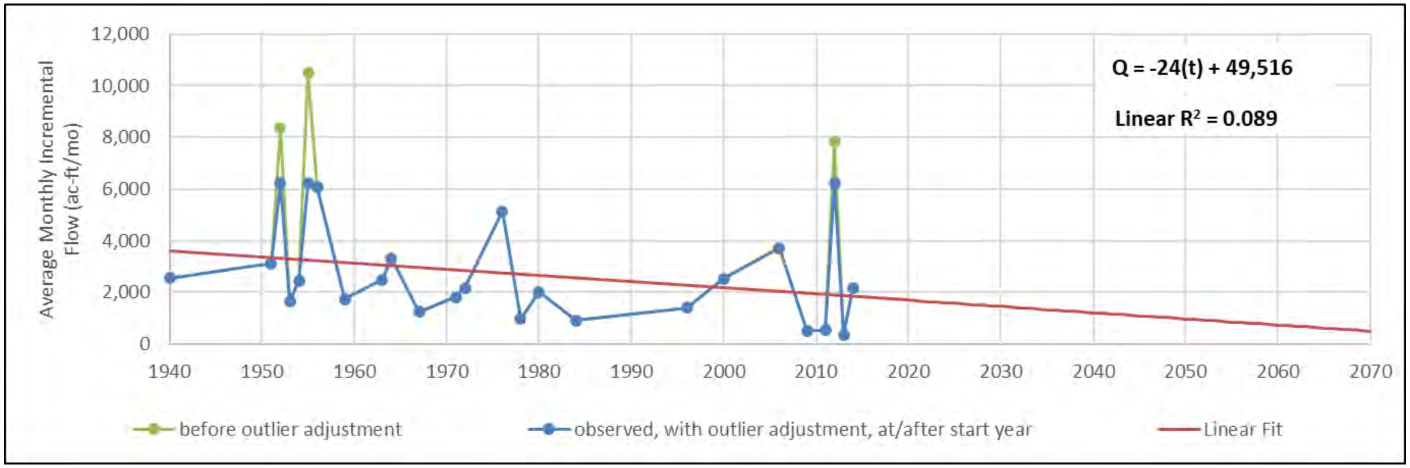


Figure 2-C-67 – Dry Spring Trend for Average Monthly Incremental Flow

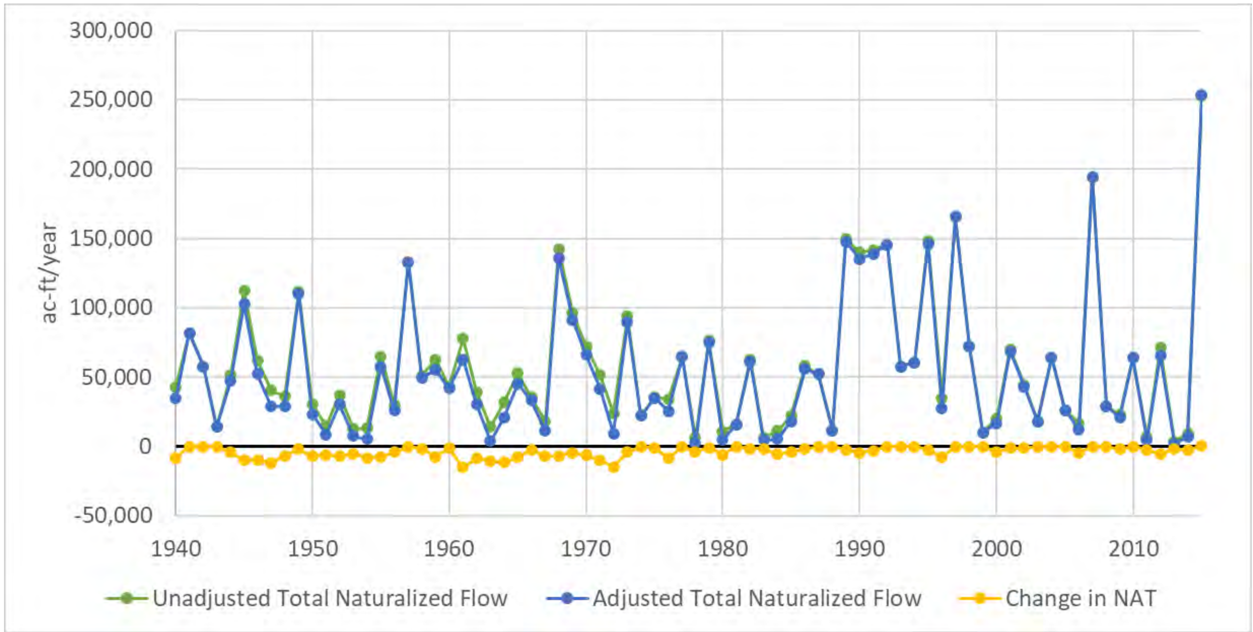


Figure 2-C-68 – Original and Adjusted Naturalized Flow Time Series for PAGR31 for 2070 Conditions

NRBL32 - Nolan River at Blum

Table 2-C-34 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.04	0.03	-0.01	0.02	0.29	-0.39	0.12	0.01	0.05	-0.09	-0.06	0.14	0.09
	P	0.597	0.708	0.925	0.851	0.045	0.007	0.413	0.981	0.708	0.573	0.662	0.369	0.537
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.435	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.05	0.01	0.01	0.01	0.31	-0.39	-0.03	0.09	-0.05	-0.07	-0.08	0.09	0.11
	P	0.560	0.894	0.943	0.943	0.031	0.007	0.862	0.559	0.694	0.652	0.588	0.561	0.427
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

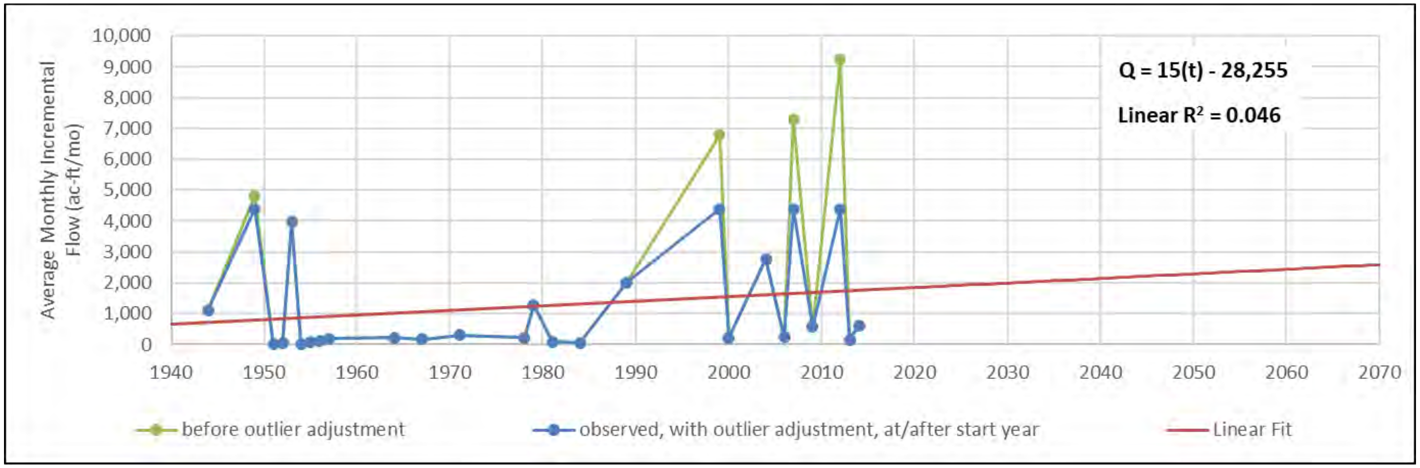


Figure 2-C-69 – Dry Winter Trend for Average Monthly Incremental Flow

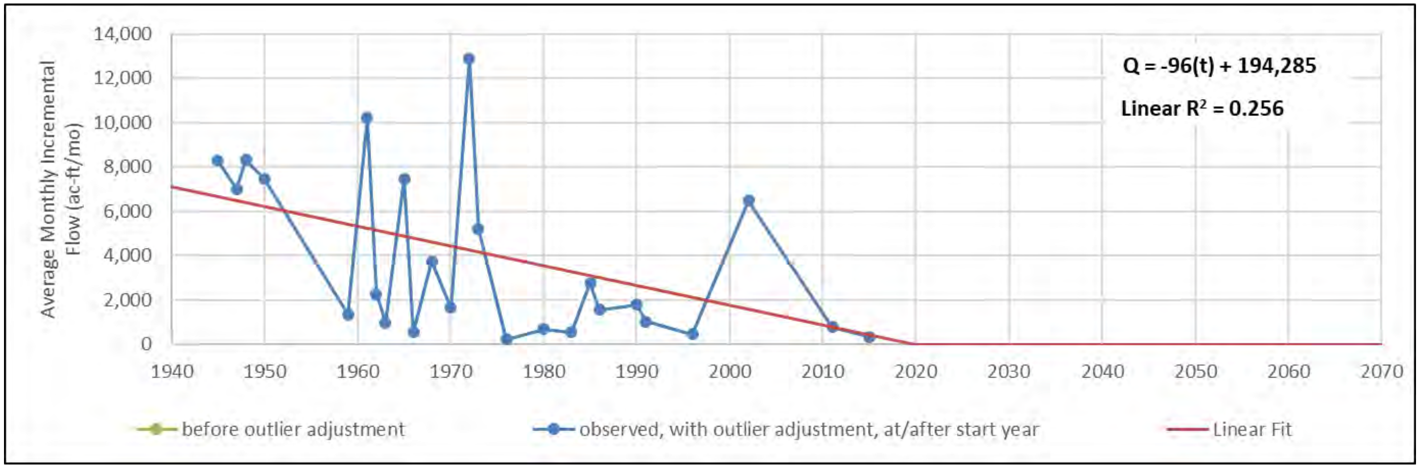


Figure 2-C-70 – Average Winter Trend for Average Monthly Incremental Flow

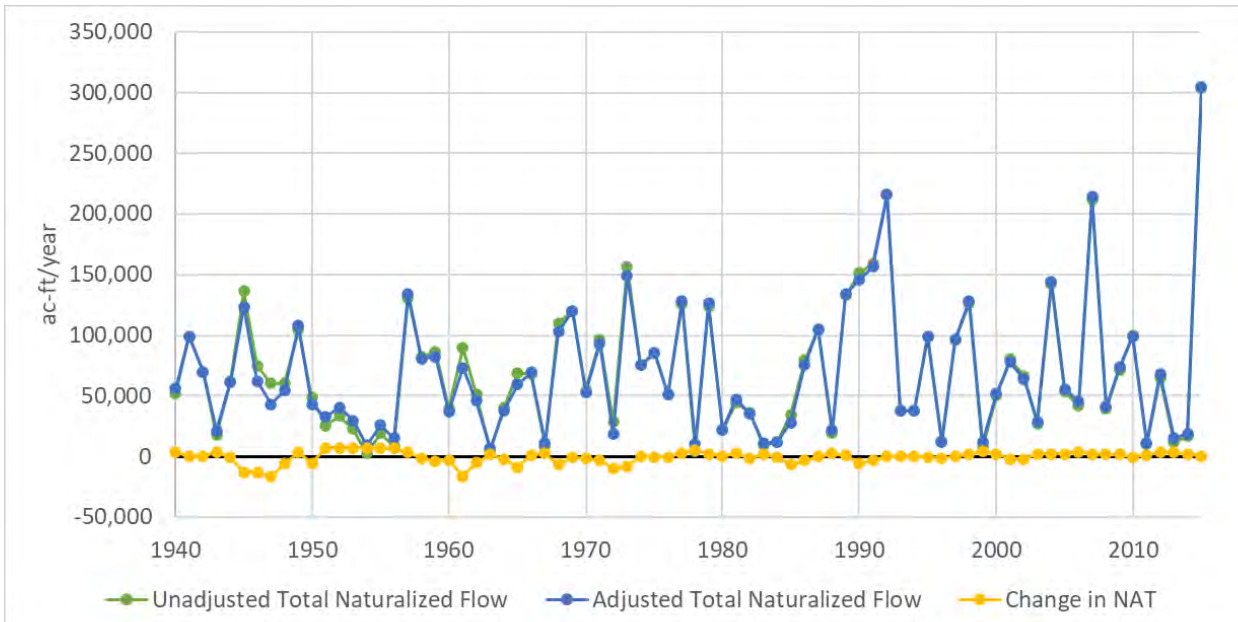


Figure 2-C-71 – Original and Adjusted Naturalized Flow Time Series for NRBL32 for 2070 Conditions

BRAQ33 - Brazos River near Aquilla

Table 2-C-35 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.21	0.07	0.15	0.19	0.24	-0.28	-0.02	0.09	0.20	0.01	0.21	0.21	0.19
	P	0.012	0.385	0.071	0.020	0.093	0.068	0.922	0.535	0.168	1.000	0.140	0.206	0.248
P	τ	0.14	0.08	0.06	0.05	0.04	-0.08	0.12	-0.08	0.13	-0.04	0.21	-0.04	-0.01
	P	0.093	0.317	0.488	0.518	0.797	0.635	0.496	0.602	0.388	0.834	0.134	0.820	0.955
Q/P	τ	0.19	0.06	0.17	0.17	0.18	-0.22	-0.07	0.15	0.17	0.09	0.14	0.27	0.25
	P	0.020	0.488	0.036	0.038	0.207	0.146	0.697	0.309	0.252	0.624	0.311	0.105	0.114
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1948)		68	68	68	68	25	23	20	24	25	19	26	20	22

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

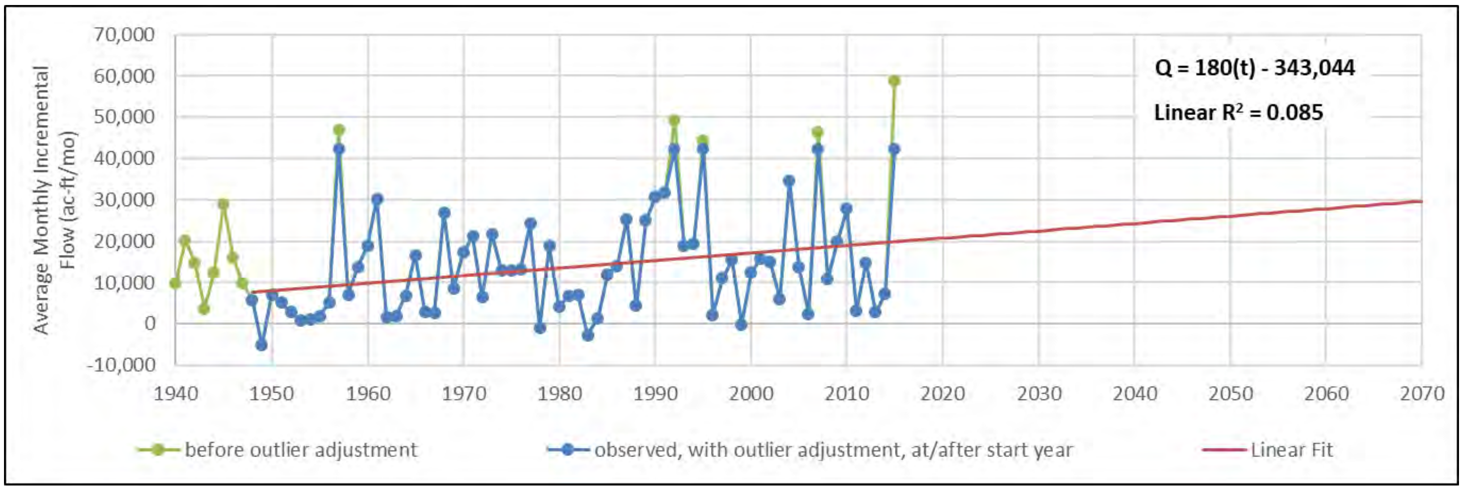


Figure 2-C-72 – Annual Trend for Average Monthly Incremental Flow

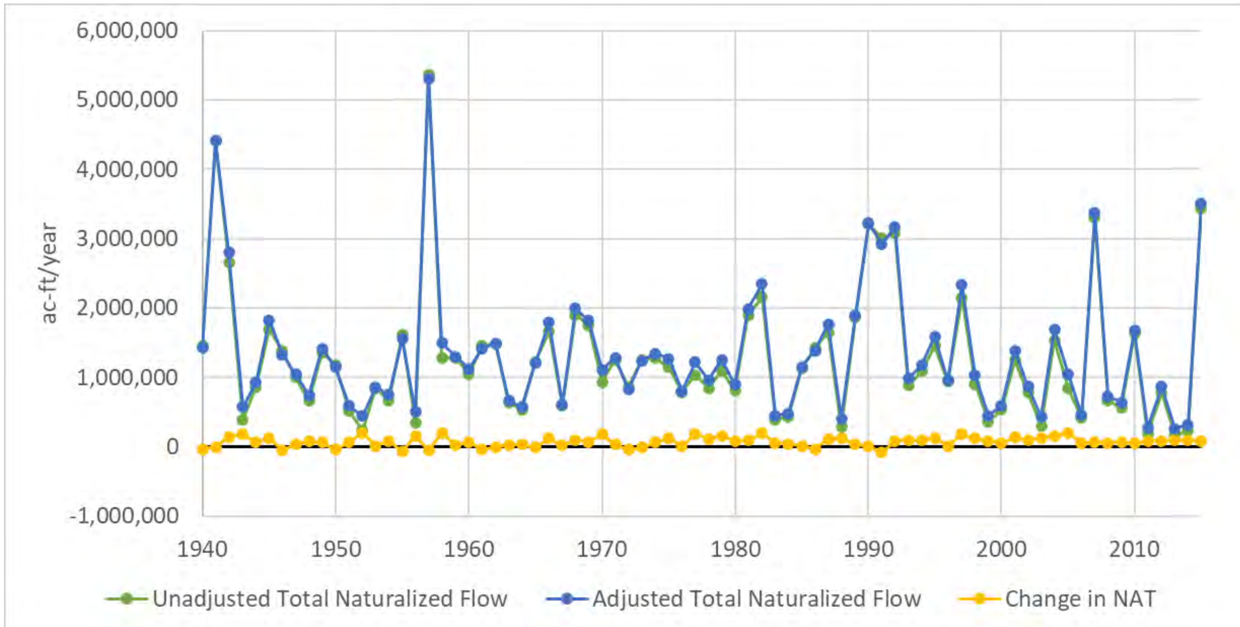


Figure 2-C-73 – Original and Adjusted Naturalized Flow Time Series for BRAQ33 for 2070 Conditions

AQAQ34 - Aquilla Creek near Aquilla

Table 2-C-36 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.03	0.08	-0.11	0.04	0.11	-0.14	0.23	-0.18	-0.07	-0.31	-0.08	0.25	0.06
	P	0.703	0.319	0.146	0.628	0.427	0.338	0.118	0.216	0.586	0.048	0.574	0.096	0.692
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.03	0.08	-0.10	0.03	0.15	-0.15	0.18	-0.11	-0.10	-0.25	-0.13	0.25	0.08
	P	0.737	0.334	0.203	0.754	0.290	0.293	0.224	0.441	0.464	0.114	0.348	0.096	0.597
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

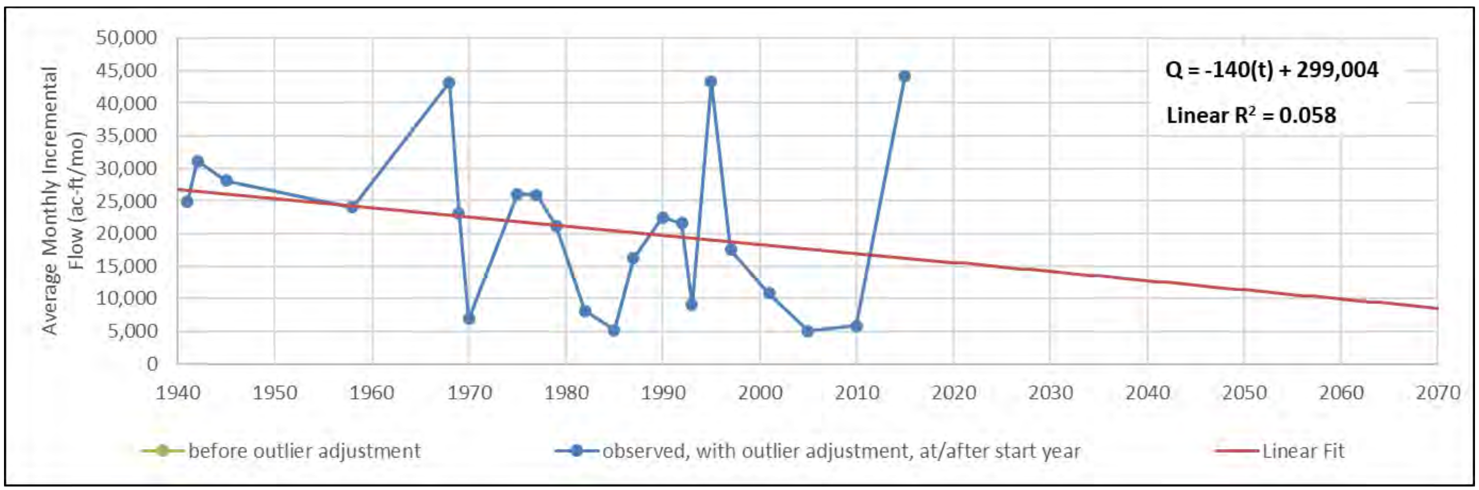


Figure 2-C-74 – Wet Spring Trend for Average Monthly Incremental Flow

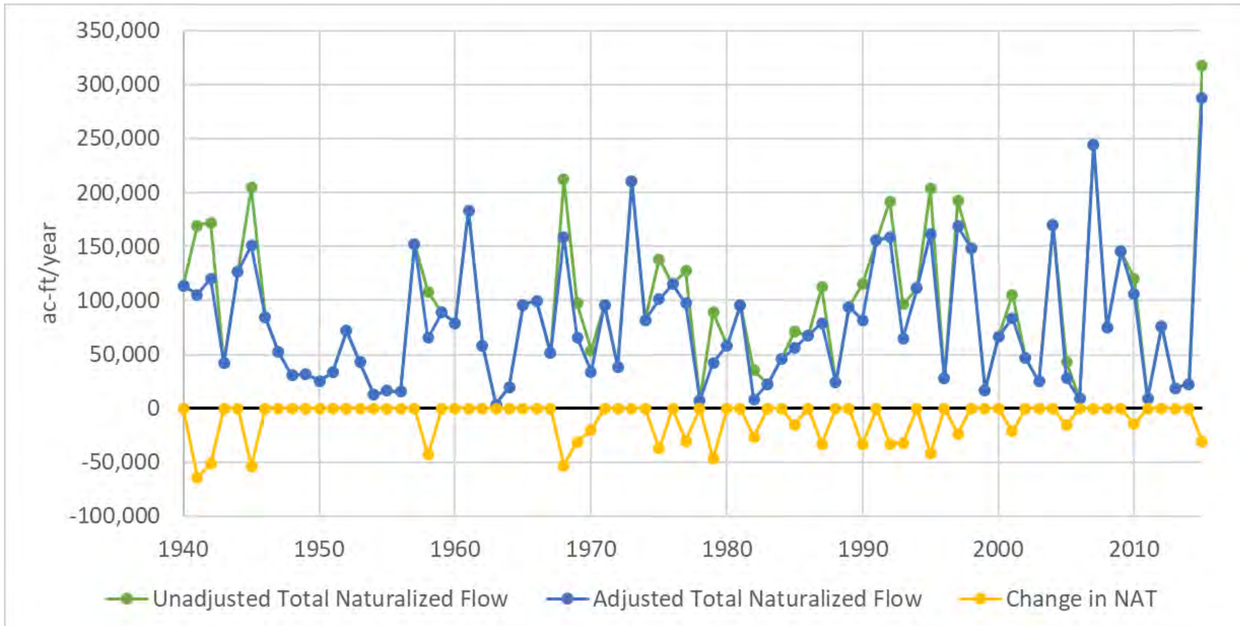


Figure 2-C-75 – Original and Adjusted Naturalized Flow Time Series for AQAQ34 for 2070 Conditions

NBHI35 - North Bosque River at Hico

Table 2-C-37 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.01	-0.04	-0.01	0.00	-0.01	-0.29	0.11	-0.29	0.12	-0.16	-0.10	0.06	0.18
	P	0.858	0.583	0.882	0.971	0.965	0.047	0.457	0.042	0.368	0.310	0.466	0.692	0.201
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.01	-0.07	0.00	0.00	-0.01	-0.29	0.05	-0.24	0.11	-0.06	-0.13	0.02	0.25
	P	0.925	0.390	0.989	0.964	0.947	0.047	0.766	0.093	0.420	0.693	0.348	0.895	0.078
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

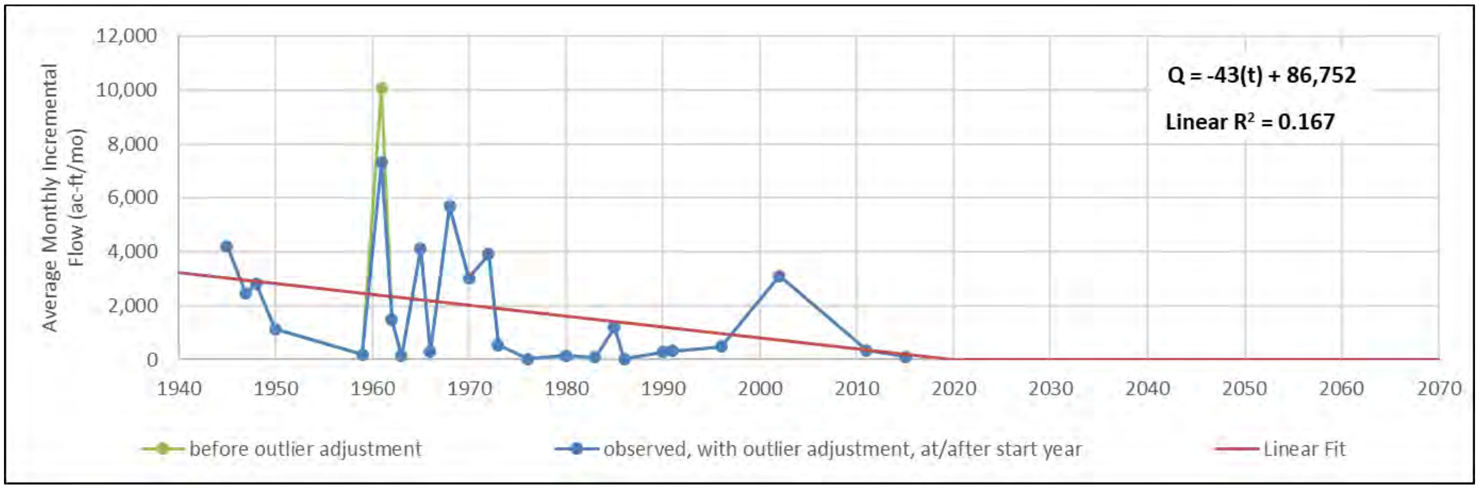


Figure 2-C-76 – Average winter Trend for Average Monthly Incremental Flow

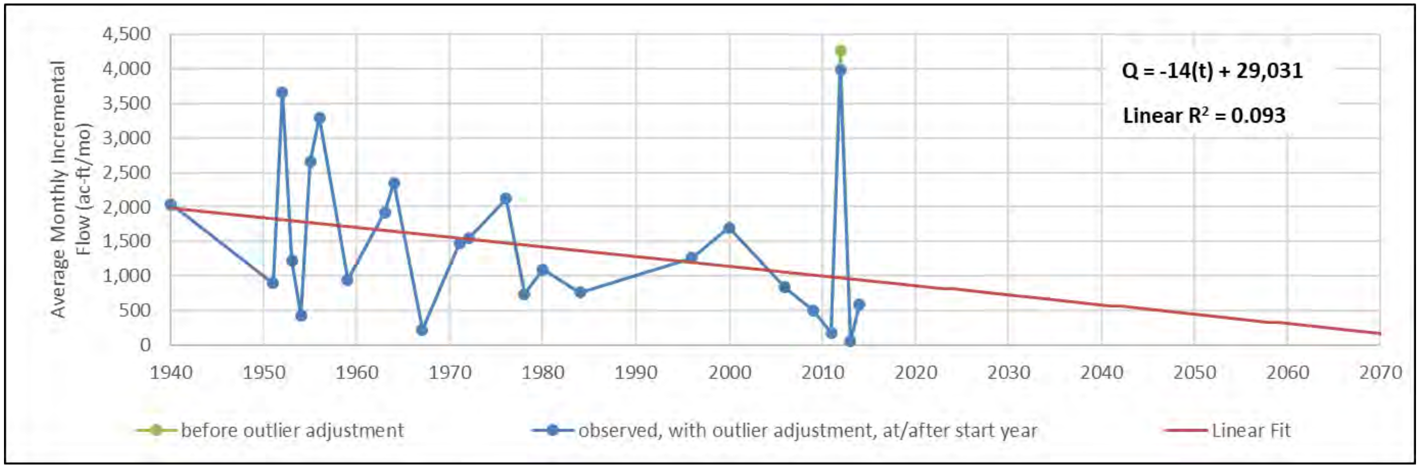


Figure 2-C-77 – Dry Spring Trend for Average Monthly Incremental Flow

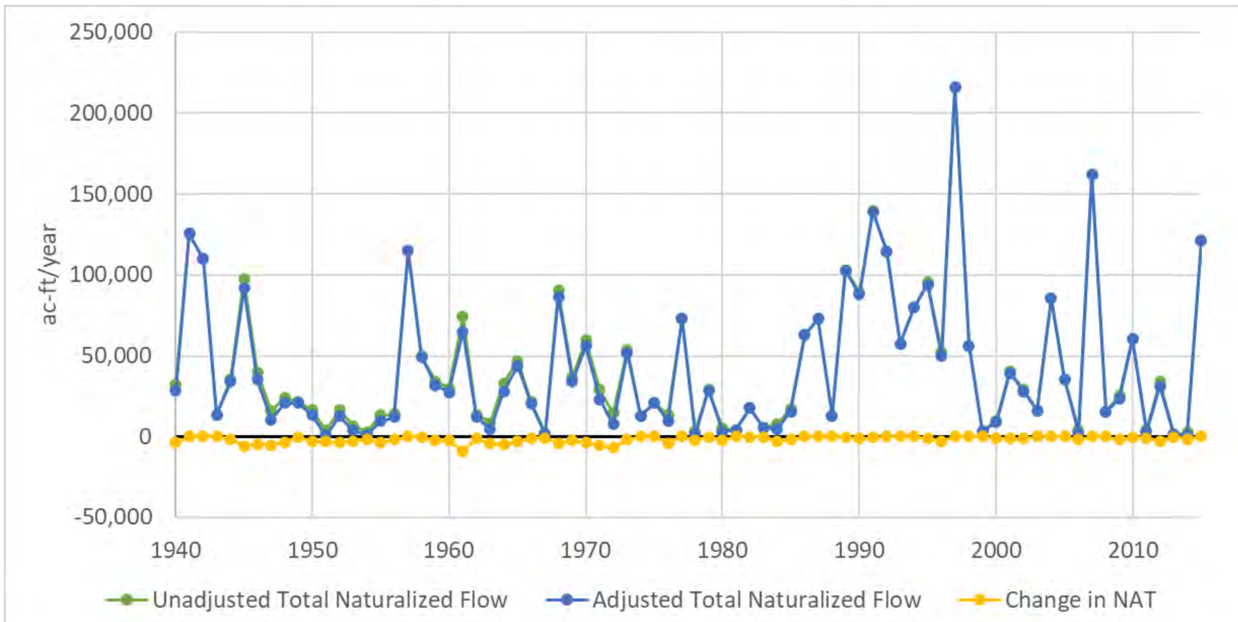


Figure 2-C-78 – Original and Adjusted Naturalized Flow Time Series for NBHI35 for 2070 Conditions

NBCL36 - North Bosque River near Clifton

Table 2-C-38 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.00	-0.07	-0.03	-0.05	-0.04	-0.35	0.08	-0.28	0.10	-0.24	-0.15	0.12	-0.16
	P	1.000	0.387	0.691	0.496	0.774	0.014	0.585	0.063	0.476	0.128	0.269	0.444	0.262
P	τ	0.06	0.03	-0.01	0.05	-0.03	-0.20	0.20	-0.08	0.14	-0.19	0.24	0.15	-0.15
	P	0.431	0.735	0.873	0.540	0.826	0.168	0.189	0.602	0.285	0.236	0.080	0.342	0.293
Q/P	τ	-0.01	-0.10	-0.04	-0.07	-0.06	-0.30	-0.01	-0.29	0.07	-0.21	-0.20	0.09	-0.08
	P	0.916	0.229	0.647	0.370	0.708	0.036	0.980	0.056	0.586	0.176	0.150	0.579	0.607
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		75	75	75	75	26	25	24	24	29	22	27	23	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

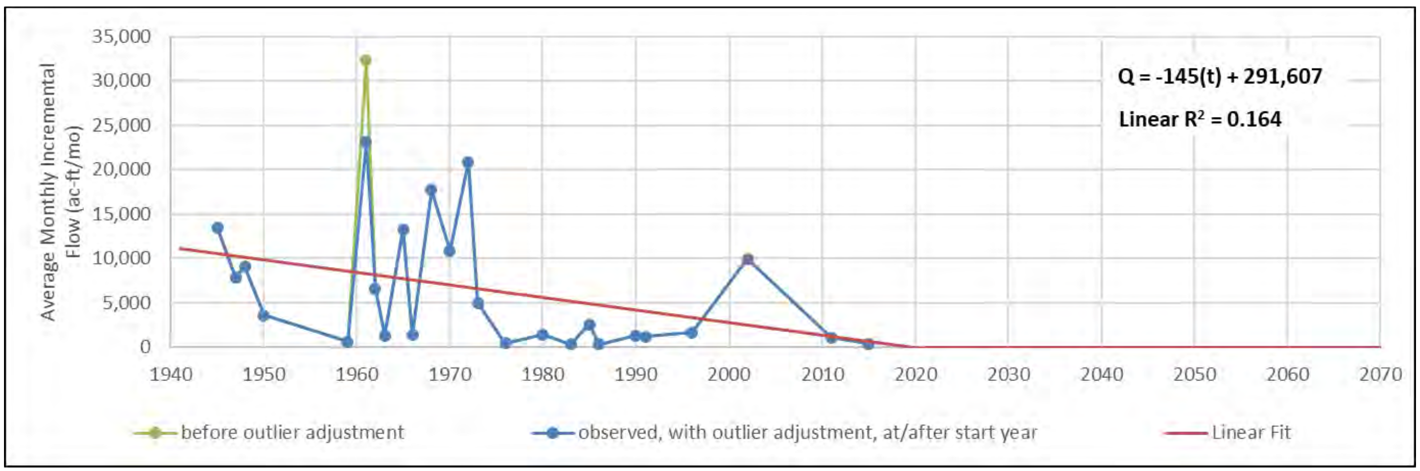


Figure 2-C-79 – Average Winter Trend for Average Monthly Incremental Flow

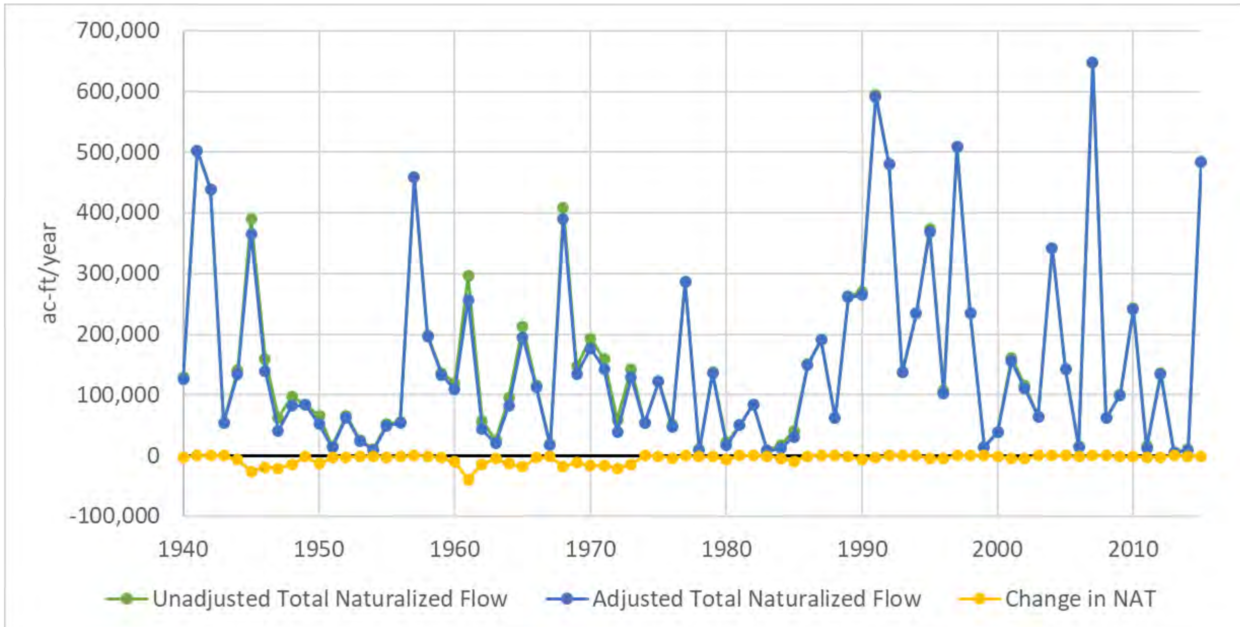


Figure 2-C-80 – Original and Adjusted Naturalized Flow Time Series for NBCL36 for 2070 Conditions

NBVM37 - North Bosque River At Valley Mills

Table 2-C-39 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.07	0.03	0.02	0.09	0.19	-0.27	0.20	-0.09	0.03	-0.02	0.17	0.12	0.17
	P	0.375	0.732	0.778	0.262	0.179	0.059	0.189	0.559	0.807	0.933	0.235	0.428	0.243
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.716	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.07	0.02	0.04	0.09	0.19	-0.24	0.08	-0.01	0.07	0.03	0.11	0.09	0.19
	P	0.394	0.794	0.625	0.244	0.193	0.093	0.620	0.963	0.599	0.866	0.416	0.561	0.179
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

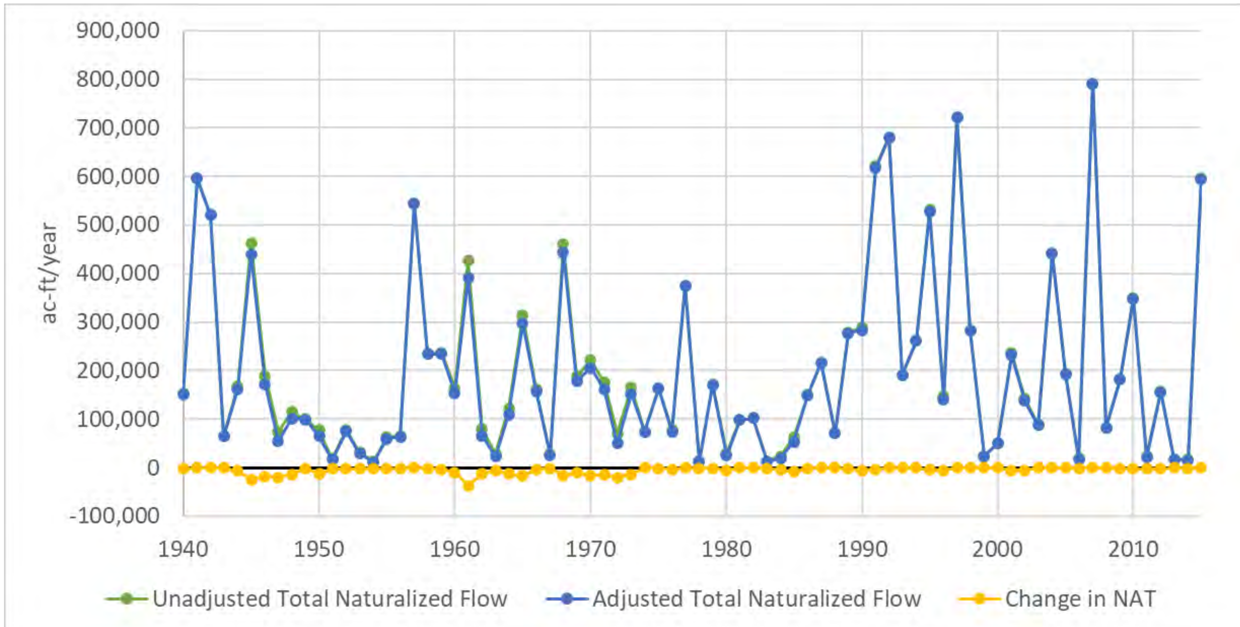


Figure 2-C-81 – Original and Adjusted Naturalized Flow Time Series for NBVM37 for 2070 Conditions

MBMG38 - Middle Bosque River near McGregor

Table 2-C-40 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.04	0.06	-0.05	0.00	0.13	-0.02	0.12	-0.10	-0.02	-0.19	-0.03	0.21	-0.11
	P	0.587	0.450	0.560	0.996	0.355	0.926	0.413	0.498	0.881	0.236	0.819	0.178	0.440
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.435	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.04	0.05	-0.05	-0.02	0.14	0.03	0.07	-0.11	-0.02	-0.19	-0.09	0.21	-0.16
	P	0.587	0.528	0.545	0.781	0.343	0.870	0.673	0.469	0.896	0.236	0.532	0.178	0.261
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

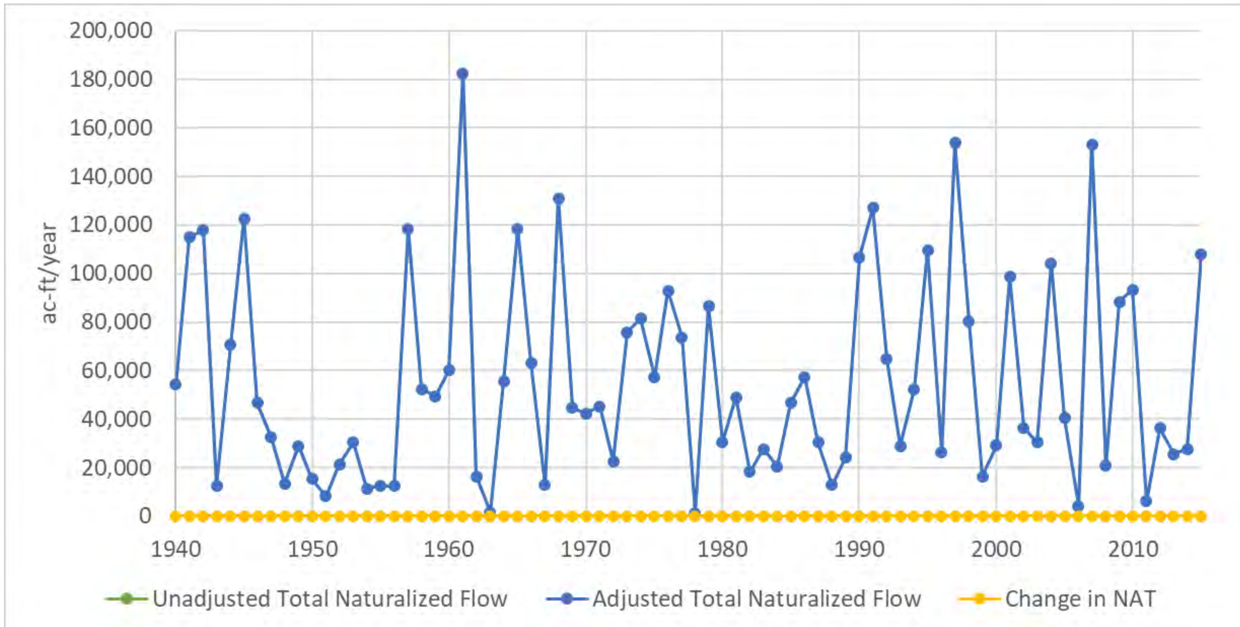


Figure 2-C-82 – Original and Adjusted Naturalized Flow Time Series for MBMG38 for 2070 Conditions

HGCR39 - Hog Creek near Crawford

Table 2-C-41 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.00	0.01	-0.05	-0.06	-0.04	-0.20	0.20	-0.24	0.04	-0.15	-0.25	0.19	-0.14
	P	1.000	0.884	0.518	0.435	0.791	0.168	0.189	0.097	0.793	0.338	0.073	0.224	0.332
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.738	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.01	-0.01	-0.07	-0.10	0.00	-0.19	0.12	-0.25	0.01	-0.19	-0.33	0.17	-0.12
	P	0.921	0.938	0.363	0.224	1.000	0.199	0.442	0.080	0.925	0.236	0.017	0.267	0.402
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

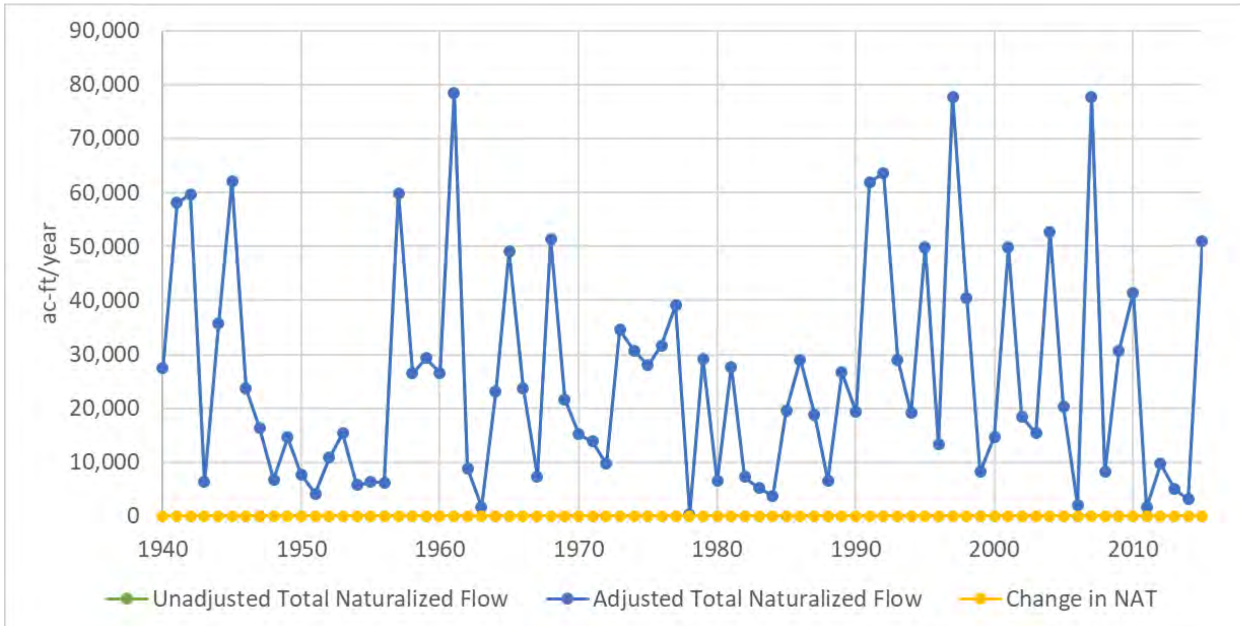


Figure 2-C-83 – Original and Adjusted Naturalized Flow Time Series for HGCR39 for 2070 Conditions

BOWA40 - Bosque River near Waco

Table 2-C-42 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.01	0.10	-0.11	0.01	0.06	-0.02	0.26	-0.17	-0.08	-0.21	-0.09	0.09	-0.02
	P	0.872	0.189	0.155	0.865	0.692	0.907	0.078	0.252	0.548	0.176	0.545	0.561	0.930
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.732	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.00	0.09	-0.11	-0.03	0.10	-0.03	0.18	-0.14	-0.09	-0.21	-0.17	0.07	-0.04
	P	0.986	0.243	0.155	0.716	0.494	0.834	0.224	0.338	0.488	0.176	0.227	0.673	0.774
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

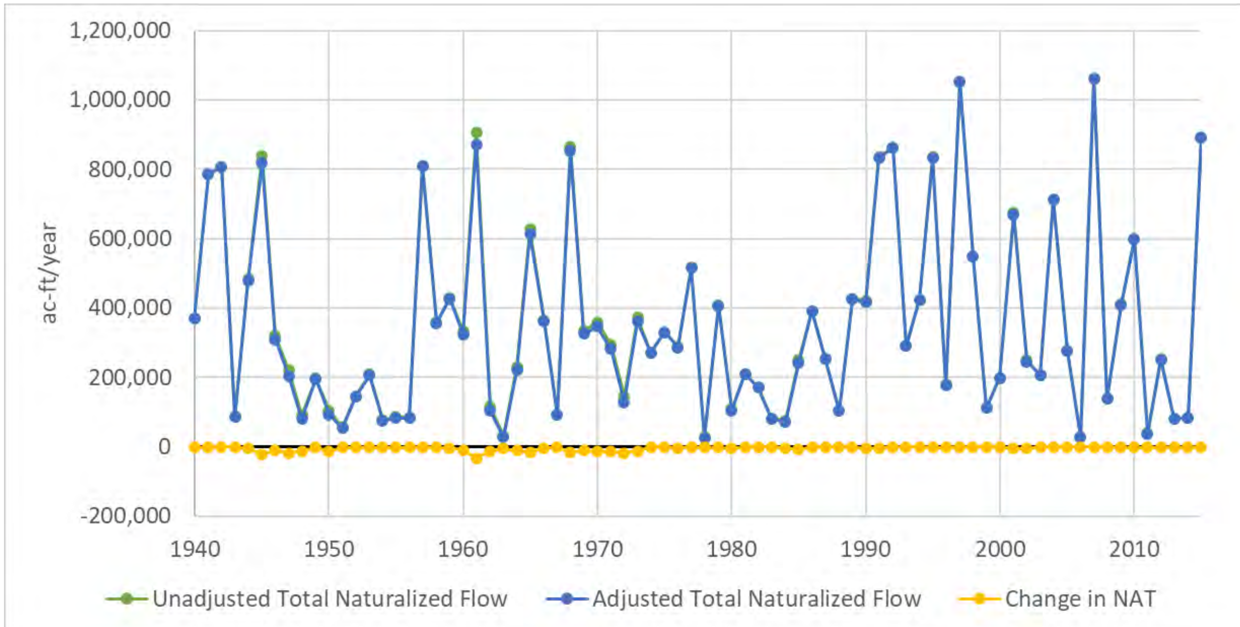


Figure 2-C-84 – Original and Adjusted Naturalized Flow Time Series for BOWA40 for 2070 Conditions

BRWA41 - Brazos River at Waco

Table 2-C-43 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.01	0.04	-0.04	-0.08	0.18	-0.02	0.04	0.02	0.03	-0.30	-0.17	0.01	-0.06
	P	0.858	0.647	0.638	0.309	0.217	0.907	0.823	0.907	0.807	0.055	0.235	0.979	0.675
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.15	-0.19	0.24	0.15	-0.09
	P	0.606	0.732	0.716	0.435	0.826	0.168	0.189	0.293	0.277	0.236	0.080	0.342	0.537
Q/P	τ	0.03	0.02	-0.04	-0.07	0.11	0.03	-0.02	0.06	0.01	-0.21	-0.19	0.04	-0.06
	P	0.710	0.816	0.625	0.379	0.454	0.870	0.901	0.691	0.925	0.176	0.169	0.812	0.675
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

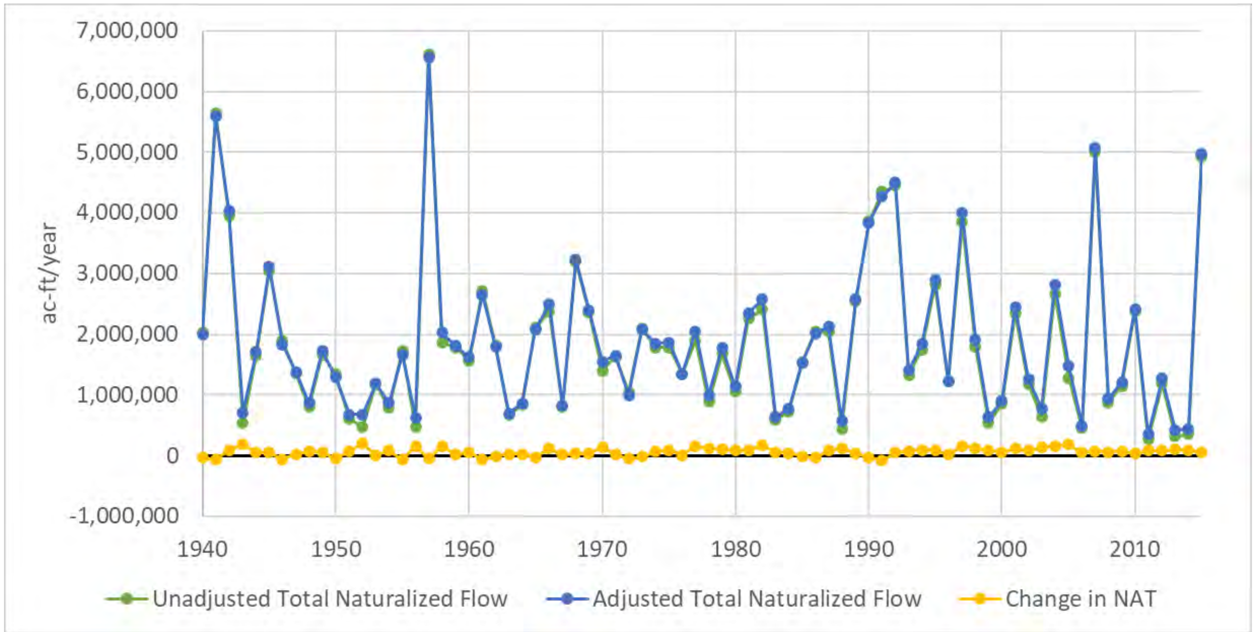


Figure 2-C-85 – Original and Adjusted Naturalized Flow Time Series for BRWA41 for 2070 Conditions

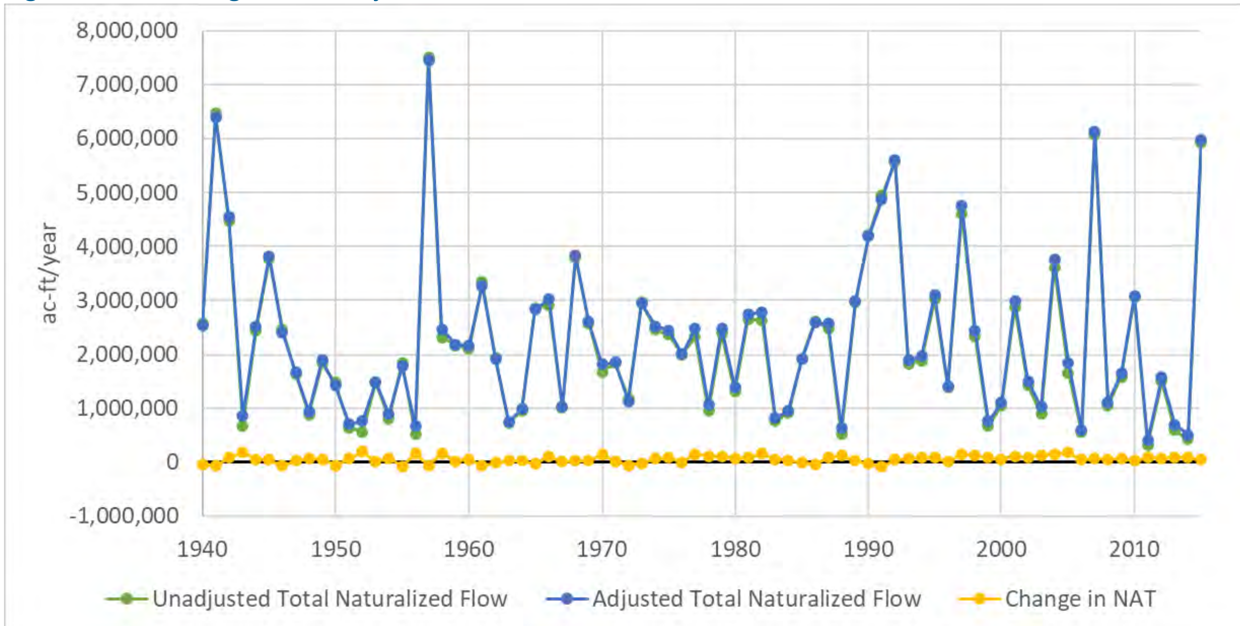
BRHB42 - Brazos River near Highbank

Table 2-C-44 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.02	0.05	-0.05	0.04	0.24	-0.02	0.05	-0.09	-0.08	-0.08	0.16	-0.02	-0.05
	P	0.757	0.516	0.563	0.609	0.094	0.907	0.766	0.528	0.536	0.612	0.260	0.895	0.758
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.738	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.02	0.07	-0.04	0.02	0.31	0.04	-0.04	-0.08	-0.12	0.00	0.03	-0.08	0.00
	P	0.757	0.408	0.569	0.795	0.029	0.779	0.785	0.591	0.358	1.000	0.819	0.635	1.000
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

Figure 2-C-86 – Original and Adjusted Naturalized Flow Time Series for BRHB42 for 2070 Conditions



LEDL43 - Leon River near De Leon

Table 2-C-45 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.08	-0.13	-0.11	-0.06	-0.23	-0.30	0.01	-0.38	0.01	-0.16	-0.18	-0.23	0.27
	P	0.302	0.091	0.171	0.454	0.108	0.040	0.960	0.008	0.970	0.310	0.203	0.132	0.058
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.09	-0.15	-0.11	-0.09	-0.26	-0.22	-0.08	-0.36	-0.01	-0.13	-0.22	-0.32	0.25
	P	0.268	0.051	0.173	0.236	0.071	0.123	0.620	0.012	0.925	0.398	0.118	0.037	0.078
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

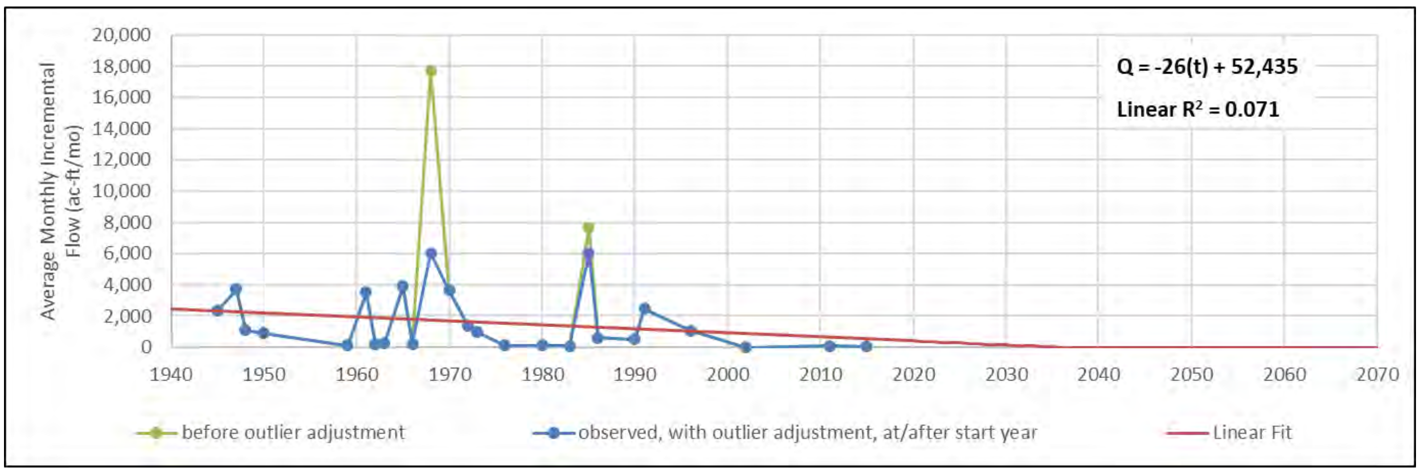


Figure 2-C-87 – Average winter Trend for Average Monthly Incremental Flow

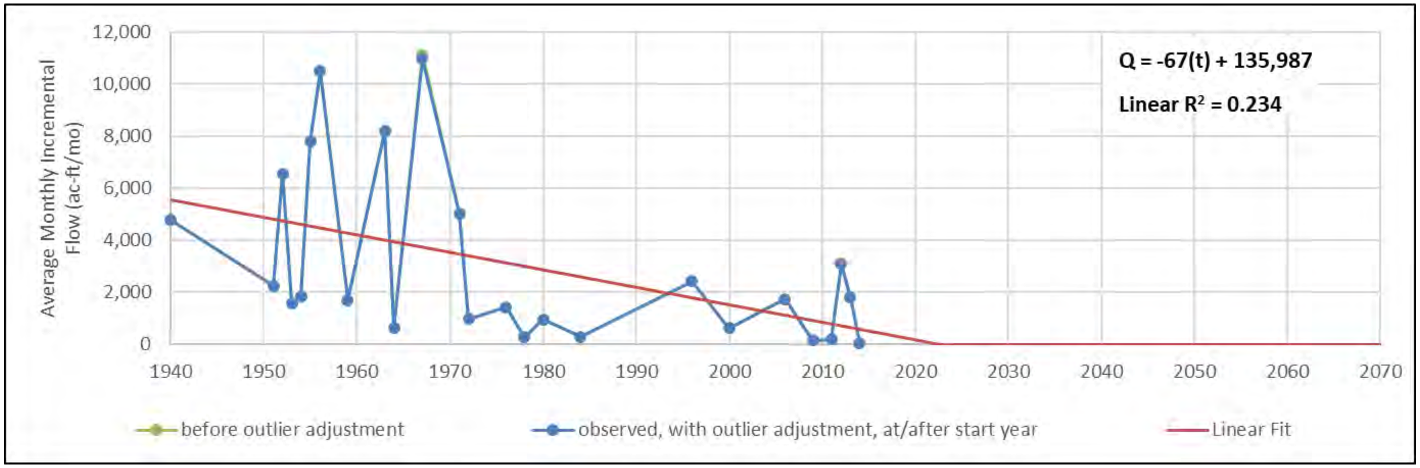


Figure 2-C-88 – Dry spring Trend for Average Monthly Incremental Flow

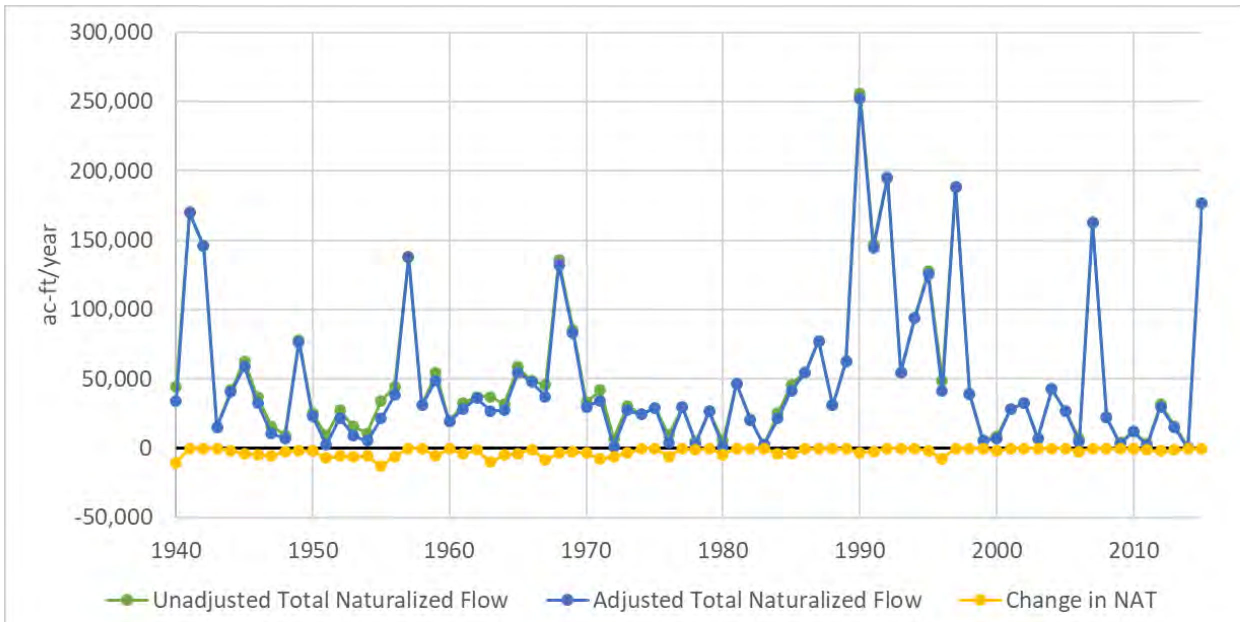


Figure 2-C-89 – Original and Adjusted Naturalized Flow Time Series for LEDL43 for 2070 Conditions

SADL44 - Sabana River near De Leon

Table 2-C-46– Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.09	-0.13	-0.10	-0.09	-0.28	-0.28	0.03	-0.33	0.03	-0.19	-0.14	-0.30	0.23
	P	0.231	0.112	0.204	0.253	0.052	0.055	0.843	0.023	0.822	0.215	0.327	0.048	0.103
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.11	-0.15	-0.11	-0.12	-0.26	-0.25	-0.08	-0.35	0.02	-0.17	-0.18	-0.35	0.24
	P	0.173	0.058	0.159	0.121	0.071	0.080	0.620	0.017	0.896	0.284	0.189	0.022	0.094
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

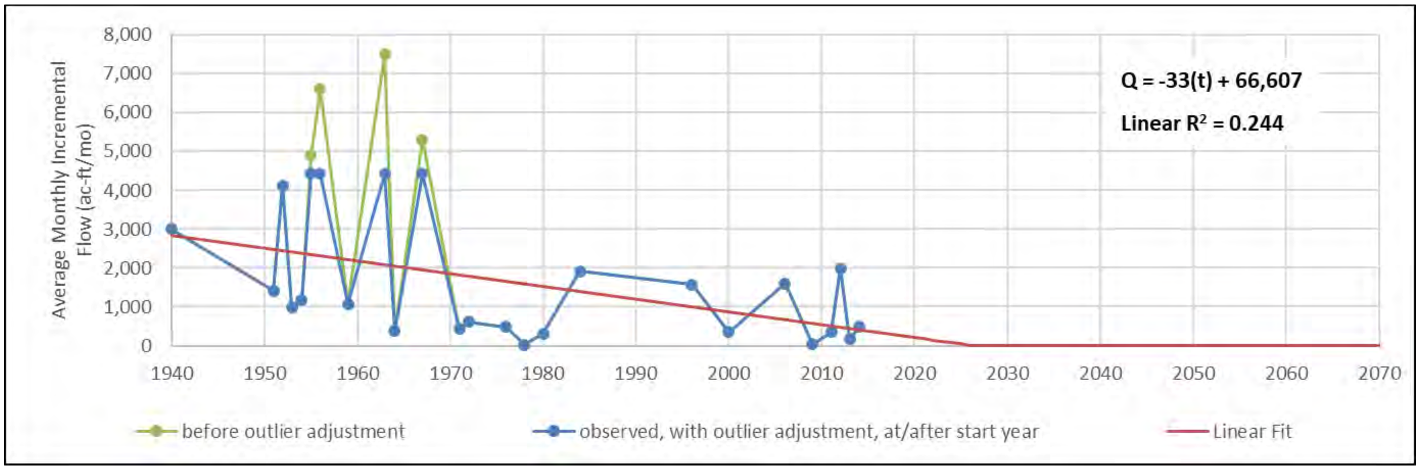


Figure 2-C-90 – Dry spring Trend for Average Monthly Incremental Flow

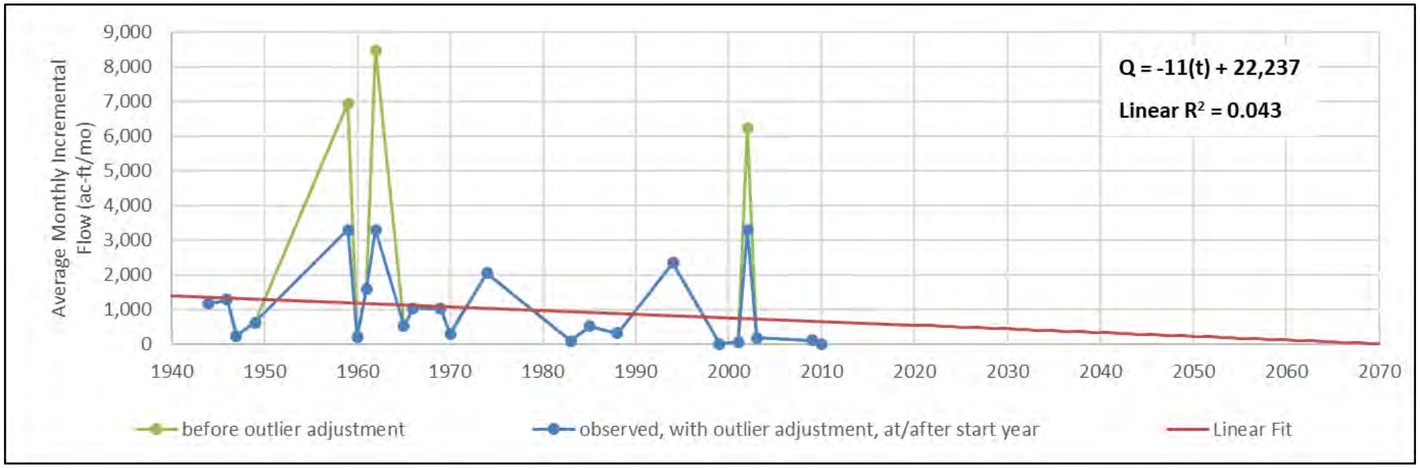


Figure 2-C-91 – Average summer Trend for Average Monthly Incremental Flow

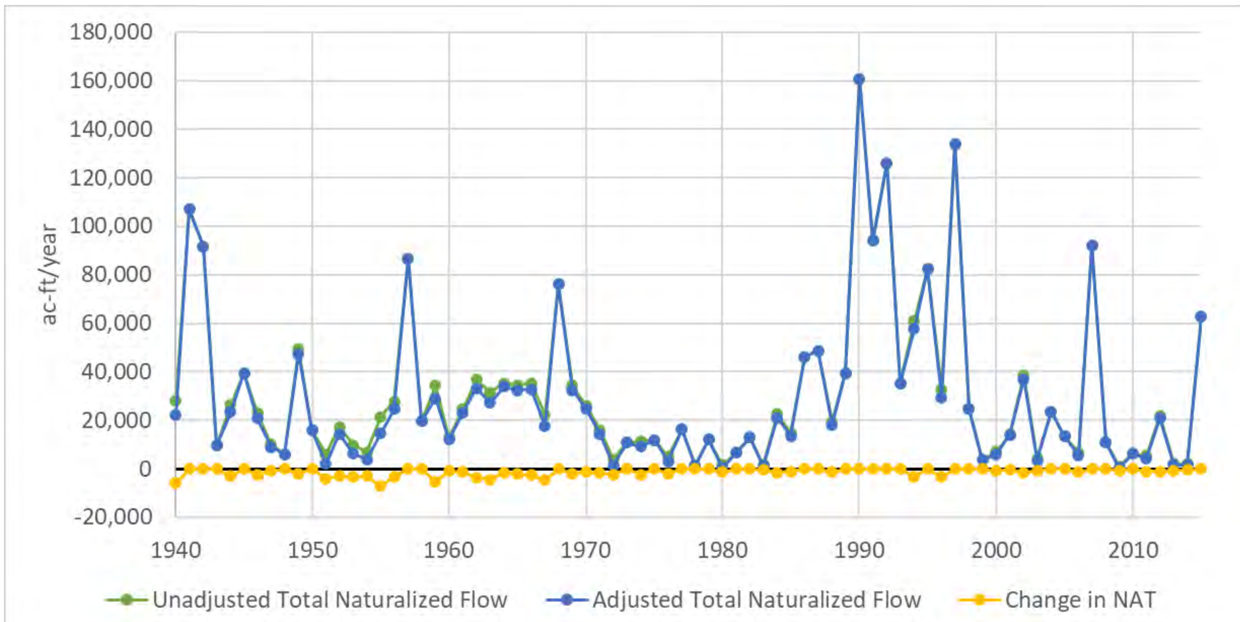


Figure 2-C-92 – Original and Adjusted Naturalized Flow Time Series for SADL44 for 2070 Conditions

LEHS45 - Leon River near Hasse

Table 2-C-47 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.11	-0.23	-0.13	-0.09	-0.28	-0.39	-0.11	-0.47	0.04	-0.18	-0.21	-0.39	0.38
	P	0.151	0.003	0.096	0.249	0.047	0.007	0.457	0.001	0.793	0.259	0.139	0.010	0.006
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.732	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.12	-0.26	-0.13	-0.11	-0.26	-0.37	-0.25	-0.45	0.01	-0.17	-0.23	-0.41	0.39
	P	0.119	0.001	0.099	0.163	0.064	0.010	0.092	0.002	0.955	0.284	0.095	0.007	0.006
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

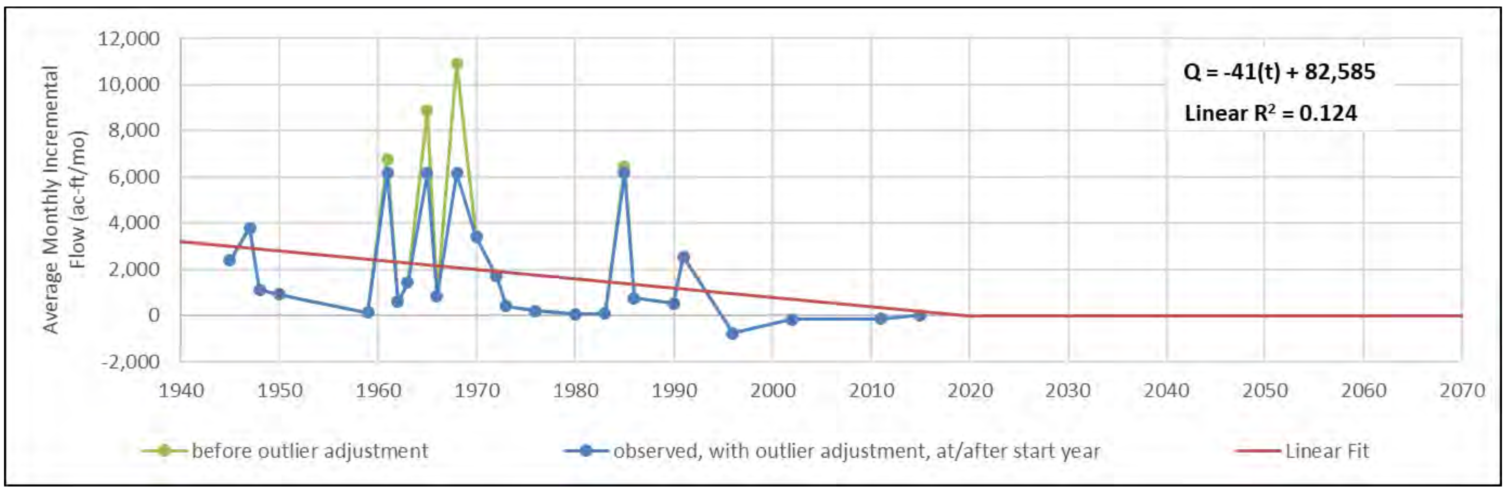


Figure 2-C-93 – Average winter Trend for Average Monthly Incremental Flow

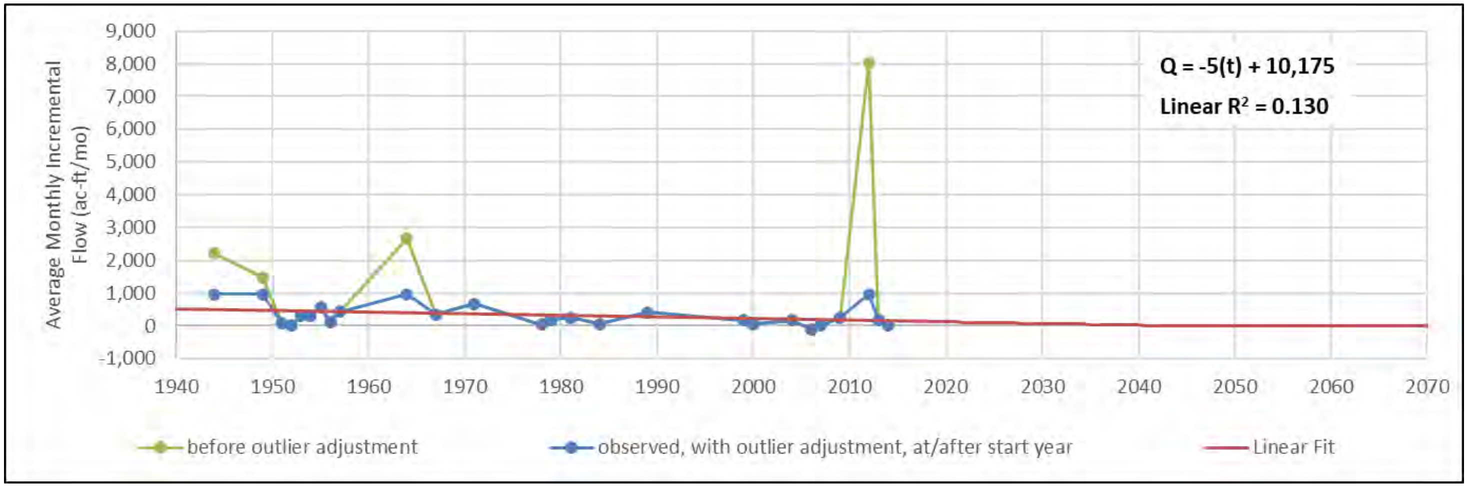


Figure 2-C-94 – Dry winter Trend for Average Monthly Incremental Flow

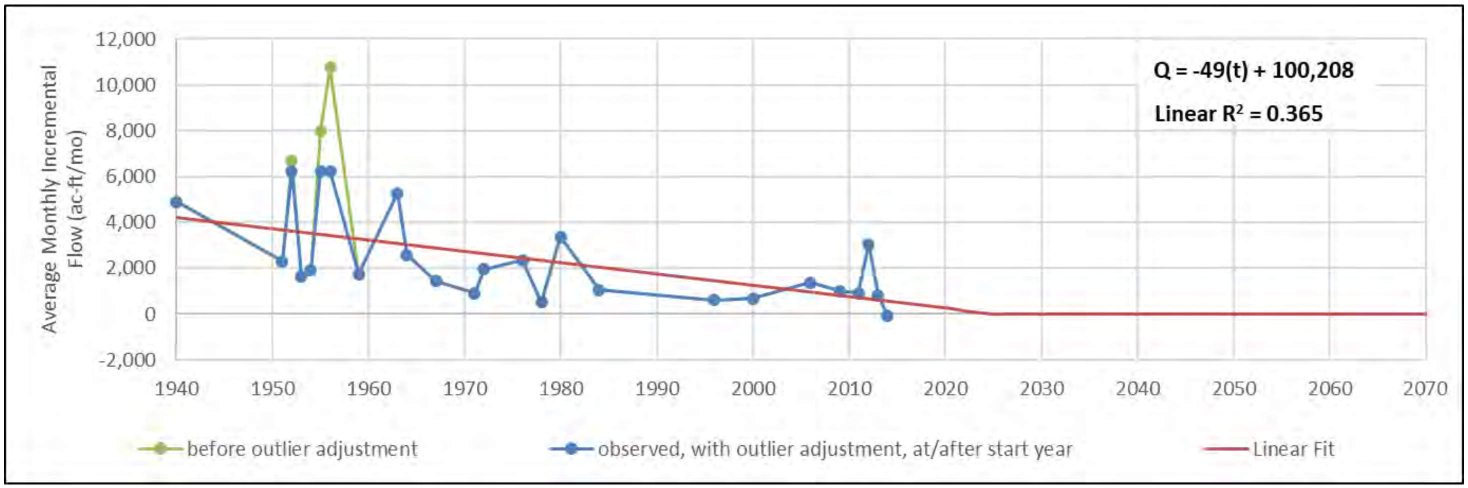


Figure 2-C-95 – Dry spring Trend for Average Monthly Incremental Flow

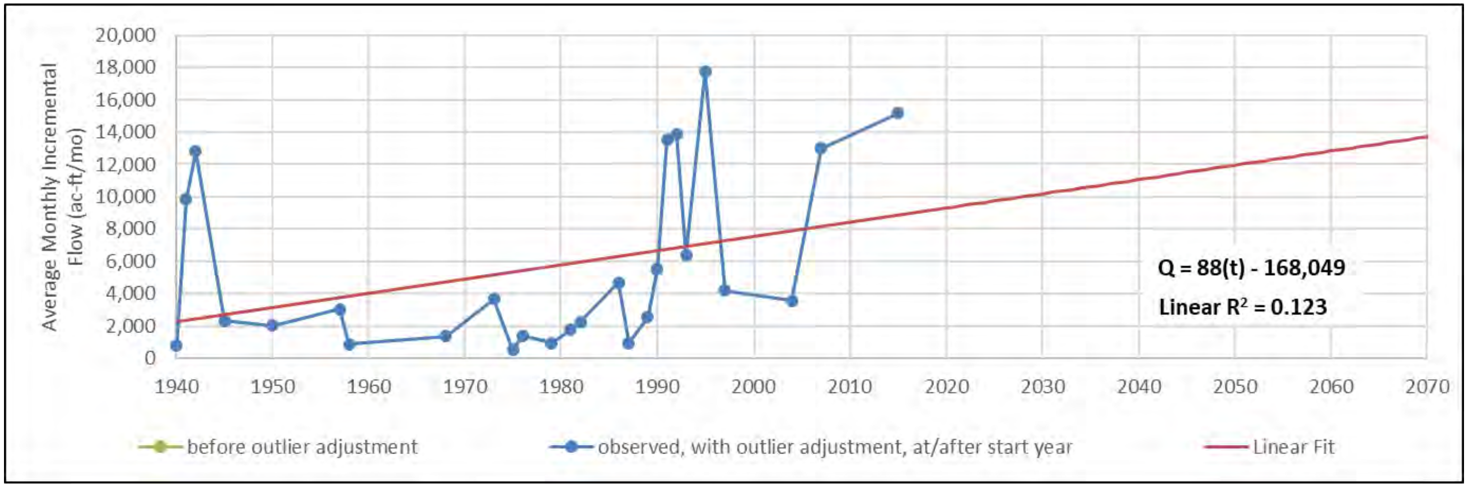


Figure 2-C-96 – Wet summer Trend for Average Monthly Incremental Flow

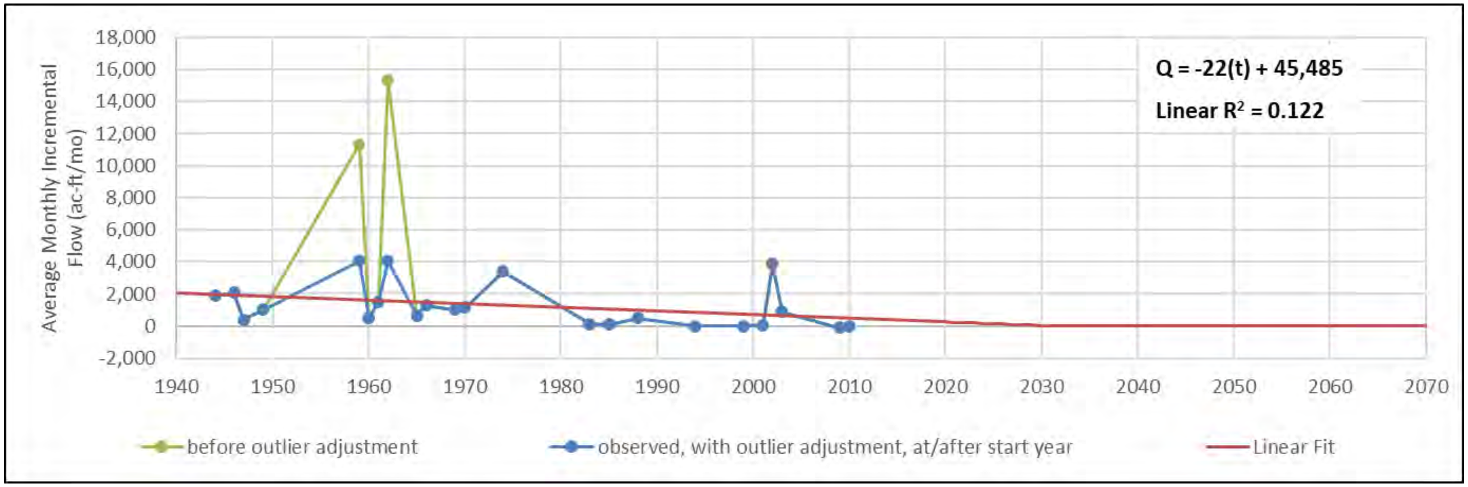


Figure 2-C-97 – Average summer Trend for Average Monthly Incremental Flow

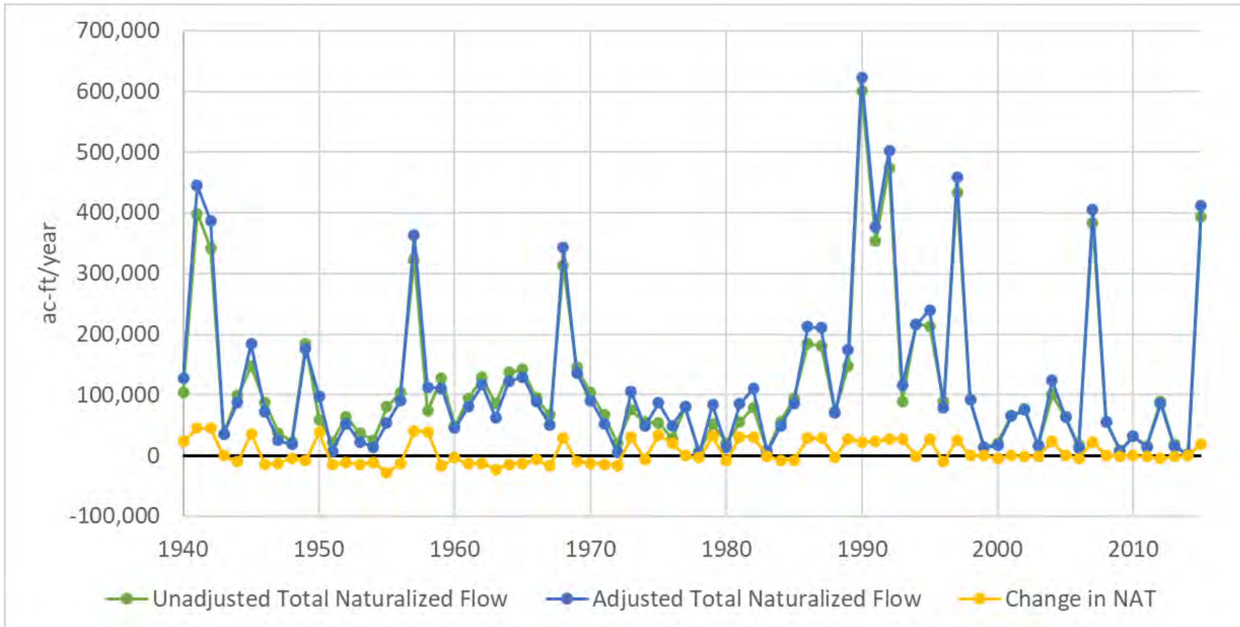


Figure 2-C-98 – Original and Adjusted Naturalized Flow Time Series for LEHS45 for 2070 Conditions

LEHM46 - Leon River near Hamilton

Table 2-C-48 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.07	-0.04	0.03	0.09	-0.06	-0.24	0.19	-0.23	0.11	0.05	0.07	-0.11	0.40
	P	0.387	0.628	0.720	0.238	0.692	0.097	0.197	0.118	0.409	0.778	0.646	0.460	0.004
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.710	0.435	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.08	-0.04	0.04	0.07	-0.05	-0.24	0.19	-0.18	0.11	0.10	0.01	-0.12	0.38
	P	0.339	0.615	0.594	0.344	0.758	0.097	0.197	0.216	0.420	0.535	0.950	0.428	0.006
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

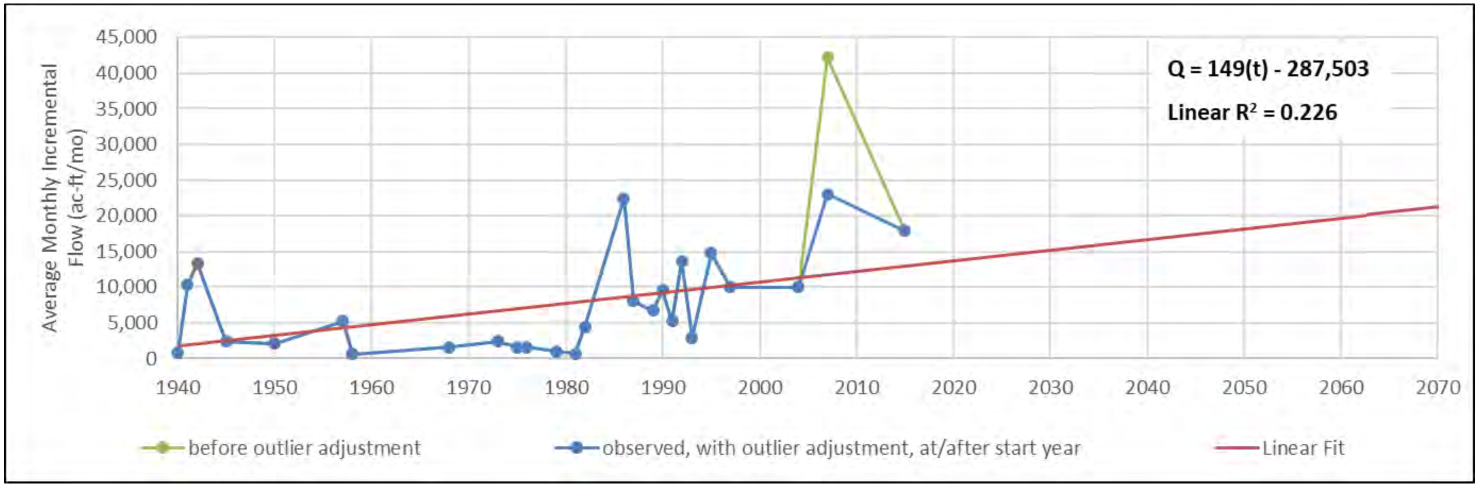


Figure 2-C-99 – Wet Summer Trend for Average Monthly Incremental Flow

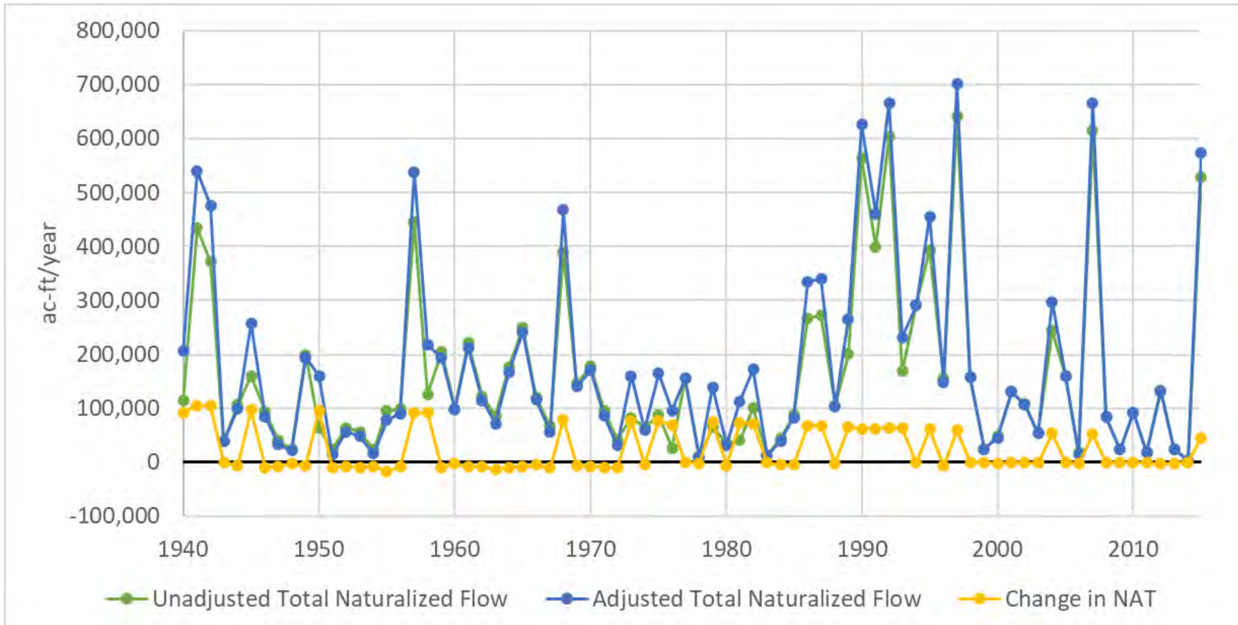


Figure 2-C-100 – Original and Adjusted Naturalized Flow Time Series for LEHM46 for 2070 Conditions

LEGT47 - Leon River at Gatesville

Table 2-C-49 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.03	-0.02	-0.06	0.04	0.22	-0.34	0.07	-0.08	-0.08	-0.17	0.00	0.17	0.02
	P	0.710	0.808	0.468	0.654	0.118	0.018	0.655	0.591	0.561	0.271	1.000	0.256	0.895
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	-0.06	-0.05	-0.07	-0.01	0.22	-0.35	-0.02	-0.06	-0.14	-0.18	-0.09	0.16	0.02
	P	0.433	0.528	0.384	0.925	0.113	0.014	0.901	0.691	0.285	0.259	0.545	0.291	0.912
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

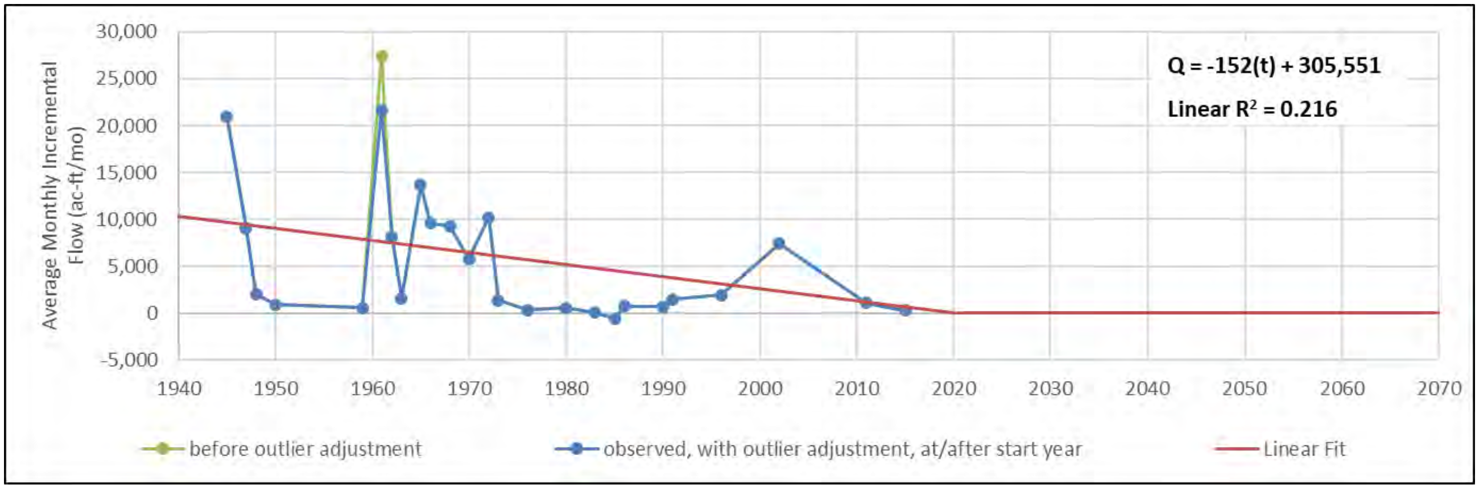


Figure 2-C-101 – Average Winter Trend for Average Monthly Incremental Flow

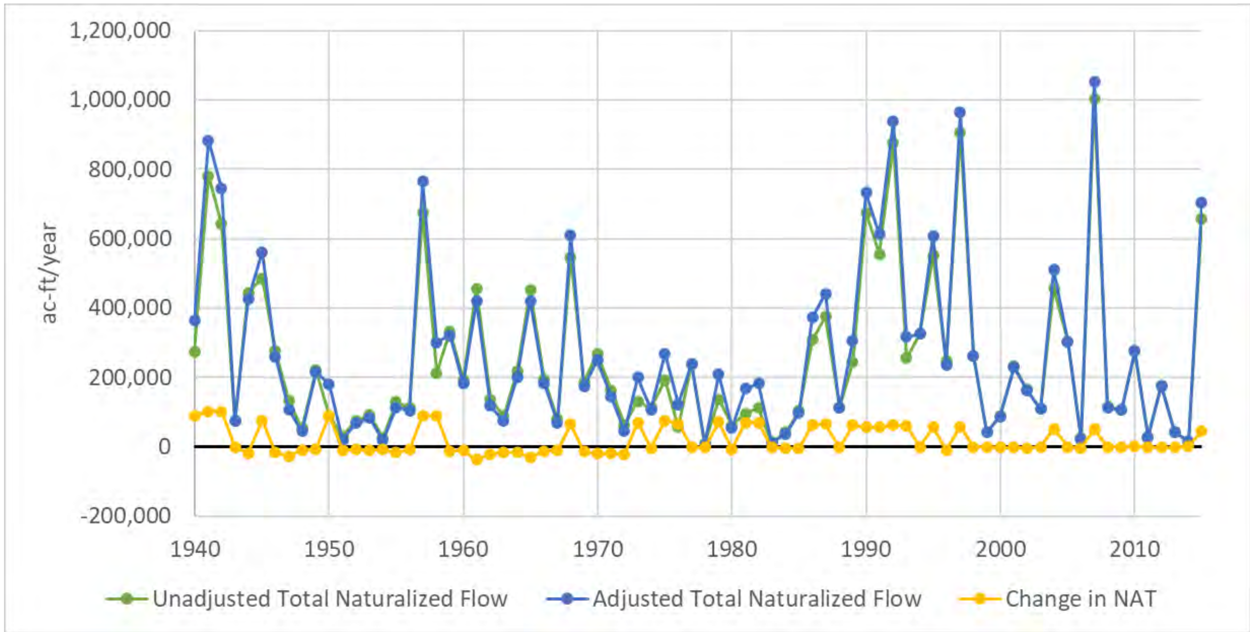


Figure 2-C-102 – Original and Adjusted Naturalized Flow Time Series for LEGT47 for 2070 Conditions

COPI48 - Cowhouse Creek at Pidcoke

Table 2-C-50 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.05	-0.08	-0.07	-0.05	-0.03	-0.40	0.04	-0.17	-0.08	-0.16	-0.01	0.01	-0.09
	P	0.513	0.293	0.384	0.536	0.860	0.005	0.823	0.252	0.561	0.310	0.967	0.958	0.552
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.21	-0.14	0.14	-0.17	0.25	0.15	-0.09
	P	0.594	0.721	0.726	0.409	0.826	0.168	0.157	0.338	0.294	0.284	0.073	0.342	0.537
Q/P	τ	-0.08	-0.09	-0.07	-0.09	0.02	-0.33	-0.07	-0.12	-0.14	-0.13	-0.07	-0.08	-0.12
	P	0.311	0.233	0.342	0.253	0.877	0.023	0.673	0.400	0.302	0.398	0.602	0.635	0.390
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

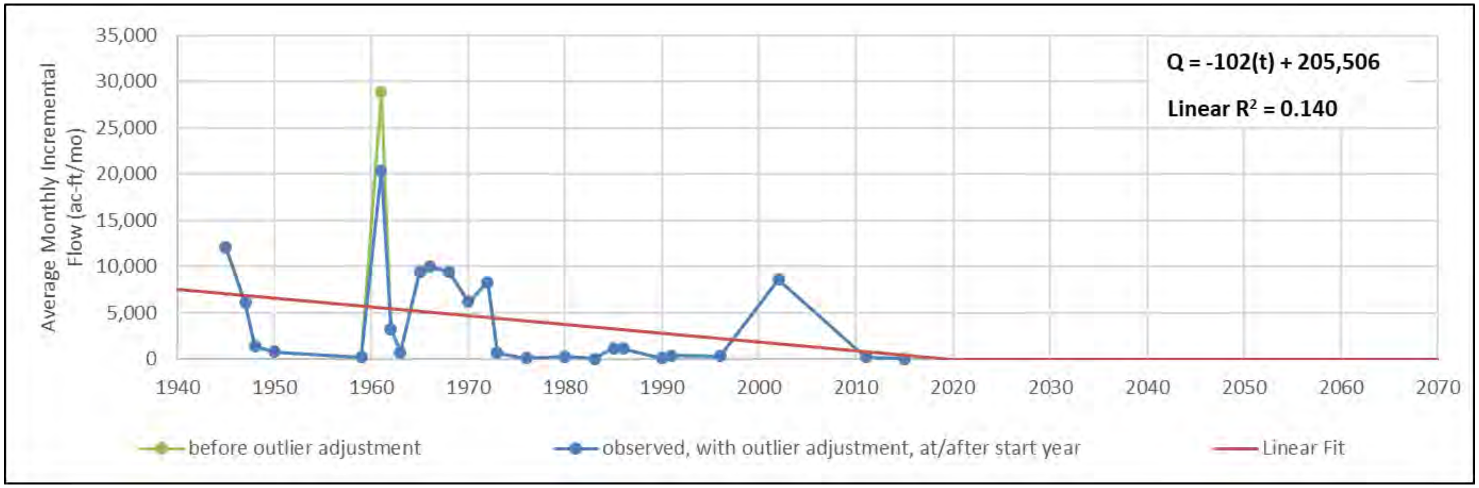


Figure 2-C-103 – Average Winter Trend for Average Monthly Incremental Flow

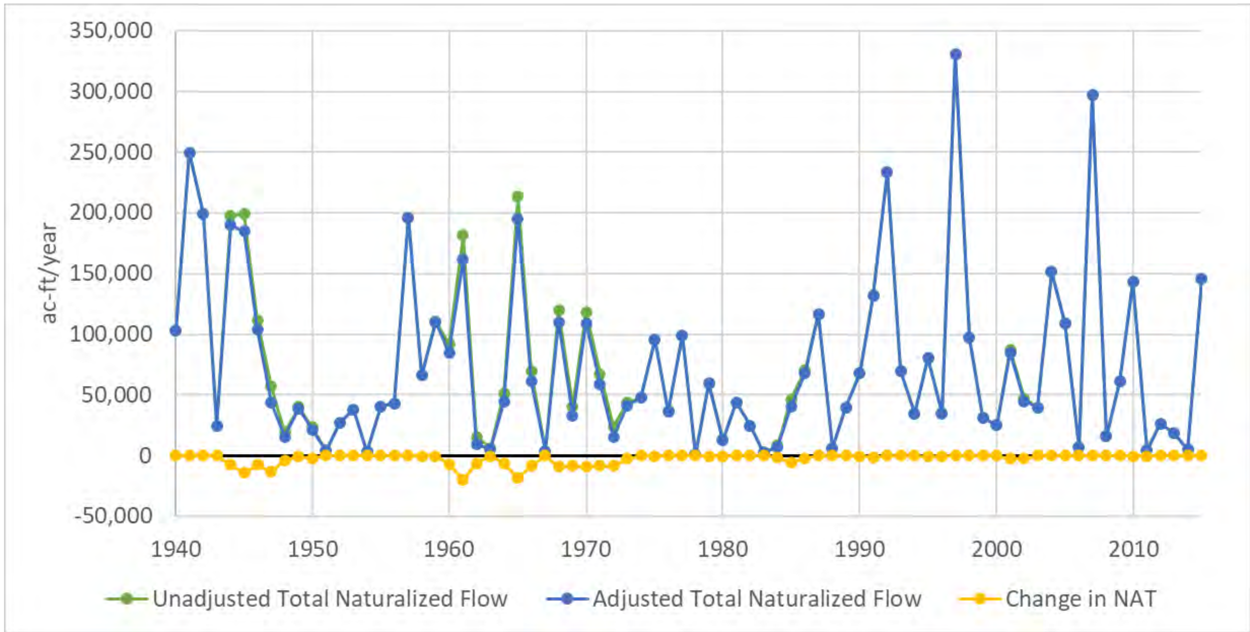


Figure 2-C-104 – Original and Adjusted Naturalized Flow Time Series for COPI48 for 2070 Conditions

LEBE49 - Leon River near Belton

Table 2-C-51 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.01	0.04	-0.05	0.03	0.23	-0.16	0.07	0.03	-0.03	-0.34	0.06	0.15	-0.11
	P	0.932	0.602	0.524	0.706	0.098	0.262	0.673	0.834	0.837	0.028	0.662	0.328	0.454
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.15	-0.19	0.24	0.15	-0.09
	P	0.587	0.721	0.720	0.440	0.826	0.168	0.172	0.315	0.277	0.236	0.080	0.342	0.537
Q/P	τ	-0.02	0.02	-0.05	0.01	0.22	-0.12	-0.01	0.06	-0.03	-0.31	-0.03	0.19	-0.07
	P	0.771	0.791	0.504	0.861	0.113	0.400	0.980	0.691	0.822	0.048	0.851	0.205	0.628
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

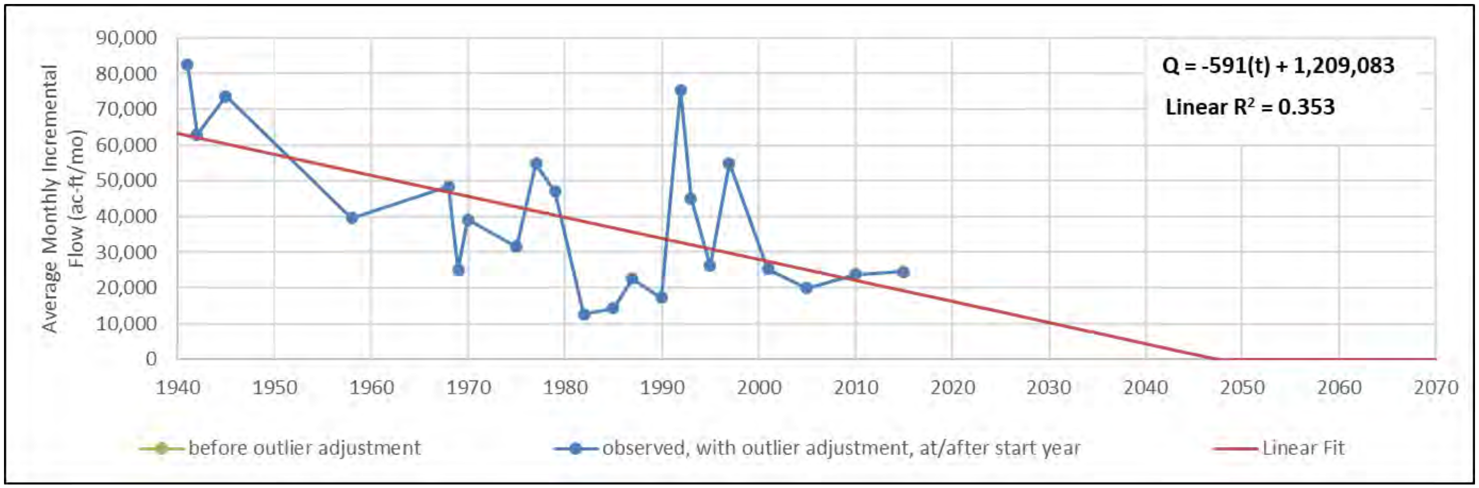


Figure 2-C-105 – Wet Spring Trend for Average Monthly Incremental Flow

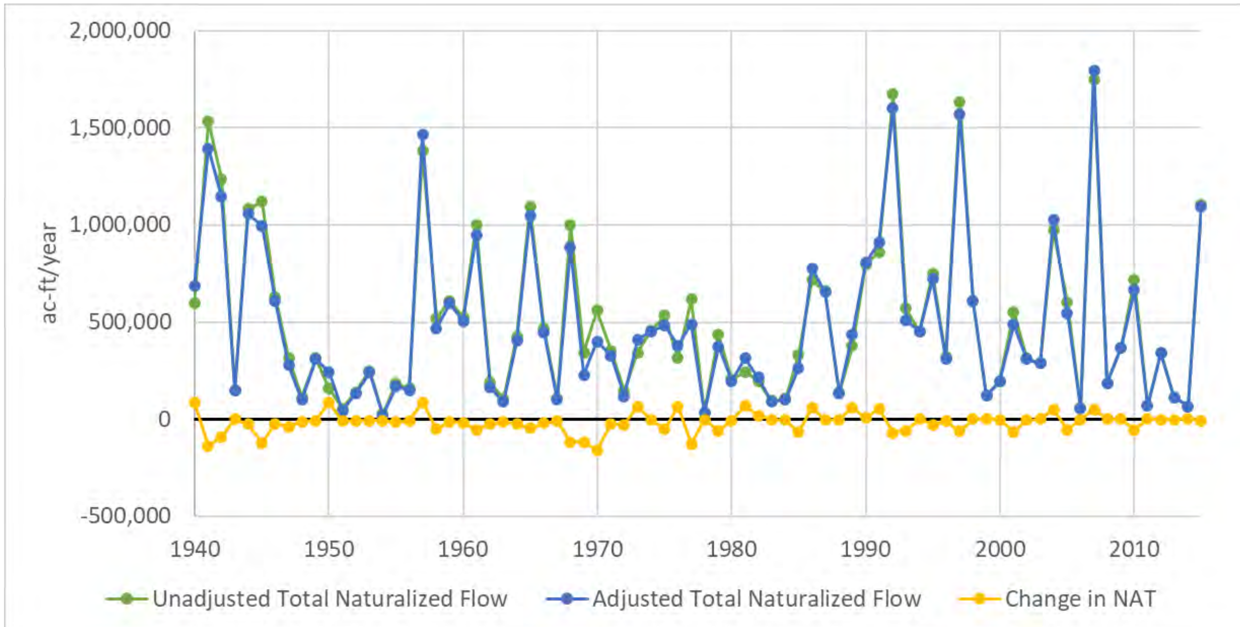


Figure 2-C-106 – Original and Adjusted Naturalized Flow Time Series for LEBE49 for 2070 Conditions

LAKE50 - Lampasas River near Kempner

Table 2-C-52 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.04	-0.05	-0.02	-0.02	0.01	-0.07	-0.01	0.00	-0.11	-0.05	0.07	-0.09	0.02
	P	0.615	0.504	0.819	0.816	0.980	0.599	0.955	1.000	0.487	0.758	0.621	0.535	0.921
P	τ	0.06	0.04	-0.02	0.06	0.06	-0.03	0.12	-0.07	-0.17	0.14	0.25	0.05	-0.07
	P	0.459	0.641	0.830	0.481	0.710	0.807	0.463	0.628	0.264	0.321	0.066	0.747	0.637
Q/P	τ	-0.06	-0.05	-0.03	-0.04	0.10	-0.06	-0.05	0.02	-0.11	-0.06	-0.05	-0.15	0.04
	P	0.457	0.513	0.750	0.597	0.519	0.680	0.778	0.895	0.457	0.659	0.722	0.309	0.804
Period of Record (1940:2015)		76	75	76	76	24	29	22	26	24	26	28	24	24
Period of Analysis (Start Year: 1940)		76	75	76	76	24	29	22	26	24	26	28	24	24

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

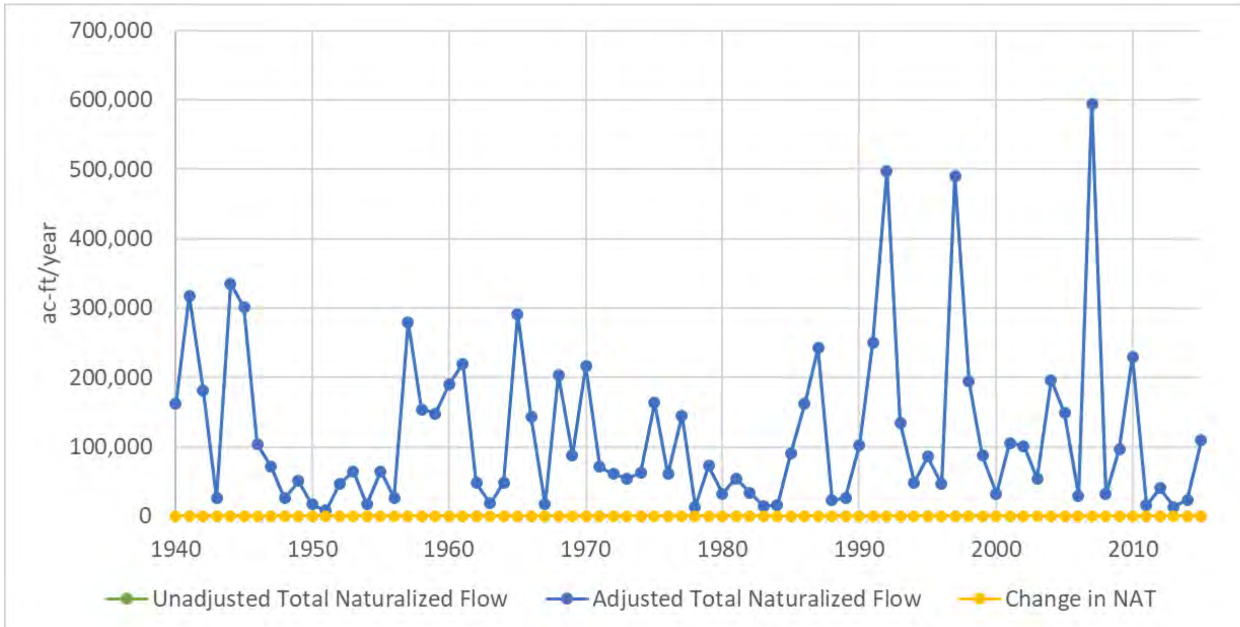


Figure 2-C-107 – Original and Adjusted Naturalized Flow Time Series for LAKE50 for 2070 Conditions

LAYO51 - Lampasas River at Youngsport

Table 2-C-53 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.06	-0.03	-0.06	-0.02	0.11	-0.12	0.05	-0.02	-0.13	-0.13	0.01	-0.13	0.05
	P	0.435	0.721	0.462	0.844	0.457	0.378	0.778	0.877	0.399	0.355	0.968	0.385	0.766
P	τ	0.06	0.04	-0.02	0.05	0.04	-0.02	0.12	-0.09	-0.16	0.14	0.24	0.06	-0.09
	P	0.476	0.647	0.830	0.527	0.785	0.896	0.463	0.523	0.286	0.332	0.072	0.710	0.568
Q/P	τ	-0.09	-0.05	-0.06	-0.04	0.05	-0.14	0.00	-0.03	-0.13	-0.22	-0.08	-0.17	0.06
	P	0.255	0.507	0.414	0.609	0.728	0.294	1.000	0.843	0.399	0.123	0.567	0.244	0.691
Period of Record (1940:2015)		76	75	76	76	24	29	22	26	24	26	28	24	24
Period of Analysis (Start Year:1940)		76	75	76	76	24	29	22	26	24	26	28	24	24

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

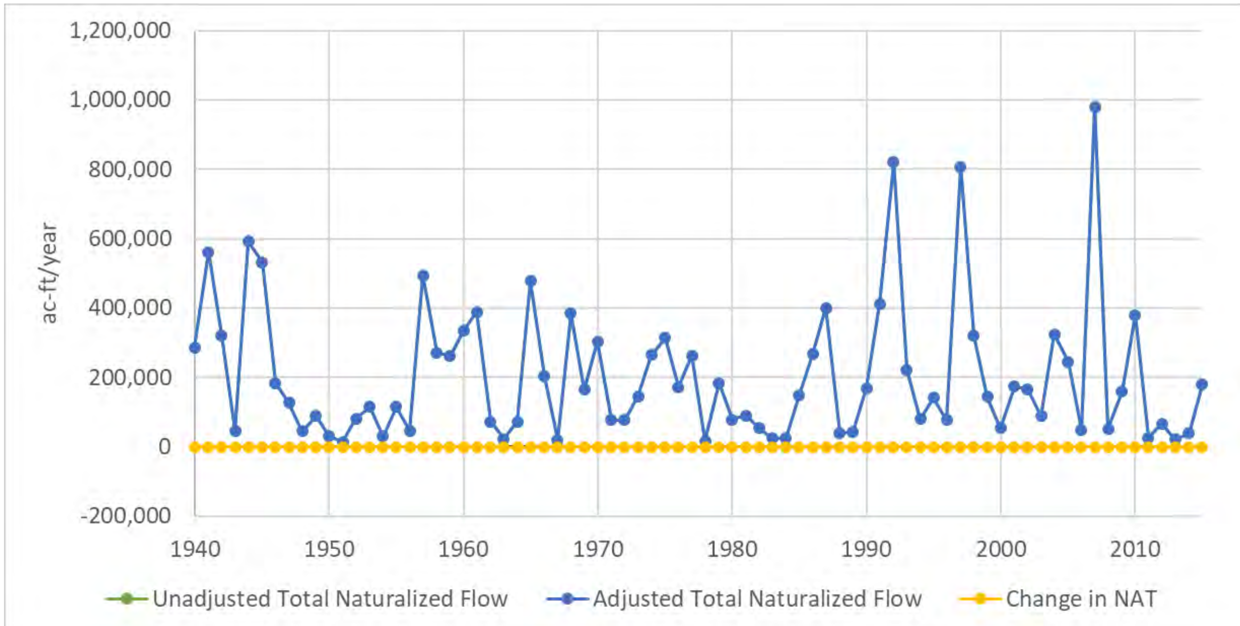


Figure 2-C-108 – Original and Adjusted Naturalized Flow Time Series for LAYO51 for 2070 Conditions

LABE52 - Lampasas River near Belton

Table 2-C-54 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.10	-0.08	0.02	0.05	-0.28	-0.05	0.13	-0.10	0.04	0.06	0.08	-0.11	0.21
	P	0.219	0.291	0.791	0.536	0.045	0.761	0.399	0.513	0.750	0.735	0.588	0.476	0.134
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.732	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.11	-0.06	0.05	0.05	-0.25	-0.01	0.21	-0.04	0.05	0.11	0.06	-0.10	0.22
	P	0.156	0.478	0.554	0.542	0.074	0.981	0.150	0.779	0.722	0.499	0.677	0.509	0.113
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

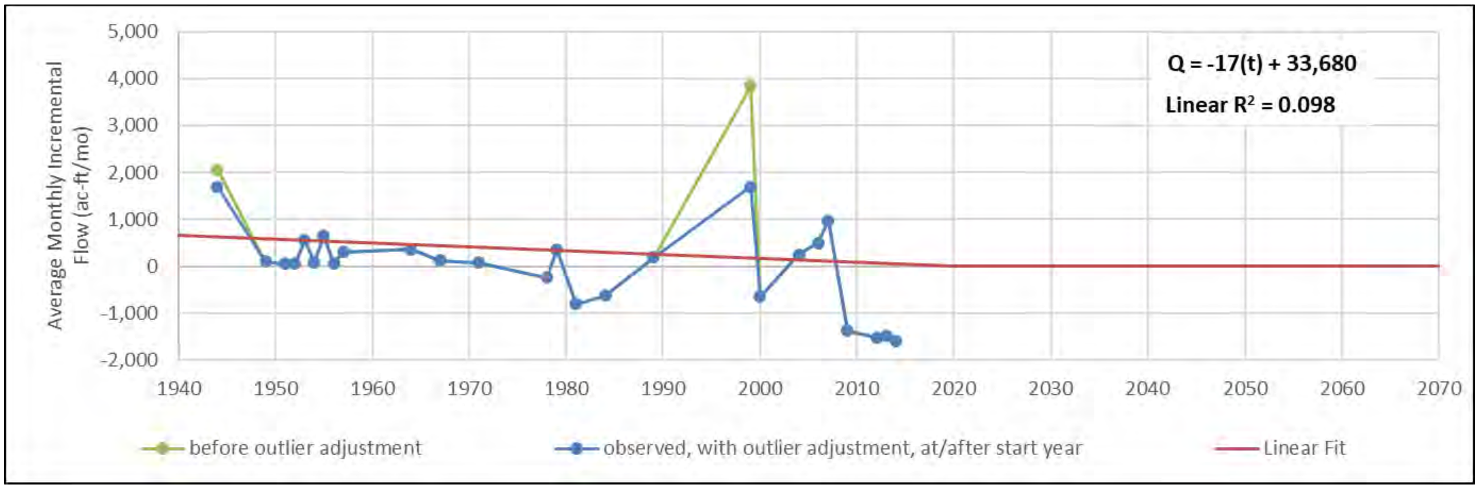


Figure 2-C-109 – Dry Winter Trend for Average Monthly Incremental Flow

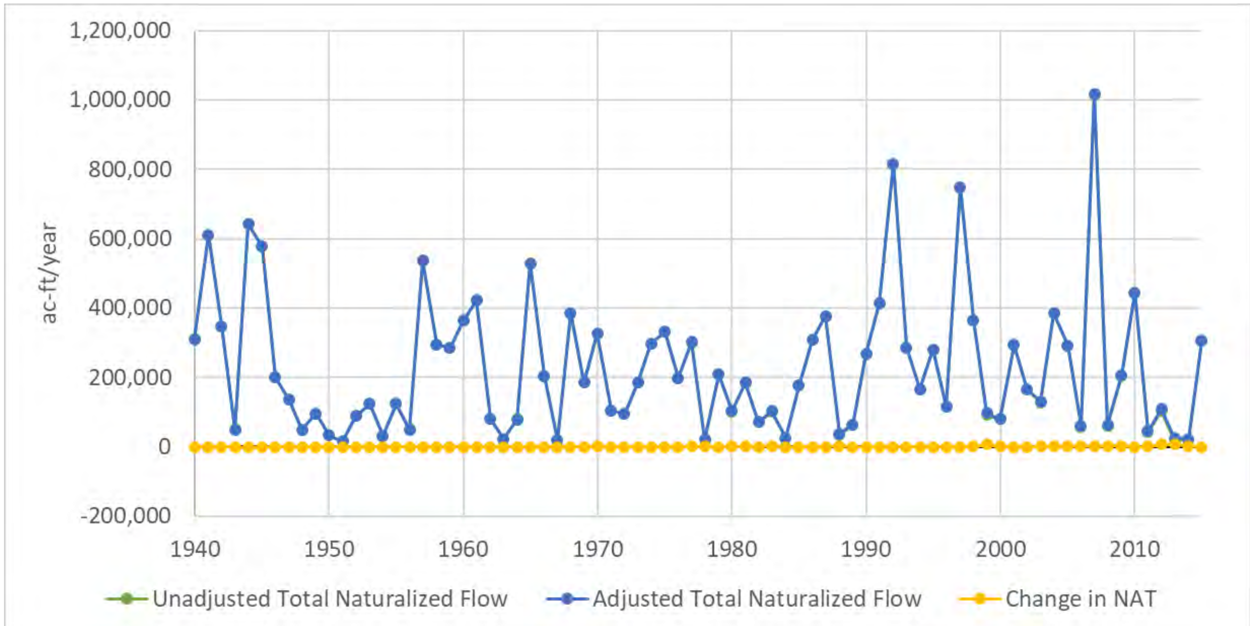


Figure 2-C-110 – Original and Adjusted Naturalized Flow Time Series for LABE52 for 2070 Conditions

LRLR53 - Little River near Little River

Table 2-C-55 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.07	0.11	-0.01	0.08	0.43	-0.03	0.06	0.02	0.01	-0.11	0.23	0.20	-0.05
	P	0.344	0.156	0.918	0.290	0.003	0.870	0.710	0.926	0.940	0.499	0.091	0.187	0.724
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.738	0.710	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.09	0.10	0.00	0.08	0.41	-0.03	0.00	0.08	-0.02	0.00	0.17	0.30	-0.05
	P	0.276	0.219	0.954	0.288	0.004	0.834	1.000	0.591	0.881	1.000	0.235	0.051	0.741
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

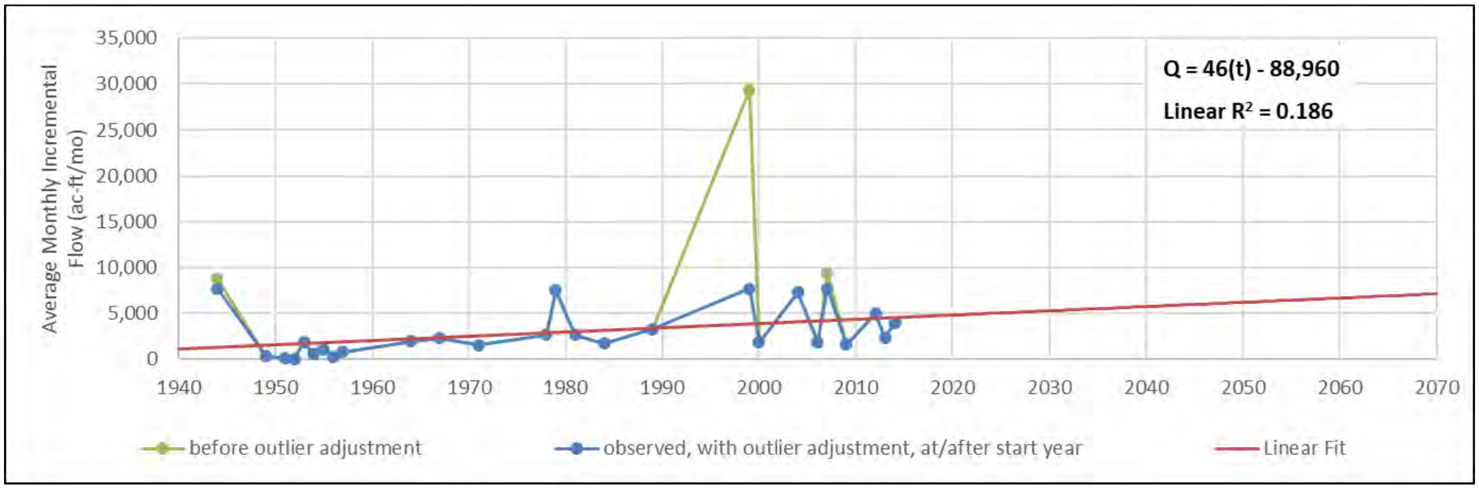


Figure 2-C-111 – Dry Winter Trend for Average Monthly Incremental Flow

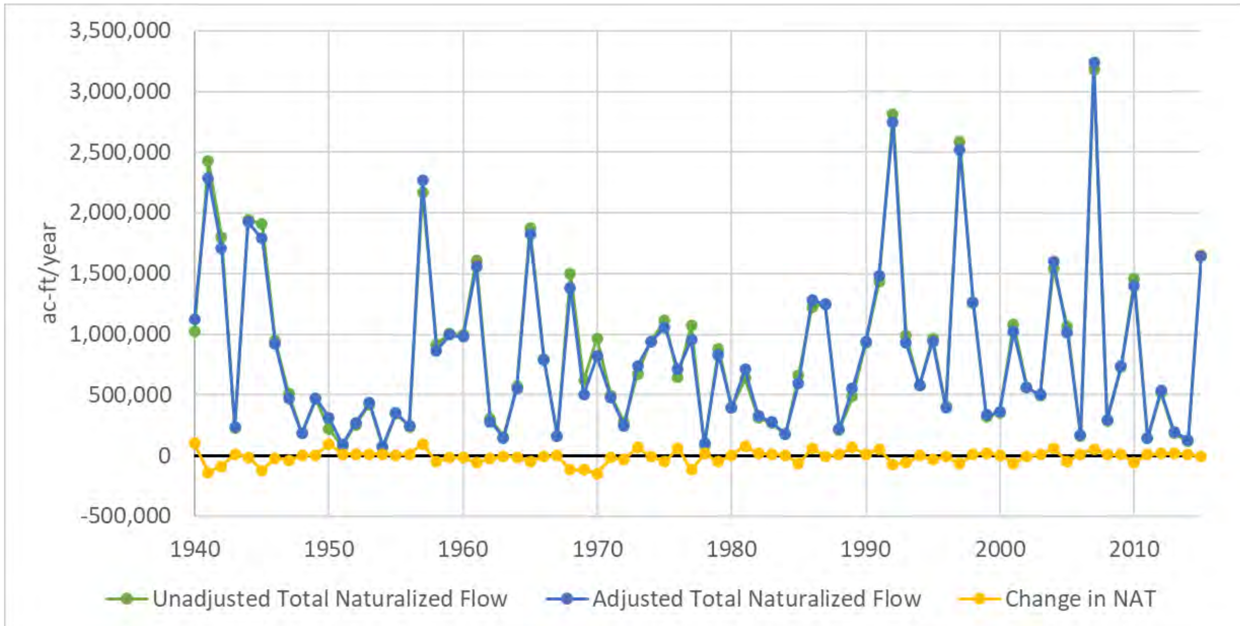


Figure 2-C-112 – Original and Adjusted Naturalized Flow Time Series for LRLR53 for 2070 Conditions

NGGE54 - North Fork San Gabriel River near Georgetown

Table 2-C-56 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.04	-0.09	-0.07	-0.06	-0.24	-0.05	-0.02	-0.16	-0.24	-0.01	-0.07	-0.12	0.05
	P	0.635	0.245	0.342	0.425	0.107	0.722	0.910	0.252	0.107	0.965	0.607	0.427	0.747
P	τ	0.06	0.04	-0.01	0.05	0.06	-0.03	0.12	-0.06	-0.16	0.15	0.25	0.06	-0.09
	P	0.481	0.634	0.875	0.487	0.710	0.807	0.463	0.692	0.286	0.300	0.066	0.710	0.568
Q/P	τ	-0.06	-0.11	-0.07	-0.08	-0.25	-0.08	-0.06	-0.15	-0.22	-0.10	-0.21	-0.13	0.06
	P	0.459	0.158	0.358	0.311	0.092	0.561	0.693	0.290	0.130	0.481	0.119	0.385	0.710
Period of Record (1940:2015)		76	75	76	76	24	29	22	26	24	26	28	24	24
Period of Analysis (Start Year: 1940)		76	75	76	76	24	29	22	26	24	26	28	24	24

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

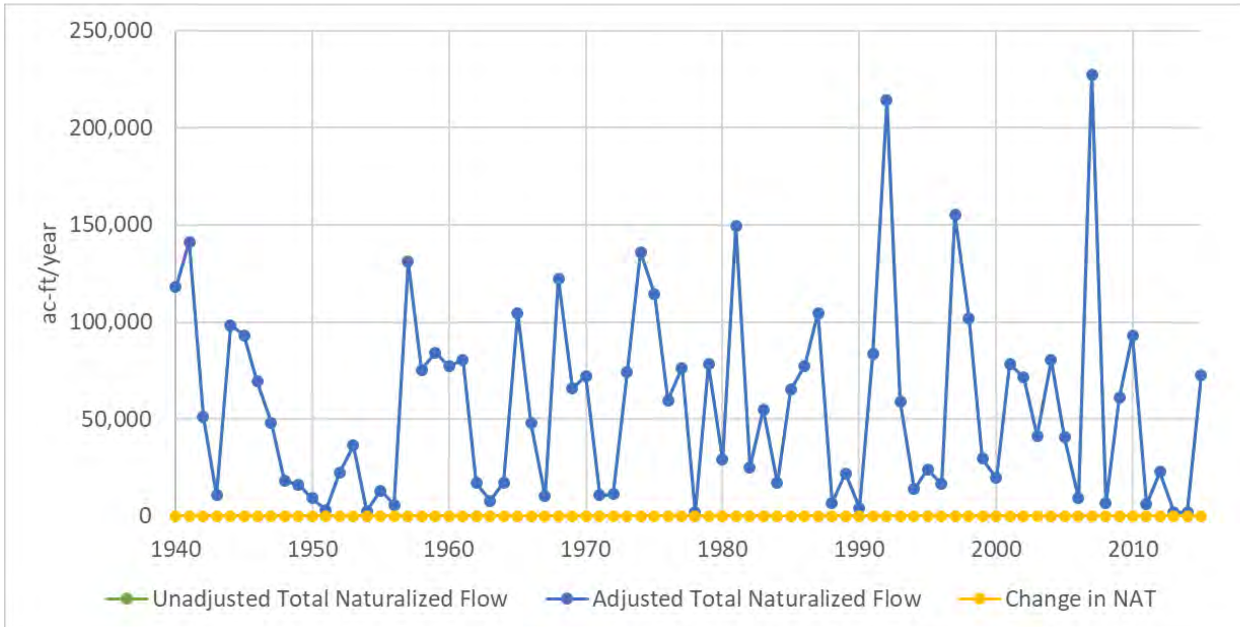


Figure 2-C-113 – Original and Adjusted Naturalized Flow Time Series for NGGE54 for 2070 Conditions

SGGE55 - South Fork San Gabriel River at Georgetown

Table 2-C-57 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.03	-0.03	-0.09	-0.04	-0.07	-0.15	0.08	-0.28	-0.06	-0.13	-0.05	0.03	-0.15
	P	0.743	0.671	0.278	0.638	0.628	0.304	0.585	0.055	0.666	0.398	0.707	0.874	0.300
P	τ	0.04	0.03	-0.02	0.05	-0.02	-0.17	0.23	-0.12	0.10	-0.07	0.20	0.13	-0.16
	P	0.575	0.661	0.816	0.498	0.895	0.234	0.118	0.414	0.453	0.652	0.144	0.413	0.270
Q/P	τ	-0.05	-0.07	-0.08	-0.04	-0.11	-0.17	-0.09	-0.30	-0.09	-0.09	-0.23	0.01	-0.09
	P	0.487	0.344	0.304	0.569	0.427	0.252	0.568	0.040	0.488	0.573	0.095	0.958	0.523
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

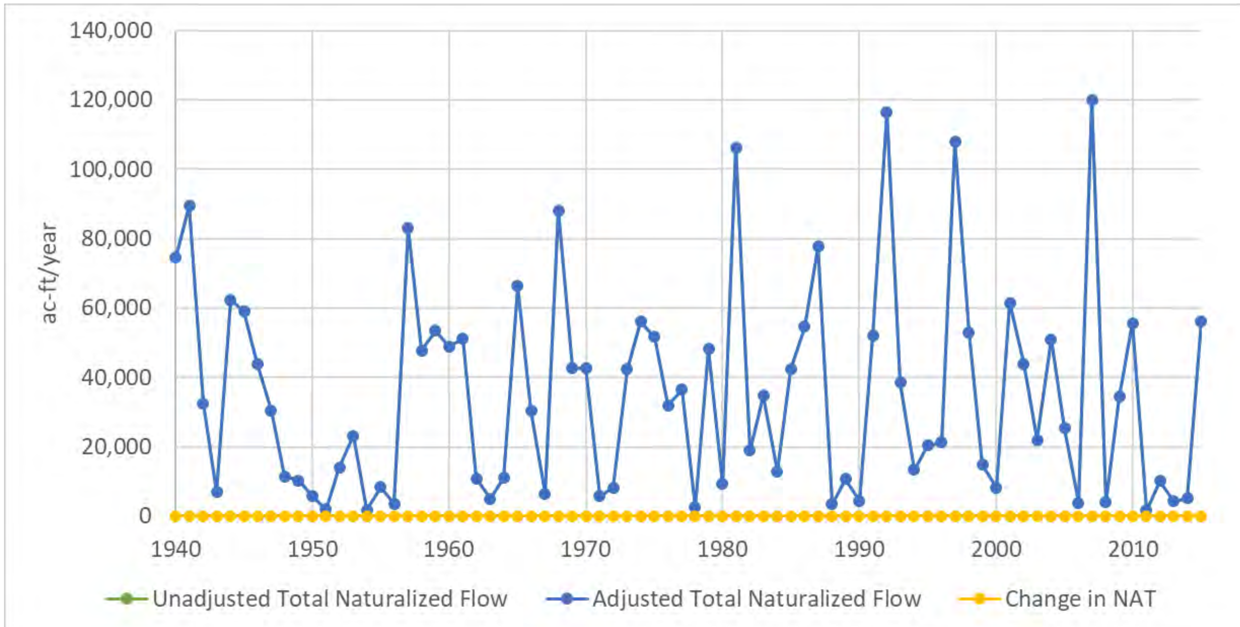


Figure 2-C-114 – Original and Adjusted Naturalized Flow Time Series for SGGE55 for 2070 Conditions

GAGE56 - San Gabriel River at Georgetown

Table 2-C-58 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.04	-0.02	-0.01	0.01	-0.03	-0.09	0.08	-0.14	0.04	0.02	0.03	0.10	-0.10
	P	0.597	0.823	0.897	0.939	0.826	0.528	0.602	0.338	0.764	0.910	0.851	0.526	0.481
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.710	0.435	0.826	0.168	0.189	0.293	0.294	0.236	0.080	0.342	0.537
Q/P	τ	0.04	-0.03	0.02	0.00	-0.04	-0.09	0.02	-0.10	0.05	0.06	-0.11	0.13	-0.05
	P	0.619	0.732	0.826	0.954	0.808	0.559	0.901	0.498	0.694	0.693	0.416	0.398	0.724
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

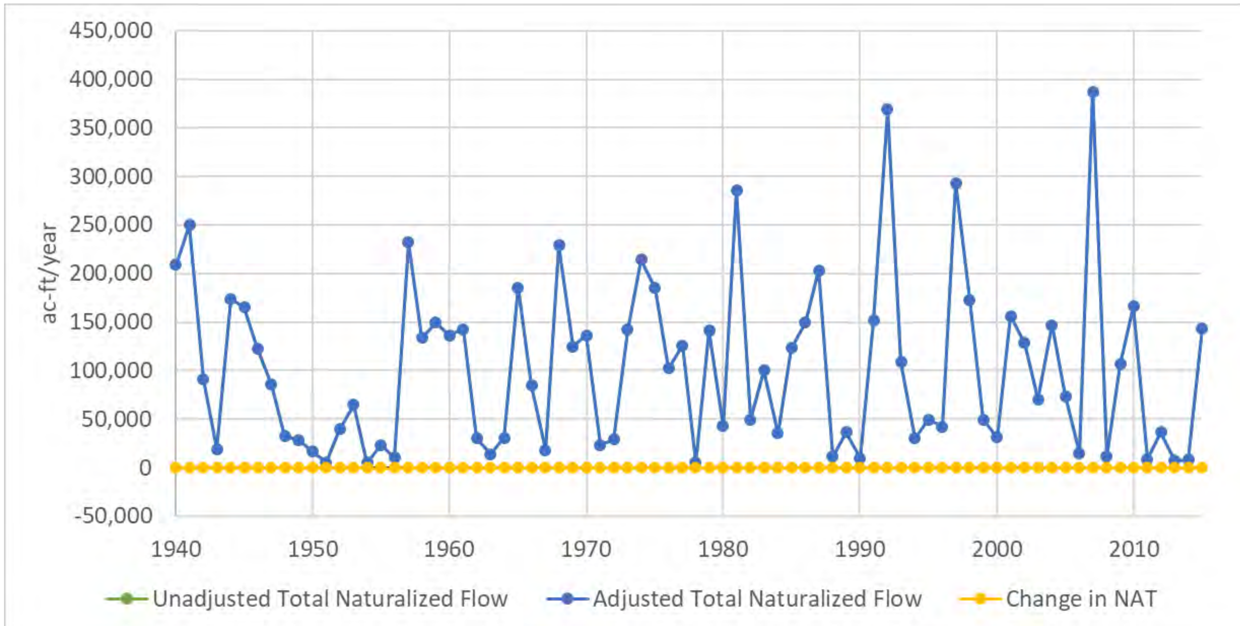


Figure 2-C-115 – Original and Adjusted Naturalized Flow Time Series for GAGE56 for 2070 Conditions

GALA57 - San Gabriel River at Laneport

Table 2-C-59 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.08	0.12	0.01	0.07	0.23	0.00	0.13	-0.04	0.04	0.04	0.13	0.09	0.04
	P	0.288	0.145	0.907	0.353	0.103	1.000	0.385	0.797	0.778	0.822	0.338	0.579	0.808
P	τ	0.04	0.03	-0.03	0.07	-0.03	-0.20	0.21	-0.14	0.14	-0.16	0.25	0.15	-0.09
	P	0.594	0.714	0.720	0.399	0.826	0.168	0.157	0.338	0.294	0.310	0.073	0.342	0.537
Q/P	τ	0.08	0.12	0.02	0.06	0.24	0.04	0.06	-0.03	0.00	0.14	0.05	0.01	0.06
	P	0.300	0.141	0.833	0.440	0.090	0.797	0.710	0.870	0.985	0.367	0.723	0.979	0.659
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

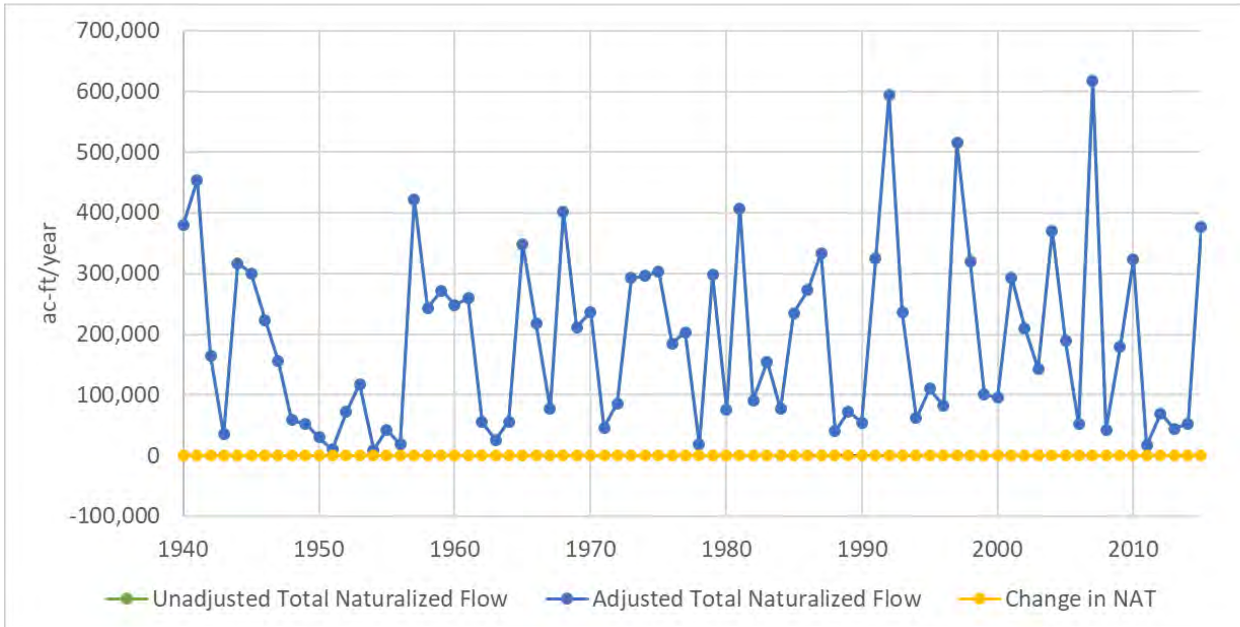


Figure 2-C-116 – Original and Adjusted Naturalized Flow Time Series for GALA57 for 2070 Conditions

LRCA58 - Little River at Cameron

Table 2-C-60 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.04	0.05	0.01	0.03	0.13	-0.12	0.10	-0.01	-0.09	0.17	0.26	-0.01	-0.22
	P	0.572	0.525	0.879	0.677	0.355	0.427	0.503	0.963	0.511	0.284	0.058	0.979	0.128
P	τ	0.04	0.03	-0.03	0.06	-0.04	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.594	0.735	0.713	0.435	0.791	0.168	0.172	0.293	0.294	0.236	0.080	0.342	0.537
Q/P	τ	0.06	0.02	0.06	0.04	0.18	-0.11	-0.03	0.01	-0.06	0.27	0.27	-0.03	-0.19
	P	0.454	0.756	0.470	0.622	0.217	0.441	0.862	0.944	0.666	0.080	0.053	0.853	0.179
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

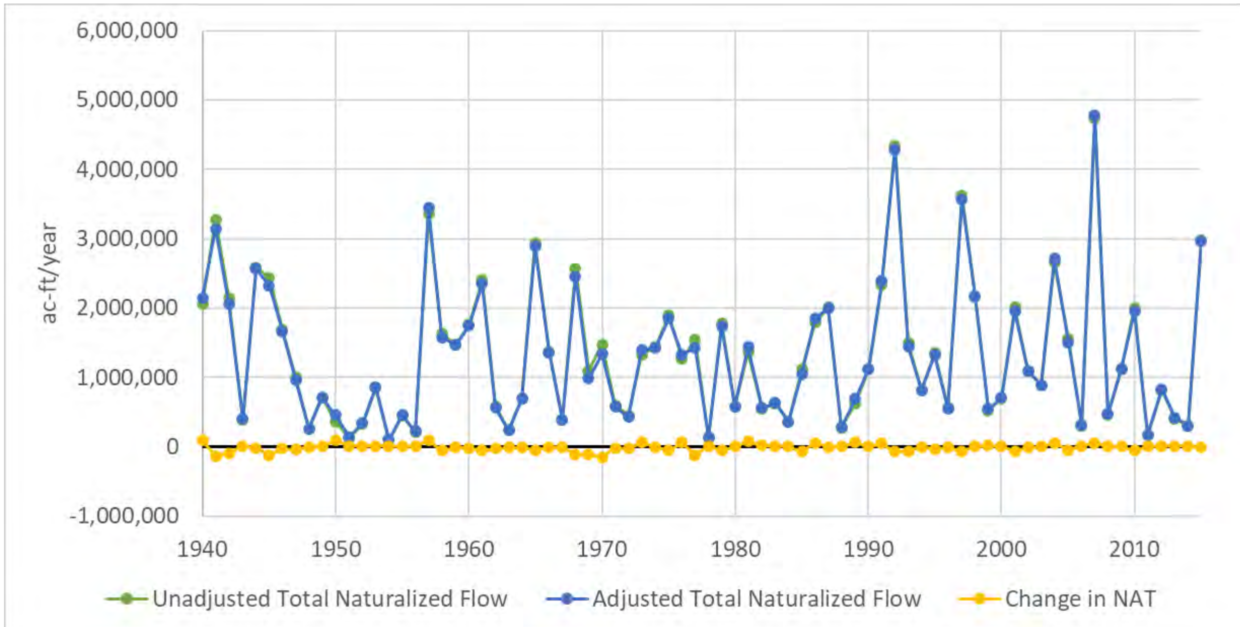


Figure 2-C-117 – Original and Adjusted Naturalized Flow Time Series for LRCA58 for 2070 Conditions

BRBR59 - Brazos River near Bryan

Table 2-C-61 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.05	0.03	0.01	0.07	0.17	-0.06	0.04	0.14	-0.08	0.08	0.11	0.09	-0.04
	P	0.487	0.711	0.911	0.344	0.234	0.691	0.785	0.350	0.536	0.632	0.428	0.579	0.774
P	τ	0.04	0.02	-0.05	0.07	-0.03	-0.21	0.23	-0.11	0.06	-0.16	0.28	0.10	-0.18
	P	0.606	0.794	0.524	0.392	0.826	0.141	0.118	0.469	0.653	0.310	0.045	0.526	0.201
Q/P	τ	0.07	0.02	0.04	0.07	0.19	-0.03	-0.11	0.11	-0.03	0.13	0.02	0.00	0.16
	P	0.358	0.837	0.657	0.358	0.179	0.834	0.472	0.455	0.837	0.398	0.884	1.000	0.261
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

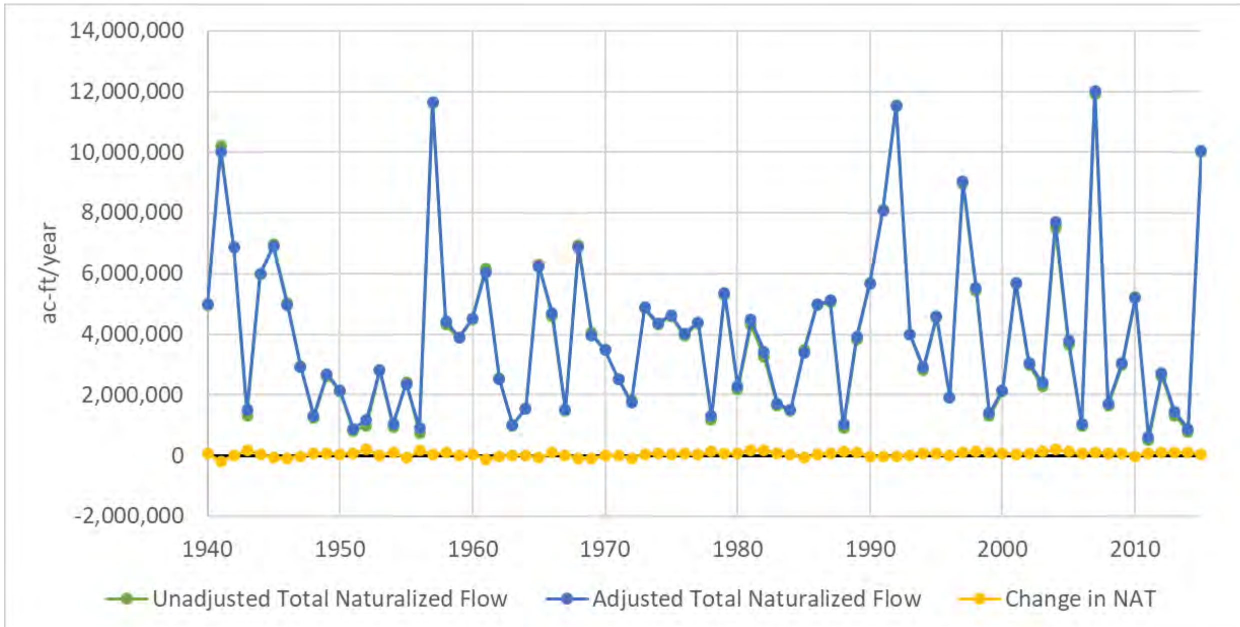


Figure 2-C-118 – Original and Adjusted Naturalized Flow Time Series for BRBR59 for 2070 Conditions

MYDB60 - Middle Yegua Creek near Dime Box

Table 2-C-62 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.00	0.05	-0.12	0.20	0.16	0.23	0.09	0.34	-0.37	0.09	0.28	0.25	0.17
	P	1.000	0.632	0.223	0.035	0.443	0.147	0.653	0.101	0.034	0.624	0.127	0.228	0.315
P	τ	-0.08	-0.03	-0.07	-0.02	-0.14	0.07	0.10	0.16	0.00	0.02	-0.24	0.32	0.00
	P	0.407	0.795	0.475	0.871	0.511	0.695	0.620	0.443	1.000	0.944	0.202	0.125	1.000
Q/P	τ	0.01	0.05	-0.10	0.22	0.21	0.22	0.02	0.36	-0.40	0.10	0.32	0.27	0.22
	P	0.884	0.615	0.295	0.027	0.324	0.184	0.964	0.080	0.023	0.576	0.084	0.189	0.194
Period of Record (1940:2015)		76	75	76	76	24	28	23	26	25	25	29	20	27
Period of Analysis (Start Year: 1940)		51	51	51	51	14	21	16	14	18	19	17	14	20

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

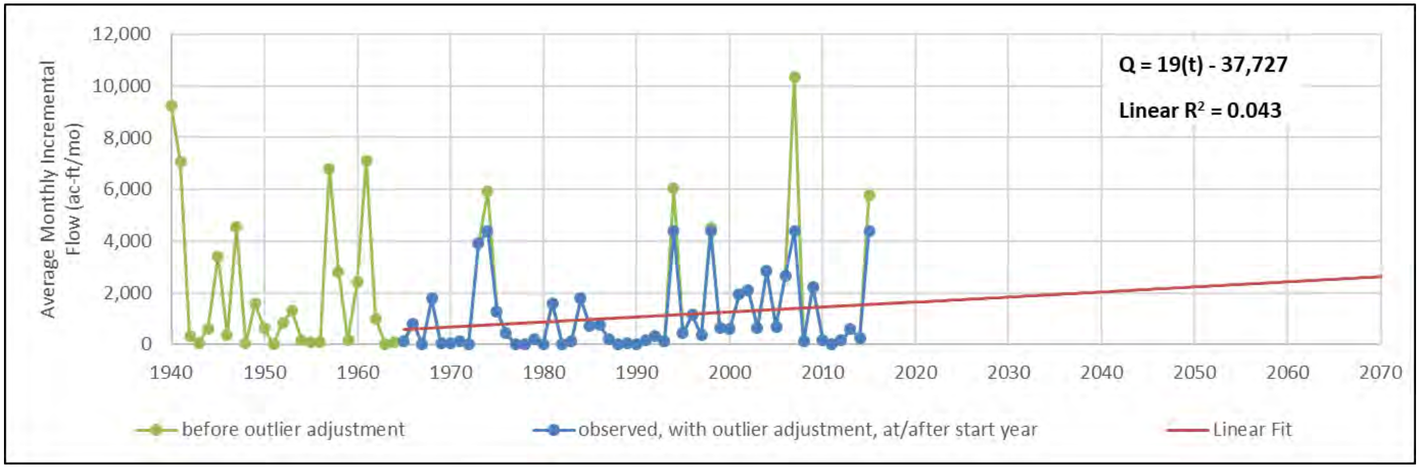


Figure 2-C-119 – Summer Trend for Average Monthly Incremental Flow

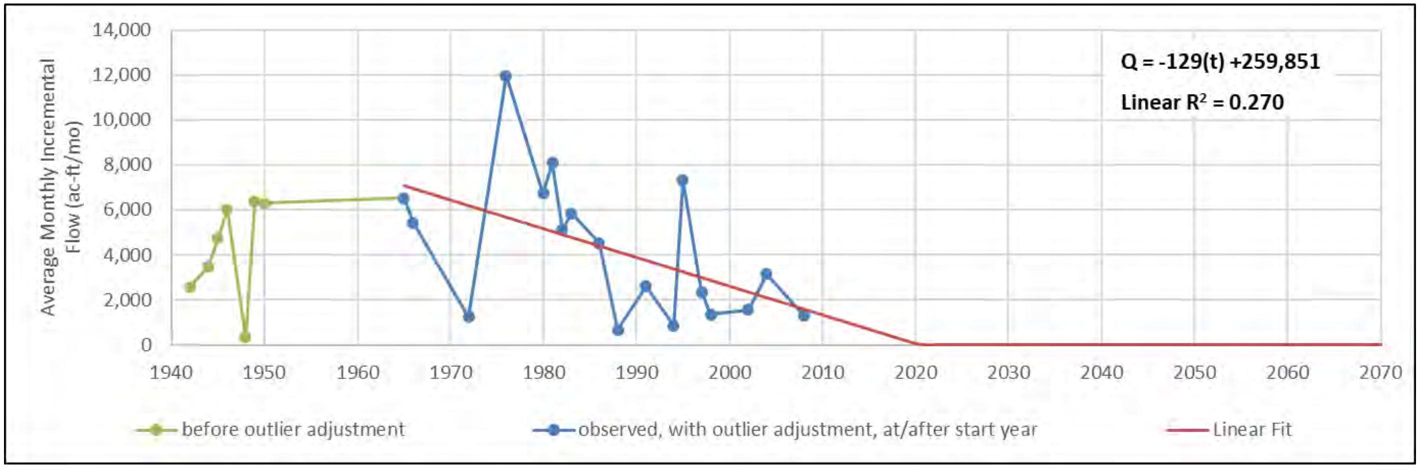


Figure 2-C-120 – Average Spring Trend for Average Monthly Incremental Flow

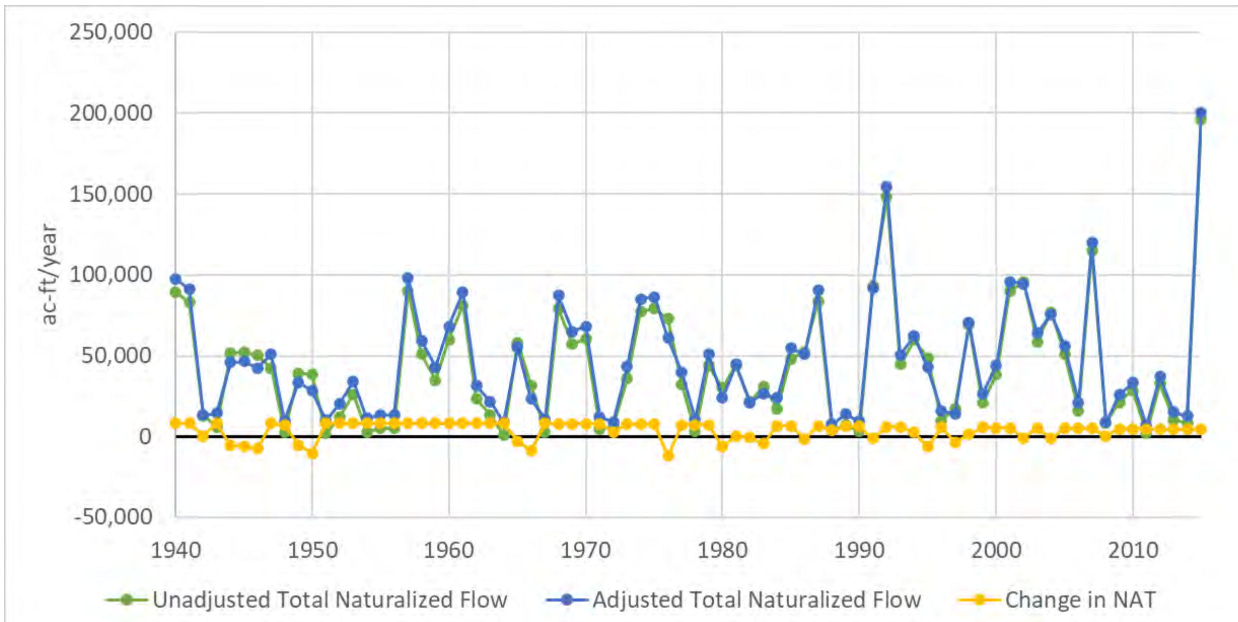


Figure 2-C-121 – Original and Adjusted Naturalized Flow Time Series for MYDB60 for 2070 Conditions

EYDB61 - East Yegua Creek near Dime Box

Table 2-C-63 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.07	0.06	0.04	0.12	0.22	0.03	0.14	0.08	-0.01	0.17	0.22	0.16	0.06
	P	0.392	0.434	0.569	0.142	0.137	0.859	0.355	0.582	0.944	0.234	0.103	0.347	0.677
P	τ	0.03	0.02	-0.01	0.06	0.10	-0.01	0.03	-0.12	0.05	0.11	0.18	0.26	-0.23
	P	0.703	0.798	0.950	0.417	0.503	0.953	0.874	0.402	0.744	0.469	0.183	0.112	0.104
Q/P	τ	0.11	0.07	0.06	0.12	0.28	0.00	0.17	0.12	-0.05	0.18	0.21	0.06	0.09
	P	0.177	0.400	0.412	0.133	0.059	1.000	0.267	0.415	0.726	0.216	0.111	0.746	0.518
Period of Record (1940:2015)		76	75	76	76	24	28	23	26	25	25	29	20	27
Period of Analysis (Start Year: 1940)		76	75	76	76	24	28	23	26	25	25	29	20	27

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

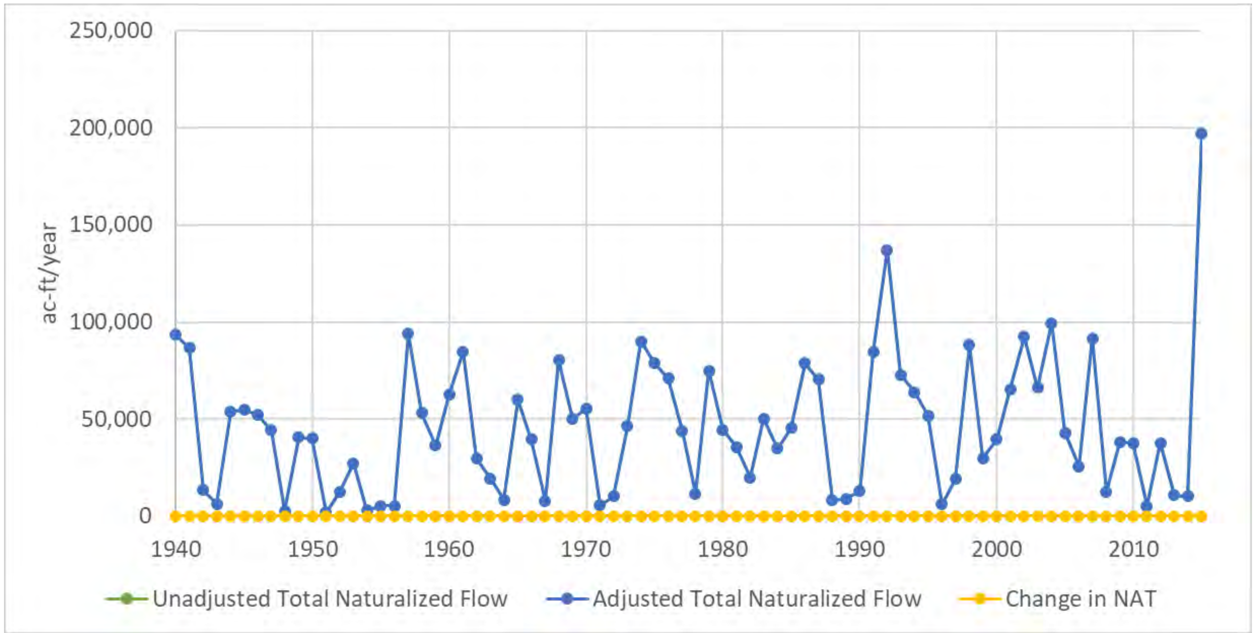


Figure 2-C-122 – Original and Adjusted Naturalized Flow Time Series for EYDB61 for 2070 Conditions

YCSO62 - Yegua Creek near Somerville

Table 2-C-64 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.02	0.02	-0.04	-0.04	0.13	-0.01	0.06	0.02	-0.14	-0.07	-0.09	-0.03	-0.05
	P	0.826	0.808	0.597	0.657	0.399	0.984	0.712	0.877	0.338	0.657	0.488	0.897	0.723
P	τ	0.03	0.00	0.00	0.04	0.04	-0.02	0.07	-0.11	0.02	0.15	0.10	0.27	-0.28
	P	0.750	0.985	0.961	0.657	0.785	0.921	0.673	0.427	0.907	0.315	0.476	0.098	0.045
Q/P	τ	-0.04	0.04	-0.04	-0.07	0.22	0.04	0.07	0.06	-0.14	-0.14	-0.13	-0.17	0.00
	P	0.569	0.634	0.625	0.360	0.137	0.767	0.673	0.675	0.338	0.338	0.320	0.315	1.000
Period of Record (1940:2015)		76	75	76	76	24	28	23	26	25	25	29	20	27
Period of Analysis (Start Year: 1940)		76	75	76	76	24	28	23	26	25	25	29	20	27

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

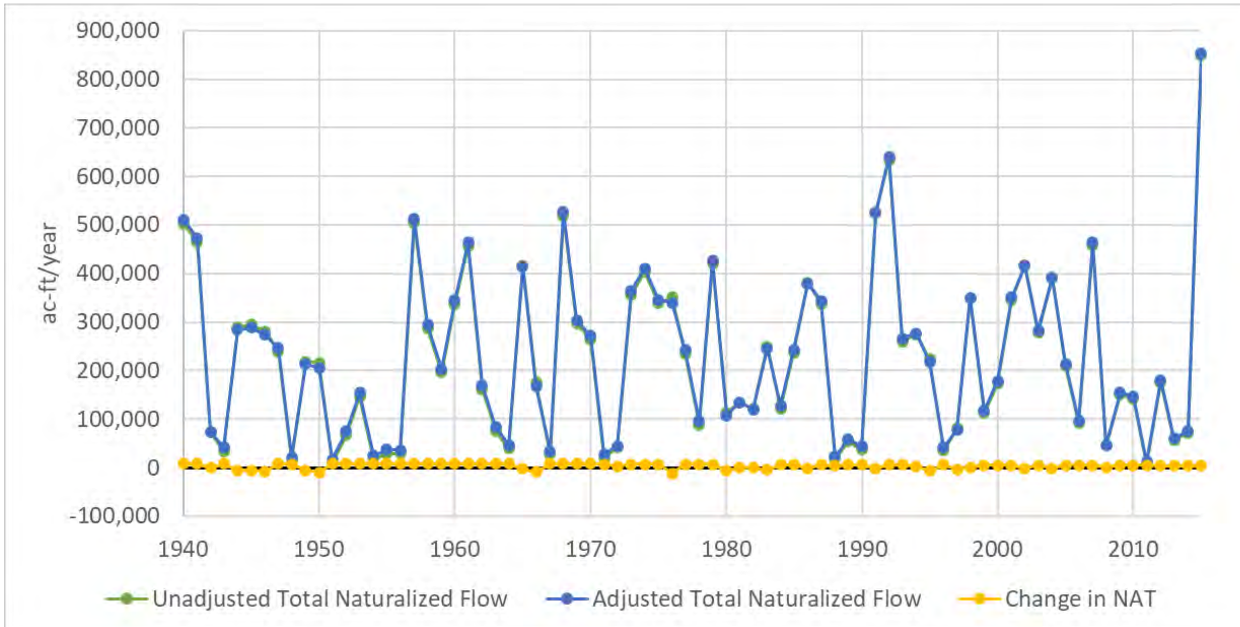


Figure 2-C-123 – Original and Adjusted Naturalized Flow Time Series for YCSO62 for 2070 Conditions

DCLY63 - Davidson Creek near Lyons

Table 2-C-65 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.04	0.07	0.01	-0.05	0.14	0.05	0.24	-0.05	-0.09	0.03	-0.09	-0.03	-0.12
	P	0.581	0.368	0.936	0.498	0.346	0.707	0.119	0.741	0.559	0.870	0.536	0.897	0.393
P	τ	0.03	0.01	0.00	0.05	0.07	-0.02	0.06	-0.11	0.03	0.13	0.13	0.26	-0.27
	P	0.743	0.942	0.968	0.539	0.637	0.921	0.712	0.454	0.834	0.388	0.320	0.112	0.050
Q/P	τ	0.06	0.08	0.03	-0.07	0.21	0.05	0.26	0.00	0.00	-0.01	-0.12	-0.16	-0.09
	P	0.443	0.314	0.670	0.349	0.165	0.707	0.081	1.000	1.000	0.981	0.399	0.347	0.545
Period of Record (1940:2015)		76	75	76	76	24	28	23	26	25	25	29	20	27
Period of Analysis (Start Year: 1940)		76	75	76	76	24	28	23	26	25	25	29	20	27

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

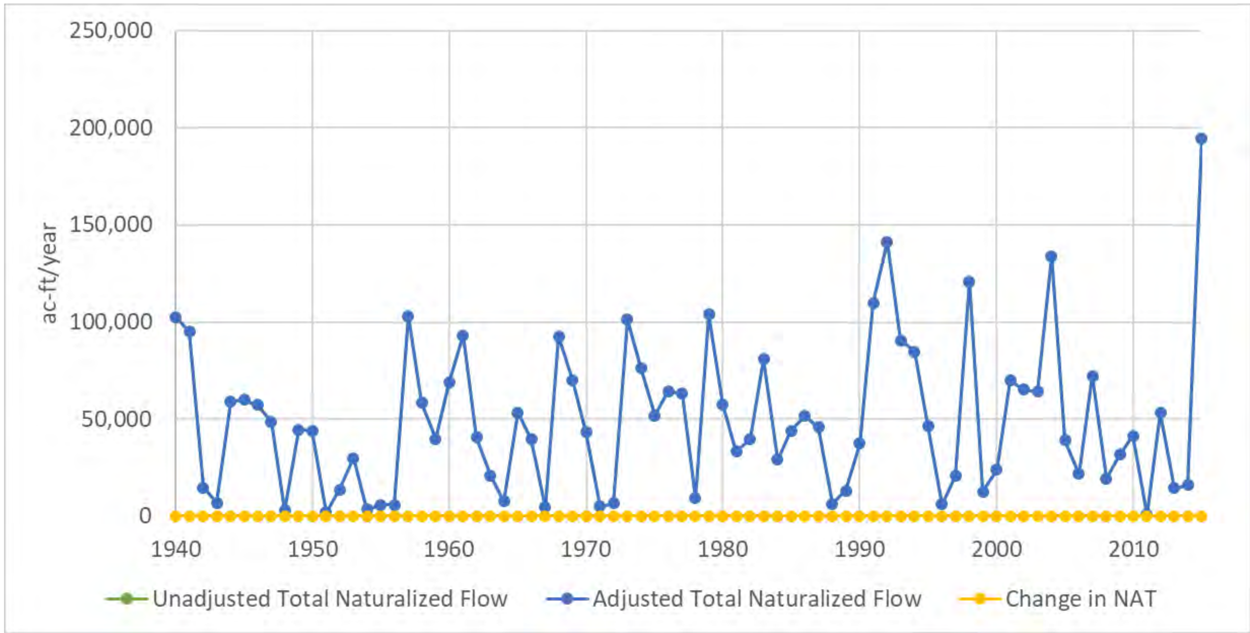


Figure 2-C-124 – Original and Adjusted Naturalized Flow Time Series for DCLY63 for 2070 Conditions

NAGR64 - Navasota River above Groesbeck

Table 2-C-66 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.07	0.05	0.00	0.04	0.04	-0.06	0.12	0.02	-0.10	0.05	0.16	0.04	0.00
	P	0.407	0.513	0.989	0.644	0.774	0.674	0.413	0.907	0.442	0.778	0.243	0.812	1.000
P	τ	0.04	0.03	-0.03	0.06	-0.03	-0.20	0.20	-0.15	0.14	-0.19	0.24	0.15	-0.09
	P	0.606	0.735	0.713	0.438	0.826	0.168	0.189	0.293	0.285	0.236	0.080	0.342	0.537
Q/P	τ	0.06	0.06	0.01	0.02	0.06	0.00	0.05	0.07	-0.12	0.08	0.02	0.05	0.01
	P	0.465	0.470	0.918	0.802	0.659	1.000	0.747	0.657	0.358	0.612	0.900	0.751	0.982
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

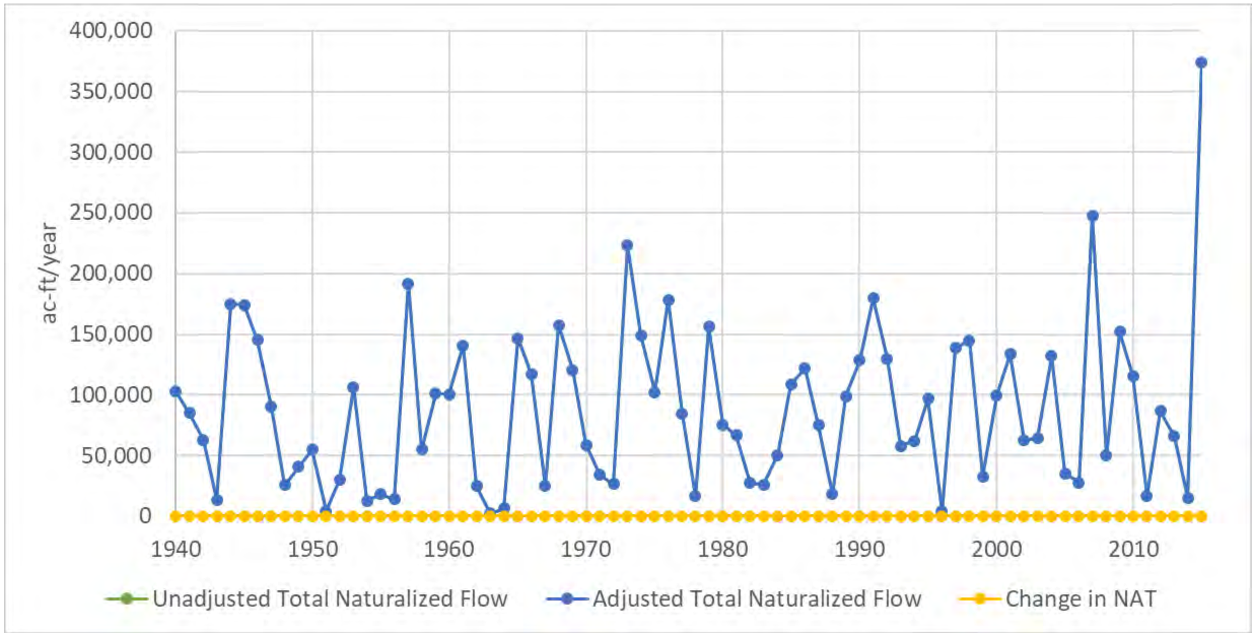


Figure 2-C-125 – Original and Adjusted Naturalized Flow Time Series for NAGR64 for 2070 Conditions

BGFR65 - Big Creek near Freestone

Table 2-C-67 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.10	0.07	0.01	0.00	-0.11	-0.01	0.17	0.04	-0.14	0.09	0.03	-0.03	-0.09
	P	0.212	0.382	0.886	0.993	0.418	0.958	0.244	0.804	0.269	0.573	0.843	0.834	0.559
P	τ	0.04	0.01	-0.06	0.09	-0.14	0.03	0.11	-0.14	-0.14	-0.06	0.29	0.12	-0.15
	P	0.625	0.953	0.470	0.260	0.295	0.874	0.472	0.359	0.284	0.735	0.043	0.414	0.315
Q/P	τ	0.12	0.08	0.06	0.00	-0.10	0.00	0.19	0.10	-0.11	0.13	-0.02	-0.05	-0.05
	P	0.142	0.293	0.481	1.000	0.465	1.000	0.206	0.503	0.412	0.430	0.930	0.761	0.761
Period of Record (1940:2015)		76	75	76	76	28	23	24	24	30	22	26	25	25
Period of Analysis (Start Year:1940)		76	75	76	76	28	23	24	24	30	22	26	25	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

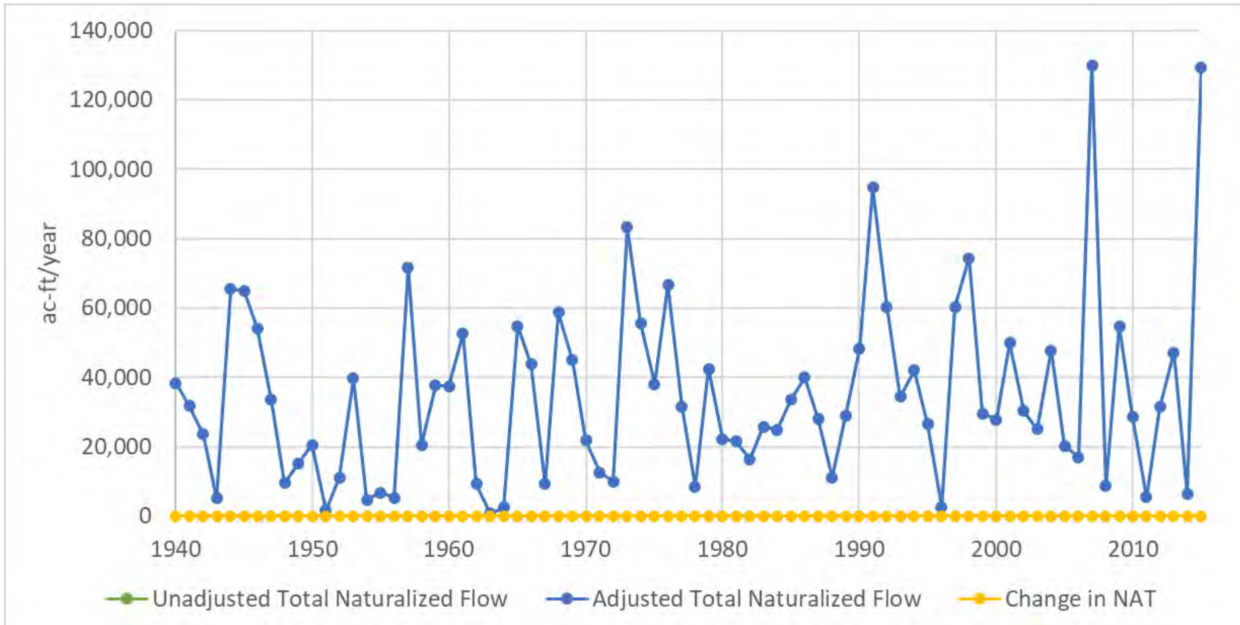


Figure 2-C-126 – Original and Adjusted Naturalized Flow Time Series for BGFR65 for 2070 Conditions

NAEA66 - Navasota River near Easterly

Table 2-C-68 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.07	0.10	0.00	0.07	0.22	-0.03	0.11	-0.01	-0.03	-0.01	0.38	0.09	-0.14
	P	0.407	0.222	0.968	0.349	0.128	0.834	0.472	0.981	0.837	0.955	0.006	0.579	0.343
P	τ	0.04	0.02	-0.05	0.06	-0.03	-0.20	0.22	-0.11	0.07	-0.17	0.26	0.09	-0.19
	P	0.587	0.787	0.536	0.417	0.860	0.168	0.130	0.441	0.626	0.284	0.061	0.561	0.186
Q/P	τ	0.07	0.11	0.00	0.07	0.22	0.00	0.07	0.06	-0.06	0.01	0.31	0.08	-0.11
	P	0.358	0.177	0.961	0.387	0.118	1.000	0.673	0.709	0.639	0.955	0.027	0.597	0.427
Period of Record (1940:2015)		76	75	76	76	26	25	24	25	29	22	27	23	26
Period of Analysis (Start Year: 1940)		76	75	76	76	26	25	24	25	29	22	27	23	26

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

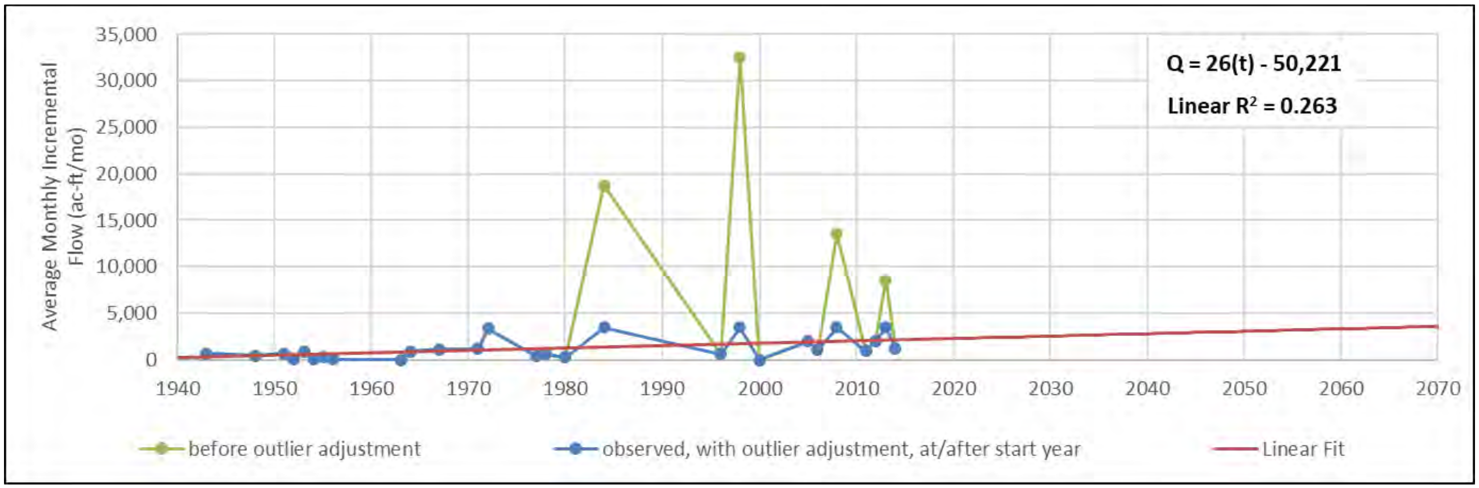


Figure 2-C-127 – Dry Summer Trend for Average Monthly Incremental Flow

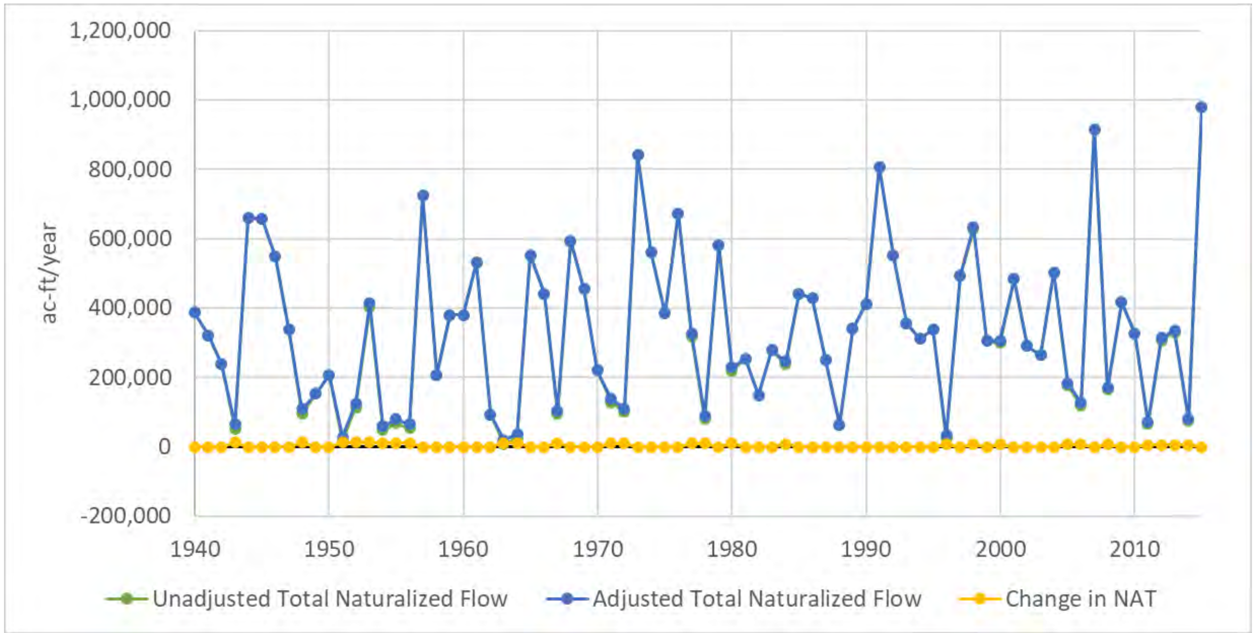


Figure 2-C-128 – Original and Adjusted Naturalized Flow Time Series for NAEA66 for 2070 Conditions

NABR67 - Navasota River near Bryan

Table 2-C-69 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.02	0.03	-0.01	0.05	-0.10	-0.07	0.03	0.06	-0.24	0.15	0.28	0.04	-0.04
	P	0.819	0.704	0.893	0.498	0.465	0.653	0.882	0.691	0.069	0.338	0.050	0.815	0.797
P	τ	0.06	0.00	-0.07	0.08	-0.14	0.03	0.10	-0.10	-0.18	0.06	0.24	0.13	-0.17
	P	0.481	0.967	0.407	0.284	0.314	0.874	0.519	0.503	0.164	0.735	0.090	0.362	0.252
Q/P	τ	0.03	0.04	0.02	0.03	-0.11	-0.14	0.09	0.08	-0.17	0.12	0.27	0.01	0.01
	P	0.703	0.651	0.809	0.680	0.441	0.369	0.535	0.602	0.199	0.446	0.061	0.963	0.981
Period of Record (1940:2015)		76	75	76	76	28	23	24	24	30	22	26	25	25
Period of Analysis (Start Year: 1940)		76	75	76	76	28	23	24	24	30	22	26	25	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

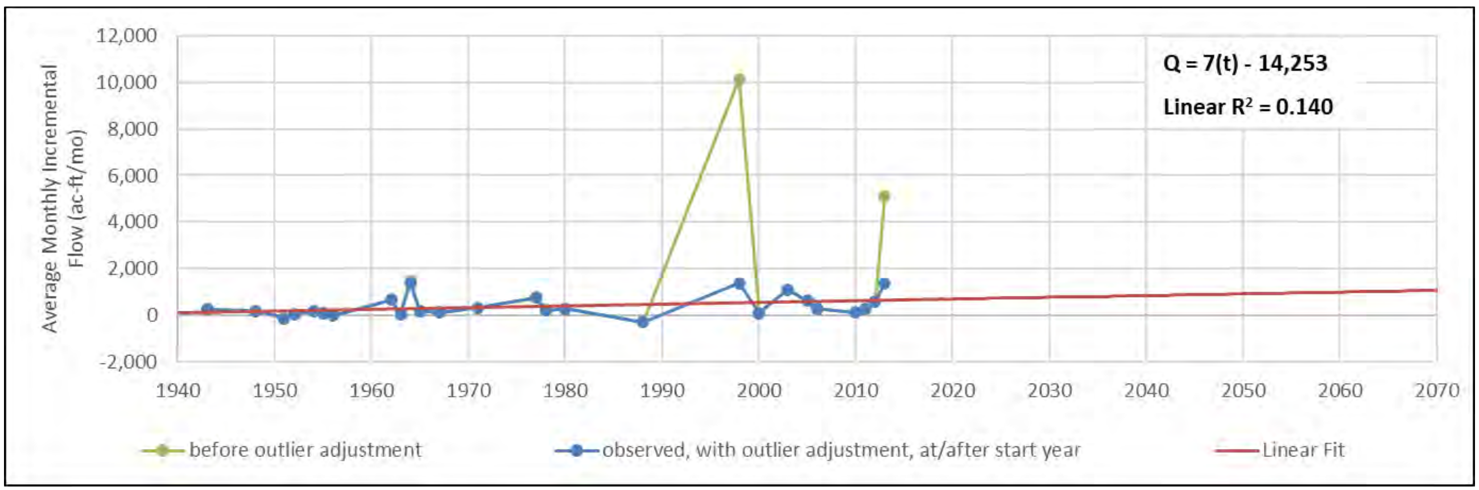


Figure 2-C-129 – Dry Summer Trend for Average Monthly Incremental Flow

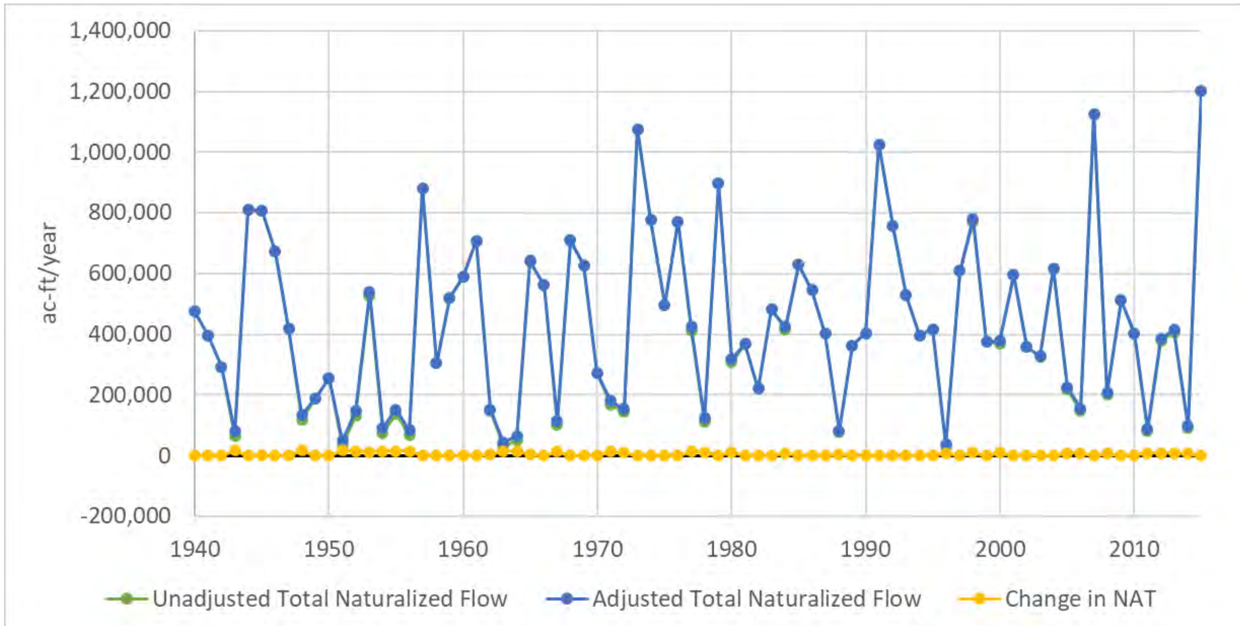


Figure 2-C-130 – Original and Adjusted Naturalized Flow Time Series for NABR67 for 2070 Conditions

BRHE68 - Brazos River near Hempstead

Table 2-C-70 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.02	0.02	-0.07	0.06	-0.13	0.00	0.09	0.07	-0.15	-0.08	0.12	0.08	0.01
	P	0.847	0.816	0.397	0.465	0.333	1.000	0.535	0.655	0.239	0.612	0.415	0.575	0.944
P	τ	0.04	0.00	-0.04	0.07	-0.13	0.02	0.09	-0.12	-0.17	0.15	0.29	0.09	-0.15
	P	0.651	1.000	0.625	0.367	0.353	0.916	0.535	0.413	0.187	0.338	0.038	0.559	0.293
Q/P	τ	-0.02	0.00	-0.05	0.01	-0.11	-0.06	0.01	0.03	-0.08	-0.19	-0.01	0.07	0.02
	P	0.771	0.985	0.515	0.861	0.441	0.712	0.980	0.882	0.544	0.236	0.947	0.640	0.907
Period of Record (1940:2015)		76	75	76	76	28	23	24	24	30	22	26	25	25
Period of Analysis (Start Year: 1940)		76	75	76	76	28	23	24	24	30	22	26	25	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

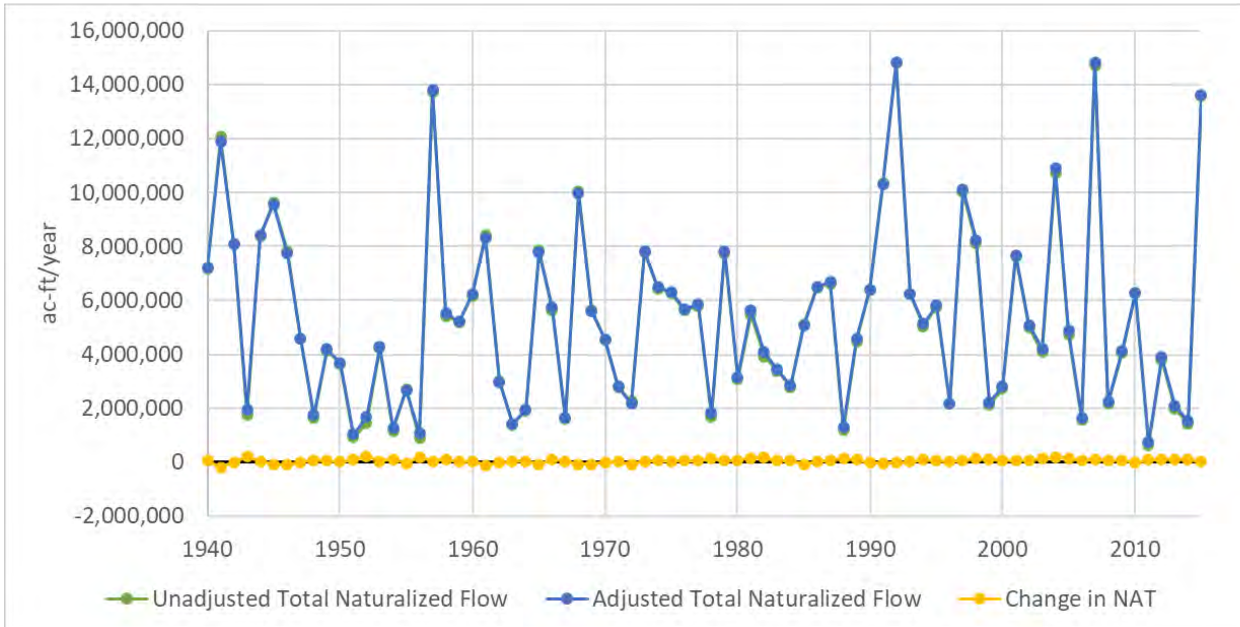


Figure 2-C-131 – Original and Adjusted Naturalized Flow Time Series for BRHE68 for 2070 Conditions

MCBL69 - Mill Creek near Bellville

Table 2-C-71 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	-0.04	0.01	-0.04	-0.06	0.10	-0.08	0.22	-0.09	-0.06	-0.05	0.01	-0.03	-0.14
	P	0.600	0.855	0.575	0.435	0.503	0.580	0.146	0.523	0.691	0.761	0.940	0.871	0.307
P	τ	0.03	0.00	0.00	0.04	0.04	-0.01	0.07	-0.11	0.02	0.15	0.10	0.27	-0.28
	P	0.750	0.982	0.954	0.657	0.804	0.953	0.673	0.427	0.907	0.315	0.476	0.098	0.045
Q/P	τ	-0.07	0.01	-0.05	-0.08	0.13	-0.18	0.23	-0.12	-0.07	-0.09	-0.01	-0.18	-0.10
	P	0.367	0.902	0.557	0.294	0.385	0.179	0.139	0.390	0.657	0.528	0.925	0.284	0.491
Period of Record (1940:2015)		76	75	76	76	24	28	23	26	25	25	29	20	27
Period of Analysis (Start Year: 1940)		76	75	76	76	24	28	23	26	25	25	29	20	27

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

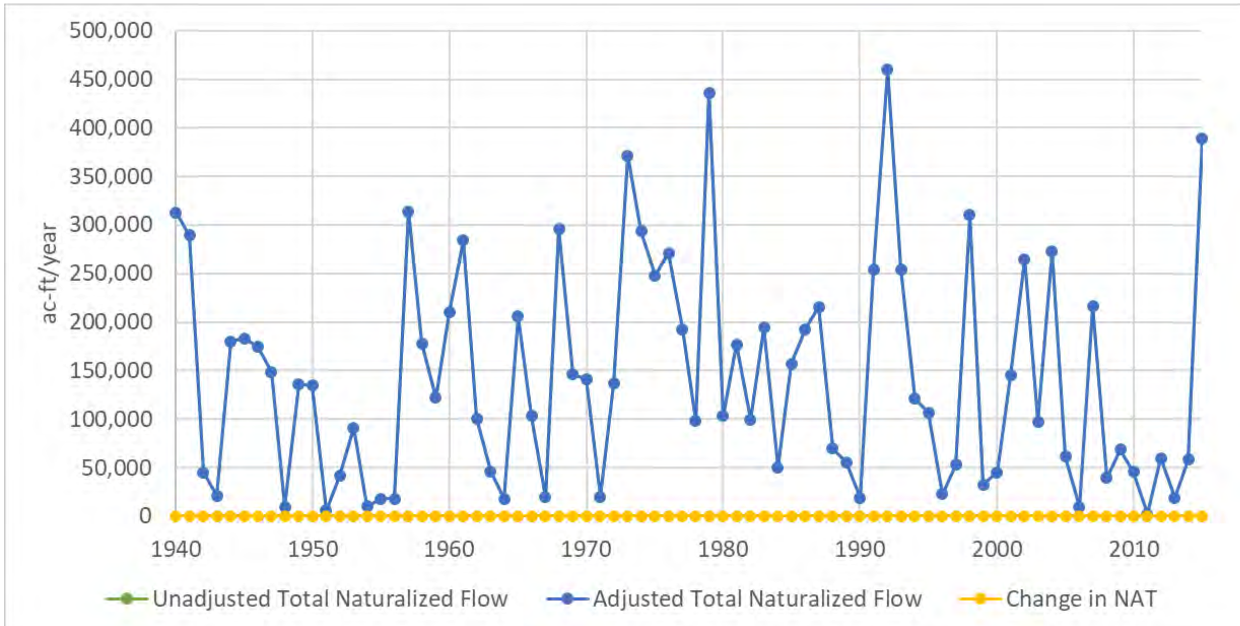


Figure 2-C-132 – Original and Adjusted Naturalized Flow Time Series for MCBL69 for 2070 Conditions

BRRI70 - Brazos River at Richmond

Table 2-C-72 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.00	-0.02	0.03	0.07	0.24	-0.06	-0.13	0.09	-0.12	0.06	-0.03	0.07	0.22
	P	0.954	0.798	0.710	0.344	0.112	0.664	0.398	0.552	0.414	0.691	0.822	0.673	0.118
P	τ	0.03	0.00	-0.01	0.05	0.04	-0.06	0.09	-0.06	-0.01	0.07	0.21	0.19	-0.33
	P	0.677	0.967	0.897	0.498	0.823	0.650	0.561	0.692	0.944	0.624	0.119	0.256	0.016
Q/P	τ	0.00	-0.03	0.06	0.06	0.19	0.02	-0.16	0.10	-0.05	0.08	-0.10	-0.17	0.36
	P	0.989	0.681	0.443	0.479	0.215	0.906	0.291	0.481	0.761	0.575	0.464	0.299	0.009
Period of Record (1940:2015)		76	75	76	76	24	28	23	26	25	25	29	20	27
Period of Analysis (Start Year: 1940)		76	75	76	76	24	28	23	26	25	25	29	20	27

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

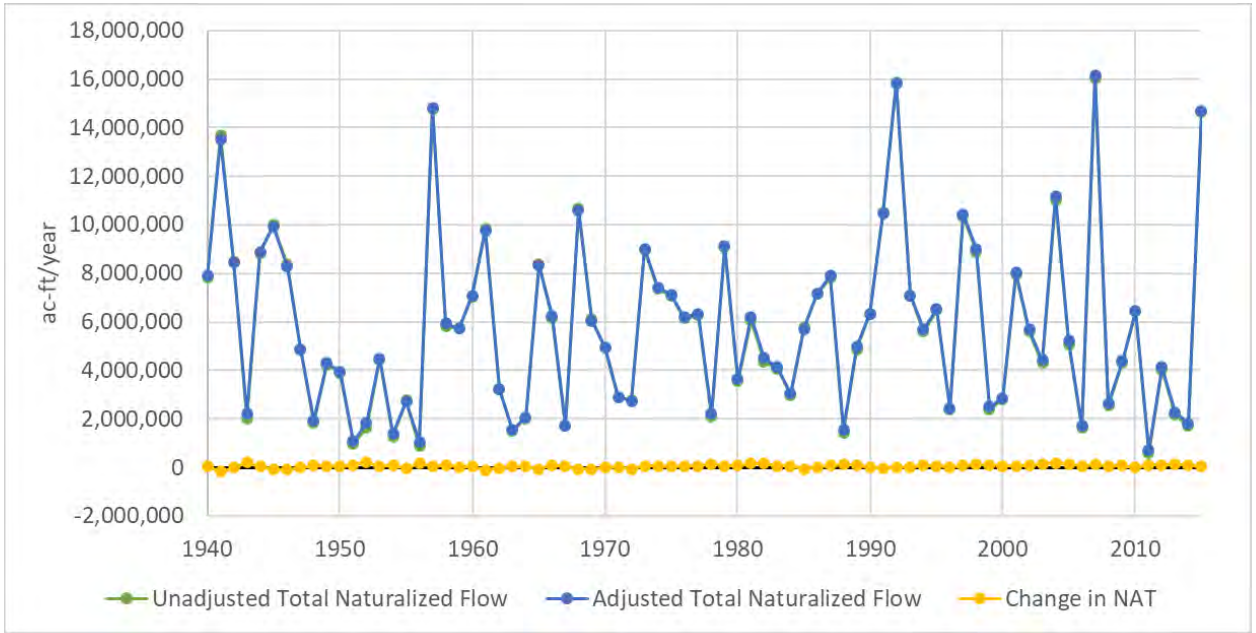


Figure 2-C-133 – Original and Adjusted Naturalized Flow Time Series for BRRI70 for 2070 Conditions

BGNE71 - Big Creek near Needville

Table 2-C-73 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.00	-0.04	0.01	0.02	-0.04	0.00	-0.08	0.06	-0.09	0.21	0.19	0.15	-0.13
	P	0.996	0.589	0.918	0.757	0.797	1.000	0.567	0.691	0.487	0.205	0.159	0.338	0.388
P	τ	0.06	-0.02	0.04	0.06	-0.13	0.03	0.05	0.07	-0.14	0.36	0.22	0.22	-0.19
	P	0.454	0.819	0.651	0.430	0.388	0.862	0.724	0.624	0.276	0.024	0.103	0.167	0.199
Q/P	τ	-0.01	-0.06	0.01	0.01	0.02	-0.11	-0.13	0.05	-0.07	0.14	0.19	0.09	-0.12
	P	0.868	0.487	0.925	0.882	0.907	0.472	0.355	0.761	0.605	0.381	0.154	0.573	0.414
Period of Record (1940:2015)		76	75	76	76	25	24	26	25	30	21	29	22	25
Period of Analysis (Start Year: 1940)		76	75	76	76	25	24	26	25	30	21	29	22	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

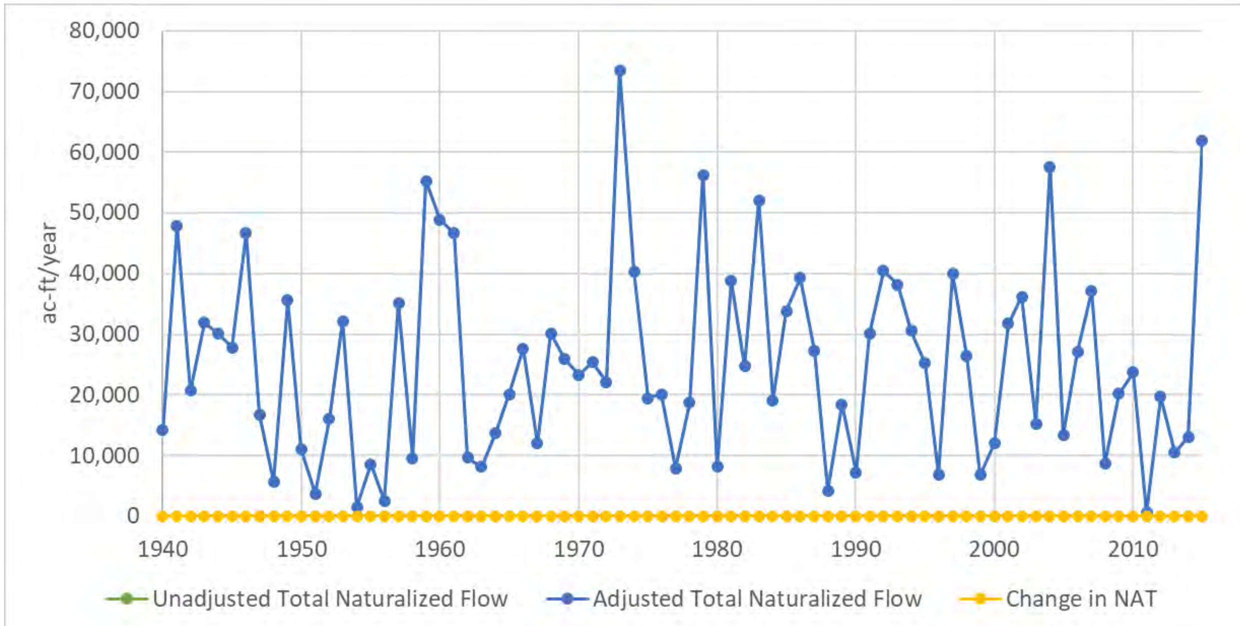


Figure 2-C-134 – Original and Adjusted Naturalized Flow Time Series for BGNE71 for 2070 Conditions

BRRO72 - Brazos River at Rosharon

Table 2-C-74 – Summary of streamflow and precipitation trends

Variable	Statistic	Annual	Winter	Spring	Summer	Dry Winter	Average Winter	Wet Winter	Dry Spring	Average Spring	Wet Spring	Dry Summer	Average Summer	Wet Summer
Q	τ	0.02	0.05	-0.05	0.18	0.23	0.22	-0.09	0.02	-0.12	0.04	0.07	0.52	0.16
	P	0.833	0.498	0.501	0.024	0.112	0.143	0.552	0.926	0.382	0.833	0.586	0.001	0.283
P	τ	0.06	-0.02	0.04	0.06	-0.13	0.03	0.05	0.07	-0.14	0.36	0.22	0.22	-0.19
	P	0.454	0.819	0.651	0.422	0.388	0.862	0.724	0.624	0.284	0.024	0.103	0.159	0.199
Q/P	τ	0.04	0.09	-0.03	0.19	0.32	0.24	-0.06	0.03	-0.02	-0.08	0.06	0.45	0.21
	P	0.654	0.249	0.740	0.016	0.027	0.107	0.675	0.852	0.915	0.651	0.666	0.004	0.141
Period of Record (1940:2015)		76	75	76	76	25	24	26	25	30	21	29	22	25
Period of Analysis (Start Year: 1940)		76	75	76	76	25	24	26	25	30	21	29	22	25

Green indicates significance (P-value≤0.05).
Blue indicates moderate (light blue) to strong (dark blue) Kendall's tau (|τ|≥0.10) when trend is significant.

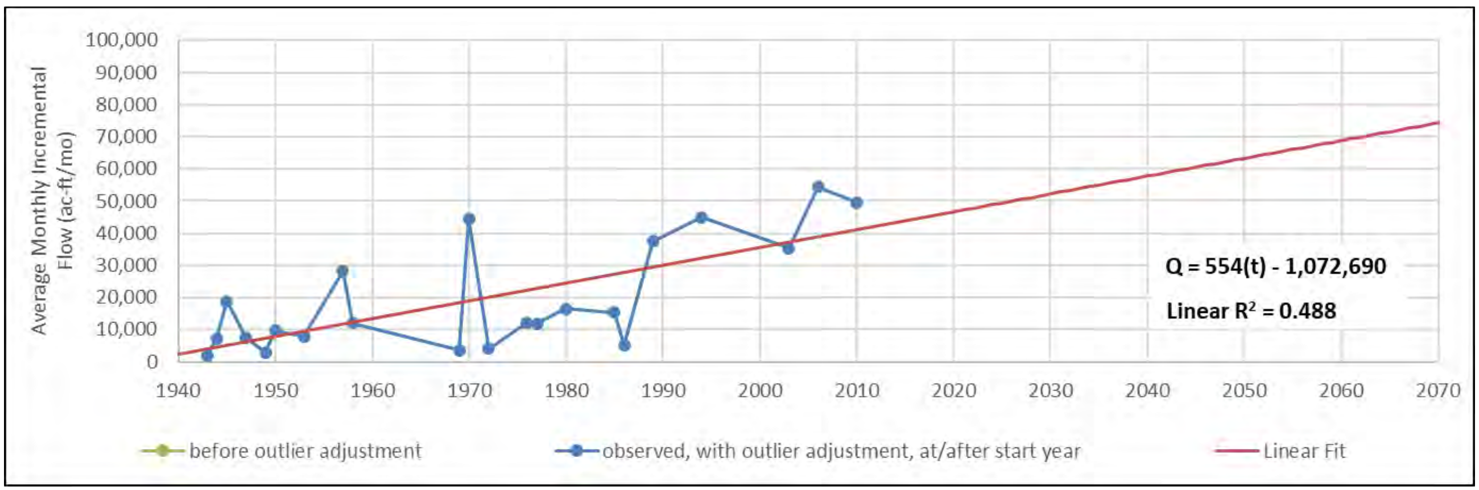


Figure 2-C-135 – Average Summer Trend for Average Monthly Incremental Flow

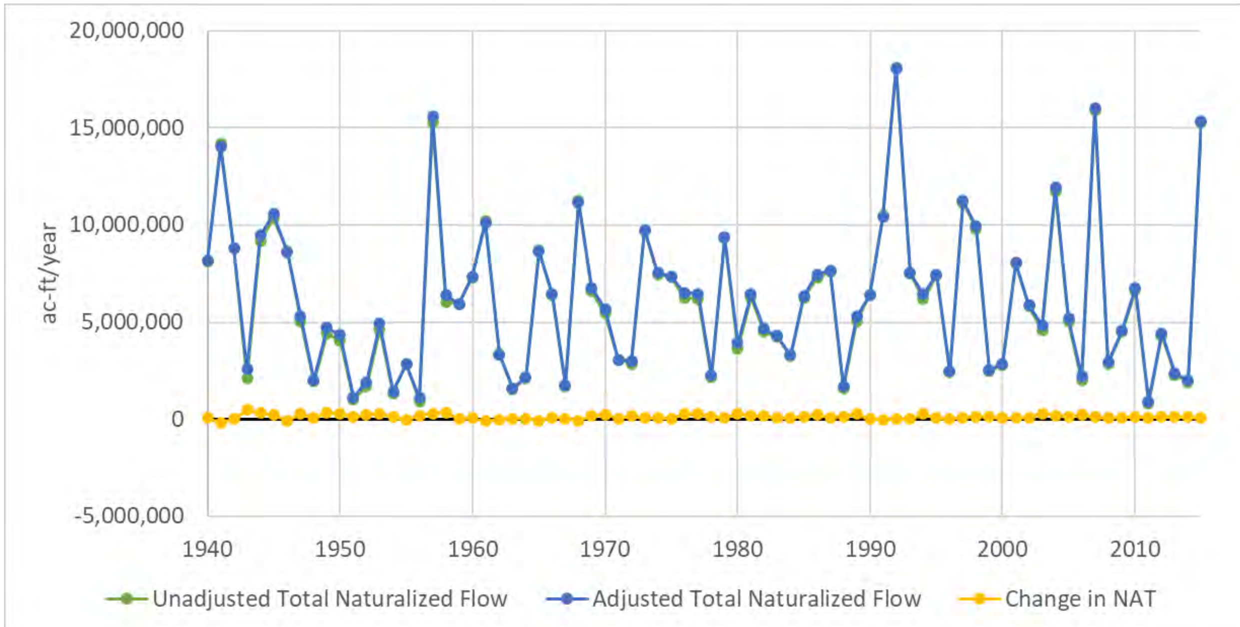


Figure 2-C-136 – Original and Adjusted Naturalized Flow Time Series for BRRO72 for 2070 Conditions

BRGM73 - Brazos River at Gulf of Mexico

Trends in incremental flow in the drainage area between the Rosharon gage (BRRO72) and the Gulf of Mexico were not assessed due to uncertainty in the naturalized flow data at BRGM73. Figure 2-C-137 shows the adjustments to total naturalized flows at BRGM73 based on upstream changes in flow.

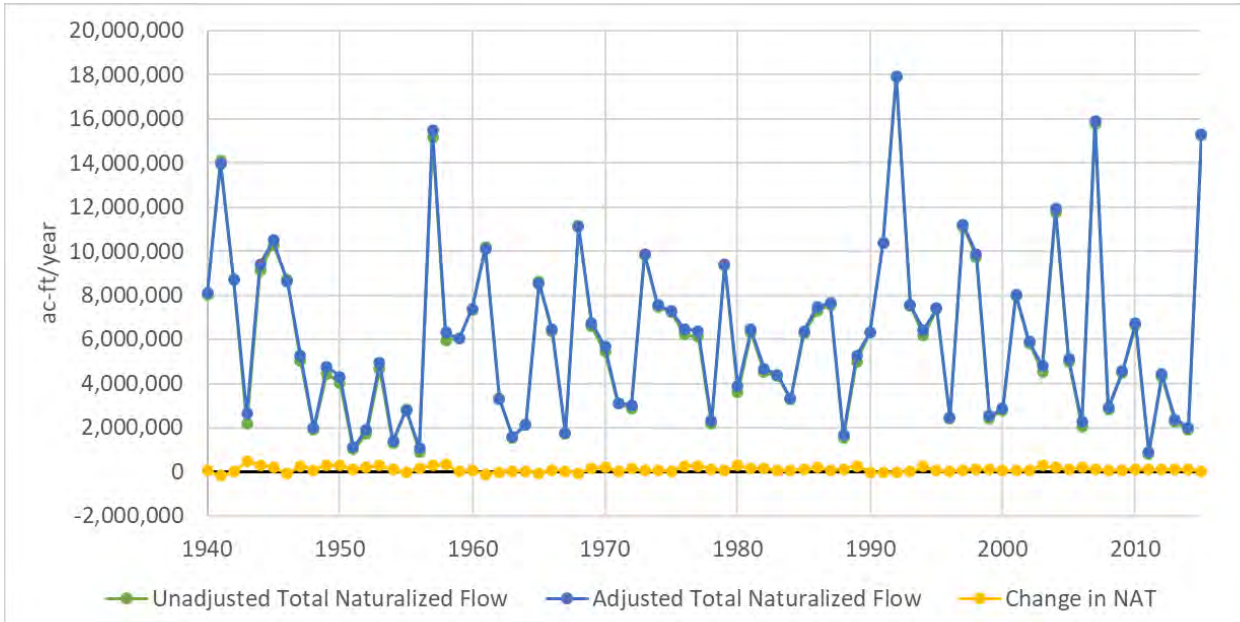


Figure 2-C-137 – Original and Adjusted Naturalized Flow Time Series for BRGM73 for 2070 Conditions

APPENDIX 2-D: SUMMARY OF RESULTS OF TEMPERATURE AND PRECIPITATION TREND ANALYSIS

Summary of All Climate Divisions

Table 2-D-1 –Summary of Temperature and Precipitation Trend Analysis

Climate Division	EVA Control Points in Division	Precipitation				Temperature			
		Trend Direction	Start Year	Equation	R^2 value	Trend Direction	Start Year	Equation	R^2 value
High Plains, 4101[a]	6	Wet winter (+)	1940	P = 0.008(t) – 14.109	0.193	Annual (+)	1968	T = 0.05(t) – 40.983	0.437
		Average summer (+)	1940	P = 0.017(t) – 30.83	0.196				
Low Rolling Plains, 4102	14	Dry summer (+)	1940	P = 0.012(t) – 21.06	0.160	Annual (+)	1968	T = 0.051(t) – 39.621	0.401
North Central, 4103	32	none	1940	---	---	Annual (+)	1968	T = 0.048(t) – 31.834	0.374
East Texas, 4104	7	none	1940	---	---	Annual (+)	1966	T = 0.044(t) – 21.372	0.372
Edwards Plateau, 4106	0	none	1940	---	---	Annual (+)	1968	T = 0.056(t) – 47.105	0.500
South Central, 4107	2	Wet summer (-)	1940	P = -0.02(t) + 43.597	0.168	Annual (+)	1968	T = 0.06(t) – 50.271	0.495
Upper Coast, 4108	6	Wet spring (+)	1940	P = 0.027(t) – 49.149	0.292	Annual (+)	1966	T = 0.058(t) – 45.59	0.552

Negative, positive signs indicate decreasing or increasing trend direction
[a]Multiple trends for this climate division

Table 2-D-2 – Summary of Gross Evaporation Analysis

Climate Division	Number	Trend Direction	E=f(T)	R^2 value
High Plains, 4101	4101	Annual (+)	E = 0.286 (T) – 11.272	0.307
Low Rolling Plains, 4102	4102	Annual (+)	E = 0.295 (T) – 13.017	0.404
North Central, 4103	4103	Annual (+)	E = 0.203 (T) – 8.334	0.367
East Texas, 4104	4104	Annual (+)	E = 0.165 (T) – 6.664	0.345
Edwards Plateau, 4106	4106	Annual (+)	E = 0.217 (T) – 9.023	0.298
South Central, 4107	4107	Annual (+)	E = 0.103 (T) – 2.682	0.140
Upper Coast, 4108	4108	Annual (+)	E = 0.102 (T) – 3.078	0.143

Negative, positive signs indicate decreasing or increasing trend direction

Table 2-D-3 – Average Annual Adjustments for EVA Control Points

Name	Climate Division	Climate Division Name	Average Change in Net Reservoir Evaporation (ft/mo)	Percent Change in Net Reservoir Evaporation by 2070
305	4101	High Plains	0.084	25%
306	4101	High Plains	0.085	26%
405	4101	High Plains	0.084	24%
406	4101	High Plains	0.085	26%
407	4102	Low Rolling Plains	0.100	30%
408	4102	Low Rolling Plains	0.100	35%
409	4103	North Central	0.071	31%
506	4102	Low Rolling Plains	0.099	28%
507	4102	Low Rolling Plains	0.100	32%
508	4102	Low Rolling Plains	0.100	36%
509	4103	North Central	0.071	31%
510	4103	North Central	0.071	39%
609	4103	North Central	0.071	33%
610	4103	North Central	0.071	40%
611	4104	East Texas	0.053	37%
710	4103	North Central	0.071	49%
711	4104	East Texas	0.053	56%
712	4104	East Texas	0.053	248%
812	4108	Upper Coast	0.023	642%
813	4108	Upper Coast	0.023	106%
Abilene	4102	Low Rolling Plains	0.100	33%
Alan Henry	4102	Low Rolling Plains	0.100	30%
Alcoa	4103	North Central	0.071	53%
Allens Creek	4107	South Central	0.063	153%
Aquilla	4103	North Central	0.071	44%
Belton	4103	North Central	0.071	45%
Brazoria	4108	Upper Coast	0.023	293%
Bryan Utilities	4104	East Texas	0.053	50%
Buffalo Springs	4101	High Plains	0.085	26%
Camp Creek	4104	East Texas	0.053	59%
Cisco	4103	North Central	0.071	28%
Daniel	4103	North Central	0.071	28%
Davis	4102	Low Rolling Plains	0.100	33%
Eagle Nest	4108	Upper Coast	0.023	585%
Fort Phantom Hill	4102	Low Rolling Plains	0.100	34%
Georgetown	4103	North Central	0.071	56%
Gibbons Creek	4104	East Texas	0.053	72%

Name	Climate Division	Climate Division Name	Average Change in Net Reservoir Evaporation (ft/mo)	Percent Change in Net Reservoir Evaporation by 2070
Graham	4103	North Central	0.071	29%
Granbury	4103	North Central	0.071	36%
Granger	4103	North Central	0.071	48%
Hubbard Creek	4103	North Central	0.071	28%
Kirby	4102	Low Rolling Plains	0.100	34%
Lake Creek	4103	North Central	0.071	44%
Leon	4103	North Central	0.071	29%
Limestone	4103	North Central	0.071	62%
Marlin City	4103	North Central	0.071	49%
Mexia	4103	North Central	0.071	48%
Millers Creek	4102	Low Rolling Plains	0.100	36%
Mineral Wells	4103	North Central	0.071	35%
Palo Pinto	4103	North Central	0.071	33%
Pat Cleburne	4103	North Central	0.071	42%
Possum Kingdom	4103	North Central	0.071	31%
Post	4102	Low Rolling Plains	0.100	21%
Proctor	4103	North Central	0.071	34%
Sandow Surface Mine	4103	North Central	0.071	53%
Smithers	4108	Upper Coast	0.023	447%
Somerville	4107	South Central	0.063	74%
Squaw Creek	4103	North Central	0.071	36%
Stamford	4102	Low Rolling Plains	0.100	34%
Stillhouse Hollow	4103	North Central	0.071	46%
Sweetwater	4102	Low Rolling Plains	0.100	32%
Tradinghouse Creek	4103	North Central	0.071	44%
Twin Oaks	4104	East Texas	0.053	40%
Waco	4103	North Central	0.071	39%
White River	4101	High Plains	0.085	26%
Whitney	4103	North Central	0.071	42%
William Harris	4108	Upper Coast	0.023	671%

Table 2-D-4 – Climate Division start years for precipitation and temperature

Climate Division	Variable	Start year
4101	P	1940
4101	T	1968
4102	P	1940
4102	T	1968
4103	P	1940*
4103	T	1968
4104	P	1940*
4104	T	1966
4106	P	1940
4106	T	1968
4107	P	1940
4107	T	1968
4108	P	1940*
4108	T	1966

*Start year manually set to 1940.

Table 2-D-5 – Trendline Slopes of TWDB Gross Quadrangle Evaporation and E[T]

Climate Division	Variable	Annual	Winter	Spring	Summer	Dry Winter	Avg Winter	Wet Winter	Dry Spring	Avg Spring	Wet Spring	Dry Summer	Avg Summer	Wet Summer
4101	E[T]	0.014	0.011	0.018	0.014	0.006	0.012	0.012	0.013	0.024	0.010	0.010	0.005	0.009
4101	TWDB Gross Evap	0.018	0.022	0.018	0.014	0.016	0.021	0.022	0.026	0.030	-0.003	0.005	0.016	0.017
4102	E[T]	0.015	0.013	0.017	0.014	0.010	0.017	0.010	0.008	0.006	0.012	0.003	0.007	0.010
4102	TWDB Gross Evap	0.016	0.020	0.013	0.016	0.010	0.031	0.016	0.005	0.010	0.006	0.001	0.018	0.015
4103	E[T]	0.010	0.008	0.009	0.012	0.011	0.006	0.006	0.003	0.008	0.005	0.007	0.004	0.007
4103	TWDB Gross Evap	0.004	0.009	0.001	0.003	0.010	0.009	0.004	-0.004	-0.002	0.001	0.006	-0.007	0.003
4104	E[T]	0.007	0.004	0.005	0.011	0.007	0.003	0.002	0.004	0.003	0.005	0.011	0.002	0.010
4104	TWDB Gross Evap	0.007	0.008	0.004	0.008	0.017	0.007	0.002	0.007	0.007	0.000	0.008	0.001	0.010
4106	E[T]	0.012	0.009	0.017	0.015	0.002	0.010	0.007	0.006	0.016	0.007	0.011	0.001	0.021
4106	TWDB Gross Evap	0.007	0.006	0.002	0.012	-0.003	0.010	0.002	-0.004	0.004	0.000	-0.003	0.000	0.015
4107	E[T]	0.006	0.005	0.009	0.009	-0.001	0.004	0.005	0.006	0.007	0.002	0.010	0.000	0.007
4107	TWDB Gross Evap	-0.002	-0.001	-0.001	-0.002	-0.007	-0.002	-0.001	-0.012	0.001	-0.005	-0.001	-0.024	0.000
4108	E[T]	0.006	0.004	0.006	0.007	0.006	0.003	0.003	0.005	0.008	-0.001	0.005	0.002	0.008
4108	TWDB Gross Evap	0.001	0.001	0.002	0.001	0.007	0.000	-0.004	-0.001	0.010	-0.005	0.000	-0.012	0.005

For E[T] datasets, green indicates a significant (P-value≤0.05) trendline is associated with the slope of average temperature (degrees Fahrenheit) versus year for that climate division. For TWDB quadrangle gross evaporation datasets, green indicates a significant (P-value≤0.05) trendline is associated with the slope of average TWDB gross quadrangle evaporation (inches per month) versus year for that climate division.

Table 2-D-6 – Average Annual Change in Net Evaporation

Climate Division	Slope of Precipitation (in/mo/yr)	Slope of E[T] (in/mo/yr)	Slope of E[T] - Slope of P (in/mo/yr)
4101	Wet Winter: 0.008, Average Summer: 0.017, All others: none	0.014	Wet Winter: 0.006, Average Summer: -0.003, All others: 0.014
4102	0.012	0.015	Wet Summer: 0.003, All Others: 0.015
4103	none	0.01	0.01
4104	none	0.007	0.007
4106*	none	0.012	none
4107	Wet Summer: -0.02, All others: none	0.006	Wet Summer: 0.026, All Others: 0.006
4108	Wet Spring: 0.027, All others: none	0.006	Wet Spring: -0.021, All Others: 0.006

*There are no control points in the EVA file assigned to this climate division.

Climate Division 4101

Table 2-D-7 – Summary of Variable Trend Results for 2070 Conditions

	P				T				E			
	τ	p	Slope	Intercept	τ	p	Slope	Intercept	τ	p	Slope	Intercept
Annual	0.07	0.36	0.00	-1.10	**0.46**	**0.00**	0.05	-40.98	0.33	0.00	0.02	-29.93
Winter	0.06	0.44	0.00	-1.18	0.23	0.02	0.05	-57.30	0.38	0.00	0.02	-40.88
Spring	0.05	0.52	0.00	-0.17	0.28	0.00	0.05	-44.45	0.22	0.02	0.02	-29.50
Summer	0.06	0.47	0.00	0.11	0.30	0.00	0.05	-20.38	0.18	0.05	0.01	-20.21
Dry Winter	0.13	0.39	0.00	-3.03	0.16	0.53	0.03	-27.23	0.38	0.12	0.02	-29.44
Average Winter	-0.19	0.15	-0.01	10.96	0.14	0.34	0.04	-45.13	0.31	0.03	0.02	-38.14
Wet Winter	**0.31**	**0.03**	0.01	-14.11	0.31	0.11	0.08	-107.99	0.48	0.01	0.02	-40.18
Dry Spring	-0.02	0.88	0.00	6.00	0.19	0.38	0.04	-24.44	0.47	0.02	0.03	-44.15
Average Spring	-0.09	0.52	0.00	4.83	0.50	0.00	0.08	-104.22	0.37	0.02	0.03	-53.13
Wet Spring	0.16	0.26	0.00	-3.55	0.25	0.17	0.04	-8.60	-0.04	0.84	0.00	11.98
Dry Summer	0.18	0.17	0.01	-9.24	0.10	0.57	0.03	18.60	-0.05	0.82	0.00	-1.77
Average Summer	**0.34**	**0.03**	0.02	-30.83	0.17	0.40	0.02	30.03	0.16	0.43	0.02	-23.88
Wet Summer	-0.23	0.09	-0.01	25.63	0.48	0.00	0.06	-48.48	0.33	0.05	0.02	-25.91

Bold text indicates trend used.
Green indicates significance (P-value<=0.05)
Light blue indicates moderate to strong Kendall's tau.

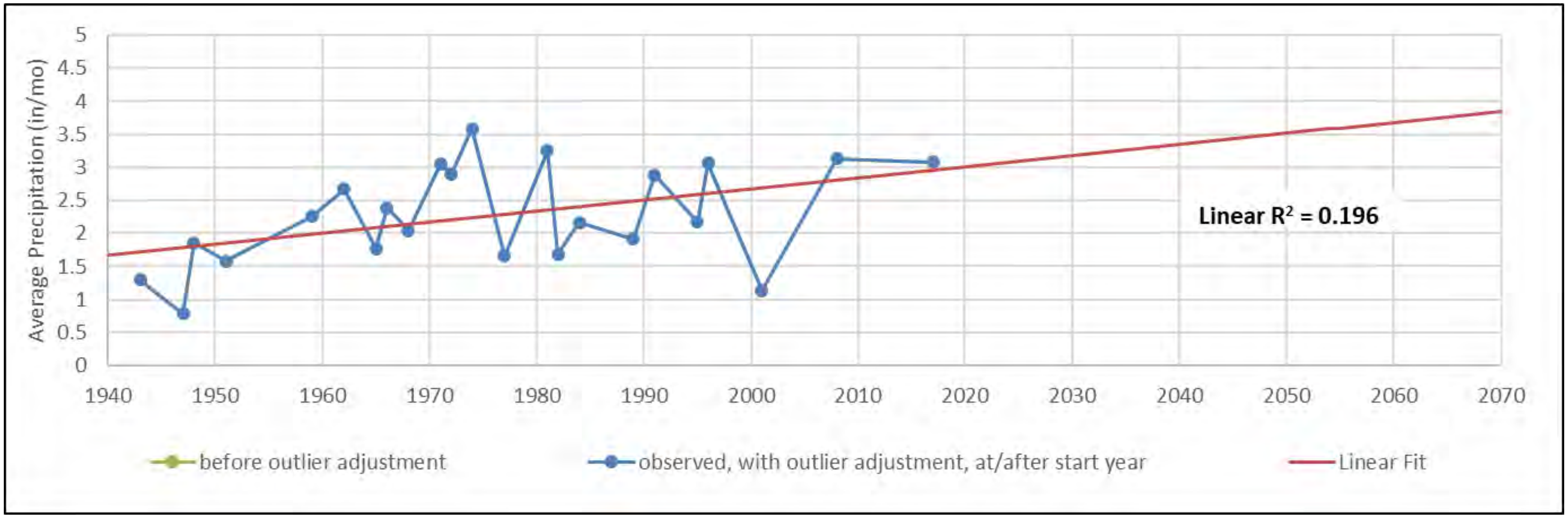


Figure 2-D-1 – Average Summer Trend for Monthly Average Precipitation in Climate Division 4101

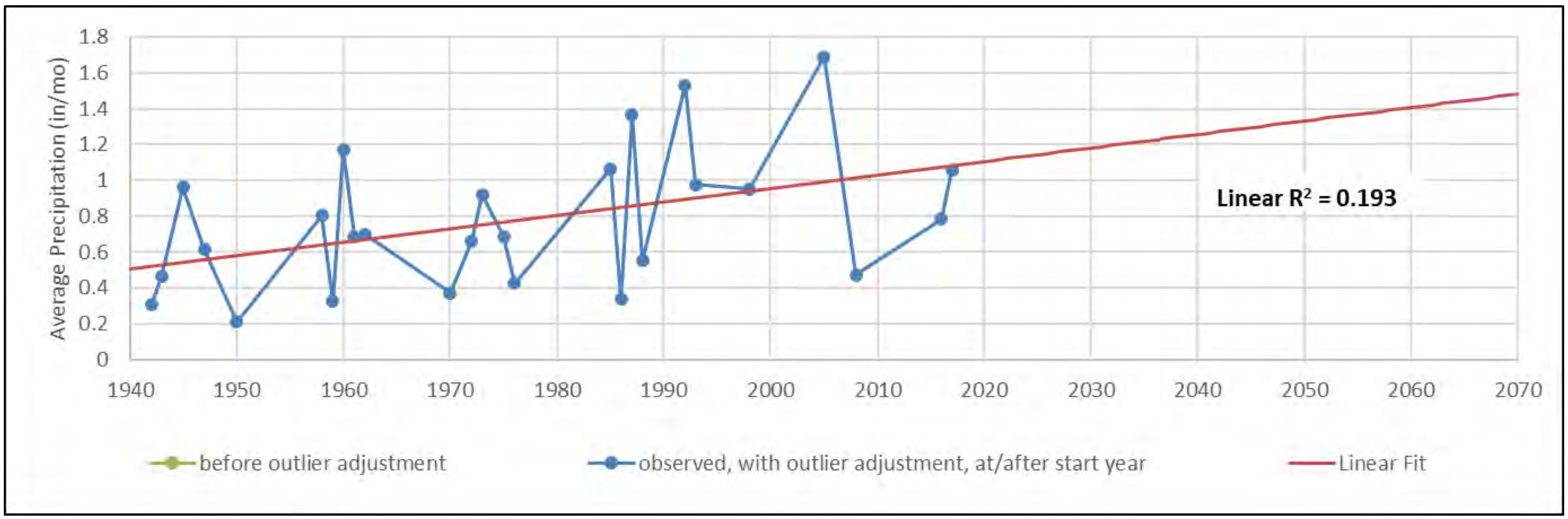


Figure 2-D-2 – Wet Winter Trend for Monthly Average Precipitation in Climate Division 4101

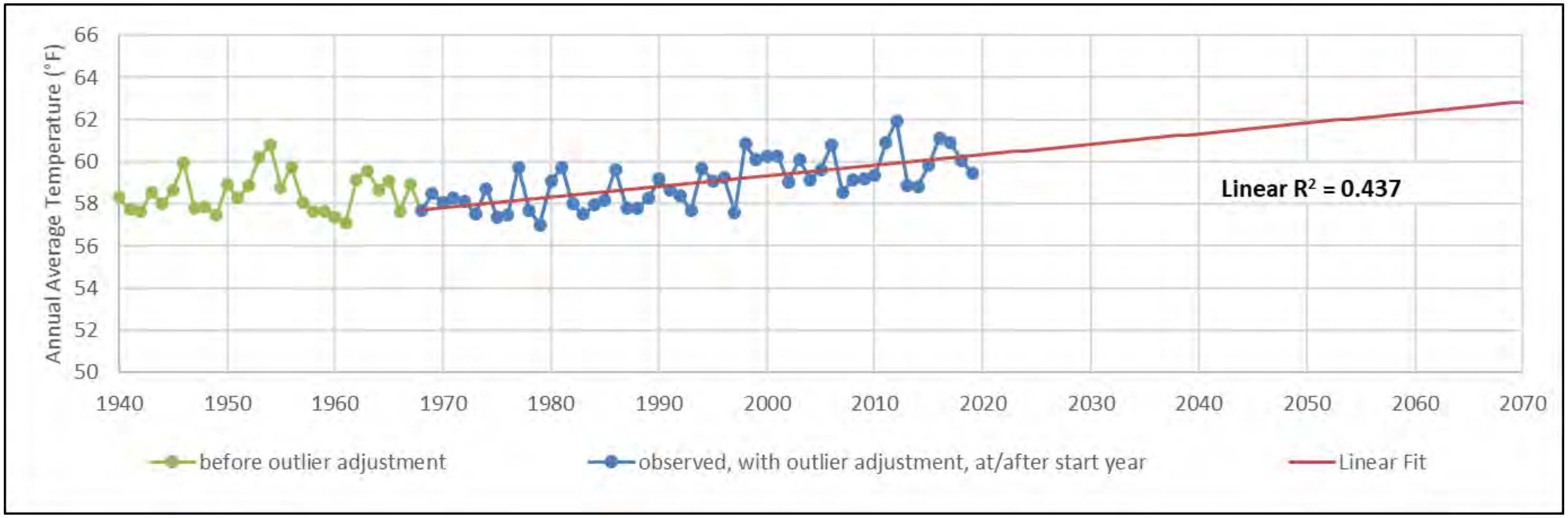


Figure 2-D-3 – Annual Trend for Average Air Temperature in Climate Division 4101

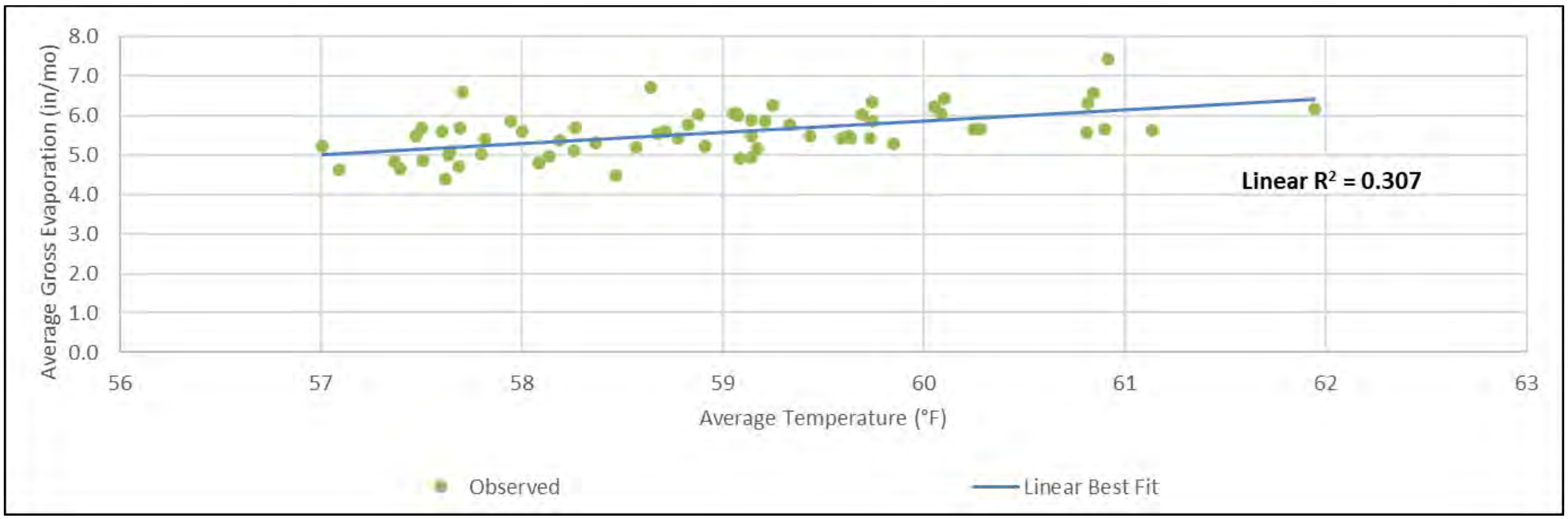


Figure 2-D-4 – Relationship between Annual Average Air Temperature and Gross Evaporation in Climate Division 4101

Changes to Net Reservoir Evaporation for Climate Division 4101

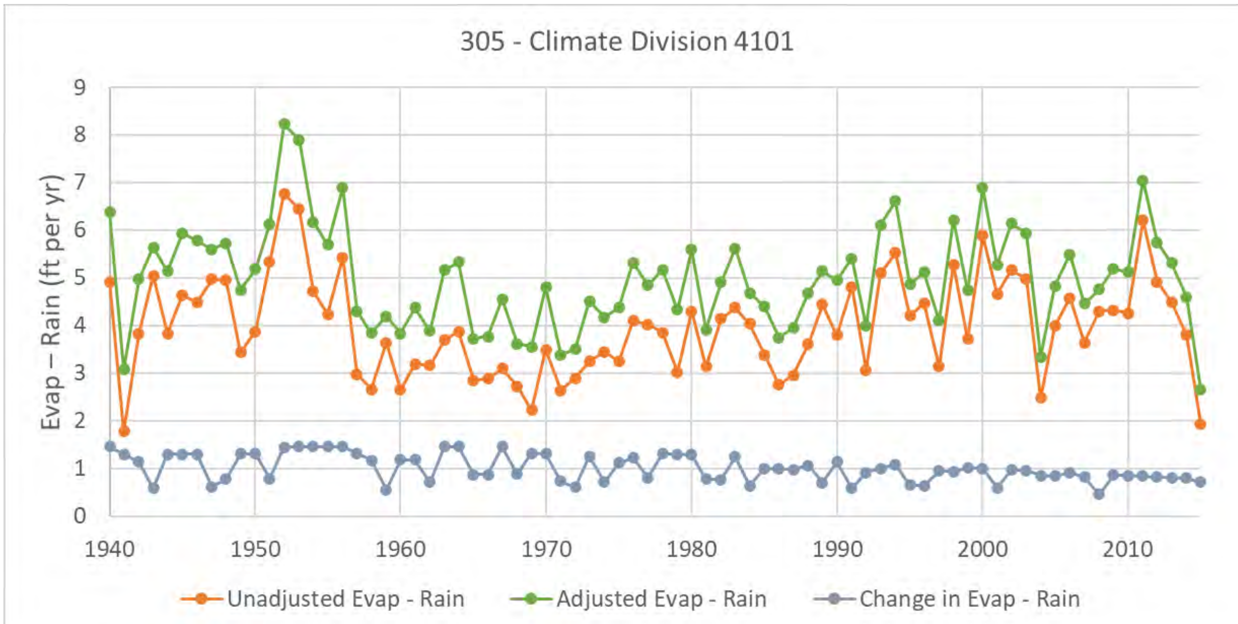


Figure 2-D-5 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 305 for 2070 Conditions

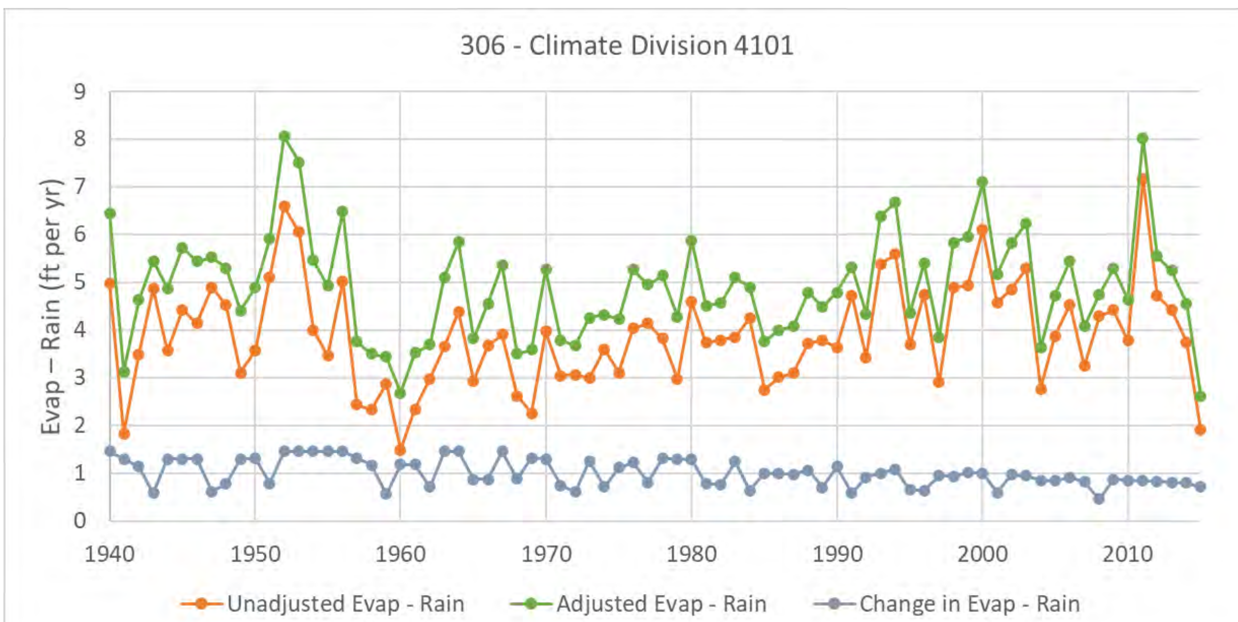


Figure 2-D-6 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 306 for 2070 Conditions

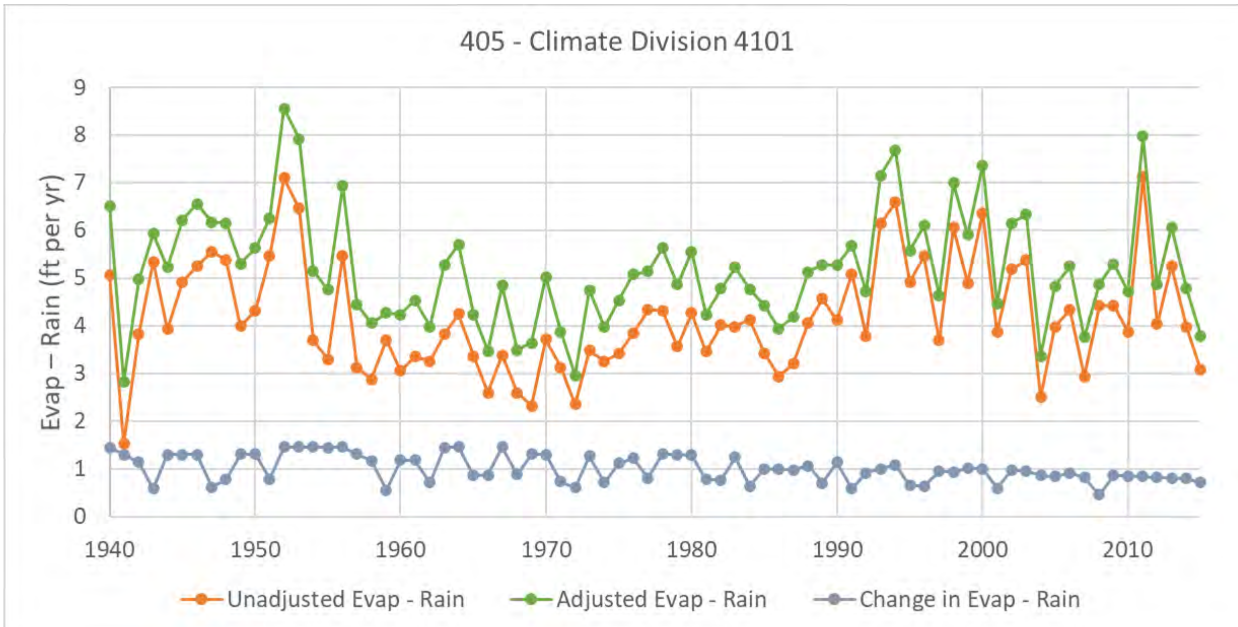


Figure 2-D-7 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 405 for 2070 Conditions

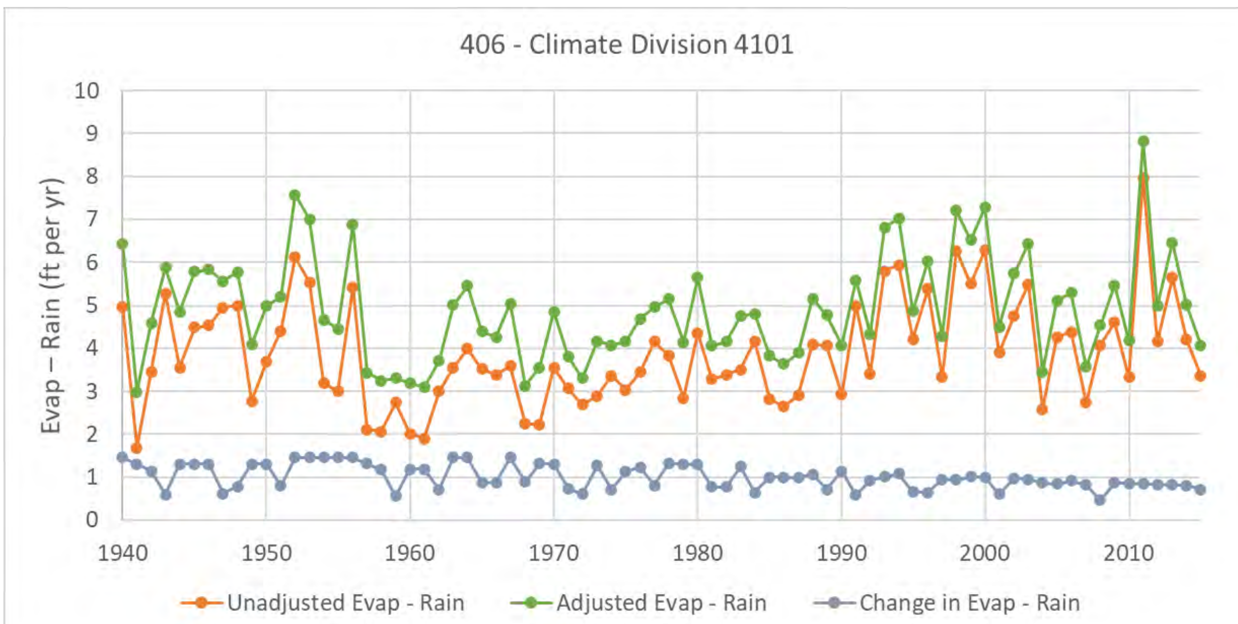


Figure 2-D-8 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 406 for 2070 Conditions

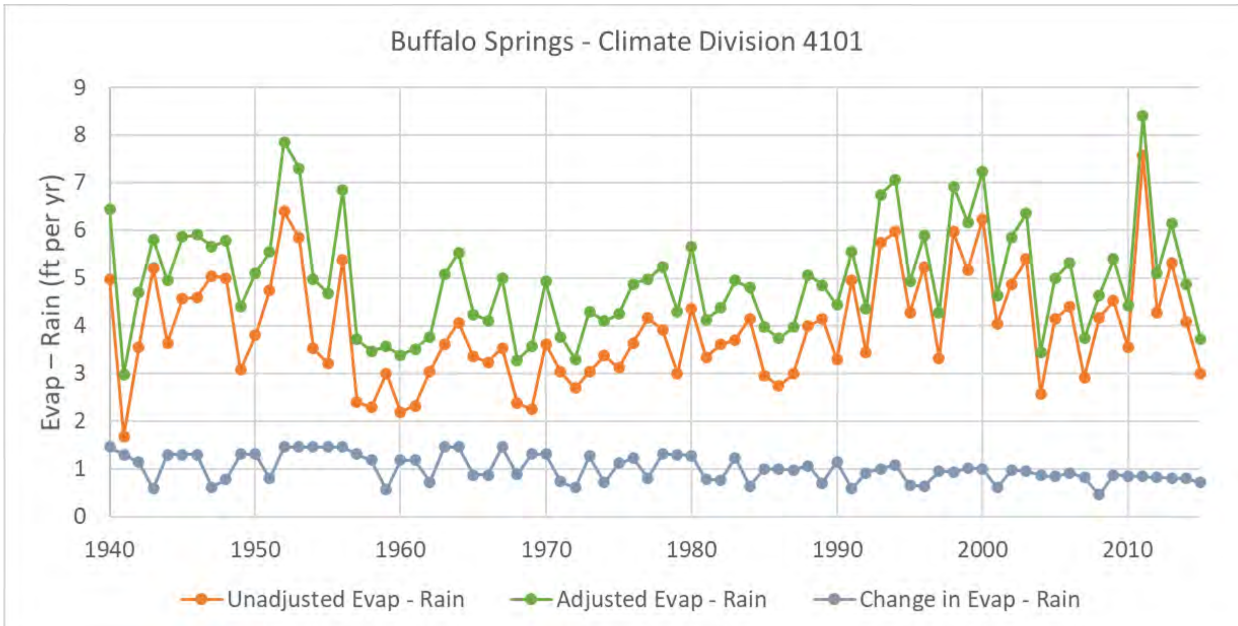


Figure 2-D-9 – Original and Adjusted Naturalized Net Reservoir Evaporation at Buffalo Springs Lake for 2070 Conditions

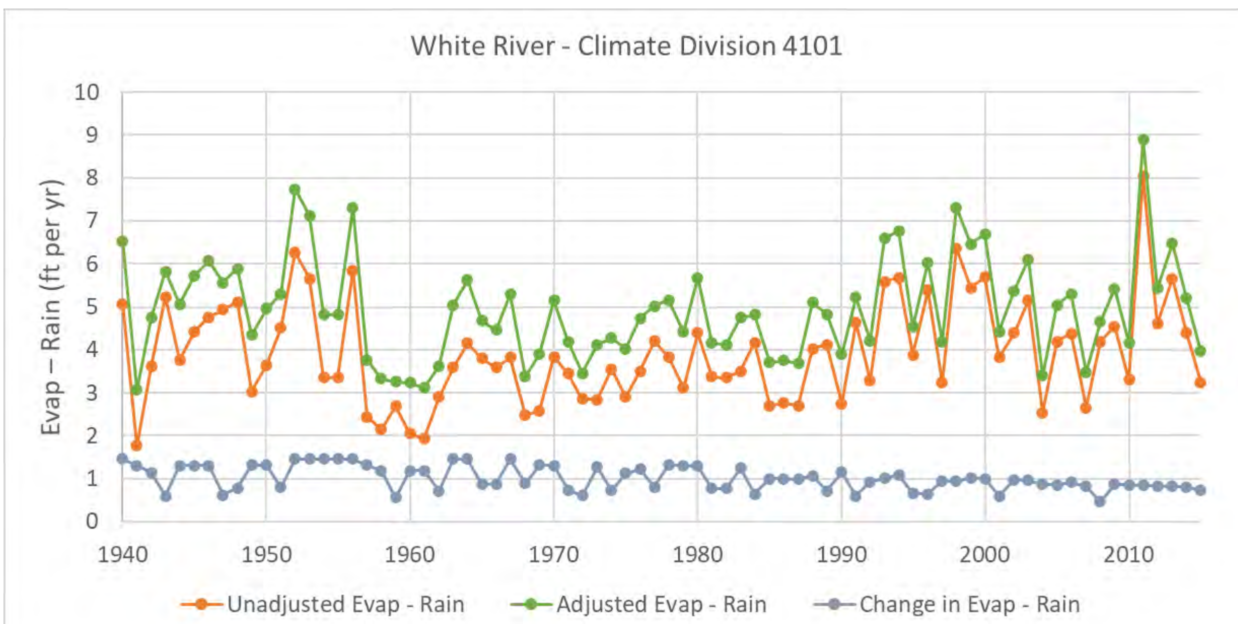


Figure 2-D-10 – Original and Adjusted Naturalized Net Reservoir Evaporation at White River Reservoir for 2070 Conditions

Climate Division 4102

Table 2-D-8 – Summary of Variable Trend Results for 2070 Conditions

	P				T				E			
	τ	p	Slope	Intercept	τ	p	Slope	Intercept	τ	p	Slope	Intercept
Annual	0.11	0.15	0.00	-3.88	**0.44**	**0.00**	0.05	-39.62	0.34	0.00	0.02	-25.88
Winter	0.06	0.47	0.00	-3.58	0.28	0.00	0.06	-77.80	0.38	0.00	0.02	-37.56
Spring	0.06	0.45	0.00	-3.16	0.27	0.01	0.05	-33.39	0.17	0.07	0.01	-19.20
Summer	0.04	0.62	0.00	-2.24	0.26	0.01	0.04	-8.36	0.23	0.02	0.02	-24.53
Dry Winter	0.13	0.35	0.00	-4.85	0.08	0.74	0.05	-61.51	0.16	0.44	0.01	-17.10
Average Winter	-0.17	0.21	-0.01	11.63	0.24	0.17	0.06	-67.98	0.41	0.02	0.03	-58.86
Wet Winter	0.24	0.09	0.01	-18.85	0.27	0.10	0.06	-76.11	0.46	0.00	0.02	-28.85
Dry Spring	-0.14	0.33	0.00	11.49	0.12	0.63	0.03	2.85	0.15	0.54	0.00	-2.43
Average Spring	0.19	0.18	0.00	-6.70	0.18	0.32	0.03	15.55	0.14	0.45	0.01	-13.73
Wet Spring	0.11	0.43	0.00	-5.19	0.39	0.01	0.05	-31.39	0.15	0.34	0.01	-6.52
Dry Summer	**0.27**	**0.05**	0.01	-21.06	-0.01	1.00	0.01	56.66	0.05	0.84	0.00	5.88
Average Summer	-0.03	0.86	0.00	3.45	0.08	0.72	0.03	25.59	0.30	0.12	0.02	-27.80
Wet Summer	-0.10	0.46	-0.01	18.62	0.41	0.01	0.05	-24.15	0.22	0.17	0.01	-21.90

Bold text indicates trend used.
Green indicates significance (P-value<=0.05)
Light blue indicates moderate to strong Kendall's tau.

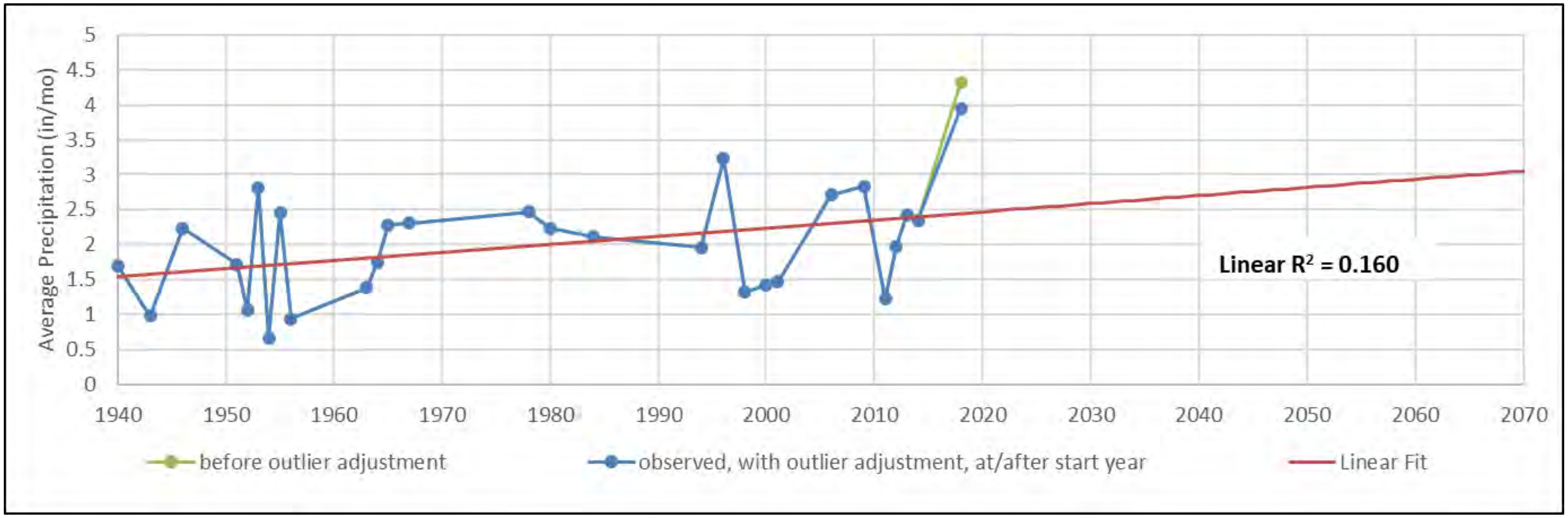


Figure 2-D-11 – Dry Summer Trend for Monthly Average Precipitation in Climate Division 4102

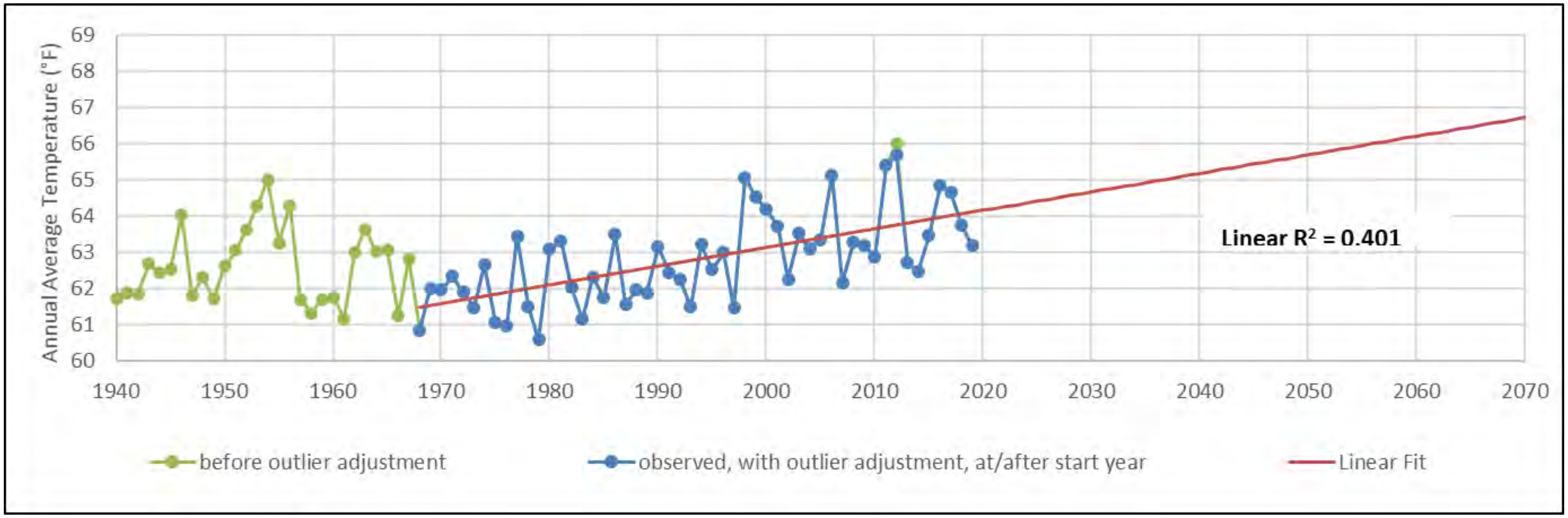


Figure 2-D-12 – Annual Trend for Average Air Temperature in Climate Division 4102

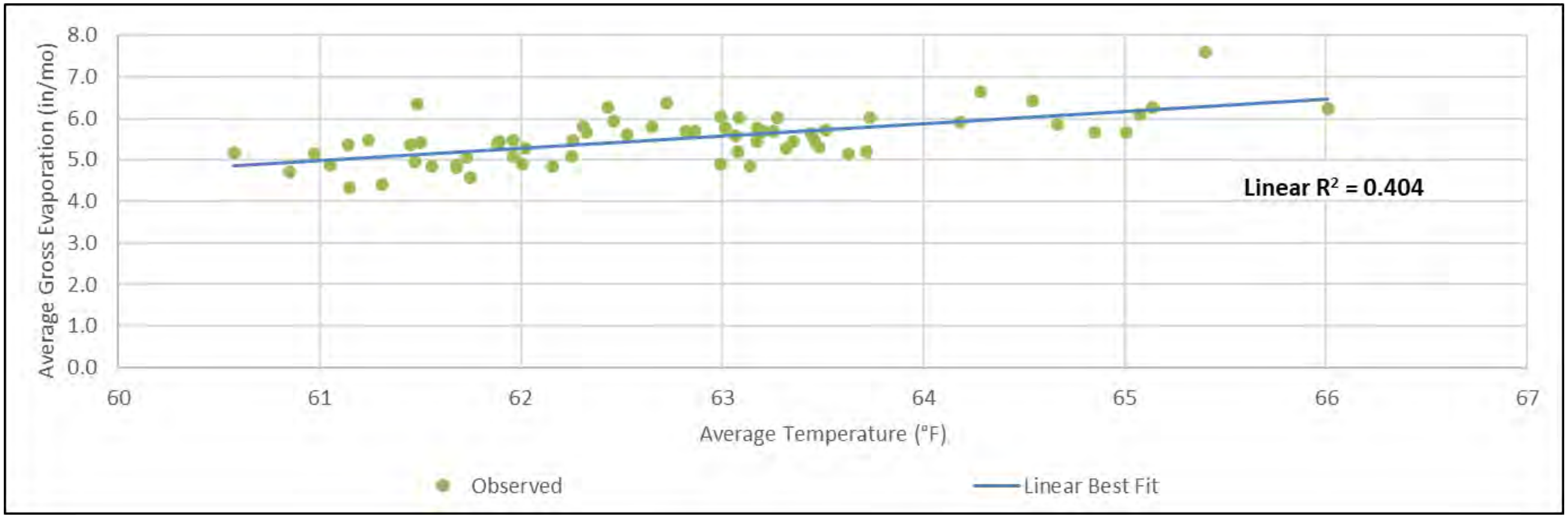


Figure 2-D-13 – Relationship between Annual Average Air Temperature and Gross Evaporation in Climate Division 4102

Changes to Net Reservoir Evaporation for Climate Division 4102

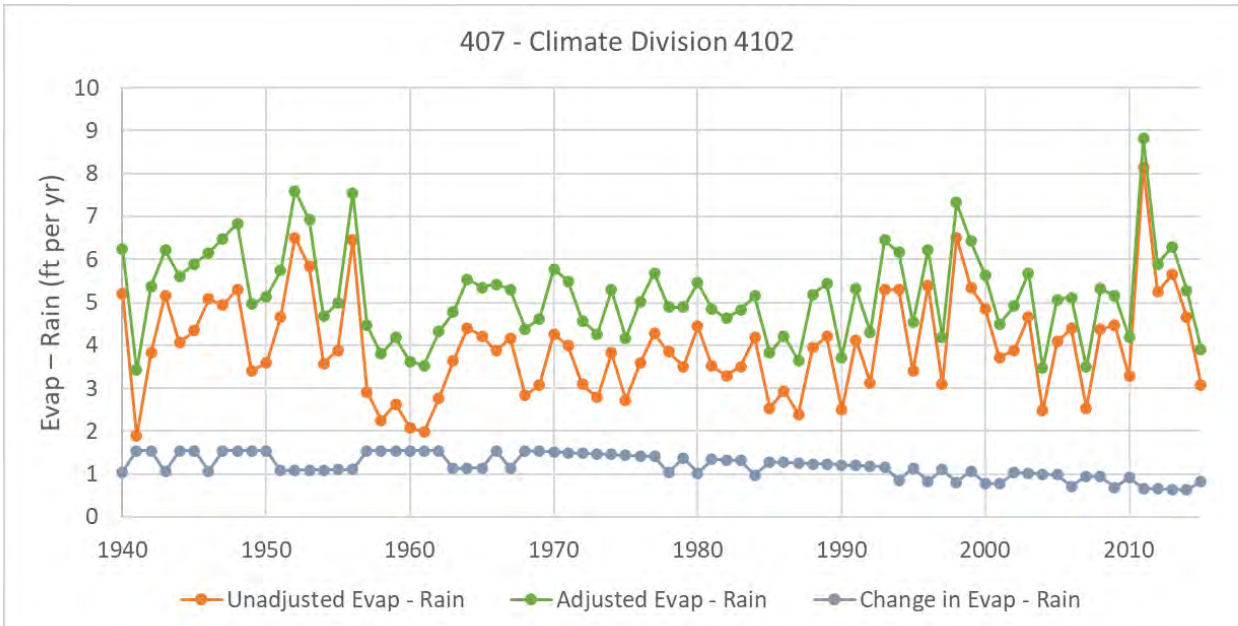


Figure 2-D-14 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 407 for 2070 Conditions

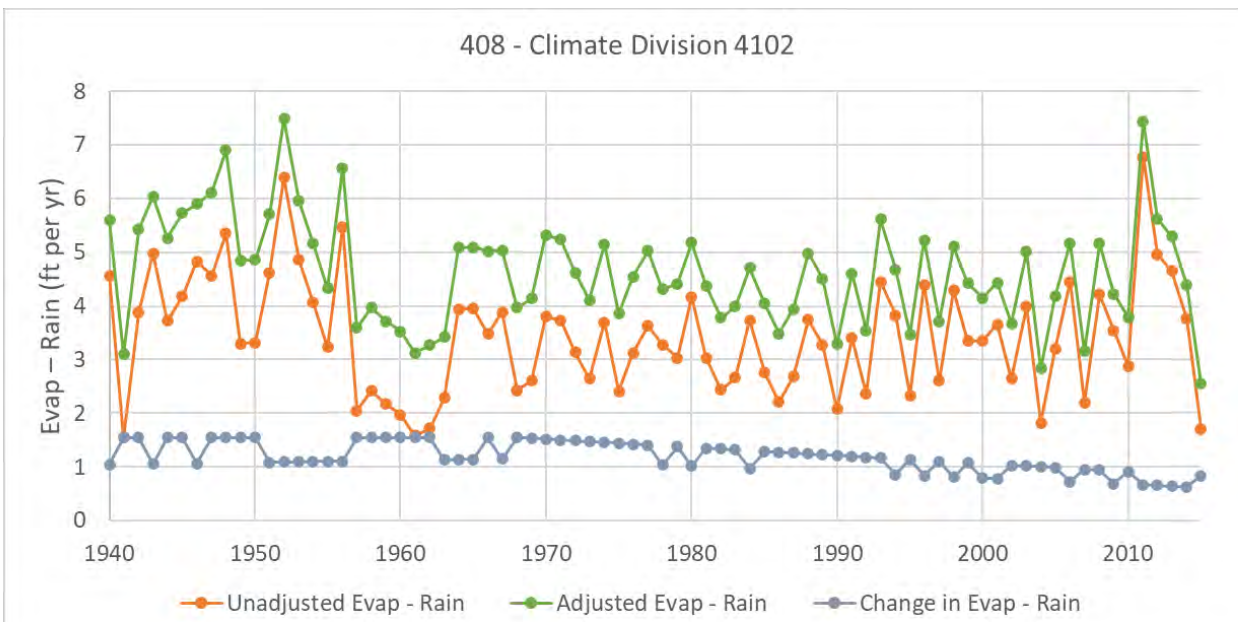


Figure 2-D-15 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 408 for 2070 Conditions

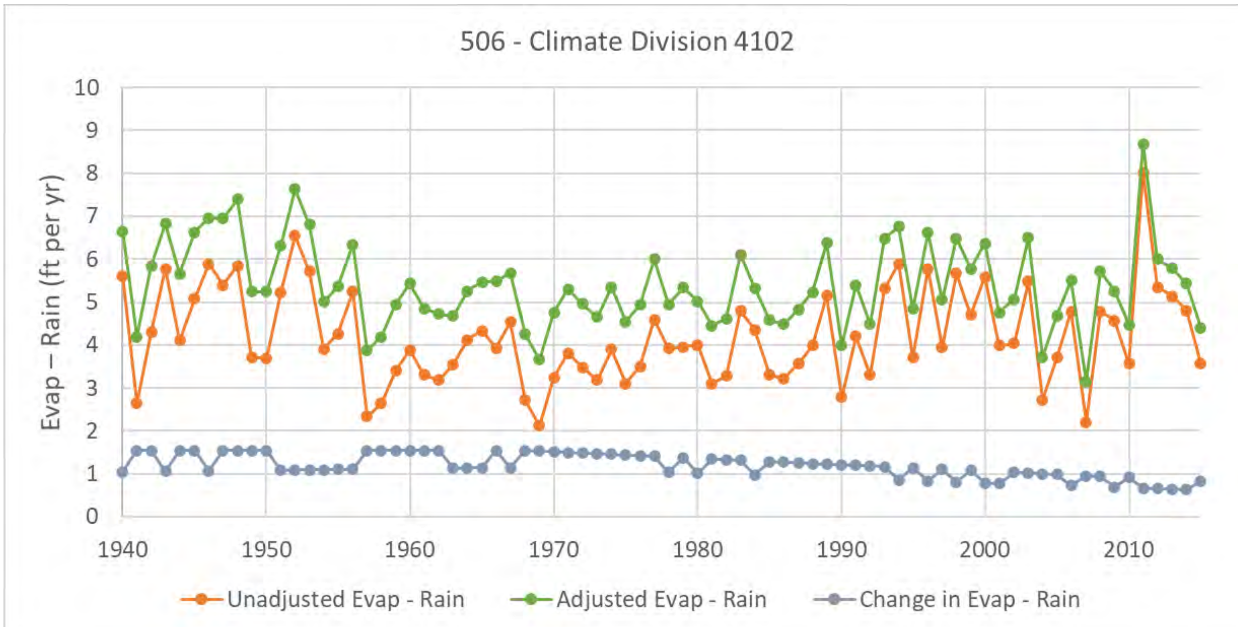


Figure 2-D-16 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 506 for 2070 Conditions

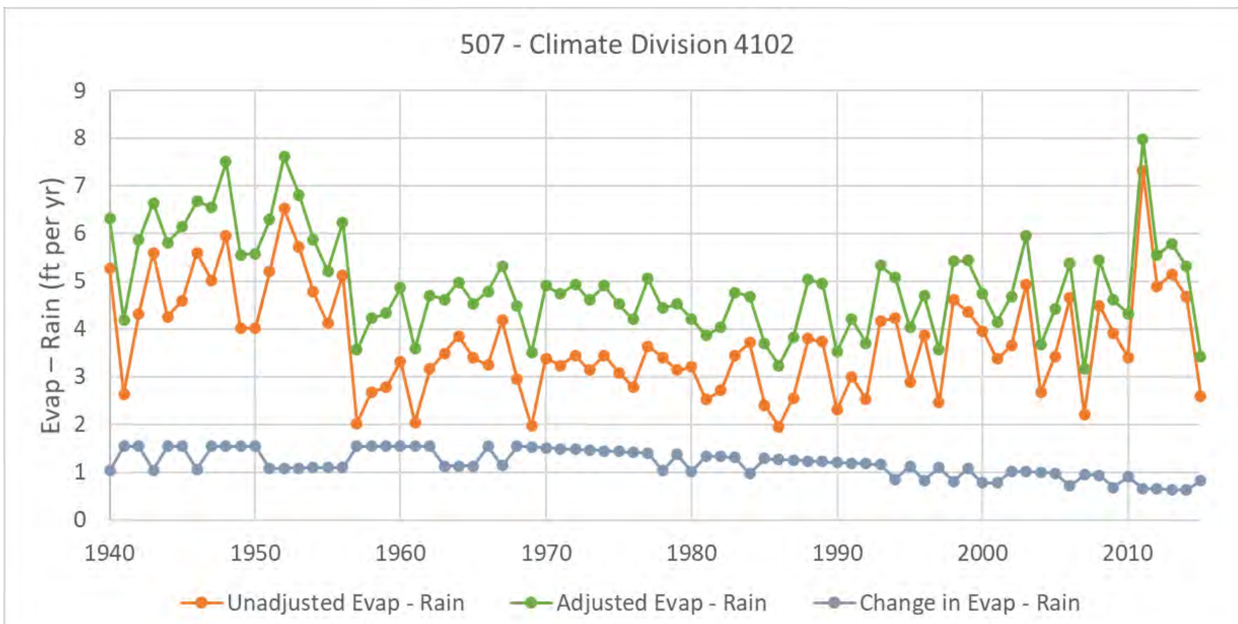


Figure 2-D-17 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 507 for 2070 Conditions

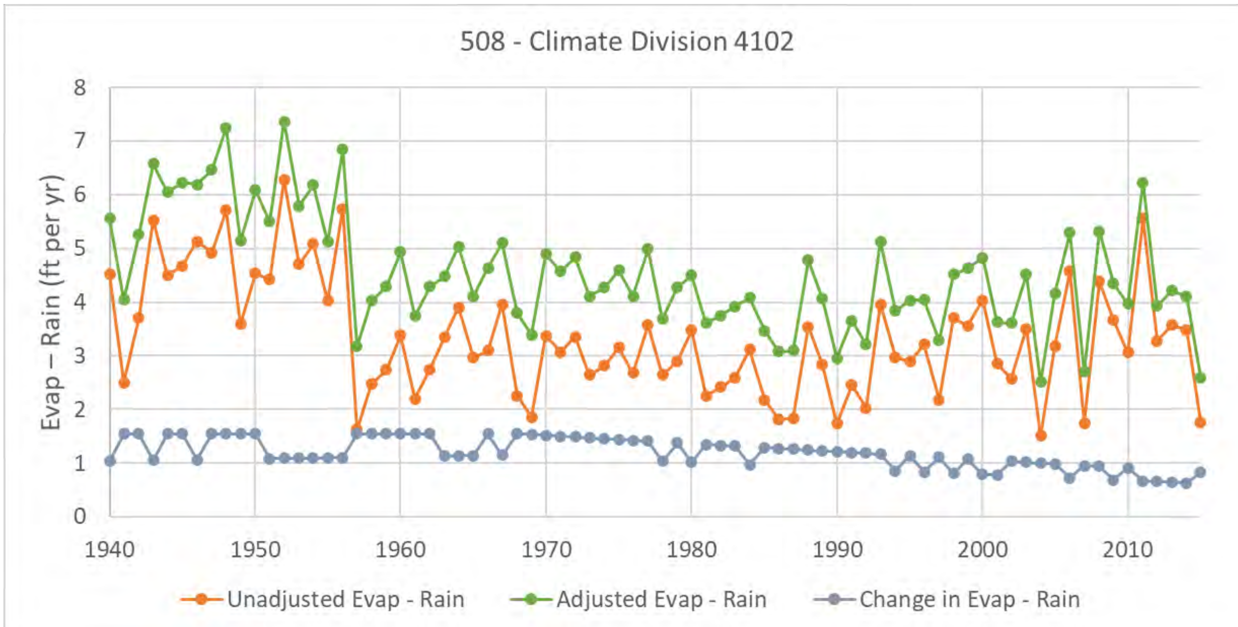


Figure 2-D-18 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 508 for 2070 Conditions

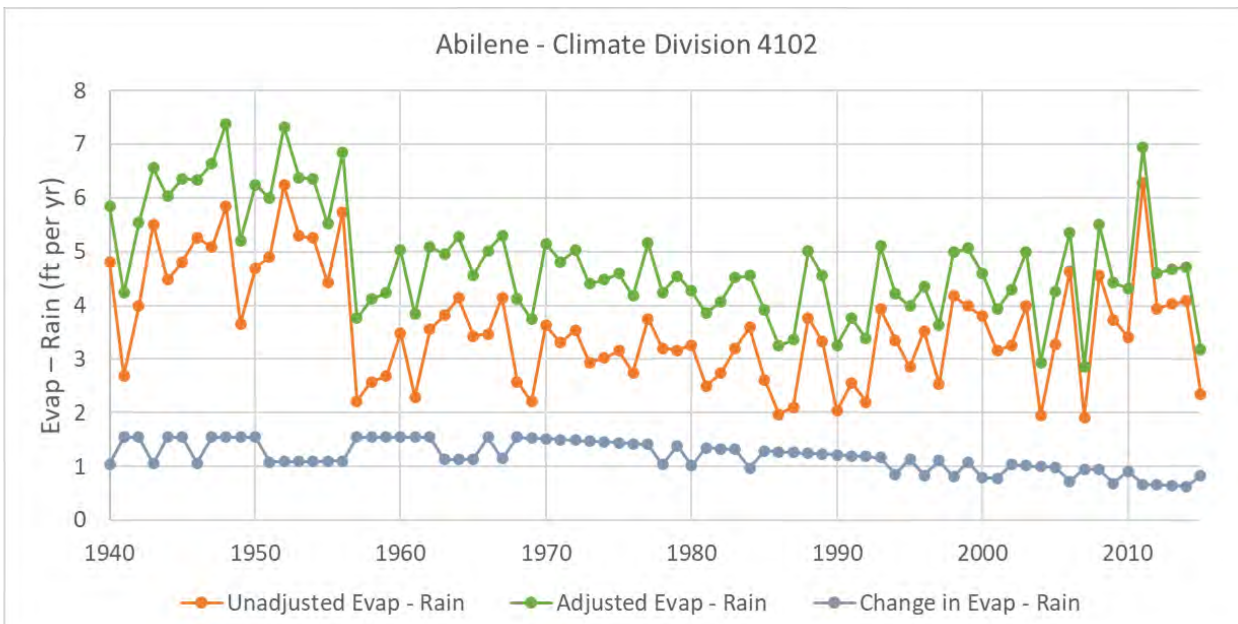


Figure 2-D-19 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Abilene for 2070 Conditions

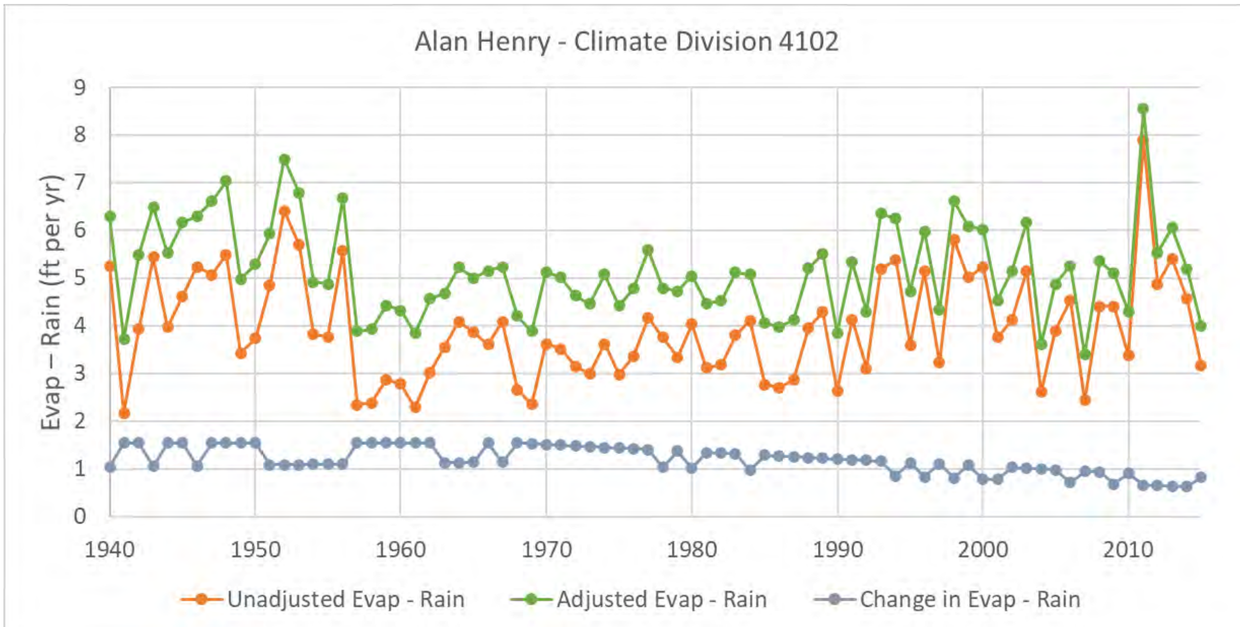


Figure 2-D-20 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Alan Henry for 2070 Conditions

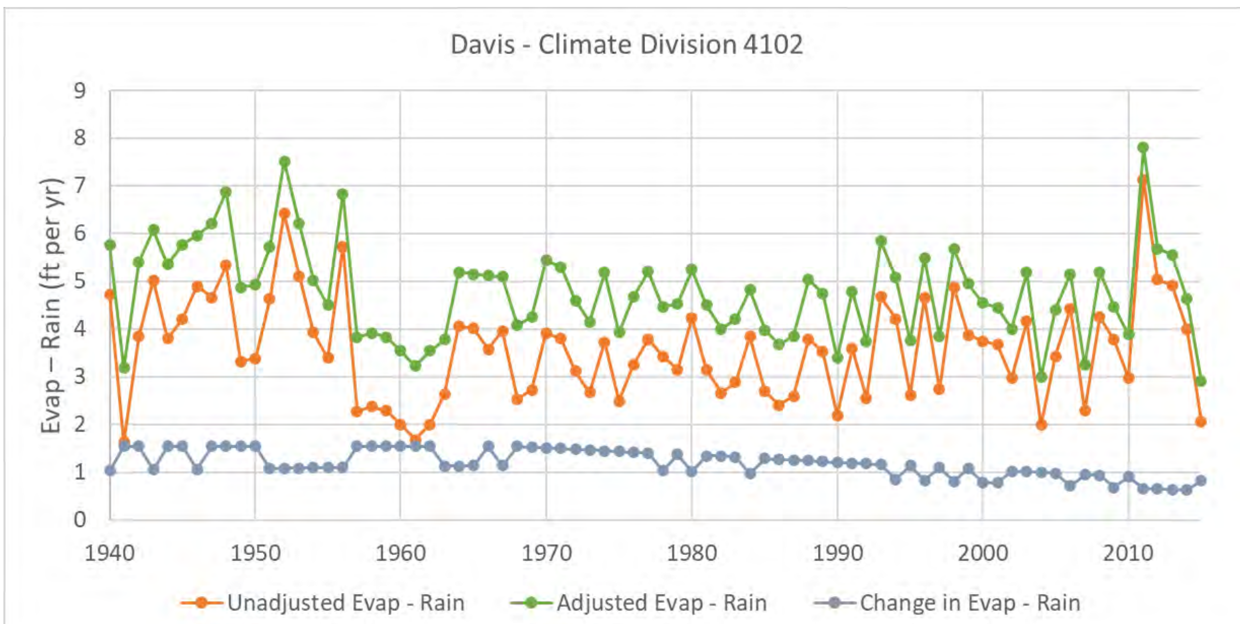


Figure 2-D-21 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Davis for 2070 Conditions

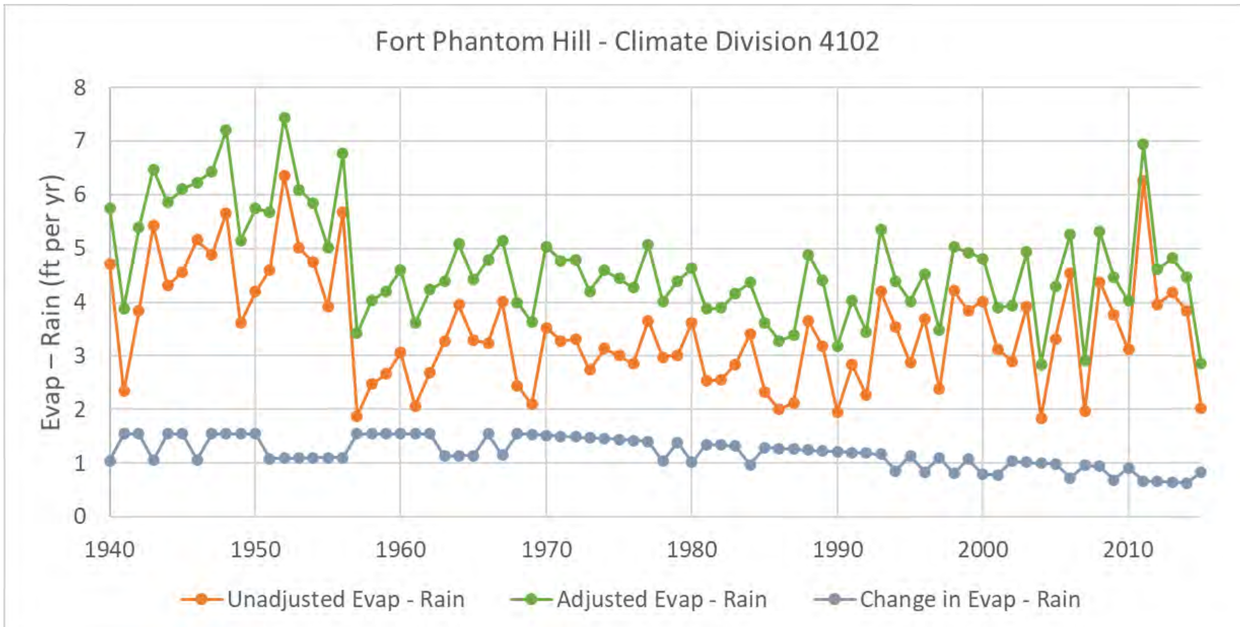


Figure 2-D-22 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Fort Phantom Hill for 2070 Conditions

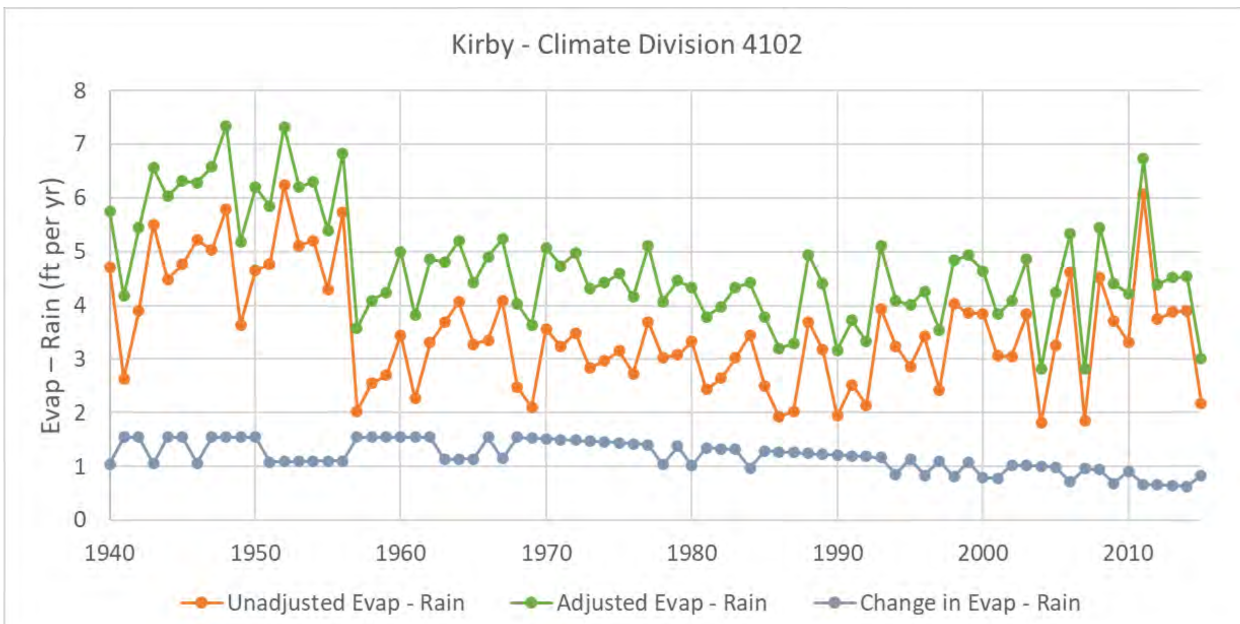


Figure 2-D-23 – Original and Adjusted Naturalized Net Reservoir Evaporation at Kirby Lake for 2070 Conditions

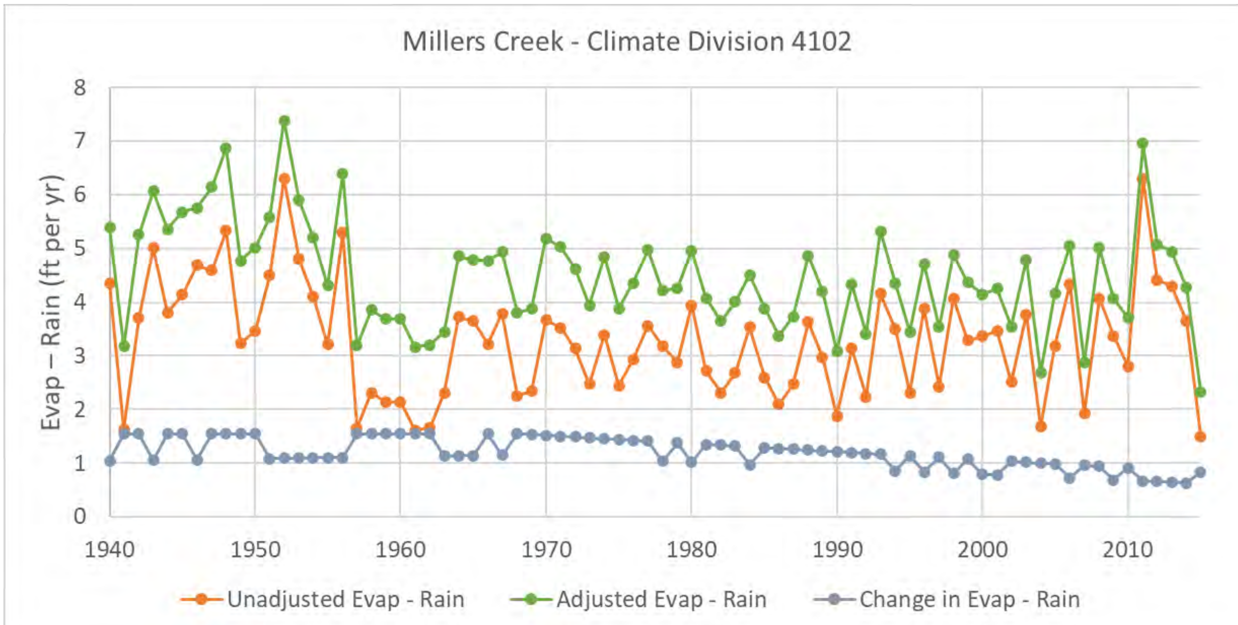


Figure 2-D-24 – Original and Adjusted Naturalized Net Reservoir Evaporation at Millers Creek Reservoir for 2070 Conditions

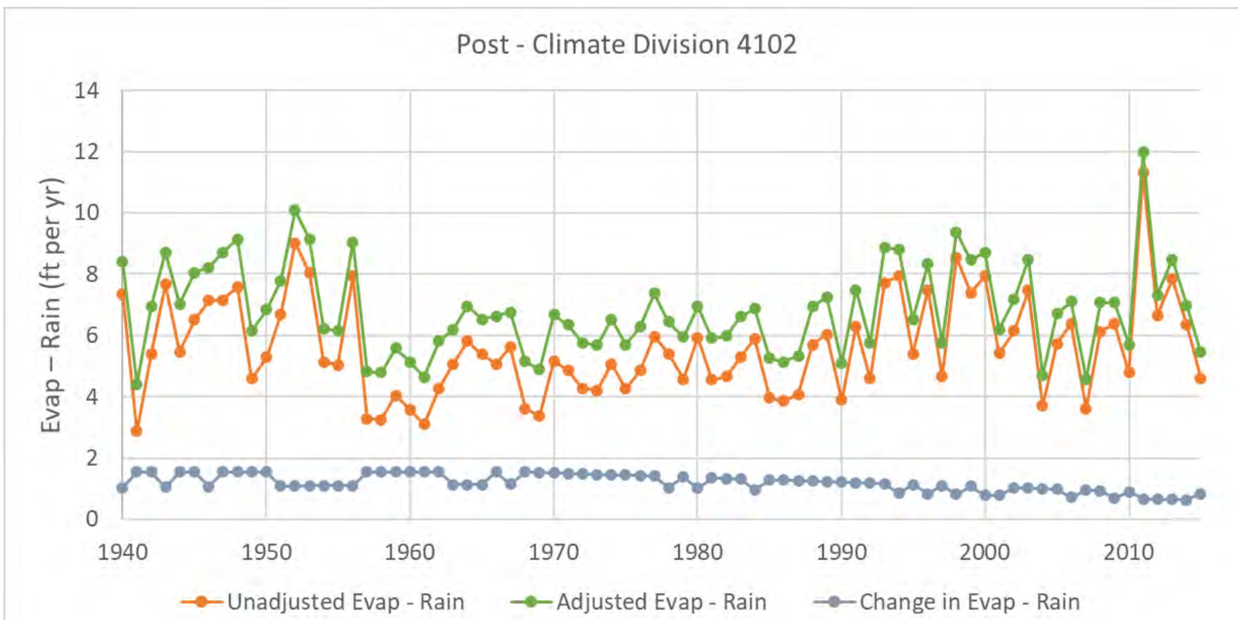


Figure 2-D-25 – Original and Adjusted Naturalized Net Reservoir Evaporation at Post Reservoir for 2070 Conditions

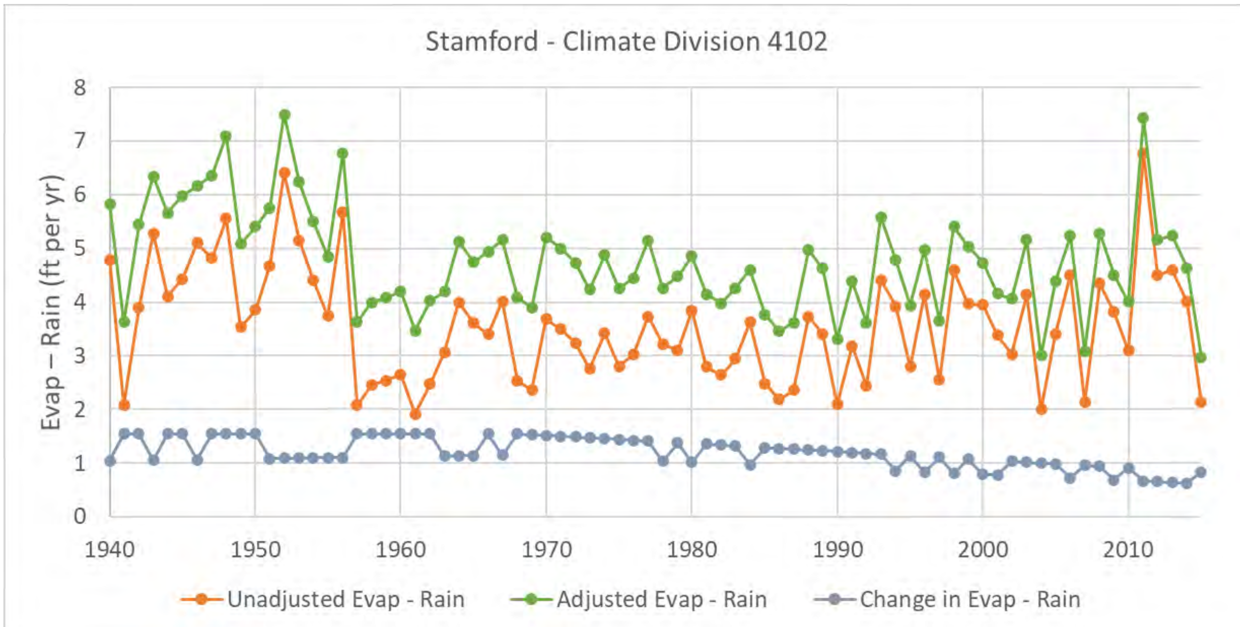


Figure 2-D-26 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Stamford for 2070 Conditions

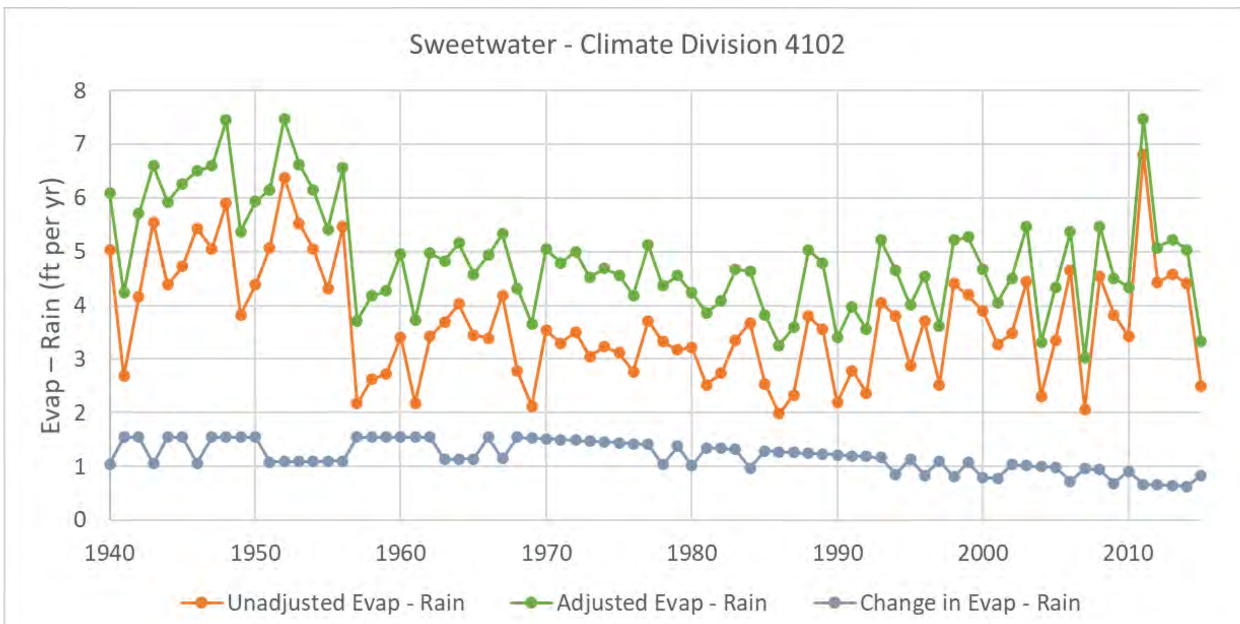


Figure 2-D-27 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Sweetwater for 2070 Conditions

Climate Division 4103

Table 2-D-9 – Summary of Variable Trend Results for Climate Division 4103

	P				T				E			
	τ	p	Slope	Intercept	τ	p	Slope	Intercept	τ	p	Slope	Intercept
Annual	0.08	0.30	0.00	-4.74	**0.44**	**0.00**	0.05	-31.83	0.13	0.19	0.00	-3.51
Winter	0.06	0.42	0.00	-4.79	0.29	0.00	0.06	-72.90	0.24	0.01	0.01	-14.48
Spring	0.00	0.97	0.00	0.18	0.27	0.01	0.04	-17.49	0.06	0.53	0.00	2.71
Summer	0.08	0.31	0.01	-8.52	0.29	0.00	0.04	-7.25	0.04	0.66	0.00	0.01
Dry Winter	-0.04	0.77	0.00	0.44	0.29	0.15	0.09	-138.25	0.26	0.20	0.01	-17.84
Average Winter	-0.19	0.19	-0.01	19.63	0.23	0.24	0.04	-28.26	0.33	0.08	0.01	-15.73
Wet Winter	0.20	0.14	0.01	-18.39	0.19	0.24	0.06	-66.73	0.12	0.45	0.00	-6.06
Dry Spring	-0.20	0.16	-0.01	14.12	0.23	0.26	0.04	-9.82	-0.16	0.43	0.00	14.08
Average Spring	0.14	0.30	0.00	-6.11	0.26	0.15	0.04	-14.04	0.07	0.74	0.00	9.54
Wet Spring	-0.01	0.94	0.00	-1.38	0.33	0.05	0.03	0.17	0.08	0.63	0.00	3.13
Dry Summer	0.24	0.08	0.01	-20.39	0.09	0.65	0.02	37.08	0.07	0.75	0.01	-4.19
Average Summer	0.22	0.14	0.02	-29.49	0.12	0.58	0.02	31.45	-0.21	0.32	-0.01	19.84
Wet Summer	-0.11	0.42	-0.01	14.31	0.46	0.00	0.06	-43.91	0.12	0.46	0.00	-0.52

Bold text indicates trend used.
Green indicates significance (P-value<=0.05)
Light blue indicates moderate to strong Kendall's tau.

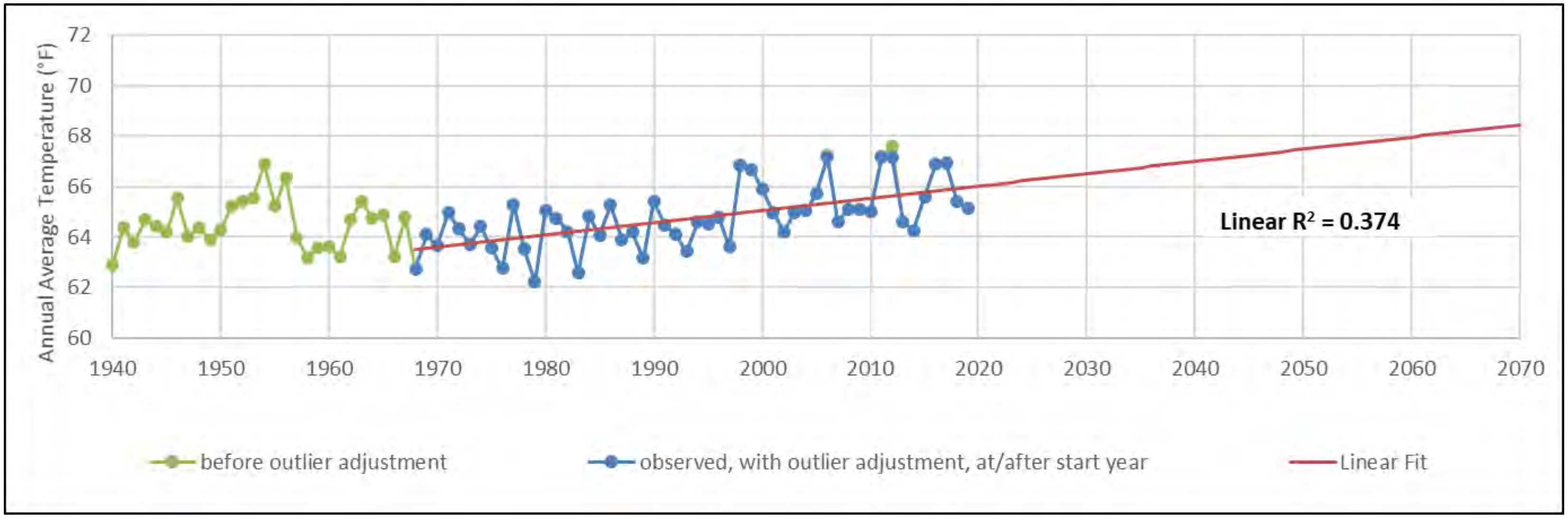


Figure 2-D-28 – Annual Trend for Average Air Temperature in Climate Division 4103

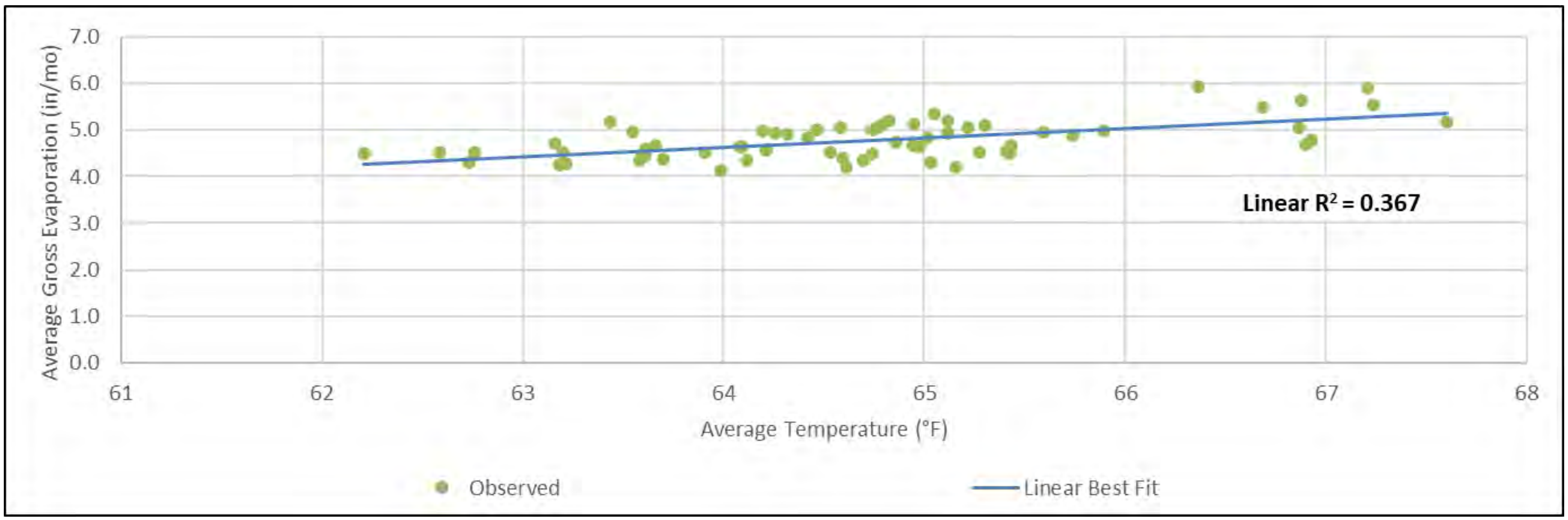


Figure 2-D-29 – Relationship between Annual Average Air Temperature and Gross Evaporation in Climate Division 4103

Changes to Net Reservoir Evaporation for Climate Division 4103

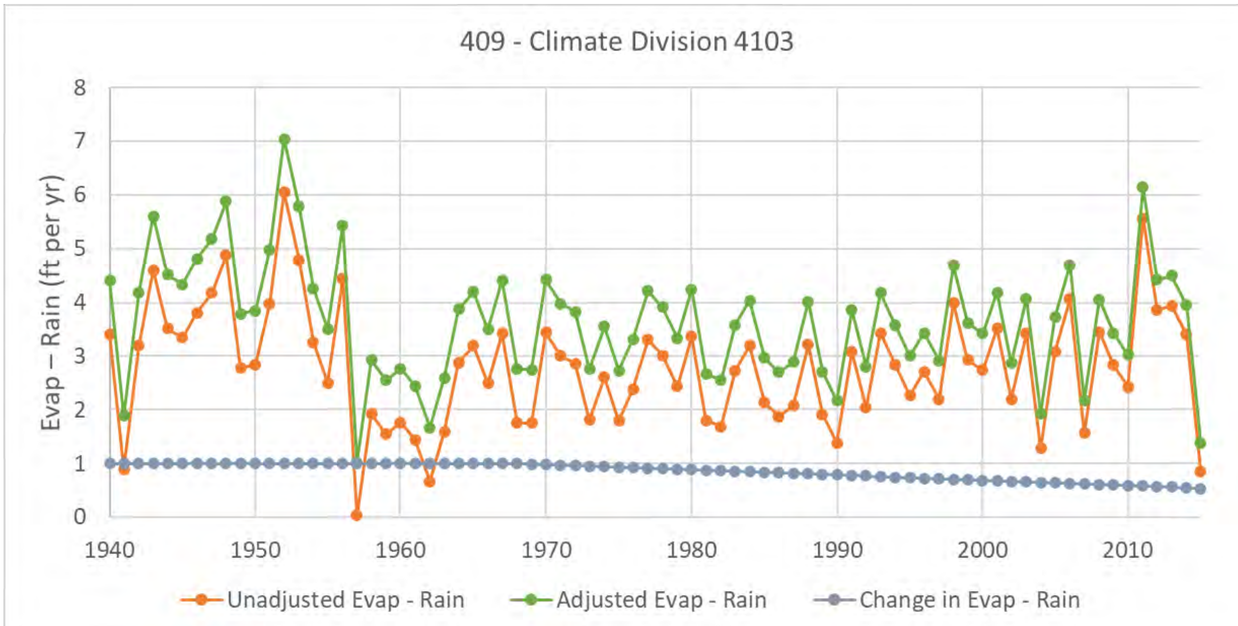


Figure 2-D-30 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 409 for 2070 Conditions

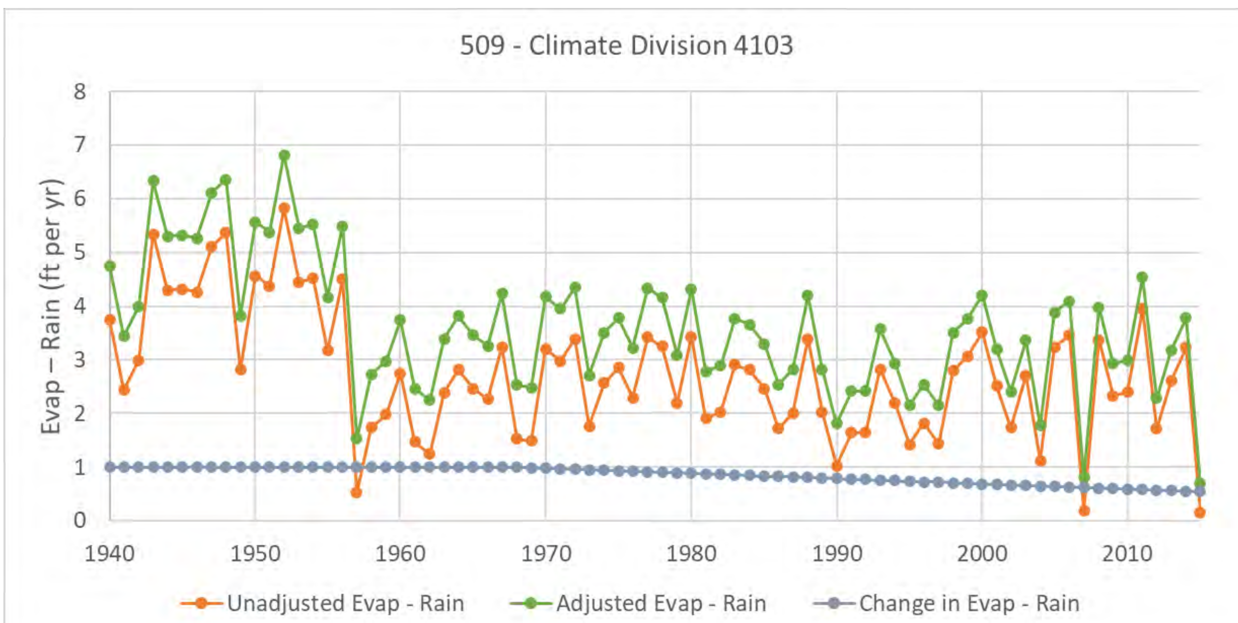


Figure 2-D-31 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 509 for 2070 Conditions

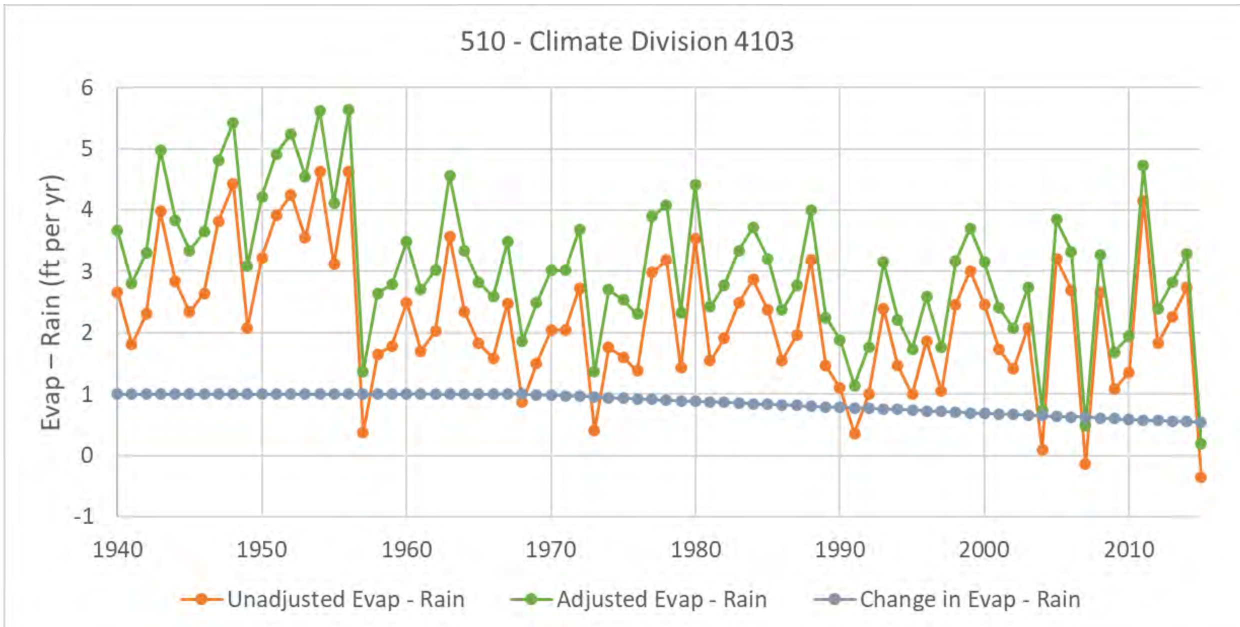


Figure 2-D-32 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 510 for 2070 Conditions

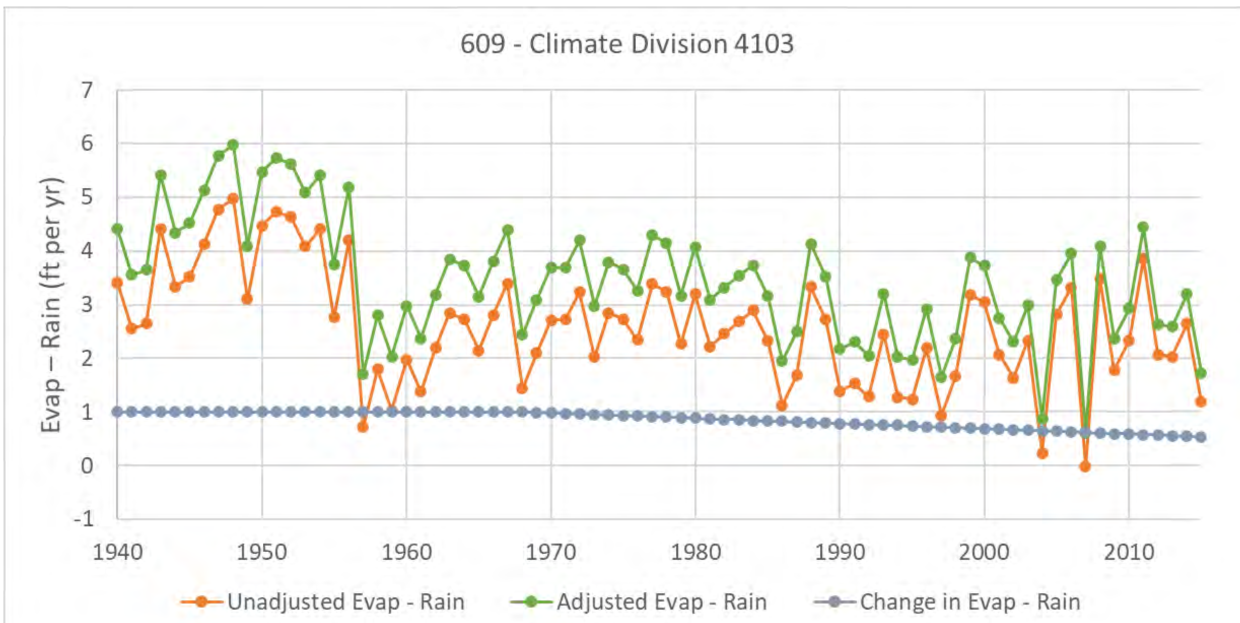


Figure 2-D-33 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 609 for 2070 Conditions

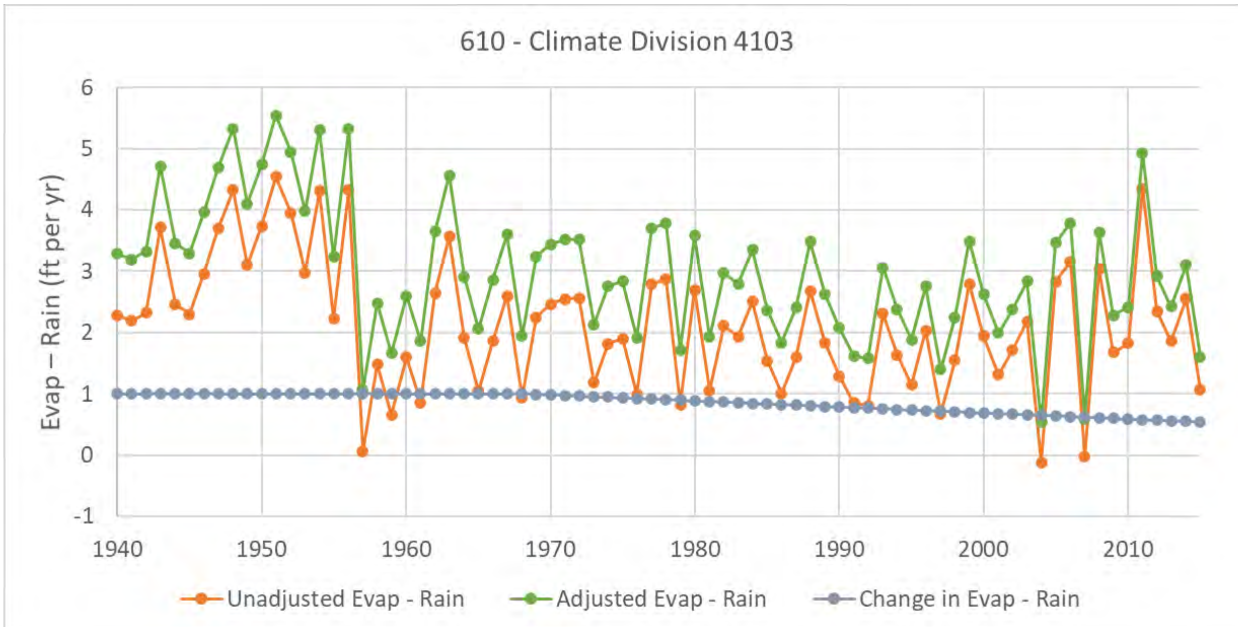


Figure 2-D-34 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 610 for 2070 Conditions

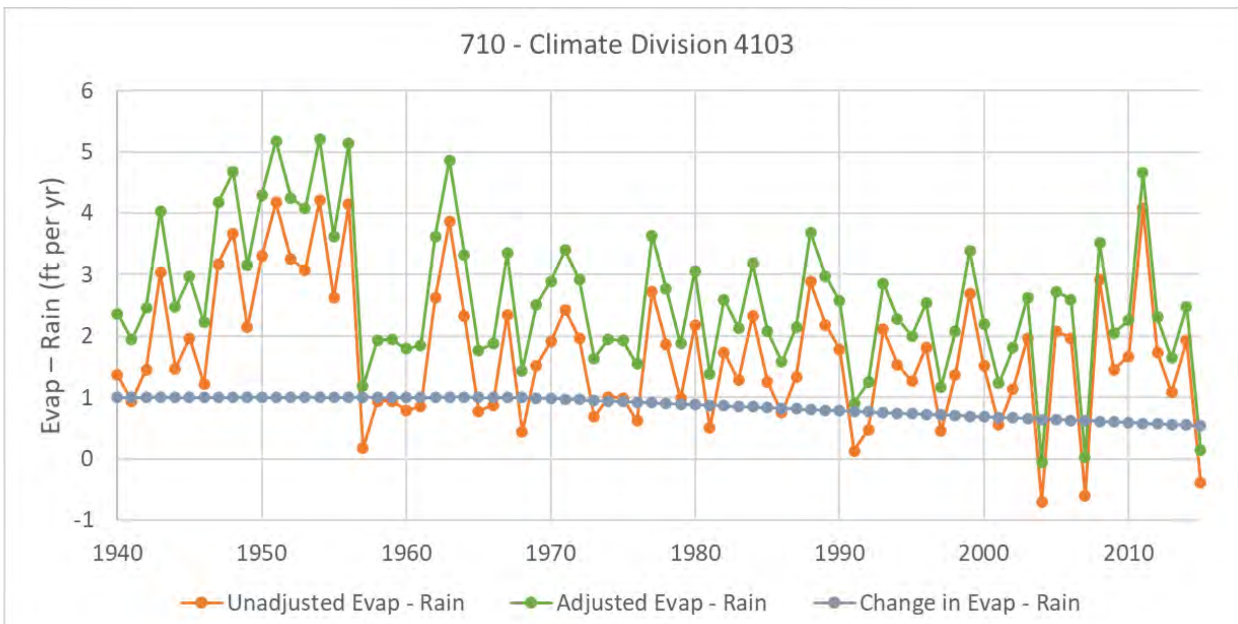


Figure 2-D-35 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 710 for 2070 Conditions

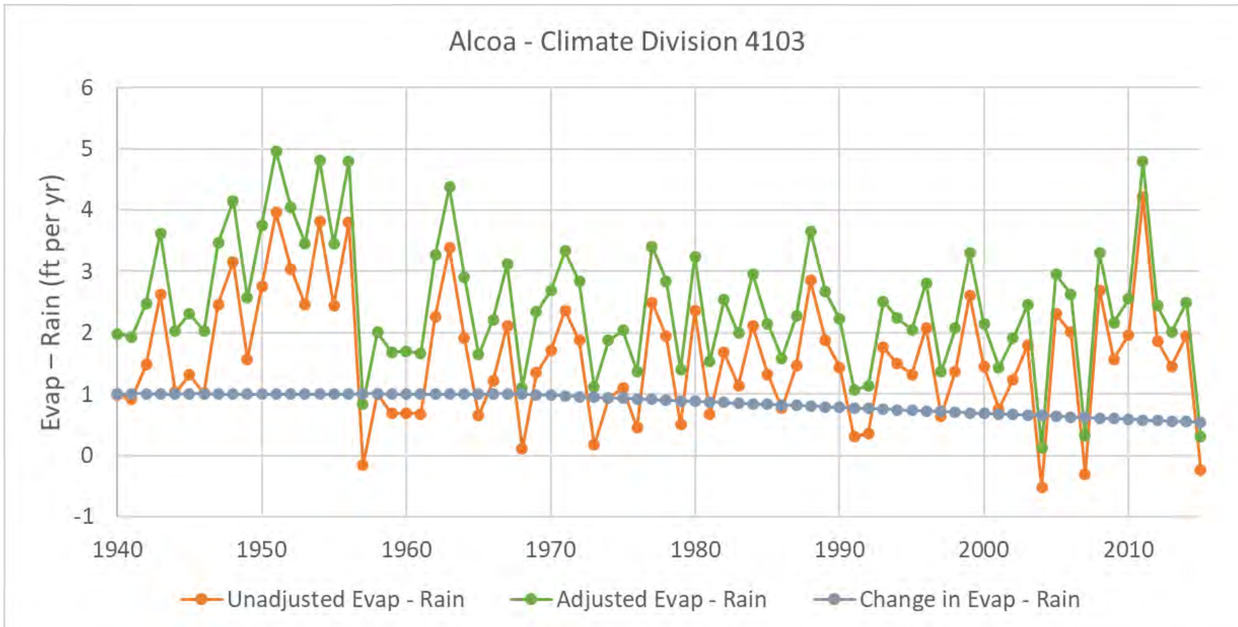


Figure 2-D-36 – Original and Adjusted Naturalized Net Reservoir Evaporation at Alcoa Lake for 2070 Conditions

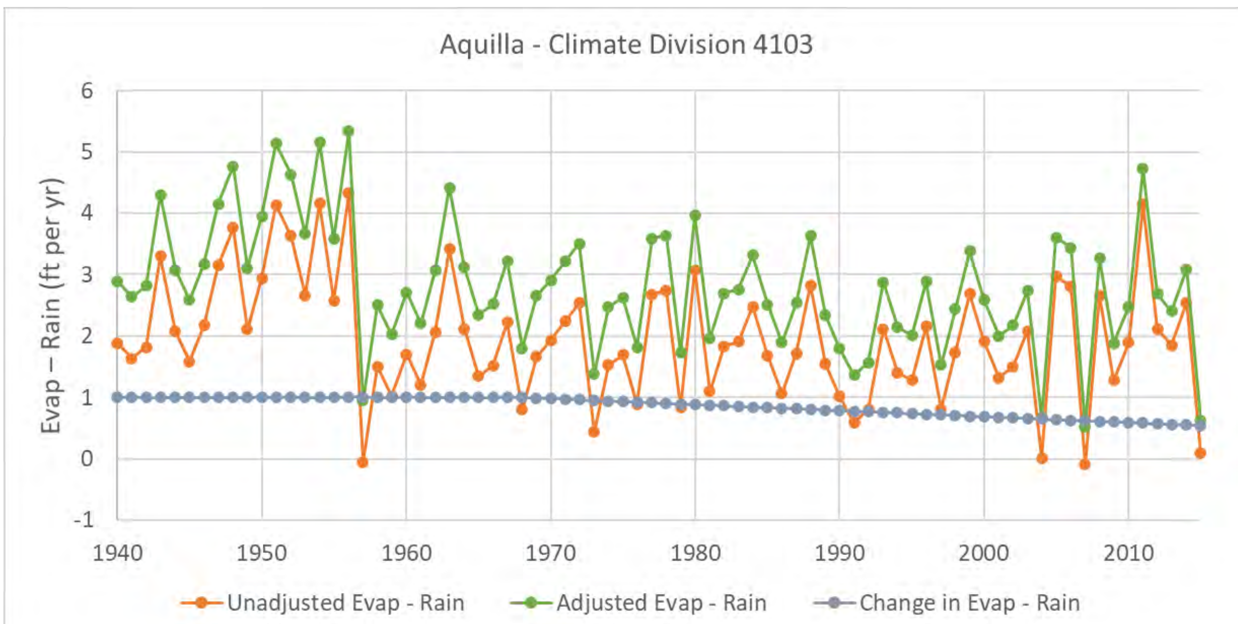


Figure 2-D-37 – Original and Adjusted Naturalized Net Reservoir Evaporation at Aquilla Lake for 2070 Conditions

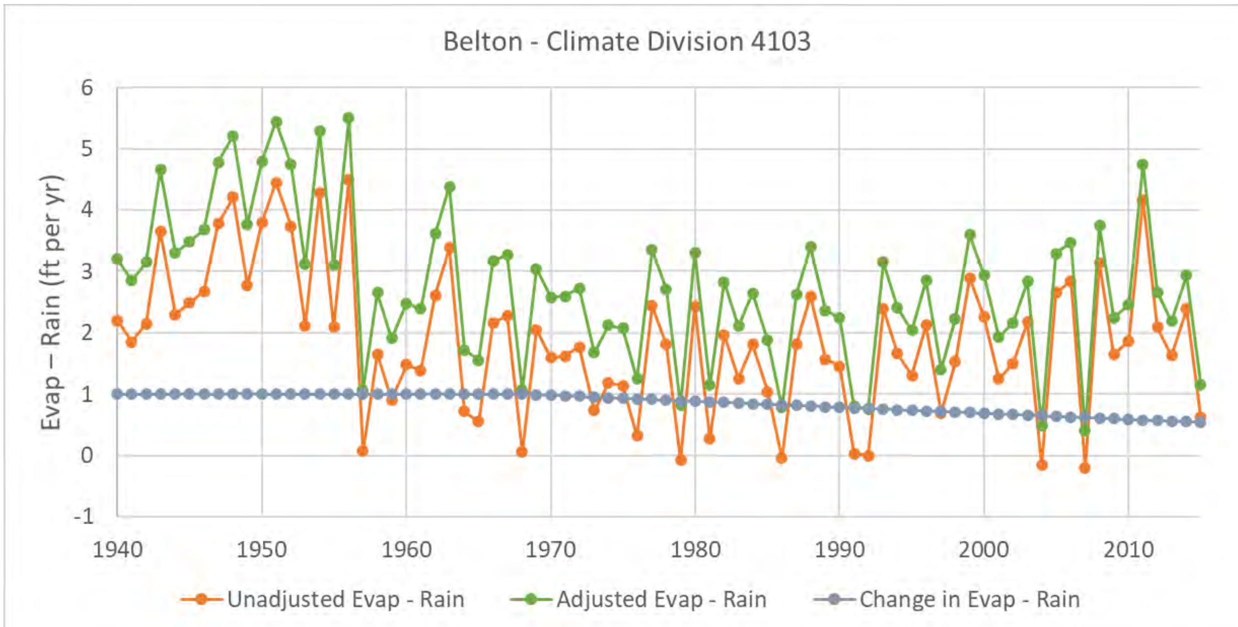


Figure 2-D-38 – Original and Adjusted Naturalized Net Reservoir Evaporation at Belton Lake for 2070 Conditions

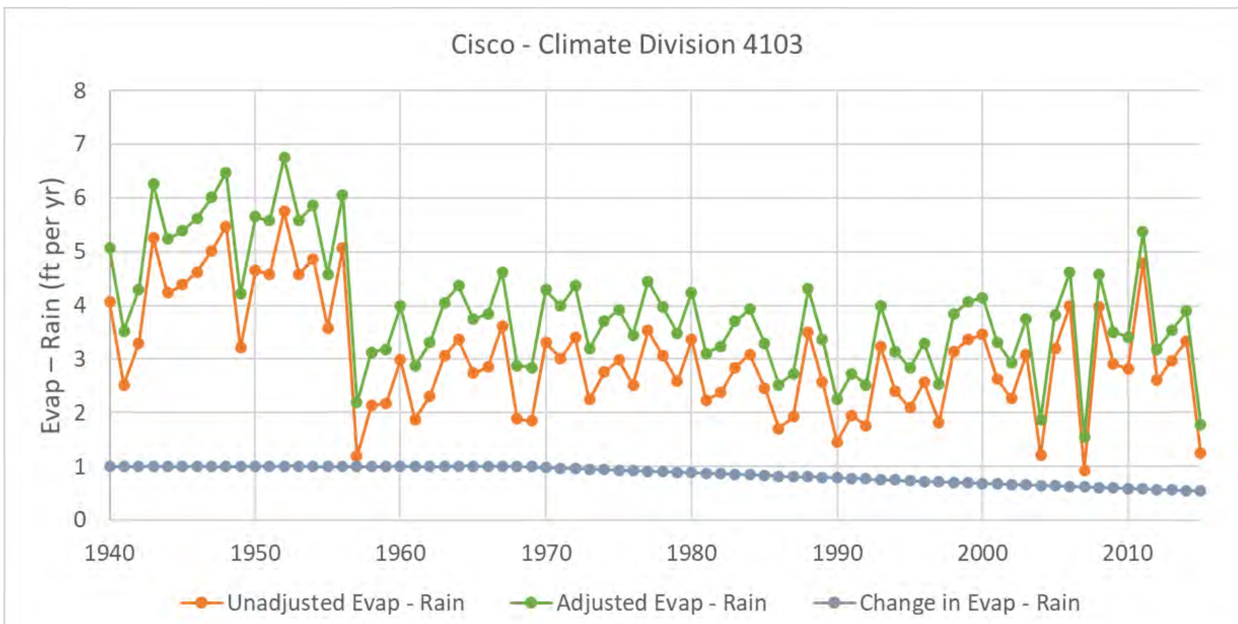


Figure 2-D-39 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Cisco for 2070 Conditions

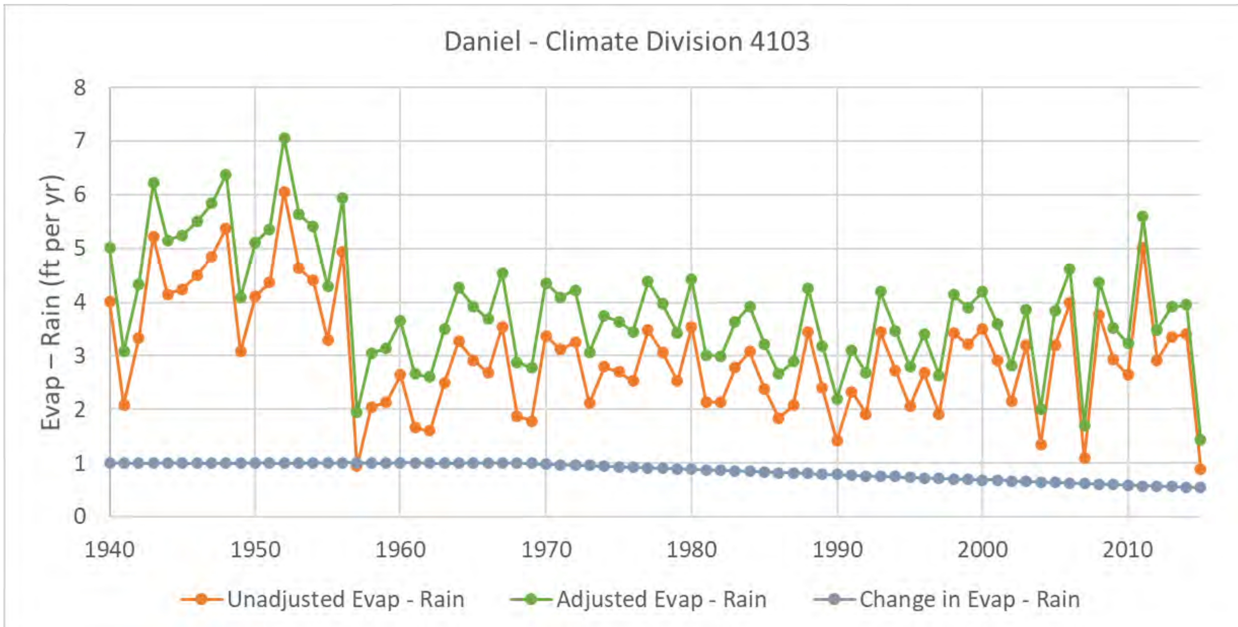


Figure 2-D-40 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Daniel for 2070 Conditions

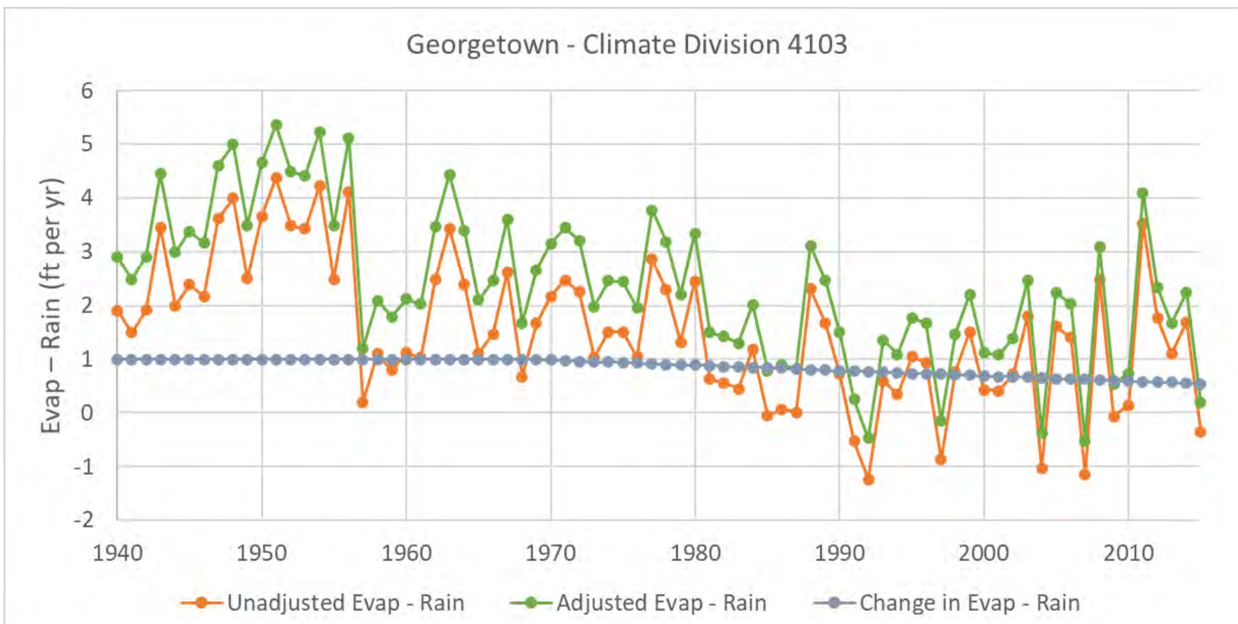


Figure 2-D-41 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Georgetown for 2070 Conditions

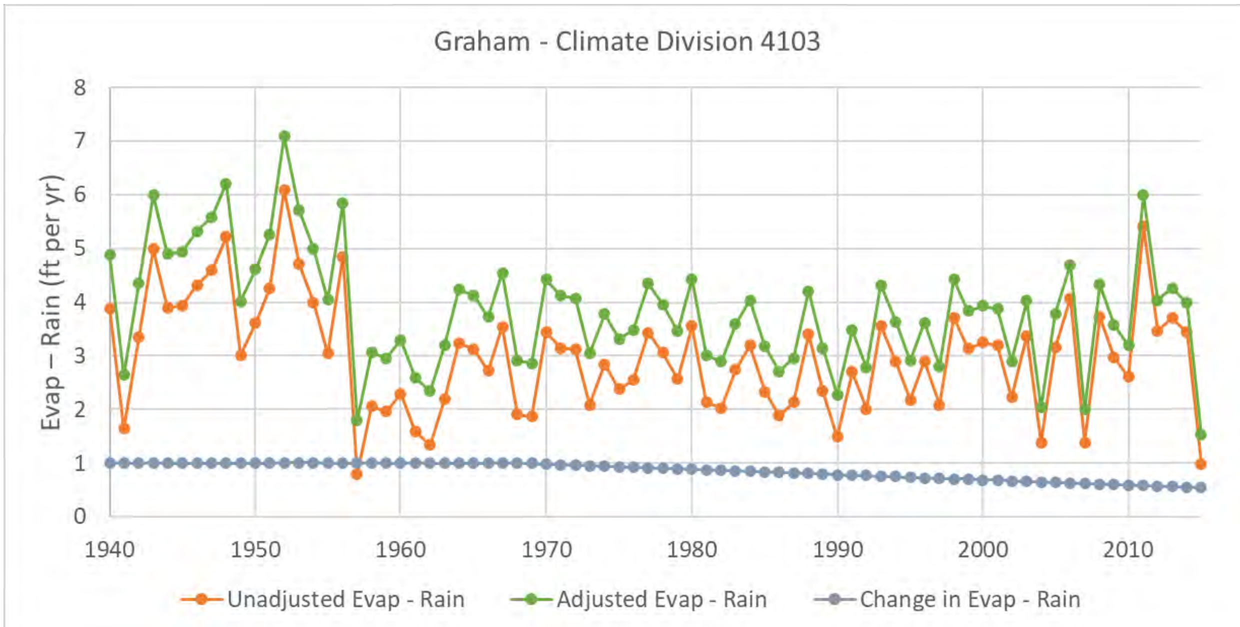


Figure 2-D-42 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Graham for 2070 Conditions

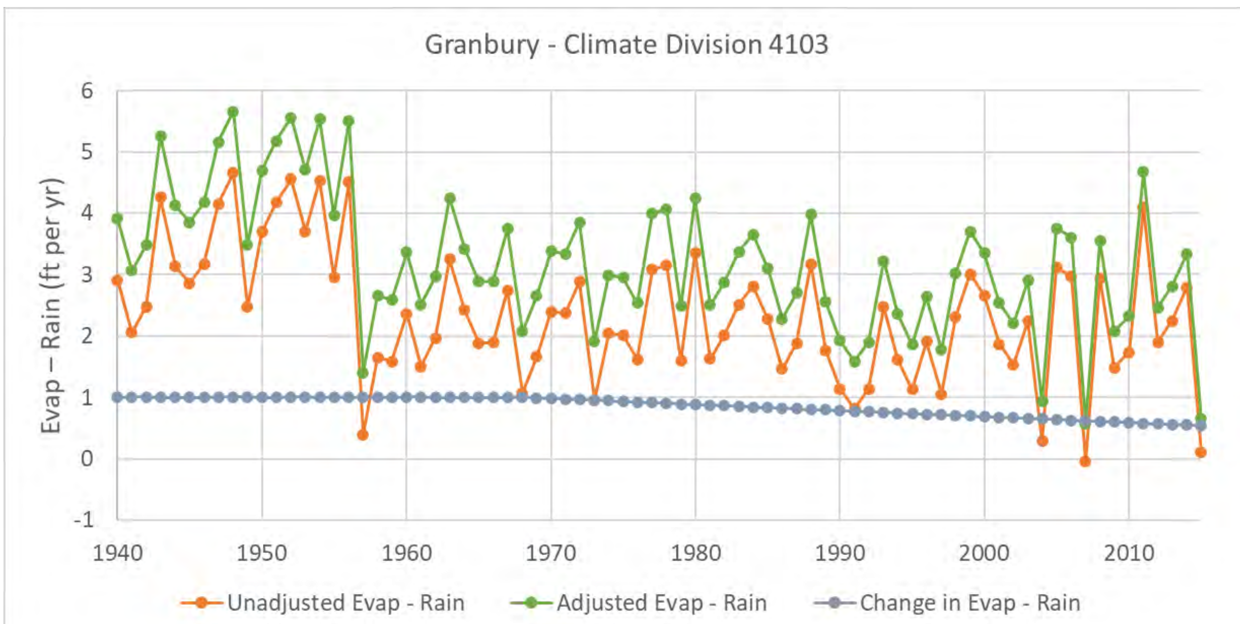


Figure 2-D-43 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Granbury for 2070 Conditions

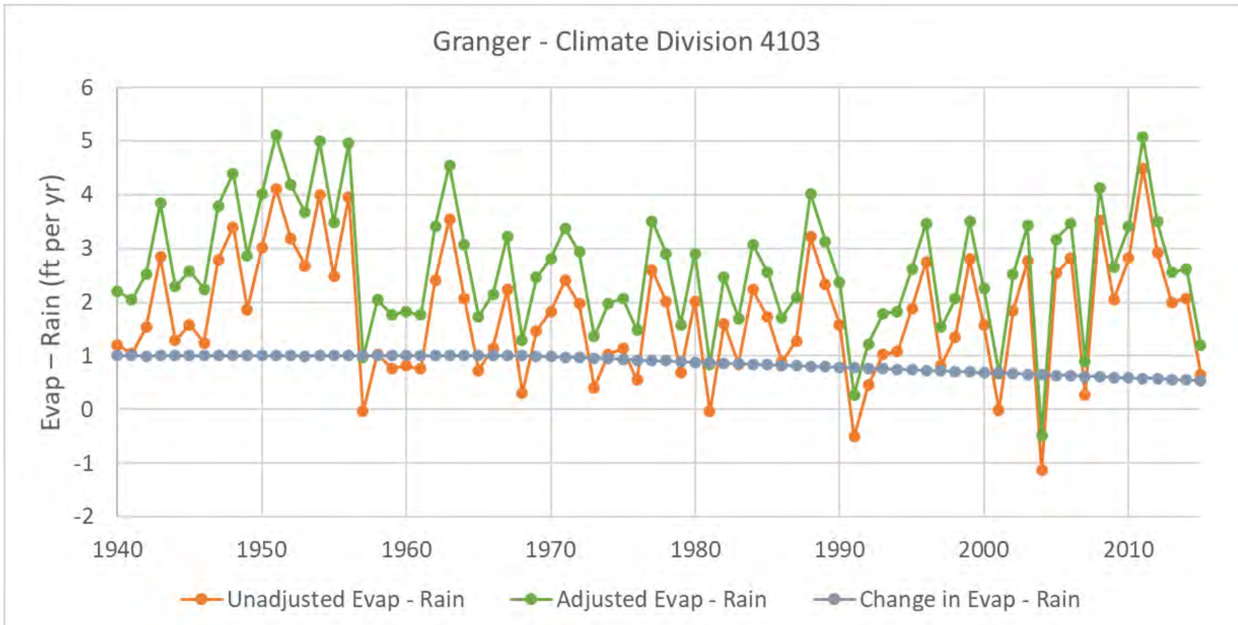


Figure 2-D-44 – Original and Adjusted Naturalized Net Reservoir Evaporation at Granger Lake for 2070 Conditions

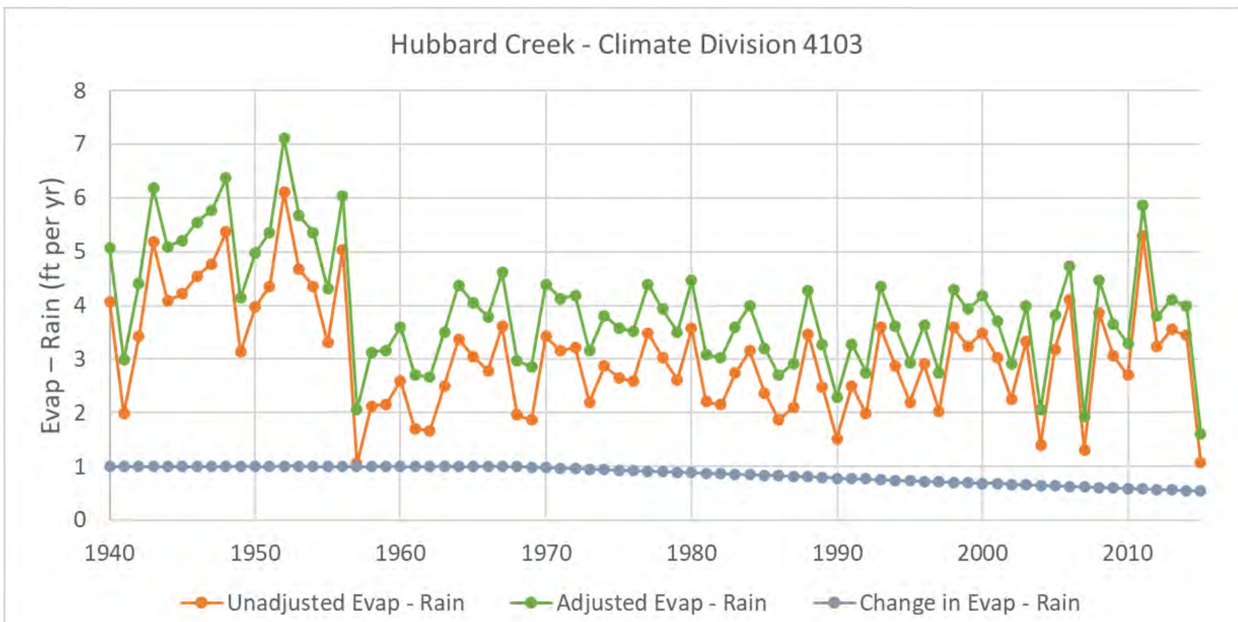


Figure 2-D-45 – Original and Adjusted Naturalized Net Reservoir Evaporation at Hubbard Creek Lake for 2070 Conditions

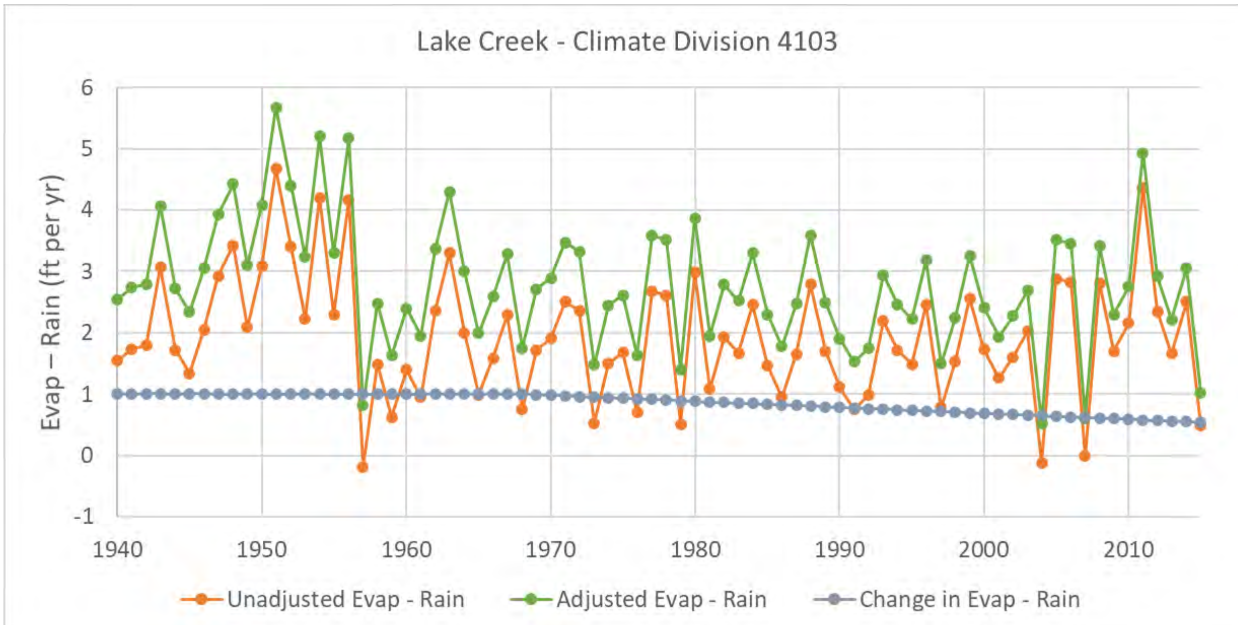


Figure 2-D-46 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Creek Reservoir for 2070 Conditions

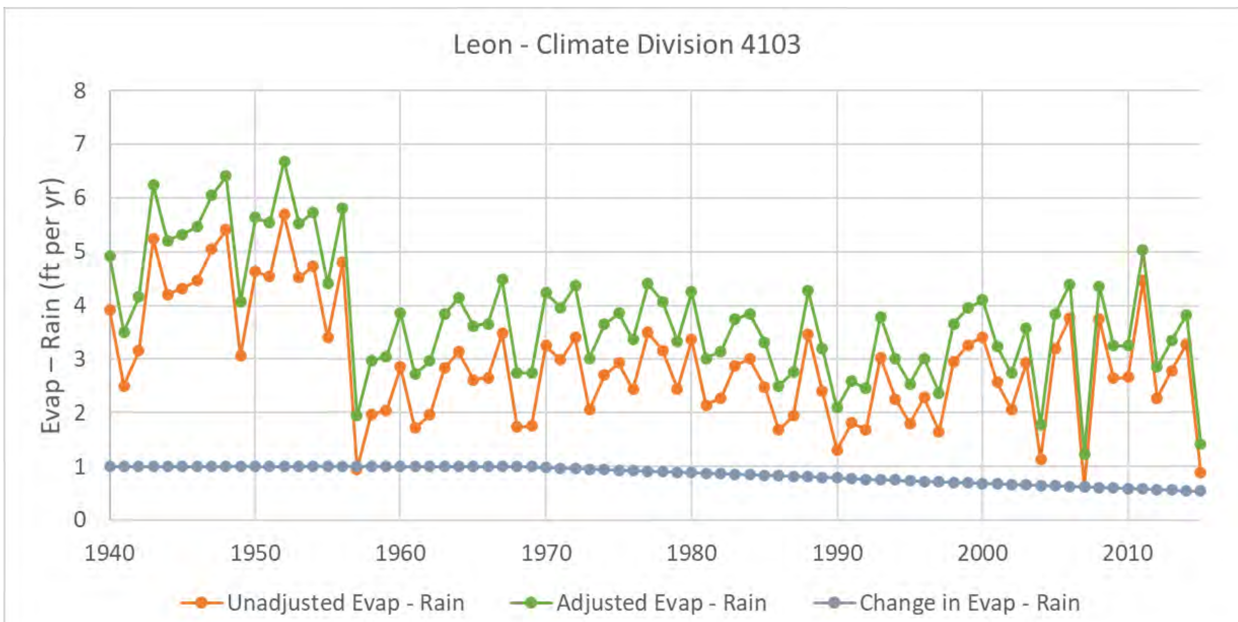


Figure 2-D-47 – Original and Adjusted Naturalized Net Reservoir Evaporation at Leon Reservoir for 2070 Conditions

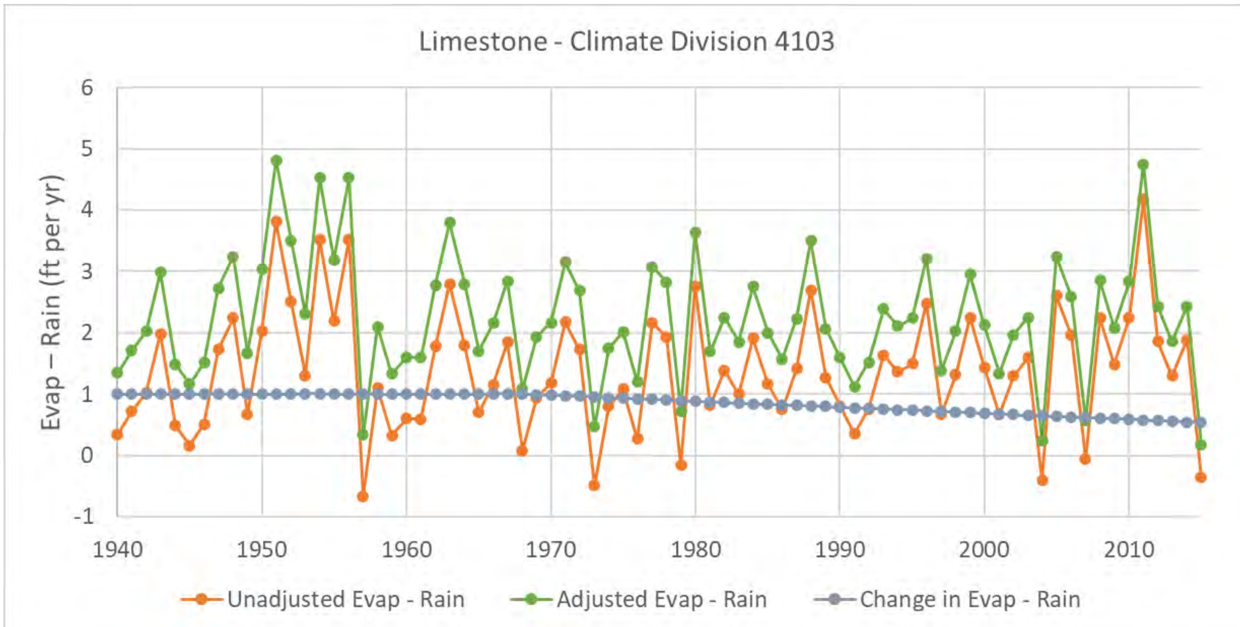


Figure 2-D-48 – Original and Adjusted Naturalized Net Reservoir Evaporation at Leon Reservoir for 2070 Conditions

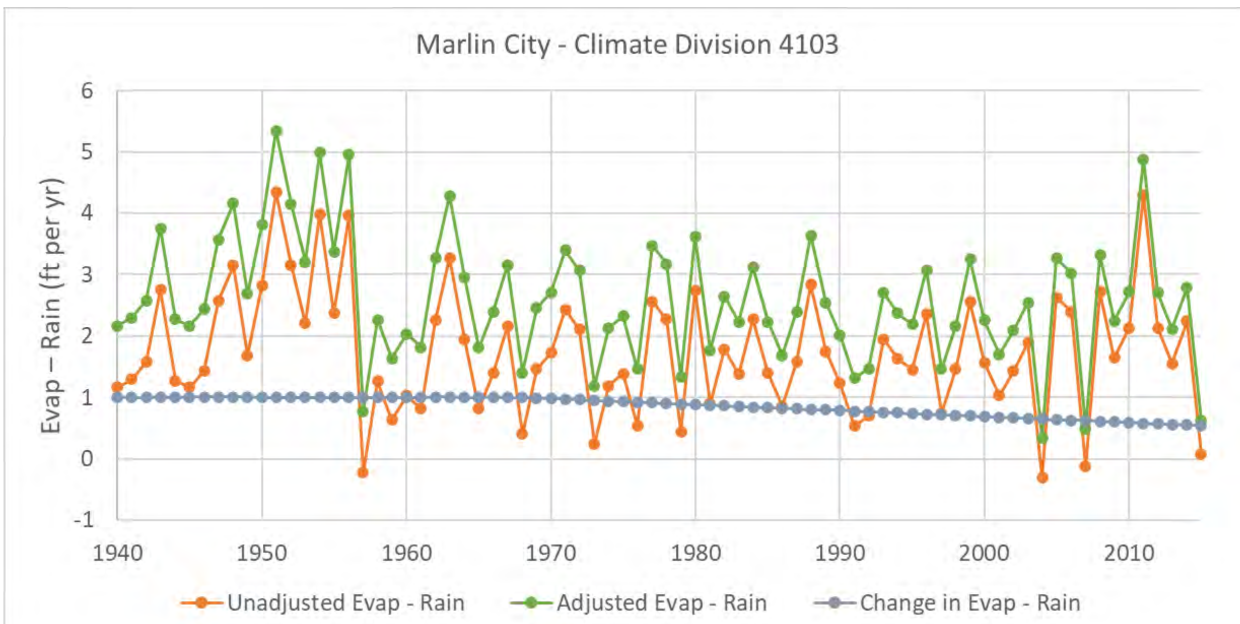


Figure 2-D-49 – Original and Adjusted Naturalized Net Reservoir Evaporation at Marlin City Lake for 2070 Conditions

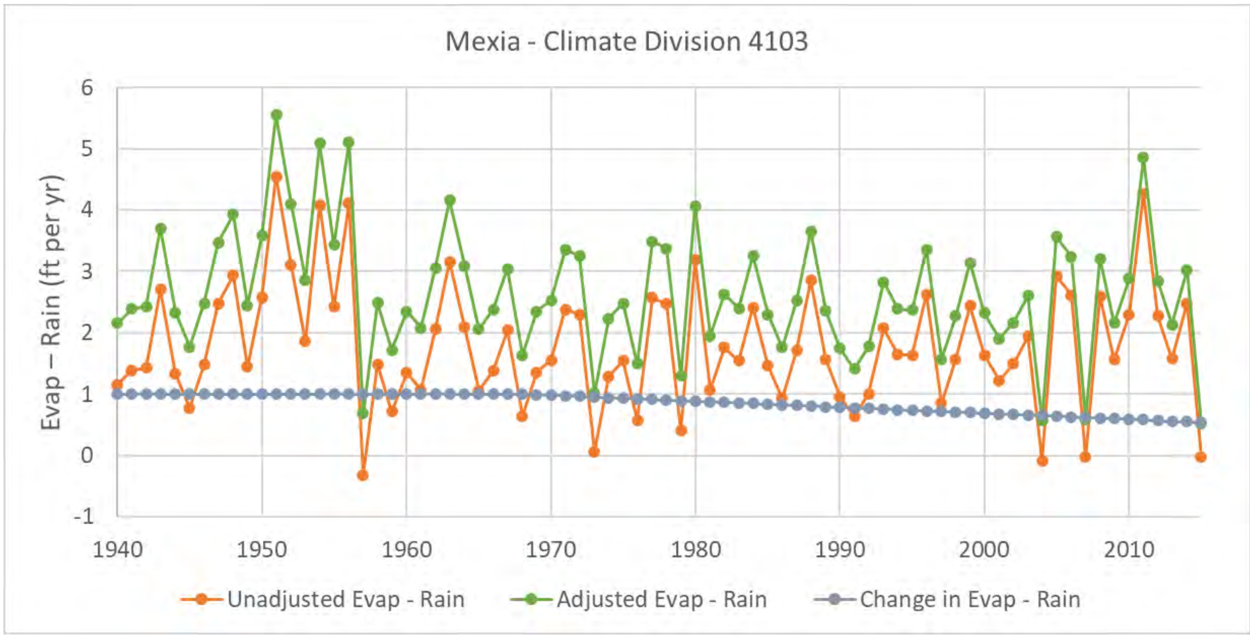


Figure 2-D-50 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Mexia for 2070 Conditions

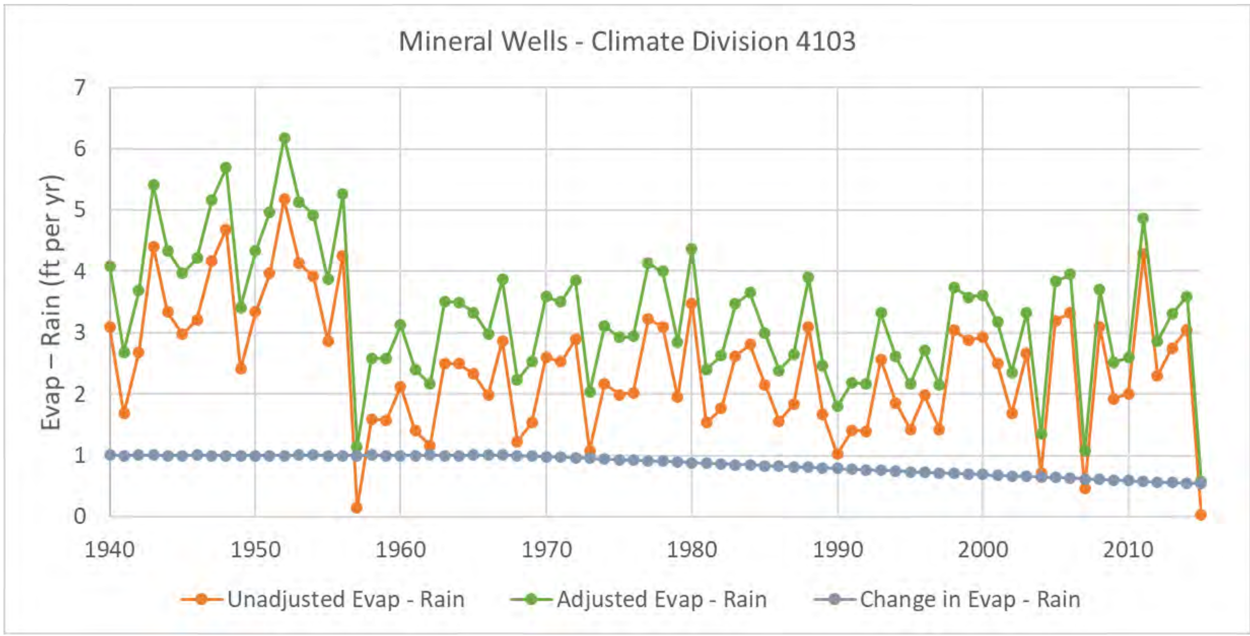


Figure 2-D-51 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Mineral Wells for 2070 Conditions

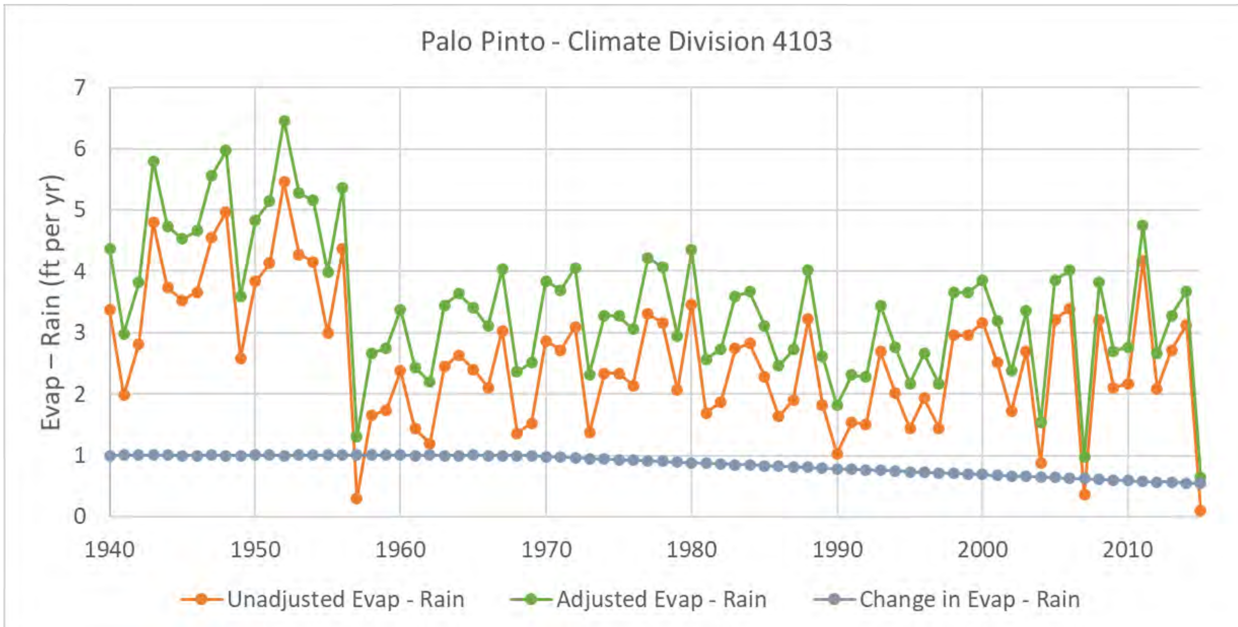


Figure 2-D-52 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Palo Pinto for 2070 Conditions

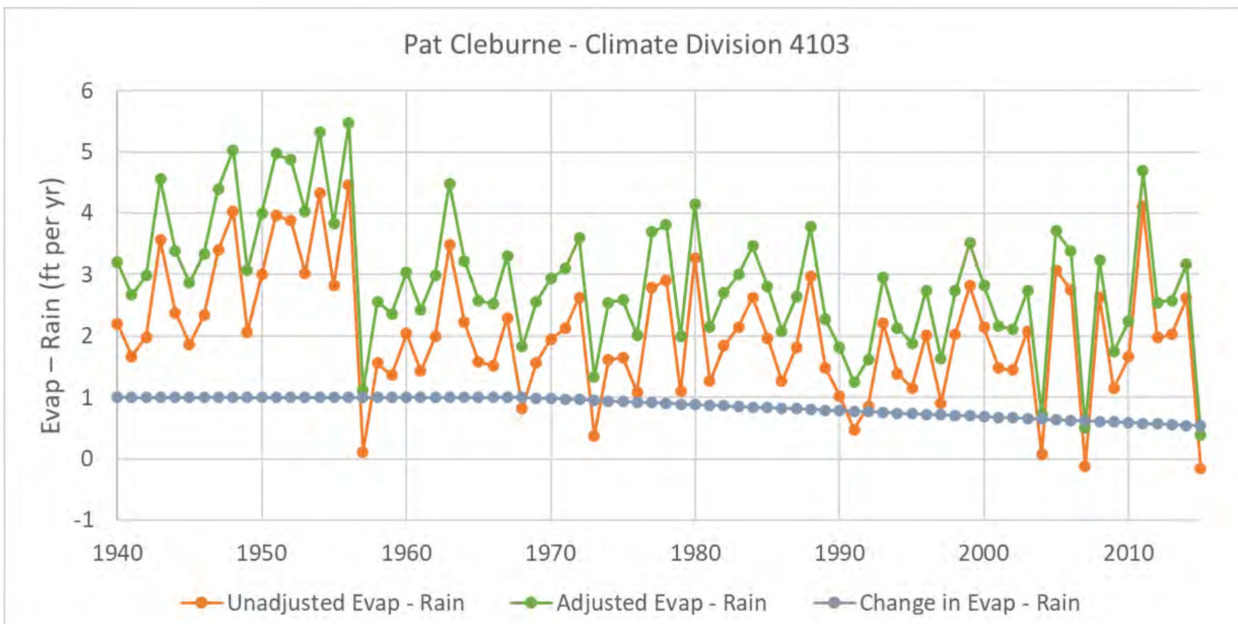


Figure 2-D-53 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Pat Cleburne for 2070 Conditions

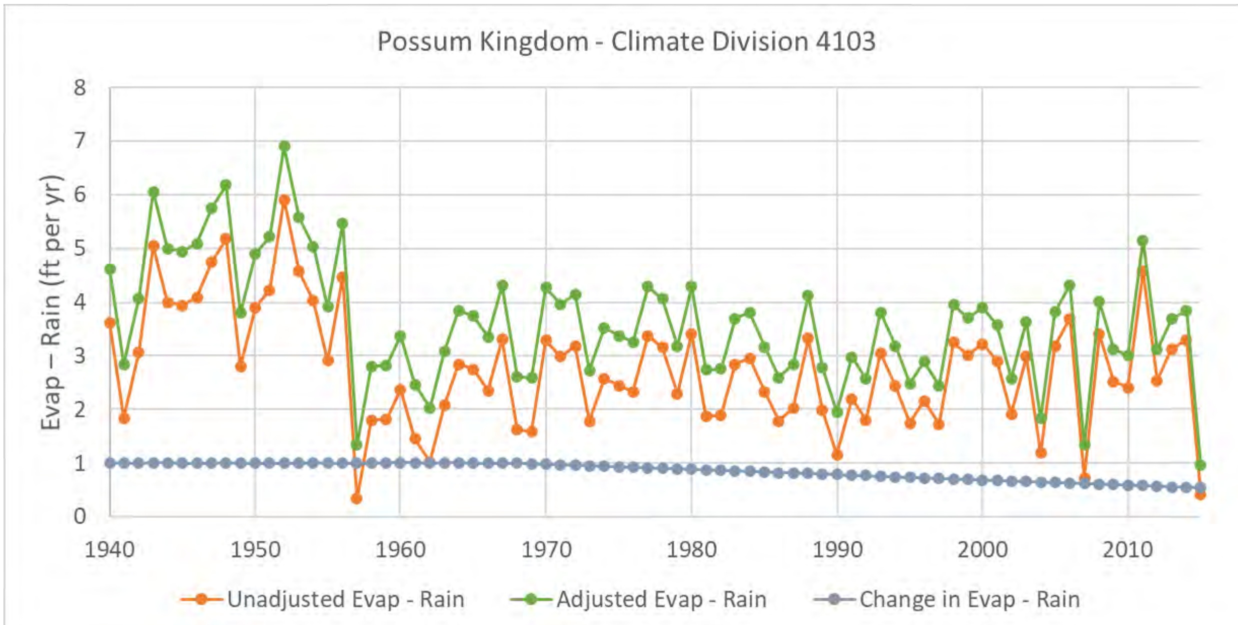


Figure 2-D-54 – Original and Adjusted Naturalized Net Reservoir Evaporation at Possum Kingdom Lake for 2070 Conditions

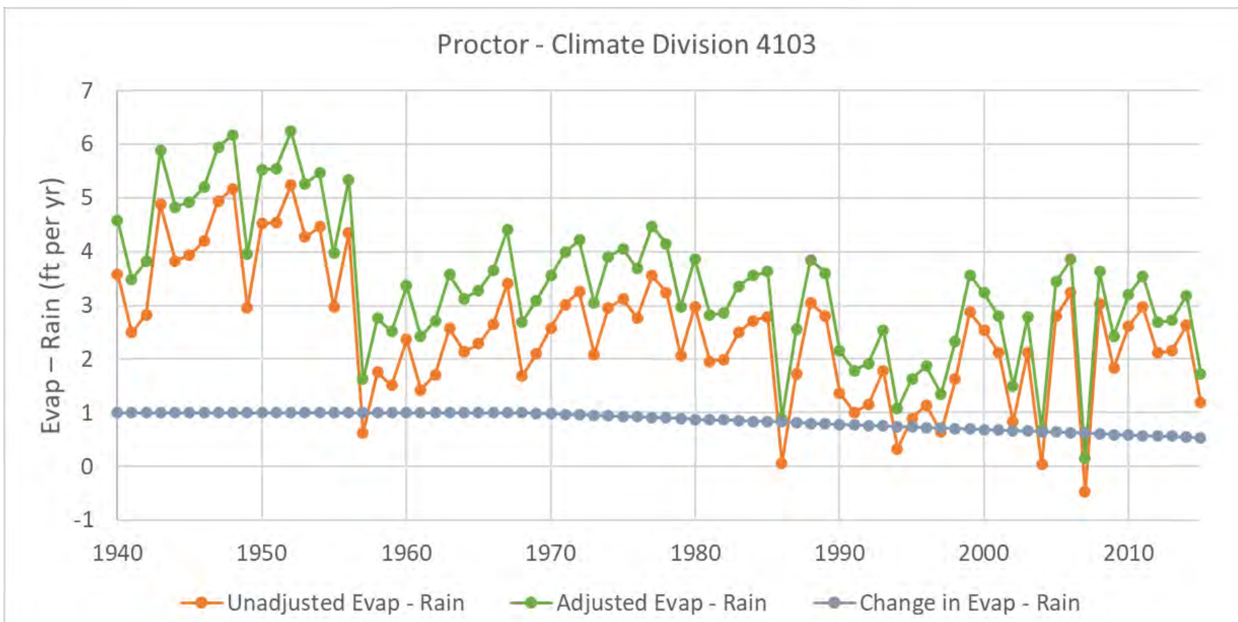


Figure 2-D-55 – Original and Adjusted Naturalized Net Reservoir Evaporation at Proctor Lake for 2070 Conditions

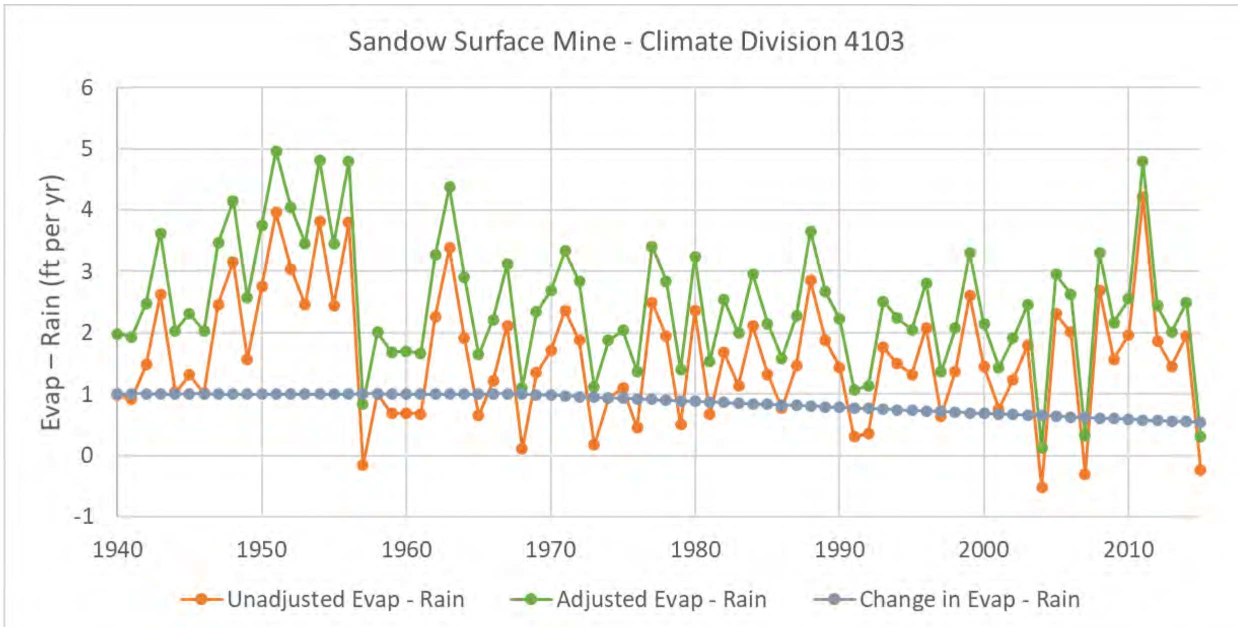


Figure 2-D-56 – Original and Adjusted Naturalized Net Reservoir Evaporation at Sandow Surface Mine for 2070 Conditions

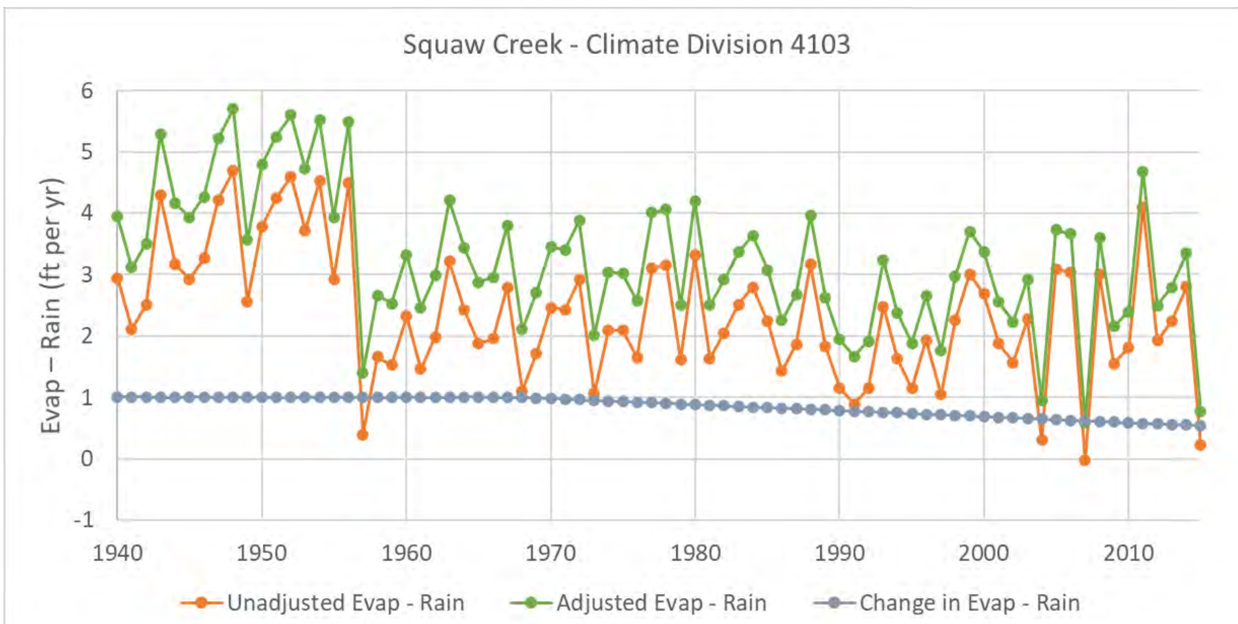


Figure 2-D-57 – Original and Adjusted Naturalized Net Reservoir Evaporation at Squaw Creek Reservoir for 2070 Conditions

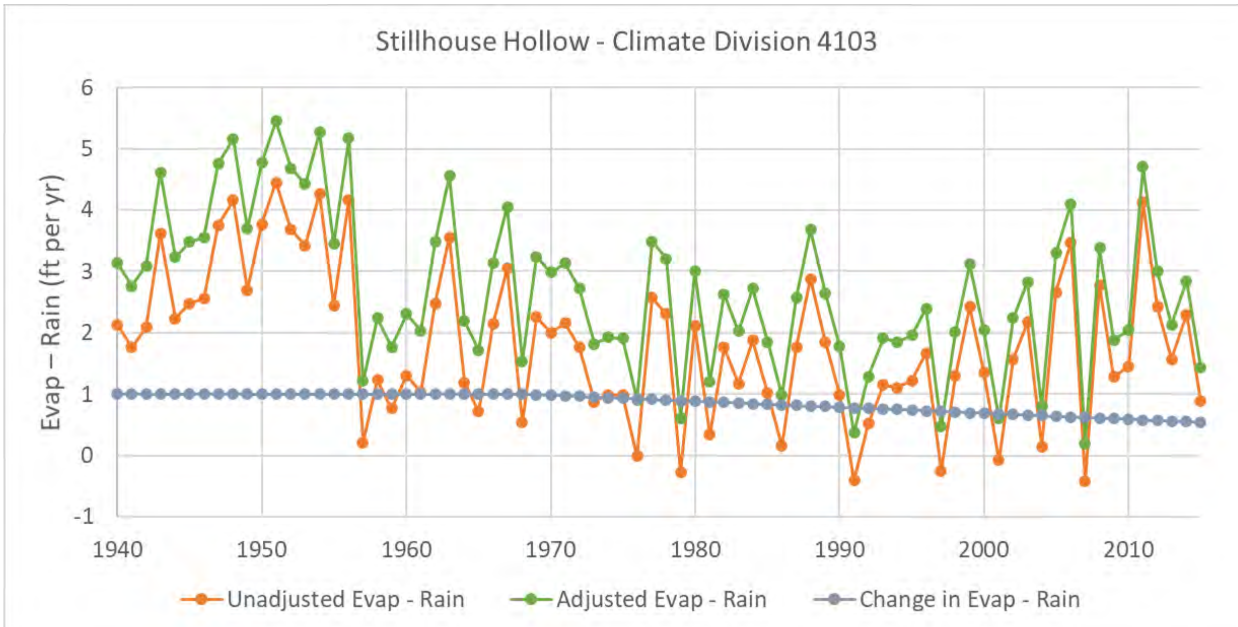


Figure 2-D-58 – Original and Adjusted Naturalized Net Reservoir Evaporation at Stillhouse Hollow Lake for 2070 Conditions

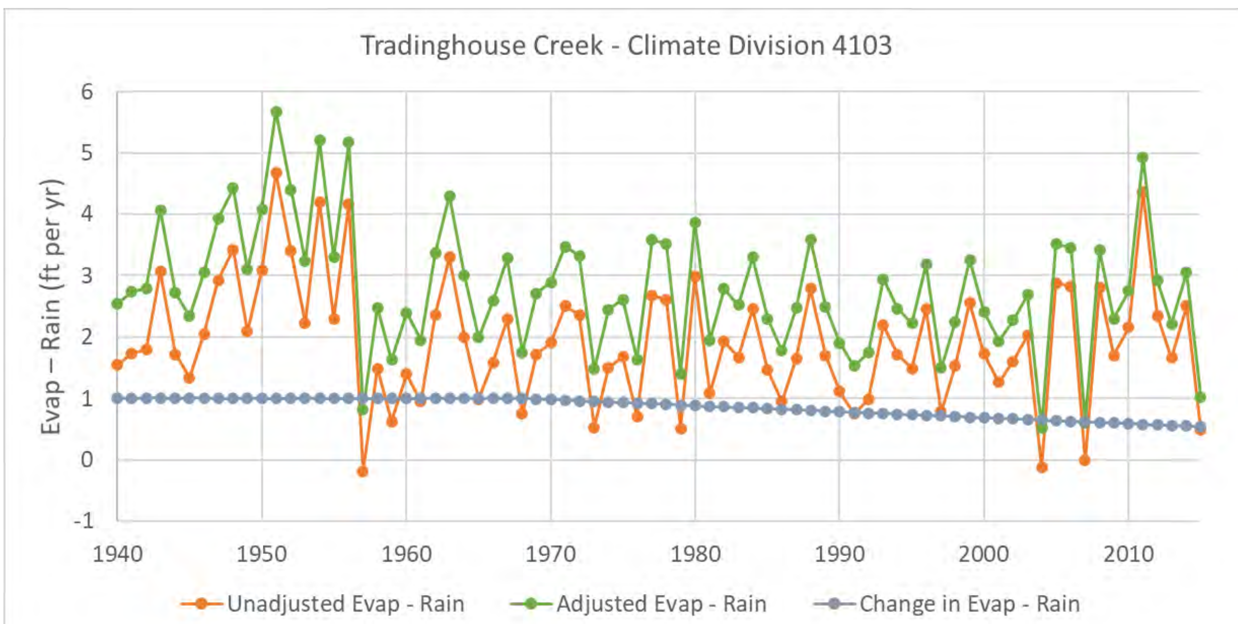


Figure 2-D-59 – Original and Adjusted Naturalized Net Reservoir Evaporation at Tradinghouse Creek Reservoir for 2070 Conditions

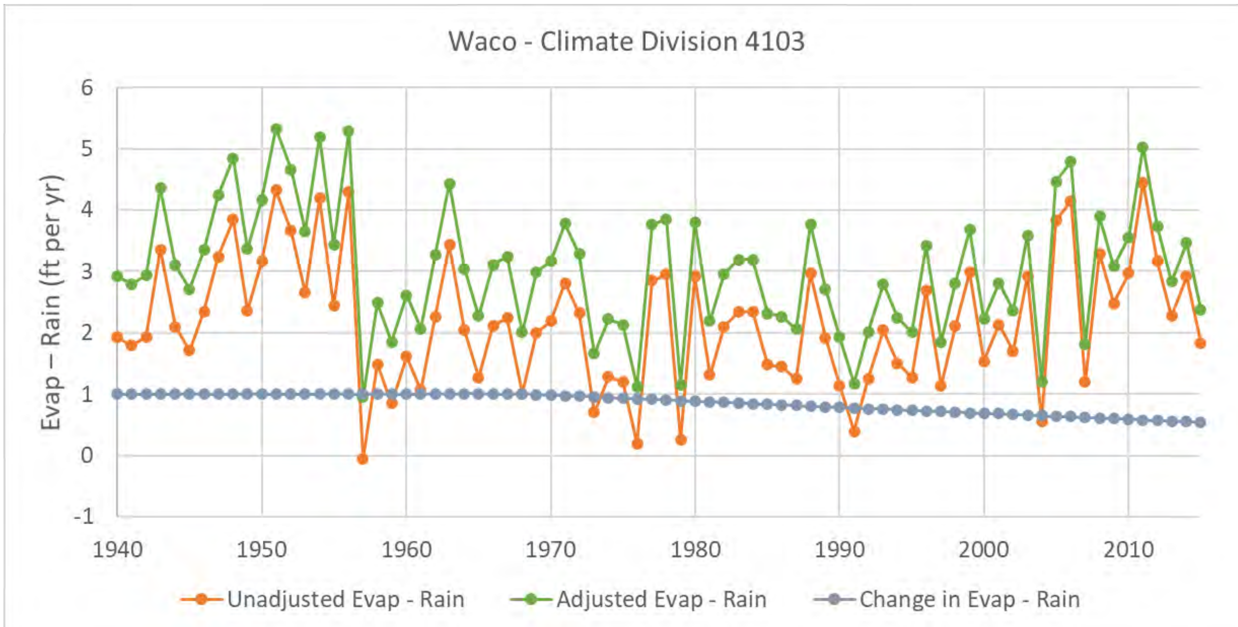


Figure 2-D-60 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Waco for 2070 Conditions

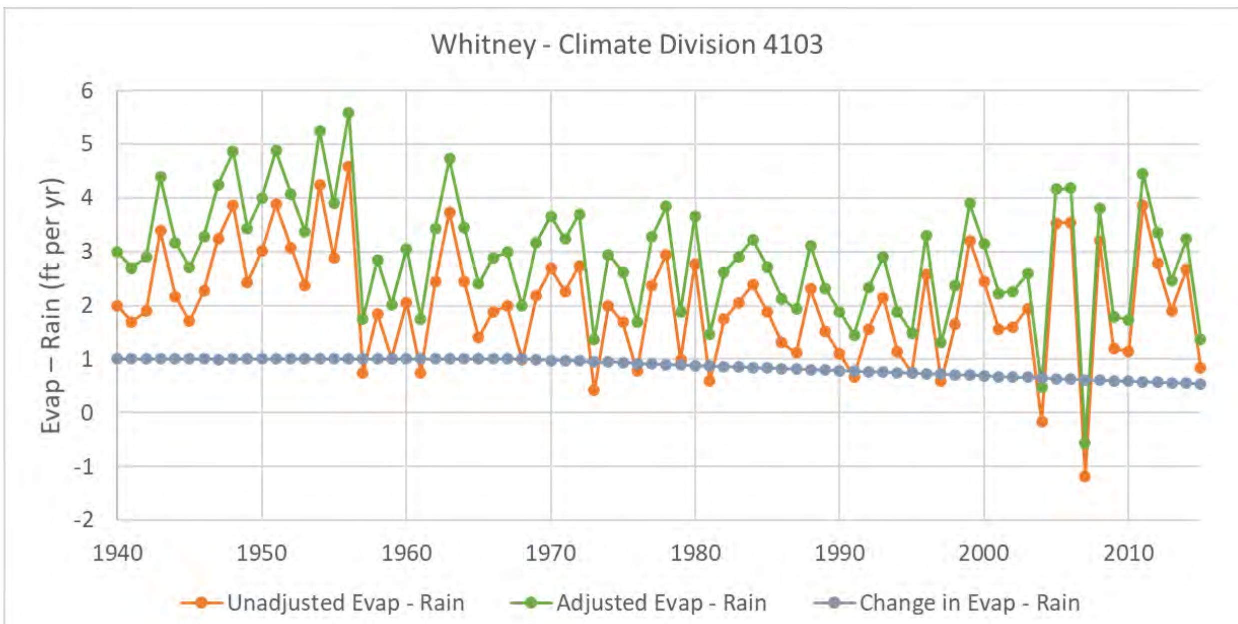


Figure 2-D-61 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Whitney for 2070 Conditions

Climate Division 4104

Table 2-D-10 – Summary of Variable Trend Results in Climate Division 4104

	P				T				E			
	τ	p	Slope	Intercept	τ	p	Slope	Intercept	τ	p	Slope	Intercept
Annual	0.10	0.18	0.00	-3.73	**0.46**	**0.00**	0.04	-21.37	0.28	0.00	0.01	-8.85
Winter	0.05	0.50	0.00	-2.09	0.23	0.01	0.05	-48.82	0.30	0.00	0.01	-13.81
Spring	-0.01	0.85	0.00	3.52	0.29	0.00	0.03	1.49	0.10	0.28	0.00	-4.10
Summer	0.11	0.14	0.01	-14.73	0.37	0.00	0.05	-14.37	0.21	0.03	0.01	-10.63
Dry Winter	-0.13	0.32	-0.01	19.72	0.39	0.05	0.08	-100.28	0.60	0.00	0.02	-30.88
Average Winter	0.02	0.90	0.00	2.39	0.12	0.50	0.04	-34.18	0.24	0.14	0.01	-11.30
Wet Winter	0.13	0.34	0.01	-5.90	0.12	0.48	0.04	-26.41	0.04	0.83	0.00	-1.57
Dry Spring	-0.03	0.87	0.00	-3.42	0.31	0.14	0.03	1.45	0.10	0.66	0.01	-8.08
Average Spring	-0.18	0.16	-0.02	46.00	0.25	0.09	0.03	8.72	0.12	0.41	0.01	-8.77
Wet Spring	0.10	0.50	0.01	-15.85	0.43	0.02	0.04	-3.61	0.13	0.53	0.00	4.47
Dry Summer	0.24	0.09	0.02	-29.16	0.26	0.20	0.04	-6.43	0.31	0.11	0.01	-10.98
Average Summer	0.20	0.16	0.02	-35.86	0.16	0.33	0.01	50.23	-0.03	0.86	0.00	4.36
Wet Summer	-0.14	0.30	-0.01	14.79	0.59	0.00	0.07	-67.65	0.33	0.06	0.01	-14.24

Bold text indicates trend used.
Green indicates significance (P-value<=0.05)
Light blue indicates moderate to strong Kendall's tau.

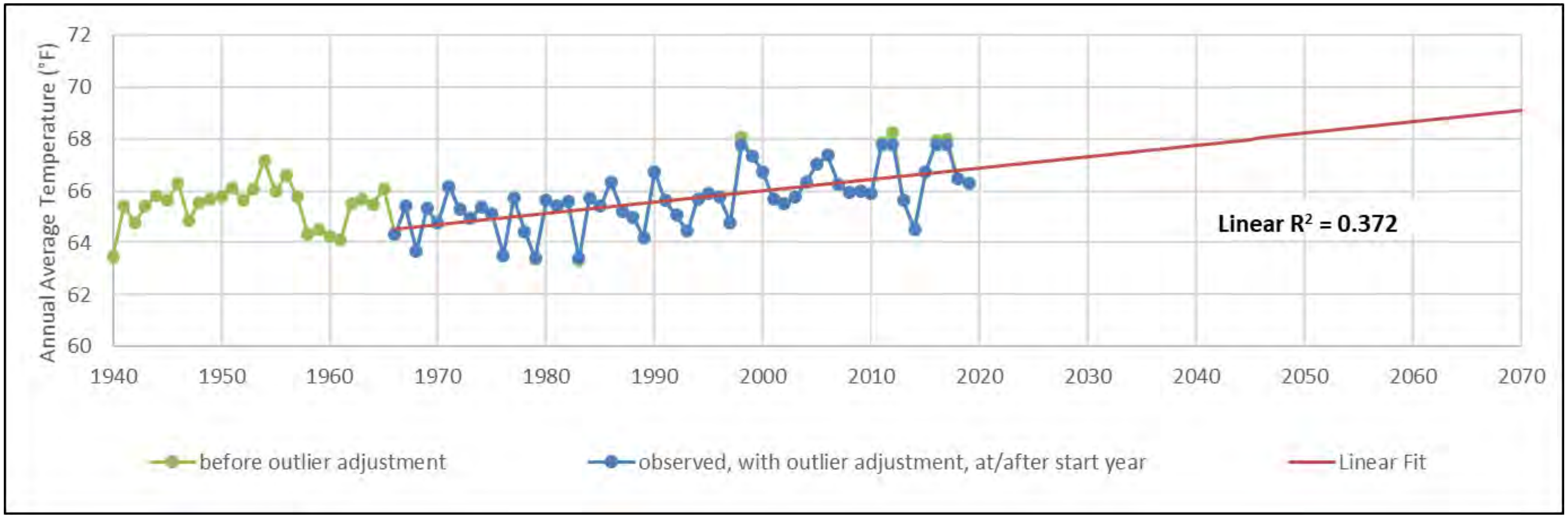


Figure 2-D-62 – Annual Trend for Average Air Temperature in Climate Division 4104

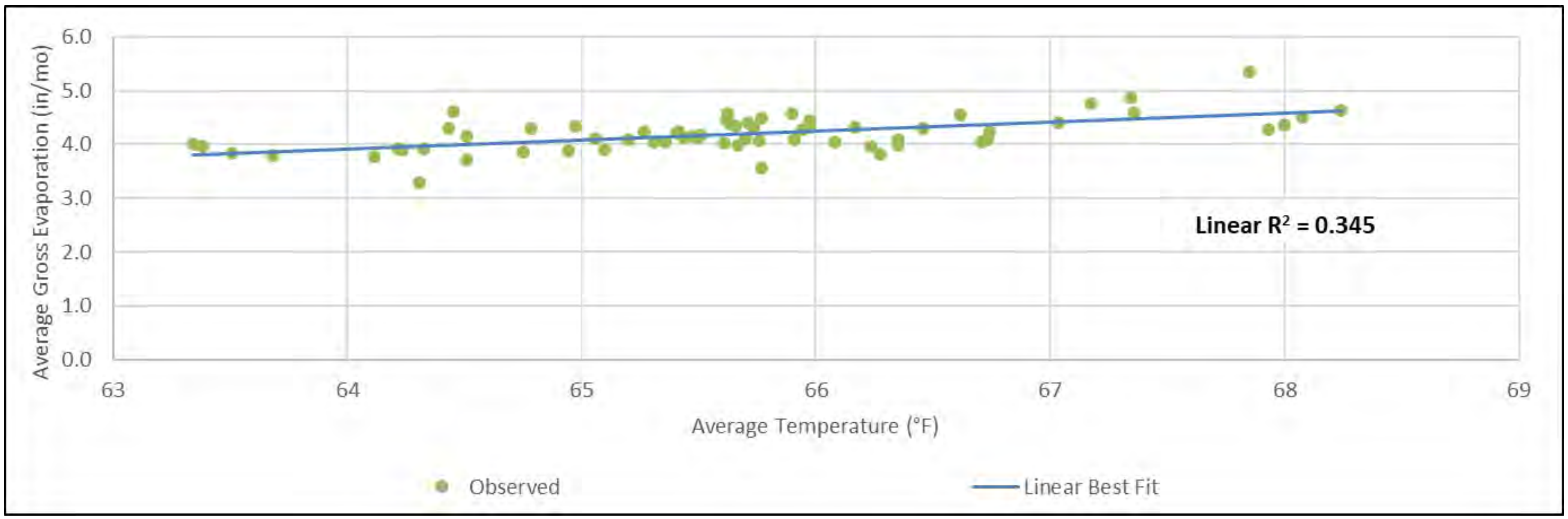


Figure 2-D-63 – Relationship between Annual Average Air Temperature and Gross Evaporation in Climate Division 4104

Changes to Net Reservoir Evaporation for Climate Division 4104

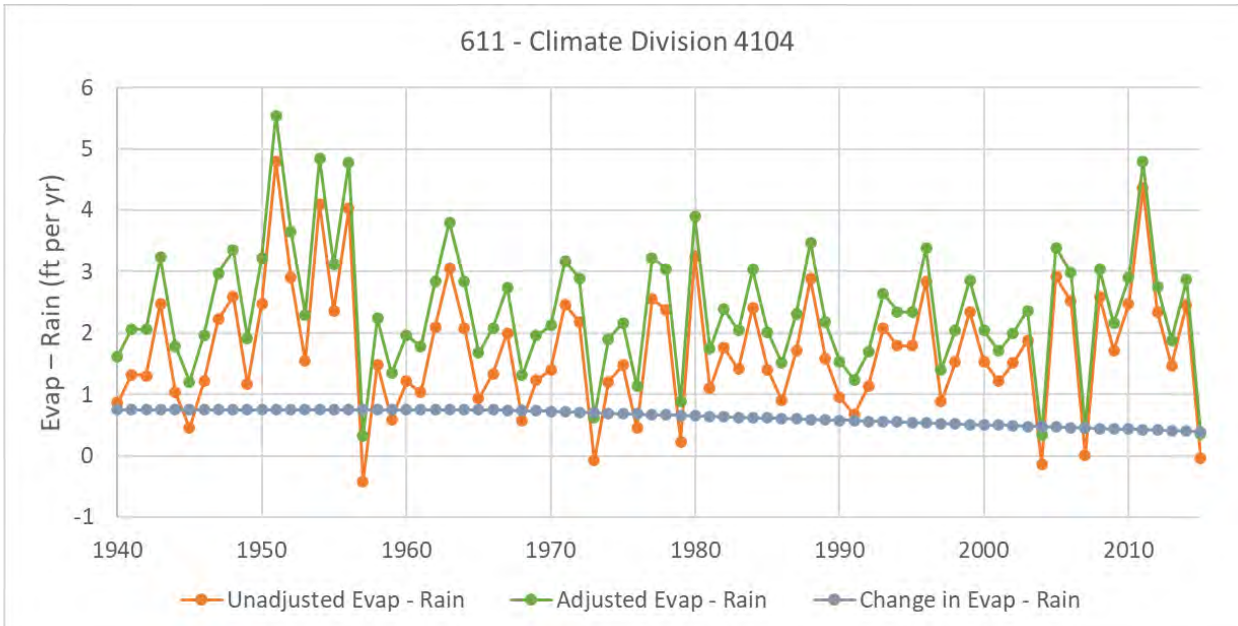


Figure 2-D-64 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 611 for 2070 Conditions

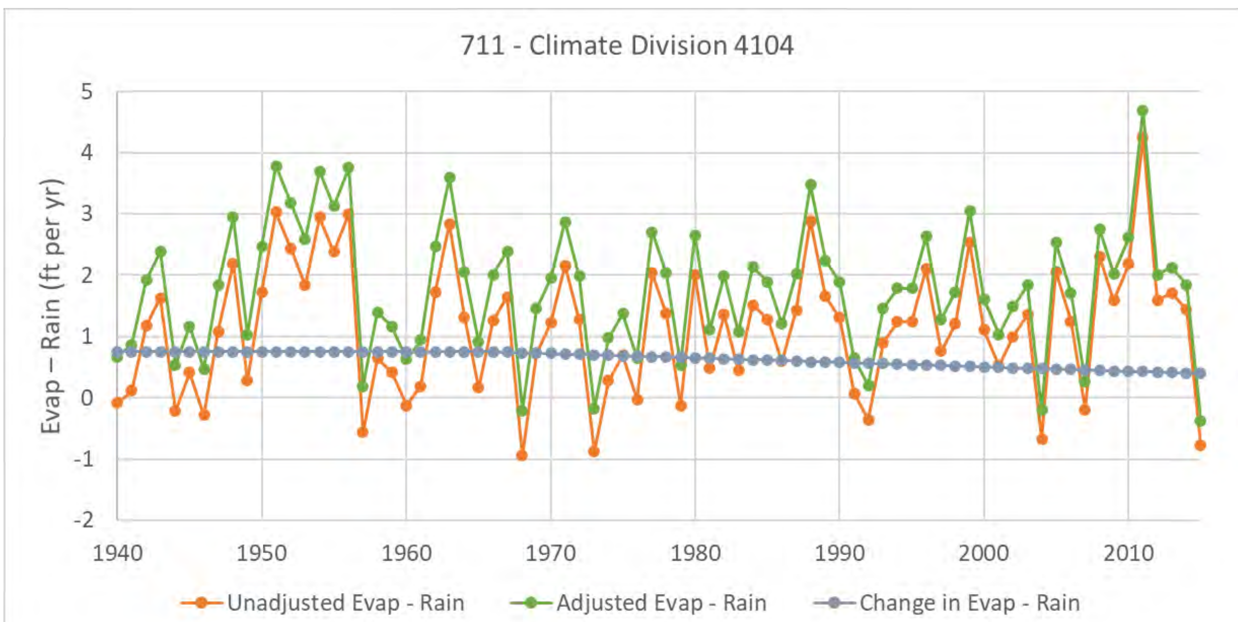


Figure 2-D-65 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 711 for 2070 Conditions

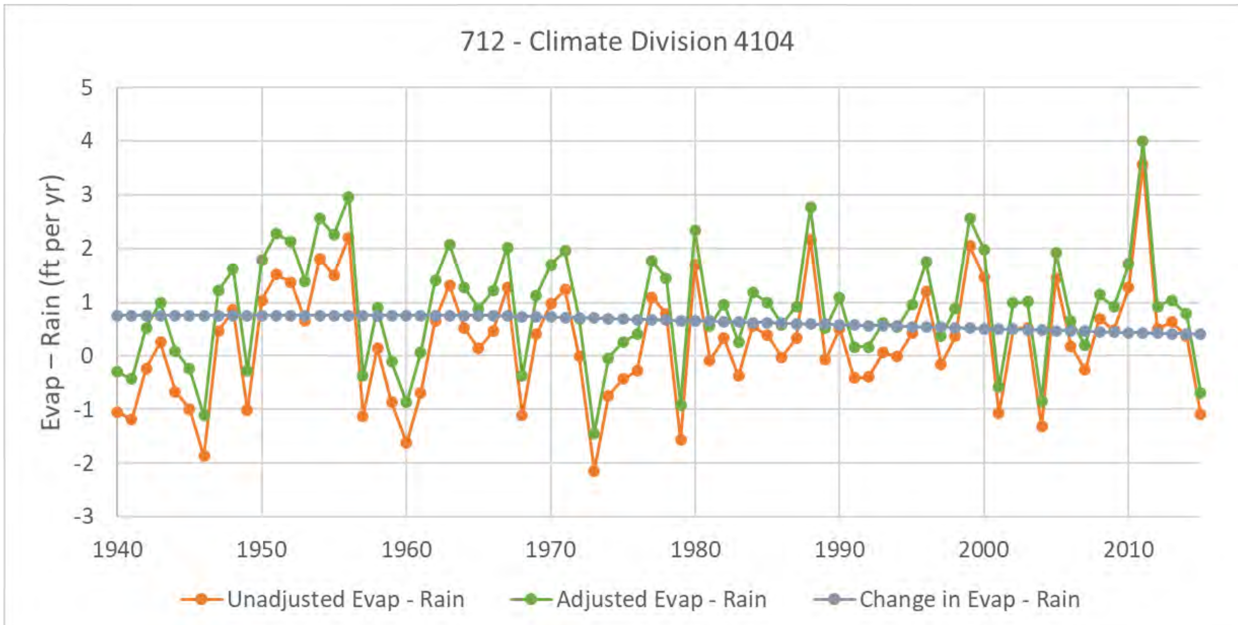


Figure 2-D-66 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 712 for 2070 Conditions

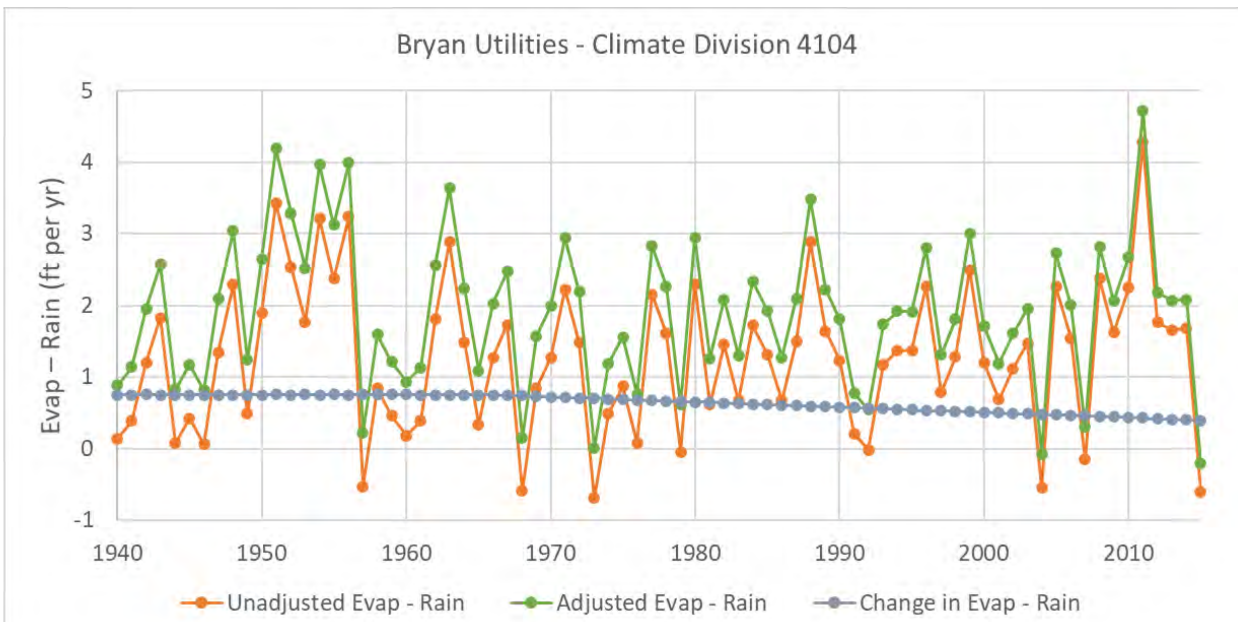


Figure 2-D-67 – Original and Adjusted Naturalized Net Reservoir Evaporation at Bryan Utilities Lake for 2070 Conditions

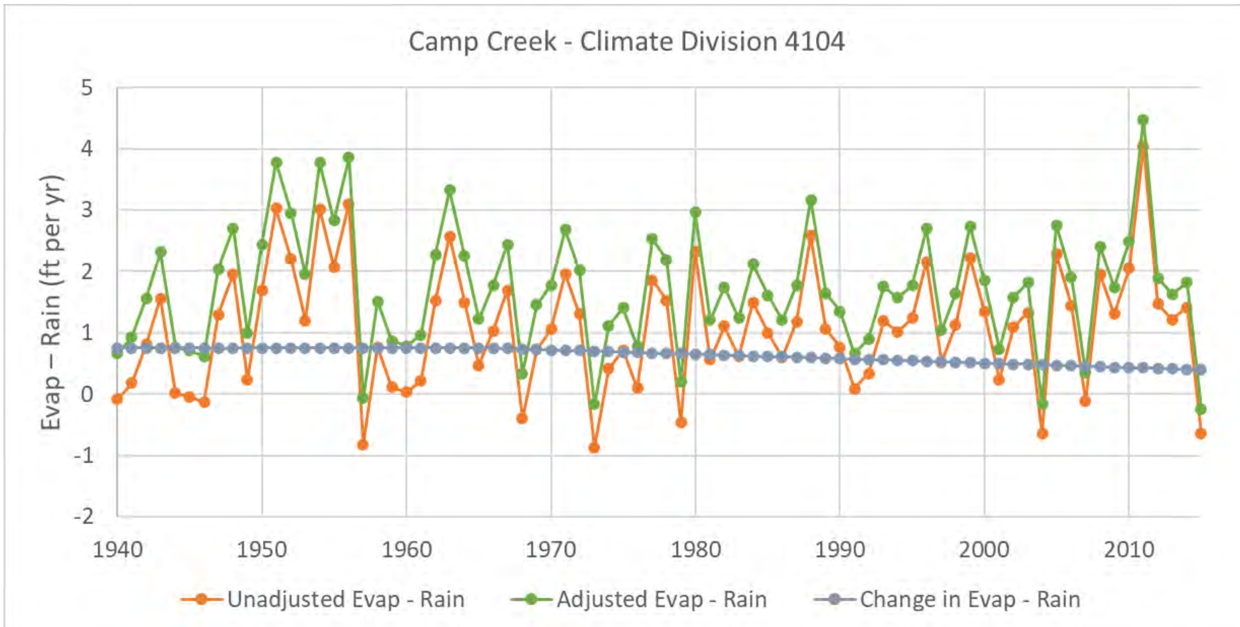


Figure 2-D-68 – Original and Adjusted Naturalized Net Reservoir Evaporation at Camp Creek Lake for 2070 Conditions

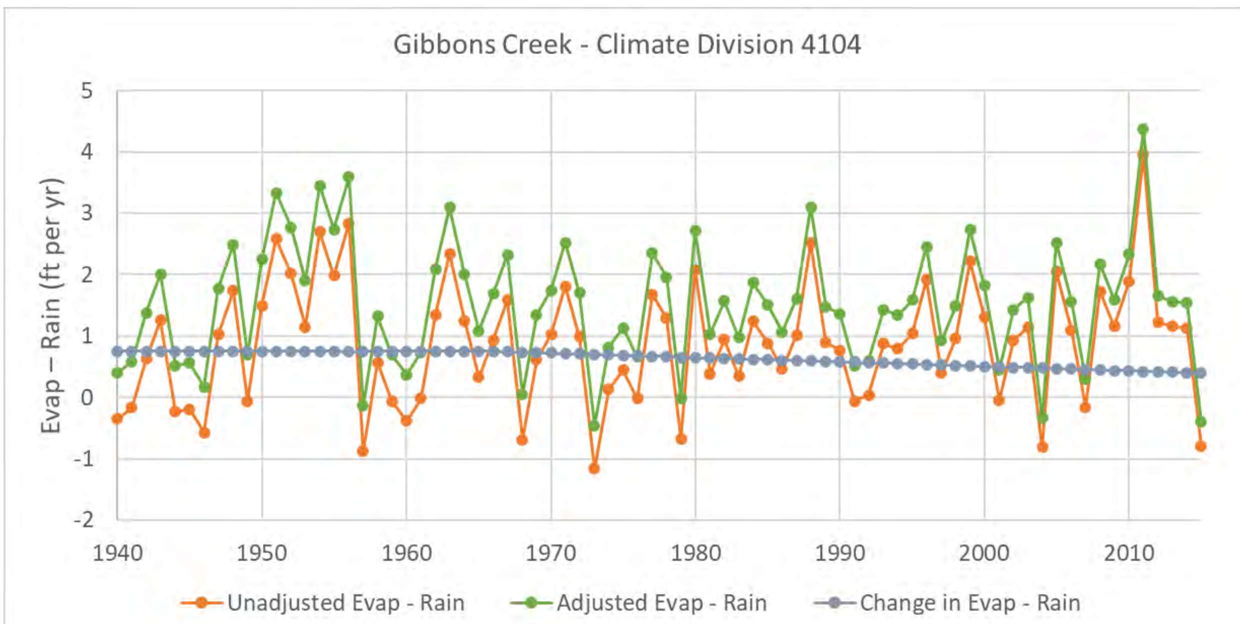


Figure 2-D-69 – Original and Adjusted Naturalized Net Reservoir Evaporation at Gibbons Creek Reservoir for 2070 Conditions

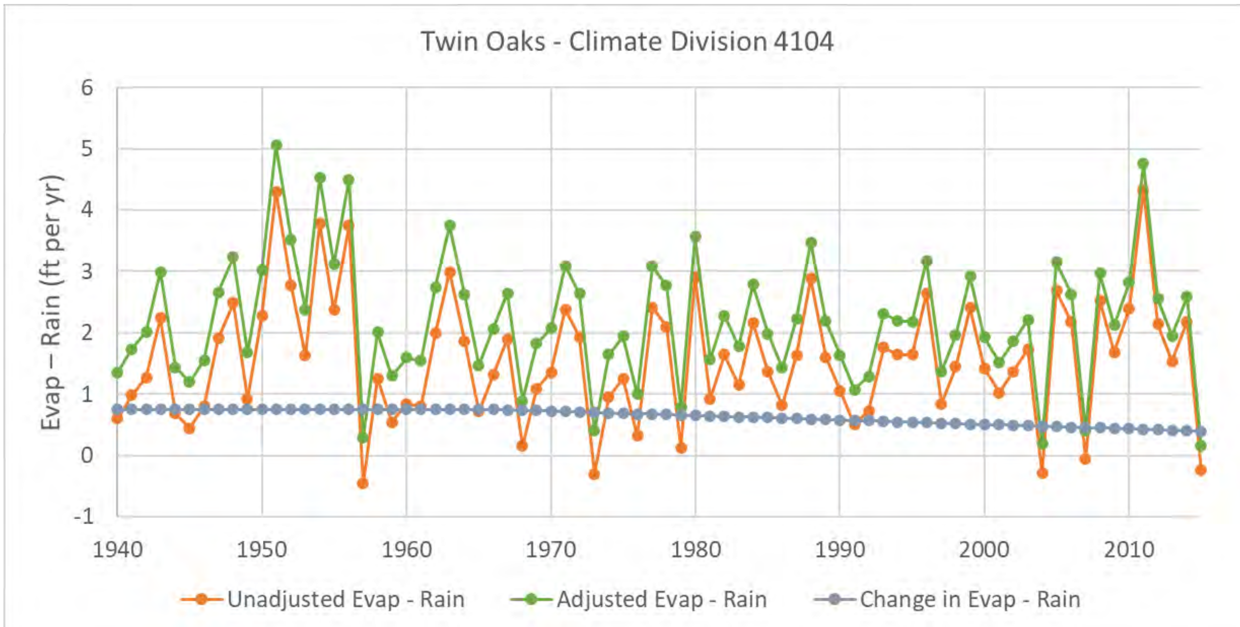


Figure 2-D-70 – Original and Adjusted Naturalized Net Reservoir Evaporation at Twin Oaks Reservoir for 2070 Conditions

Climate Division 4106

Table 2-D-11 – Summary of Variable Trend Results for Climate Division 4016

	P				T				E			
	τ	p	Slope	Intercept	τ	p	Slope	Intercept	τ	p	Slope	Intercept
Annual	0.08	0.27	0.00	-3.25	0.53	0.00	0.06	-47.10	0.16	0.09	0.01	-8.06
Winter	0.04	0.65	0.00	-1.53	0.31	0.00	0.06	-67.78	0.18	0.06	0.01	-9.50
Spring	0.02	0.83	0.00	-2.59	0.30	0.00	0.06	-42.97	0.02	0.82	0.00	1.57
Summer	0.04	0.60	0.00	-2.68	0.40	0.00	0.05	-25.01	0.17	0.08	0.01	-16.34
Dry Winter	-0.01	0.94	0.00	1.23	-0.06	0.84	0.01	22.16	-0.18	0.45	0.00	9.39
Average Winter	-0.05	0.73	0.00	3.92	0.38	0.02	0.08	-107.16	0.35	0.03	0.01	-17.93
Wet Winter	0.07	0.62	0.00	-5.67	0.36	0.03	0.05	-56.19	0.05	0.78	0.00	-0.66
Dry Spring	-0.04	0.80	0.00	2.52	0.24	0.23	0.04	-16.75	-0.16	0.43	0.00	13.83
Average Spring	-0.10	0.50	0.00	9.94	0.39	0.05	0.08	-85.17	0.05	0.84	0.00	-2.82
Wet Spring	0.09	0.51	0.01	-14.07	0.44	0.00	0.05	-25.69	-0.03	0.87	0.00	4.79
Dry Summer	0.23	0.10	0.01	-14.96	0.44	0.03	0.04	-3.07	-0.10	0.62	0.00	12.44
Average Summer	0.14	0.31	0.01	-19.36	0.05	0.79	0.01	62.00	-0.08	0.65	0.00	7.57
Wet Summer	-0.17	0.23	-0.01	23.56	0.54	0.00	0.08	-81.11	0.29	0.09	0.01	-22.67

Green indicates significance (P-value<=0.05)
Light blue indicates moderate to strong Kendall's tau.
No reservoirs located in the Brazos River Basin are in this climate division, so no adjustments were made based on these trends.

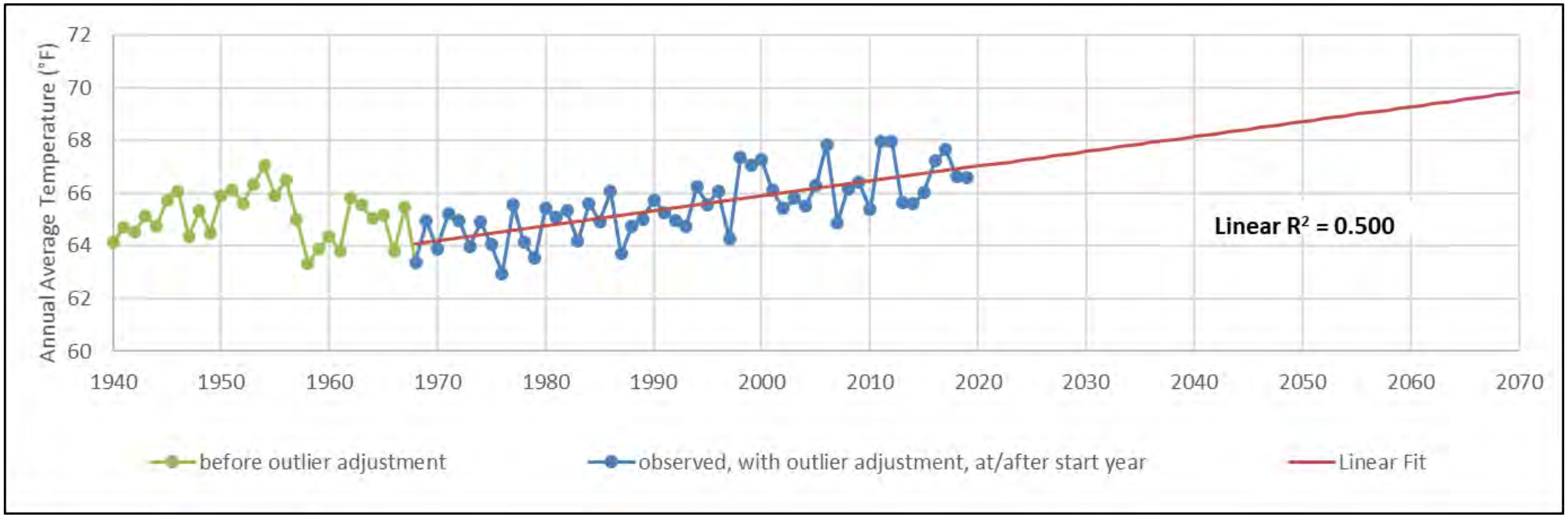


Figure 2-D-71– Annual Trend for Average Air Temperature in Climate Division 4106

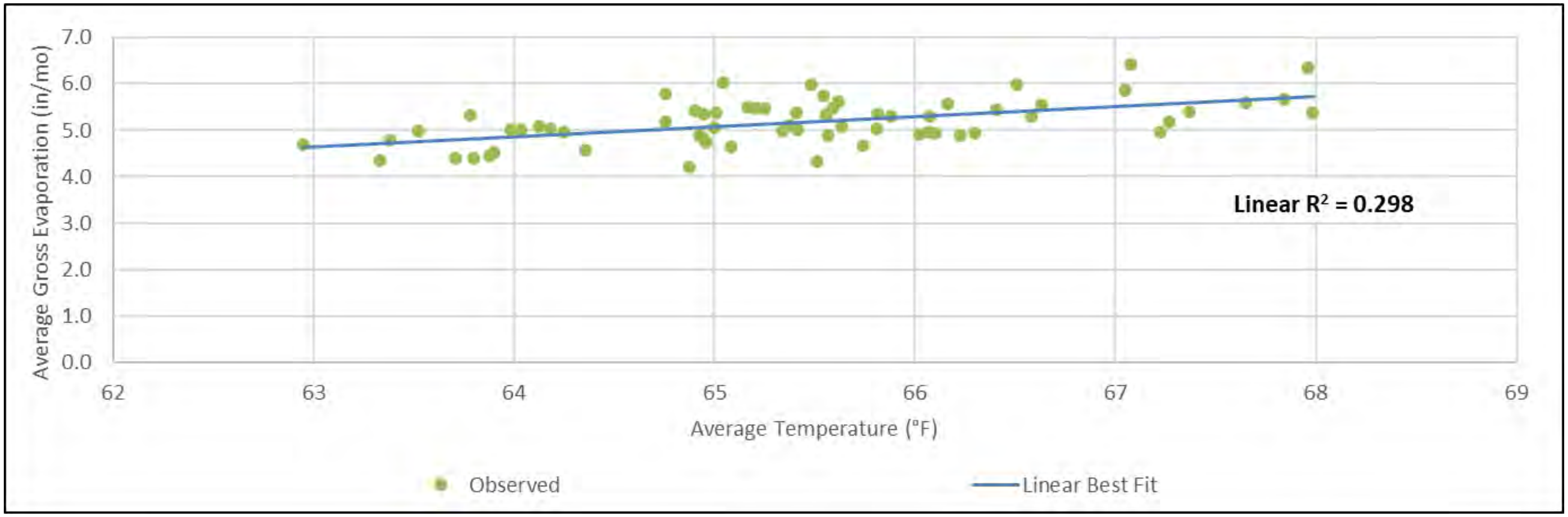


Figure 2-D-72– Relationship between Annual Average Air Temperature and Gross Evaporation in Climate Division 4106

Changes to Net Reservoir Evaporation for Climate Division 4106

No reservoirs located in the Brazos River Basin are in this climate division.

Climate Division 4107

Table 2-D-12 – Summary of Variable Trend Results for Climate Division 4107

	P				T				E			
	τ	p	Slope	Intercept	τ	p	Slope	Intercept	τ	p	Slope	Intercept
Annual	0.04	0.61	0.00	-1.01	**0.52**	**0.00**	0.06	-50.27	-0.05	0.61	0.00	7.59
Winter	0.02	0.79	0.00	0.98	0.32	0.00	0.07	-77.49	-0.01	0.94	0.00	3.80
Spring	0.02	0.85	0.00	-0.14	0.38	0.00	0.06	-44.80	0.01	0.96	0.00	7.46
Summer	0.04	0.60	0.00	-3.67	0.47	0.00	0.05	-22.95	-0.03	0.75	0.00	9.93
Dry Winter	0.05	0.74	0.00	0.10	-0.03	0.95	-0.01	85.86	-0.27	0.24	-0.01	16.67
Average Winter	0.00	1.00	0.00	1.44	0.20	0.19	0.06	-59.31	-0.05	0.76	0.00	6.53
Wet Winter	0.01	0.94	0.00	1.78	0.49	0.01	0.08	-99.05	-0.01	1.00	0.00	3.66
Dry Spring	-0.11	0.43	-0.01	12.46	0.18	0.43	0.04	-10.21	-0.28	0.20	-0.01	28.73
Average Spring	-0.04	0.77	0.00	5.20	0.45	0.01	0.07	-63.94	-0.01	1.00	0.00	3.11
Wet Spring	0.18	0.20	0.01	-13.94	0.47	0.00	0.05	-23.58	-0.05	0.79	0.00	13.85
Dry Summer	0.10	0.48	0.01	-8.46	0.45	0.02	0.05	-12.11	-0.03	0.89	0.00	7.17
Average Summer	0.24	0.11	0.02	-37.84	-0.06	0.80	0.01	55.31	-0.43	0.03	-0.02	54.28
Wet Summer	**-0.31**	**0.02**	-0.02	43.60	0.56	0.00	0.06	-44.62	0.03	0.88	0.00	6.63

Bold text indicates trend used.
Green indicates significance (P-value<=0.05)
Light blue indicates moderate to strong Kendall's tau.

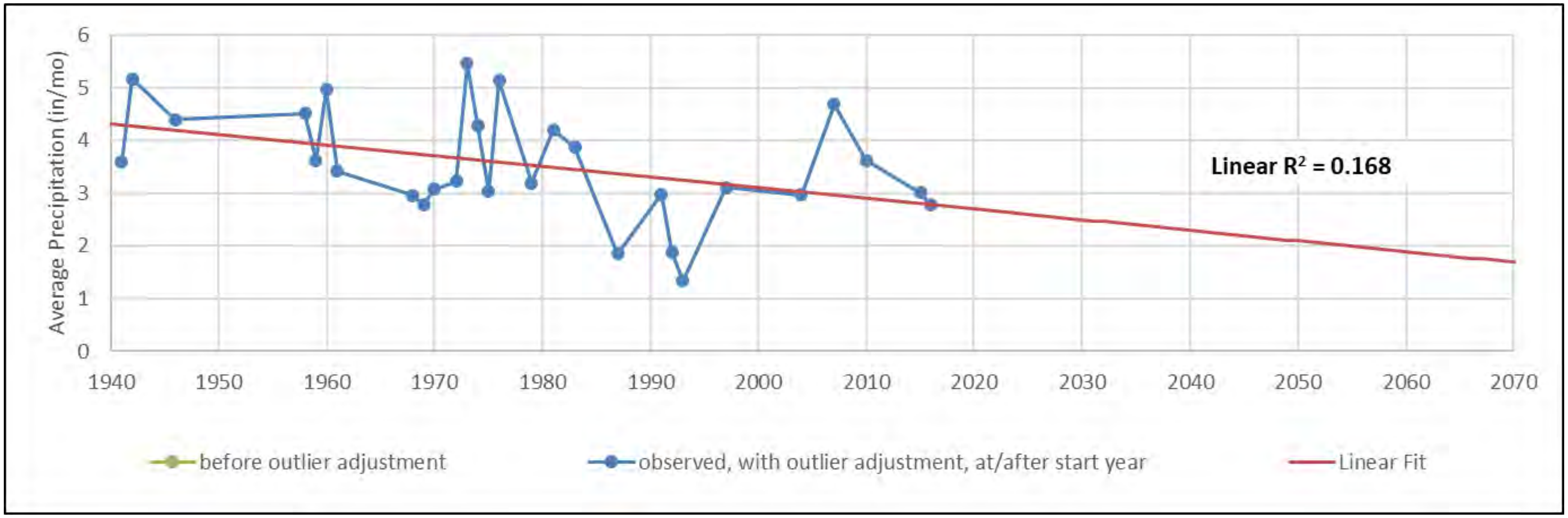


Figure 2-D-73 – Wet Summer Trend for Monthly Average Precipitation in Climate Division 4107

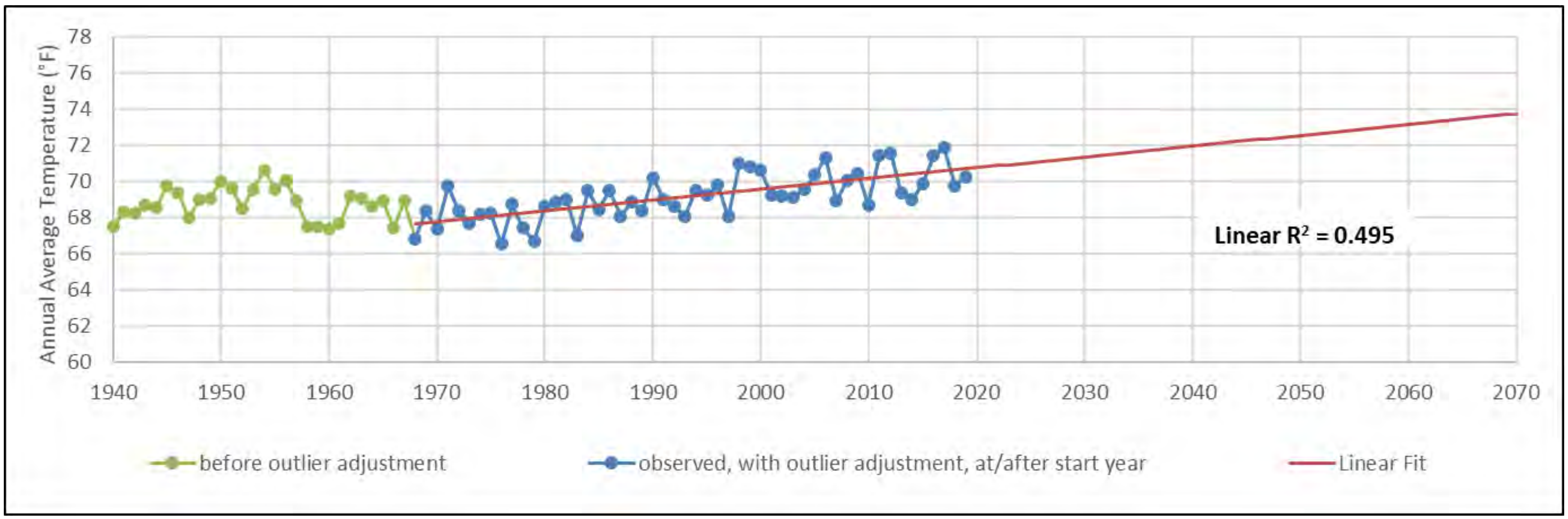


Figure 2-D-74 – Annual Trend for Average Air Temperature in Climate Division 4107

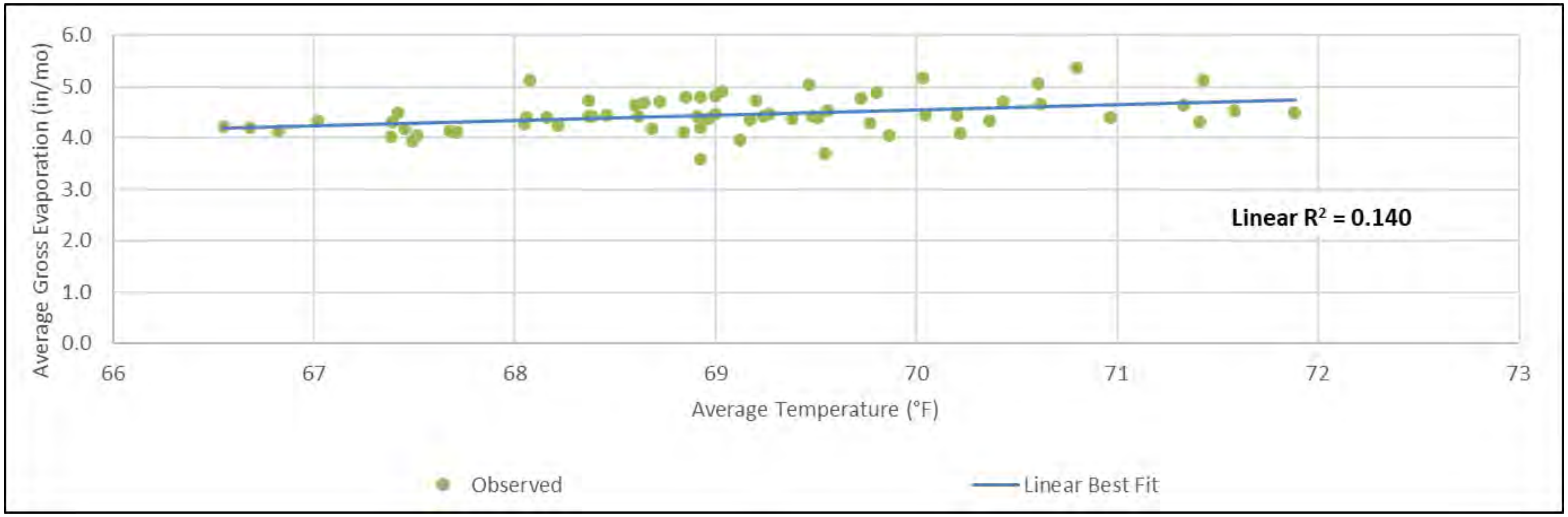


Figure 2-D-75 – Relationship between Annual Average Air Temperature and Gross Evaporation in Climate Division 4107

Changes to Net Reservoir Evaporation for Climate Division 4107

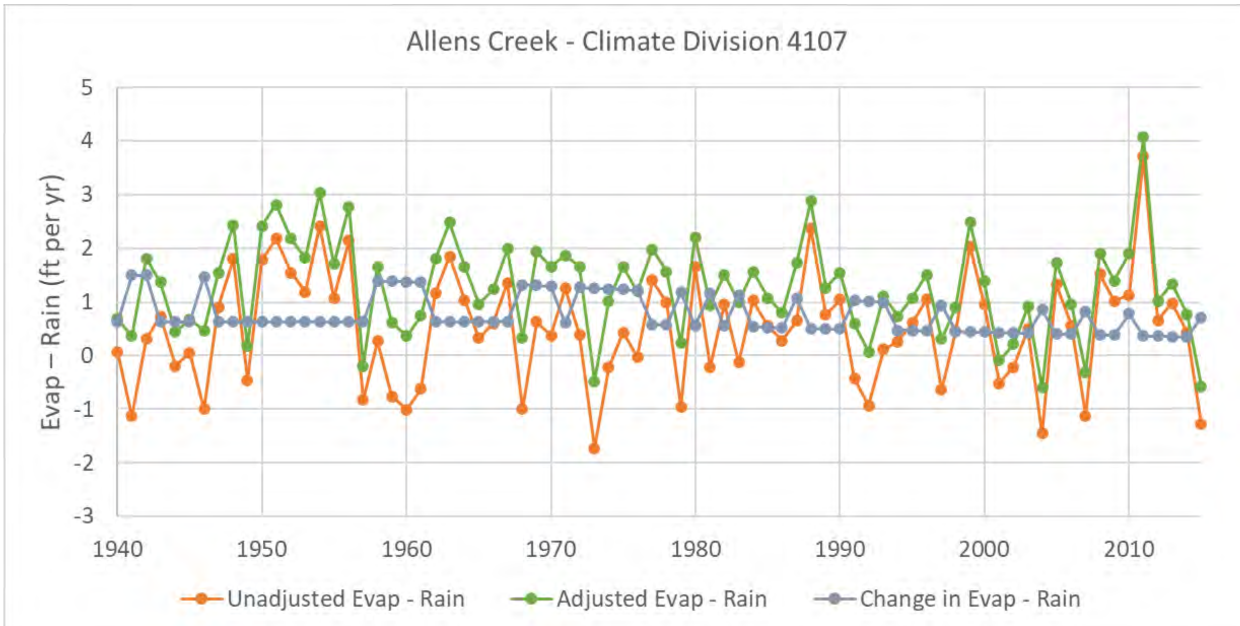


Figure 2-D-76 – Original and Adjusted Naturalized Net Reservoir Evaporation at Allens Creek Reservoir for 2070 Conditions

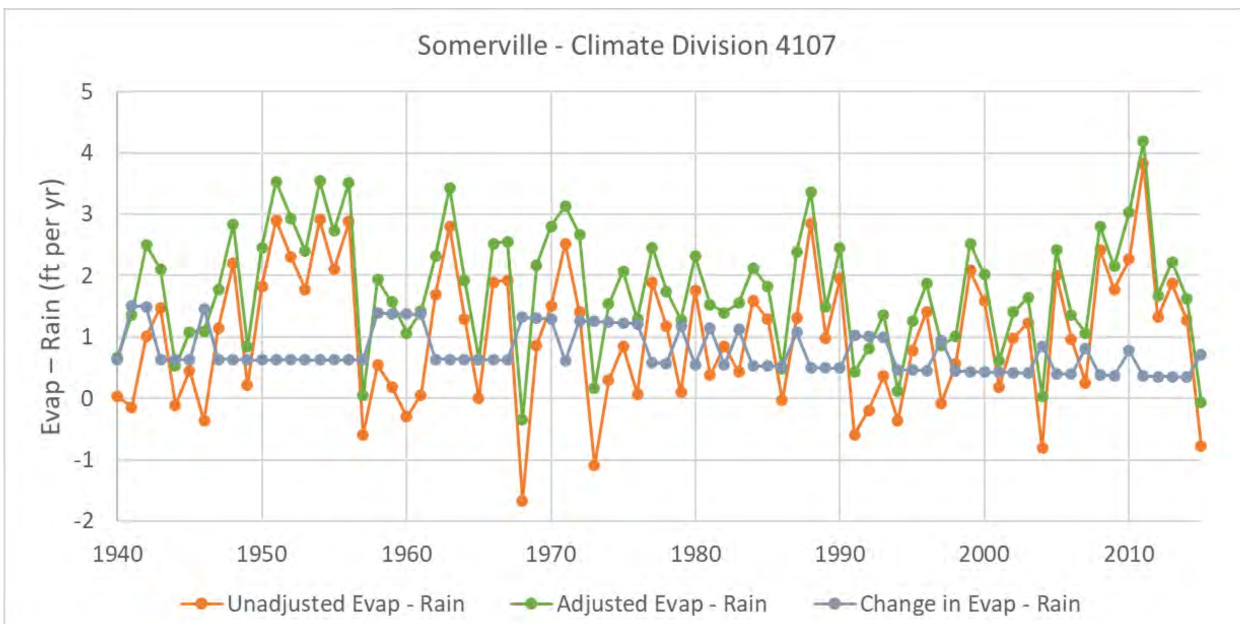


Figure 2-D-77 – Original and Adjusted Naturalized Net Reservoir Evaporation at Lake Somerville for 2070 Conditions

Climate Division 4108

Table 2-D-13 – Summary of Variable Trend Results for Climate Division 4108

	P				T				E			
	τ	p	Slope	Intercept	τ	p	Slope	Intercept	τ	p	Slope	Intercept
Annual	0.11	0.14	0.01	-7.95	**0.54**	**0.00**	0.06	-45.59	0.04	0.69	0.00	1.66
Winter	0.01	0.92	0.00	4.95	0.32	0.00	0.07	-74.81	0.04	0.71	0.00	0.13
Spring	0.08	0.32	0.01	-12.44	0.41	0.00	0.05	-29.80	0.05	0.57	0.00	0.16
Summer	0.11	0.15	0.01	-19.07	0.48	0.00	0.05	-29.36	0.03	0.75	0.00	3.17
Dry Winter	-0.09	0.54	-0.01	13.27	0.33	0.09	0.06	-72.92	0.18	0.37	0.01	-11.08
Average Winter	0.03	0.87	0.00	5.95	0.09	0.62	0.03	-11.73	-0.01	1.00	0.00	3.27
Wet Winter	-0.01	0.93	0.00	4.77	0.37	0.03	0.08	-111.06	-0.20	0.23	0.00	11.14
Dry Spring	0.07	0.62	0.00	-5.67	0.23	0.27	0.03	6.48	-0.19	0.38	0.00	7.47
Average Spring	-0.08	0.52	0.00	13.01	0.46	0.00	0.06	-48.37	0.24	0.11	0.01	-14.86
Wet Spring	**0.34**	**0.02**	0.03	-49.15	0.50	0.01	0.05	-32.92	-0.13	0.50	-0.01	14.36
Dry Summer	0.22	0.10	0.02	-30.75	0.41	0.02	0.05	-24.00	-0.05	0.79	0.00	4.78
Average Summer	0.27	0.08	0.02	-42.24	0.20	0.35	0.03	22.53	-0.27	0.19	-0.01	29.14
Wet Summer	-0.10	0.49	0.00	14.72	0.69	0.00	0.07	-56.22	0.14	0.37	0.01	-4.95

Bold text indicates trend used.
Green indicates significance (P-value<=0.05)
Light blue indicates moderate to strong Kendall's tau.

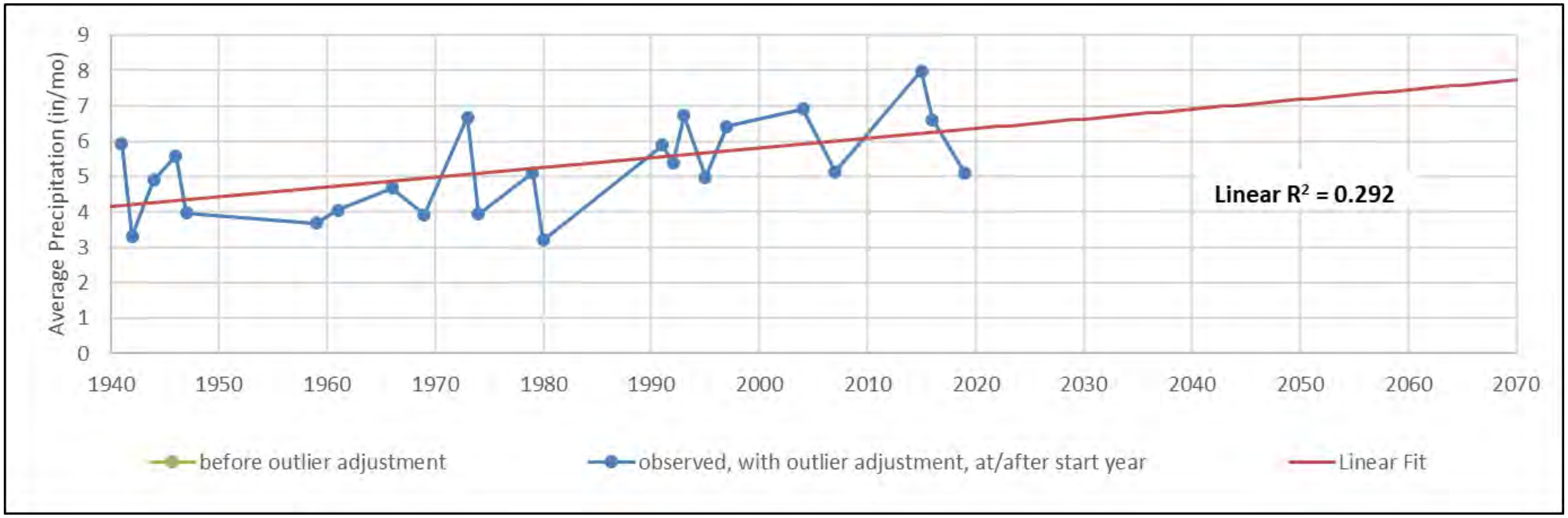


Figure 2-D-78 – Wet Spring Trend for Monthly Average Precipitation in Climate Division 4108

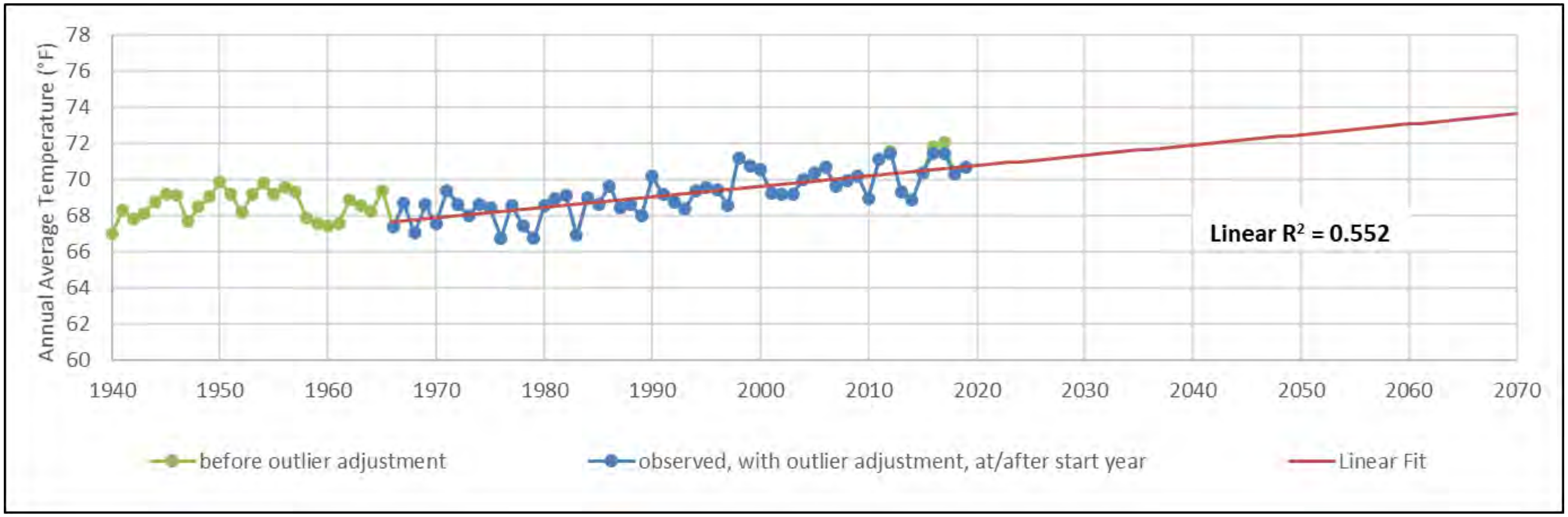


Figure 2-D-79 – Annual Trend for Average Air Temperature in Climate Division 4108

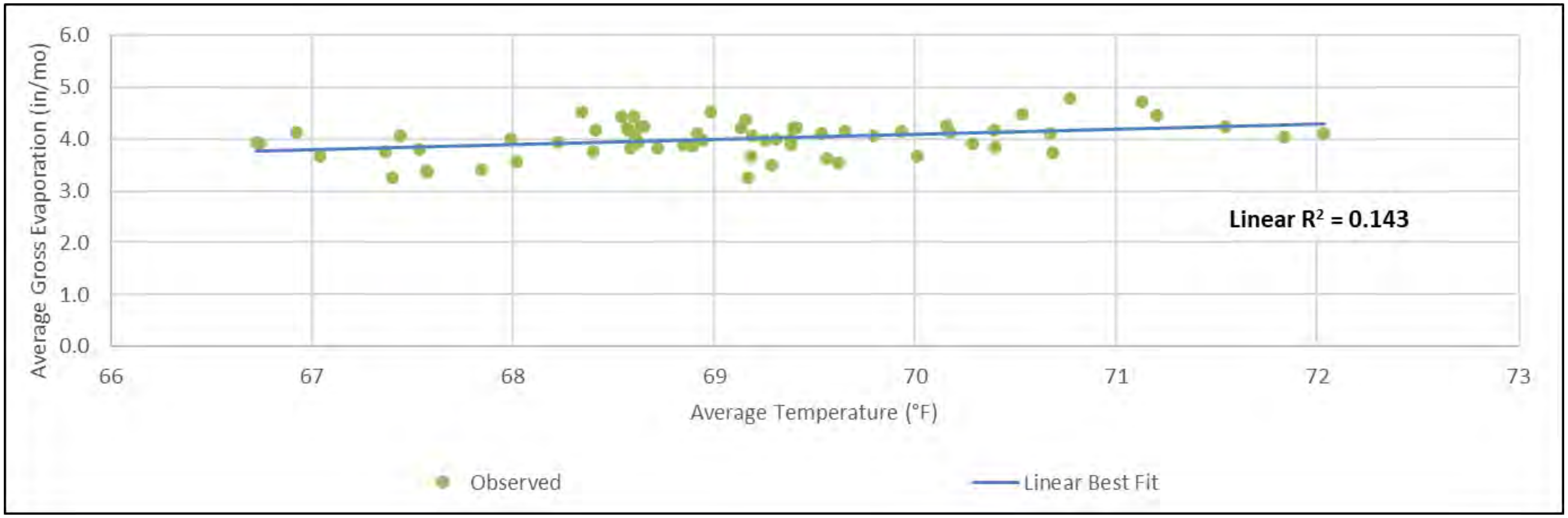


Figure 2-D-80 – Relationship between Annual Average Air Temperature and Gross Evaporation in Climate Division 4108

Changes to Net Reservoir Evaporation for Climate Division 4108

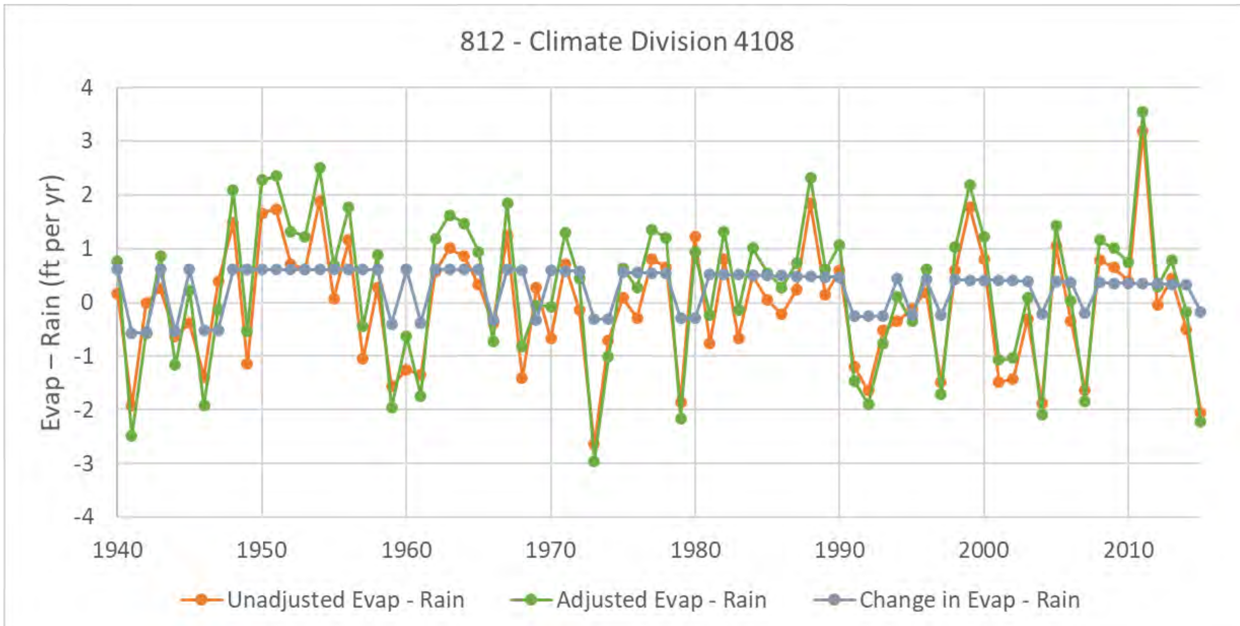


Figure 2-D-81– Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 812 for 2070 Conditions

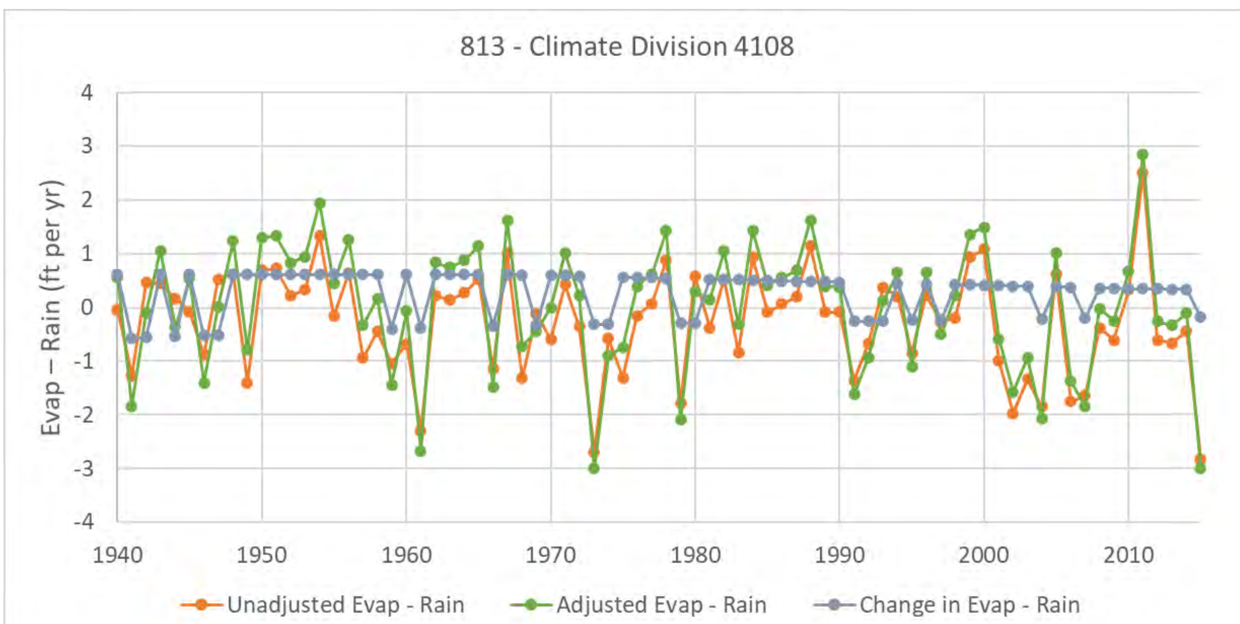


Figure 2-D-82 – Original and Adjusted Naturalized Net Reservoir Evaporation at Quadrangle 813 for 2070 Conditions

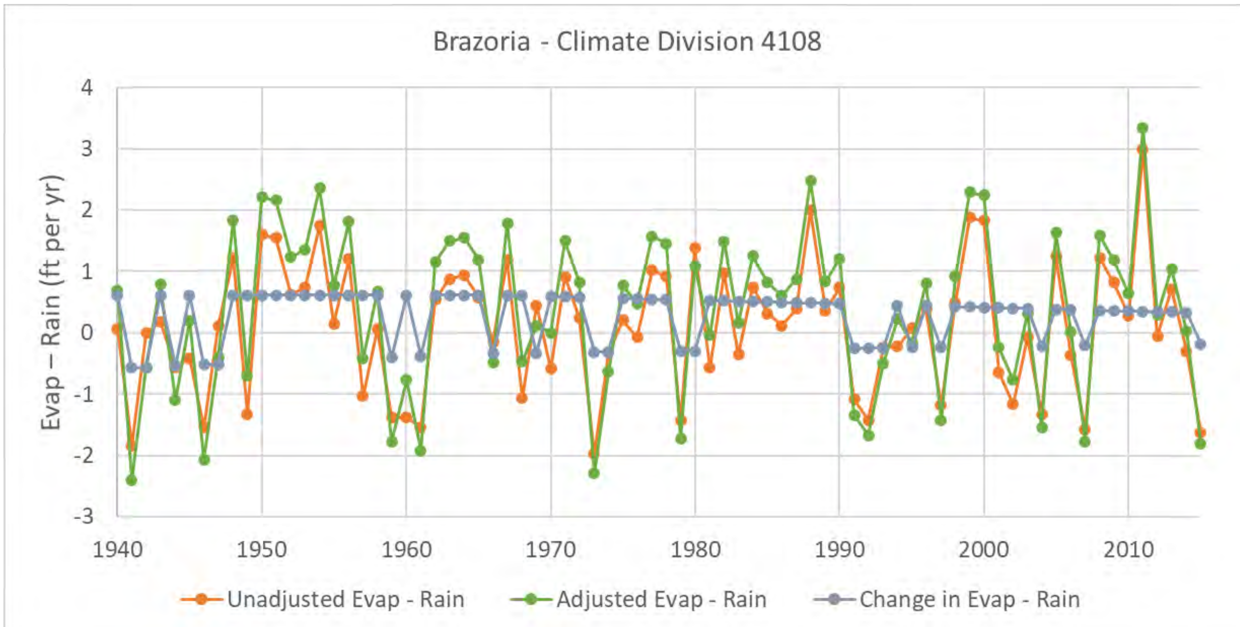


Figure 2-D-83 – Original and Adjusted Naturalized Net Reservoir Evaporation at Brazoria Reservoir for 2070 Conditions

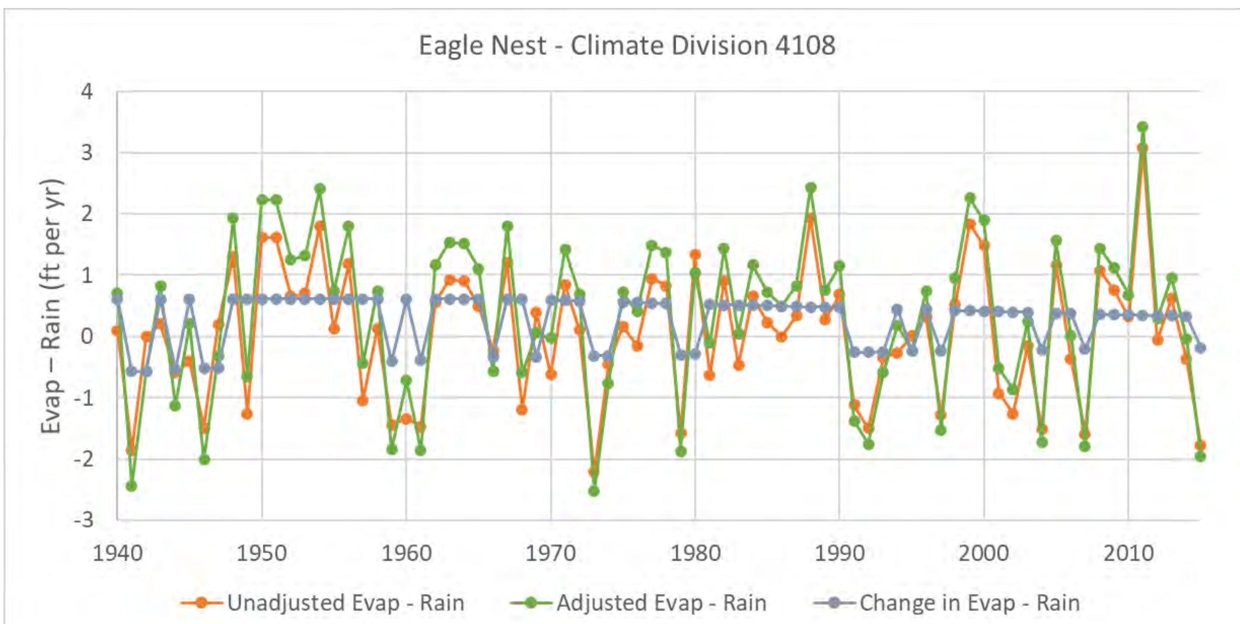


Figure 2-D-84 – Original and Adjusted Naturalized Net Reservoir Evaporation at Eagle Nest Reservoir for 2070 Conditions

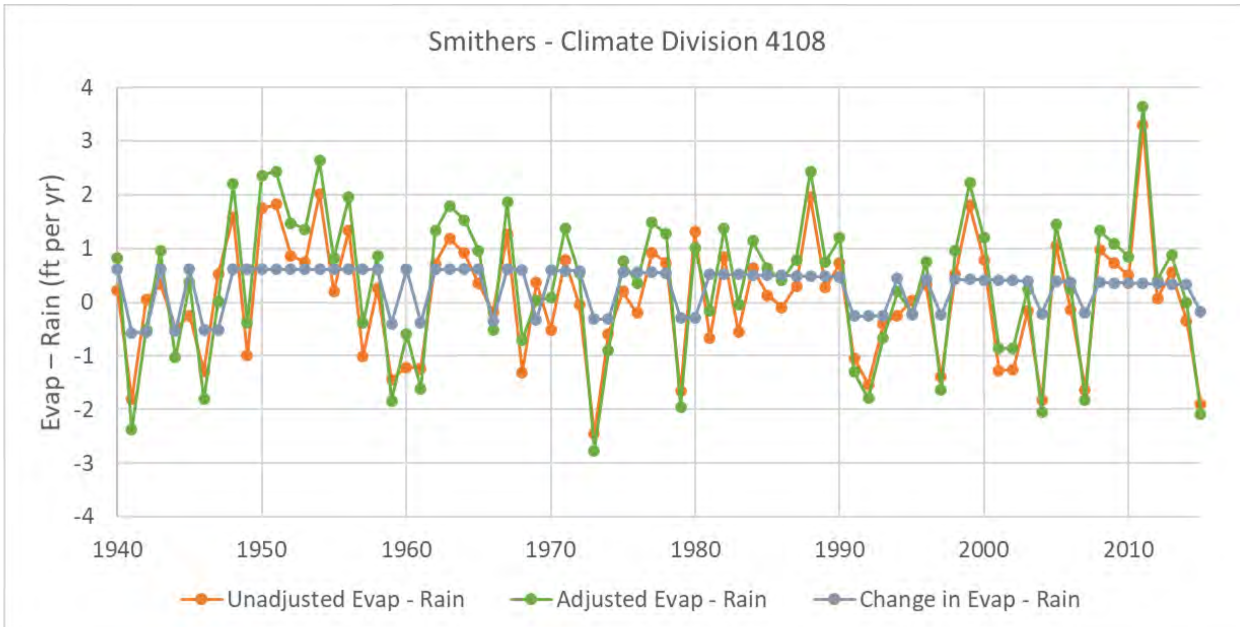


Figure 2-D-85 – Original and Adjusted Naturalized Net Reservoir Evaporation at Smithers Lake for 2070 Conditions

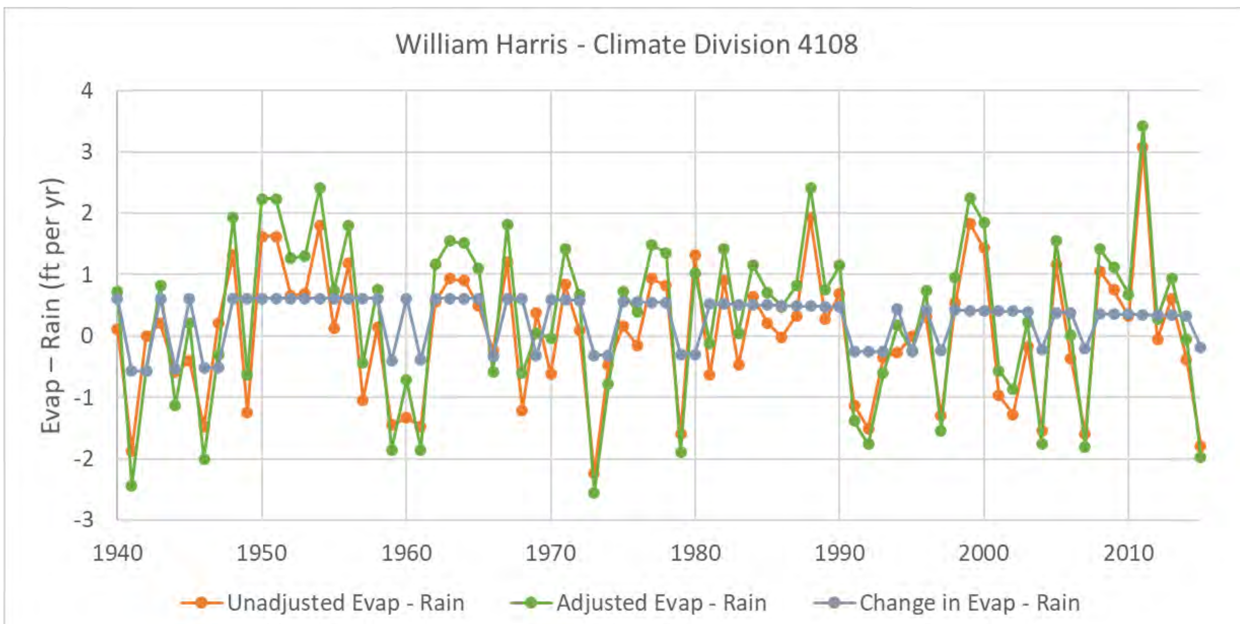


Figure 2-D-86 – Original and Adjusted Naturalized Net Reservoir Evaporation at William Harris Reservoir for 2070 Conditions

APPENDIX 2-E: CHANGES TO SURFACE WATER SUPPLY AVAILABILITY

Reservoir Yields

Table 2-E-1 provides a summary of the calculated firm yields for all reservoirs located in the Brazos G planning area with an authorized diversion amount greater than 1,000 ac-ft/yr. No existing reservoirs were included in the 2021 Region H RWP in the Brazos Basin. The Table 2-Compares the firm yields calculated considering the trend adjustments to those calculated in the 2021 Brazos G RWP with no trend adjustments.

Run-of-River Availability

Table 2-E-2 provides a summary of the minimum annual diversions of all run-of-river water rights in the Brazos G and Region H water planning areas with authorized diversions greater than 1,000 ac-ft/yr. The table includes water right identification numbers, current owners, stream location of diversions, and comparisons to the values included in the 2021 Brazos G and Region H water plans with no trend adjustments.

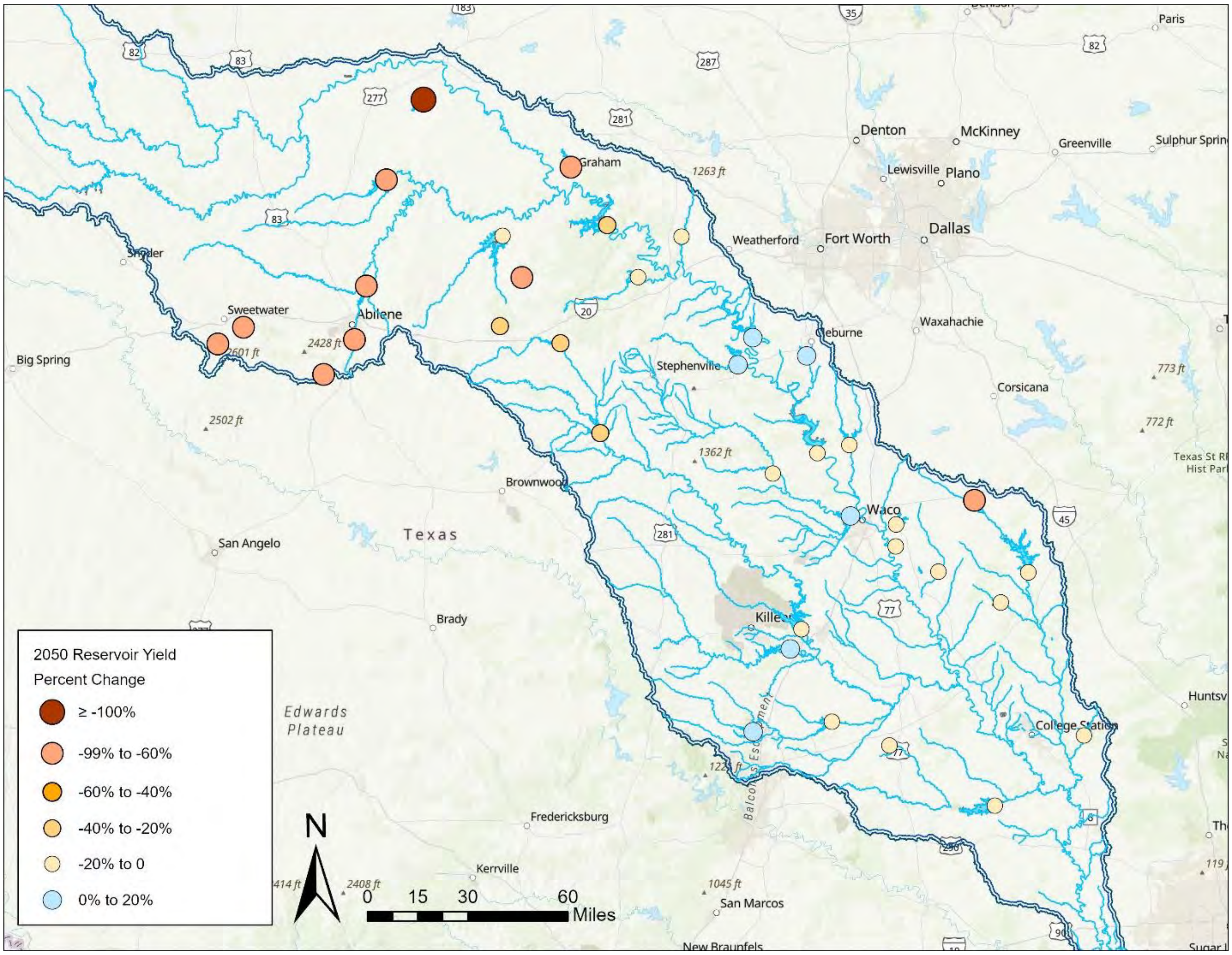


Figure 2-E-1. Modeled Percent Change in 2050 Reservoir Yield between the Original Hydrology and the 2050 Trended Hydrology (the results for Squaw Creek were omitted for 2050; see Section 2.4.4)

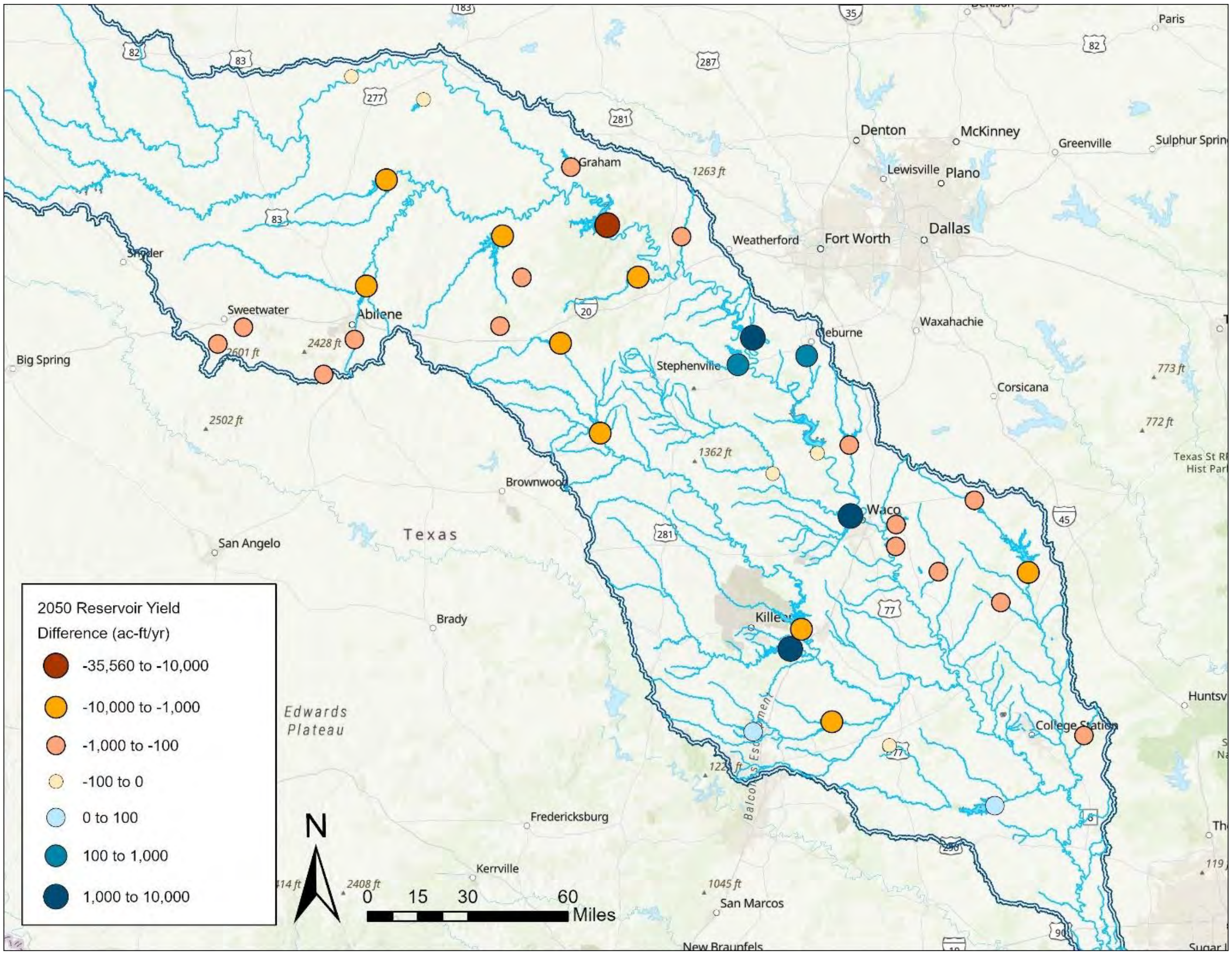


Figure 2-E-2. Modeled Difference in 2050 Reservoir Yield (in Acre-Feet Per Year) between the Original Hydrology and the 2050 Trended Hydrology (the results for Squaw Creek were omitted for 2050; see Section 2.4.4)

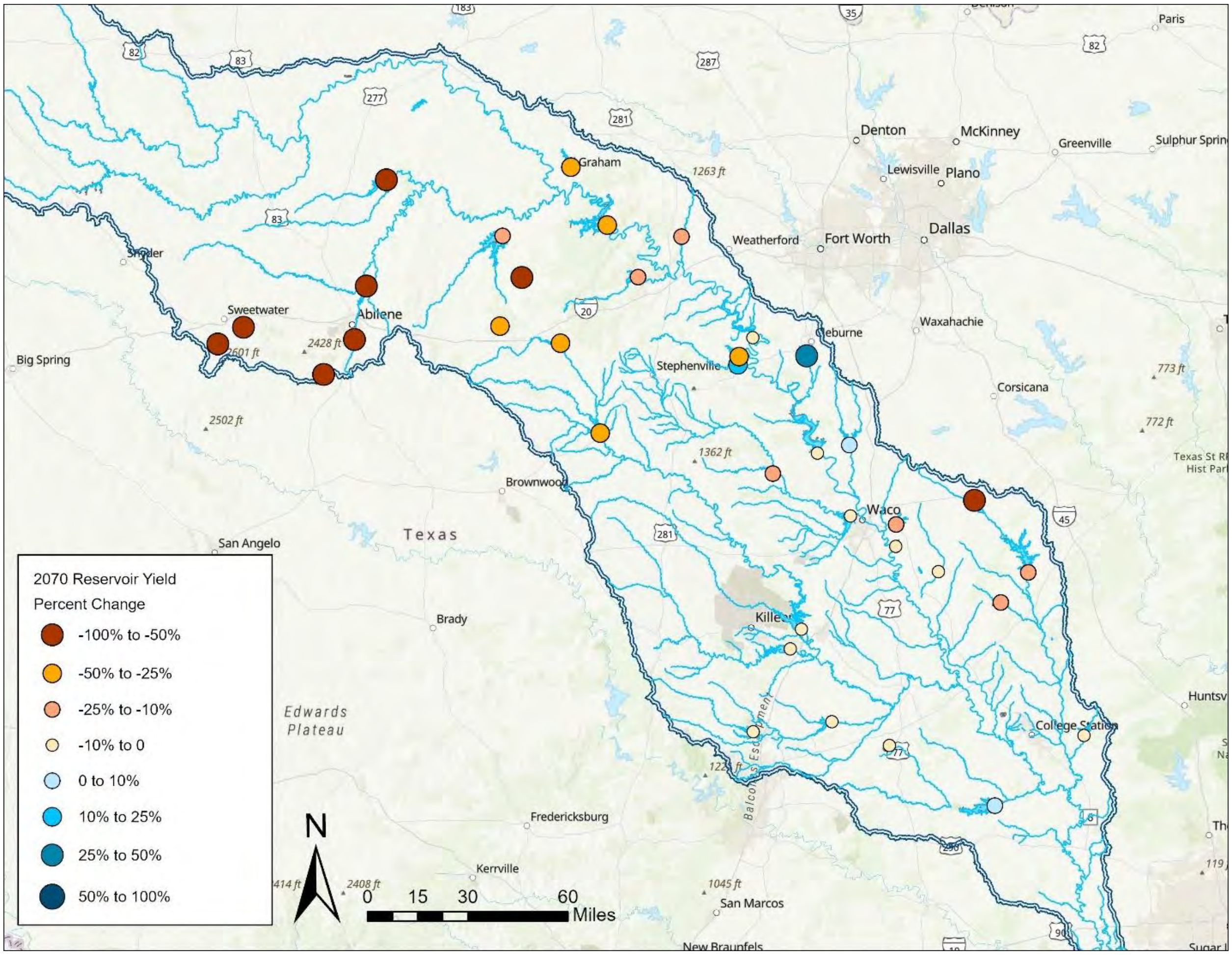


Figure 2-E-3. Modeled Percent Change in 2070 Reservoir Yield between the Original Hydrology and the 2070 Trended Hydrology (the results for Squaw Creek follow the alternative modeling described in Section 2.4.4)

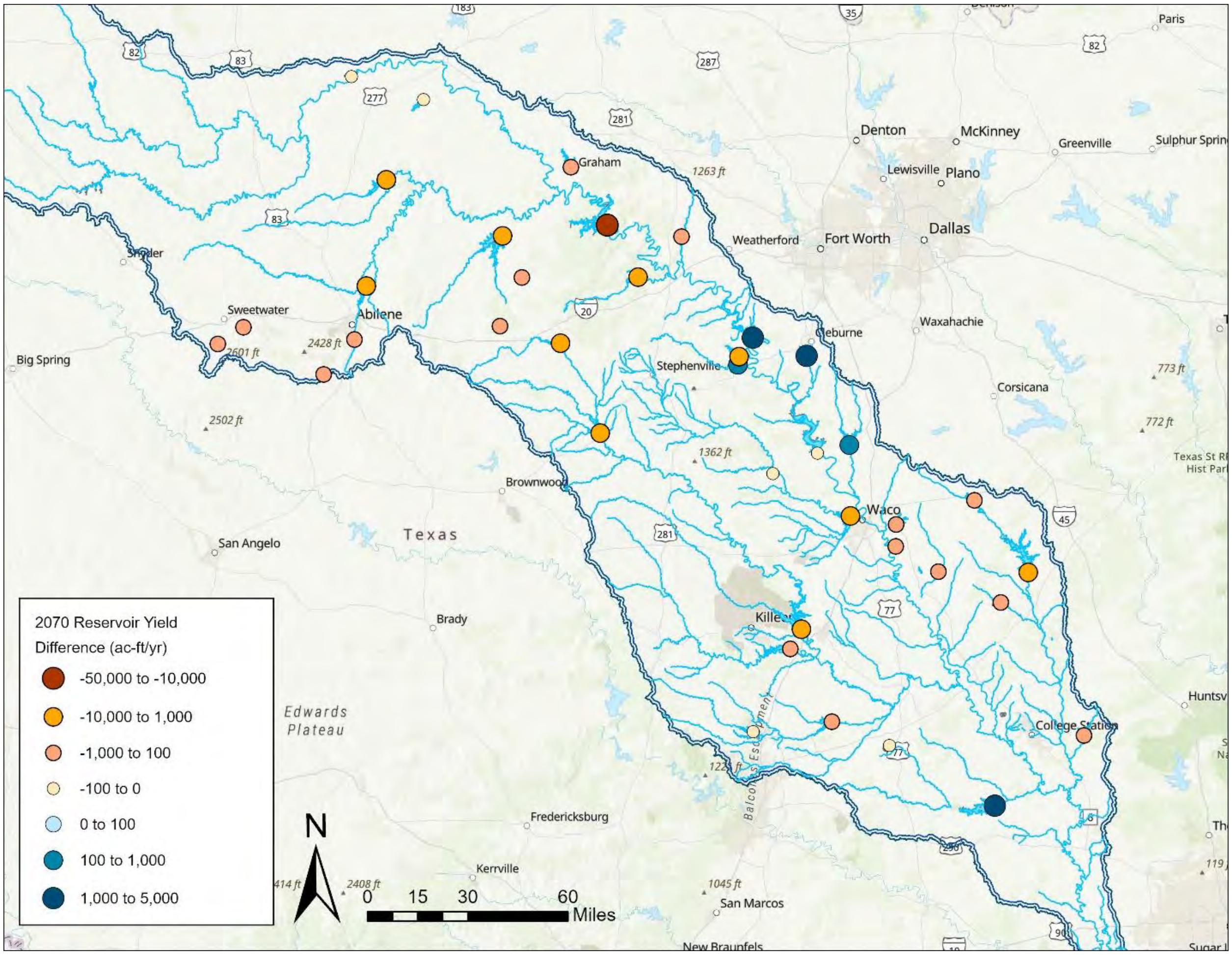


Figure 2-E-3. Modeled Difference in 2070 Reservoir Yield (in Acre-Feet Per Year) between the Original Hydrology and the 2070 Trended Hydrology (the results for Squaw Creek follow the alternative modeling described in Section 2.4.4)

Table 2-E-1. Summary Comparison of Reservoir Firm Yields with and without Trends (ac-ft/yr)

Water Right ID	Reservoir Name	Authorized Diversion	Firm Yield - No Trends				Firm Yield - With Trends			Firm Yield Comparison- With and Without Trends					
			2020	2050[1]	2060[1]	2070	2050	2060[2]	2070	2050 Difference	2050 % Difference	2060 Difference	2060 % Difference	2070 Difference	2070 % Difference
BRA Reservoirs and System Operations Permit[3]															
C5155	Possum Kingdom	230,750	152,100	149,460	148,580	147,700	113,900	110,500	107,100	(35,560)	(24%)	(38,080)	(26%)	(40,600)	(27%)
C5156	Granbury	64,712	59,400	56,340	55,320	54,300	58,250	58,375	58,500	1,910	3%	3,055	6%	4,200	8%
C5157	Whitney[4]	18,336	18,336	18,336	18,336	18,336	18,336	18,336	18,336	0	0%	0	0%	0	0%
C5158	Aquilla	13,896	13,400	11,900	11,400	10,900	11,350	11,325	11,300	(550)	(5%)	(75)	(1%)	400	4%
C5159	Proctor	19,658	13,300	11,380	10,740	10,100	7,800	7,650	7,500	(3,580)	(31%)	(3,090)	(29%)	(2,600)	(26%)
C5160, C2936	Belton[5]	112,257	120,000	118,620	118,160	117,700	112,200	112,150	112,100	(6,420)	(5%)	(6,010)	(5%)	(5,600)	(5%)
C5161	Stillhouse Hollow	67,768	66,400	65,560	65,280	65,000	71,600	68,100	64,600	6,040	9%	2,820	4%	(400)	(1%)
C5162	Georgetown	13,610	11,600	11,540	11,520	11,500	11,600	11,550	11,500	60	1%	30	0%	0	0%
C5163	Granger	19,840	17,600	16,280	15,840	15,400	15,100	14,900	14,700	(1,180)	(7%)	(940)	(6%)	(700)	(5%)
C5164	Somerville	48,000	42,200	40,220	39,560	38,900	40,300	40,650	41,000	80	0%	1,090	3%	2,100	5%
C5165	Limestone	65,074	64,000	59,320	57,760	56,200	51,400	51,100	50,800	(7,920)	(13%)	(6,660)	(12%)	(5,400)	(10%)
Sum of Stand-alone Yields for System Operations[7]		---	558,593	540,593	534,593	528,593	499,836	492,636	485,436	(40,757)	(8%)	(41,957)	(8%)	(43,157)	(8%)
Min Year Total BRA Contract Deliveries[6]		---	669,003	642,306	633,406	624,507	620,683	610,162	599,640	(21,622)	(3%)	(23,245)	(4%)	(24,868)	(4%)
Incremental BRA System Operations Yield[7]		434,703	110,410	101,713	98,813	95,914	120,847	117,526	114,204	19,135	19%	18,712	19%	18,289	19%
Upper Basin Non-BRA Reservoirs (Located Upstream of Possum Kingdom Reservoir)															
C4142	Abilene	1,675	800	770	760	750	60	55	50	(710)	(92%)	(705)	(93%)	(700)	(93%)
C4211	Cisco	2,971	1,300	1,300	1,300	1,300	1,000	975	950	(300)	(23%)	(325)	(25%)	(350)	(27%)
C4214	Daniel	2,100	250	235	230	225	20	13	5	(215)	(91%)	(218)	(95%)	(220)	(98%)
C4151, C4161, C4139, C4165	Fort Phantom Hill[8]	30,690	7,500	7,140	7,020	6,900	1,350	1,200	1,050	(5,790)	(81%)	(5,820)	(83%)	(5,850)	(85%)
C3458	Graham-Eddleman	20,000	1,800	1,395	1,260	1,125	470	575	680	(925)	(66%)	(685)	(54%)	(445)	(40%)
C4213	Hubbard Creek	56,000	26,900	26,540	26,420	26,300	21,900	21,300	20,700	(4,640)	(17%)	(5,120)	(19%)	(5,600)	(21%)
C4150	Kirby[9]	3,880	300	300	300	300	20	15	10	(280)	(93%)	(285)	(95%)	(290)	(97%)
C4179	Stamford	10,000	4,400	4,190	4,120	4,050	1,050	925	800	(3,140)	(75%)	(3,195)	(78%)	(3,250)	(80%)
C4130	Sweetwater	3,740	650	650	650	650	60	50	40	(590)	(91%)	(600)	(92%)	(610)	(94%)
C4128	Sweetwater/Trammel	2,000	300	300	300	300	60	55	50	(240)	(80%)	(245)	(82%)	(250)	(83%)
C3444	Millers Creek Reservoir	5,000	125	50	25	0	0	0	0	(50)	(100%)	(25)	(100%)	0	---

1. 2050 and 2060 firm yields with no trends are linear interpolated from 2020 and 2070 values.
2. 2060 firm yields with trends are linear interpolated from 2050 and 2070 values.
3. BRA reservoir firm yield estimates are considered a stand-alone yield and do not include system operations.
4. Diversions from Lake Whitney authorized under Certificate of Adjudication 12-5157 were fully reliable in all model simulations. Due to the complexity of the Lake Whitney water rights and operations, a hypothetical junior water right was not added to the reservoir to determine the additional firm yield available. This approach is consistent with the approach used in the 2021 Brazos G RWP.
5. Lake Belton firm yield includes 12,000 ac-ft/yr of water rights held by the Department of the Army.
6. "Min Year Total BRA Contract Deliveries" is the minimum annual delivery amount (or diversion amount) throughout the model period of record of the combined BRA contracts included in the Brazos G WAM.
7. The incremental firm yield of the BRA System Operations permit is estimated as the difference of the minimum year of the total BRA contract deliveries and the sum of the stand-alone yields of the BRA Reservoirs. The sum of the stand-alone yields does not include the 12,000 ac-ft/yr of water rights held by the Department of the Army in Lake Belton or the portion of the yield greater than the authorized amount.
8. Fort Phantom Hill Reservoir is utilized as part of the City of Abilene's indirect reuse system and for raw water supply. Yield estimates for Fort Phantom Hill Reservoir do not include effluent inflows.
9. Lake Kirby is utilized as part of the City of Abilene's indirect reuse system and not for raw water supply. Yield estimates for Lake Kirby do not include effluent inflows.

Table 2-E-1. Summary Comparison of Reservoir Firm Yields with and without Trends (ac-ft/yr) (continued)

Water Right ID	Reservoir Name	Authorized Diversion	Firm Yield - No Trends				Firm Yield - With Trends			Firm Yield Comparison- With and Without Trends					
			2020	2050[1]	2060[1]	2070	2050	2060[2]	2070	2050 Difference	2050 % Difference	2060 Difference	2060 % Difference	2070 Difference	2070 % Difference
Middle Basin Non-BRA Reservoirs (Located Downstream of Possum Kingdom Reservoir)															
C3758, C5272	Alcoa	14,000	14,600	14,660	14,680	14,700	14,650	14,675	14,700	(10)	(0%)	(5)	(0%)	0	0%
C5311, C5307	Gibbons Creek	9,740	13,000	12,820	12,760	12,700	12,550	12,575	12,600	(270)	(2%)	(185)	(1%)	(100)	(1%)
C4345	Lake Creek	10,000	9,900	9,900	9,900	9,900	9,500	9,450	9,400	(400)	(4%)	(450)	(5%)	(500)	(5%)
C3440	Davis	2,000	0	0	0	0	0	0	0	0	---	0	---	0	---
C3470	Leon	6,300	4,000	3,910	3,880	3,850	2,855	2,810	2,765	(1,055)	(27%)	(1,070)	(28%)	(1,085)	(28%)
C4039	Mineral Wells	2,520	1,550	1,520	1,510	1,500	1,340	1,310	1,280	(180)	(12%)	(200)	(13%)	(220)	(15%)
C4031	Palo Pinto	18,500	9,800	9,290	9,120	8,950	7,700	7,425	7,150	(1,590)	(17%)	(1,695)	(19%)	(1,800)	(20%)
C4106	Pat Cleburne	6,000	5,040	4,824	4,752	4,680	5,790	5,965	6,140	966	20%	1,213	26%	1,460	31%
C4097	Squaw Creek	23,180	8,050	7,846	7,778	7,710	17,900	18,950	20,000	10,054	128%	11,172	144%	12,290	159%
C4342	Tradinghouse	27,000	4,970	4,922	4,906	4,890	4,380	4,315	4,250	(542)	(11%)	(591)	(12%)	(640)	(13%)
C5298	Twin Oaks	13,200	2,900	2,816	2,788	2,760	2,530	2,480	2,430	(286)	(10%)	(308)	(11%)	(330)	(12%)
C2315, P5094	Waco	79,870	75,800	73,940	73,320	72,700	76,400	73,500	70,600	2,460	3%	180	0%	(2,100)	(3%)
C4355	Marlin	4,000	3,690	3,666	3,658	3,650	3,530	3,515	3,500	(136)	(4%)	(143)	(4%)	(150)	(4%)
P5744	Wheeler Branch	1,900	1,960	1,924	1,912	1,900	2,040	2,170	2,300	116	6%	258	13%	400	21%
C5287	Mexia	2,952	1,100	800	700	600	310	290	270	(490)	(61%)	(410)	(59%)	(330)	(55%)
P5551	Clifton	2,004	400	376	368	360	350	325	300	(26)	(7%)	(43)	(12%)	(60)	(17%)

1. 2050 and 2060 firm yields with no trends are linear interpolated from 2020 and 2070 values.
2. 2060 firm yields with trends are linear interpolated from 2050 and 2070 values.
3. BRA reservoir firm yield estimates are considered a stand-alone yield and do not include system operations.
4. Diversions from Lake Whitney authorized under Certificate of Adjudication 12-5157 were fully reliable in all model simulations. Due to the complexity of the Lake Whitney water rights and operations, a hypothetical junior water right was not added to the reservoir to determine the additional firm yield available. This approach is consistent with the approach used in the 2021 Brazos G RWP.
5. Lake Belton firm yield includes 12,000 ac-ft/yr of water rights held by the Department of the Army.
6. The firm yield of the BRA System Operations permit is estimated as the difference of the minimum year of the total BRA contract deliveries and the sum of the stand-alone yields of the BRA Reservoirs. The sum of the stand-alone yields does not include the 12,000 ac-ft/yr of water rights held by the Department of the Army in Lake Belton or the portion of the yield greater than the authorized amount.
7. Fort Phantom Hill Reservoir is utilized as part of the City of Abilene's indirect reuse system and for raw water supply. Yield estimates for Fort Phantom Hill Reservoir do not include effluent inflows.
8. Lake Kirby is utilized as part of the City of Abilene's indirect reuse system and not for raw water supply. Yield estimates for Lake Kirby do not include effluent inflows.

Table 2-E-2. Summary Comparison of Minimum Annual Diversion for Run-of-River Water Rights with and without Trends (ac-ft/yr)

Water Right ID	Owner	Stream	Authorized Diversion	Minimum Annual Diversion - No Trends				Minimum Annual Diversion - With Trends			Minimum Annual Diversion Comparison of With and Without Trends					
				2020	2050[1]	2060[1]	2070	2050	2060[2]	2070	2050 Difference	2050 % Difference	2060 Difference	2060 % Difference	2070 Difference	2070 % Difference
Brazos G Upper Basin (Upstream of Possum Kingdom Reservoir)																
C4212	City of Cisco	Battle Creek	1,000	0	0	0	0	0	0	0	0	---	0	---	0	---
C3718	Occidental Permian LTD.	Double Mountain Fork Brazos River	5,900	0	0	0	0	0	0	0	0	---	0	---	0	---
C3724	Frances Davis	Double Mountain Fork Brazos River	1,016	0	0	0	0	0	0	0	0	---	0	---	0	---
P4266	City of Abilene	Cedar Creek	4,330	0	0	0	0	0	0	0	0	---	0	---	0	---
P5242	Phillips Petroleum Co	Brazos River	1,552	0	0	0	0	0	0	0	0	---	0	---	0	---
Brazos G Middle Basin (Downstream of Possum Kingdom Reservoir)																
C2938	City of Temple	Leon River	15,804	10,503	9,838	9,616	9,394	9,766	9,547	9,328	(71)	(1%)	(69)	(1%)	(67)	(1%)
C2971	City of Lampasas	Sulphur Creek	3,760	815	815	815	815	815	815	815	0	0%	0	0%	0	0%
C3468	Eastland Industrial Foundation	Leon River	1,607	1,068	983	955	927	792	640	487	(191)	(19%)	(315)	(33%)	(440)	(47%)
C3761	City of Cameron	Little River	2,792	2,792	2,792	2,792	2,792	2,792	2,792	2,792	0	0%	0	0%	0	0%
C3773	Hanover Ranch, L.P.	Little River	1,653	130	130	130	130	228	228	228	98	75%	98	75%	98	75%
C3775	Lloyd E. Leifeste Et Ux	Little River	1,767	114	114	114	114	184	184	184	70	61%	70	61%	70	61%
C4104	Arcosa Aggregates, Inc.	Brazos River	3,811	232	232	232	232	834	834	834	602	259%	602	259%	602	259%
C4318	CHS Farms, LTD.	Brazos River	3,467	2,147	2,063	2,035	2,008	3,292	3,290	3,287	1,229	60%	1,254	62%	1,280	64%
C4340	City of Waco	Brazos River	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	0	0%	0	0%	0	0%
C4344	Lola Robinson	Brazos River	1,060	414	475	495	516	692	793	893	217	46%	297	60%	378	73%
C4363	Joe Reistino Estate	Brazos River	1,500	88	88	88	88	97	97	97	10	11%	10	11%	10	11%
C5271	Texas A&M University	Brazos River	1,883	229	229	229	229	316	361	406	87	38%	132	58%	177	77%
C5289	City of Groesbeck	Navasota River	2,500	1,142	1,142	1,142	1,142	1,141	1,141	1,141	(1)	(0%)	(1)	(0%)	(1)	(0%)
P3936	Holy Land & Cattle	Brazos River	2,600	52	52	52	52	52	75	99	0	0%	23	45%	47	90%
P4011	KHK Foggy Bottom Farms, Inc.	Brazos River	1,403	31	31	31	31	31	31	31	0	0%	0	0%	0	0%
P4013	Robert L. Macha Et Al	Brazos River	1,200	24	24	24	24	24	35	46	0	0%	11	45%	22	90%
P4014	Walsh Ranch, LTD.	Brazos River	1,851	37	37	37	37	37	54	70	0	0%	17	45%	33	90%
P4016	KR Sod – Brazos L.P.	Brazos River	5,440	120	120	120	120	120	120	120	0	0%	0	0%	0	0%
P4080	Gathan Reistino	Brazos River	1,500	30	30	30	30	30	30	30	0	0%	0	0%	0	0%
P5085	City of Robinson	Brazos River	6,021	5,437	4,827	4,624	4,421	5,752	5,887	6,021	925	19%	1,263	27%	1,600	36%
P5899	City of Meridian	North Bosque River	1,336	522	475	459	443	342	334	326	(133)	(28%)	(125)	(27%)	(117)	(26%)

1. 2050 and 2060 minimum annual diversion values with no trends are linear interpolated from 2020 and 2070 values.
2. 2060 minimum annual diversion values with trends are linear interpolated from 2050 and 2070 values

Table 2-E-2. Summary Comparison of Minimum Annual Diversion for Run-of-River Water Rights with and without Trends (ac-ft/yr) (continued)

Water Right ID	Owner	Stream	Authorized Diversion	Minimum Annual Diversion - No Trends				Minimum Annual Diversion - With Trends			Minimum Annual Diversion Comparison of With and Without Trends					
				2020	2050[1]	2060[1]	2070	2050	2060[2]	2070	2050 Difference	2050 % Difference	2060 Difference	2060 % Difference	2070 Difference	2070 % Difference
Region H (Lower Basin)																
C5168	Gulf Coast Water Authority	Brazos River	99,932	97,906	97,861	97,846	97,831	99,932	99,932	99,932	2,071	2%	2,086	2%	2,101	2%
C5171	Gulf Coast Water Authority	Brazos River	125,000	63,847	63,603	63,522	63,441	68,614	72,331	76,047	5,011	8%	8,808	14%	12,606	20%
C5320	NRG Texas Power LLC	Brazos River	40,000	25,032	24,960	24,936	24,912	31,234	34,227	37,219	6,274	25%	9,291	37%	12,307	49%
C5322	Gulf Coast Water Authority	Brazos River	155,000	64,911	64,988	65,014	65,040	70,616	72,356	74,095	5,628	9%	7,341	11%	9,055	14%
C5325	NRG Texas Power LLC	Dry Creek	34,300	34,300	34,300	34,300	34,300	34,300	34,300	34,300	0	0%	0	0%	0	0%
C5328	Dow Chemical	Brazos River	305,656	144,004	143,009	142,677	142,345	170,116	171,709	173,302	27,107	19%	29,032	20%	30,957	22%
C5366	Brazos Sport Water Authority	Brazos River	45,000	19,967	19,876	19,845	19,815	26,624	26,731	26,838	6,748	34%	6,886	35%	7,023	35%
C5492	U.S. Fish & Wildlife Service	Eagle Nest Lake	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	0	0%	0	0%	0	0%
P5552	Campbell Concrete & Materials, LP	Brazos River	2,300	378	378	378	378	567	567	567	189	50%	189	50%	189	50%
P5567	Campbell Concrete & Materials, LP	Brazos River	2,100	369	370	370	370	370	370	370	0	0%	0	0%	0	0%

1. 2050 and 2060 minimum annual diversion values with no trends are linear interpolated from 2020 and 2070 values.
2. 2060 minimum annual diversion values with trends are linear interpolated from 2050 and 2070 values.

APPENDIX 2-F: TREND-ADJUSTED WAM INPUT DATASETS

This appendix is provided as a separate file due to the number of pages.

APPENDIX 2-G: OTHER WAM INPUT FILES

This appendix is provided as a separate file due to the number of pages.

CHAPTER 3

Attainment of Environmental Flow Standards Under Future Water Use Scenarios and Changed Hydrological Conditions

TWDB Contract Number 2100012466

August 2021

Prepared by:

TEXAS WATER DEVELOPMENT BOARD
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3.0 ATTAINMENT OF ENVIRONMENTAL FLOW STANDARDS UNDER FUTURE WATER USE SCENARIOS AND CHANGED HYDROLOGICAL CONDITIONS

The objective of Task 3 of the study is to assess the frequency of attainment of environmental flow standards in the Brazos River Basin under changed hydrological conditions, i.e., the adjusted historical hydrology for 2050 condition developed for Task 2, using the updated daily Brazos WAM under full authorized diversions. This chapter documents the metrics used for, and summarizes the results of, the assessment. Only results depicting the comparison of the frequency of attainment under original versus adjusted hydrology are presented here. For a detailed review of the attainment of environmental flow metrics under changed hydrological conditions, please see **Appendices 3-A through 3-I**.

3.1 ENVIRONMENTAL FLOW STANDARDS (EFS)

Historically, environmental flows (e-flows) have been established as a minimum flow in the river; however, research suggests that all flow regimes (subsistence flow, baseflow, and pulse flow) are ecologically or environmentally important (Poff et al., 1997). Pauls and Wurbs (2016) demonstrated that the daily time step water availability model (WAM) can help assess the attainment of e-flow targets at multiple WAM control points while taking into consideration how various water use scenarios affect the attainment of e-flow standards.

Texas Administration Code (TAC) Title 30, Subsection 298 Environmental Flow Standards (EFS) for Surface Water, Subchapter G: Brazos River and its Associated Bay and Estuary System were adopted by Texas Commission on Environmental Quality (TCEQ) on February 12, 2014 (Effective March 6, 2014). It includes the e-flow (subsistence flow, baseflow, and pulse flow) standards of spring, summer, and winter under dry, average, and wet conditions for 19 sites (aka, control points (Figure 3-1 and Table 3-1)) in the Brazos River Basin. All e-flows in the Brazos River Basin are assigned a water right priority of March 1st, 2012. A total of 14 (out of 19) e-flow sites (control points) are selected in this study because this project focuses on the Region G and Region H Water Planning Areas downstream of Possum Kingdom Reservoir (BRSB23 is exceptionally included since it is close to this reservoir). Other control points are upstream of Possum Kingdom Reservoir. These control points are SFAS06, DMAS09, BRSE11, CFNU16 and 417431 (blank dots in Figure 3-1). When we discuss the e-flow locations in this report, we refer to the control points BRSB23, BRPP27 and BRGR30 as upstream control points. We refer to all locations below BRWA41 as downstream, while BRWA41 is in the middle.

The daily Brazos WAM input file obtained from Texas A&M University used control point CON026 for EFS at Clear Fork Brazos River at Lueders (USGS Gage # 08084200). However, per TCEQ official information (water right viewer and WAM file), this e-flow site is located at control point 417431. For consistency, we updated the identifier CON026 to 417431 in the WAM input files for this EFS control point (CON026 is about 10 miles upstream of Lueders).

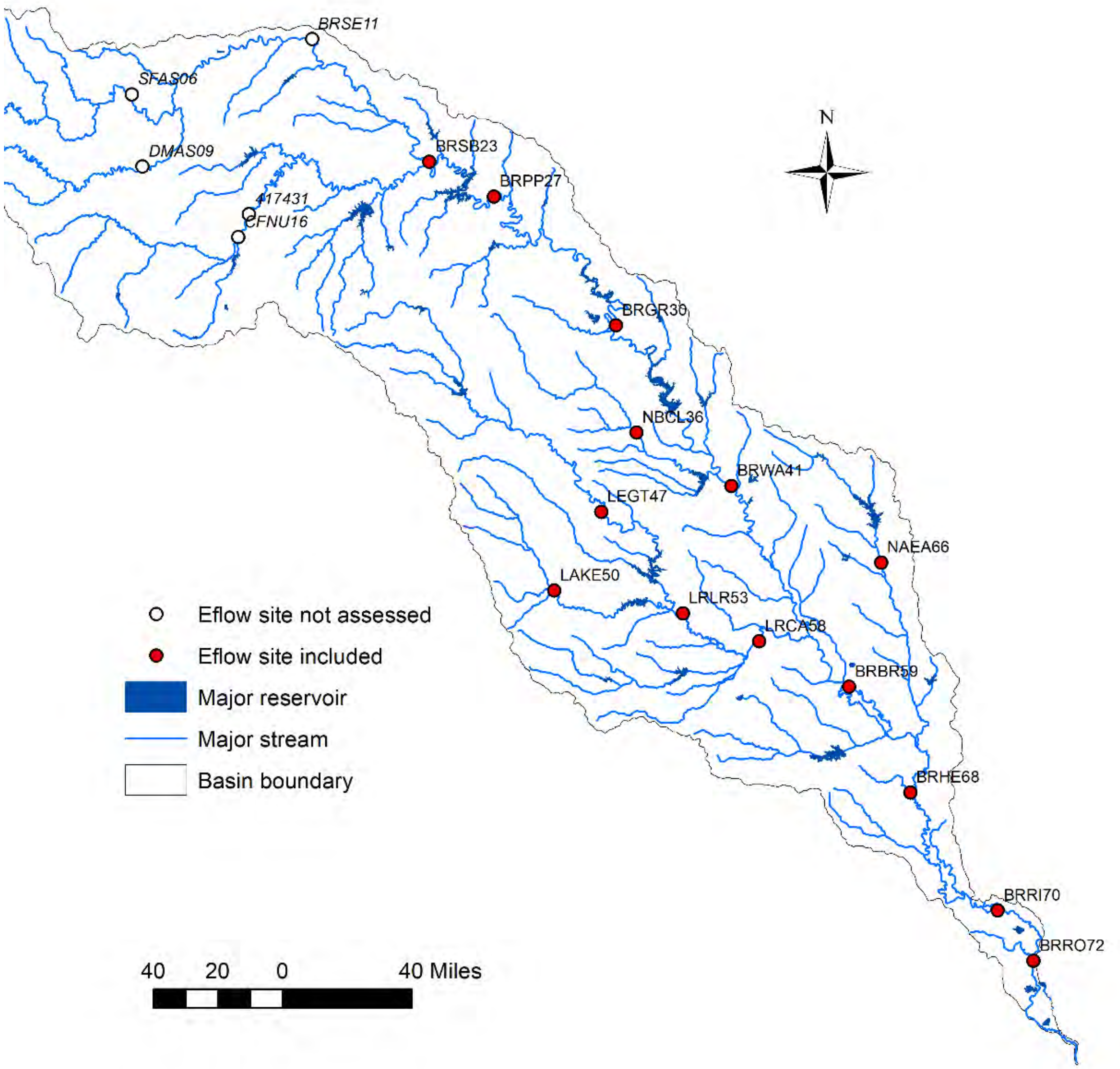

Figure 3-1 – WAM Control Point (CP) Locations for Environmental Flow Standards in Brazos River Basin

Table 3-1 – WAM Control Point (CP) Locations for Environmental Flow Standards (EFS) in Brazos River Basin

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area (square miles)[a]
SFAS06	*Salt Fork Brazos River*	*Aspermont*	*08082000*	*2,504*
DMAS09	*Double Mountain Fork*	*Aspermont*	*08080500*	*1,891*
BRSE11	*Brazos River*	*Seymour*	*08082500*	*5,996*
CFNU16	*Clear Fork Brazos*	*Nugent*	*08084000*	*2,236*
417431	*Clear Fork Brazos*	*Lueders*	*08084200*	*2,542*
BRSB23	Brazos River	South Bend	08088000	13,171
BRPP27	Brazos River	Palo Pinto	08089000	14,309
BRGR30	Brazos River	Glen Rose	08091000	16,320
NBCL36	North Bosque River	Clifton	08095000	977
BRWA41	Brazos River	Waco	08096500	20,065
LEGT47	Leon River	Gatesville	08100500	2,379
LAKE50	Lampasas River	Kempner	08103800	817
LRLR53	Little River	Little River	08104500	5,266
LRCA58	Little River	Cameron	08106500	7,100
BRBR59	Brazos River	Bryan	08109000	30,016
NAEA66	Navasota River	Easterly	08110500	936
BRHE68	Brazos River	Hempstead	08111500	34,374
BRRI70	Brazos River	Richmond	08114000	35,454
BRRO72	Brazos River	Rosharon	08116650	35,775

Italics indicate the control point was not assessed as part of Task 3.
[a] *Watershed areas from the DIS file for the Brazos WAM.*

3.2 DAILY BRAZOS WAM

3.2.1 Original daily Brazos WAM from Texas A&M University

The Texas WAM System is based on a monthly computational time step. However, certain environmental flow metrics, such as pulse flows, cannot be resolved with a monthly WAM. To simulate environmental flow requirements and reservoir flood control processes, Texas Commission of Environmental Quality (TCEQ) contracted with Texas A&M University in 2012 (Wurbs and Hoffpauir, 2012) to develop and update (up to 2020) a daily WAM model for the Brazos River Basin for a better simulation for all e-flow regimes (subsistence flow, baseflow, and pulse flow) (Wurbs, R. A., 2019).

At the daily time step, the monthly naturalized flow inputs are disaggregated into daily naturalized flow by a methodology called "daily flow pattern" identified from historical daily flow records. The daily instream flow targets for EFS can be simulated and be summed to monthly quantities within the daily SIMD simulation for input to the monthly SIM simulation model. The monthly SIM model is commonly used in Texas water resource management and planning processes. The SIMD and SIM are executable programs for running the daily and monthly model, respectively. The daily version of the Brazos WAM was created by Dr. Wurbs' group at Texas A&M University in 2019 (and finalized in 2020), by converting the monthly WAM (TCEQ WAM Run3 version of 2008) to daily, adding routing parameters for 67 selected river reaches, flood control operations of 19 U.S. Army Corps of Engineers (USACE) reservoirs, and environmental flow standards at 19 gaged sites. The hydrologic period of analysis was updated to extend from January 1940 through December 2017. Monthly naturalized stream flows at 77 primary gaged control points are disaggregated to daily based on daily pattern hydrographs at 58 gaging stations. Other monthly input datasets, including net reservoir evaporation and diversions, are disaggregated evenly for all days in a month. Routing and forecasting are also included in the daily WAM.

The Hydrologic [Drought] Index (HI) records in the Brazos daily WAM contain a hydrologic condition parameter with values of 1, 2, or 3 indicating dry, average, or wet hydrologic conditions for each month for the lower, middle, or upper basin. Each of the 19 EFS gaged sites are in either the upper, middle, or lower basin.

3.2.2 TWDB updates to the existing daily Brazos WAM

TWDB updates to the existing daily Brazos WAM include use of the adjusted hydrology for the 2050 condition. Due to limited manpower and time, we did not include 2070 for this e-flow evaluation. All changes and additions are marked/commented with "TWDB" in the WAM input files. For detailed updates, please refer to **Appendix 3-J**.

3.3 DAILY BRAZOS WAM IMPLEMENTATION FOR E-FLOW STANDARD

Instream flow targets for subsistence flow and baseflow requirements - As described by Dr. Wurbs (Wurbs, 2019), the subsistence and baseflow limits are applied differently for dry hydrologic conditions than for average and wet hydrologic conditions. A 50% rule (described below) is applied if the hydrologic condition is dry as measured by the Palmer Hydrologic Drought Index (PHDI) being in the lowest quartile. A target for a particular day at a particular location is set based on subsistence and baseflow requirements as follows.

Under dry hydrologic conditions:

1. If the flow in that day is less than the subsistence flow limit in Table 3-2, then the instream flow target is set equal to the subsistence flow limit.

2. If the flow equals or exceeds the subsistence flow limit but is less than the baseflow limit in Table 3-2, then the instream flow target is equal to the subsistence flow limit plus 50 percent of the difference between the actual flow and the subsistence flow limit.

Under average or wet hydrologic conditions, the minimum instream flow limit is set at the baseflow limit which varies seasonally as shown in Table 3-2**.** The subsistence flow limits are not considered.

Table 3-2 – EFS for the subsistence flow and baseflow in Brazos River Basin

Gage and Control Point	Subsistence Flow (cfs)	Baseflow (cfs)								
		Winter			Spring			Summer		
		Dry	Avg	Wet	Dry	Avg	Wet	Dry	Avg	Wet
BRSB23	1	36	73	120	29	60	100	16	46	95
BRPP27	17	40	61	100	39	75	120	40	72	120
BRGR30	16	42	77	160	47	92	170	37	70	160
NBCL36	1	5	12	25	7	16	33	3	8	17
BRWA41	56	120	210	480	150	270	690	140	250	590
LEGT47	1	9	20	52	10	24	54	4	12	27
LAKE50	10	18	27	39	21	29	43	16	23	32
LRLR53	55	82	110	190	95	150	340	84	120	200
LRCA58	32	110	190	460	140	310	760	97	160	330
BRBR59	300	540	860	1,760	710	1,260	2,460	630	920	1,470
NAEA66	1	9	14	23	10	19	29	3	8	16
BRHE68	510	920	1,440	2,890	1,130	1,900	3,440	950	1,330	2,050
BRRI70	550	990	1,650	3,310	1,190	2,140	3,980	930	1,330	2,190
BRRO72	430	1,140	2,090	4,700	1,250	2,570	4,740	930	1,420	2,630

Instream flow target for pulse flow requirements - The quantities used to set pulse flow targets are tabulated in Table 3-3. A qualifying pulse event is initiated when the flow exceeds the prescribed peak trigger flow (Qp) tabulated in Table 3-3 in units of cubic feet per second (cfs). A pulse flow event is terminated when either the volume limit (Vol in acre-feet in Table 3-3) or the duration limit (Dur in days in Table 3-3) is reached. Pulse flow events initiated in a particular season or year continue into the following season or year if and as necessary to meet the volume and/or duration termination criteria.

Pulse flow events are tracked in the SIMD modeling system to set minimum instream flow targets for each day of the tracked flow event. The daily pulse flow target is computed as the lesser of the (1) daily regulated flow, (2) peak trigger volume Qp tabulated in Table 3-3, or (3) remaining volume that will satisfy the volume criterion. The daily minimum instream flow target is the greater of the subsistence and baseflow target and high pulse target.

Table 3-3 – EFS for the pulse flow component in the Brazos River Basin

	Winter				Spring				Summer			
	Qp (cfs)	Freq	Vol (ac-ft)	Dur (day)	Qp (cfs)	Freq	Vol (ac-ft)	Dur (day)	Qp (cfs)	Freq	Vol (ac-ft)	Dur (day)
BRSB23	Brazos River at South Bend											
dry	–	–	–	–	1,260	1	7,280	10	580	1	3,140	8
average	–	–	–	–	1,260	2	7,280	10	580	2	3,140	8
wet	–	–	–	–	2,480	1	15,700	13	1,180	1	7,050	11
BRPP27	Brazos River at Palo Pinto											
dry	850	2	3,690	5	1,400	2	6,600	6	1,230	2	5,920	6
average	850	4	3,690	5	1,400	4	6,600	6	1,230	4	5,920	6
average	1,390	2	7,180	7	3,370	2	20,200	10	2,260	2	13,000	9
wet	850	4	3,690	5	1,400	4	6,600	6	1,230	4	5,920	6
wet	1,390	3	7,180	7	3,370	3	20,200	10	2,260	3	13,000	9
BRGR30	Brazos River at Glen Rose											
dry	930	2	5,400	8	2,350	2	14,300	10	1,320	2	7,830	8
average	930	4	5,400	8	2,350	4	14,300	10	1,320	4	5,920	6
average	1,700	2	10,800	10	6,480	2	46,700	14	3,090	2	21,200	12
wet	930	4	5,400	8	2,350	4	14,300	10	1,230	4	7,830	6
wet	1,700	3	10,800	10	6,480	3	46,700	14	3,090	2	21,200	12
NBCL36	North Bosque River at Clifton											
dry	–	–	–	–	710	1	3,490	12	–	–	–	–
average	–	–	–	–	710	3	3,490	12	–	–	–	–
wet	120	2	750	10	710	3	3,490	12	130	2	500	6
BRWA41	Brazos River at Waco											
dry	2,320	1	12,400	7	5,330	1	32,700	10	1,980	1	10,500	7
average	2,320	3	12,400	7	5,330	3	32,700	10	1,980	3	10,500	7
wet	4,180	2	25,700	9	13,600	2	102,000	14	4,160	2	26,400	10
LEGT47	Leon River at Gatesville											
dry	–	–	–	–	340	1	1,910	10	58	1	220	4
average	–	–	–	–	340	3	1,910	10	58	3	220	4
wet	100	2	540	6	630	2	4,050	13	140	2	600	6
LAKE50	Lampasas River at Kempner											
dry	78	1	430	8	780	1	4,020	13	77	1	270	4
average	78	3	430	8	780	3	4,020	13	77	3	270	4
wet	190	2	1,150	11	1,310	2	6,860	16	190	2	680	6
LRLR53	Little River at Little River											
dry	520	1	2,350	5	1,420	1	9,760	10	430	1	1,560	4
average	520	3	2,350	5	1,420	3	9,760	10	430	3	1,560	4
wet	1,600	2	11,800	11	3,290	2	32,200	17	1,060	2	5,890	8

Table 3-3 – EFS for the pulse flow component in the Brazos River Basin (continued)

	Winter				Spring				Summer			
	Qp (cfs)	Freq	Vol (ac-ft)	Dur (day)	Qp (cfs)	Freq	Vol (ac-ft)	Dur (day)	Qp (cfs)	Freq	Vol (ac-ft)	Dur (day)
LRCA58	Little River near Cameron											
dry	1,080	1	6,680	8	3,200	1	23,900	12	560	1	2,860	6
average	1,080	3	6,680	8	3,200	3	23,900	12	560	3	2,860	6
wet	2,140	2	14,900	10	4,790	2	38,400	14	990	2	5,550	8
BRBR59	Brazos River at Bryan											
dry	3,230	1	21,100	7	6,050	1	49,000	11	2,060	1	12,700	7
average	3,230	3	21,100	7	6,050	3	49,000	11	2,060	3	12,700	7
wet	5,570	2	41,900	10	10,400	2	97,000	14	2,990	2	20,100	8
NAEA66	Navasota River at Easterly											
dry	260	1	1,610	9	720	1	4,590	11	–	–	–	–
average	260	3	1,610	9	720	3	4,590	11	–	–	–	–
wet	800	2	5,440	12	1,340	2	8,990	13	49	2	220	5
BRHE68	Brazos River at Hempstead											
dry	5,720	1	49,800	10	8,530	1	85,000	13	2,620	1	17,000	7
average	5,720	3	49,800	10	8,530	3	85,000	13	2,620	3	17,000	7
wet	11,200	2	125,000	15	16,800	2	219,000	19	5,090	2	40,900	9
BRRI70	Brazos River at Richmond											
dry	6,410	1	60,600	11	8,930	1	94,000	13	2,460	1	16,400	6
average	6,410	3	60,600	11	8,930	3	94,000	13	2,460	3	16,400	6
wet	12,400	2	150,000	16	16,300	2	215,000	19	5,430	2	46,300	10
BRRO72	Brazos River at Rosharon											
dry	9,090	1	94,700	12	6,580	1	58,500	10	2,490	1	14,900	6
average	9,090	3	94,700	12	6,580	3	58,500	10	2,490	3	14,900	6
wet	13,600	2	168,000	16	14,200	2	184,000	18	4,980	2	39,100	9

The parameters used in defining high flow pulse events as shown in Table 3-3 are:

The flow rate as trigger for a pulse (Qp in Table 3-3) − The trigger flow rates (Qp) for high pulse events were originally established as the peak daily flow rates associated with specified annual exceedance frequencies. Tracking of a pulse flow event is initiated on the day in which the flow rate exceeds Qp. For a tracked flow pulse, the instream flow target for each day is the minimum of Qp, the actual flow rate, or the remaining volume required to meet the volume criterion.

The pulse frequency (Freq in Table 3-3) − The frequency (Freq) is the target number of pulse events with the specified metrics to initiate, track, and preserve in the specified season.

The pulse flow volume (Vol in Table 3-3) − The summation of the daily flow volumes from the day in which tracking of a pulse event begins through the current day serves as one of the criteria for terminating the tracking of a pulse event. Accumulated flow volume is in acre-feet.

The duration limit for a pulse (Dur in Table 3-3) − The prescribed pulse duration in days also serves as a criterion for terminating the tracking of a high flow pulse event.

A pulse event is initiated when the flow exceeds its Qp, which is tabulated in Table 3-3. When there are multiple pulse requirements (i.e., regular pulse and overbank pulse) and during the tracking of these pulse events, flows may increase to a magnitude that exceeds the greater Qp of a larger pulse (i.e., overbank pulse), as shown in Table 3-3. In this case, the parameters of the higher flow pulse take control of the continued tracking. The higher magnitude pulse event is considered to satisfy all lower magnitude events in the same season. A big pulse includes a small pulse, and both are engaged and counted.

An accounting is maintained of the number of pulse flow events that satisfy the prescribed criteria outlined in Table 3-3. Pulses are used to set instream flow targets only to the extent necessary to satisfy the frequency criteria in Table 3-3. For example, after two pulses that satisfy the two-per-season event criteria, additional pulses occurring in that season are not required to be preserved, and hence are not engaged (it is known as excessive pulse).

3.4 ATTAINMENT METRICS FOR THE ENVIRONMENTAL FLOW STANDARDS

In the context of this chapter, attainment metrics can refer to engaged frequency, both engaged and met frequency, and period or volume reliability. Commonly, we define attainment as the estimated frequency at which an engaged standard is met. Attainment metrics may also include the amount by which a standard is not met, such as percent shortage. These metrics can also be divided by season or other subset of the data, such as hydrologic (dry, average, and wet) conditions.

We used the attainment metrics defined in Pauls and Wurbs (2016) for this study. In addition, we also assessed attainment of metrics at the seasonal timescale (instead of for a full year), and all hydrologic conditions (dry, average, and wet conditions), except for subsistence flow which is only applicable to the dry condition. In addition, we added total zero flow days (ZFD) and maximum length of consecutive zero flow days (MLZFD), maximum length of consecutive shortage days (MLSD), and number of shortage events (SE), because metrics such as no flow or shortage condition are critical in ecological assessments. The following definitions are used for subsistence flow and baseflow metrics.

1) Engaged (**E** (day)) - all days that engaged with an E-flow regime, subsistence flow or baseflow target.

2) Engagement Frequency (**EF** (%)) – number of engaged days expressed as a percentage of all days in a hydrologic condition of a season.

3) Zero-flow days (**ZFD** (day)) – total zero-flow days in the entire simulation period.

4) Maximum length of consecutive zero-flow days (**MLZFD** (day)) – maximum length of consecutive zero-flow days in the entire simulation period.

5) Total shortage days (**TSD** (day)) – total days having shortage for the subsistence flow or baseflow requirement for a hydrologic condition in a season.

6) Maximum length of consecutive shortage days (**MLSD** (day)) – maximum length of consecutive shortage days for the subsistence flow or baseflow requirement for a hydrologic condition in a season.

7) Shortage event (**SE** (count)) – number of shortage events. A shortage event is defined as a period that has consecutive days of shortages.

8) Engaged volume reliability (**EVR** (%)) - engaged volume reliability is defined as the total engaged regulated flow volume as a percentage of the total target volume of the same period.

9) Engaged and met period reliability (**EMPR** (%)) - engaged and met period reliability is defined as total days of both engaged and met target as percentage of total days of engaged.

10) Average shortage (**AS or Average_S** (ac-ft)) - average shortage is defined as total shortage volume divided by the number of days having a shortage.

11) Average percent shortage (**APS or Average_PS** (%)) – average percent shortage is defined as total shortage volume divided by total target for the engaged days having shortage.

12) Average percent shortage for the whole applicable period (**ASPAT** (%)) - average percent shortage for the whole applicable period is defined as total shortage volume divided by total target of the applicable period which is defined as engaged period with and without shortage.

ZFD and MLZFD are listed in subsistence flow metrics table and not repeated in other tables.

For pulse flow attainment metrics, in addition to all pulse flow attainment metrics defined in Pauls and Wurbs (2016) study, we also included season counts and pulse event counts to assess the reliability of pulse event counts.

Pulse flow metrics were assessed for three seasons and three types of hydrologic condition (HC), as well as by pulse specification as described in the attainment metrics table (Table 3-3). We count total season numbers encountered for a type of HC during the entire simulation period. Total season numbers under different hydrologic (drought) conditions in the upper, middle, and lower basins vary, since those drought index values from 1940 to 2017 (78 years) were determined by Dr. Wurbs (2019) based on lower 25 percentile for dry, upper 25% (>75 percentile) for wet, and middle 50% (25-75 percentile) for average conditions. However, our simulation is from 1940 to 2015 (76 years). Therefore, it may not be 25%, 50% and 25% for the dry, average, and wet distribution, because we excluded 2016 and 2017. For instance, in lower basin, the spring season with dry condition is 22 years, out of 76 years. Others are 35 years for average, and 19 years for wet condition. Hence, the dry, average, and wet drought condition used here is consistent with Dr. Wurbs daily Brazos WAM, and it may differ with the trend analysis in the previous chapters. Below are our definitions of the metrics for the pulse flow.

1) Percent of Season Engaged (**PSE** (%)) – total number of seasons that have pulse engagement as percent of total number of applicable seasons.
2) Percent of Seasons Met (**PSM** (%)) – total number of seasons that met the required pulse frequency as percent of total number of applicable seasons.
3) Engaged (**E** (day)) - total days of pulse flow engagement in an applicable season and hydrologic condition.
4) Engaged Frequency (**EF** (%)) – percent of days that are engaged in an applicable season and hydrologic condition.
5) Engaged Volume Reliability (**EVR** (%)) – total regulated flow of the engaged period as a percent of the total target during the same period.
6) Engaged Pulse (**EP** (count)) – The number of engaged pulse events in an applicable season and hydrologic condition.

7) Percent of Engaged Pulse (**PEP** (%)) – number of engaged pulses as a percent of total required pulse number for an applicable season and hydrologic condition.

Supplementary metrics:

8) Total days that meet and exceed pulse trigger (**days >= trigger** (day)). This is used to check the overall high flow situation which may be less or more than the required high flows. Please note that the final regulated flow is often greater than the regulated flow at the EFS priority, due to pass through flow and flood releases.

9) Average days between engaged pulses (**ADBP** (day)). For those seasons that have two or more pulse engagements. This is useful for checking distance (days) between engaged pulses.

Since all e-flow engagement assessments are based on regulated flow, we included comparisons of regulated flows and their exceedance frequency, as simulated with the original versus adjusted hydrology. **Appendices 3-A through 3-I** also includes raster hydrographs of subsistence flow and baseflow shortage, zero flow days, days flow is greater than pulse flow trigger, and the days that a pulse is engaged.

3.5 SIMULATION BY DAILY BRAZOS WAM

The **routing and forecast** option is activated for better accuracy of the final simulations with input parameter FCST in the JU record field 6 set at 2. The forecast period FPRD is entered in the JU record field 7, with a blank JU field 7 activating a SIMD routine that automatically computes the forecast period. The automatic default forecast period for the Brazos WAM is 93 days computed within SIMD as twice the longest flow path plus one day (Wurbs, 2019). This ensures that every water right is simulated during the forecast period with future downstream flows for each forecast day that covers the current forecast day with enough future days from the previous forecast simulation to provide downstream future flows at the relevant control points all the way to the outlet. Therefore, allowing negative incremental flow is appropriate and is implemented by changing the ADJINC parameter to 7 in JD field 9.

3.6 MAJOR FINDINGS AND DISCUSSIONS

3.6.1 Regulated flow changes

At the upstream site BRSB23, on the main stem of the Brazos River, regulated flows by adjusted hydrology (red line in Figure 3-2) show a decline from the original hydrology, except for the very high flood flows (i.e., exceedance frequency less than three), which have little to no change.

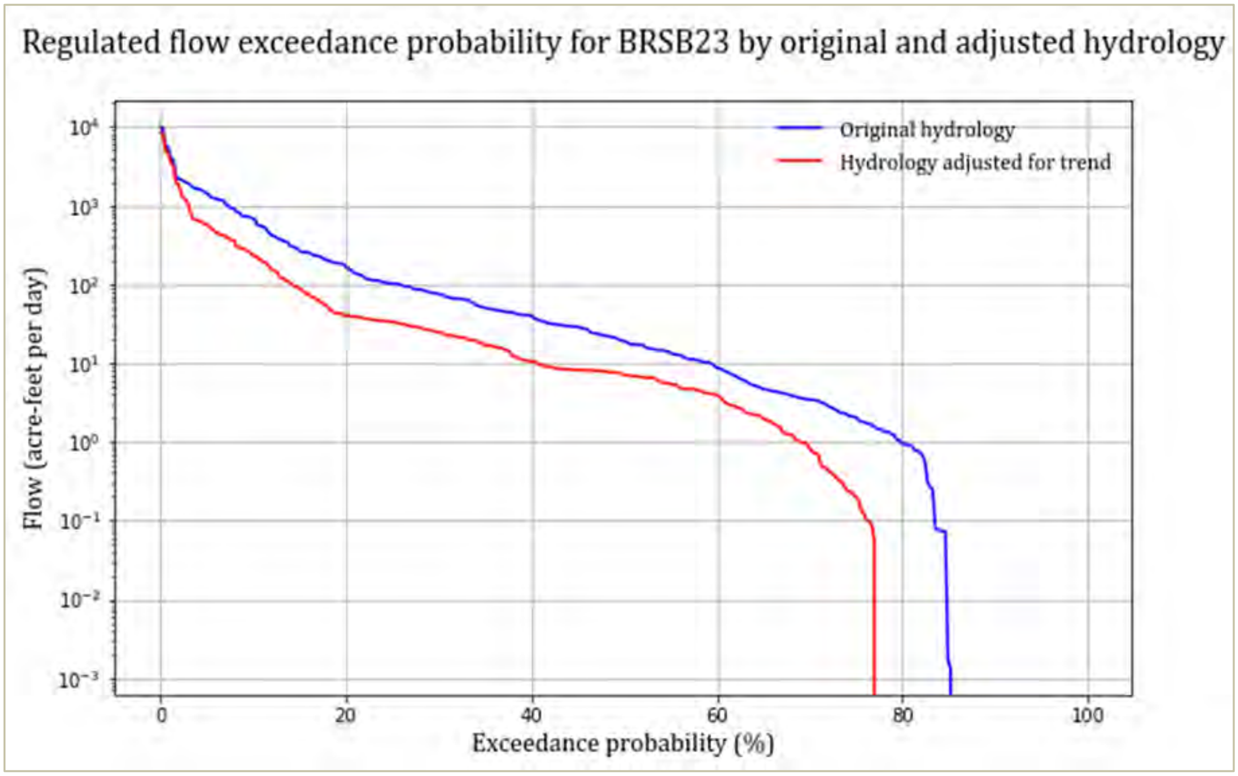

Figure 3-2 – Comparison of the exceedance probability of regulated flow simulated from the daily Brazos WAM using adjusted hydrology (red) versus original hydrology (blue) at BRSB23

Changes in regulated flow at the upstream site BRPP27 are mixed. There are changes at very high flows (< 7% exceedance probability), a decrease in medium flows (8–60% of exceedance probability), an increase at low flow (70–95% exceedance probability), and a decrease for very low flow (95–100% exceedance probability) (Figure 3-3, top). At BRGR30, there is a slight decrease in medium flows (8–60% of exceedance probability) and an increase in low flows (> 80% exceedance probability) under adjusted hydrology (Figure 3-3 bottom).

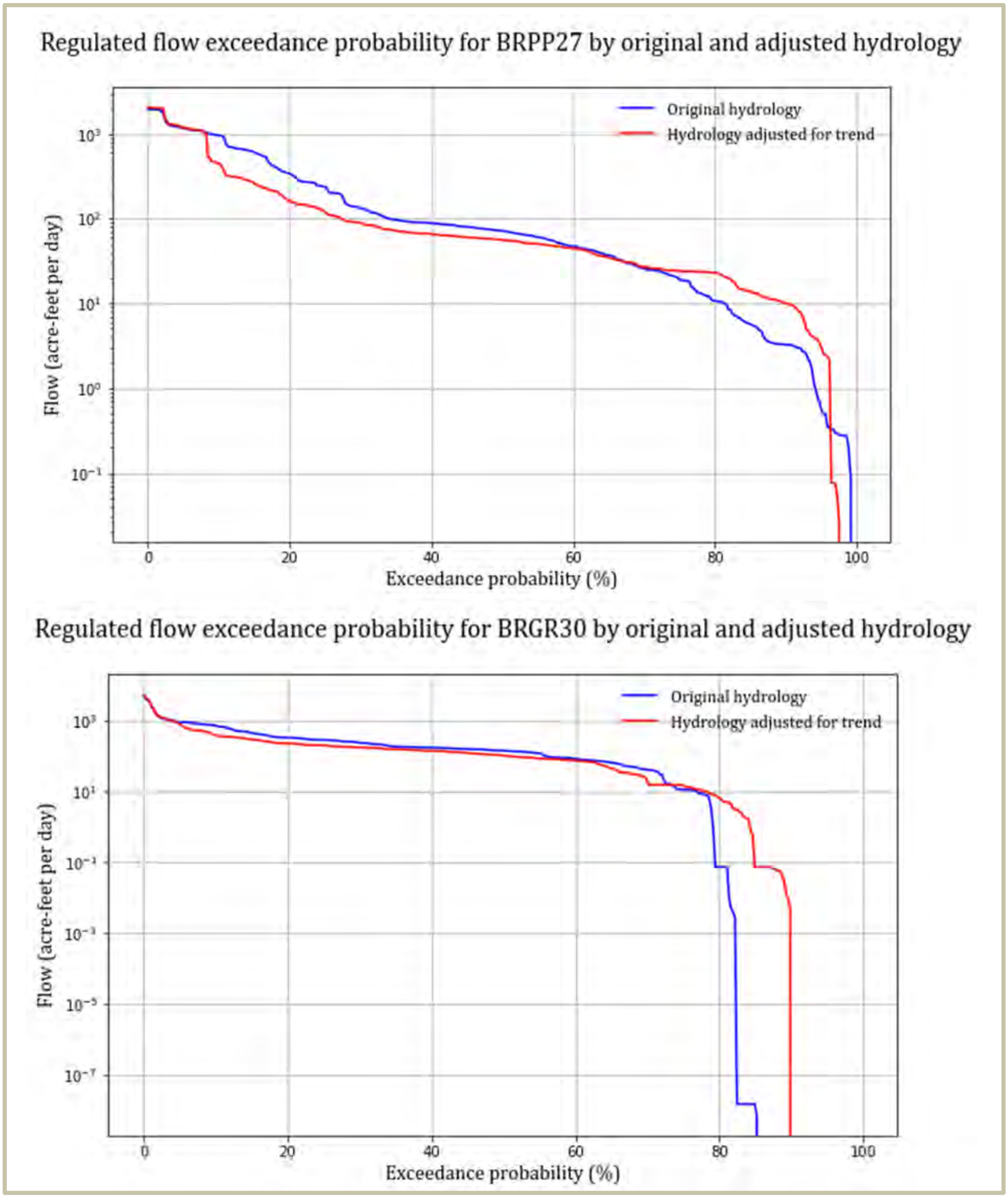

Figure 3-3 – Comparison of the exceedance probability of regulated flow simulated from the daily Brazos WAM using adjusted hydrology (red) versus original hydrology (blue) at BRPP27 (top) and at BRGR30 (bottom).

At all other middle and downstream sites along the Brazos River, regulated flows for the adjusted hydrology exhibit minor increases compared with the original hydrology, and some increases in lower flows at sites BRWA41, BRHE68 and BRRI70. Figure 3-4 shows this for BRHE68. BRWA41 and B44170 have similar increases (not shown).

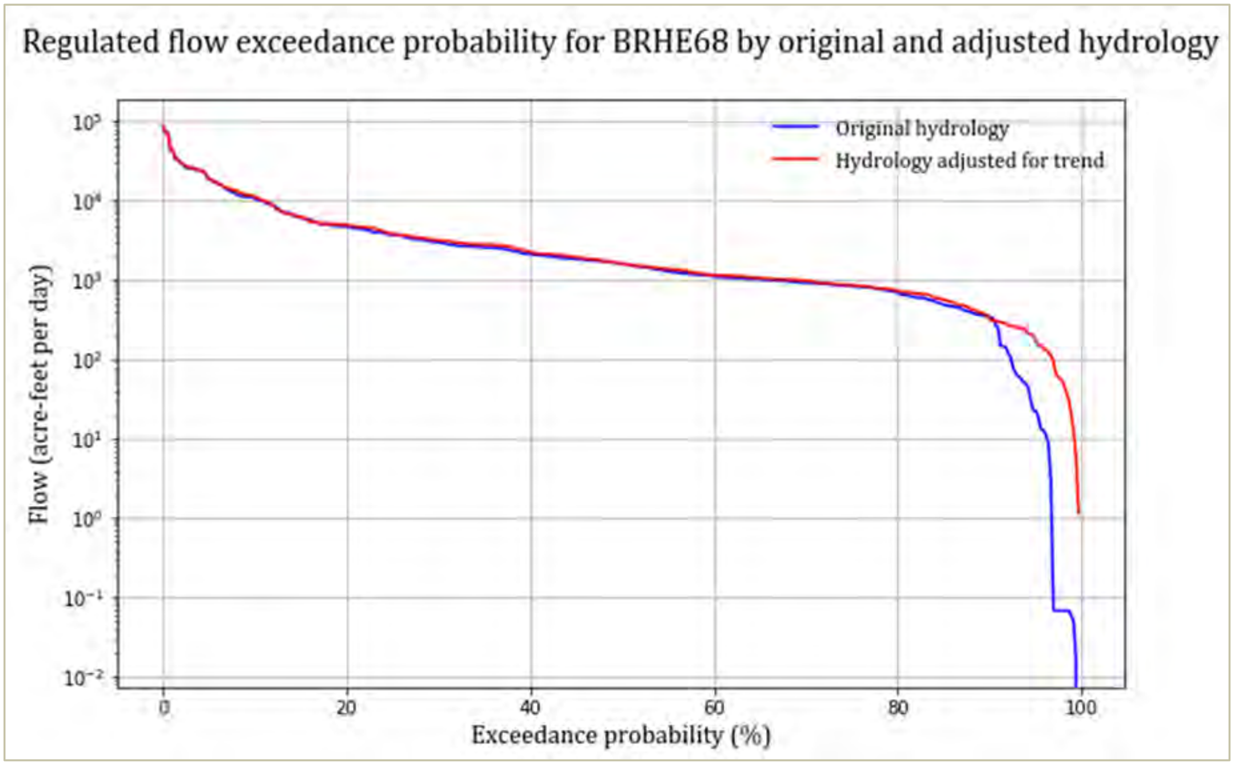

Figure 3-4 –Comparison of the exceedance probability of regulated flow simulated from the daily Brazos WAM using adjusted hydrology (red) versus original hydrology (blue) at BRHE68

In the Little River watershed (LEGT47, LAKE50, LRLR53 and LRCA58) and at two other tributary sites (NBCL36 and NAEA66), there is much less change to the regulated flow from original hydrology to adjusted hydrology, except at NAEA66, where there is a major increase in low flows (Figure 3-5).

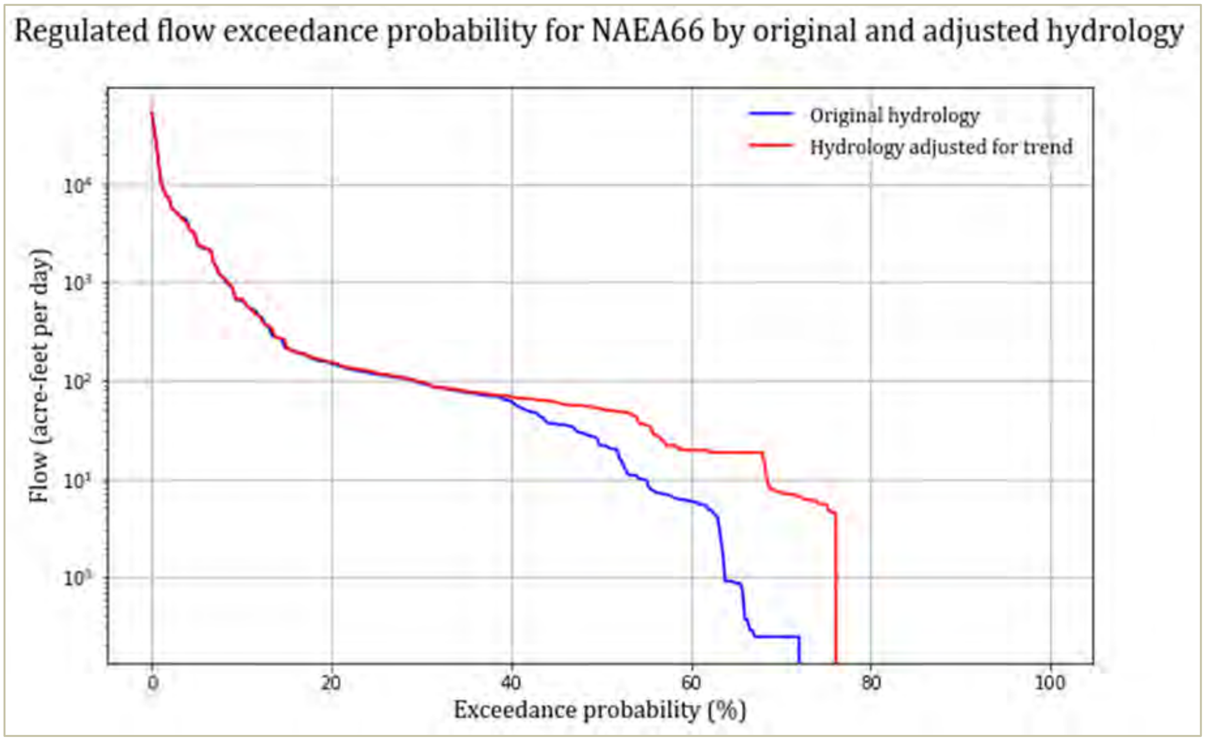

Figure 3-5 – Comparison of the exceedance probability of regulated flow simulated from the daily Brazos WAM using adjusted hydrology (red) versus original hydrology (blue) at NAEA66

For detailed results on regulated flow changes at all sites, please refer to **Appendix 3-I**.

3.6.2 Zero-flow day changes

There is an increase in zero-flow days (ZFD) in the adjusted hydrology (Figure 3-6, solid blue bars) at the upstream locations of BRSB23, BRPP27, and BRGR30, and at the most downstream location of BRO72. At the mid- and lower-basin locations of BRWA41, BRBR59, BRHE68, and BRRI70, there is a decrease in ZFDs in the adjusted hydrology, with the decrease at BRRI70 being particularly significant. Conversely, the increase in ZFD at the most downstream location is more than double the number of ZFDs in the original hydrology.

The maximum length of zero-flow days (MLZFD) increases in the adjusted hydrology at the upstream locations of BRSB23 and BRPP27 (Figure 3-6, solid orange bars). We see decreases in MLZFD in the adjusted hydrology in all locations downstream of BRPP27 through to BRRI70. As with ZFD, there is a greater than two-fold increase in MLZFD at the most downstream location of BRRO72.

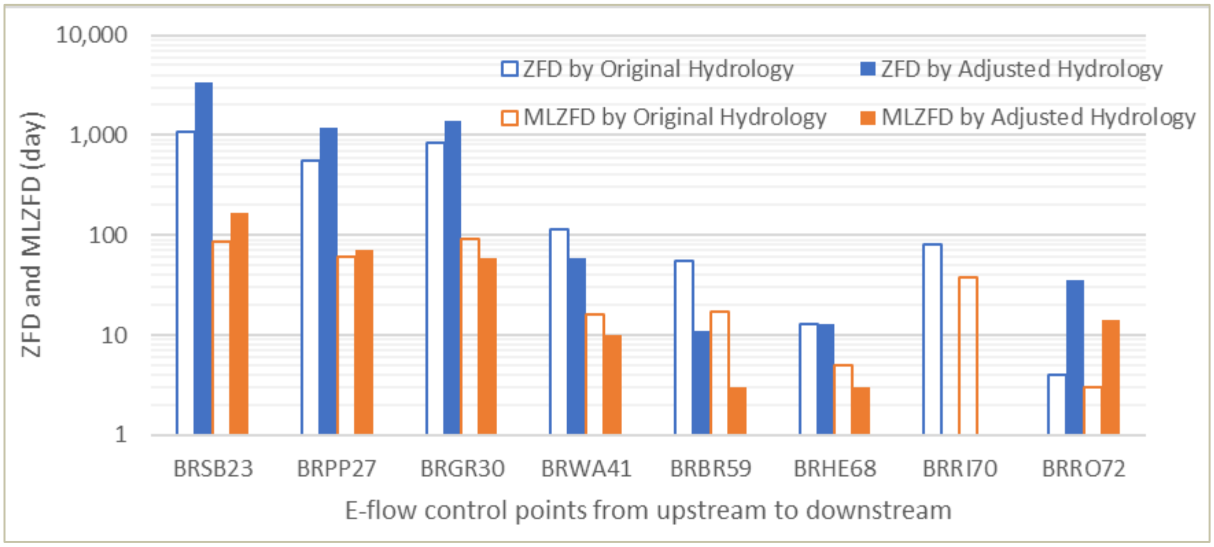

Figure 3-6 – Comparison of the number of zero-flow days (blue bars) and maximum length of zero-flow days (orange bars) along the Brazos River simulated from the daily Brazos WAM using original hydrology (open bar) versus adjusted hydrology (solid bar).

For the Little River tributary, changes in ZFD and MLZFD days are minimal between original and adjusted hydrology (Figure 3-7, first four bar plots on left).

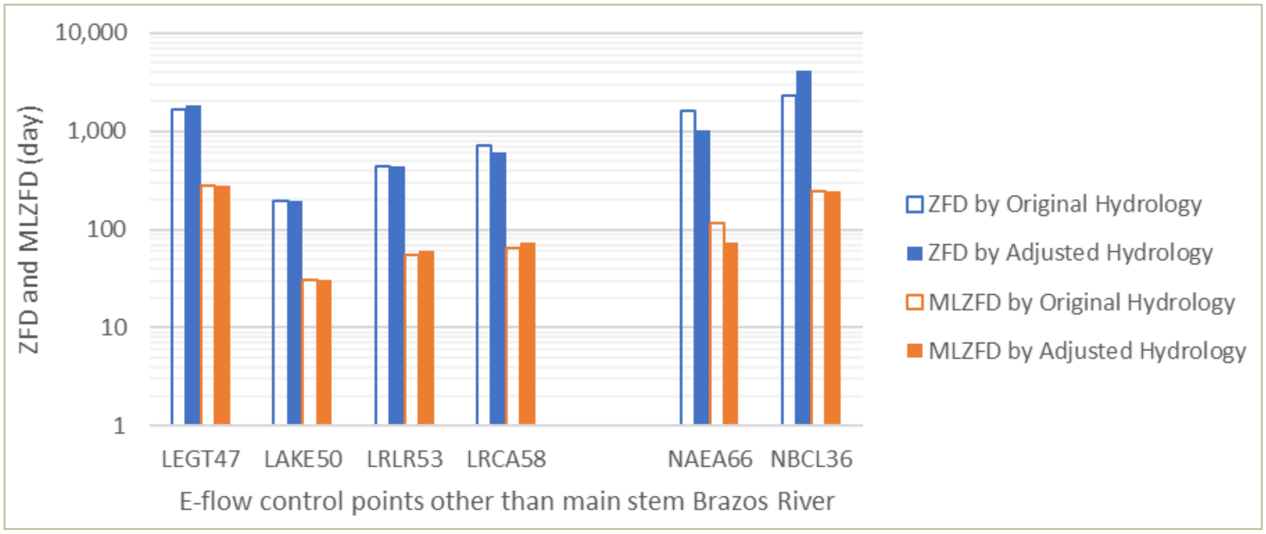

Figure 3-7 – Comparison of the number of zero-flow day(ZFD) and maximum length of zero-flow day (MLZFD) along the Little River (left 4 sites), Navasota River (NAEA66), and North Bosque River (NBCL36) simulated using original hydrology (open bar) versus adjusted hydrology (solid bar).

In the Navasota River (NAEA66) and North Bosque River (NBCL36) tributaries, the adjusted hydrology shows a decrease in both ZFD and MLZFD at NAEA66 compared to the original hydrology. At NBCL36, the adjusted hydrology shows an increase in ZFD and a slight decrease in MLZFD compared to the original hydrology.

3.6.3 Attainment of subsistence flow requirements

Subsistence flow is only applicable during dry seasons in the Brazos River Basin.

Spring dry condition: The change in engagement frequency (EF) of subsistence flow between the original and adjusted hydrology is minimal (Figure 3-8, light blue vs. dark blue bars in) for the dry spring hydrologic condition. However, there are decreases in the engaged and met percent reliability (EMPR) requirement, as simulated by the adjusted hydrology (dark orange bars in Figure 3-8), at three upstream points (i.e., BRSB23, BRPP27, and BRGR30). There are minor increases in EMPR under adjusted hydrology at control points in the middle to lower basins (i.e., from BRWA41 to BRRO72).

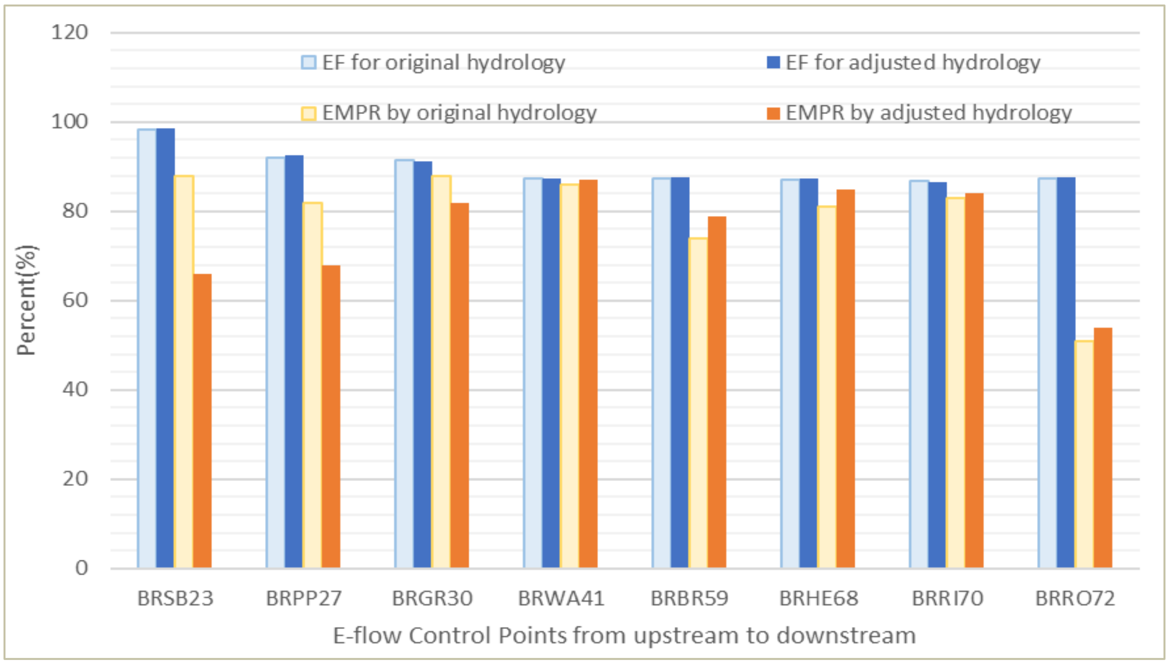

Figure 3-8 – Comparison of engagement (EF) and engage plus met (EMPR) simulated using original (light shade) versus adjusted hydrology (dark shade) for subsistence flow in the spring dry condition.

Summer dry condition: The change in engagement frequency (EF) of subsistence flow between the original and adjusted hydrology is minimal (Figure 3-9) for the dry summer hydrologic condition. There are decreases in the Engaged and Met Percent Reliability (EMPR) as simulated by original and adjusted hydrology at three upstream points (i.e., BRSB23, BRPP27 and BRGR30) (light orange vs. orange in Figure 3-9). There are increases in EMPRs at several points from and downstream of BRWA41.

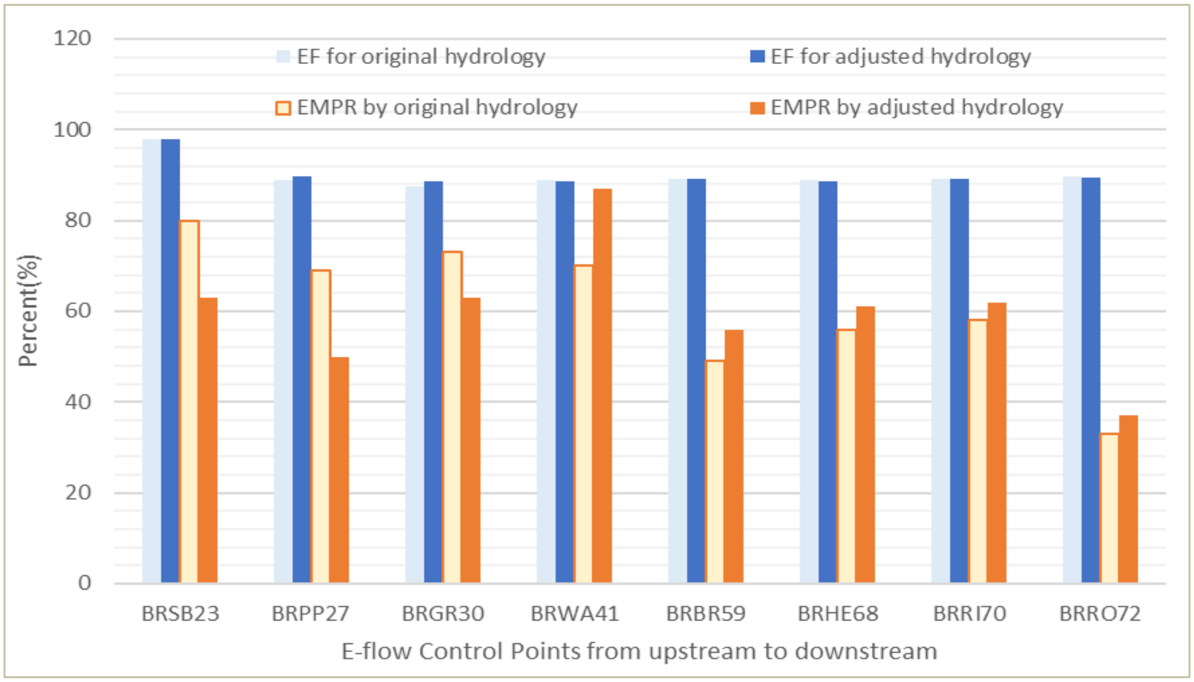

Figure 3-9 – Comparison of engagement (EF) and engage plus met (EMPR) simulated using original (light blue and light orange) versus adjusted hydrology (blue and orange) for subsistence flow in the summer dry condition.

Winter dry condition: The change in engagement frequency (EF) of subsistence flow between the original and adjusted hydrology is minimal (Figure 3-10, light blue vs. dark blue bars in) for the dry winter hydrologic condition. However, there are decreases in the Engaged and Met Percent Reliability (EMPR) as simulated by adjusted hydrology at two upstream points (i.e., BRSB23 and BRGR30) (Figure 3-10, light orange vs. orange in). In contrast, there are increases EMPRs at several other points, most notably at BRWA41 and BRBR59, where the EMPR increases by over 10%.

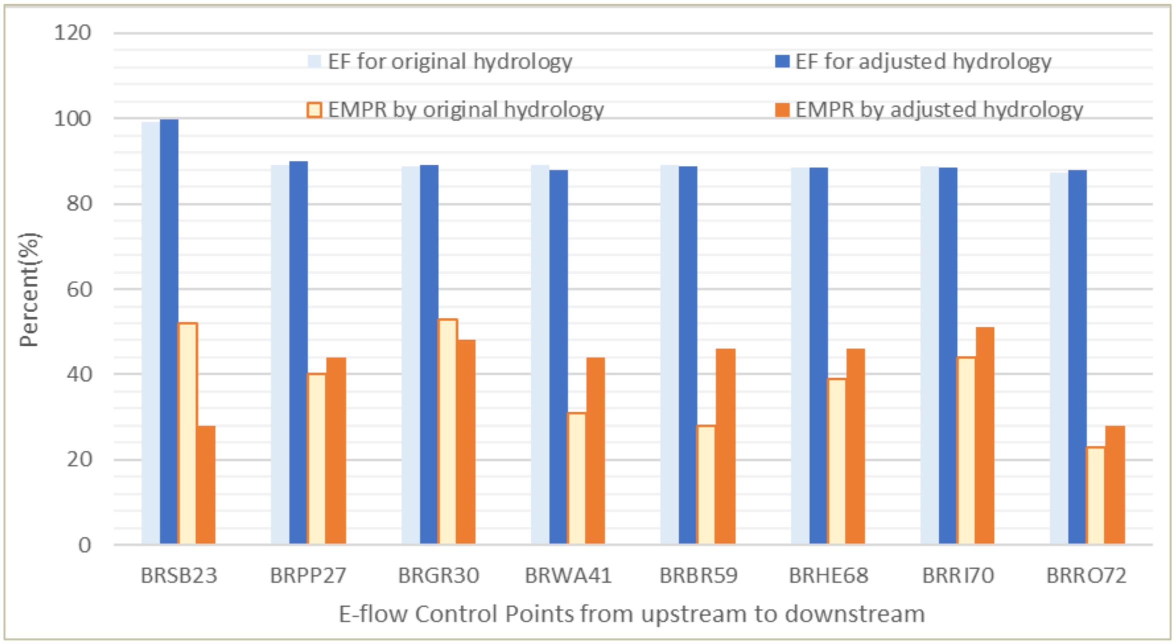

Figure 3-10 – Comparison of engagement (EF) and engage plus met (EMPR) simulated using original (light blue and light orange) versus adjusted hydrology (blue and orange) for subsistence flow in the winter dry condition.

For more detailed results on subsistence flow attainment, please refer to **Appendix 3-A**.

3.6.4 Attainment of baseflow requirements

In the Brazos River Basin, there is no subsistence flow requirement for average and wet (hydrologic/drought) condition. Therefore, the engagement for baseflow typically exceeds 90%.

Spring average condition: Changes to engagement frequency (EF) for baseflow under adjusted hydrology compared to original hydrology are minimal at all points (Figure 3-11, light blue versus dark blue bars) for the spring average condition. The engaged and met percent reliability (EMPR, grey vs. black bars) for baseflow decreases at all upstream points (i.e., BRSB23, BRPP27 and BRGR30), with a decrease of over 20% seen at BRSB23. The only point at which there is about a 5% increase in EMPR for baseflow by the adjusted hydrology is at BRWA41. We see increases to average percent shortage (APS) in baseflow with adjusted hydrology compared to the original hydrology at the upstream location of BRSB23 and the mid-stream location of BRWA41 (light orange versus red bars). Notably, at BRSB23 the APS increases from about 50% to above 70%.

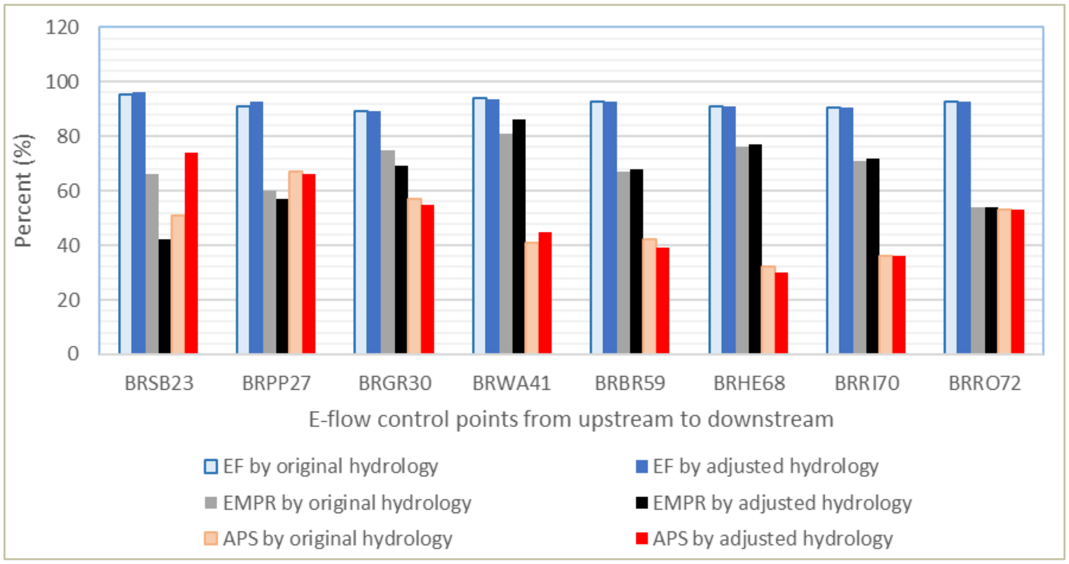

Figure 3-11 – Comparison of EF, EMPR and average percent shortage (APS) of baseflow using original (light shades) versus adjusted hydrology (dark shades) for the spring average condition.

Spring wet condition: Changes to engagement frequency (EF) for baseflow under adjusted hydrology compared to original hydrology are minimal at all points (Figure 3-12, light blue versus dark blue bars) for the spring wet condition. The engaged and met percent reliability (EMPR) for baseflow decreases at BRSB23 but increases or remains unchanged at all other points. We see increases to average percent shortage (APS) in baseflow with adjusted hydrology compared to the original hydrology at the upstream location of BRSB23 and the mid-stream location of BRWA41 (light orange versus red bars). The increase in APS at BRSB23 around 25%.

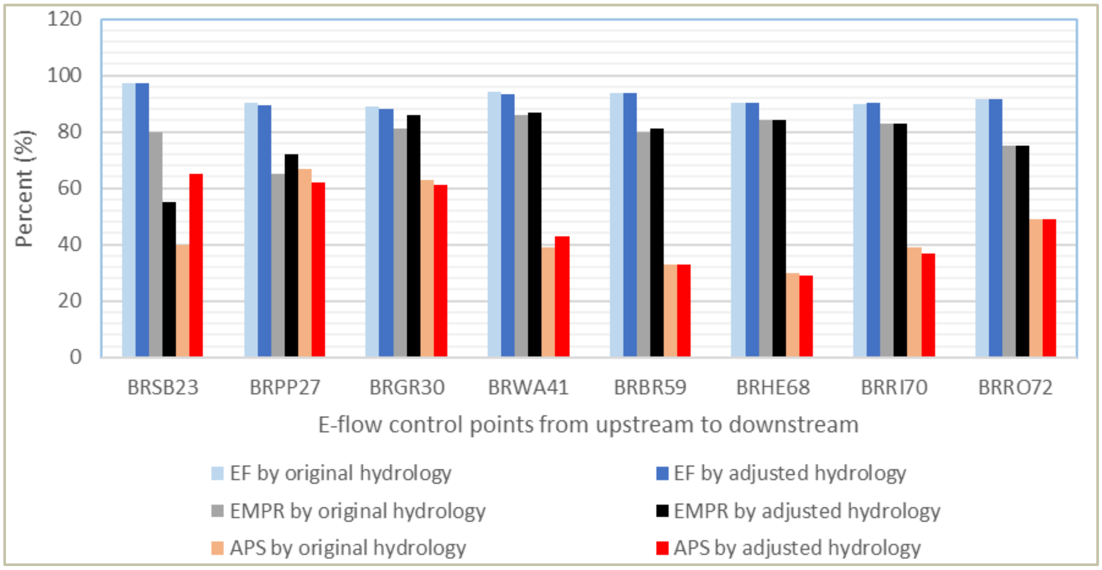

Figure 3-12 – Comparison of EF, EMPR and average percent shortage (APS) of baseflow using original (light shades) versus adjusted hydrology (dark shades) for the spring wet condition.

Summer average condition: Changes to engagement frequency (EF) for baseflow under adjusted hydrology compared to original hydrology are minimal at all points (Figure 3-13, light blue versus dark blue bars) for the summer average condition. The engaged and met percent reliability (EMPR, grey vs. black bars) for baseflow decreases at all upstream points (i.e., BRSB23, BRPP27 and BRGR30), with a decrease of over 20% seen at BRSB23. The EMPR increases at BRWA41. Downstream of the BRWA41, there is minimal or no change to EMPR under the adjusted hydrology. and remains mostly unchanged at points downstream of this location. We see increases to average percent shortage (APS) in baseflow with adjusted hydrology compared to the original hydrology at the upstream location of BRSB23 and BRPP27. There is a decrease in APS at BRWA41 and BRBR59, and minimal changes to APS downstream of these two locations.

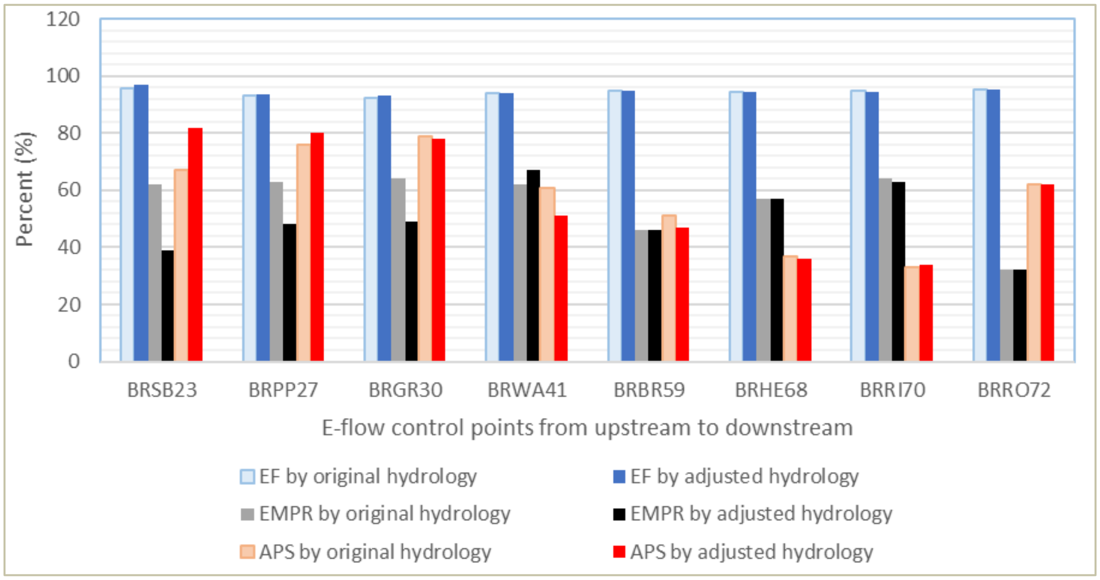

Figure 3-13 – Comparison of EF, EMPR and average percent shortage (APS) of baseflow using original (light shades) versus adjusted hydrology (dark shades) for the summer average condition.

Summer wet condition: Changes to engagement frequency (EF) for baseflow under adjusted hydrology compared to original hydrology are minimal at all points (Figure 3-14, light blue versus dark blue bars) for the summer wet condition. The engaged and met percent reliability (EMPR, grey vs. black bars) for baseflow decreases at all upstream points (i.e., BRSB23, BRPP27 and BRGR30), with a decrease of over 30% seen at BRSB23. The EMPR increases slightly at BRBR59 and BRHE68. EMPR remains mostly unchanged at BRRI70 and BRRO72. We see a ~30% increase in average percent shortage (APS) in baseflow with adjusted hydrology compared to the original hydrology at the upstream location of BRSB23, and a ~10% increase in APS at BRPP27 and BRGR30. There is a decrease in APS at BRWA41 and BRBR59, and minimal changes to APS downstream of these two locations.

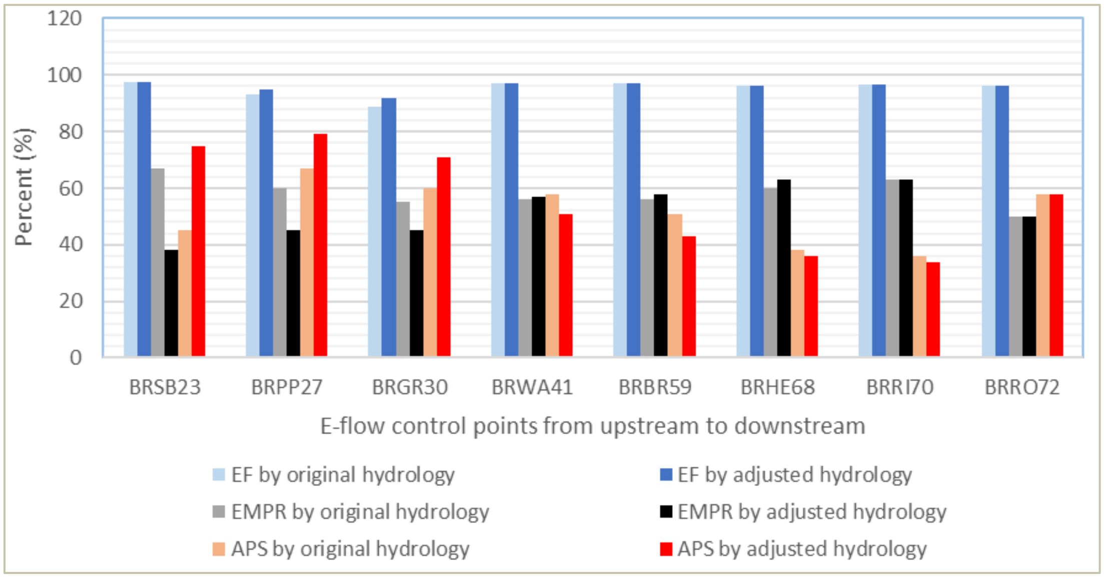

Figure 3-14 – Comparison of EF, EMPR and average percent shortage (APS) of baseflow using original (light shades) versus adjusted hydrology (dark shades) for the summer wet condition.

Winter average condition: Changes to engagement frequency (EF) for baseflow under adjusted hydrology compared to original hydrology are minimal at all points (Figure 3-15, light blue versus dark blue bars) for the winter average condition. The engaged and met percent reliability (EMPR, grey vs. black bars) for baseflow decreases significantly at all upstream points (i.e., BRSB23, BRPP27 and BRGR30), with a decrease of over ~40% seen at BRSB23. The EMPR increases by ~10% at BRWA41, and there are slight increases in EMPR at all locations downstream of BRWA41, except at BRRO72 where the there is little to no change. We see an increase in average percent shortage (APS) of over 30% in baseflow with adjusted hydrology compared to the original hydrology at the upstream location of BRSB23, and a ~5–10% increase in APS at BRPP27 and BRGR30. There is a decrease in APS in BRWA41, BRBR59, BRHE68, and BRRI70, and a minimal change to APS at BRRO72.

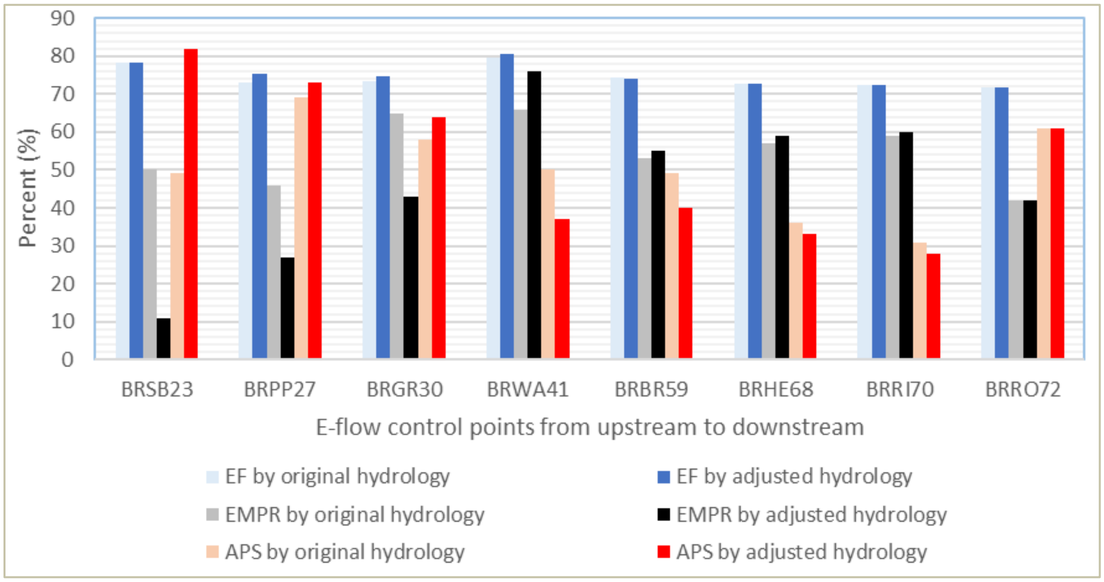

Figure 3-15 – Comparison of EF, EMPR and average percent shortage (APS) of baseflow using original (light shades) versus adjusted hydrology (dark shades) for the winter average.

Winter wet condition: Changes to engagement frequency (EF) for baseflow under adjusted hydrology compared to original hydrology are minimal at all points (Figure 3-16, light blue versus dark blue bars) for the winter average condition. The engaged and met percent reliability (EMPR, grey vs. black bars) for baseflow decreases by ~20% at the upstream location of BRSB23. At all other locations, the EMPR increases, except at BRRO71 where there is no discernible change in EMPR. We see a significant increase of ~ 35–40% in the average percent shortage (APS) baseflow with adjusted hydrology compared to the original hydrology at the upstream location of BRSB23. At all other locations, the APS decreases under adjusted hydrology, except at BRRO72 where there is no discernible change in APS.

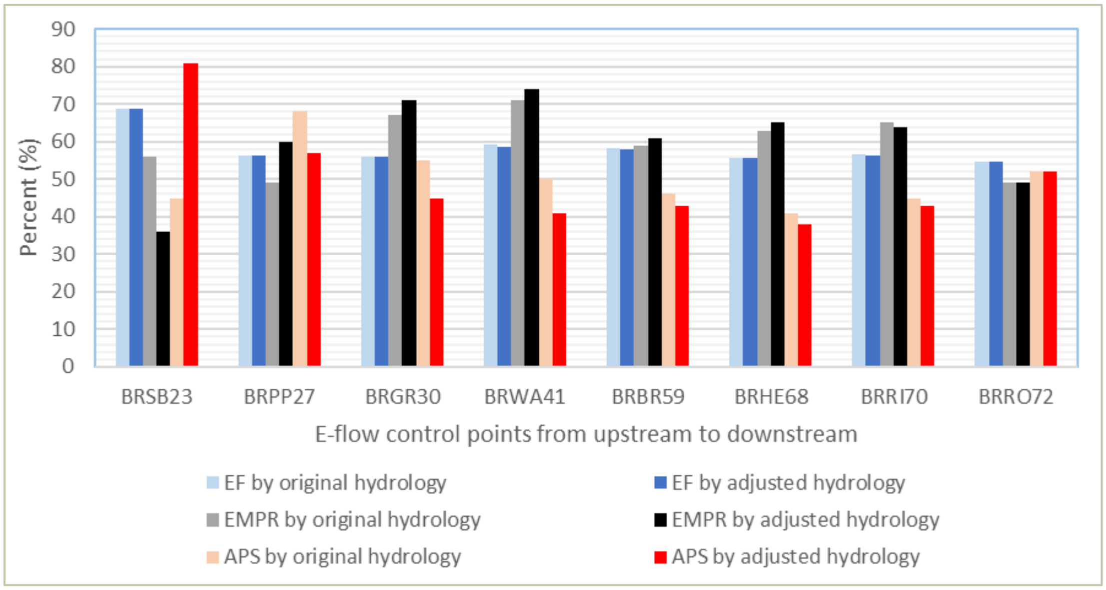

Figure 3-16 –Comparison of EF, EMPR and average percent shortage (APS) of baseflow using original (light shades) versus adjusted hydrology (dark shades) for the winter wet condition.

Little River watershed - spring average condition: In the Little River Watershed, the engagement frequency (EF), Engaged and Met Percent Reliability (EMPR) and average percent shortage (APS) simulated by adjusted versus original hydrology show minimal changes at each location (Figure 3-17), except at LRLR53 where there is a slight decrease in EMPR and a slight decrease in APS under adjusted hydrology.

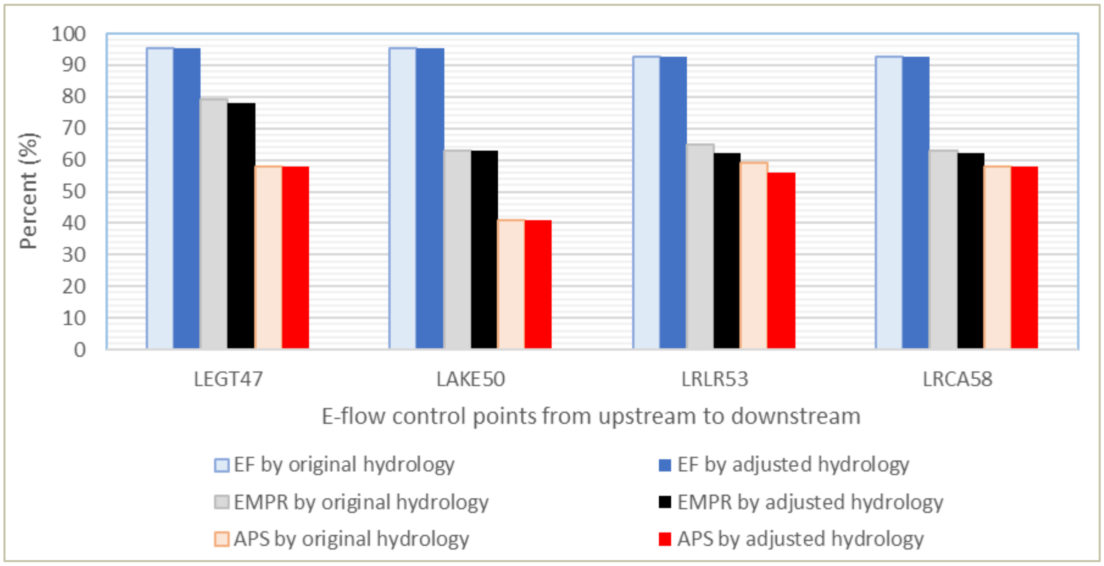

Figure 3-17 –Comparison of EF, EMPR and average percent shortage (APS) of baseflow using original (light shades) versus adjusted hydrology (dark shades) for the spring average condition in the Little River Watershed.

Little River watershed - summer average condition: In the Little River Watershed, the engagement frequency (EF), Engaged and Met Percent Reliability (EMPR) and average percent shortage (APS) simulated by adjusted versus original hydrology show minimal changes at each location (Figure 3-18), except at LRLR53 where there is a slight increase in EMPR and a slight decrease in APS under adjusted hydrology.

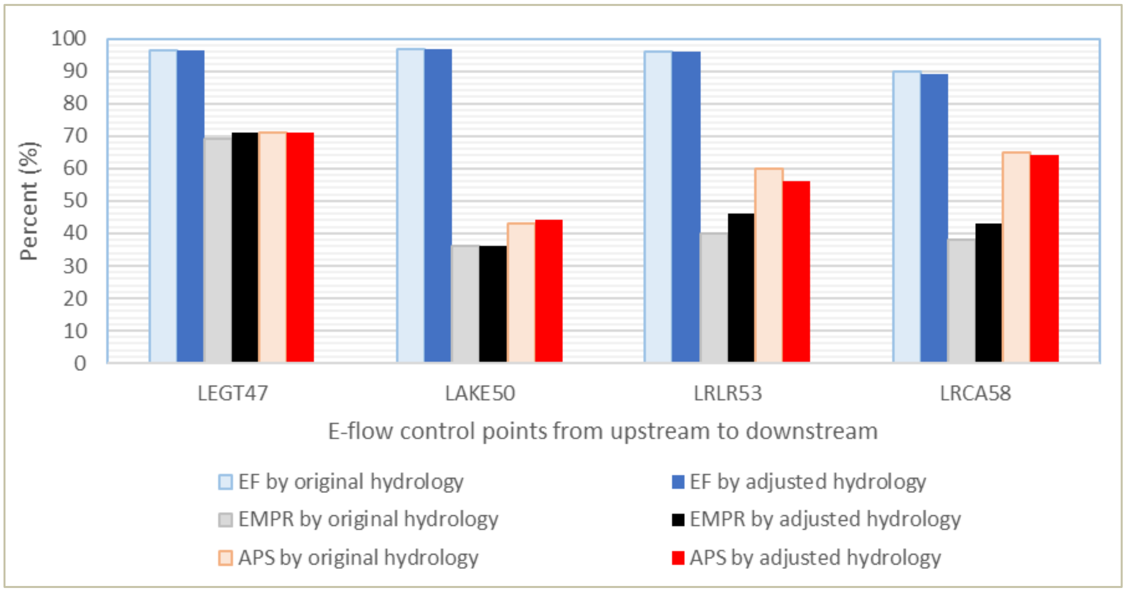

Figure 3-18 – Comparison of EF, EMPR and average percent shortage (APS) of baseflow using original (light shades) versus adjusted hydrology (dark shades) for the summer average condition in the Little River Watershed.

For more results on baseflow attainment, please refer to **Appendix 3-B**.

3.6.5 Attainment of pulse flow requirements

Many metrics can be used to measure the attainment of pulse flow requirements. Among these metrics, Percent of Engaged Pulse (PEP) is the most important metric.

The Percent of Engaged Pulse (PEPs) simulated by original and adjusted hydrology was compared at three control points, i.e., BRSB23 (upstream), BRWA41 (mid-stream), and BRRO72 (downstream).

There is no pulse flow requirement for the winter at the upstream control point BRSB23. PEPs, as simulated by the adjusted hydrology, decrease under all hydrologic conditions in both spring and summer, except during the wet spring season when there is no change (Figure 3-19). The magnitude of the change (decreases) are higher in dry seasons when the PEP decreases by around 20% and 27% for spring and summer seasons, respectively. Changes (decreases by adjusted hydrology) in PEP during spring average, summer average and wet seasons are around 7% to 9%. This indicates that there is a decrease in attainment frequency under dry conditions as simulated by the adjusted hydrology.

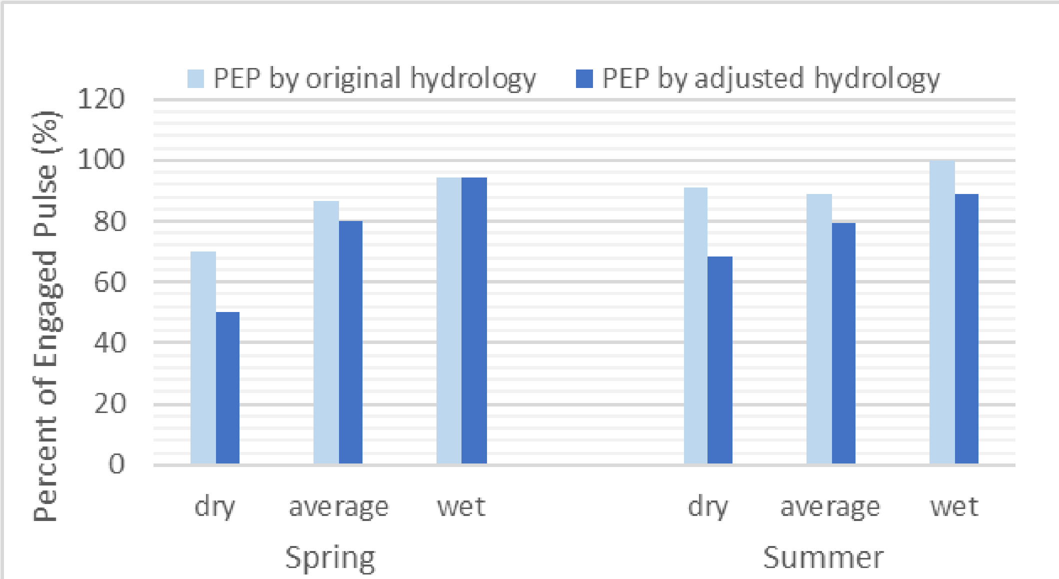

Figure 3-19 –Percent of Engaged Pulse (PEP) at BRSB23 simulated by original (light blue) and adjusted (dark blue) hydrology

In the mid-stream (BRWA41), PEP changes are minimal (Figure 3-20). PEPs decrease several percentage points in spring average, and summer dry and wet seasons, and increase several percentage points in winter dry and average conditions, spring dry, and summer average seasons. There is no change for the winter wet and spring wet seasons.

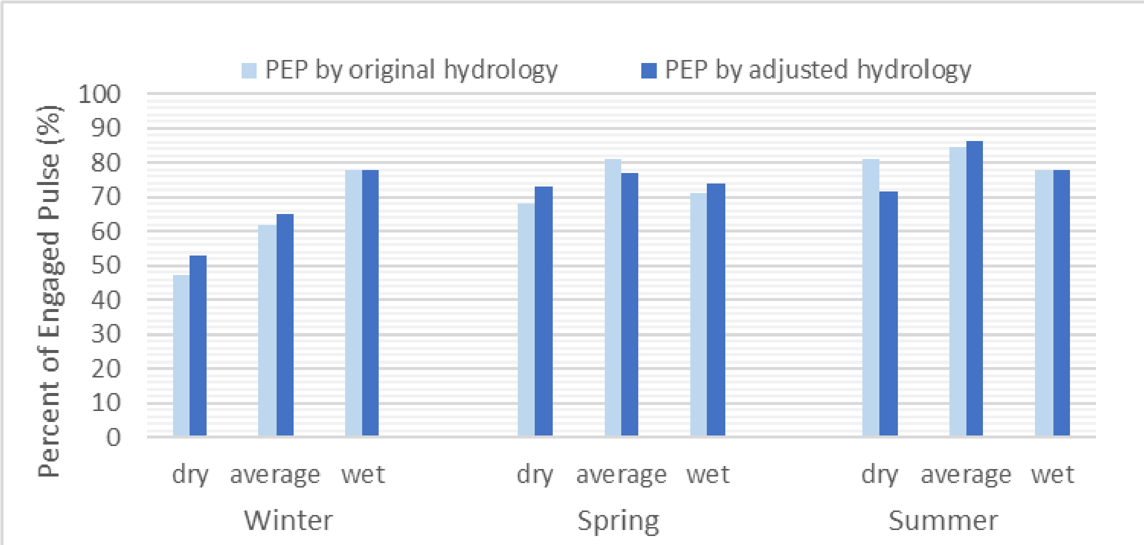

Figure 3-20 –Percent of Engaged Pulse (PEP) at BRWA41 simulated by original (light blue) and adjusted (dark blue) hydrology

At the downstream point (BRRO72), we see an increase in PEP by the adjusted hydrology in all seasons and drought conditions (Figure 3-21), except in the winter wet season. The changes are greater in magnitude during winter dry condition than during other seasons.

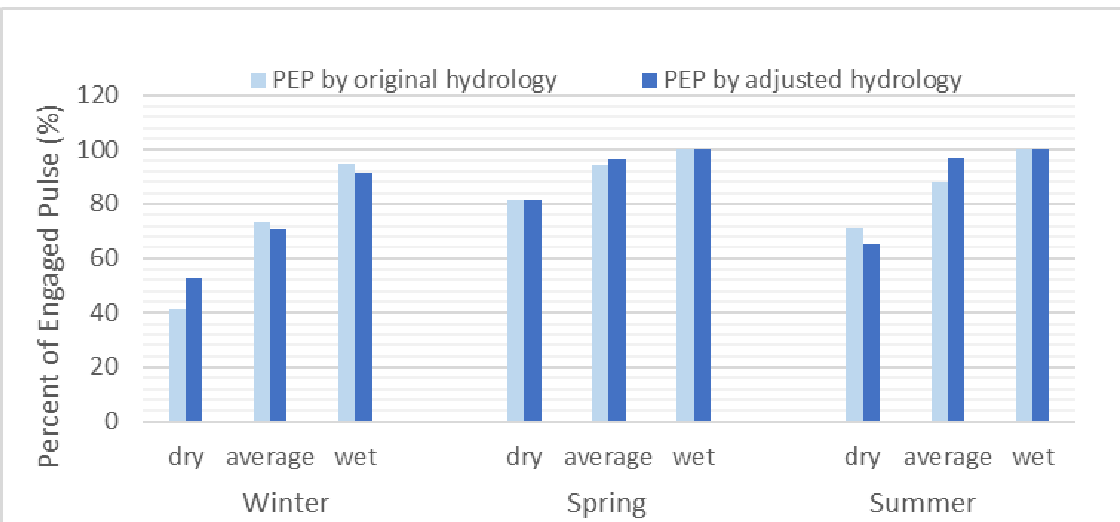

Figure 3-21 –Percent of Pulse Met (PEP) at BRRO72 simulated by original (light blue) and adjusted (dark blue) hydrology

Changes in pulse flow attainment by the adjusted hydrology for the Little River Watershed vary by season (Figure 3-22). At LRLR53, the percent of engaged pulse (PEP) increases in the winter dry condition and in the summer (all hydrologic conditions) but decreases for average and wet conditions in both the winter and spring seasons. There is little or minimal change for the spring dry condition. Overall, the magnitude of the increases is greater than the magnitude of the decreases.

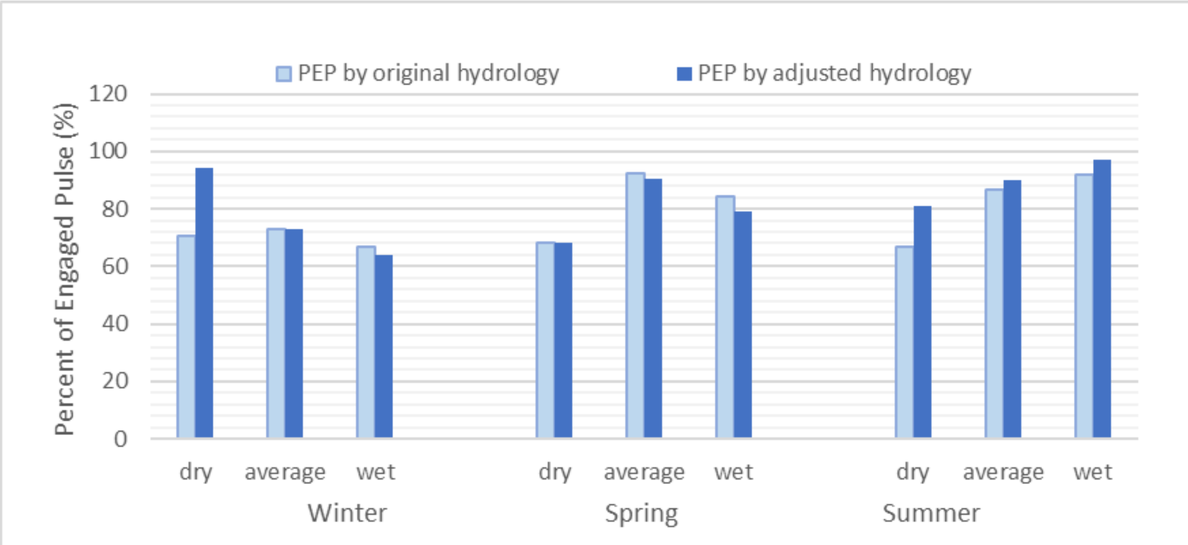

Figure 3-22 – Percent of Engaged Pulse (PEP) at LRLR53 simulated by original (light blue) and adjusted (dark blue) hydrology.

It must be noted that the current default rule for pulse initiation stipulates that a new pulse can be initiated immediately after another pulse. Therefore, if there is a large and extended rain event, there could be two or more pulses that take place back-to-back. The current rule does not provide the option to count back-to-back pulse events as a single pulse, even though in reality is a single a physical pulse. Thus, if the high flow event occurred at the beginning of the season, per the rule, the pulse frequency and engagement rule would be met, and no further counts of pulses would need to be undertaken for the remainder of the season. This leads to an under-count of actual pulse events during a season.

For detailed attainment metrics for the pulse flow requirement, please check the **Appendices 3-C** and **3-H**. For detailed pulse flow attainment plots for all e-flow control points, please refer to **Appendix 3-H**.

3.7 CONCLUSIONS

Our findings indicate that changes to the attainment of e-flow standards, when account for trends in hydrology the hydrology, are primarily evident in subsistence flow and baseflow, with less change seen in pulse flows.

The trend adjusted hydrology results in decreases to subsistence flow in the upstream section of the Brazos main stem at the control points, BRSB23, BRPP27 and BRGR30. The magnitude of the decrease is greater in summer and winter dry seasons. Baseflow also decreases at these three locations during the summer and winter seasons under both average and wet conditions. The decreases in baseflow at BRSB23 are greater in magnitude in all seasons and all hydrologic conditions compared to decreases see at BRPP27 and BRGR30. A similar decrease is seen in pulse flow in the upstream Brazos. Here too, the decrease has the largest magnitude at BRSB23 under nearly all hydrologic conditions in both the spring and summer seasons.

In contrast to changes observed for the upstream, the adjusted hydrology generally increases e-flow attainment for downstream locations, particularly locations below Waco (BRWA41). The increase in attainment is seen for subsistence flow in the summer and winter seasons. The increases in baseflow attainment along those downstream locations are less than those seen for subsistence flow, except for under the winter average condition at BRWA41, where the engaged and met percent reliability for baseflow increases by about 10%. Changes in pulse flow attainment at downstream locations is generally minimal, with no consistent increase or decrease at a given location, except for the winter dry season when pulse attainment is consistently increased by about 10%.

It also appears that changes to e-flow attainment on the tributaries of the Brazos are generally minimal, except for pulse flow at Little River at Little River (LRLR53) in winter dry season where the pulse attainment frequency increases by more than 20%.

Overall, our findings indicate that in upstream reaches of the Brazos River Basin, where the trend analysis section of this project noted significant decreasing trends in streamflow and increasing trends in evaporation, there is a decrease in the attainment frequency of e-flow standards. In the lower basin, where the trend analysis showed significant increasing trends in streamflow, there is an increase in the attainment frequency of e-flow standards.

3.8 ACKNOWLEDGEMENTS

We thank Dr. Ralph Wurbs, Professor at Texas A&M University, for assistance with the daily Brazos WAM updates.

3.9 REFERENCES

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CHAPTER 3 APPENDICES

For readers' convenience in checking from upstream to downstream, all tabular data and graphic plots are listed in the following order. For **Brazos River**, from BRSB23, through BRPP27, BRGR30, BRWA41, BRBR59, and BRHE68, BRRI70 to BRRO72. For **Little River**, from LEGT47, through LAKE50 and LRLR53, to LRCA58. For **North Bosque River**, it is NBCL36, and for **Navasota River**, NAEA66.

For the abbreviations in tables or graphics, they are defined as following:

1) Engaged (**E** (day)) - all days that engaged with an E-flow regime, subsistence flow or baseflow target.
2) Engagement Frequency (**EF** (%)) – number of engaged days expressed as a percentage of all days in a hydrologic condition of a season.
3) Zero-flow days (**ZFD** (day)) – total zero-flow days in the entire simulation period.
4) Maximum length of consecutive zero-flow days (**MLZFD** (day)) – maximum length of consecutive zero-flow days in the entire simulation period.
5) Total shortage days (**TSD** (day)) – total days having shortage for the subsistence flow or baseflow requirement for a hydrologic condition in a season.
6) Maximum length of consecutive shortage days (**MLSD** (day)) – maximum length of consecutive shortage days for the subsistence flow or baseflow requirement for a hydrologic condition in a season.
7) Shortage event (**SE** (count)) – number of shortage events. A shortage event is defined as a period that has a consecutive shortage.
8) Engaged volume reliability (**EVR** (%)) - engaged volume reliability is defined as total engaged regulated flow volume as percentage of by total target volume of the same period.
9) Engaged and met period reliability (**EMPR** (%)) - engaged and met period reliability is defined as total days of both engaged and met target as percentage of total days of engaged.
10) Average shortage (**AS or Average_S** (ac-ft)) - average shortage is defined as total shortage volume divided by the number of days having shortage.
11) Average percent shortage (**APS or Average_PS** (%)) – average percent shortage is defined as total shortage volume divided by total target for the engaged days having shortage.
12) Average percent shortage for the whole applicable period (**ASPAT** (%)) - average percent shortage for the whole applicable period is defined as total shortage volume divided by total target of whole applicable period of consideration.
13) Percent of Season Engaged (**PSE** (%)) – total number of seasons that have pulse engagement as percent of total number of applicable seasons.
14) Percent of Seasons Met (**PSM** (%)) – total number of seasons that met the required pulse frequency as percent of total number of applicable seasons.
15) Engaged (**E** (day)) - total days of pulse flow engagement in an applicable season and hydrologic condition.
16) Engaged Frequency (**EF** (%)) – percent of days are engaged in an applicable season and hydrologic condition.

17) Engaged Volume Reliability (**EVR** (%)) – total regulated flow of engaged period as percent of total target of the same period.
18) Engaged Pulse (**EP** (count)) – engaged pulse event number in an applicable season and hydrologic condition.
19) Percent of Engaged Pulse (**PEP** (%)) – number of engaged pulses as percent of total required pulse number for an applicable season and hydrologic condition.

Unless specified, all attainment metrics and graphics are based on and computed from regulated flows simulated by updated daily Brazos WAM for 2050 condition and the hydrology adjusted for trend for 2050.

APPENDIX 3-A: E-FLOW ATTAINMENT METRICS FOR THE SUBSISTENCE FLOW

Control Point	Season	EFS (ac-ft)	E (day)	EF (%)	EVR (%)	EMPR (%)	TSD (day)	MLSD (day)	S_Event (#)	Average_S (ac-ft)	Average_PS (%)	ASPAT (%)	ZFD (day)	MLZFD (day)
BRSB23	Winter	2	2400	99.83	431	28	1680	290	74	1.76	88	11	3333	169
BRSB23	Spring	2	2404	98.52	5342	66	809	63	96	1.78	89	2	3333	169
BRSB23	Summer	2	2652	98	7430	63	950	84	89	1.75	88	4	3333	169
BRPP27	Winter	34	2164	90.02	419	44	725	52	116	19.06	56	12	1177	71
BRPP27	Spring	34	2257	92.5	2472	68	711	61	105	24.22	71	12	1177	71
BRPP27	Summer	34	2424	89.58	2212	50	1187	81	114	28.17	83	26	1177	71
BRGR30	Winter	32	2138	88.94	556	48	502	61	55	22.09	69	8	1367	59
BRGR30	Spring	32	2228	91.31	2574	82	373	31	78	21.91	66	5	1367	59
BRGR30	Summer	32	2399	88.65	2246	63	863	75	82	26	81	17	1367	59
BRWA41	Winter	112	2115	87.98	103	44	143	10	60	42.77	38	10	59	10
BRWA41	Spring	112	2130	87.3	1212	93	126	8	66	70.56	63	1	59	10
BRWA41	Summer	112	2401	88.73	814	87	303	41	112	74.65	67	4	59	10
BRBR59	Winter	596	2131	88.64	251	46	670	67	111	197.41	33	7	11	3
BRBR59	Spring	596	2136	87.54	546	79	421	22	97	240.77	40	4	11	3
BRBR59	Summer	596	2410	89.06	366	56	1056	93	146	281.68	47	14	11	3
BRHE68	Winter	1013	2126	88.44	219	46	702	68	65	362.92	35	8	13	3
BRHE68	Spring	1013	2134	87.46	412	85	302	25	60	388.25	38	3	13	3
BRHE68	Summer	1013	2398	88.62	292	61	911	93	104	485.6	48	13	13	3
BRRI70	Winter	1091	2124	88.36	227	51	543	64	54	400.21	36	7	1	1
BRRI70	Spring	1091	2109	86.43	433	84	317	25	71	477.84	43	4	1	1
BRRI70	Summer	1091	2410	89.06	304	62	903	93	114	581.66	53	15	1	1
BRRO72	Winter	853	2112	87.86	192	28	1222	94	109	415.34	48	21	36	14
BRRO72	Spring	853	2136	87.54	461	54	971	38	200	525.13	61	17	36	14
BRRO72	Summer	853	2423	89.54	301	37	1497	87	160	573.14	67	32	36	14
LEGT47	Winter	2	2177	90.56	1185	45	751	292	20	1.78	89	7	1838	276
LEGT47	Spring	2	2146	87.95	3002	85	305	46	42	1.68	84	1	1838	276
LEGT47	Summer	2	2427	89.69	3332	71	686	109	60	1.75	88	8	1838	276
LAKE50	Winter	20	2156	89.68	205	36	1084	294	34	9.49	47	19	193	31
LAKE50	Spring	20	2155	88.32	696	68	680	65	73	8.97	45	9	193	31
LAKE50	Summer	20	2437	90.06	274	40	1444	74	122	9.96	50	25	193	31
LRLR53	Winter	110	2137	88.9	265	52	488	50	57	49.19	45	8	437	60
LRLR53	Spring	110	2110	86.48	649	61	805	53	104	70.95	65	18	437	60
LRLR53	Summer	110	2424	89.58	321	38	1477	93	128	71.25	65	33	437	60
LRCA58	Winter	64	2140	89.02	391	37	974	54	74	27.61	43	10	609	74
LRCA58	Spring	64	2111	86.52	855	66	704	53	106	43.43	68	8	609	74
LRCA58	Summer	64	2371	87.62	618	41	1380	161	126	51.37	80	29	609	74
NBCL36	Winter	2	2177	90.56	1689	39	976	280	44	1.89	95	17	4110	244
NBCL36	Spring	2	2142	87.79	3247	77	481	45	66	1.4	70	3	4110	244
NBCL36	Summer	2	2454	90.69	3197	37	1523	136	66	1.69	85	33	4110	244
NAEA66	Winter	2	2148	89.36	2295	57	296	40	32	1.41	70	1	1040	74
NAEA66	Spring	2	2149	88.07	4371	91	163	60	26	1.84	79	0	1040	74
NAEA66	Summer	2	2453	90.65	4546	86	333	47	36	1.93	93	4	1040	74

APPENDIX 3-B: E-FLOW ATTAINMENT METRICS FOR THE BASEFLOW FLOW

BRSB23:

Season	HC	EFS (ac-ft)	Length (days)	E (day)	EF (%)	EVR (%)	EMPR (%)	MLSD (day)	S_Event (#)	Average _S (ac-ft)	Average _PS (%)	ASPAT (%)
Winter	dry	72	2405	816	33.93	471	99	0	0	0	0	0
Winter	average	145	4450	3490	78.43	94	11	242	70	119.48	82	57
Winter	wet	239	2283	1568	68.68	446	36	120	33	192.52	81	42
Spring	dry	58	2440	1594	65.33	5497	99	0	0	0	0	0
Spring	average	120	4636	4452	96.03	1079	42	121	183	88.58	74	28
Spring	wet	199	2196	2132	97.09	1062	55	74	95	129.28	65	20
Summer	dry	32	2706	1700	62.82	7823	99	0	0	0	0	0
Summer	average	92	4428	4296	97.02	1137	39	122	138	74.89	82	39
Summer	wet	189	2214	2162	97.65	607	38	91	74	142.19	75	39

BRPP27:

Season	HC	EFS (ac-ft)	Length (days)	E (day)	EF (%)	EVR (%)	EMPR (%)	MLSD (day)	S_Event (#)	Average _S (ac-ft)	Average _PS (%)	ASPAT (%)
Winter	dry	80	1925	840	43.64	517	99	0	0	0	0	0
Winter	average	121	4928	3714	75.37	157	27	119	289	88.43	73	29
Winter	wet	199	2285	1288	56.37	520	60	55	122	114.26	57	10
Spring	dry	78	2684	1698	63.26	2873	99	0	0	0	0	0
Spring	average	149	4270	3953	92.58	914	57	61	401	99.2	66	11
Spring	wet	239	2318	2072	89.39	1192	72	15	210	149.33	62	6
Summer	dry	80	2829	1372	48.5	3438	99	0	0	0	0	0
Summer	average	143	4305	4025	93.5	680	48	122	279	115.22	80	20
Summer	wet	239	2214	2104	95.03	428	45	91	188	189.1	79	26

BRGR30:

Season	HC	EFS (ac-ft)	Length (days)	E (day)	EF (%)	EVR (%)	EMPR (%)	MLSD (day)	S_Event (#)	Average _S (ac-ft)	Average _PS (%)	ASPAT (%)
Winter	dry	84	1925	897	46.6	623	99	1	0	0	0	0
Winter	average	153	4928	3682	74.72	201	43	104	237	98.31	64	16
Winter	wet	318	2285	1281	56.06	646	71	25	117	145.01	45	6
Spring	dry	94	2684	2148	80.03	2450	99	1	7	0	0	0
Spring	average	183	4270	3806	89.13	1167	69	65	292	101.22	55	3
Spring	wet	338	2318	2045	88.22	1093	86	19	110	207.47	61	2
Summer	dry	74	2829	1708	60.37	3112	99	1	1	0	0	0
Summer	average	139	4305	4016	93.29	796	49	91	247	108.92	78	14
Summer	wet	318	2214	2038	92.05	400	45	91	124	226.99	71	19

BRWA41:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	238	2046	179	8.75	119	100	0	0	0	0	0
Winter	average	417	4928	3979	80.74	417	76	28	309	157.57	37	5
Winter	wet	953	2164	1269	58.64	633	74	22	99	391.84	41	6
Spring	dry	298	2684	2439	90.87	1181	99	0	0	0	0	0
Spring	average	536	4270	3997	93.61	966	86	16	236	244.05	45	3
Spring	wet	1371	2318	2167	93.49	673	87	16	111	591.87	43	2
Summer	dry	278	2583	2202	85.25	839	99	0	0	0	0	0
Summer	average	496	4551	4274	93.91	475	67	33	385	256.65	51	12
Summer	wet	1171	2214	2153	97.24	359	57	54	138	604.93	51	18

BRBR59:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	1072	2046	944	46.14	260	99	0	0	0	0	0
Winter	average	1707	4928	3646	73.99	331	55	92	204	692.39	40	11
Winter	wet	3453	2164	1252	57.86	453	61	41	69	1510.27	43	11
Spring	dry	1409	2684	2137	79.62	614	99	0	0	0	0	0
Spring	average	2500	4270	3960	92.74	472	68	69	202	990.63	39	9
Spring	wet	4880	2318	2175	93.83	417	81	56	96	1637.12	33	5
Summer	dry	1251	2583	1455	56.33	483	99	0	0	0	0	0
Summer	average	1826	4551	4310	94.7	236	46	109	261	863.55	47	22
Summer	wet	2917	2214	2151	97.15	392	58	67	93	1271.53	43	17

BRHE68:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	1827	2046	909	44.43	228	99	1	0	0	0	0
Winter	average	2858	4928	3577	72.59	326	59	79	142	966.81	33	7
Winter	wet	5733	2164	1202	55.55	384	65	34	49	2218.38	38	7
Spring	dry	2243	2684	2269	84.54	456	99	0	0	0	0	0
Spring	average	3770	4270	3885	90.98	436	77	49	150	1146.14	30	4
Spring	wet	6824	2318	2088	90.08	386	84	55	70	1997.81	29	3
Summer	dry	1886	2583	1604	62.1	366	99	0	0	0	0	0
Summer	average	2640	4551	4303	94.55	227	57	92	281	955.46	36	13
Summer	wet	4068	2214	2132	96.3	344	63	57	91	1464.51	36	12

BRRI70:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	1965	2046	971	47.46	228	98	1	1	0	0	0
Winter	average	3273	4928	3561	72.26	313	60	102	192	927.68	28	6
Winter	wet	6566	2164	1219	56.33	358	64	54	56	2819.29	43	8
Spring	dry	2361	2684	2048	76.3	505	99	1	0	0	0	0
Spring	average	4245	4270	3865	90.52	418	72	48	217	1545.04	36	7
Spring	wet	7895	2318	2093	90.29	352	83	51	66	2985.59	37	4
Summer	dry	1846	2583	1515	58.65	405	99	1	2	0	0	0
Summer	average	2639	4551	4299	94.46	252	63	51	351	909.28	34	11
Summer	wet	4344	2214	2138	96.57	358	63	37	113	1487.63	34	11

BRRO72:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	2262	2046	542	26.49	252	98	0	0	0	0	0
Winter	average	4146	4928	3543	71.9	208	42	120	167	2455.66	59	19
Winter	wet	9323	2164	1193	55.13	257	49	96	58	4814.51	51	15
Spring	dry	2480	2684	1511	56.3	618	99	0	0	0	0	0
Spring	average	5098	4270	3950	92.51	327	54	58	206	2718.56	53	20
Spring	wet	9402	2318	2126	91.72	289	74	59	83	4516.39	48	9
Summer	dry	1846	2583	989	38.29	524	99	0	0	0	0	0
Summer	average	2817	4551	4327	95.08	183	37	121	268	1496.05	53	30
Summer	wet	5217	2214	2127	96.07	275	49	87	81	2823.93	54	25

LEGT47:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	18	2046	918	44.87	972	99	0	0	0	0	0
Winter	average	40	4928	3843	77.98	794	65	240	87	25.54	64	14
Winter	wet	104	2164	1272	58.78	1175	73	47	26	48.34	46	9
Spring	dry	20	2684	2299	85.66	2766	99	0	0	0	0	0
Spring	average	48	4270	4069	95.29	1854	78	69	112	28.04	58	8
Spring	wet	108	2318	2242	96.72	1626	93	11	25	37.15	34	1
Summer	dry	8	2583	1860	72.01	3655	99	0	0	0	0	0
Summer	average	24	4551	4383	96.31	1666	71	77	124	16.98	71	17
Summer	wet	54	2214	2160	97.56	2372	90	30	38	33.53	62	5

LAKE50:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	36	2046	742	36.27	258	99	0	0	0	0	0
Winter	average	54	4928	3737	75.83	443	50	139	89	23.48	43	15
Winter	wet	78	2164	1288	59.52	764	64	74	30	23.42	30	6
Spring	dry	42	2684	1882	70.12	764	99	0	0	0	0	0
Spring	average	58	4270	4071	95.34	643	63	167	115	24.07	41	9
Spring	wet	86	2318	2235	96.42	964	91	40	20	24.51	28	1
Summer	dry	32	2583	1052	40.73	493	99	0	0	0	0	0
Summer	average	46	4551	4411	96.92	256	36	113	178	20.15	44	25
Summer	wet	64	2214	2161	97.61	318	47	104	69	27.05	42	20

LRLR53:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	163	2046	1050	51.32	271	100	0	0	0	0	0
Winter	average	219	4928	3705	75.18	342	52	105	244	115.7	53	16
Winter	wet	377	2164	1270	58.69	449	53	60	72	279.52	74	20
Spring	dry	189	2684	1675	62.41	840	99	0	0	0	0	0
Spring	average	298	4270	3962	92.79	640	62	57	298	169.19	56	13
Spring	wet	677	2318	2166	93.44	572	63	56	130	463.31	68	16
Summer	dry	167	2583	1028	39.8	603	99	1	0	0	0	0
Summer	average	239	4551	4370	96.02	351	46	91	291	135.08	56	26
Summer	wet	397	2214	2145	96.88	1077	70	30	135	175.27	44	11

LRCA58:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	219	2046	738	36.07	379	99	0	0	0	0	0
Winter	average	377	4928	3683	74.74	476	57	103	163	204.63	54	13
Winter	wet	914	2164	1256	58.04	457	55	58	69	503.23	55	16
Spring	dry	278	2684	1805	67.25	1015	99	0	0	0	0	0
Spring	average	615	4270	3951	92.53	515	62	64	218	361.62	58	13
Spring	wet	1509	2318	2189	94.43	428	70	48	104	745.75	49	10
Summer	dry	193	2583	1083	41.93	914	99	0	0	0	0	0
Summer	average	318	4551	4052	89.04	335	43	91	227	203.82	64	26
Summer	wet	656	2214	2024	91.42	778	60	40	117	308.95	47	14

NBCL36:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	10	2046	785	38.37	1646	0	0	0	0	0	0
Winter	average	24	4928	3843	77.98	717	237	82	70	20.01	84	40
Winter	wet	50	2164	1274	58.87	2195	52	28	37	21.97	44	7
Spring	dry	14	2684	2116	78.84	2888	0	0	0	0	0	0
Spring	average	32	4270	4091	95.81	1841	160	91	87	16.98	53	4
Spring	wet	66	2318	2203	95.04	1653	18	19	18	22.47	34	1
Summer	dry	6	2583	1019	39.45	4780	0	0	0	0	0	0
Summer	average	16	4551	4517	99.25	825	115	136	130	10.06	63	28
Summer	wet	34	2214	2155	97.34	1160	88	39	34	17.81	52	13

NAEA66:

Season	HC	EFS (ac-ft)	Length (days)	**E (day)**	**EF (%)**	**EVR (%)**	**EMPR (%)**	**MLSD (day)**	**S_Event (#)**	**Average _S (ac-ft)**	**Average _PS (%)**	**ASPAT (%)**
Winter	dry	18	2046	1070	52.3	1746	98	1	0	15.87	100	0
Winter	average	28	4928	3622	73.5	2714	81	60	153	9.91	35	2
Winter	wet	46	2164	1257	58.09	3665	74	42	54	15.89	34	2
Spring	dry	20	2684	2249	83.79	4670	99	1	6	0	0	0
Spring	average	38	4270	3972	93.02	2638	87	45	90	15.88	42	1
Spring	wet	58	2318	2185	94.26	1962	83	29	80	20.76	36	1
Summer	dry	6	2583	2202	85.25	4905	99	1	5	0	0	0
Summer	average	16	4551	4514	99.19	1522	91	41	104	9.87	62	5
Summer	wet	32	2214	2150	97.11	1283	54	122	92	12.65	39	16

APPENDIX 3-C: E-FLOW ATTAINMENT METRICS FOR THE PULSE FLOW

na – not applicable

Average days between pulses (ADBP) is only applicable to a season having 2 or more pulses per rule.

BRSB23:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Spring	dry	2498.58	7280	10	1	60.00	40.00	1834	37	2.02	163	na	10	50.00
Spring	average	2498.58	7280	10	2	86.84	0.00	1834	168	9.16	182	2.5	61	80.26
Spring	wet	4917.84	15700	13	1	94.44	77.78	1130	54	4.78	46	na	17	94.44
Summer	dry	1150.14	3140	8	1	72.73	50.00	3104	42	1.35	58	na	15	68.18
Summer	average	1150.14	3140	8	2	83.33	0.00	3104	112	3.61	260	1.1	57	79.17
Summer	wet	2339.94	7050	11	1	94.44	72.22	1916	47	2.45	52	na	16	88.89

BRPP27:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	1685.55	3690	5	2	37.50	0	380	19	5	156	0	7	21.88
Winter	average	1685.55	3690	5	4	46.34	0	380	201	52.89	328	12.4	40	24.39
Winter	average	2756.37	7180	7	2	21.95	0	207	59	28.5	195	0.8	13	15.85
Winter	wet	1685.55	3690	5	4	89.47	0	380	206	54.21	458	6.5	50	65.79
Winter	wet	2756.37	7180	7	3	73.68	0	207	79	38.16	184	5	33	57.89
Spring	dry	2776.2	6600	6	2	68.18	0	2170	60	2.76	192	2	24	54.55
Spring	average	2776.2	6600	6	4	88.57	0	2170	440	20.28	426	4.6	103	73.57
Spring	average	6682.71	20200	10	2	71.43	0	933	173	18.54	156	4.6	43	61.43
Spring	wet	2776.2	6600	6	4	100.00	0	2170	315	14.52	475	12.1	72	94.74
Spring	wet	6682.71	20200	10	3	89.47	0	933	151	16.18	141	8.5	44	77.19
Summer	dry	2439.09	5920	6	2	56.52	0	2416	47	1.95	219	2.6	23	50.00
Summer	average	2439.09	5920	6	4	74.29	0	2416	347	14.36	353	4.2	93	66.43
Summer	average	4481.58	13000	9	2	62.86	0	1398	139	9.94	153	3.5	41	58.57
Summer	wet	2439.09	5920	6	4	94.44	0	2416	173	7.16	502	0	53	73.61
Summer	wet	4481.58	13000	9	3	72.22	0	1398	70	5.01	164	0.2	35	64.81

BRGR30:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	1844.19	5400	8	2	43.75	0.00	576	35	6.08	296	7.8	10	31.25
Winter	average	1844.19	5400	8	4	65.85	4.88	576	312	54.17	369	9.2	71	43.29
Winter	average	3371.1	10800	10	2	43.90	0.00	343	105	30.61	193	13.1	26	31.71
Winter	wet	1844.19	5400	8	4	84.21	5.26	576	234	40.62	609	6	62	81.58
Winter	wet	3371.1	10800	10	3	84.21	0.00	343	105	30.61	230	3.7	44	77.19
Spring	dry	4660.05	14300	10	2	77.27	0.00	2065	98	4.75	152	3.4	32	72.73
Spring	average	4660.05	14300	10	4	100.00	0.00	2065	645	31.23	361	7	119	85.00
Spring	average	12849.84	46700	14	2	77.14	0.00	856	294	34.35	154	5.2	41	58.57
Spring	wet	4660.05	14300	10	4	100.00	0.00	2065	349	16.9	507	9.5	71	93.42
Spring	wet	12849.84	46700	14	3	84.21	0.00	856	173	20.21	145	6.4	45	78.95
Summer	dry	2617.56	7830	8	2	65.22	0.00	3048	62	2.03	212	2.4	29	63.04
Summer	average	2617.56	7830	8	4	80.00	0.00	3048	378	12.4	426	4.6	99	70.71
Summer	average	6127.47	21200	12	2	68.57	0.00	1629	130	7.98	165	5.6	46	65.71
Summer	wet	2617.56	7830	8	4	94.44	0.00	3048	245	8.04	563	3.4	66	91.67
Summer	wet	6127.47	21200	12	3	83.33	0.00	1629	124	7.61	186	1.6	38	70.37

BRWA41:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	4600.56	12400	7	1	64.71	52.94	984	46	4.67	147	na	9	52.94
Winter	average	4600.56	12400	7	3	85.37	4.88	984	241	24.49	140	10.4	80	65.04
Winter	wet	8288.94	25700	9	2	77.78	0.00	502	62	12.35	139	2.4	28	77.78
Spring	dry	10569.39	32700	10	1	81.82	68.18	2210	74	3.35	135	na	16	72.73
Spring	average	10569.39	32700	10	3	88.57	0.00	2210	269	12.17	137	7.3	81	77.14
Spring	wet	26968.8	102000	14	2	84.21	0.00	924	152	16.45	122	6	28	73.68
Summer	dry	3926.34	10500	7	1	80.95	61.90	5328	48	0.9	157	na	15	71.43
Summer	average	3926.34	10500	7	3	94.59	0.00	5328	297	5.57	158	7.3	96	86.49
Summer	wet	8249.28	26400	10	2	83.33	0.00	2748	50	1.82	146	0.6	28	77.78

BRBR59:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	6405.09	21100	7	1	76.47	64.71	2085	47	2.25	130	na	13	76.47
Winter	average	6405.09	21100	7	3	82.93	2.44	2085	254	12.18	166	4.3	94	76.42
Winter	wet	11045.31	41900	10	2	100.00	0.00	1328	95	7.15	127	1.6	34	94.44
Spring	dry	11997.15	49000	11	1	86.36	81.82	5041	84	1.67	122	na	18	81.82
Spring	average	11997.15	49000	11	3	97.14	0.00	5041	349	6.92	124	3.9	98	93.33
Spring	wet	20623.2	97000	14	2	100.00	0.00	3119	150	4.81	120	0.8	38	100.00
Summer	dry	4084.98	12700	7	1	90.48	71.43	10387	46	0.44	140	na	19	90.48
Summer	average	4084.98	12700	7	3	97.30	0.00	10387	264	2.54	164	5.2	103	92.79
Summer	wet	5929.17	20100	8	2	100.00	0.00	8183	61	0.75	179	0.2	36	100.00

BRHE68:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	11342.76	49800	10	1	64.71	52.94	2376	39	1.64	110	na	11	64.71
Winter	average	11342.76	49800	10	3	90.24	2.44	2376	367	15.45	130	5.5	94	76.42
Winter	wet	22209.6	125000	15	2	100.00	5.56	1222	161	13.18	112	3.8	34	94.44
Spring	dry	16914.99	85000	13	1	77.27	77.27	5657	80	1.41	125	na	16	72.73
Spring	average	16914.99	85000	13	3	100.00	0.00	5657	405	7.16	119	5.7	94	89.52
Spring	wet	33314.4	219000	19	2	105.26	0.00	2581	231	8.95	105	2.9	38	100.00
Summer	dry	5195.46	17000	7	1	95.24	85.71	12513	57	0.46	134	na	20	95.24
Summer	average	5195.46	17000	7	3	100.00	0.00	12513	259	2.07	145	4.1	105	94.59
Summer	wet	10093.47	40900	9	2	100.00	0.00	8274	77	0.93	132	0.8	36	100.00

BRRI70:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	12711.03	60600	11	1	64.71	58.82	2293	60	2.62	120	na	10	58.82
Winter	average	12711.03	60600	11	3	87.80	0.00	2293	375	16.35	118	3.7	98	79.67
Winter	wet	24589.2	150000	16	2	100.00	0.00	1161	132	11.37	101	2.5	34	94.44
Spring	dry	17708.19	94000	13	1	86.36	86.36	5704	125	2.19	135	na	15	68.18
Spring	average	17708.19	94000	13	3	100.00	0.00	5704	475	8.33	120	5.2	97	92.38
Spring	wet	32322.9	215000	19	2	100.00	0.00	2825	243	8.6	103	2.1	38	100.00
Summer	dry	4878.18	16400	6	1	100.00	80.95	13422	62	0.46	129	na	20	95.24
Summer	average	4878.18	16400	6	3	100.00	0.00	13422	272	2.03	150	3.3	109	98.20
Summer	wet	10767.69	46300	10	2	100.00	0.00	8257	70	0.85	140	0.8	36	100.00

BRRO72:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	18025.47	94700	12	1	64.71	64.71	1527	80	5.24	118	na	9	52.94
Winter	average	18025.47	94700	12	3	82.93	0.00	1527	430	28.16	115	8.7	89	72.36
Winter	wet	26968.8	168000	16	2	94.44	0.00	976	172	17.62	108	3.7	33	91.67
Spring	dry	13048.14	58500	10	1	86.36	81.82	6595	92	1.39	121	na	18	81.82
Spring	average	13048.14	58500	10	3	100.00	0.00	6595	377	5.72	128	3.6	101	96.19
Spring	wet	28158.6	184000	18	2	105.26	0.00	3104	220	7.09	109	1.5	38	100.00
Summer	dry	4937.67	14900	6	1	76.19	57.14	11478	41	0.36	160	na	15	71.43
Summer	average	4937.67	14900	6	3	94.59	0.00	11478	239	2.08	178	3	102	91.89
Summer	wet	9875.34	39100	9	2	100.00	0.00	7795	94	1.21	136	0.3	36	100.00

LEGT47:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	wet	198.3	540	6	2	100.00	0.00	2556	78	3.05	309	4.5	34	94.44
Spring	dry	674.22	1910	10	1	90.91	72.73	5183	57	1.1	148	na	20	90.91
Spring	average	674.22	1910	10	3	94.29	0.00	5183	201	3.88	1021	4.6	93	88.57
Spring	wet	1249.29	4050	13	2	100.00	0.00	3369	75	2.23	320	0.7	38	100.00
Summer	dry	115.014	220	4	1	85.71	14.29	13093	21	0.16	505	na	18	85.71
Summer	average	115.014	220	4	3	100.00	0.00	13093	142	1.08	2936	4.7	109	98.20
Summer	wet	277.62	600	6	2	100.00	0.00	9049	44	0.49	781	0.2	36	100.00

LAKE50:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	154.67	430	8	1	52.94	23.53	2372	27	1.14	154	na	8	47.06
Winter	average	154.67	430	8	3	65.85	7.32	2372	164	6.91	350	2.9	75	60.98
Winter	wet	376.77	1150	11	2	72.22	0.00	1266	55	4.34	773	2.4	23	63.89
Spring	dry	1546.74	4020	13	1	68.18	40.91	1000	88	8.8	260	na	10	45.45
Spring	average	1546.74	4020	13	3	80.00	0.00	1000	213	21.3	221	7.8	58	55.24
Spring	wet	2597.73	6860	16	2	84.21	0.00	516	84	16.28	144	9.5	31	81.58
Summer	dry	152.69	270	4	1	76.19	19.05	7392	20	0.27	358	na	16	76.19
Summer	average	152.691	270	4	3	83.78	0.00	7392	122	1.65	585	8	85	76.58
Summer	wet	376.77	680	6	2	83.33	0.00	4077	49	1.2	363	5.9	30	83.33

LRLR53:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	1031.16	2350	5	1	100.00	52.94	1561	35	2.24	145	na	16	94.12
Winter	average	1031.16	2350	5	3	82.93	4.88	1561	165	10.57	184	7.8	90	73.17
Winter	wet	3172.8	11800	11	2	72.22	0.00	593	85	14.33	164	1.9	23	63.89
Spring	dry	2815.86	9760	10	1	86.36	81.82	3292	120	3.65	168	na	15	68.18
Spring	average	2815.86	9760	10	3	100.00	0.00	3292	341	10.36	153	6.8	95	90.48
Spring	wet	6524.07	32200	17	2	94.74	0.00	1835	247	13.46	133	7.4	30	78.95
Summer	dry	852.69	1560	4	1	85.71	47.62	7492	33	0.44	238	na	17	80.95
Summer	average	852.69	1560	4	3	94.59	0.00	7492	170	2.27	328	4.3	100	90.09
Summer	wet	2101.98	5890	8	2	100.00	0.00	4044	64	1.58	207	3.7	35	97.22

LRCA58:

Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	2141.64	6680	8	1	88.24	64.71	1891	49	2.59	161	na	12	70.59
Winter	average	2141.64	6680	8	3	80.49	7.32	1891	217	11.48	185	4.6	91	73.98
Winter	wet	4243.62	14900	10	2	83.33	0.00	1103	78	7.07	165	2.8	30	83.33
Spring	dry	6345.6	23900	12	1	77.27	77.27	3172	127	4	151	na	12	54.55
Spring	average	6345.6	23900	12	3	94.29	0.00	3172	366	11.54	141	6.6	85	80.95
Spring	wet	9498.57	38400	14	2	100.00	0.00	2302	147	6.39	121	6.2	37	97.37
Summer	dry	1110.48	28600	6	1	85.71	85.71	9873	100	1.01	362	na	2	9.52
Summer	average	1110.48	28600	6	3	94.59	0.00	9873	524	5.31	227	9.8	28	25.23
Summer	wet	1963.17	55500	8	2	100.00	0.00	7039	201	2.86	138	2	22	61.11

NBCL36:

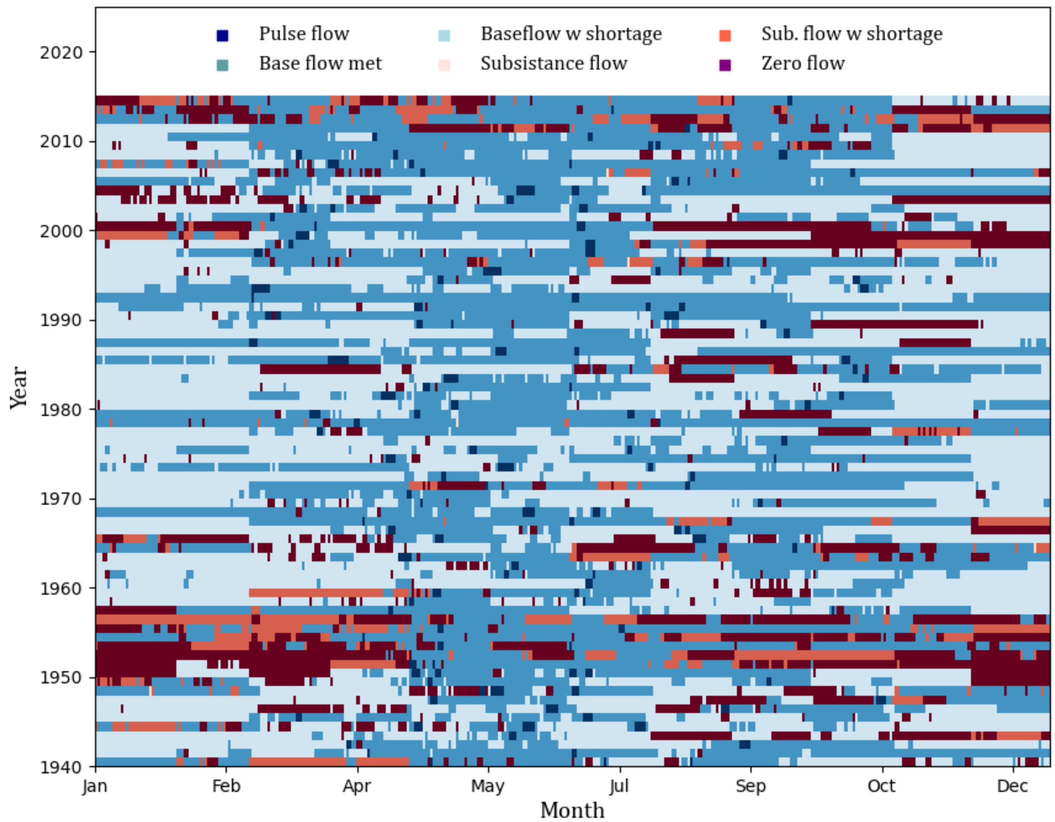
Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	wet	237.96	750	10	2	89.47	0.00	1477	62	4.2	236	2.5	30	78.95
Spring	dry	1407.93	3490	12	1	72.73	45.45	1354	59	4.36	201	na	14	63.64
Spring	average	1407.93	3490	12	3	82.86	0.00	1354	174	12.85	1405	3	78	74.29
Spring	wet	1407.93	3490	12	3	105.26	0.00	1354	109	8.05	747	3.6	55	96.49
Summer	wet	257.79	500	6	2	100.00	0.00	5233	52	0.99	1039	2.2	36	100.00

NAEA66:

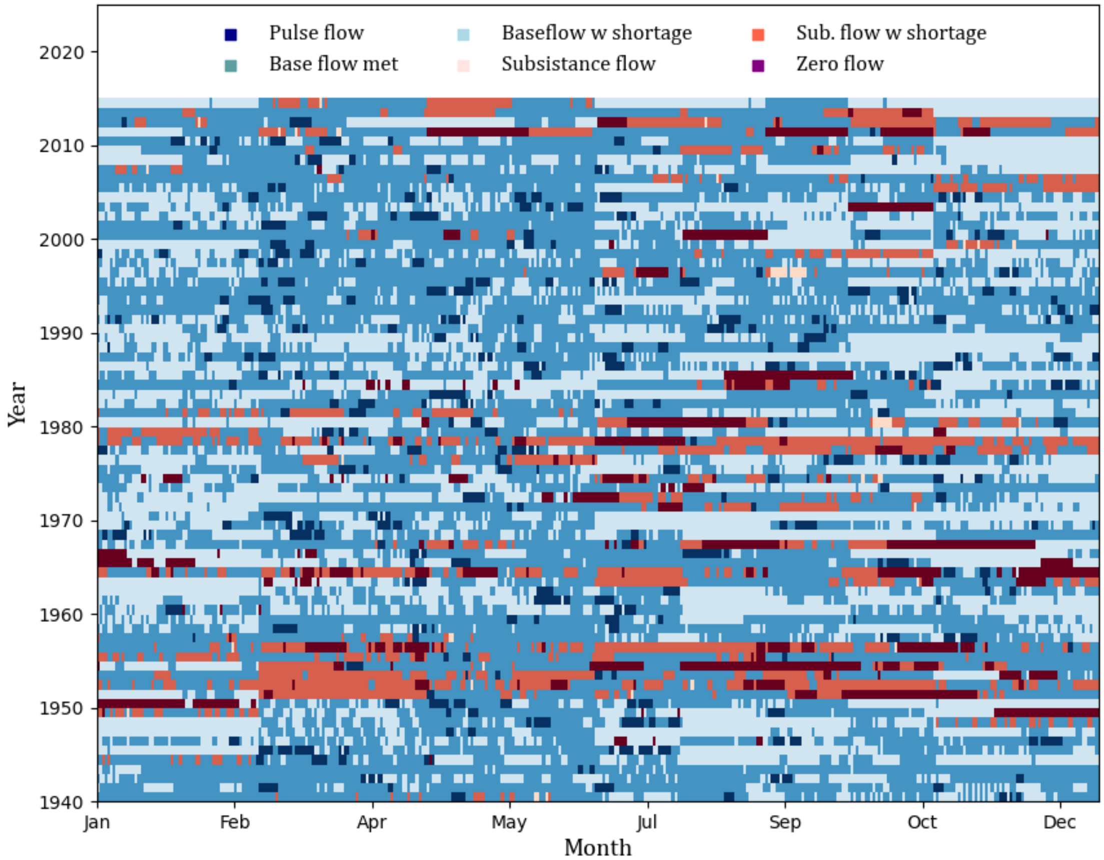
Season	HC	Triger (ac-ft)	Volume (ac-ft)	Duration (day)	Freq.	PSE (%)	PSM (%)	Day > Trigger (day)	E (day)	EF (%)	EVR (%)	ADBP (day)	EP (#)	PEP (%)
Winter	dry	515.58	1610	9	1	88.24	76.47	2101	52	2.48	264	na	13	76.47
Winter	average	515.58	1610	9	3	85.37	9.76	2101	260	12.38	313	2.8	102	82.93
Winter	wet	1586.4	5440	12	2	88.89	0.00	952	98	10.29	95	1.9	28	77.78
Spring	dry	1427.76	4590	11	1	72.73	68.18	2682	46	1.72	32	na	16	72.73
Spring	average	1427.76	4590	11	3	97.14	0.00	2682	289	10.78	237	3.7	98	93.33
Spring	wet	2657.22	8990	13	2	100.00	0.00	1619	128	7.91	63	1.4	38	100.00
Summer	wet	97.167	220	5	2	88.89	0.00	11745	54	0.46	602	2.3	31	86.11

APPENDIX 3-D: RASTER PLOTS OF ALL FLOW REGIMES SIMULATED BY HYDROLOGY ADJUSTED FOR TREND FOR 2050 CONDITION

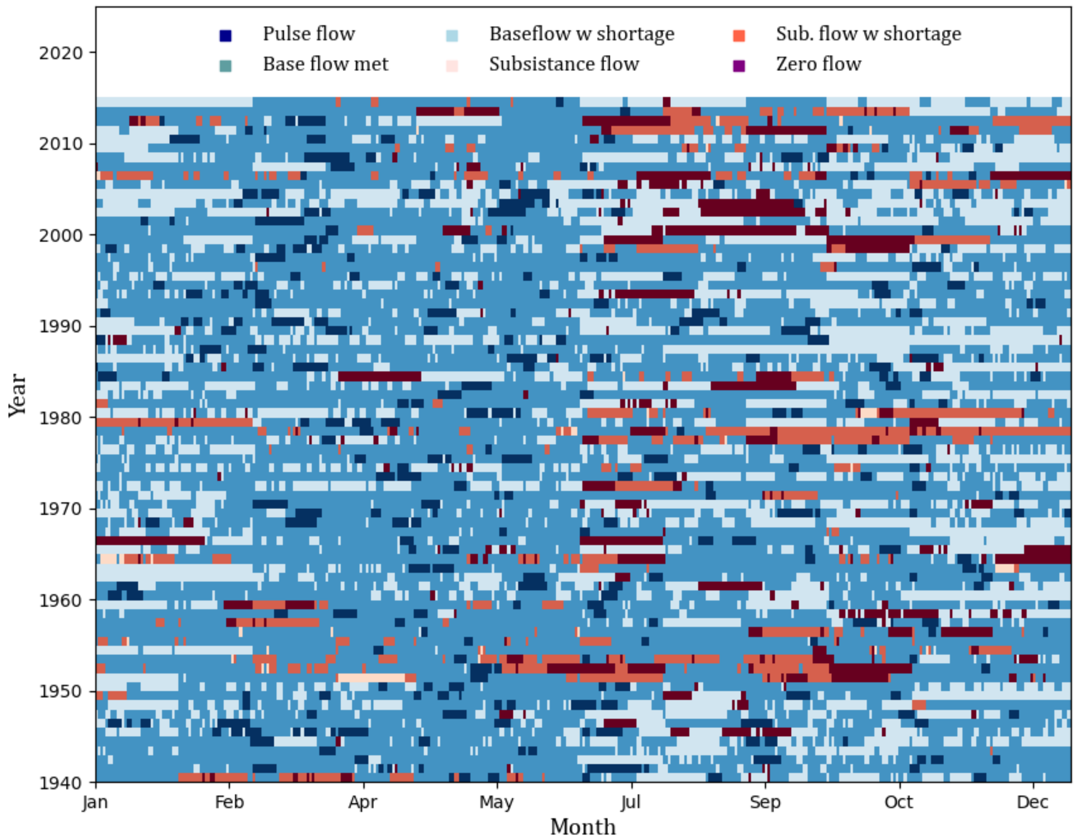
Days of E-Flow Regimes at BRSB23 by hydrology adjusted for trend for 2050



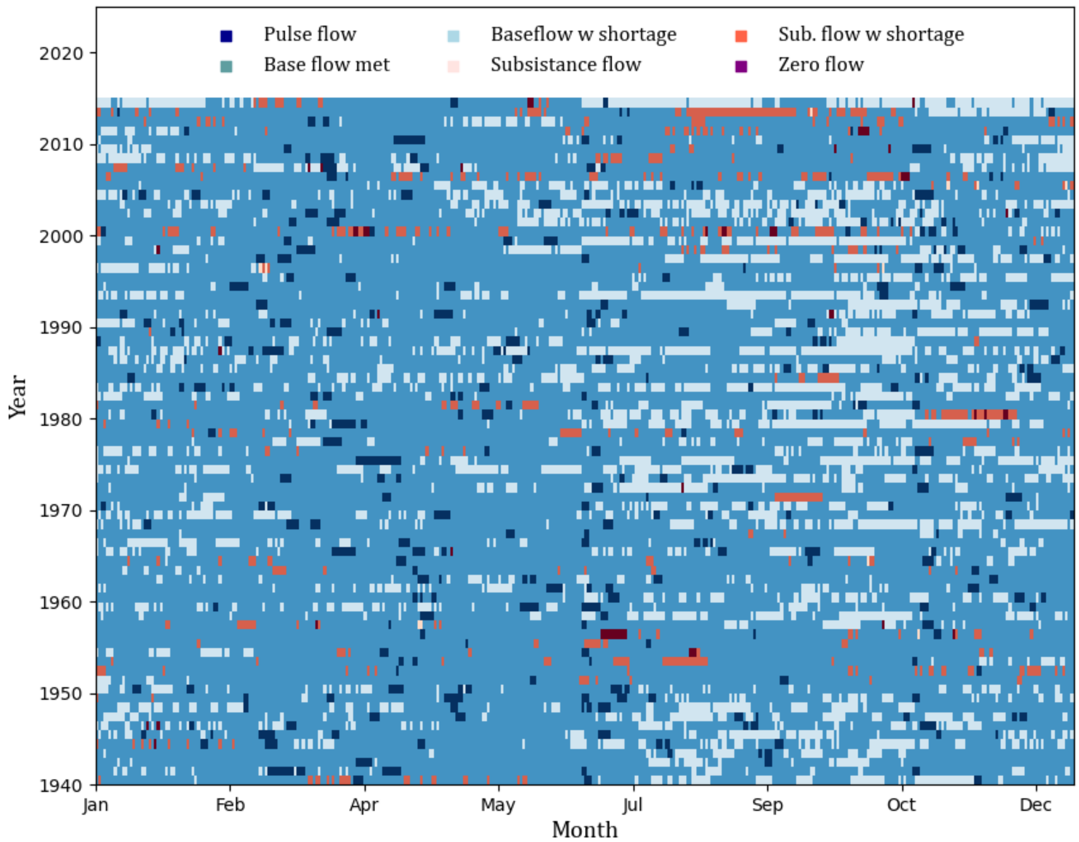
Days of E-Flow Regimes at BRPP27 by hydrology adjusted for trend for 2050

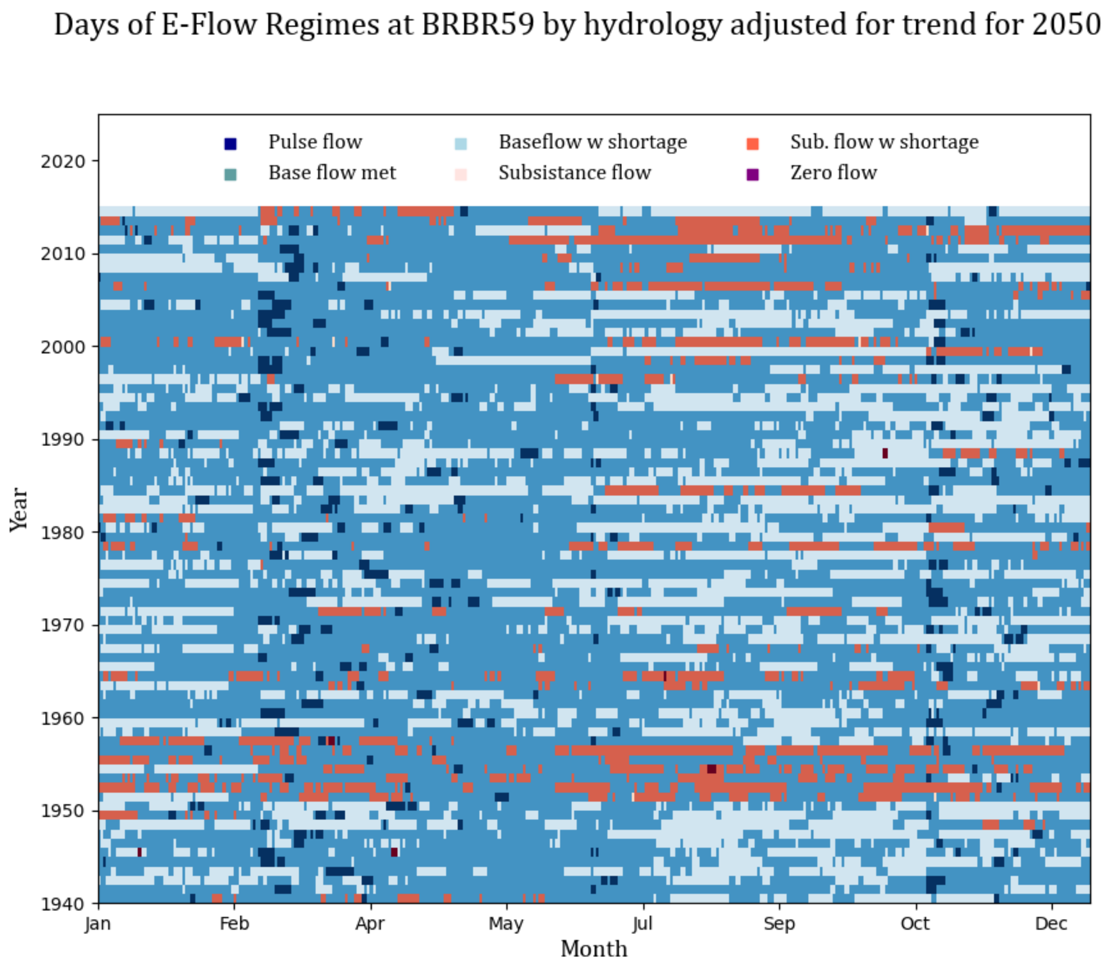


Days of E-Flow Regimes at BRGR30 by hydrology adjusted for trend for 2050

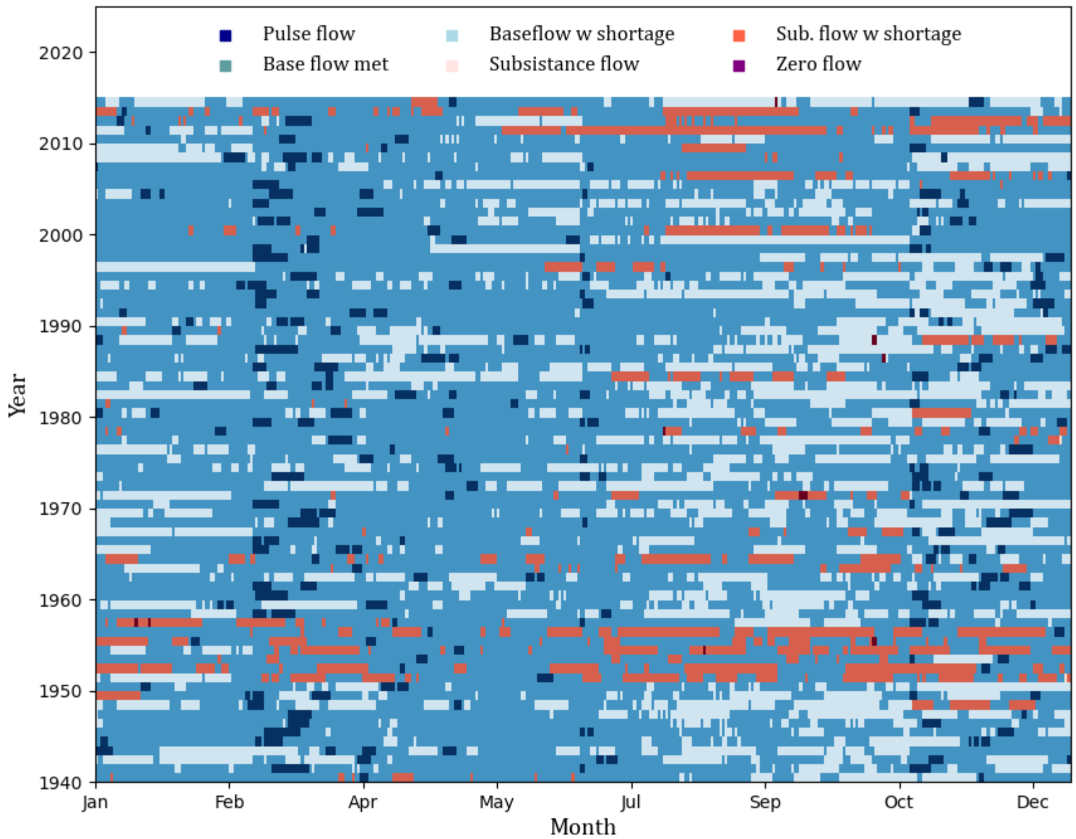


Days of E-Flow Regimes at BRWA41 by hydrology adjusted for trend for 2050

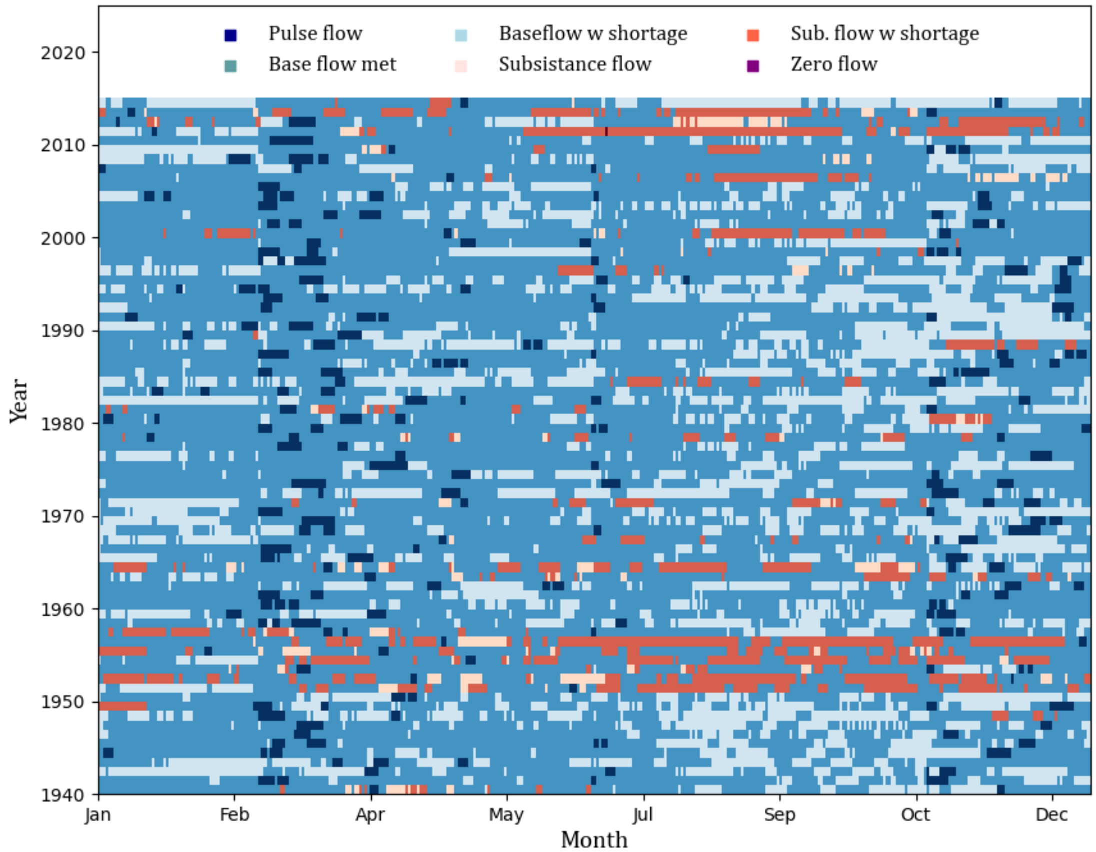



Days of E-Flow Regimes at BRBR59 by hydrology adjusted for trend for 2050
Pulse flow
Base flow met
Baseflow w shortage
Subsistance flow
Sub. flow w shortage
Zero flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Month
Jan
Feb
Apr
May
Jul
Sep
Oct
Dec

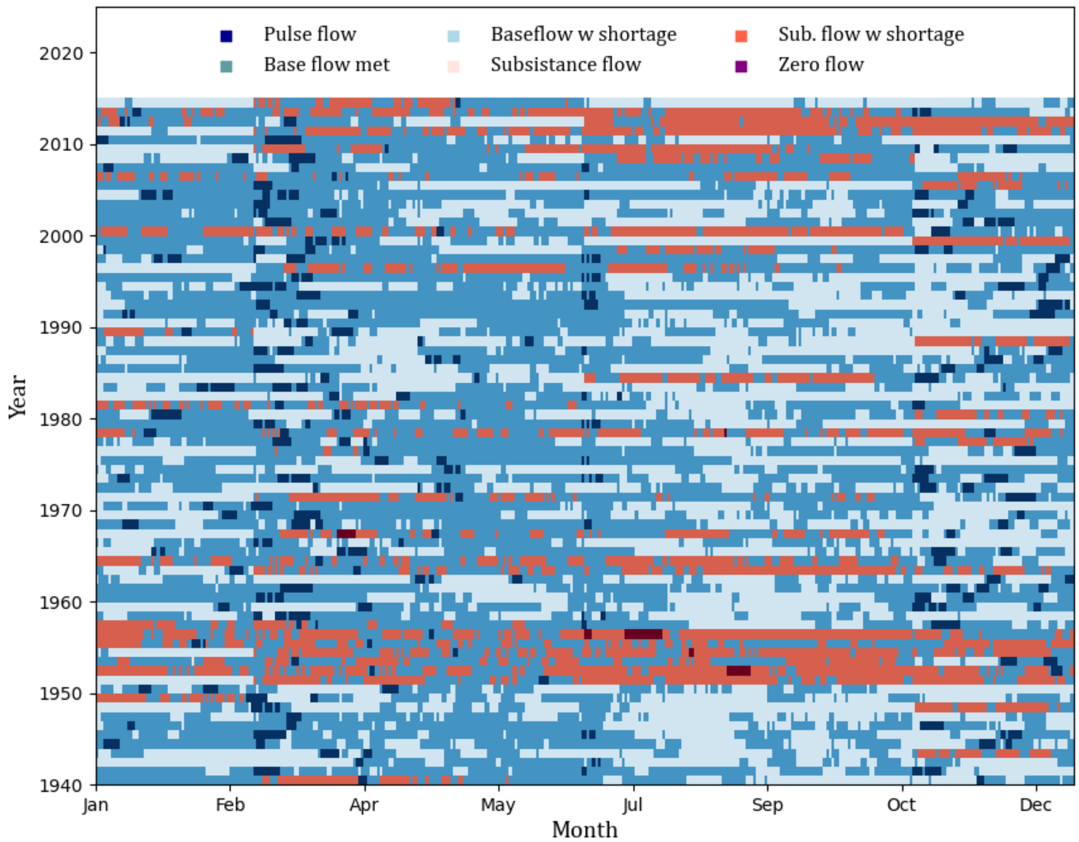
Days of E-Flow Regimes at BRHE68 by hydrology adjusted for trend for 2050

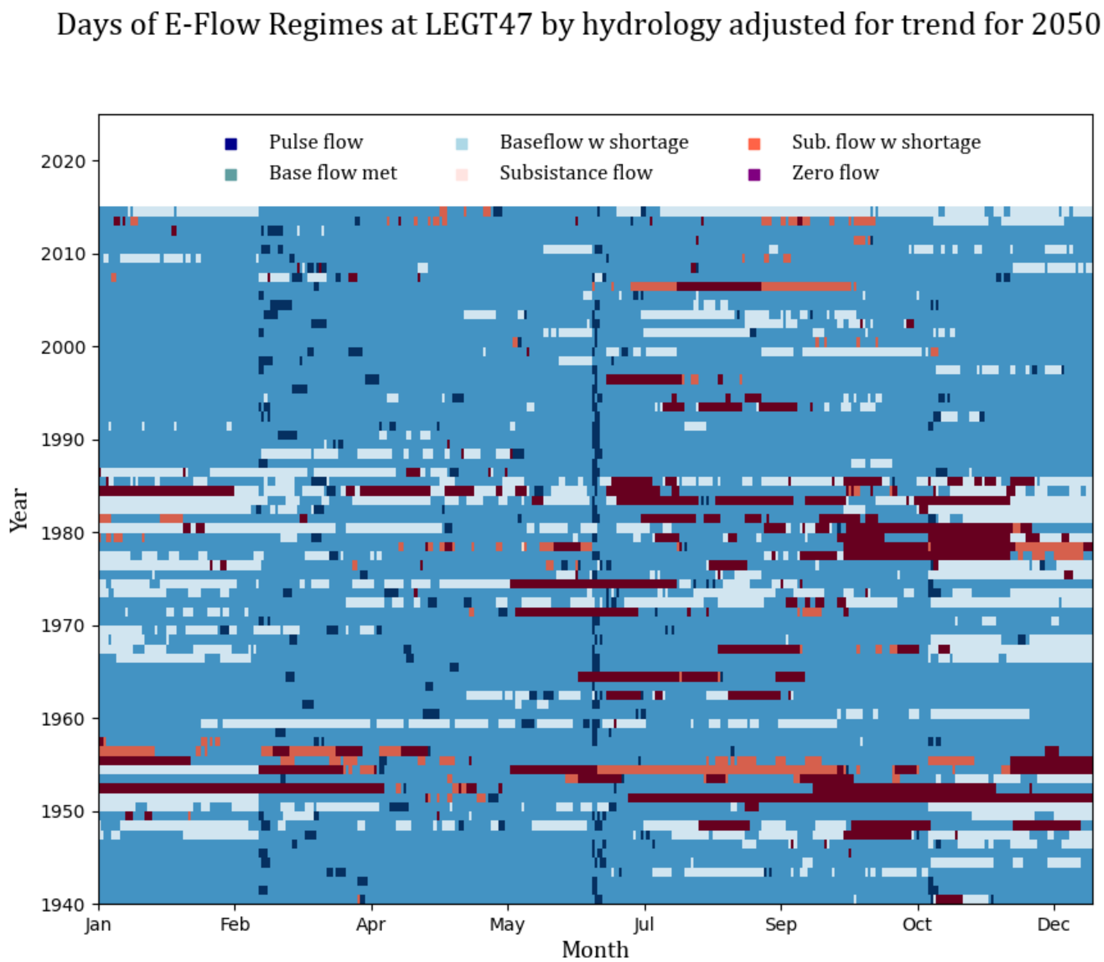


Days of E-Flow Regimes at BRRI70 by hydrology adjusted for trend for 2050

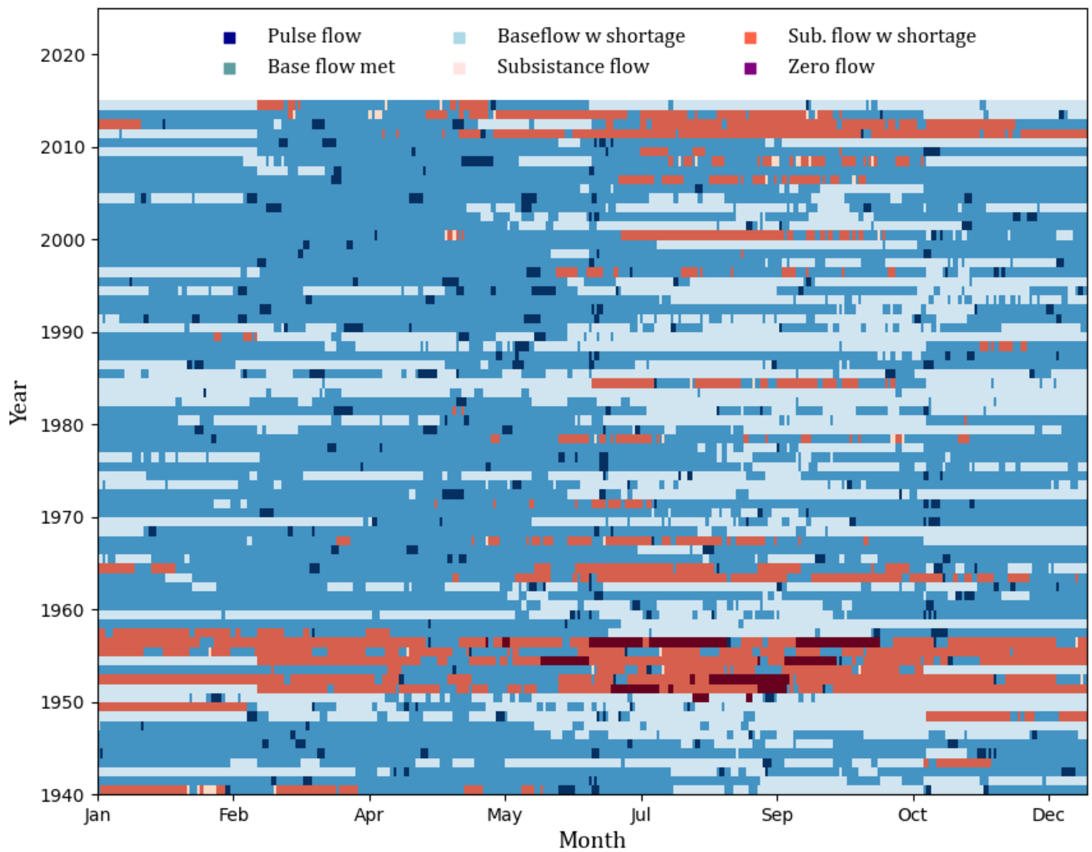


Days of E-Flow Regimes at BRRO72 by hydrology adjusted for trend for 2050

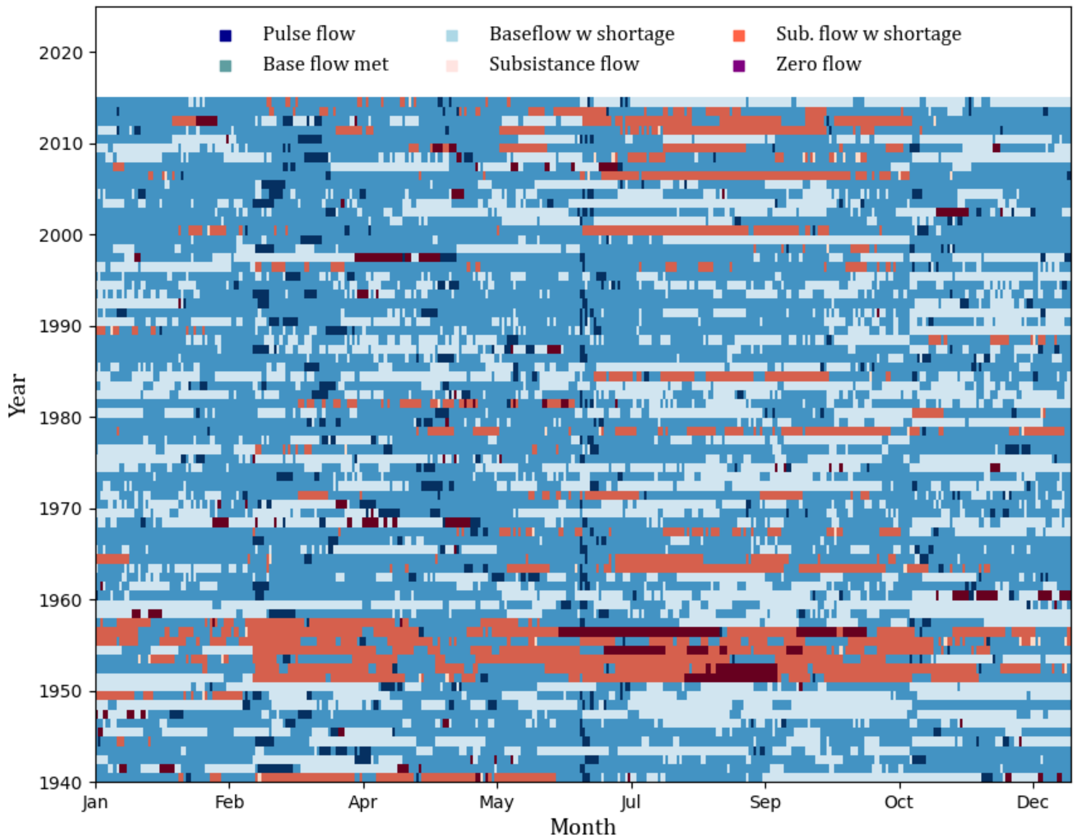



Days of E-Flow Regimes at LEGT47 by hydrology adjusted for trend for 2050
Pulse flow
Base flow met
Baseflow w shortage
Subsistance flow
Sub. flow w shortage
Zero flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Jan
Feb
Apr
May
Jul
Sep
Oct
Dec
Month

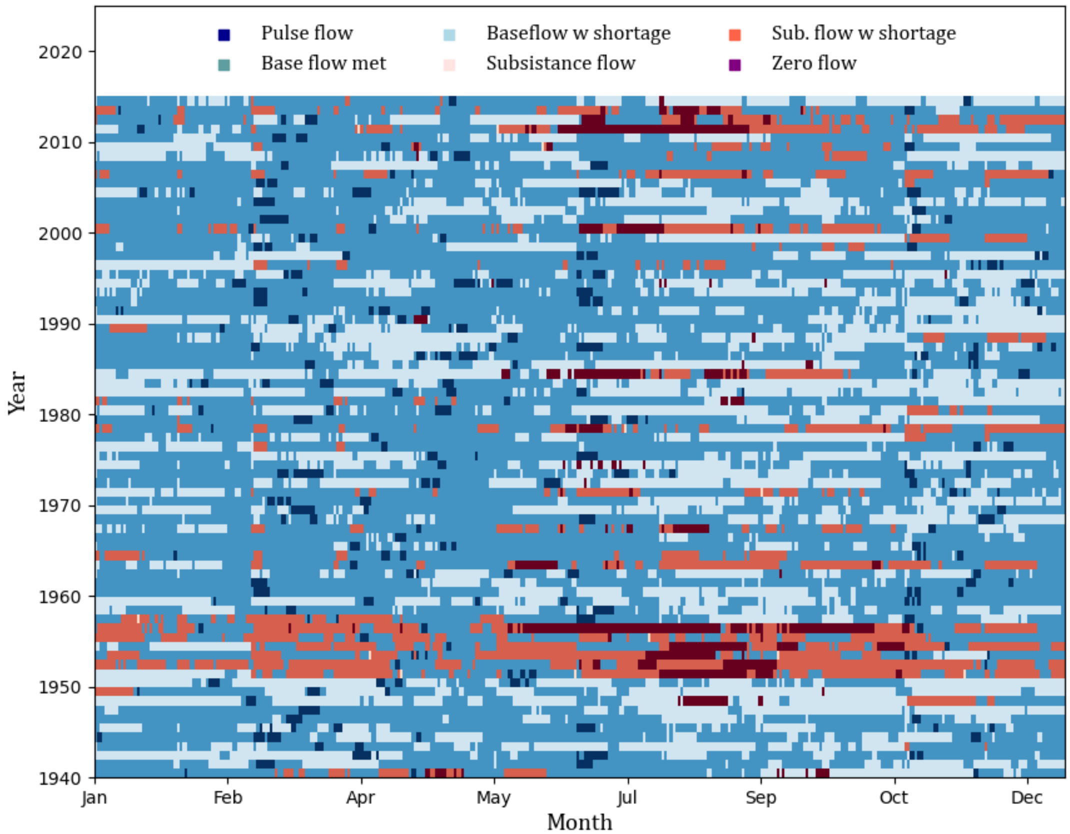
Days of E-Flow Regimes at LAKE50 by hydrology adjusted for trend for 2050

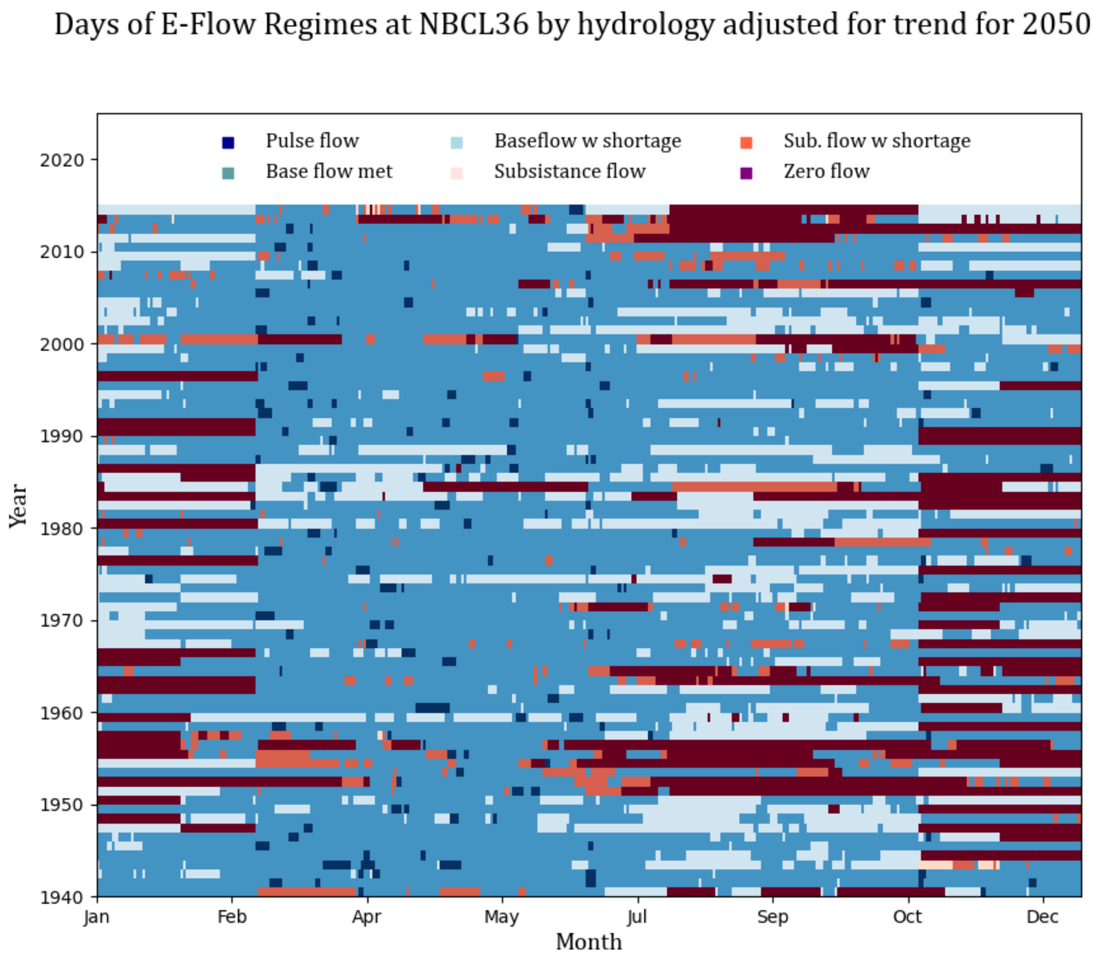


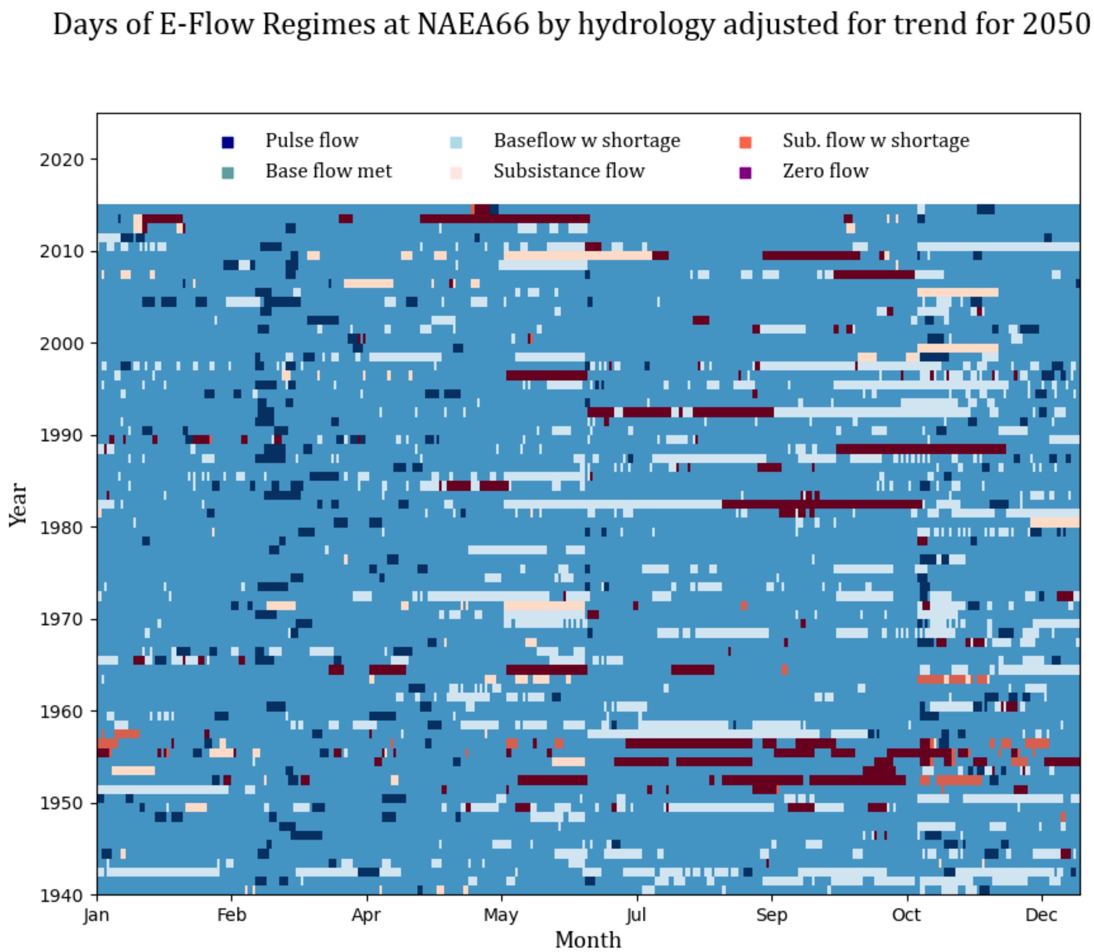
Days of E-Flow Regimes at LRLR53 by hydrology adjusted for trend for 2050



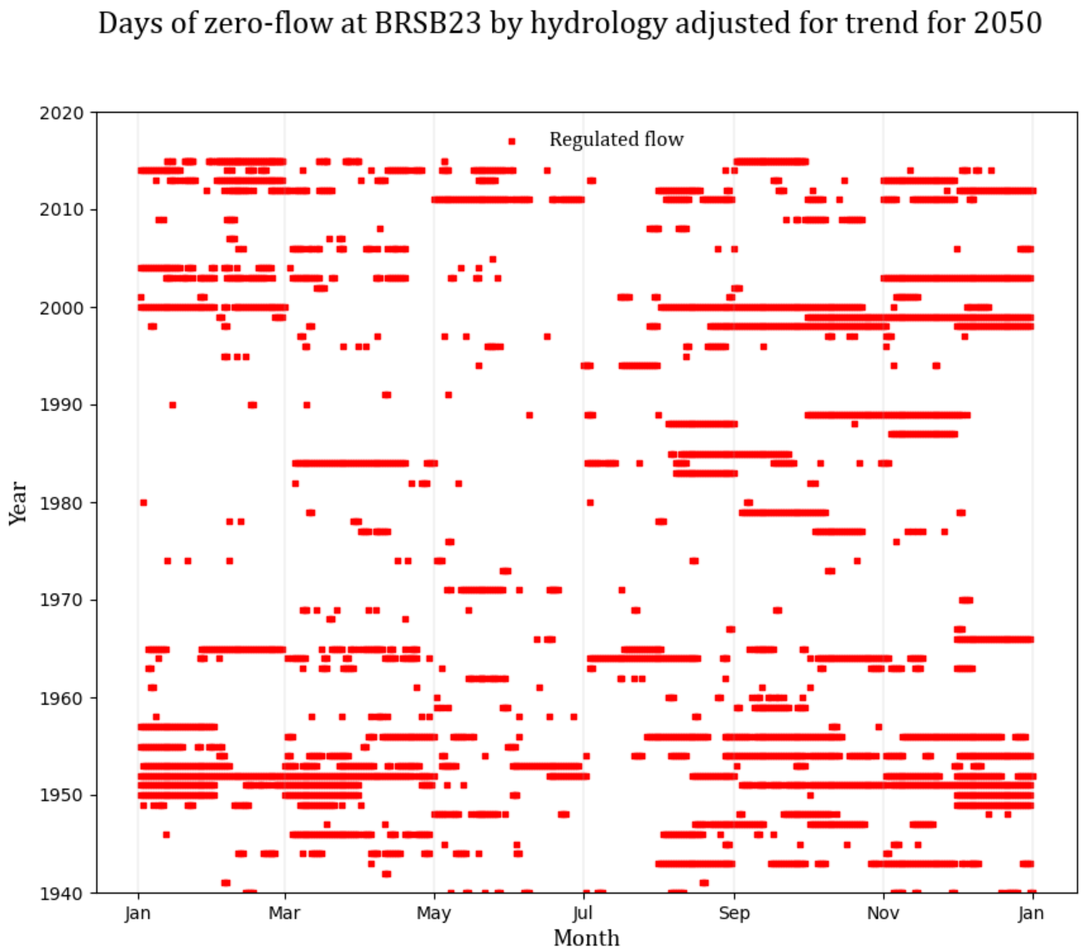
Days of E-Flow Regimes at LRCA58 by hydrology adjusted for trend for 2050

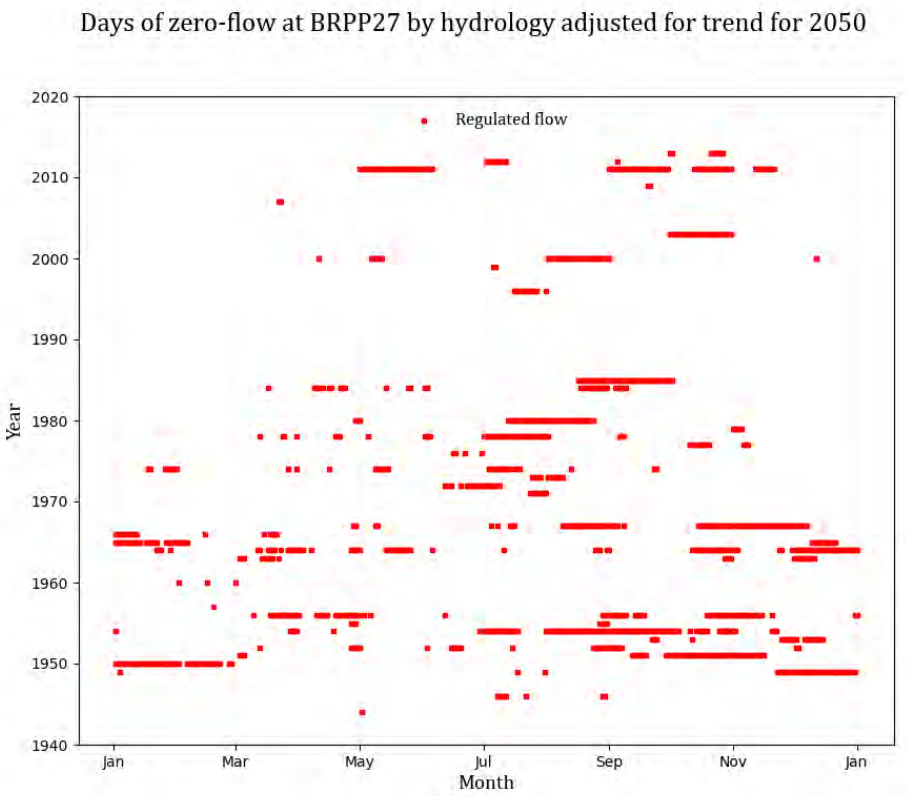


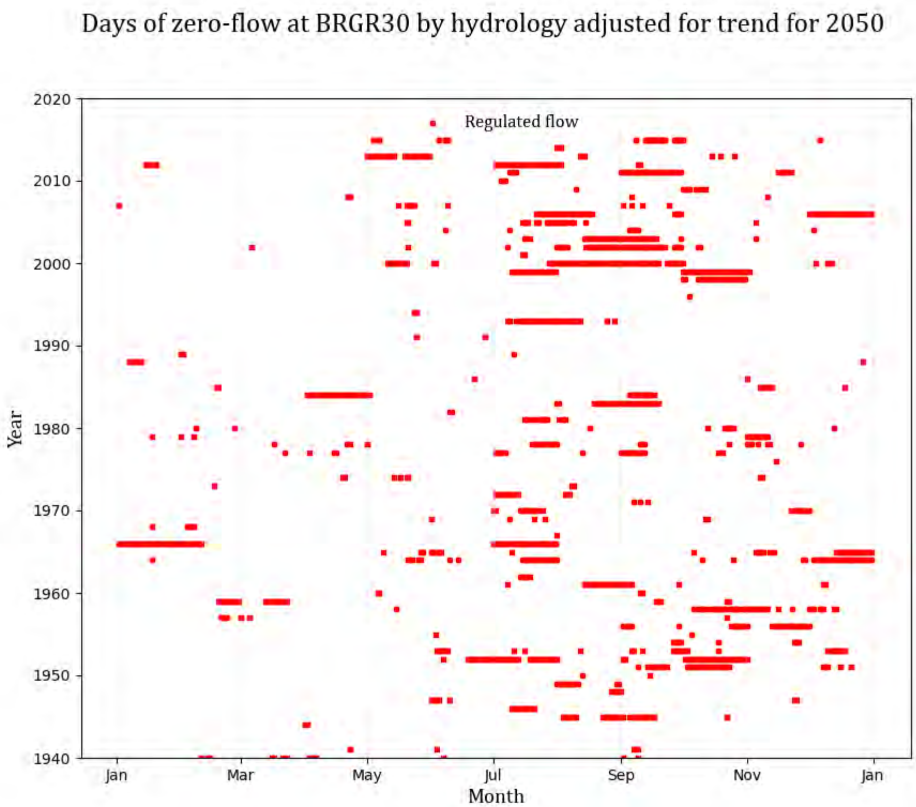

Days of E-Flow Regimes at NBCL36 by hydrology adjusted for trend for 2050
Pulse flow
Base flow met
Baseflow w shortage
Subsistance flow
Sub. flow w shortage
Zero flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Jan
Feb
Apr
May
Jul
Sep
Oct
Dec
Month

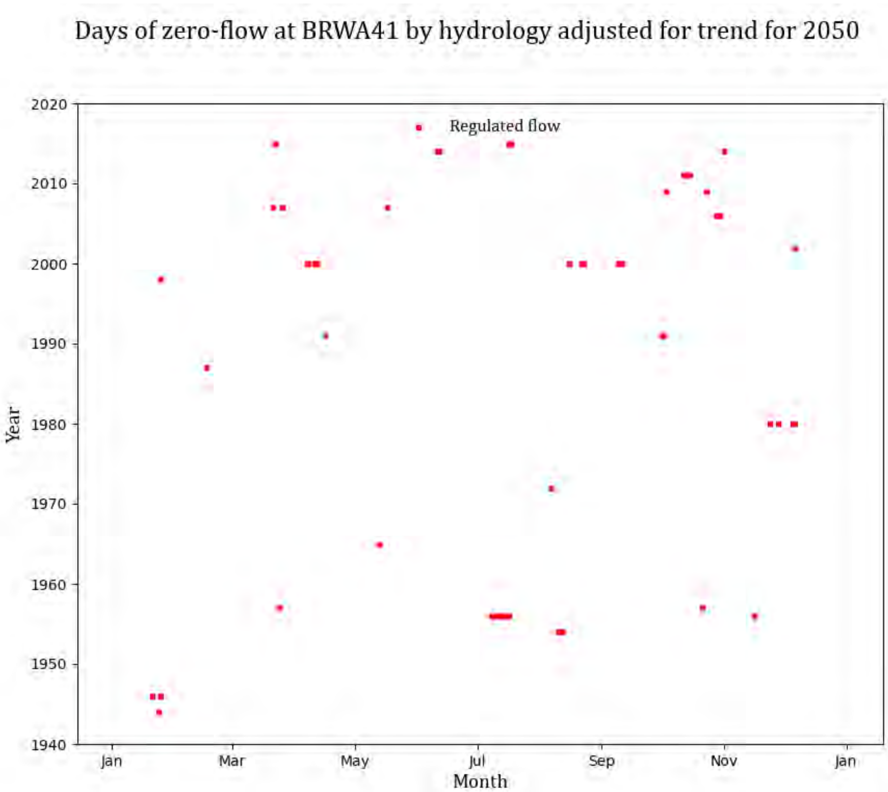

Days of E-Flow Regimes at NAEA66 by hydrology adjusted for trend for 2050
Pulse flow
Base flow met
Baseflow w shortage
Subsistance flow
Sub. flow w shortage
Zero flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Jan
Feb
Apr
May
Jul
Sep
Oct
Dec
Month

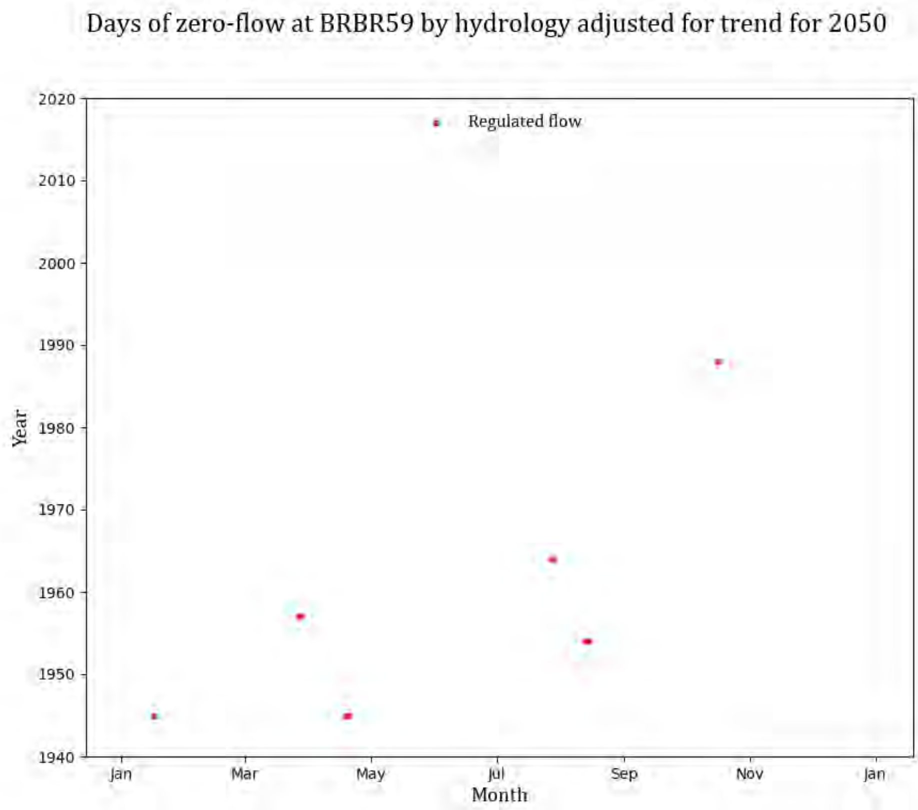
APPENDIX 3-E: RASTER PLOTS FOR ZERO-FLOW DAYS

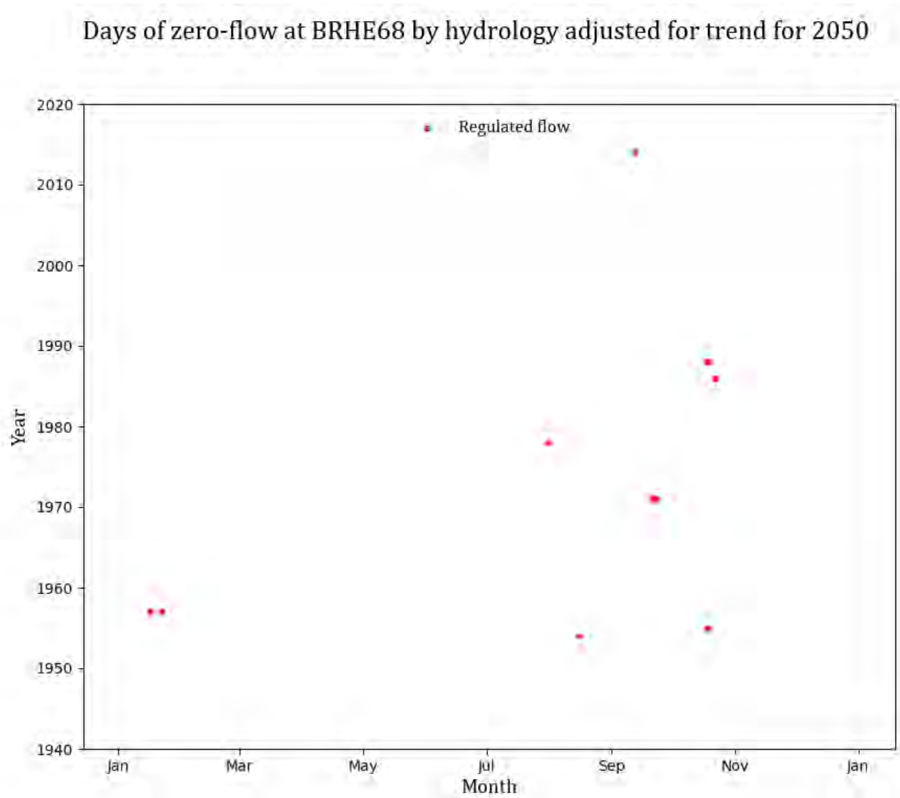


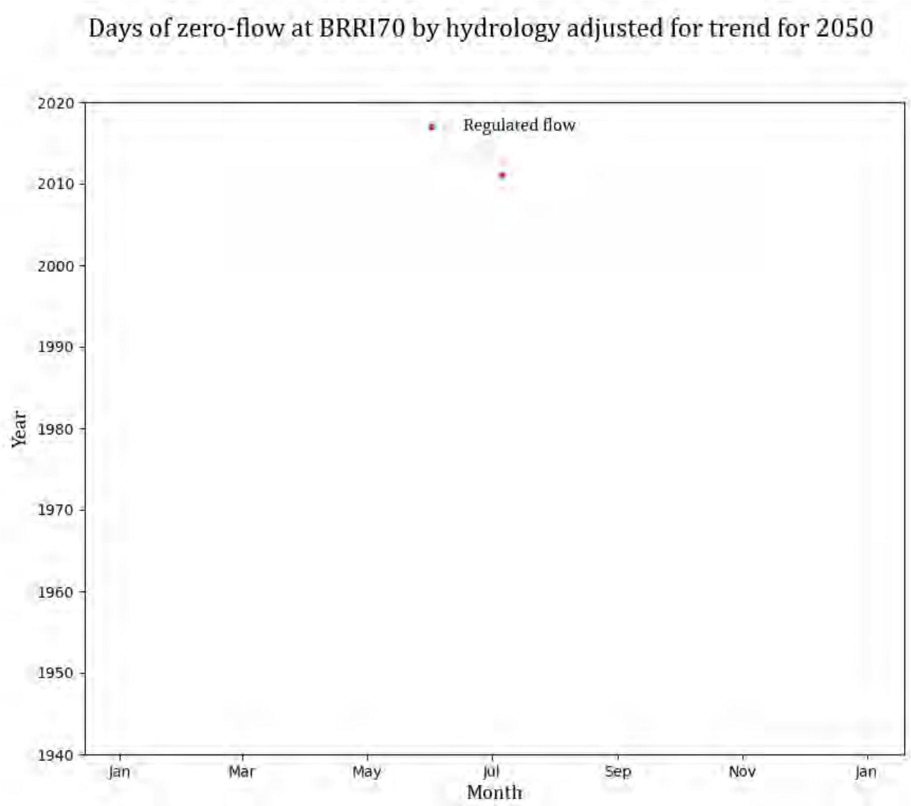

Days of zero-flow at BRPP27 by hydrology adjusted for trend for 2050
Regulated flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Jan
Mar
May
Jul
Sep
Nov
Jan
Month


Days of zero-flow at BRGR30 by hydrology adjusted for trend for 2050
Regulated flow
2020
2010
2000
1990
1980
1970
1960
1950
1940
Year
Jan
Mar
May
Jul
Sep
Nov
Jan
Month


Days of zero-flow at BRWA41 by hydrology adjusted for trend for 2050
Regulated flow
2020
2010
2000
1990
1980
1970
1960
1950
1940
Year
Jan
Mar
May
Jul
Sep
Nov
Jan
Month


Days of zero-flow at BRBR59 by hydrology adjusted for trend for 2050
Regulated flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Jan
Mar
May
Jul
Sep
Nov
Jan
Month


Days of zero-flow at BRHE68 by hydrology adjusted for trend for 2050
Regulated flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Jan
Mar
May
Jul
Sep
Nov
Jan
Month


Days of zero-flow at BRRI70 by hydrology adjusted for trend for 2050
Regulated flow
Year
Month
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2010
2000
1990
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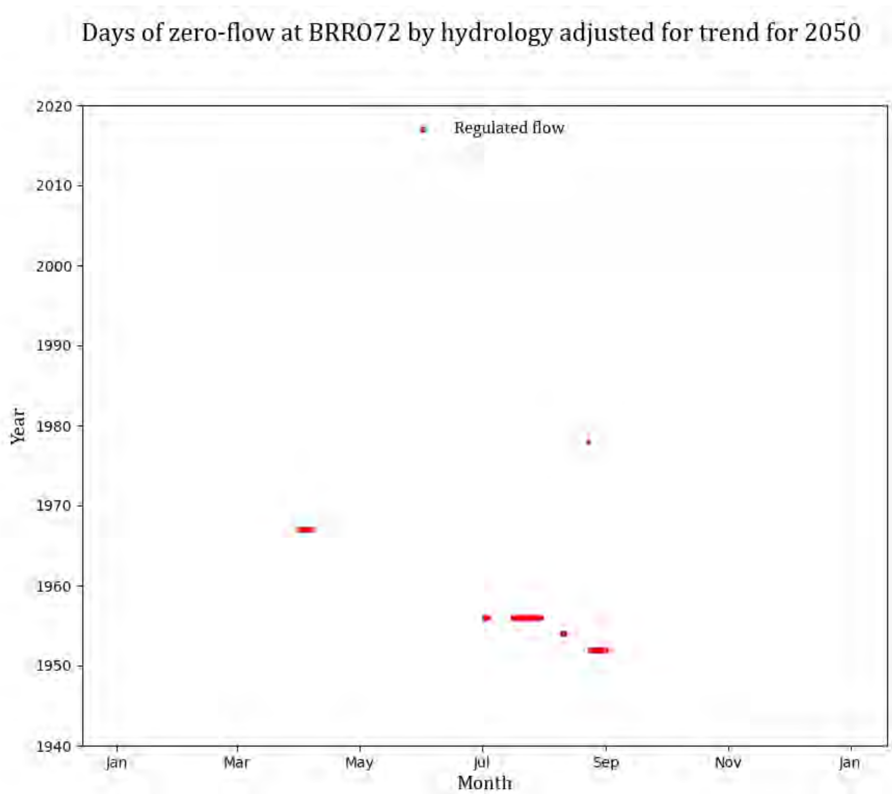
1970
1960
1950
1940
Jan
Mar
May
Jul
Sep
Nov
Jan


Days of zero-flow at BRRO72 by hydrology adjusted for trend for 2050
Regulated flow
Year
Month
2020
2010
2000
1990
1980
1970
1960
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1940
Jan
Mar
May
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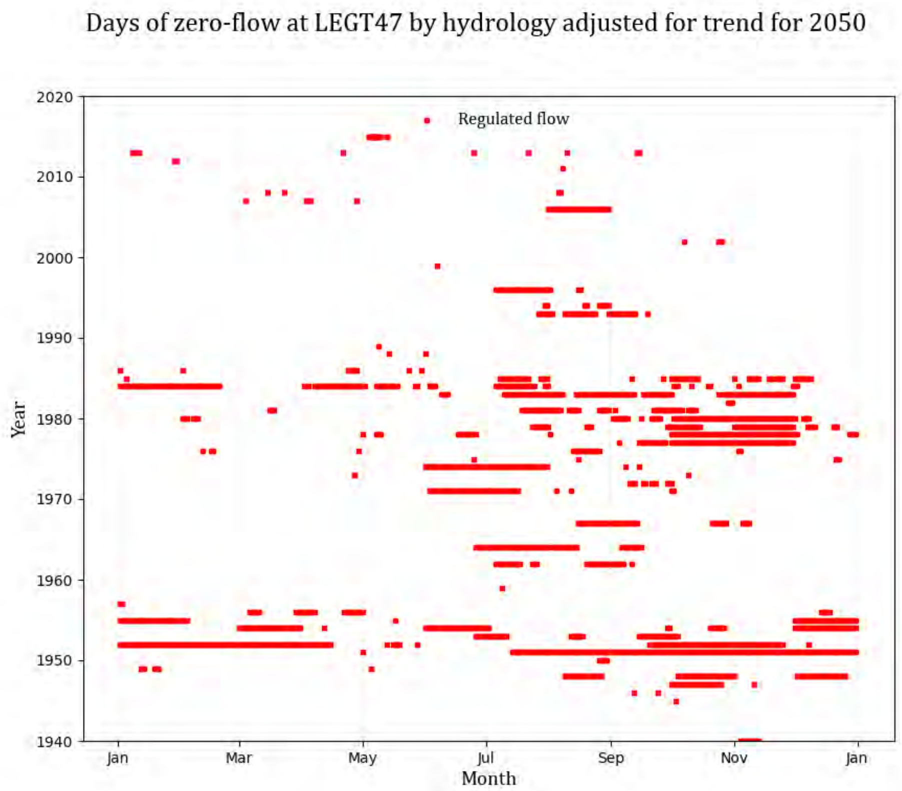
Sep
Nov
Jan


Days of zero-flow at LEGT47 by hydrology adjusted for trend for 2050
Regulated flow
Year
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2010
2000
1990
1980
1970
1960
1950
1940
Jan
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May
Jul
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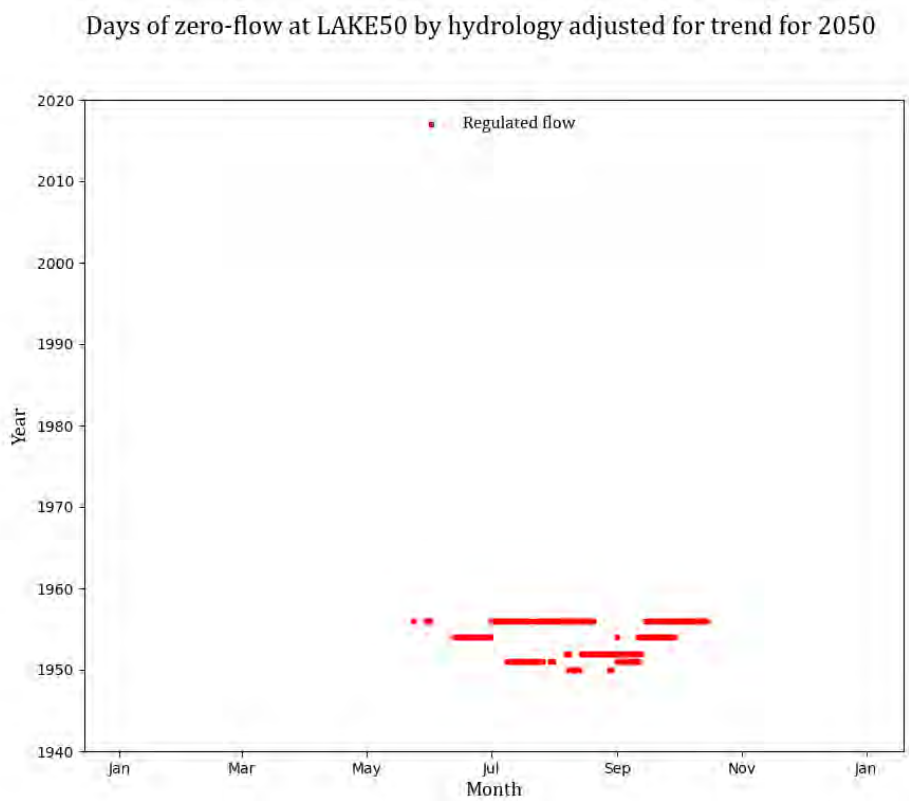
Nov
Jan
Month


Days of zero-flow at LAKE50 by hydrology adjusted for trend for 2050
Regulated flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Jan
Mar
May
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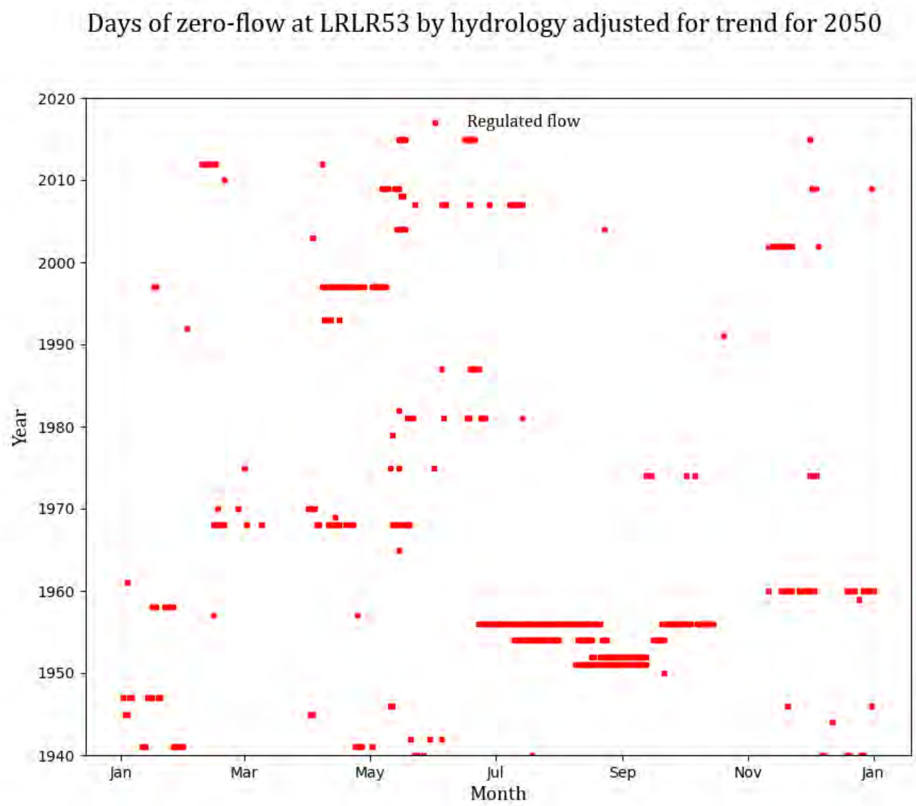
Days of zero-flow at LRLR53 by hydrology adjusted for trend for 2050
Regulated flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
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Month
Jan
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May
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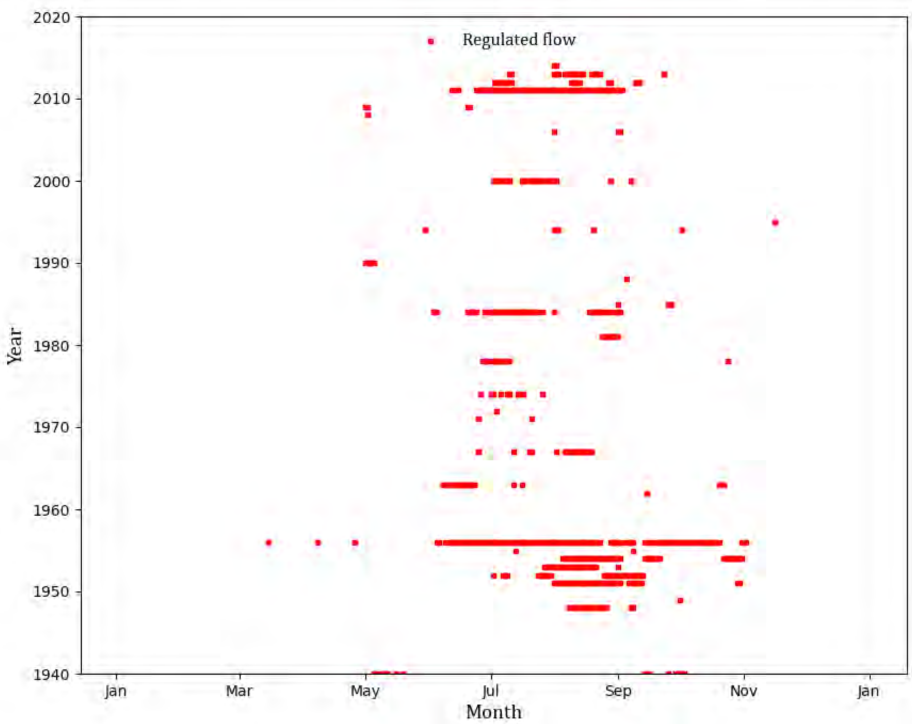
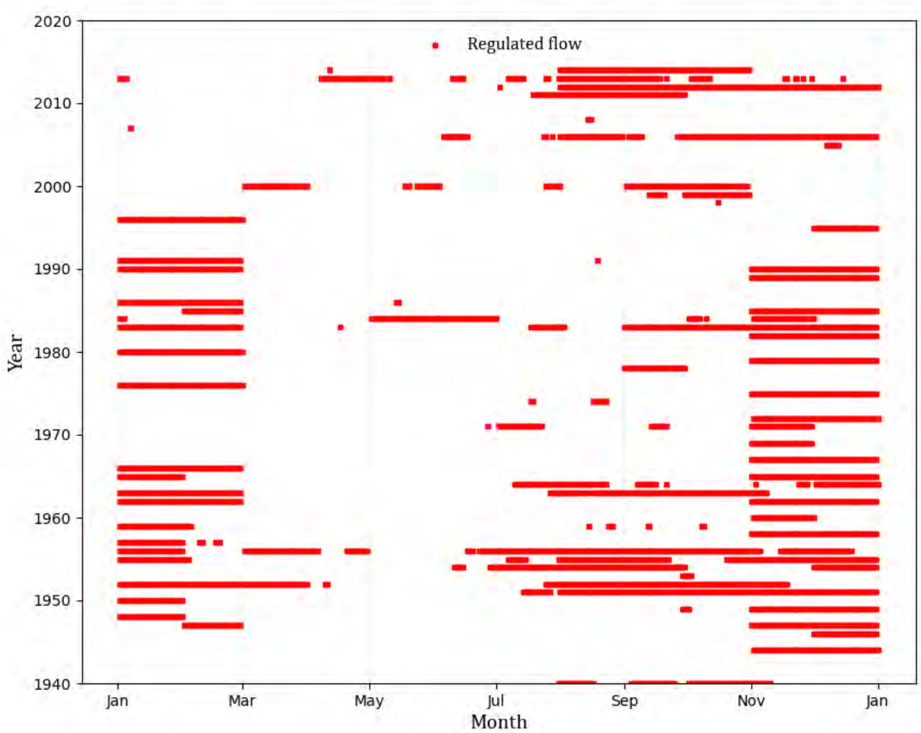
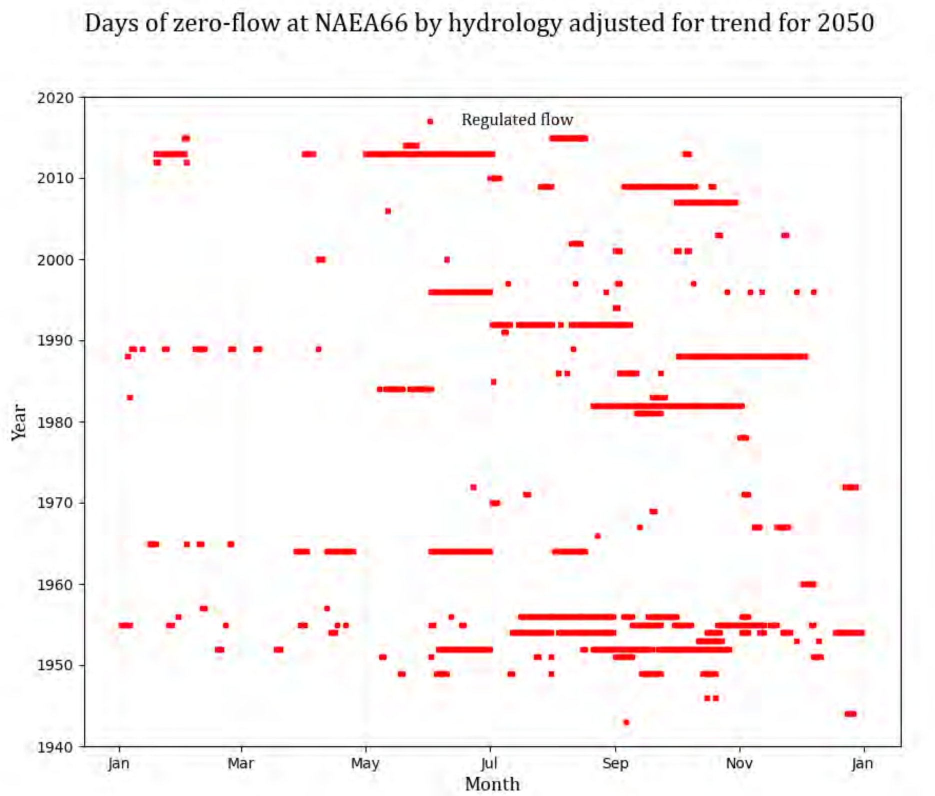
Sep
Nov
Jan

Days of zero-flow at LRCA58 by hydrology adjusted for trend for 2050



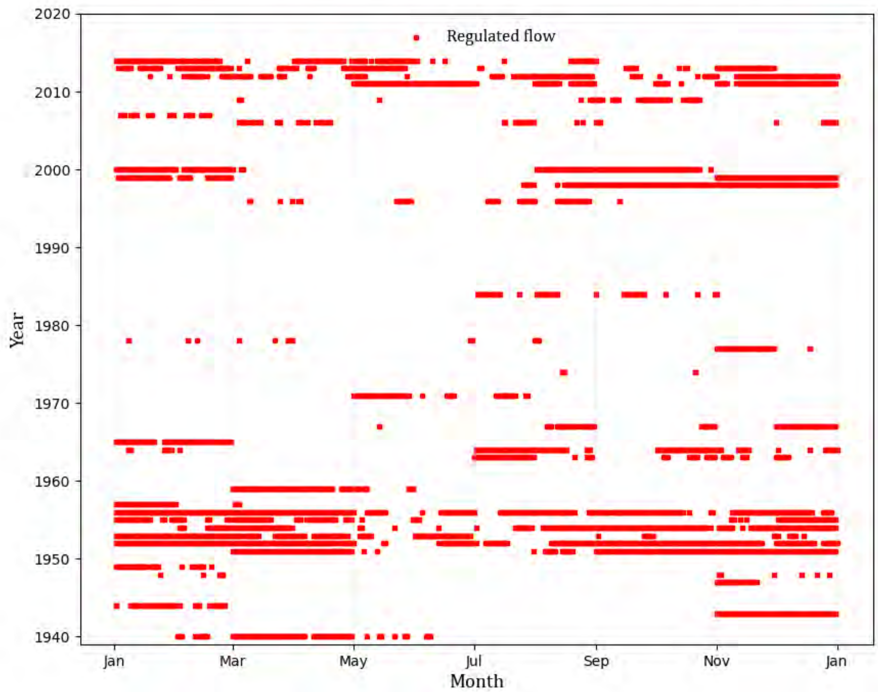
Days of zero-flow at NBCL36 by hydrology adjusted for trend for 2050



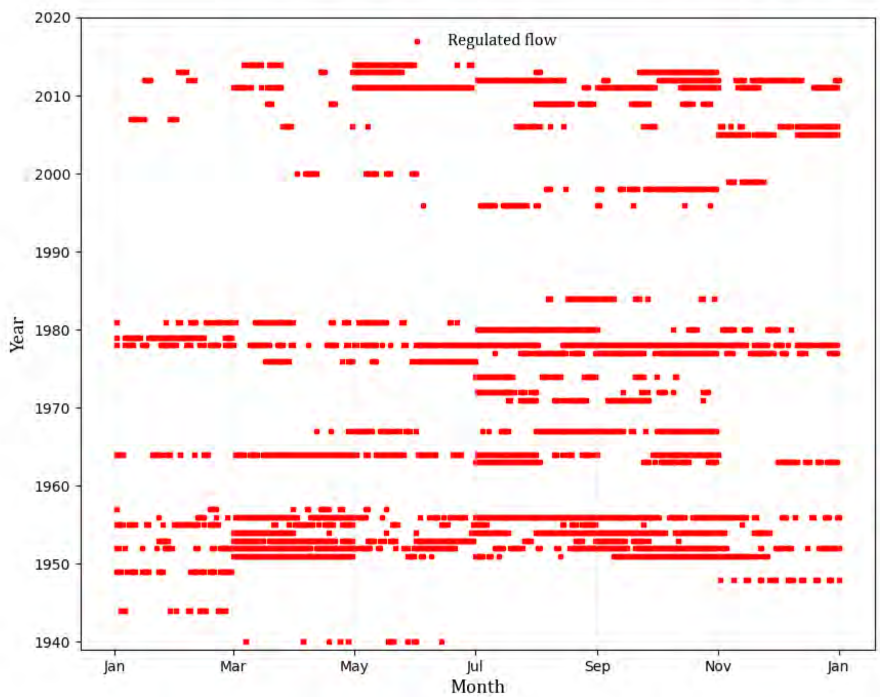

Days of zero-flow at NAEA66 by hydrology adjusted for trend for 2050
Regulated flow
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Jan
Mar
May
Jul
Sep
Nov
Jan
Month

APPENDIX 3-F: RASTER PLOTS FOR SUBSISTENCE FLOW SHORTAGE

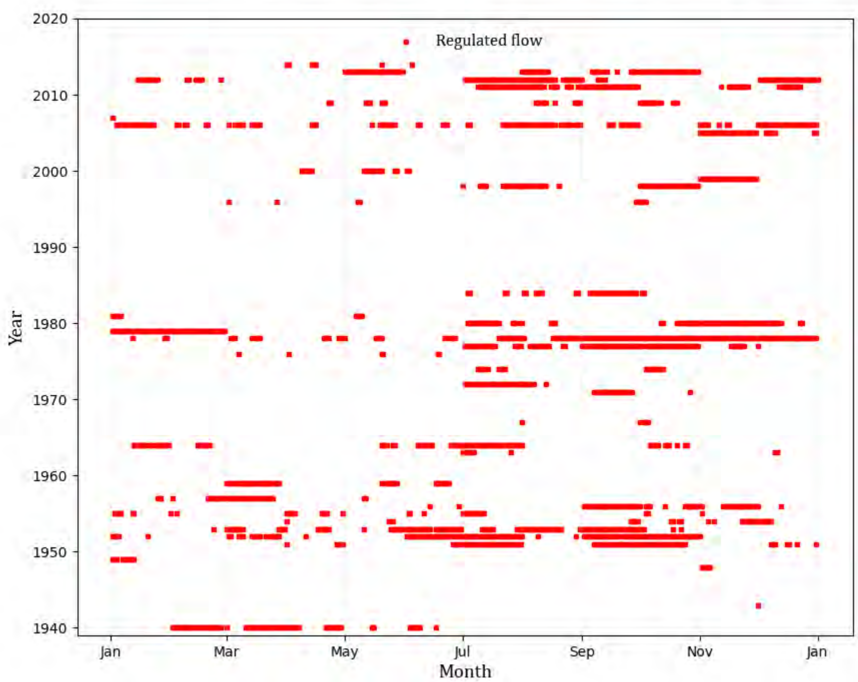
Days of shortage for subsistence flow at BRSB23 by hydrology adjusted for trend for 2050



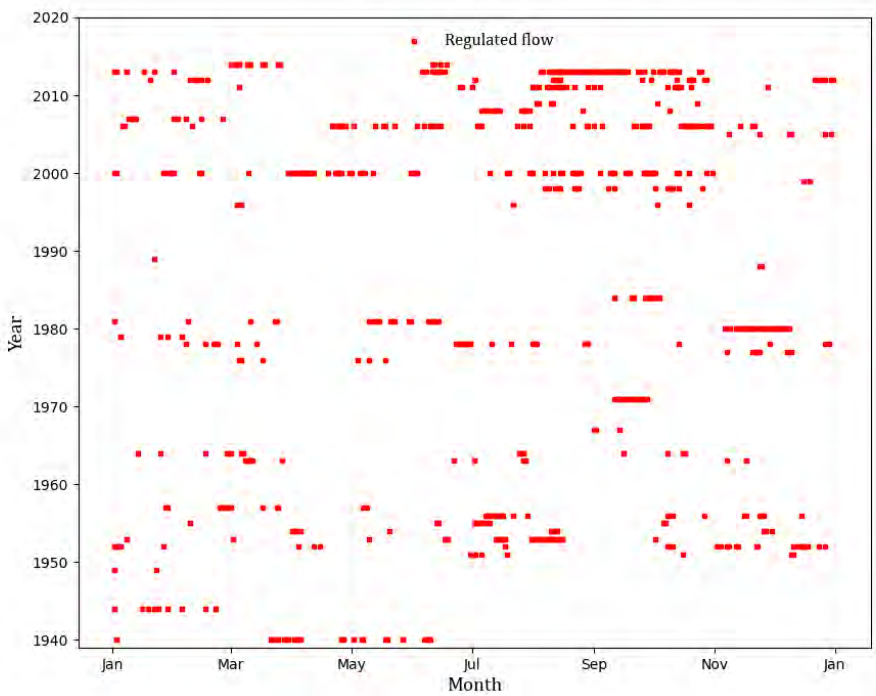
Days of shortage for subsistence flow at BRPP27 by hydrology adjusted for trend for 2050



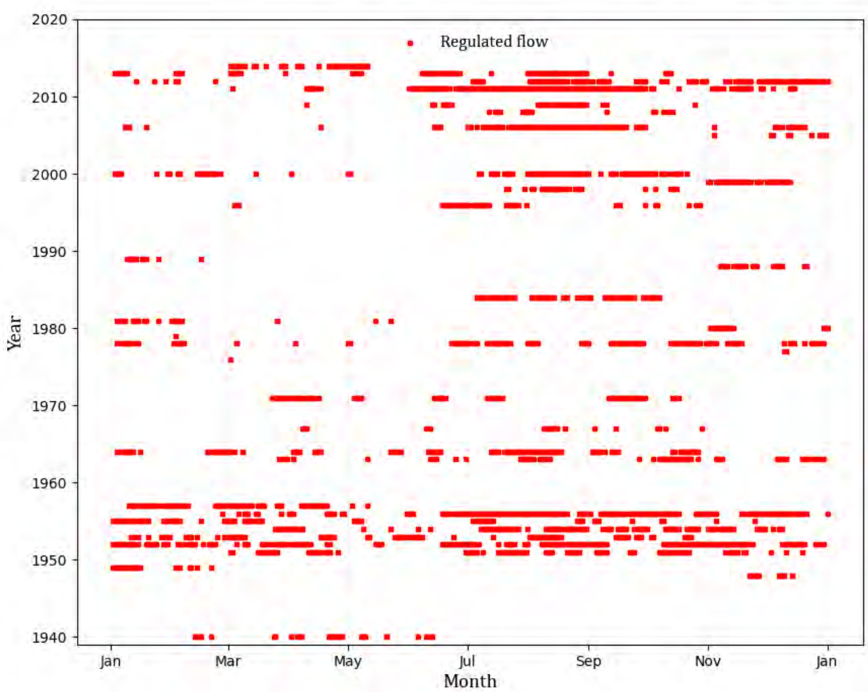
Days of shortage for subsistence flow at BRGR30 by hydrology adjusted for trend for 2050



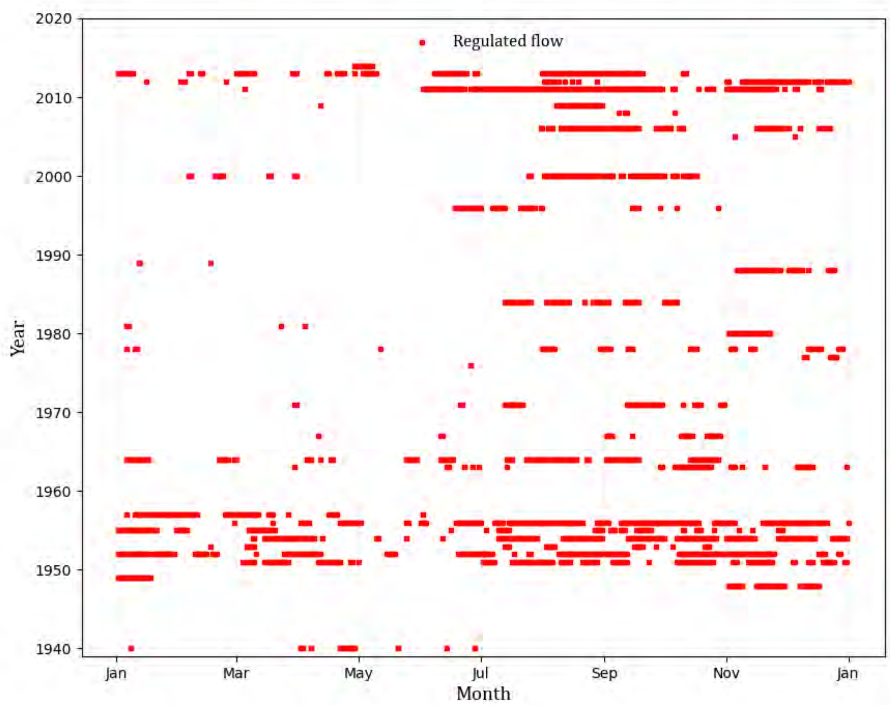
Days of shortage for subsistence flow at BRWA41 by hydrology adjusted for trend for 2050



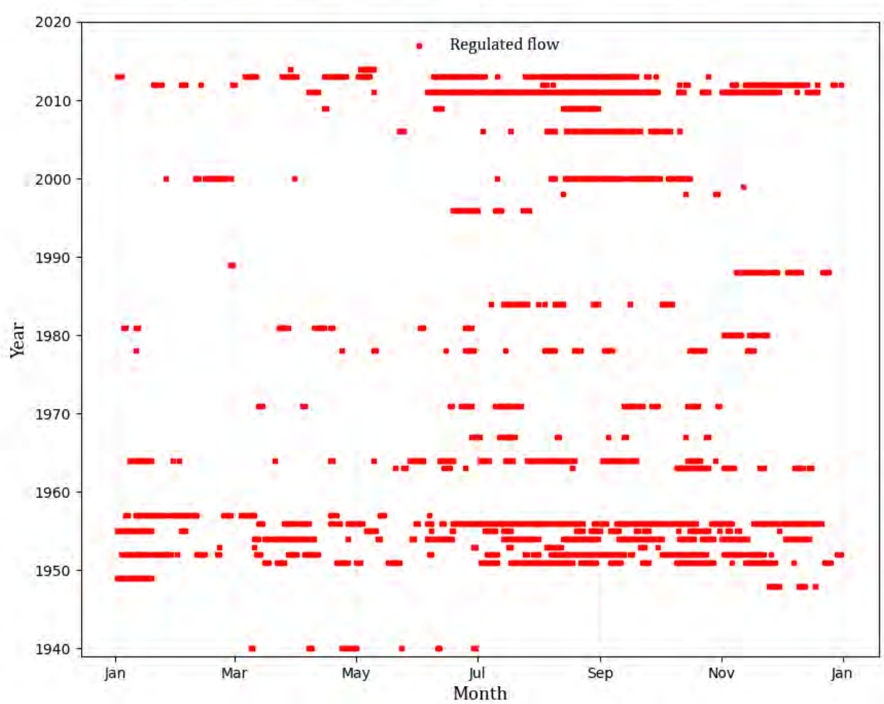
Days of shortage for subsistence flow at BRBR59 by hydrology adjusted for trend for 2050



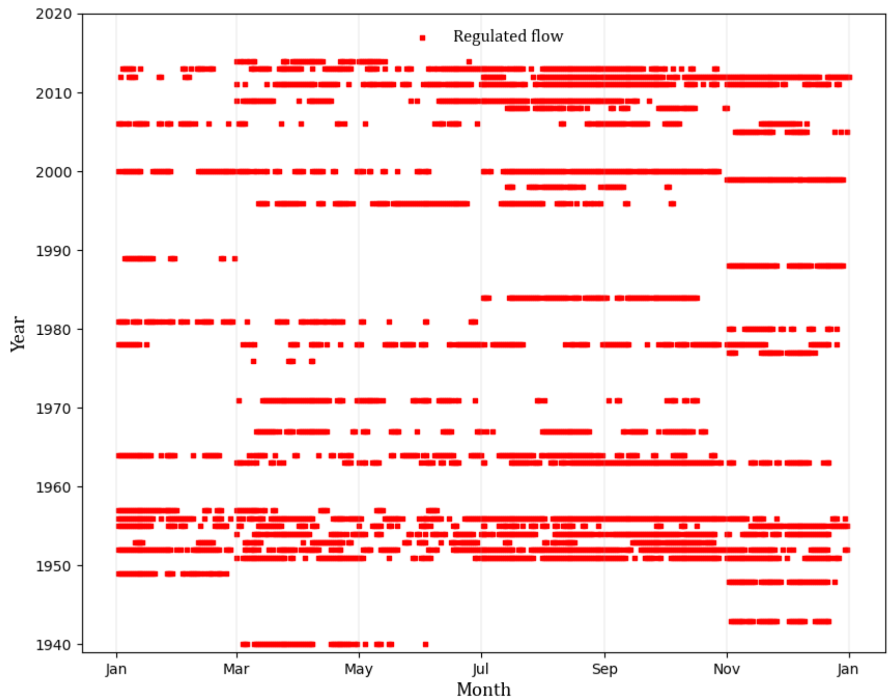
Days of shortage for subsistence flow at BRHE68 by hydrology adjusted for trend for 2050



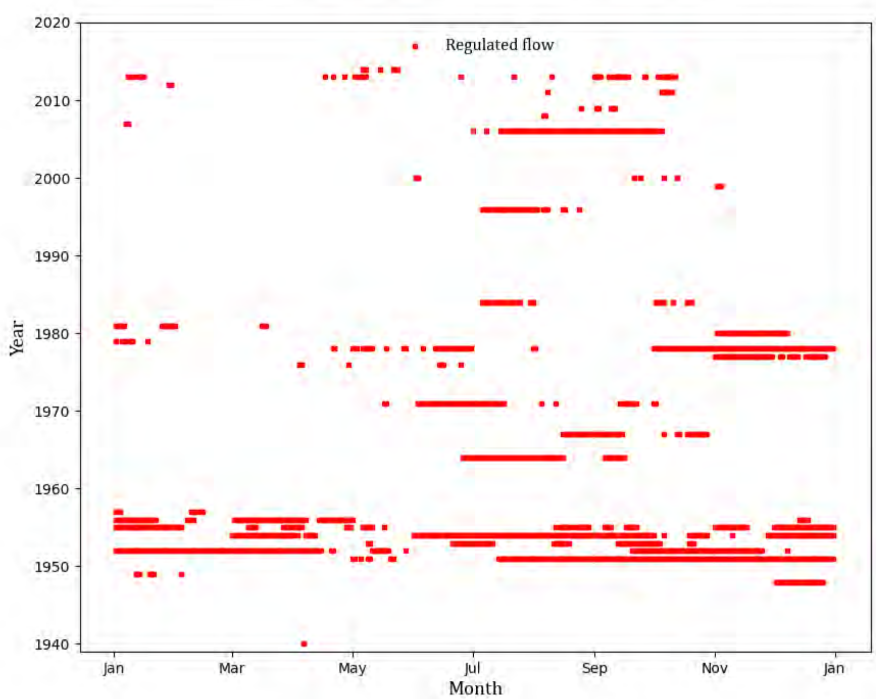
Days of shortage for subsistence flow at BRRI70 by hydrology adjusted for trend for 2050



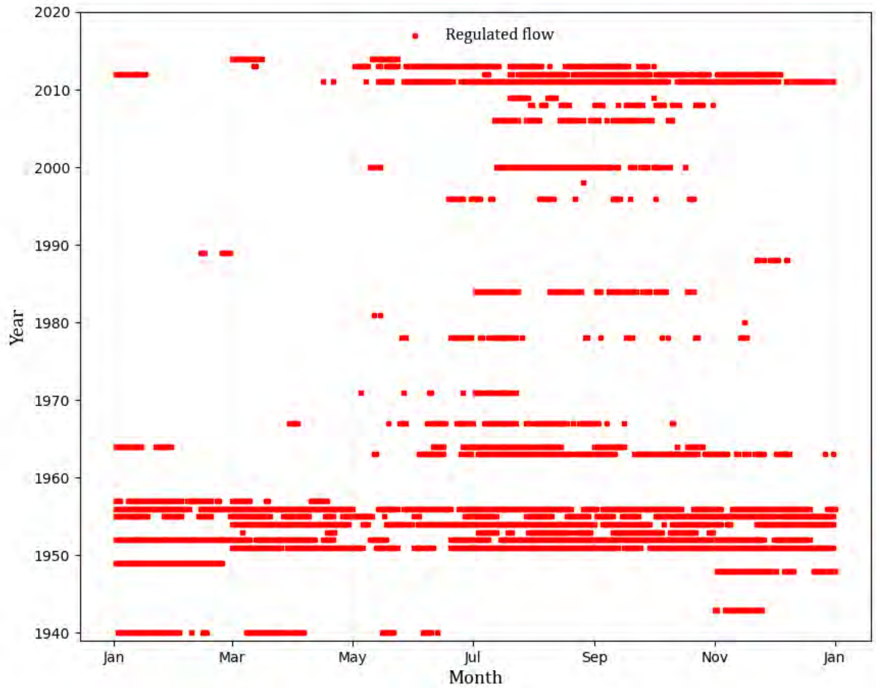
Days of shortage for subsistence flow at BRRO72 by hydrology adjusted for trend for 2050



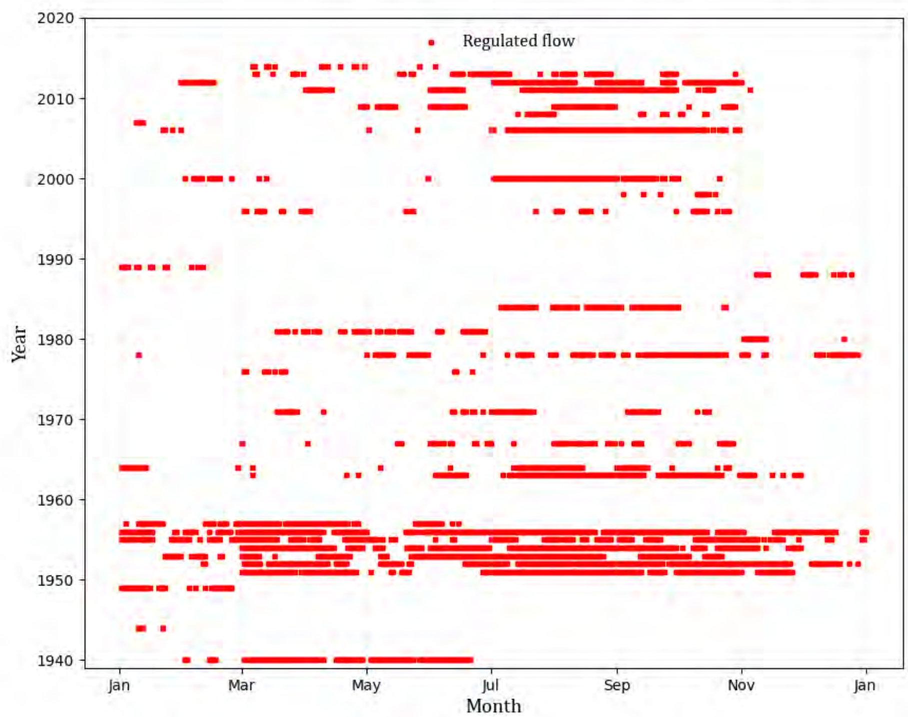
Days of shortage for subsistence flow at LEGT47 by hydrology adjusted for trend for 2050



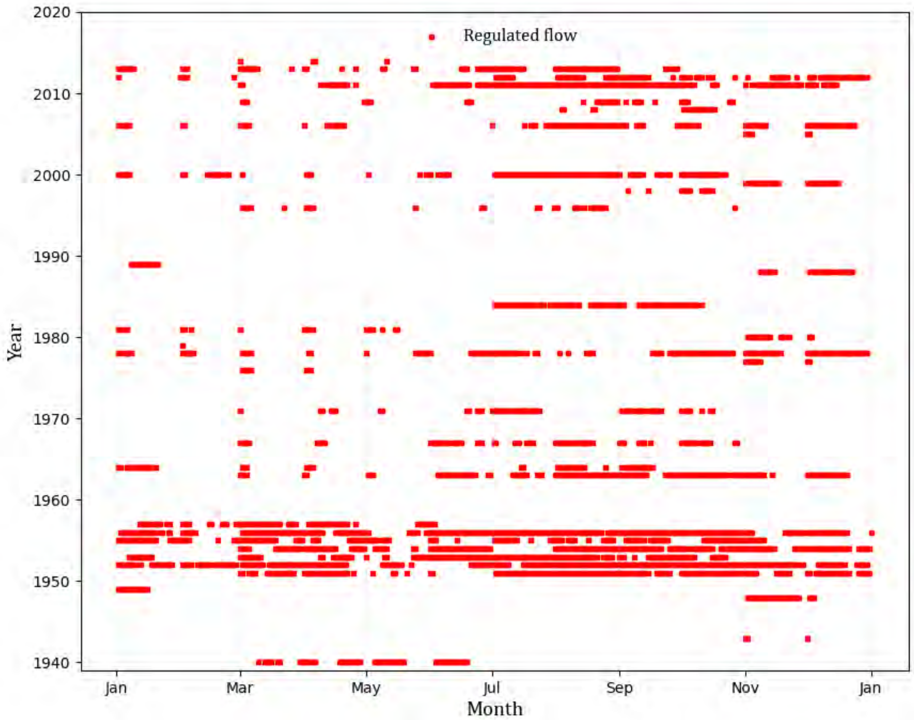
Days of shortage for subsistence flow at LAKE50 by hydrology adjusted for trend for 2050



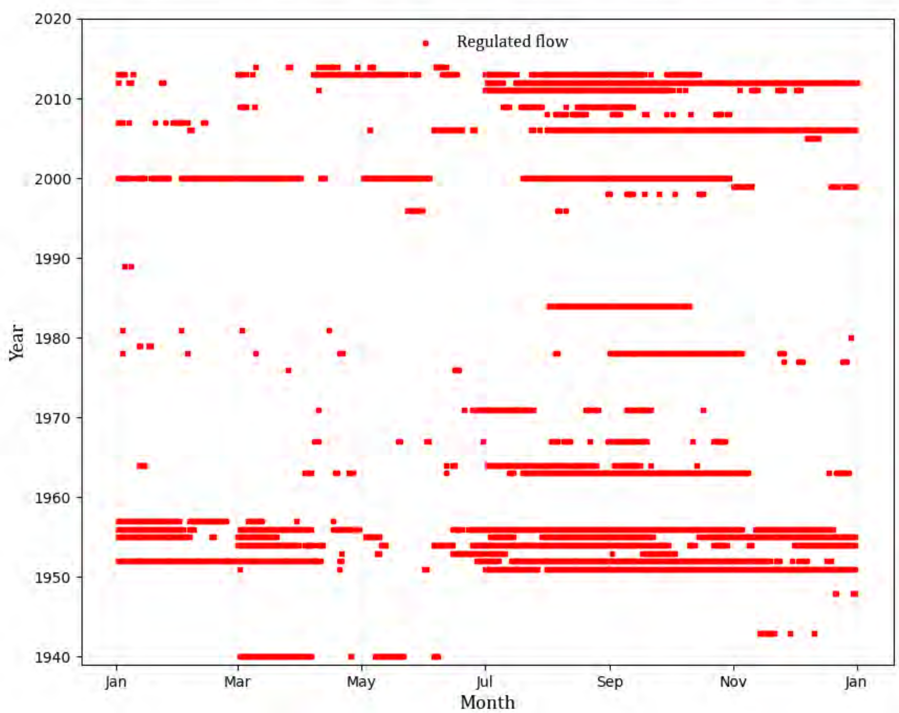
Days of shortage for subsistence flow at LRLR53 by hydrology adjusted for trend for 2050



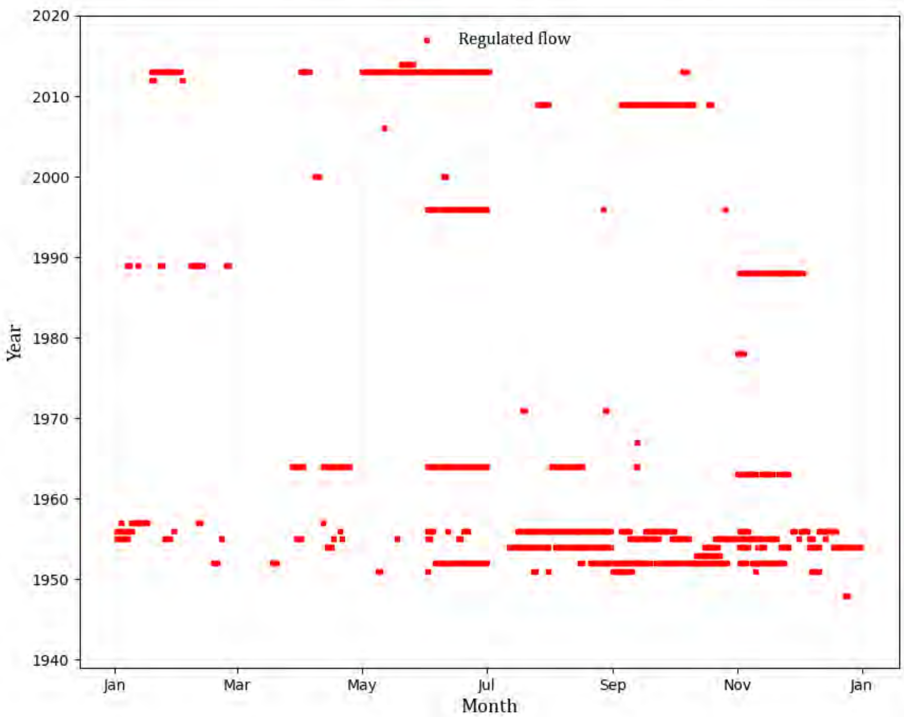
Days of shortage for subsistence flow at LRCA58 by hydrology adjusted for trend for 2050



Days of shortage for subsistence flow at NBCL36 by hydrology adjusted for trend for 2050

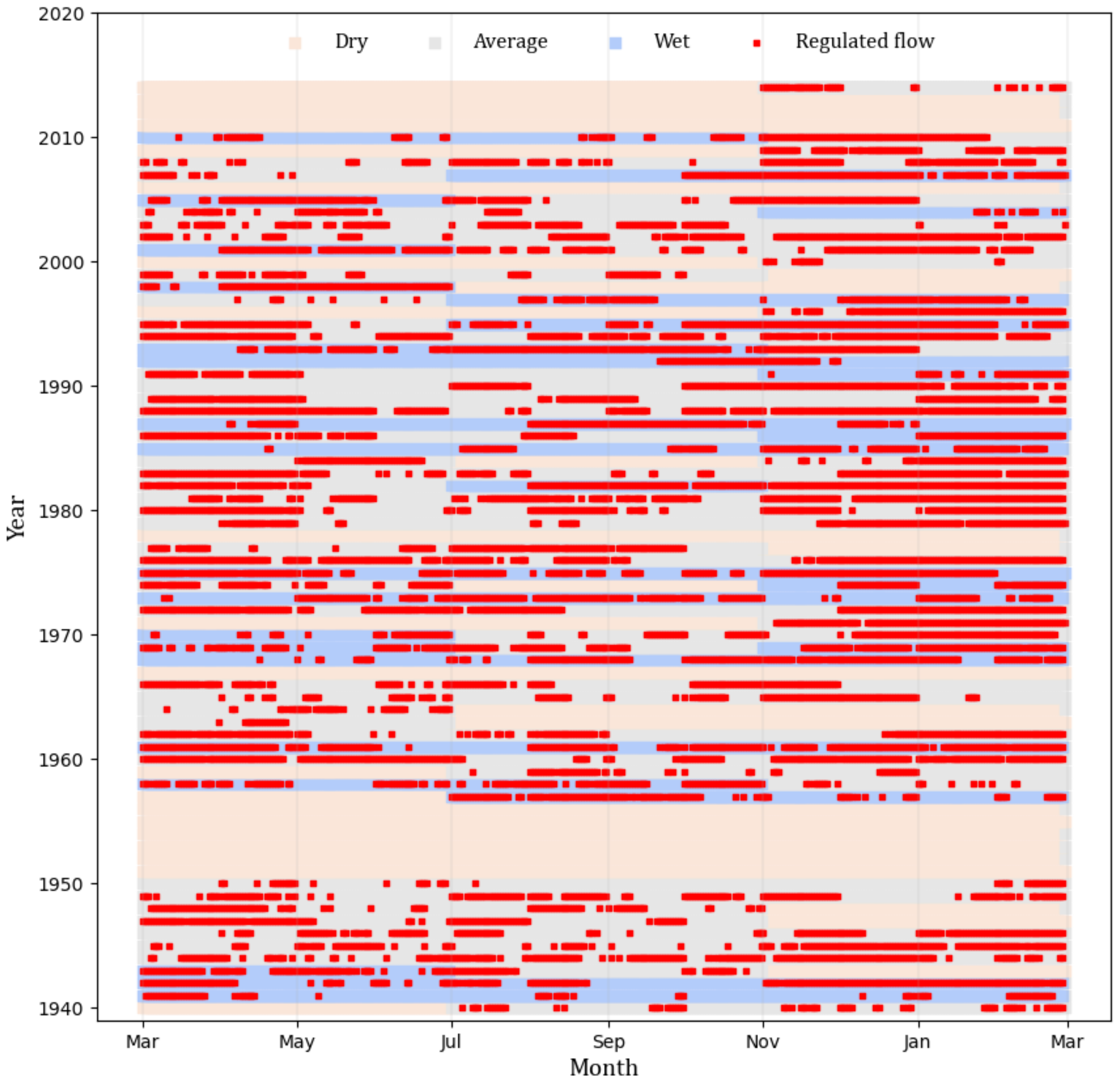


Days of shortage for subsistence flow at NAEA66 by hydrology adjusted for trend for 2050

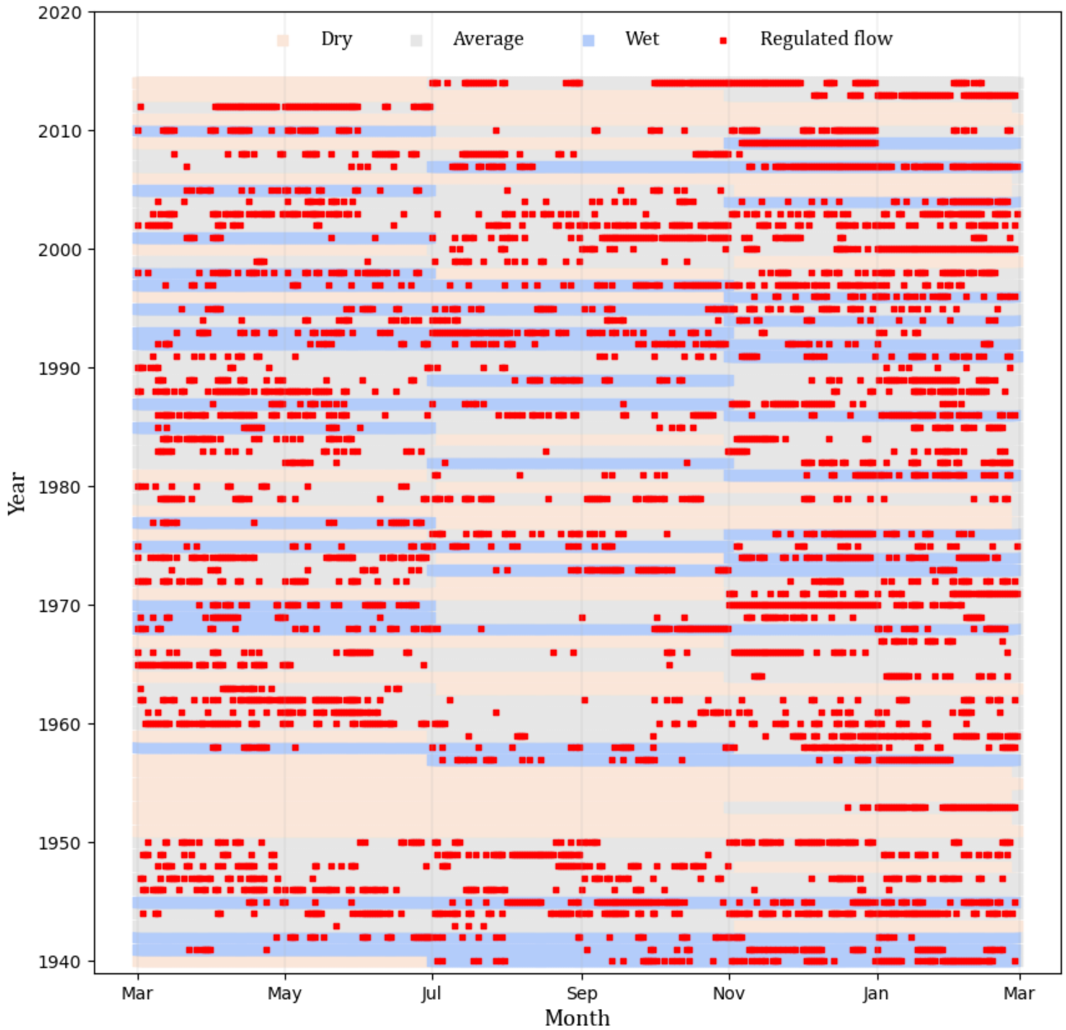


APPENDIX 3-G: RASTER PLOTS FOR BASEFLOW SHORTAGE

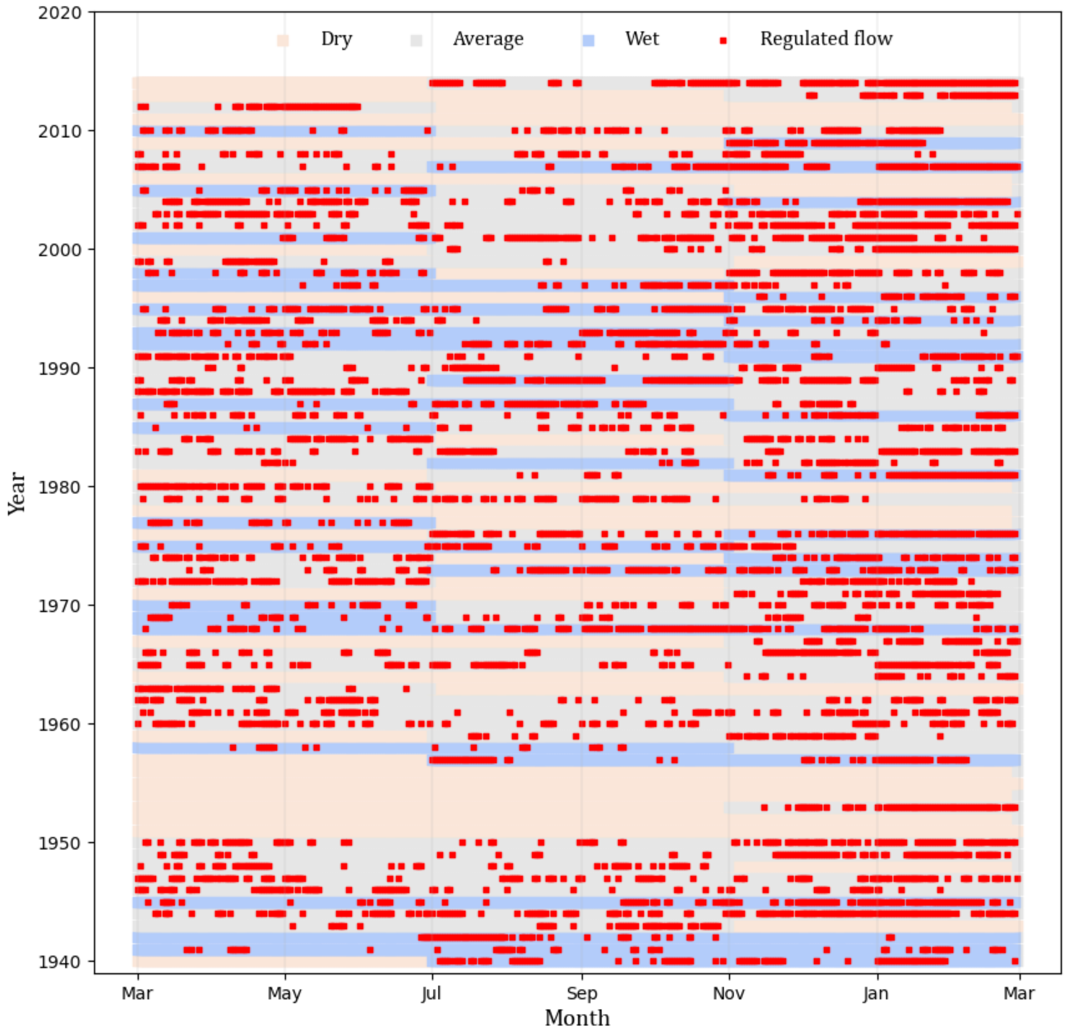
Days of baseflow shortage at BRSB23 by hydrology adjusted for trend for 2050



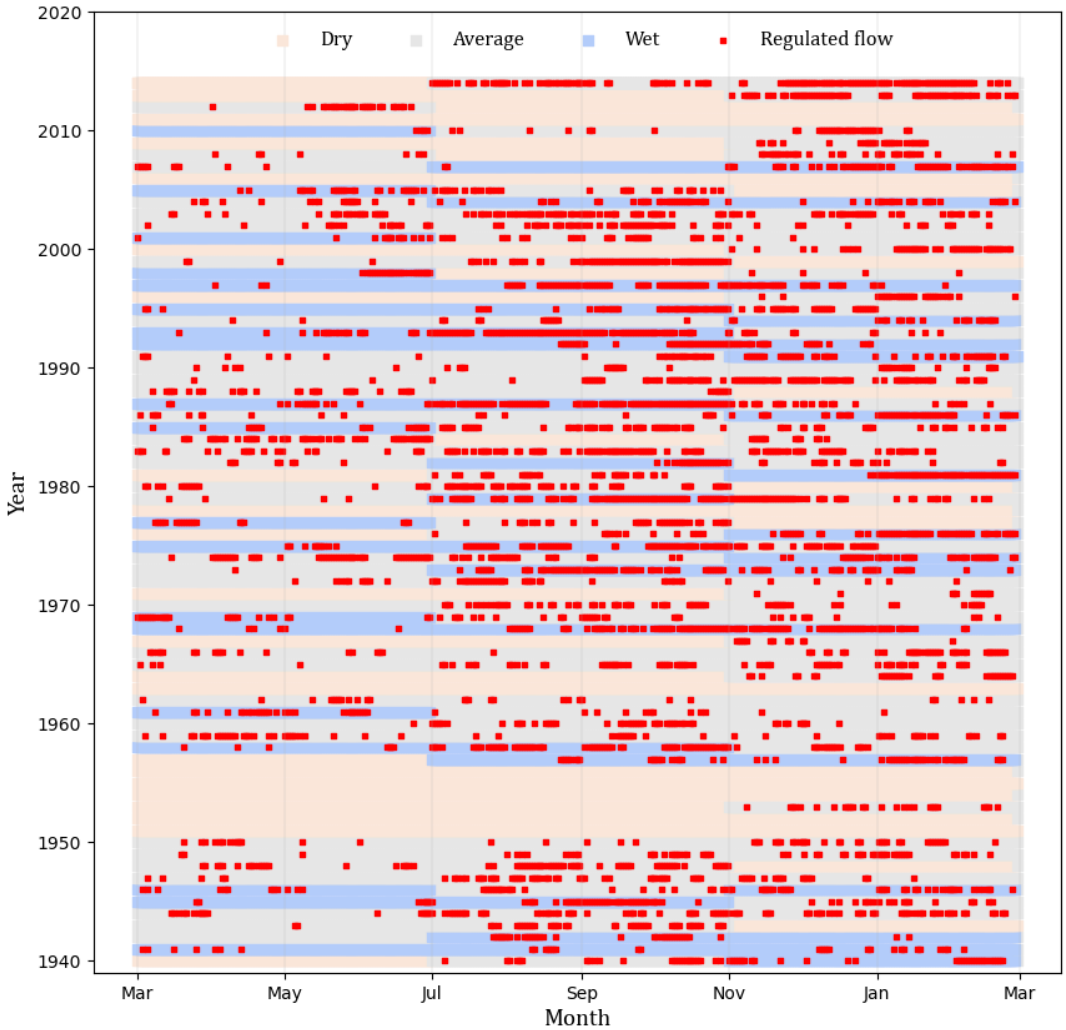
Days of baseflow shortage at BRPP27 by hydrology adjusted for trend for 2050



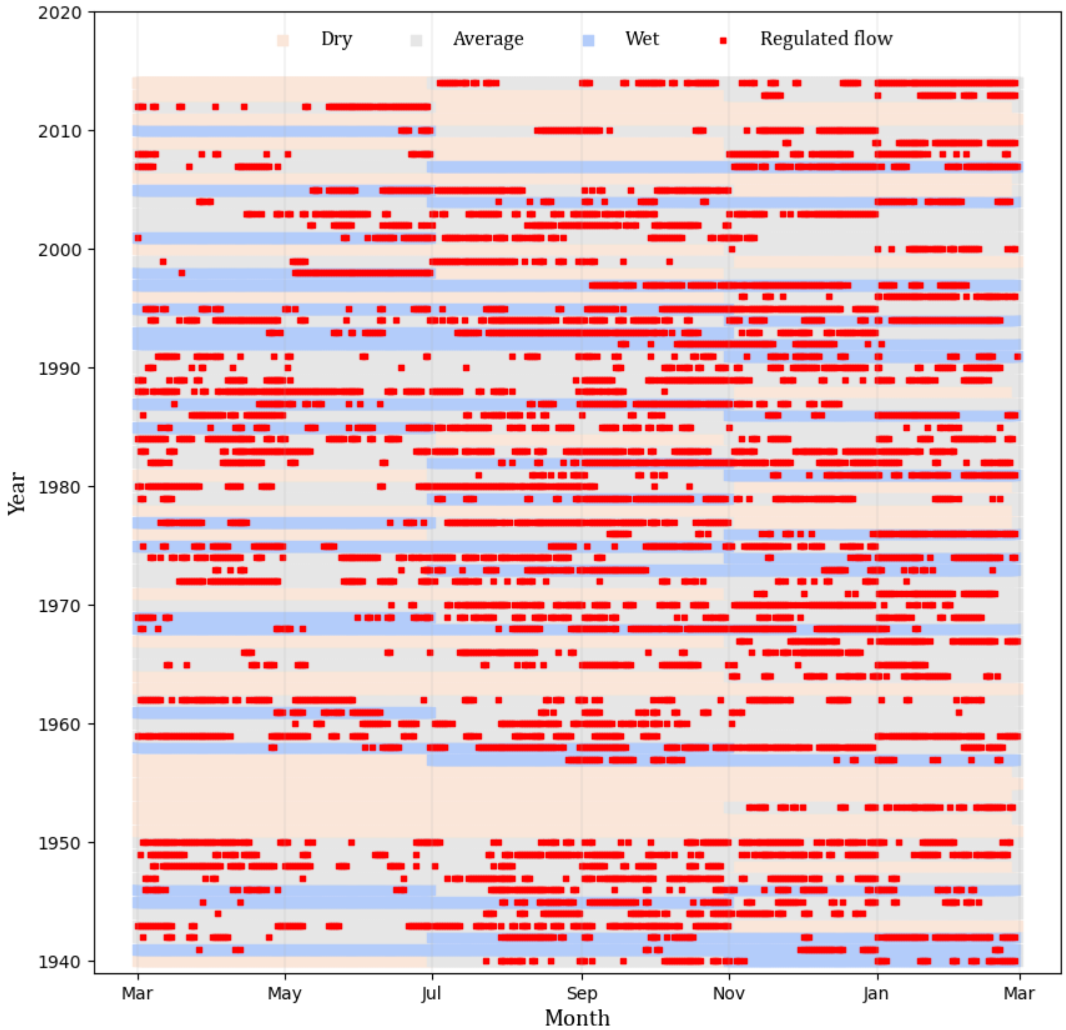
Days of baseflow shortage at BRGR30 by hydrology adjusted for trend for 2050



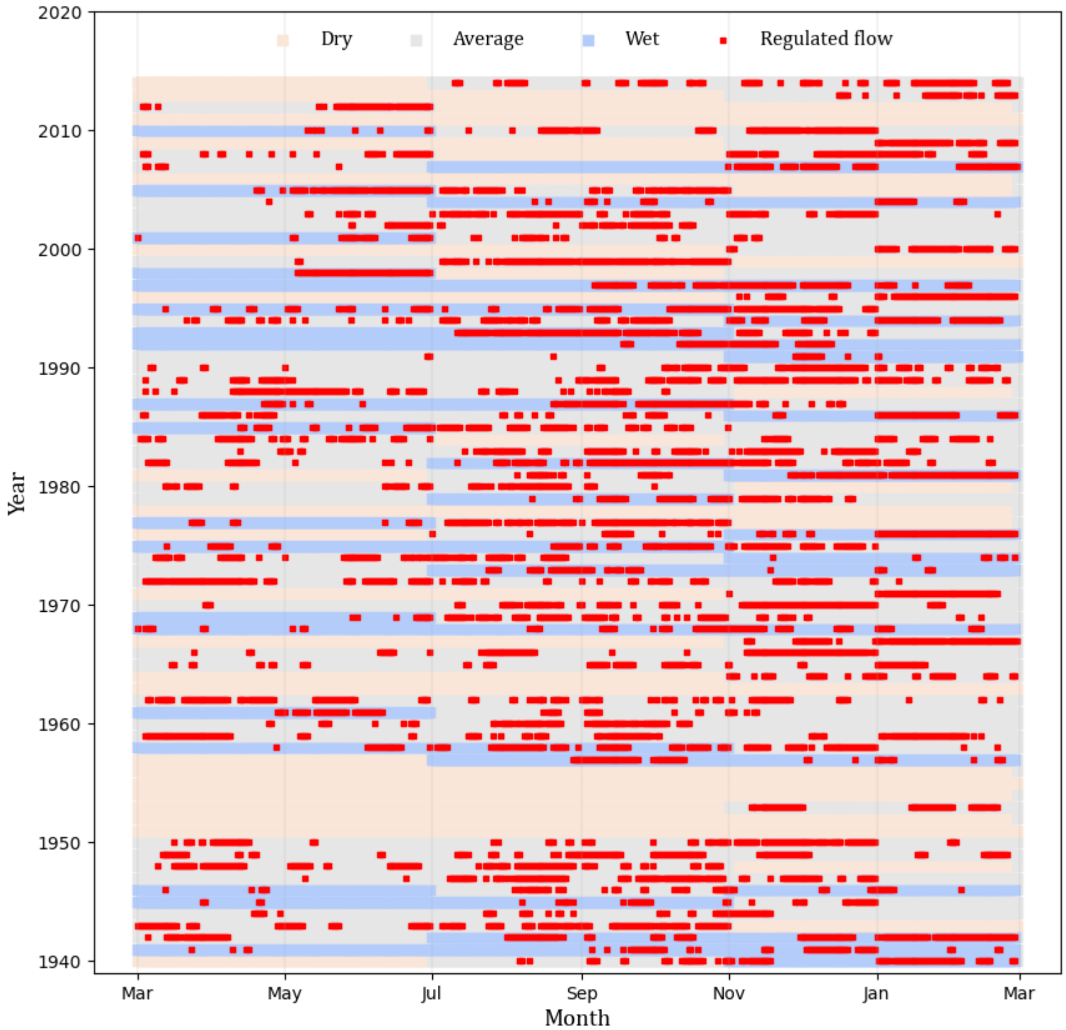
Days of baseflow shortage at BRWA41 by hydrology adjusted for trend for 2050



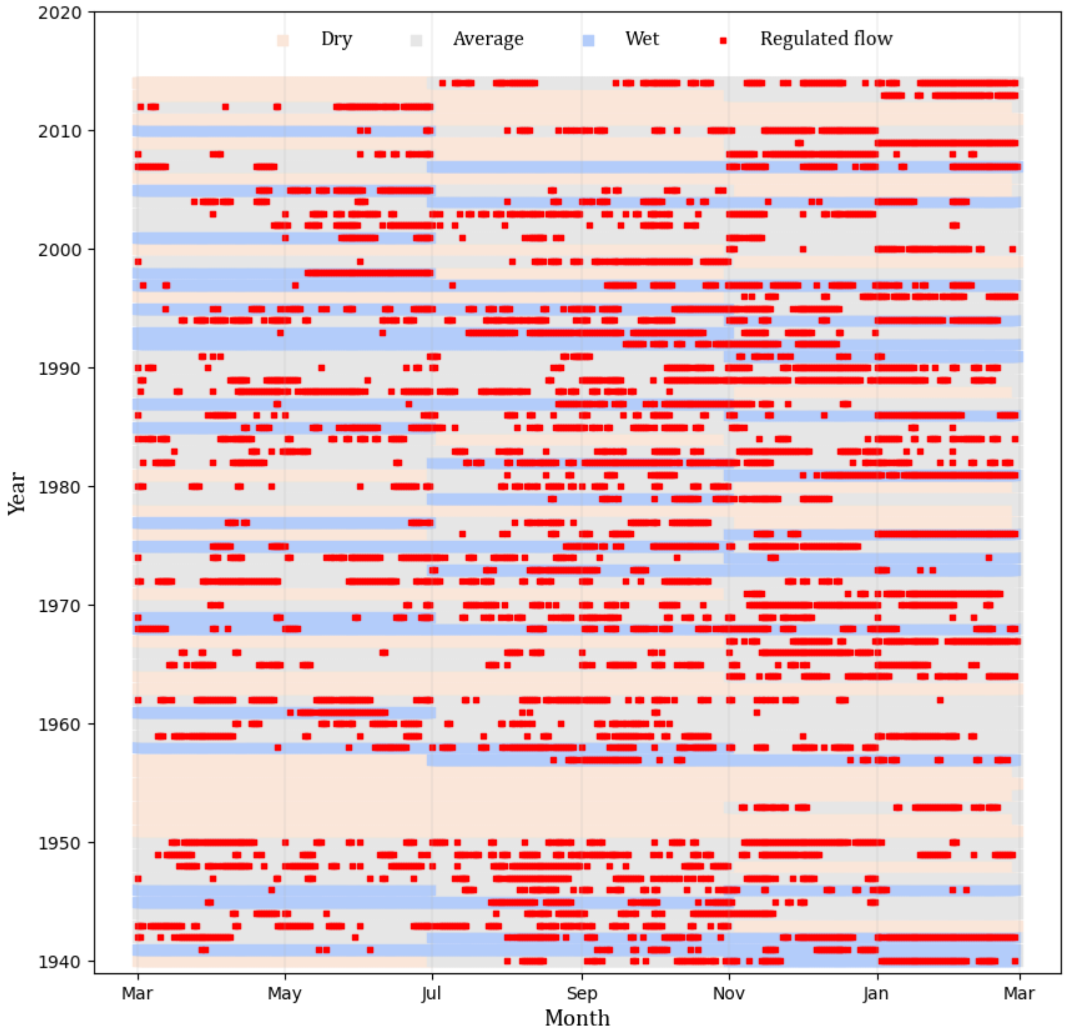
Days of baseflow shortage at BRBR59 by hydrology adjusted for trend for 2050



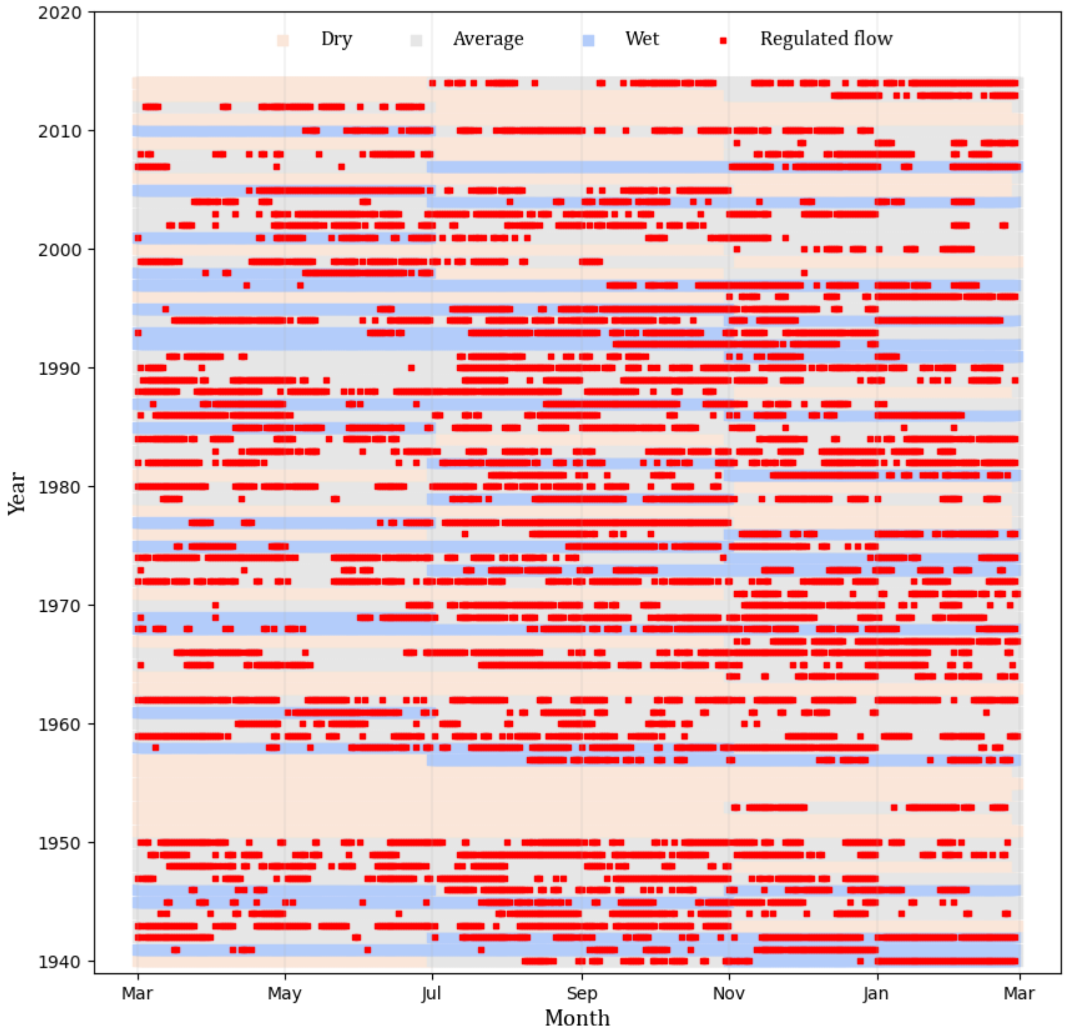
Days of baseflow shortage at BRHE68 by hydrology adjusted for trend for 2050



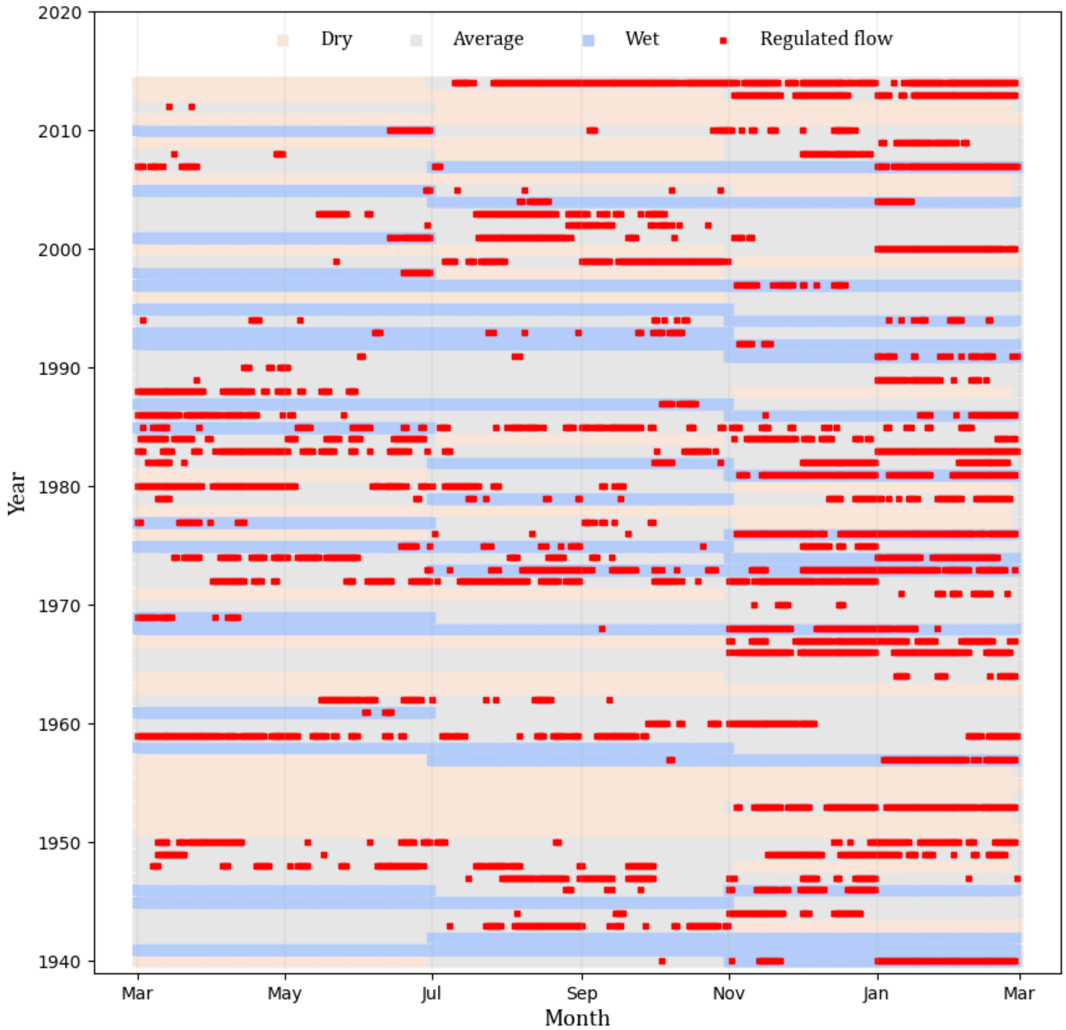
Days of baseflow shortage at BRRI70 by hydrology adjusted for trend for 2050



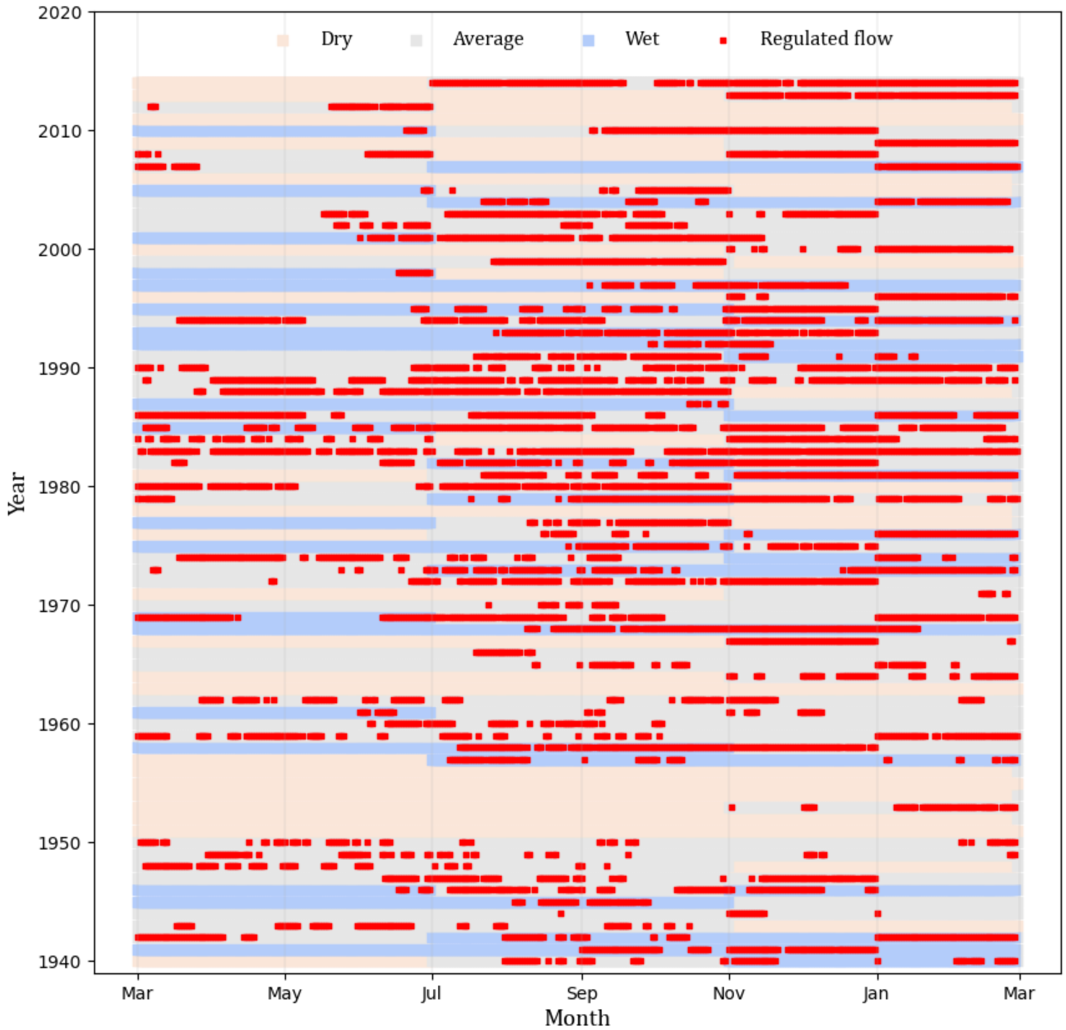
Days of baseflow shortage at BRRO72 by hydrology adjusted for trend for 2050



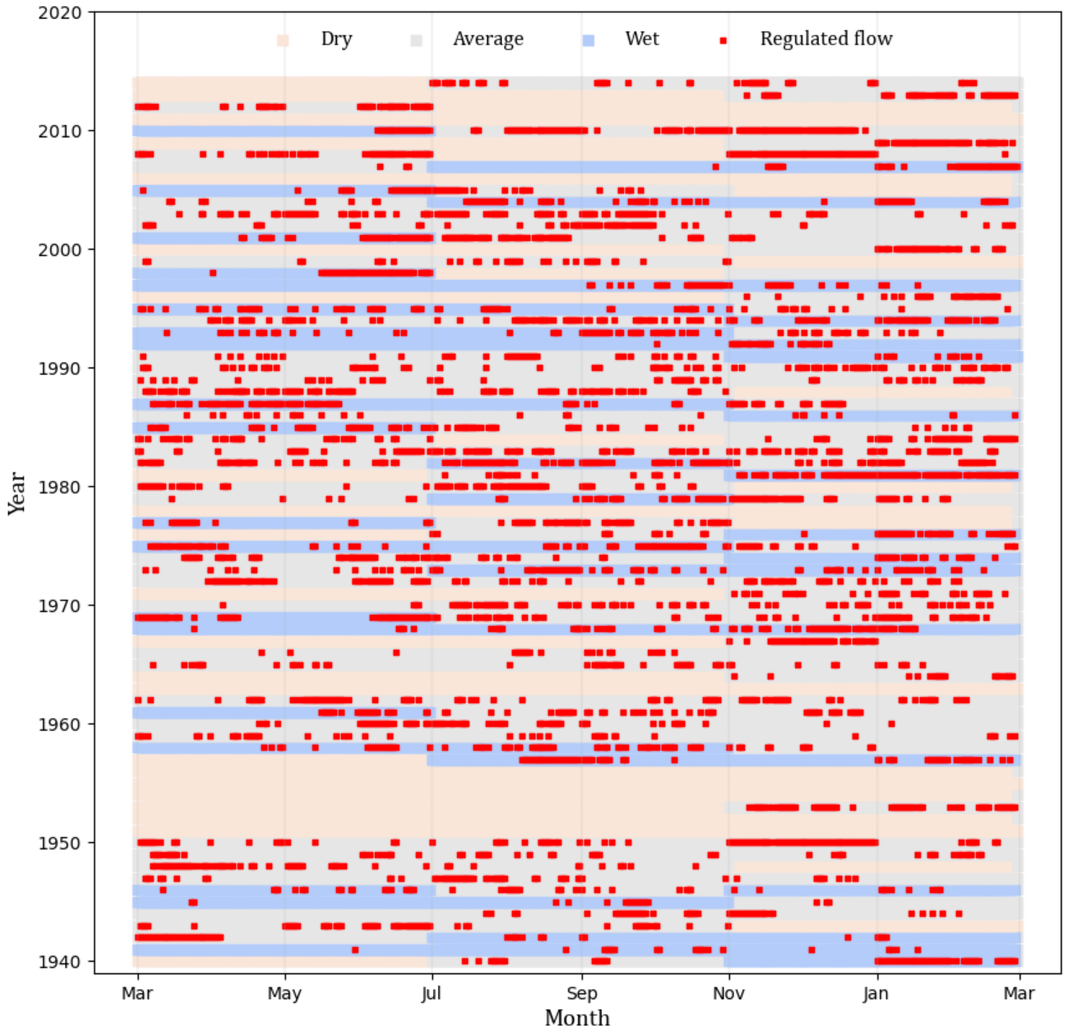
Days of baseflow shortage at LEGT47 by hydrology adjusted for trend for 2050



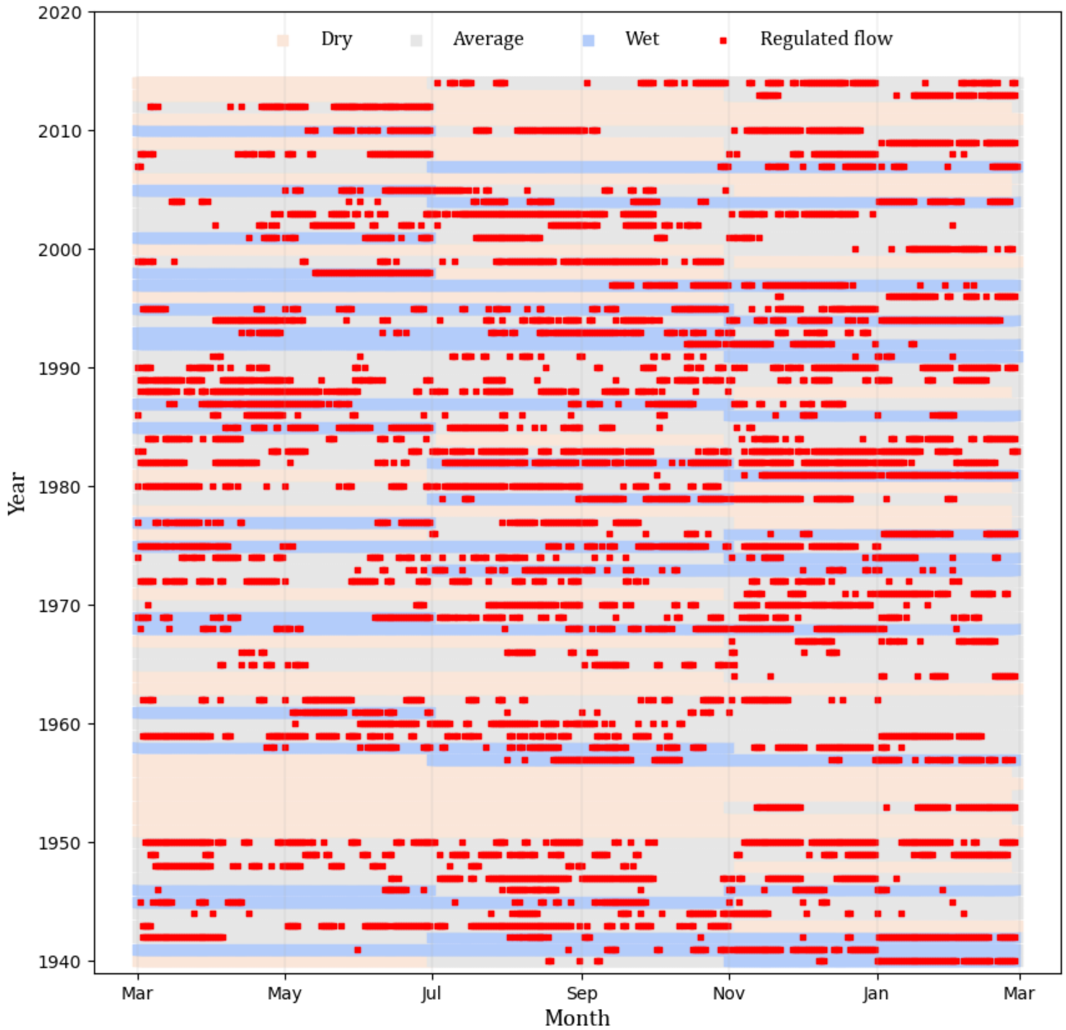
Days of baseflow shortage at LAKE50 by hydrology adjusted for trend for 2050



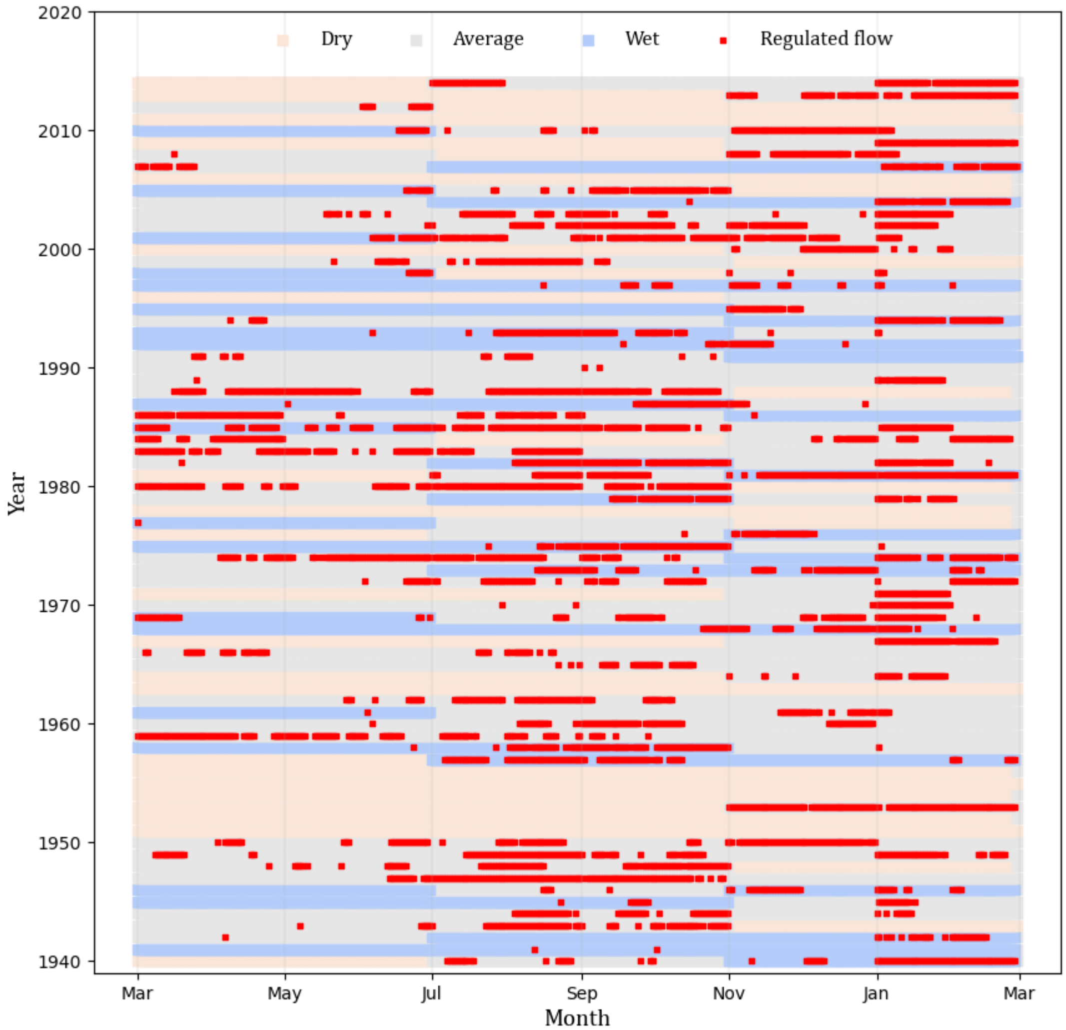
Days of baseflow shortage at LRLR53 by hydrology adjusted for trend for 2050



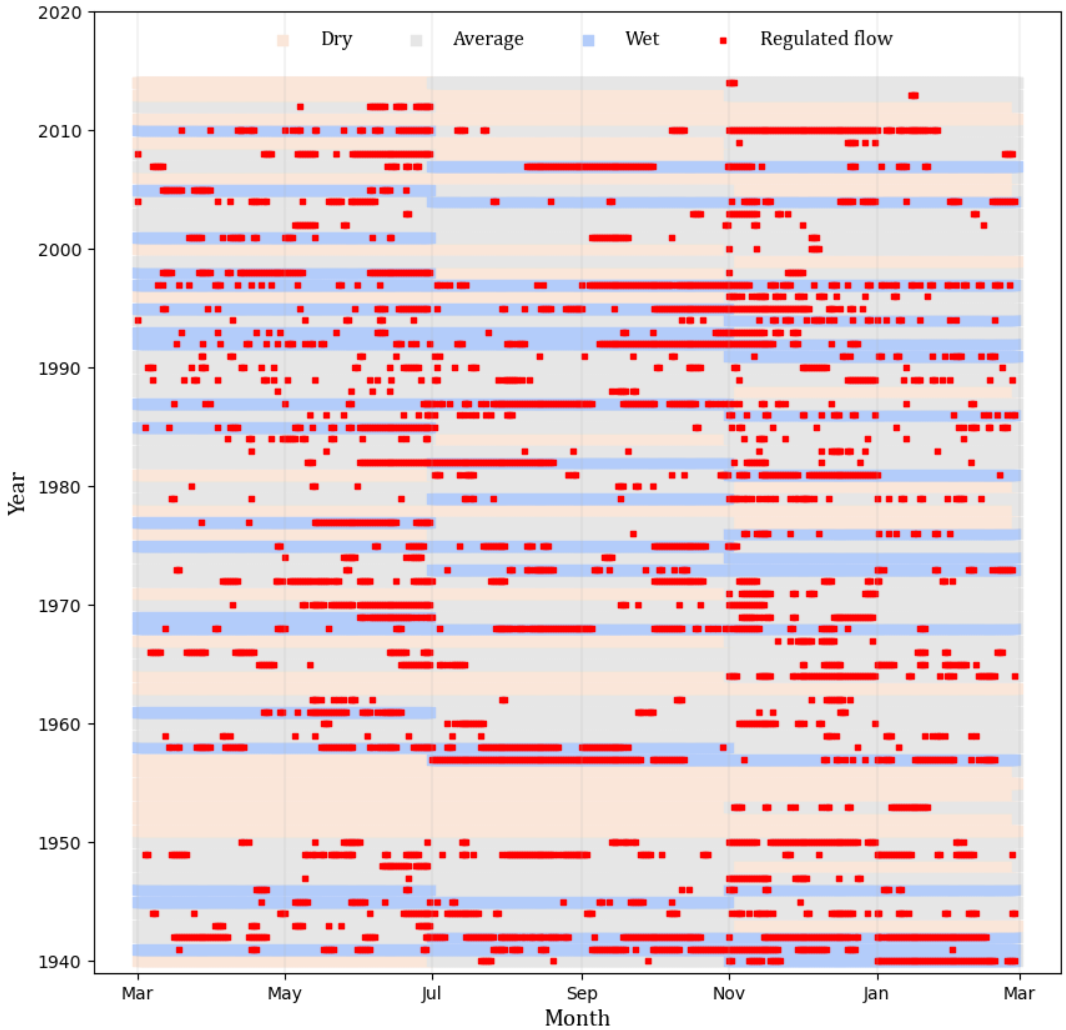
Days of baseflow shortage at LRCA58 by hydrology adjusted for trend for 2050



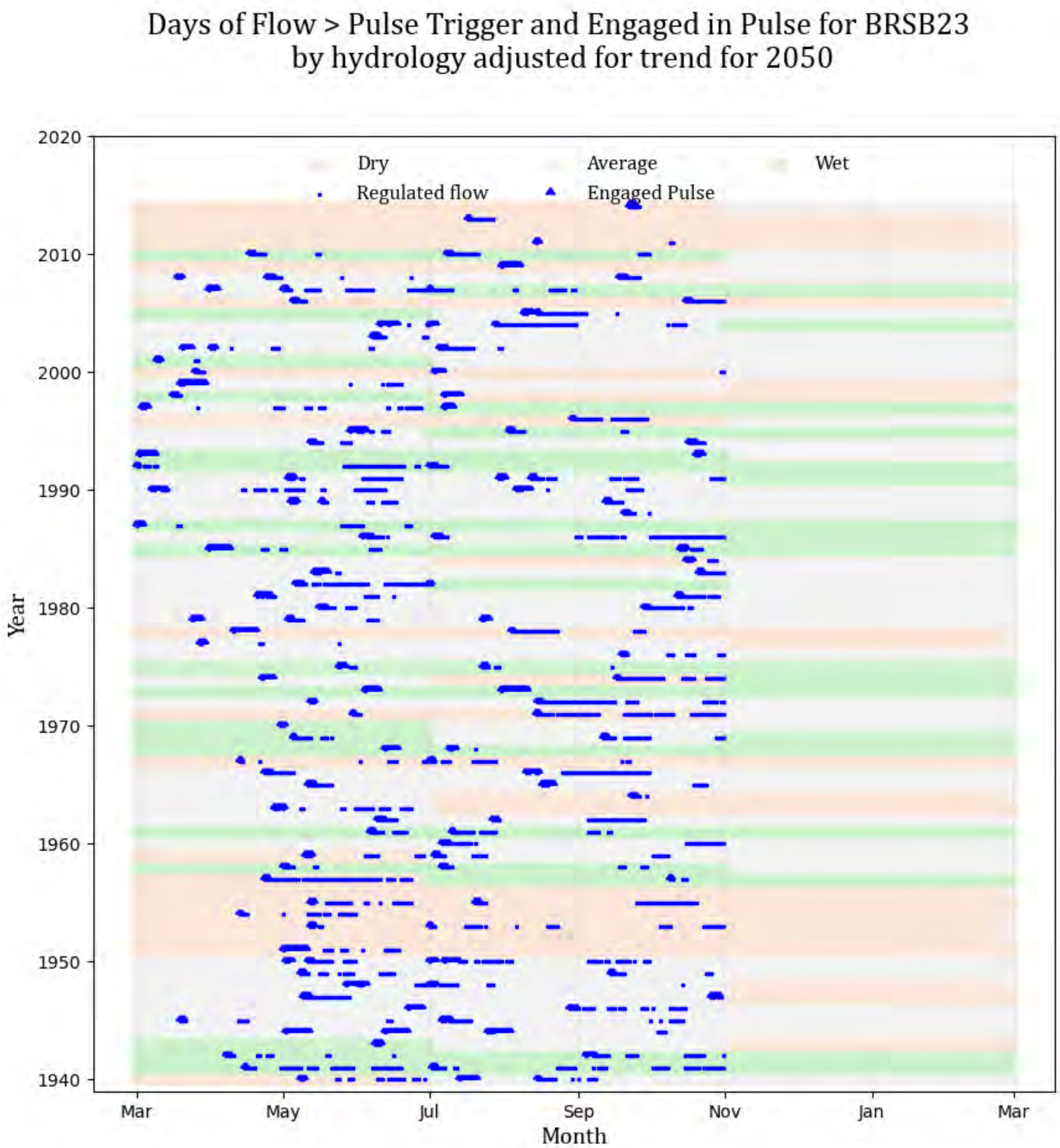
Days of baseflow shortage at NBCL36 by hydrology adjusted for trend for 2050

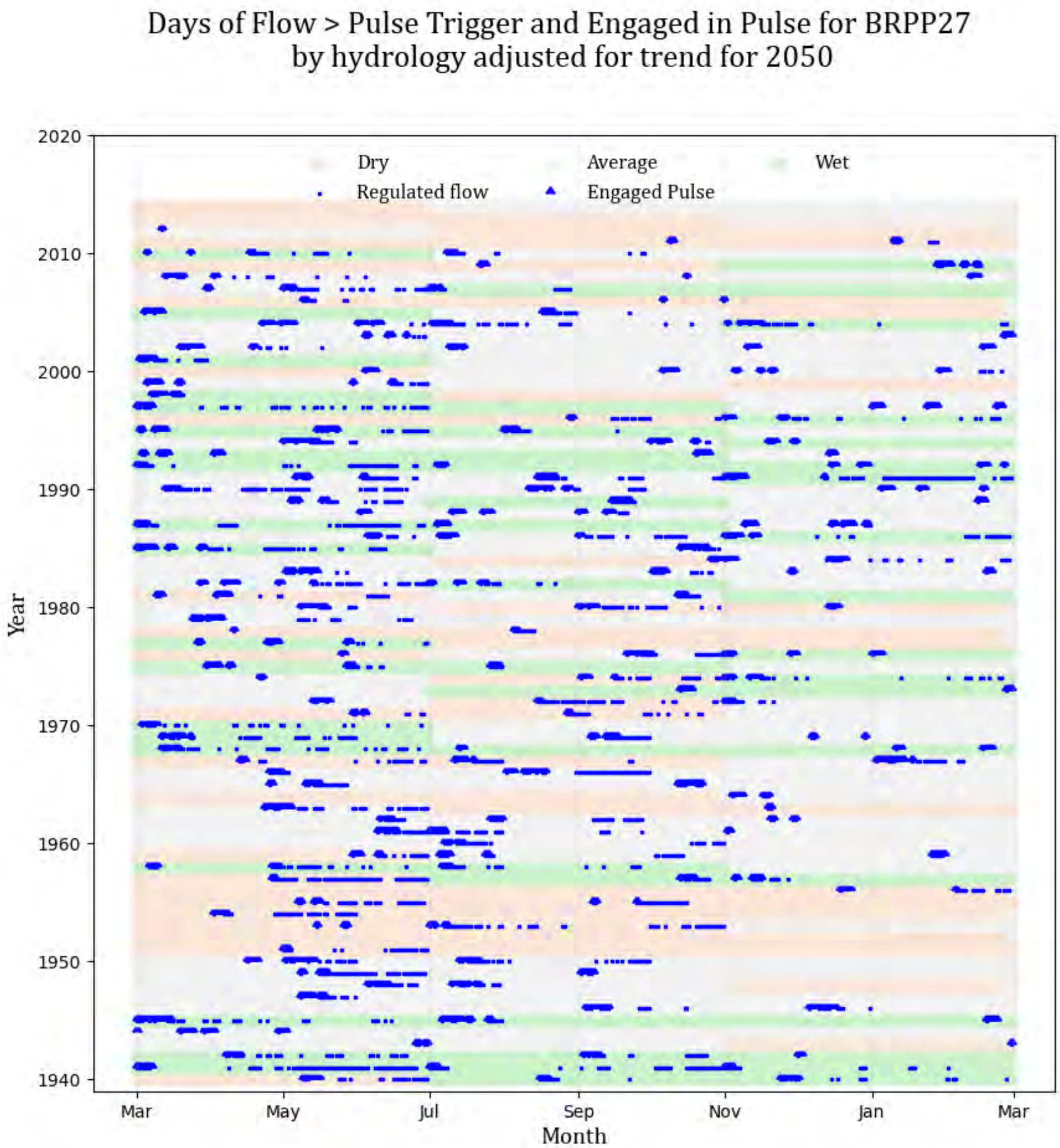


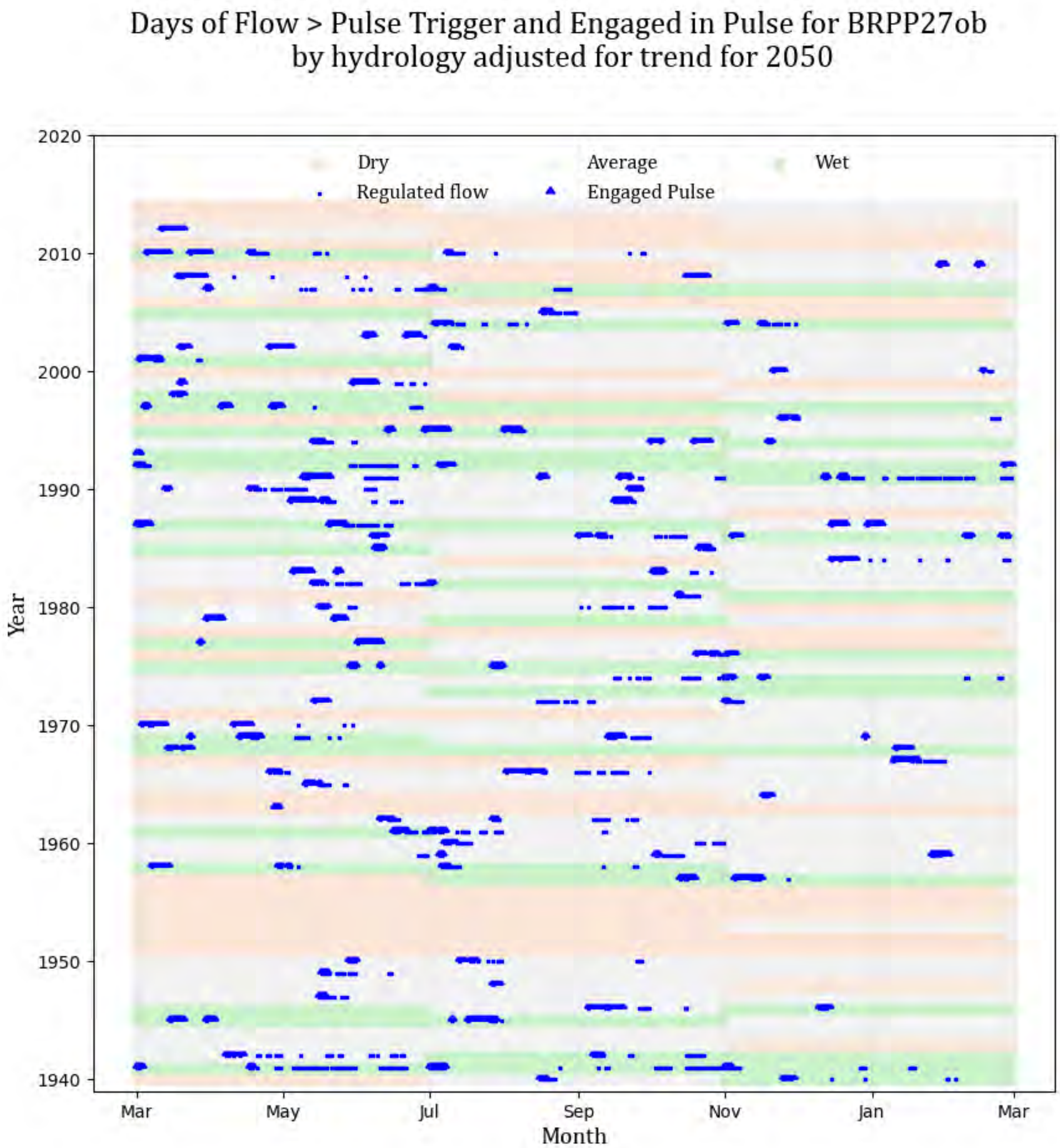
Days of baseflow shortage at NAEA66 by hydrology adjusted for trend for 2050



APPENDIX 3-H: RASTER PLOTS FOR THE PULSE FLOW AND DAYS THAT FLOW IS GREATER THAN PULSE TRIGGER




Days of Flow > Pulse Trigger and Engaged in Pulse for BRPP27
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Mar
May
Jul
Sep
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for BRPP27ob
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
2000
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Mar
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Jul
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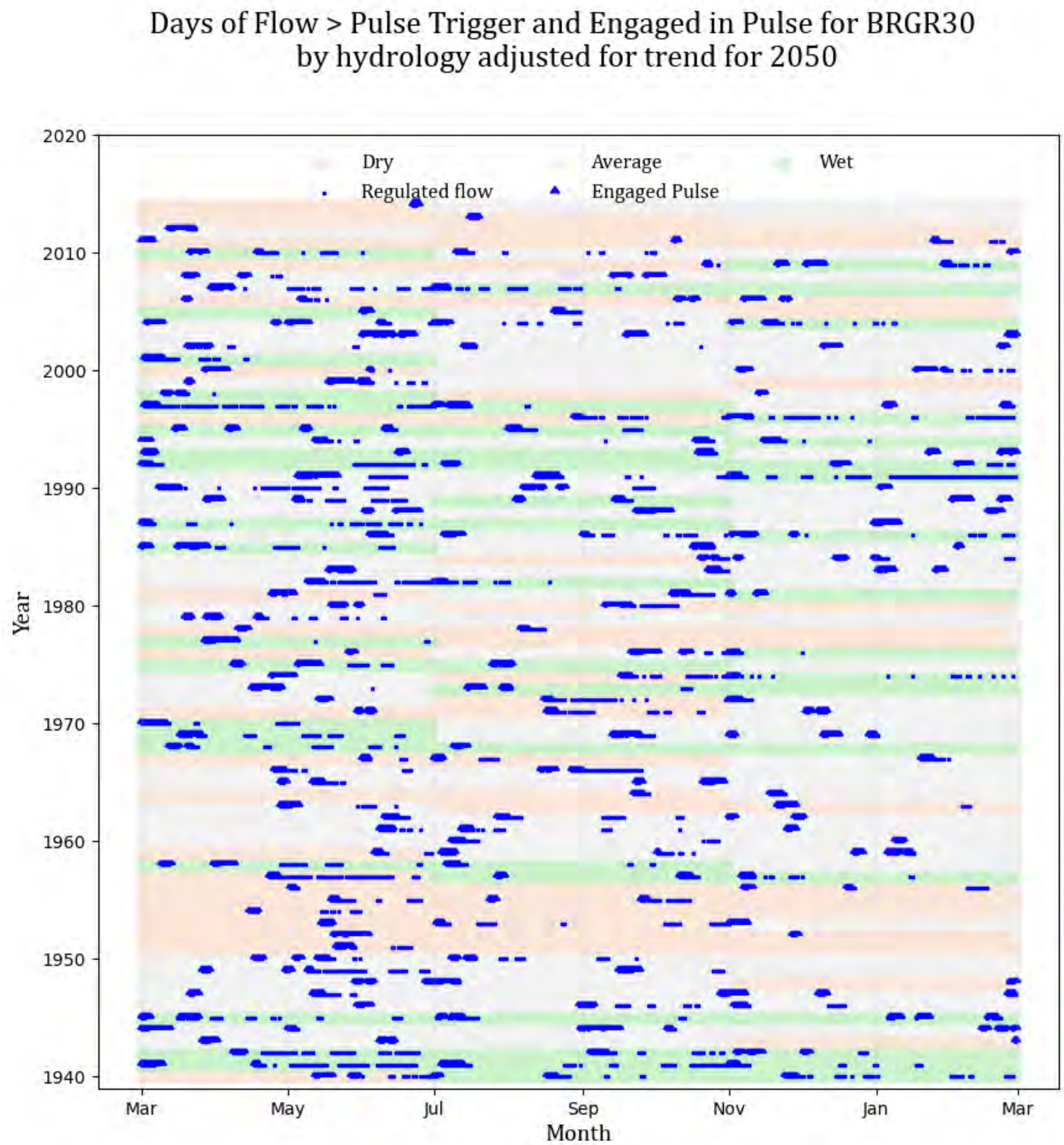
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for BRGR30
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
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Mar
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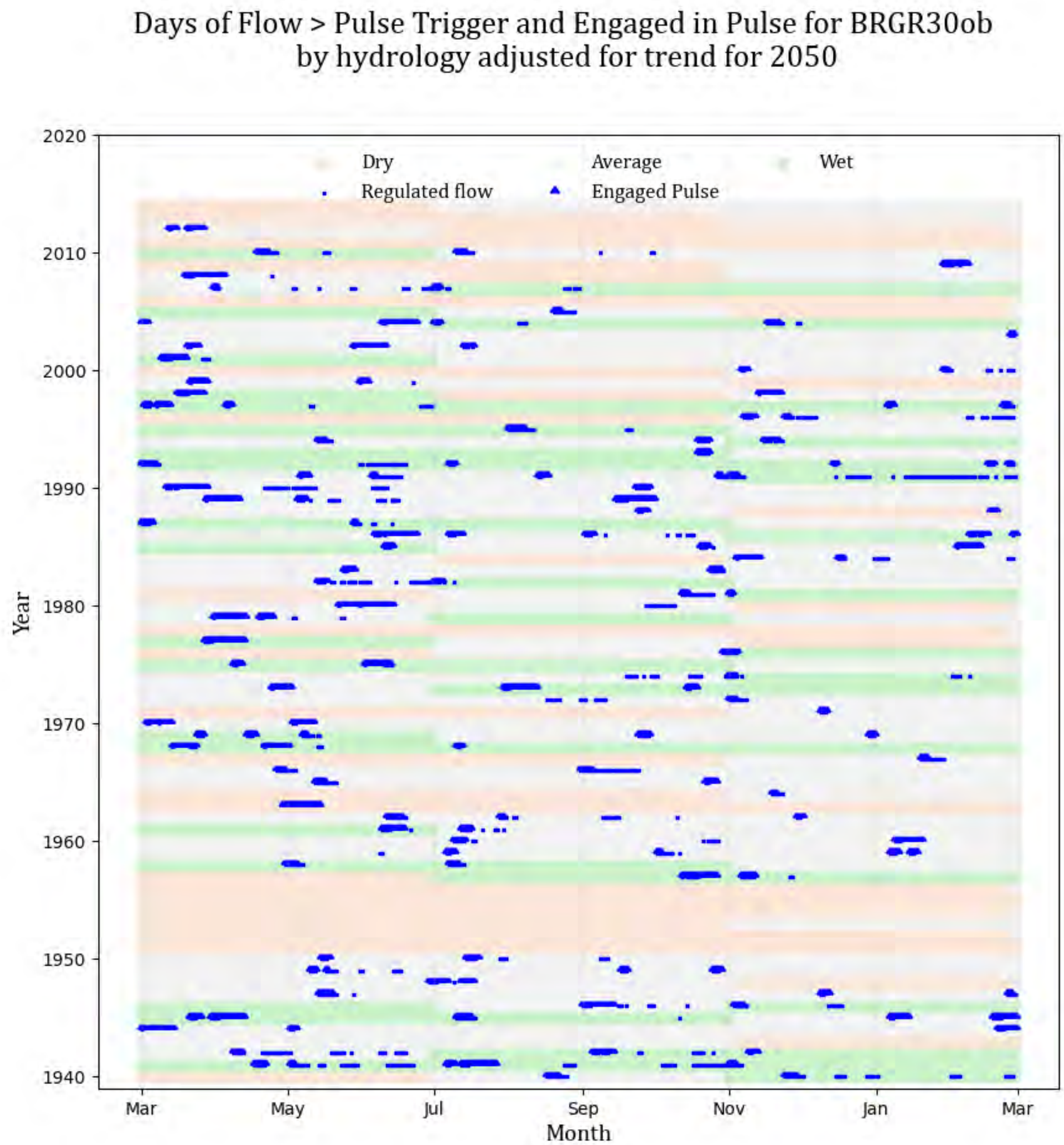
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for BRGR30ob
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
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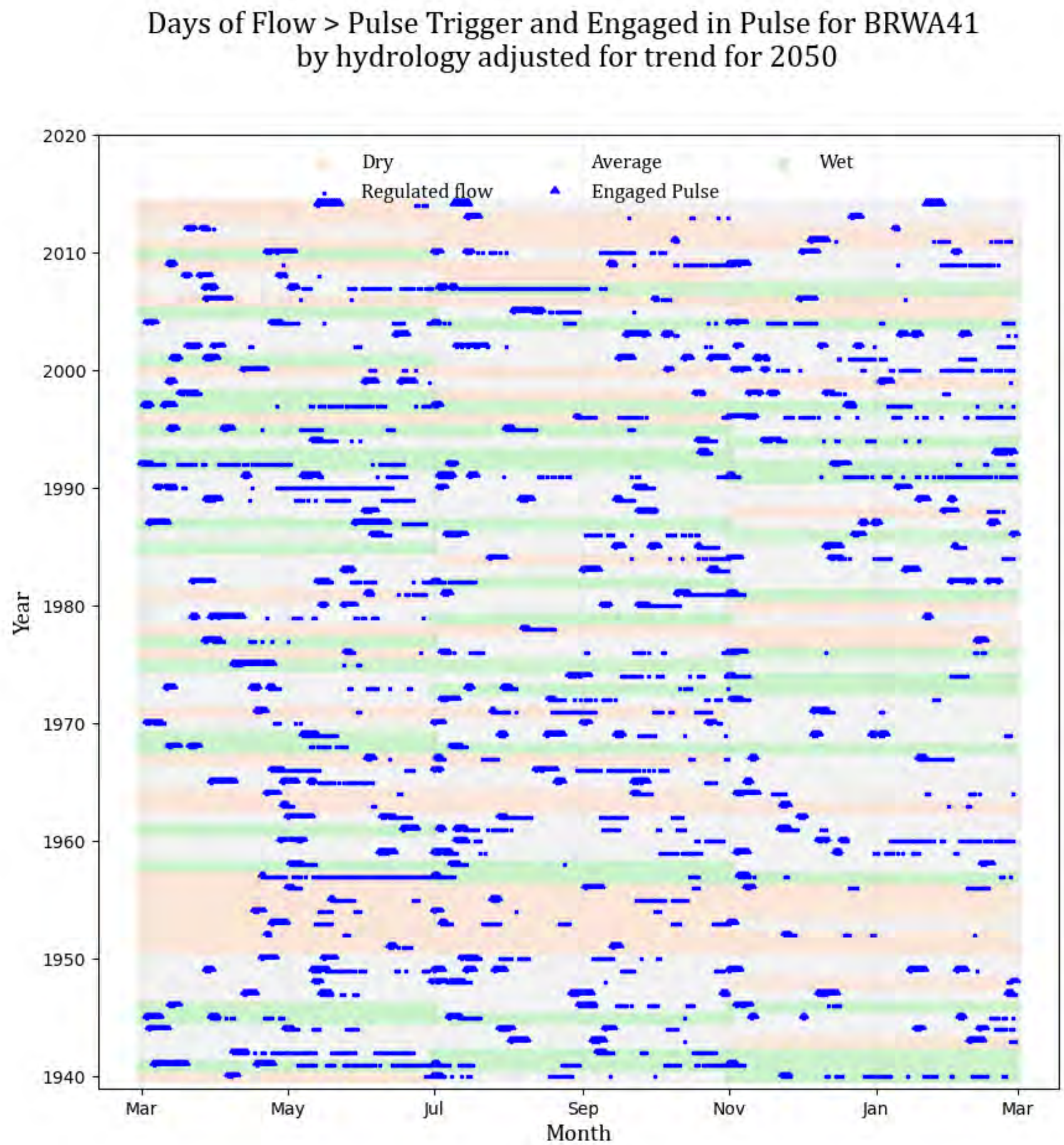
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for BRWA41
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
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2010
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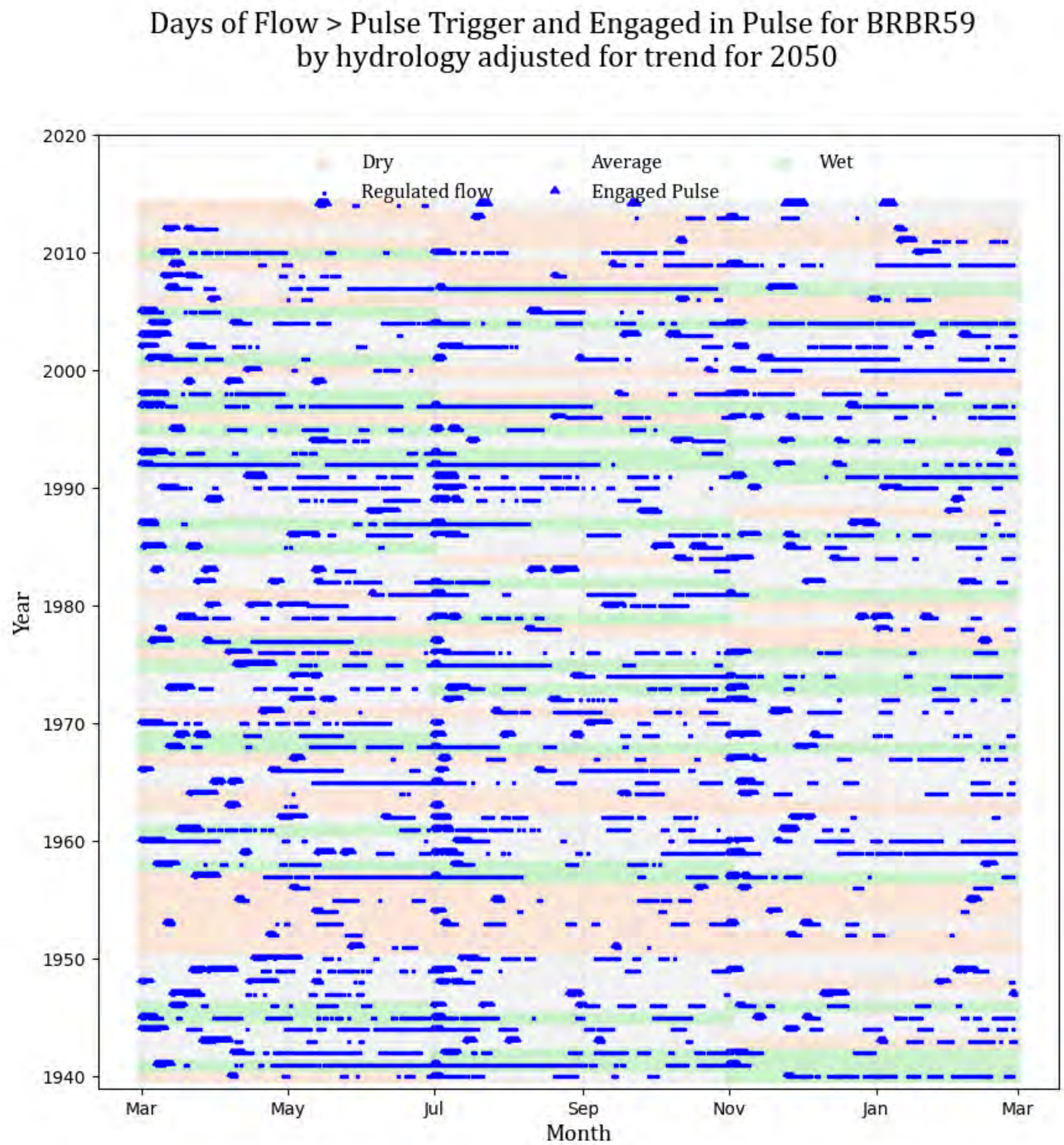
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for BRBR59
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
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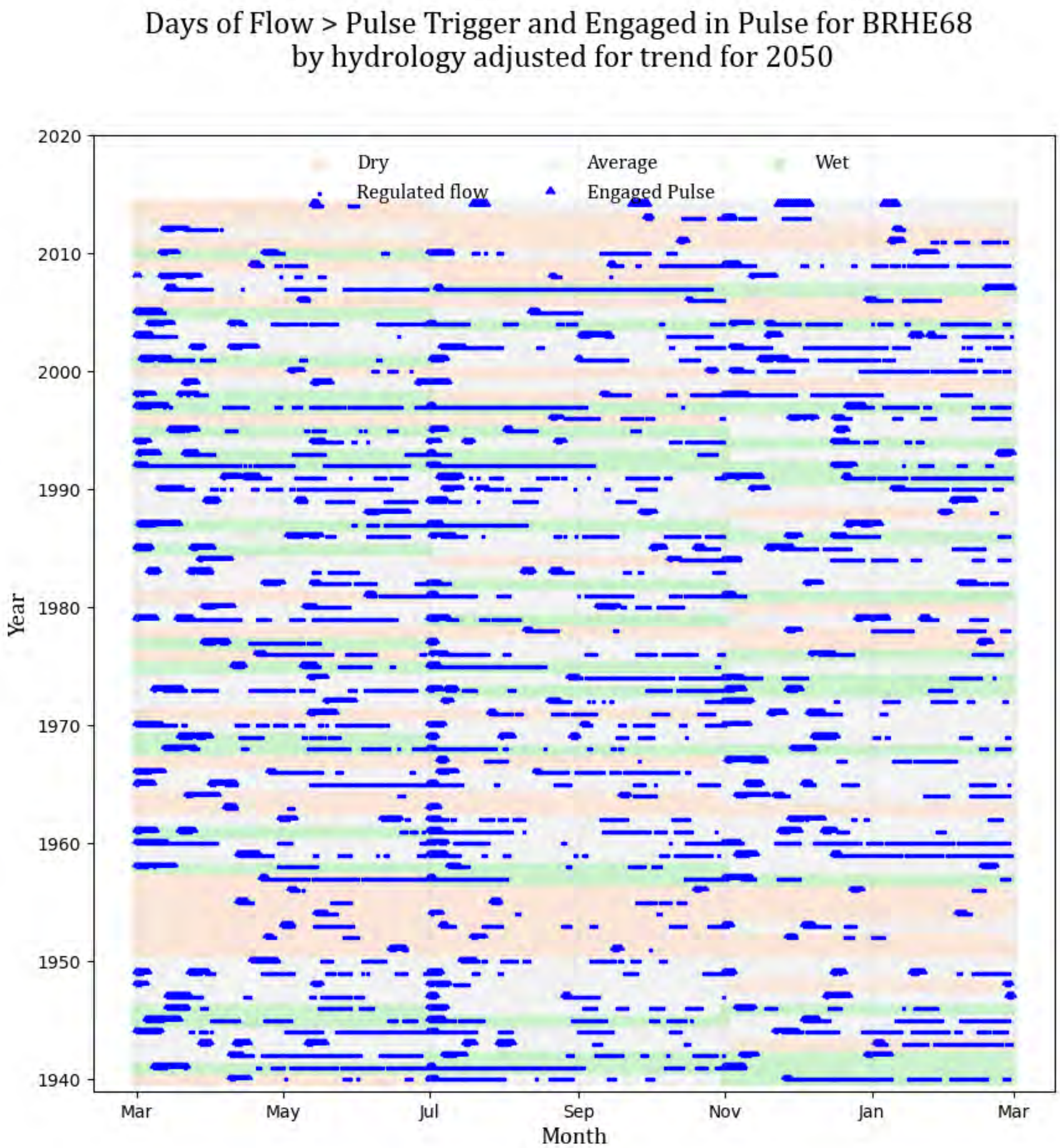
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for BRHE68
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
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Nov
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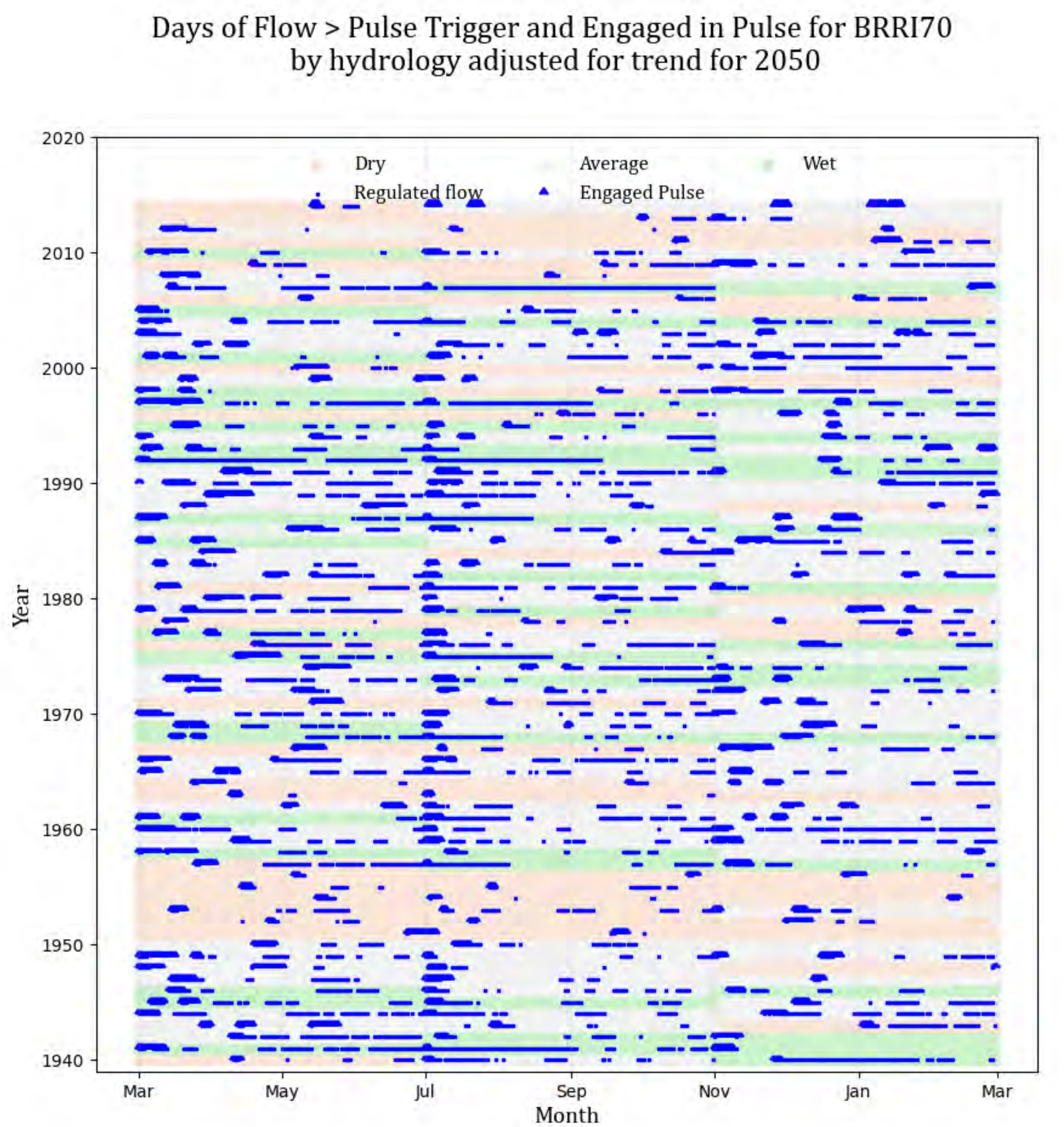
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for BRRI70
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
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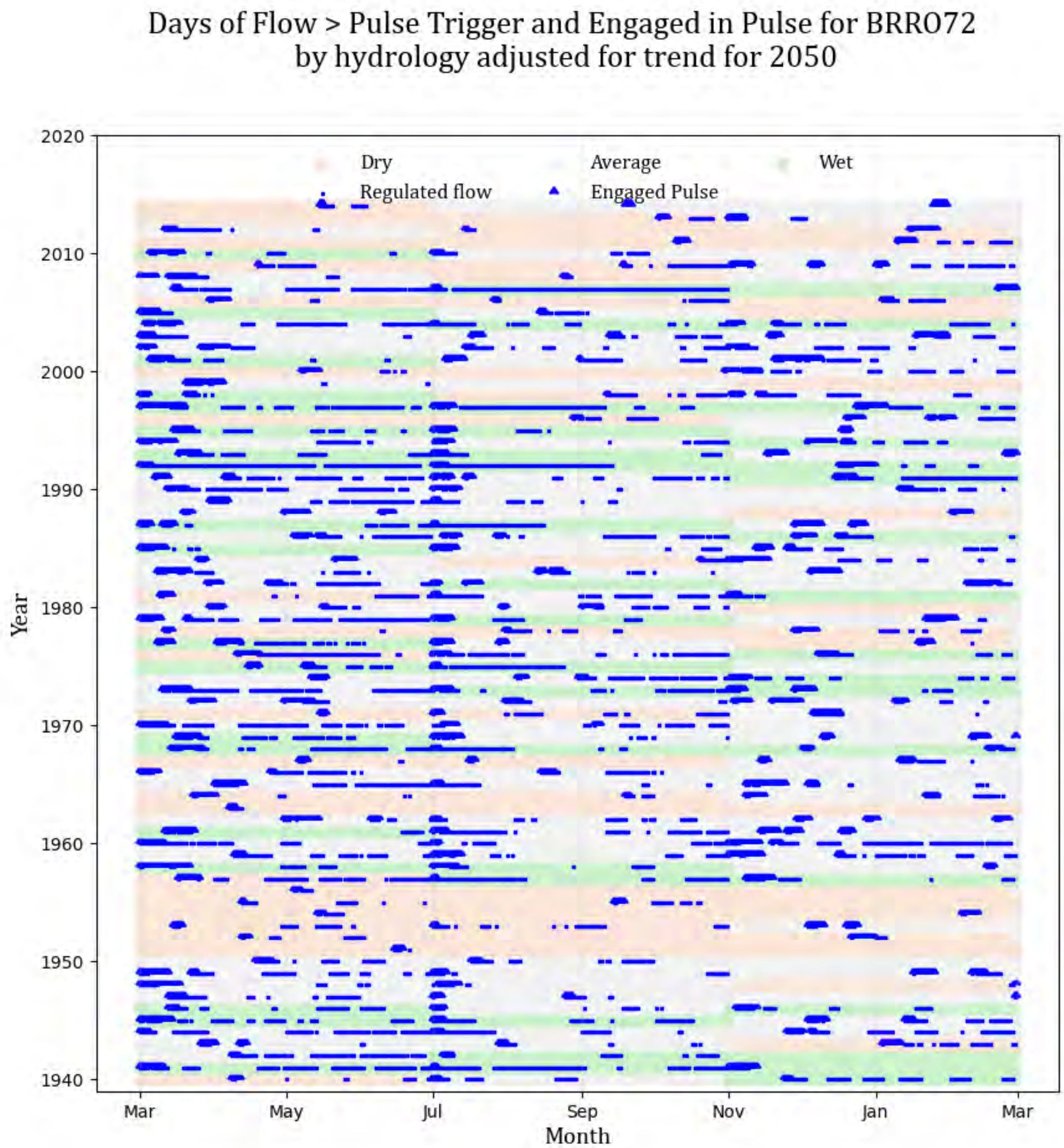
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for BRRO72
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
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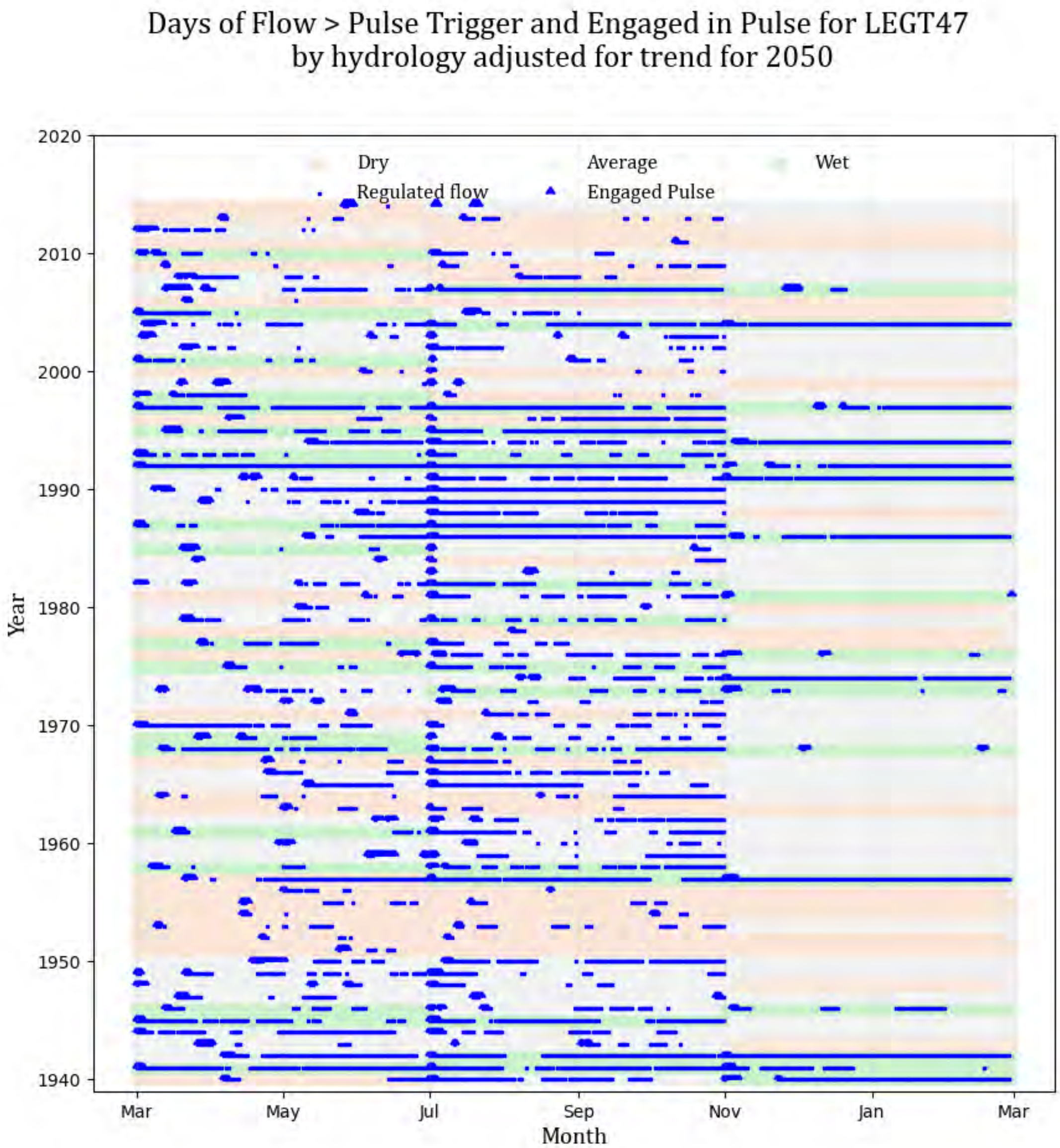
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for LEGT47
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
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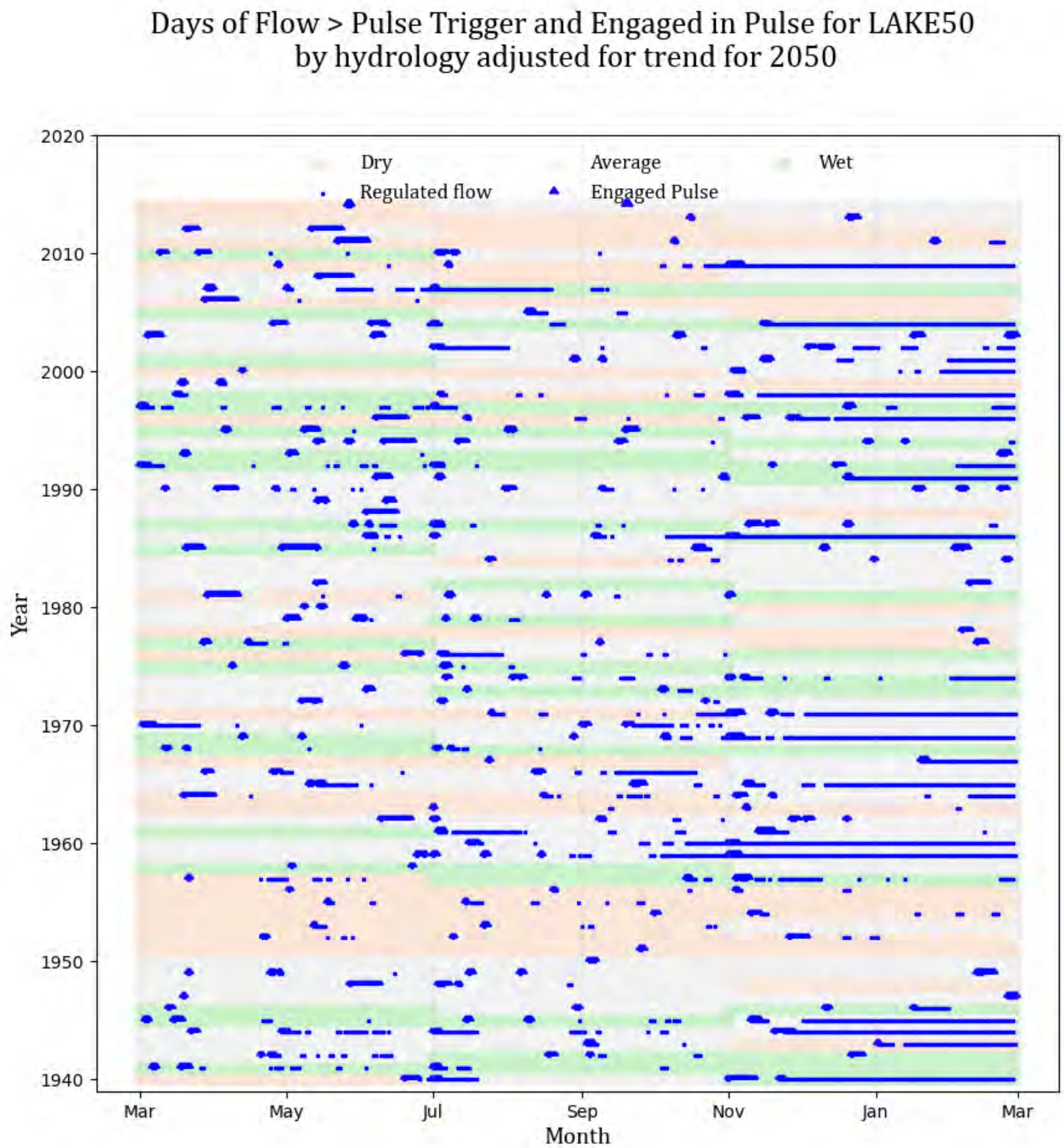
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for LAKE50
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Mar
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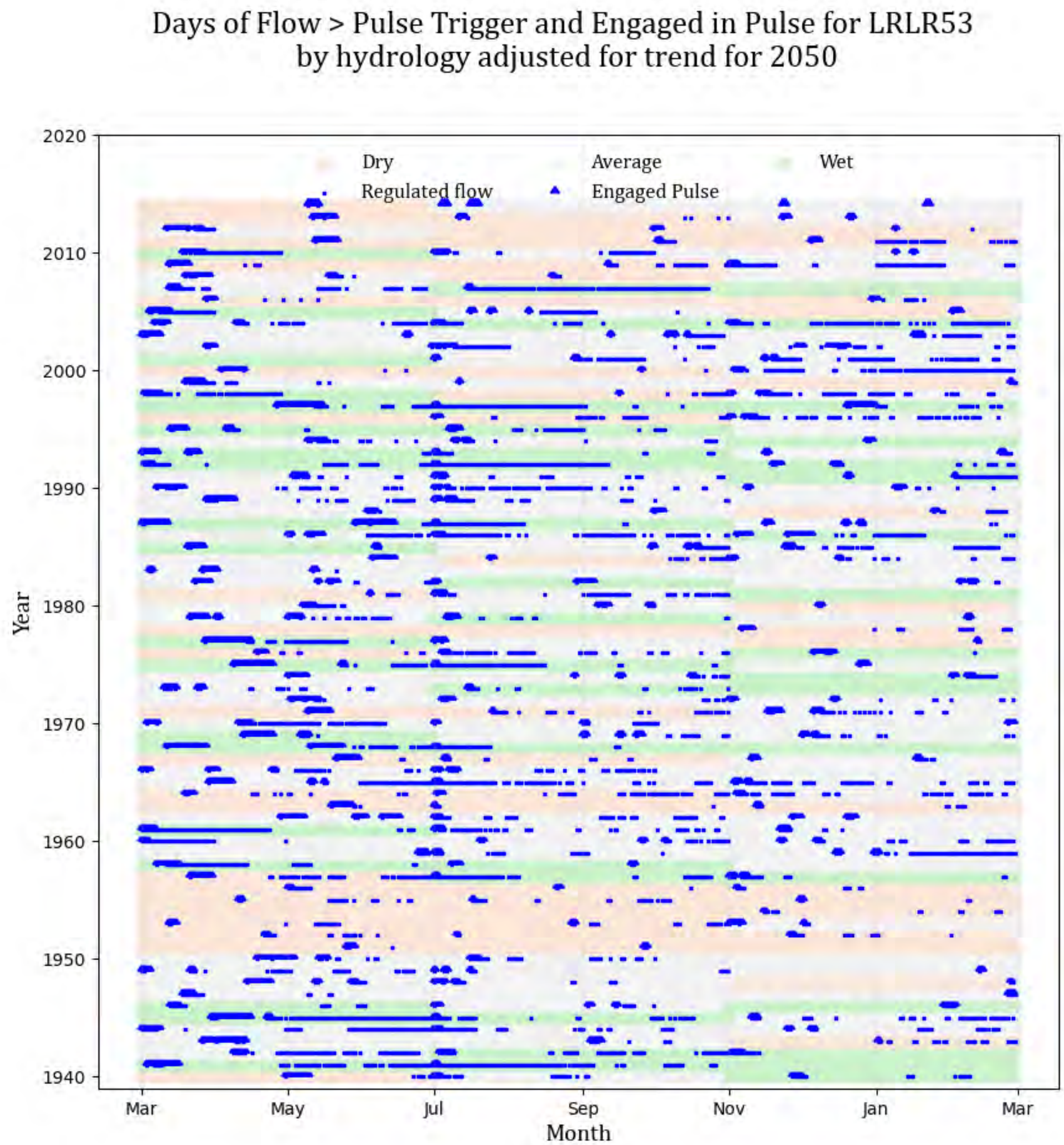
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for LRLR53
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
2000
1990
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1970
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1940
Mar
May
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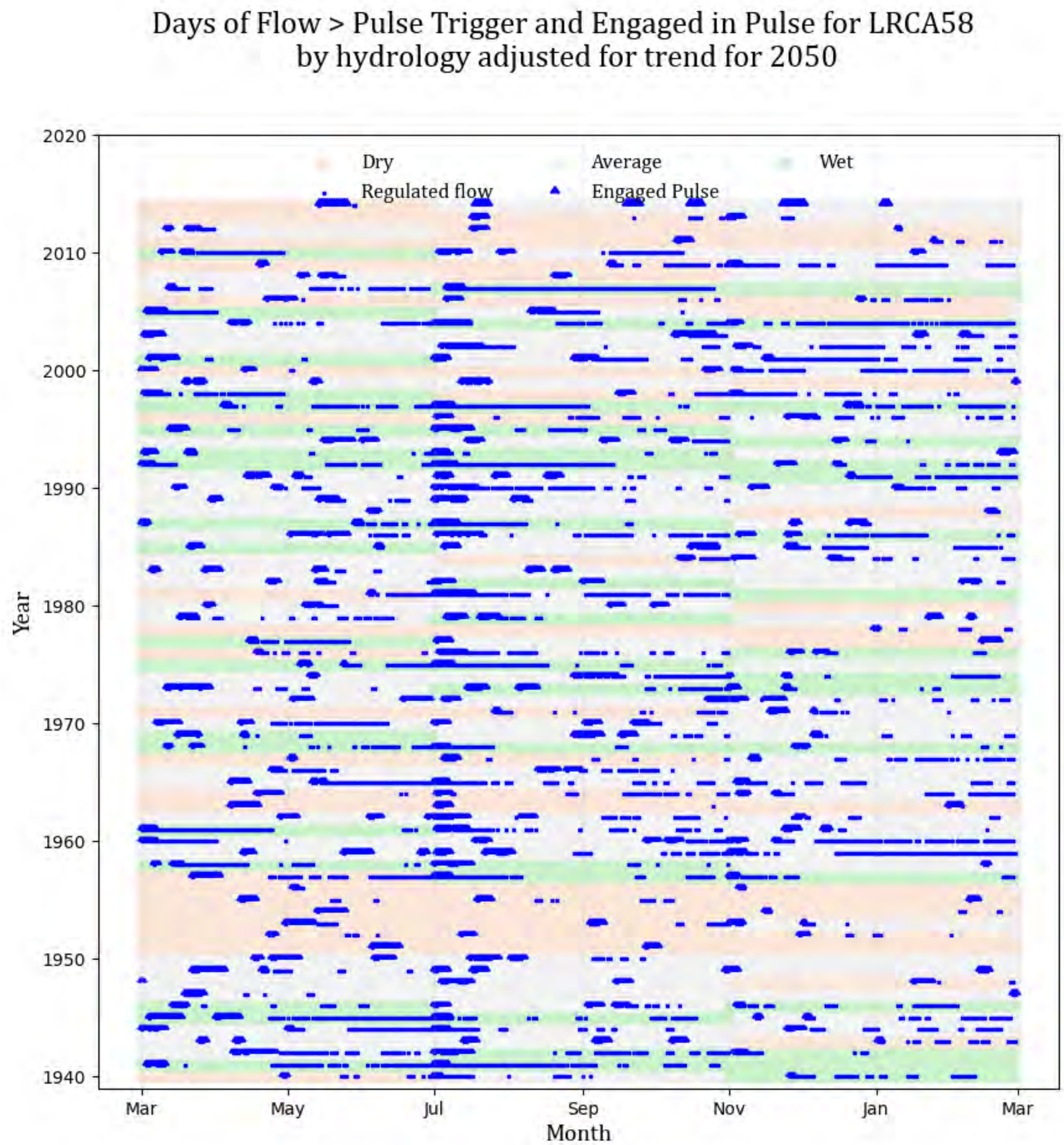
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for LRCA58
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
2000
1990
1980
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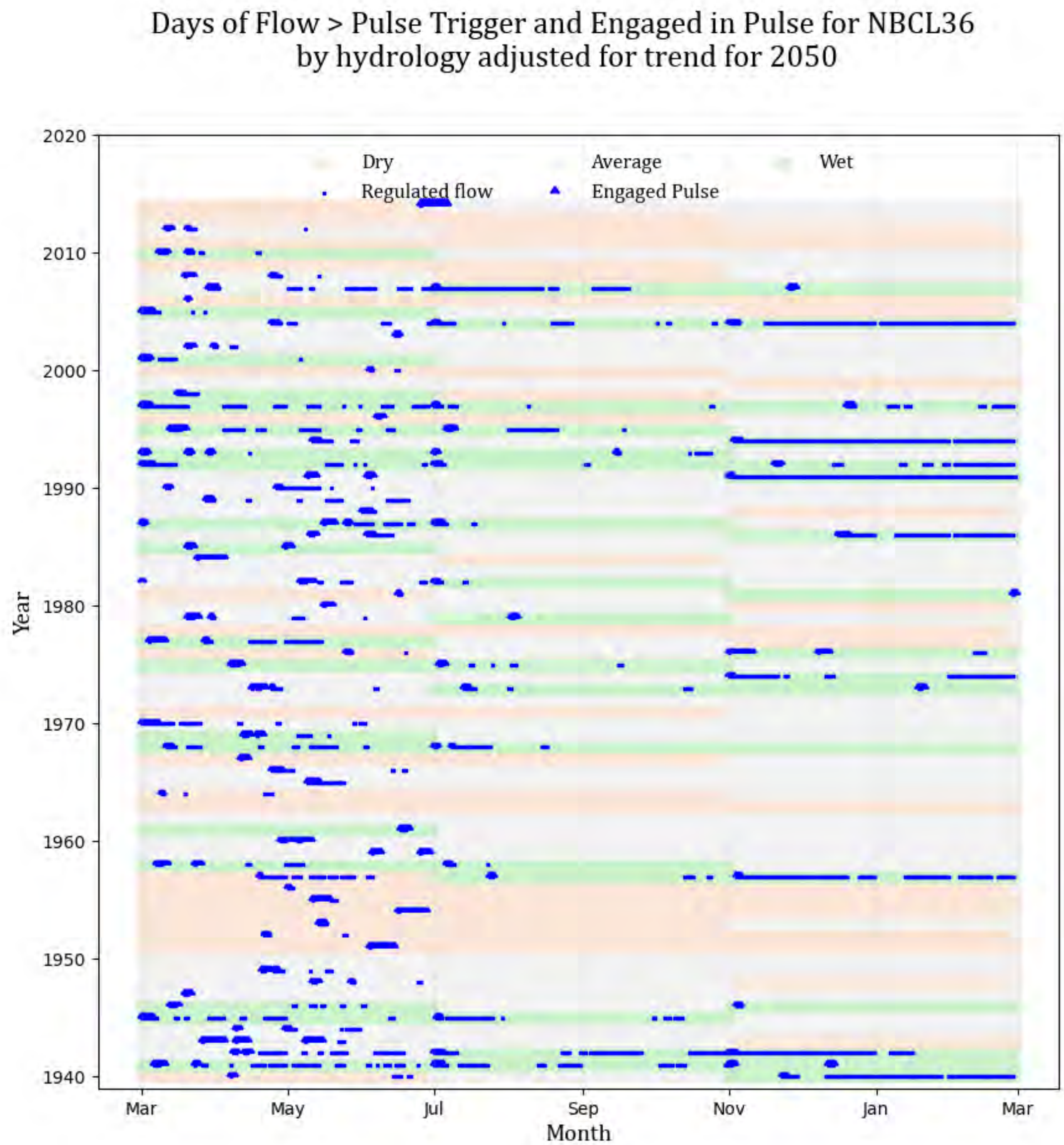
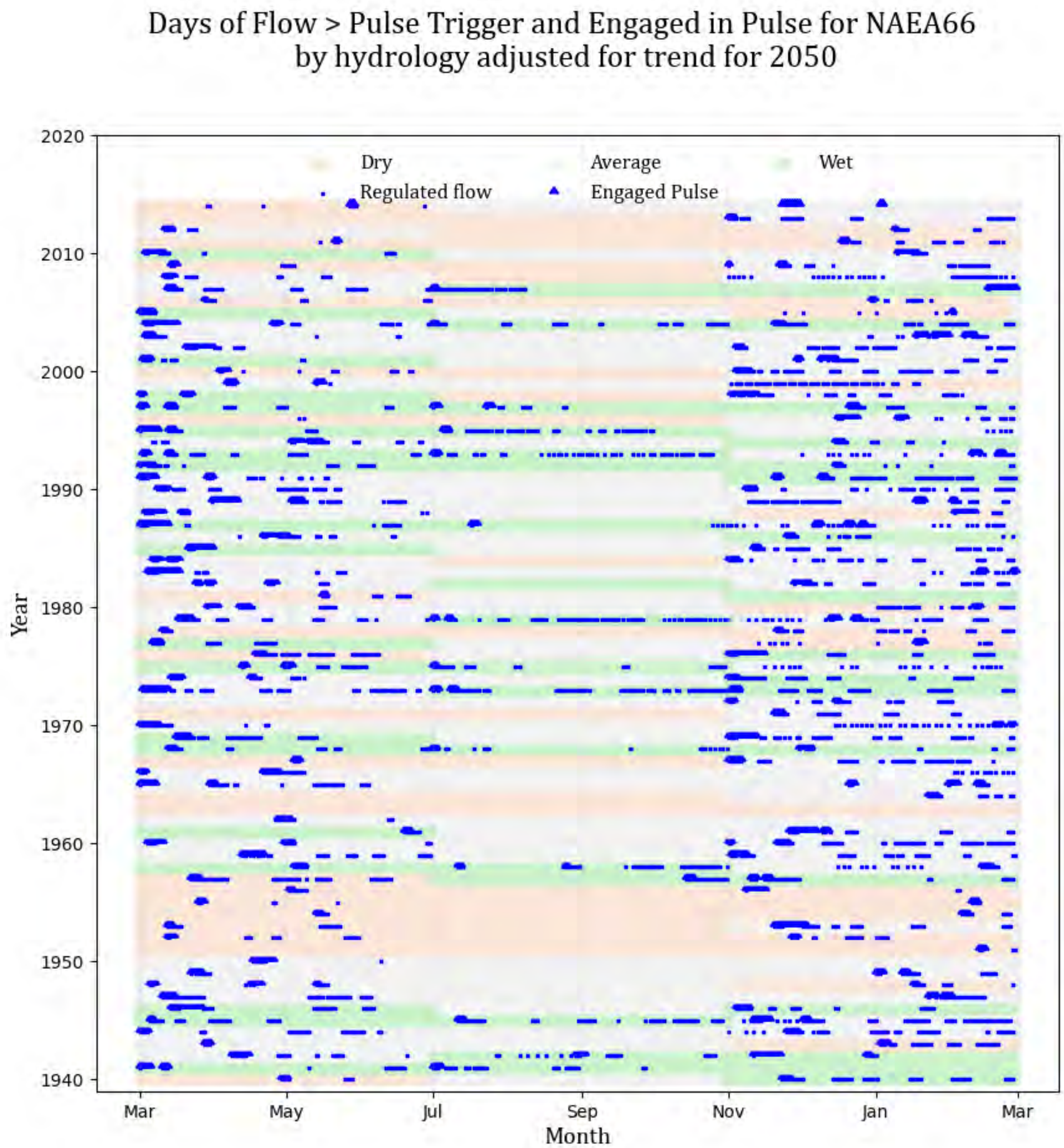
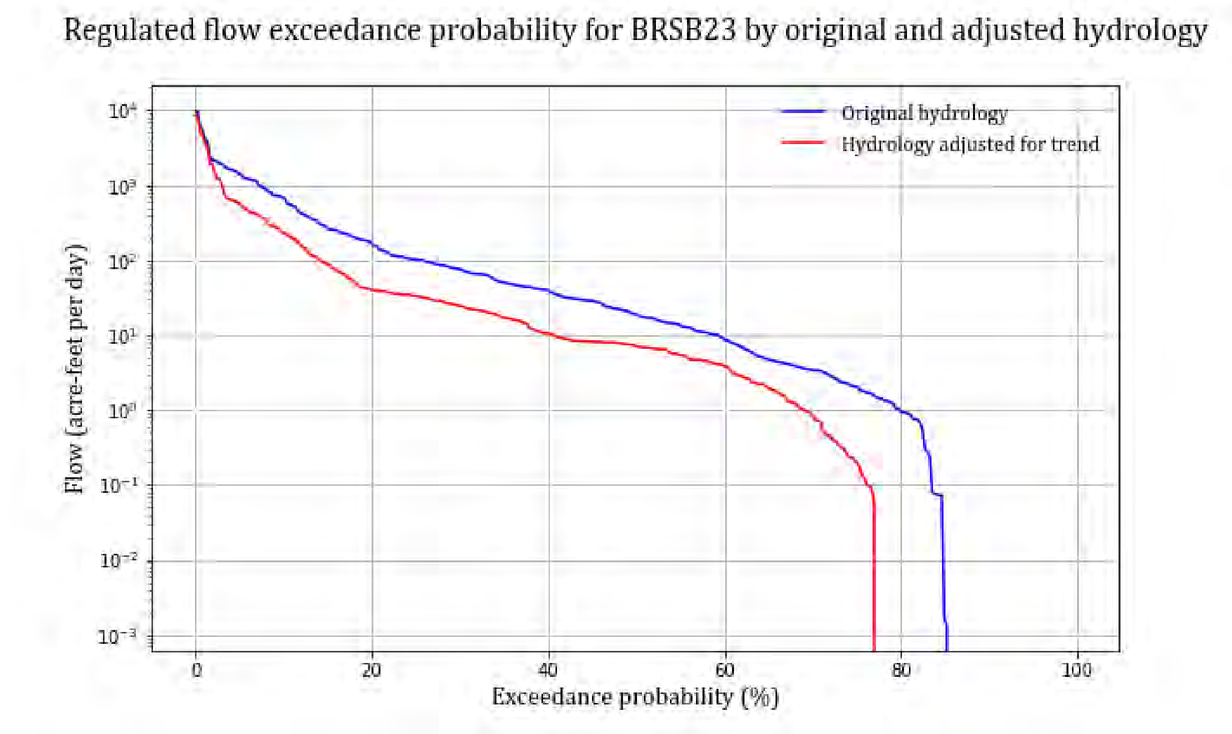
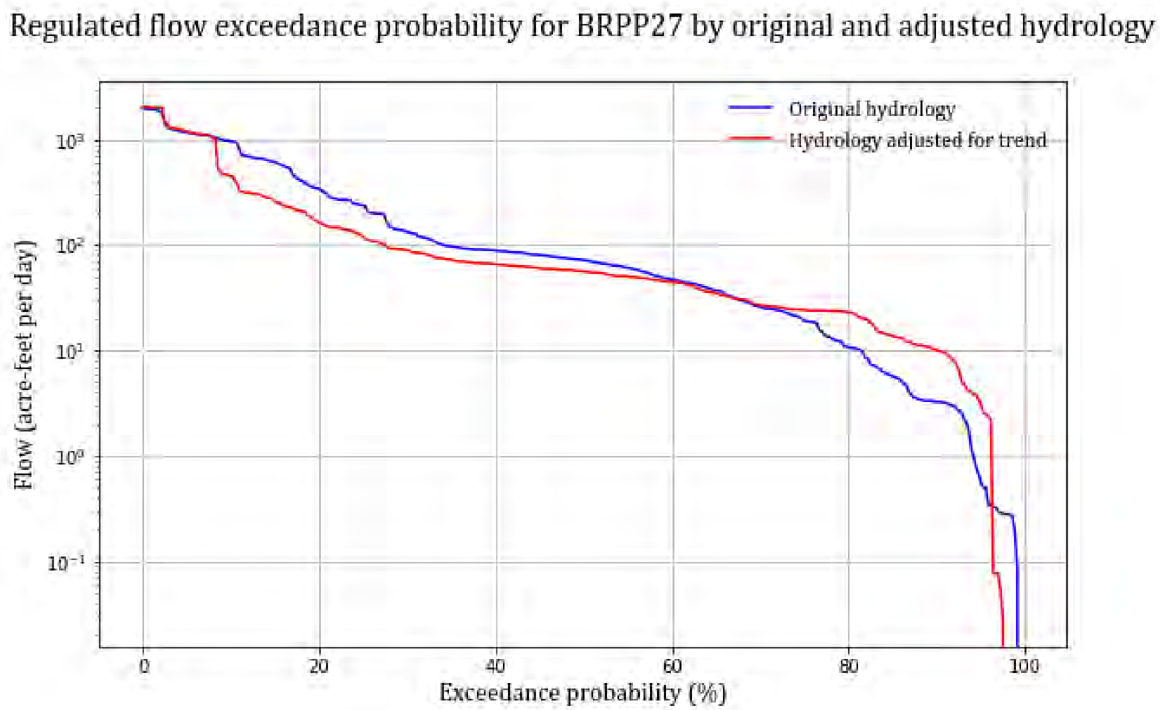
Nov
Jan
Mar
Month

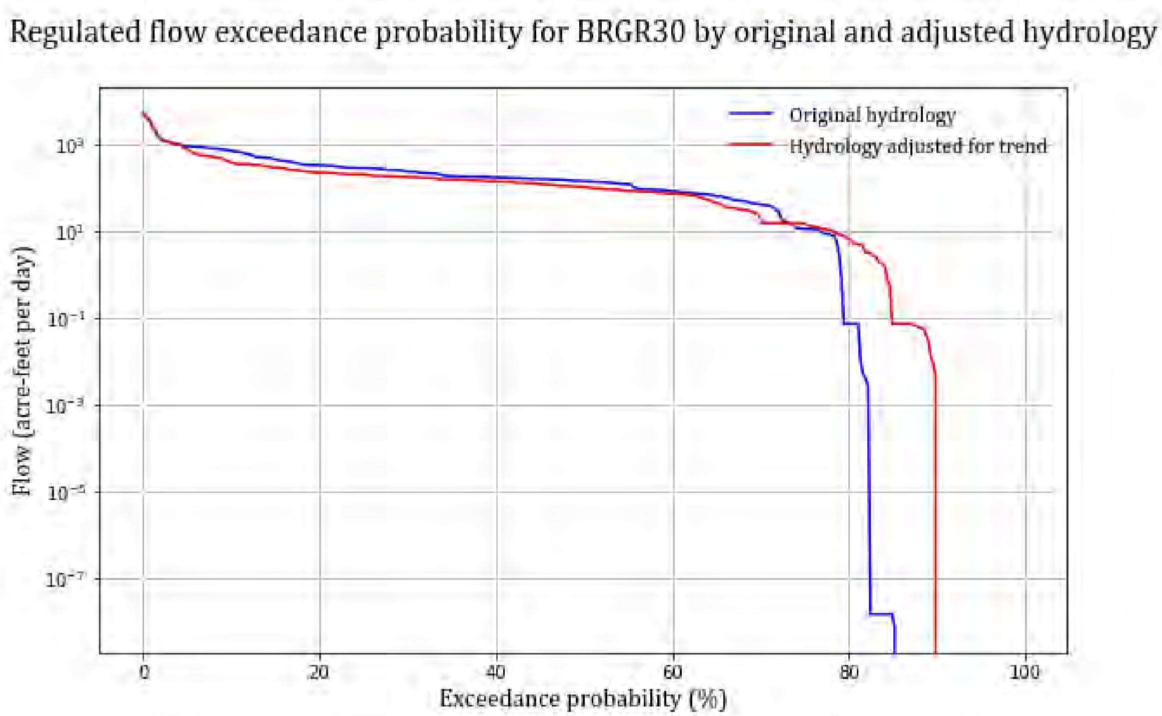

Days of Flow > Pulse Trigger and Engaged in Pulse for NBCL36
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Mar
May
Jul
Sep
Nov
Jan
Mar
Month


Days of Flow > Pulse Trigger and Engaged in Pulse for NAEA66
by hydrology adjusted for trend for 2050
Dry
Average
Wet
Regulated flow
Engaged Pulse
Year
2020
2010
2000
1990
1980
1970
1960
1950
1940
Mar
May
Jul
Sep
Nov
Jan
Mar
Month

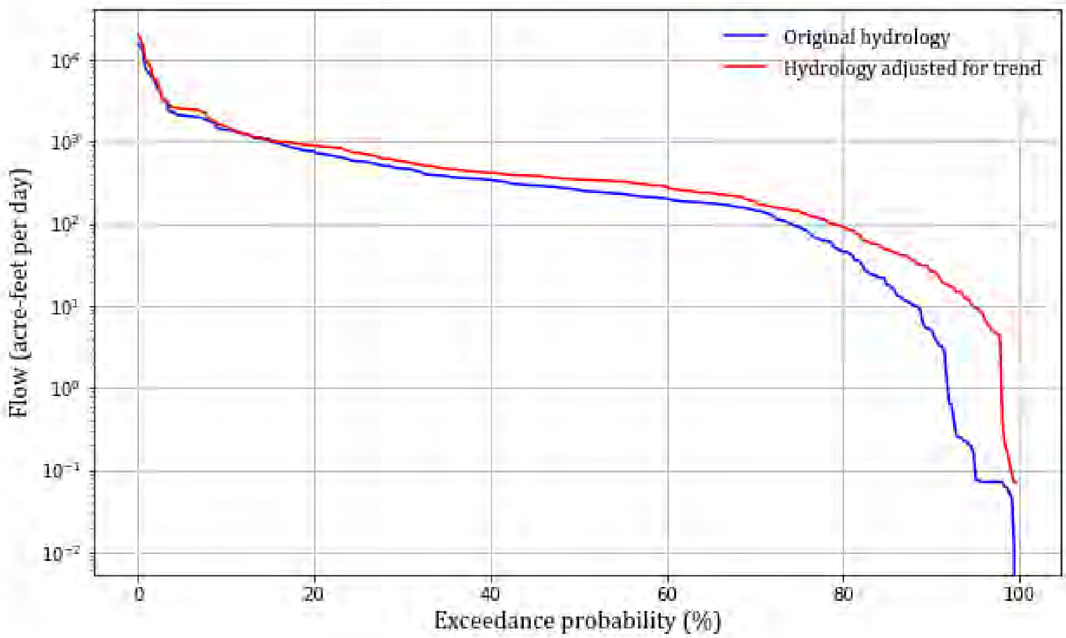
APPENDIX 3-I: EXCEEDANCE PROBABILITY FOR REGULATED FLOW FROM UPDATED DAILY BRAZOS WAM OF 2050 CONDITION SIMULATED BY ORIGINAL HYDROLOGY, AND HYDROLOGY ADJUSTED FOR TREND FOR 2050



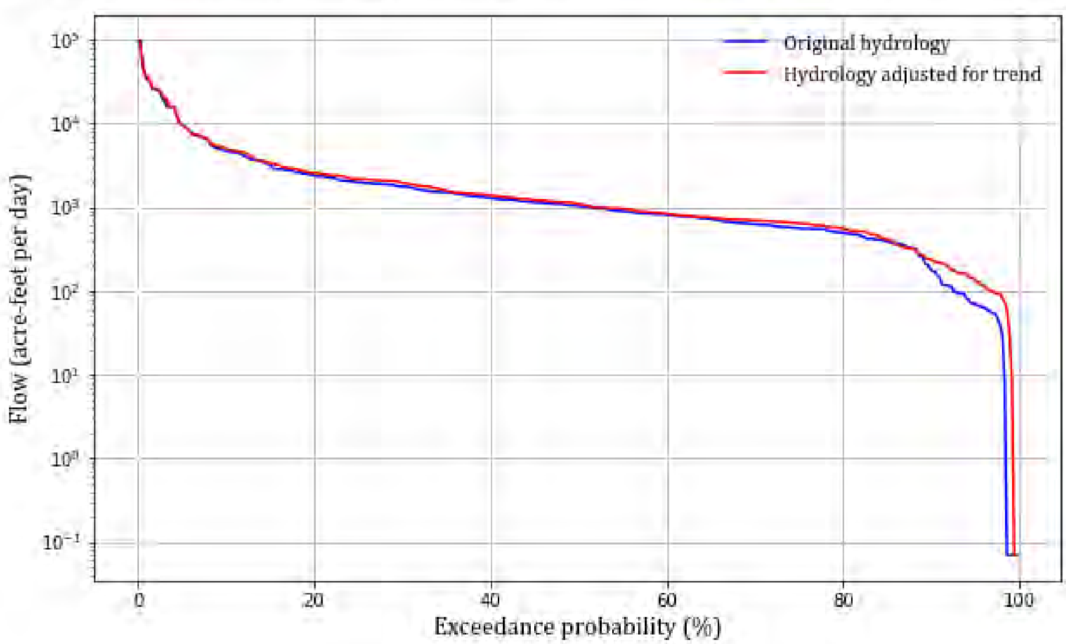

Regulated flow exceedance probability for BRPP27 by original and adjusted hydrology
Original hydrology
Hydrology adjusted for trend
Flow (acre-feet per day)
Exceedance probability (%)
10^3
10^2
10^1
10^0
10^{-1}
0
20
40
60
80
100


Regulated flow exceedance probability for BRGR30 by original and adjusted hydrology
Original hydrology
Hydrology adjusted for trend
Flow (acre-feet per day)
Exceedance probability (%)
10^3
10^1
10^{-1}
10^{-3}
10^{-5}
10^{-7}
0
20
40
60
80
100

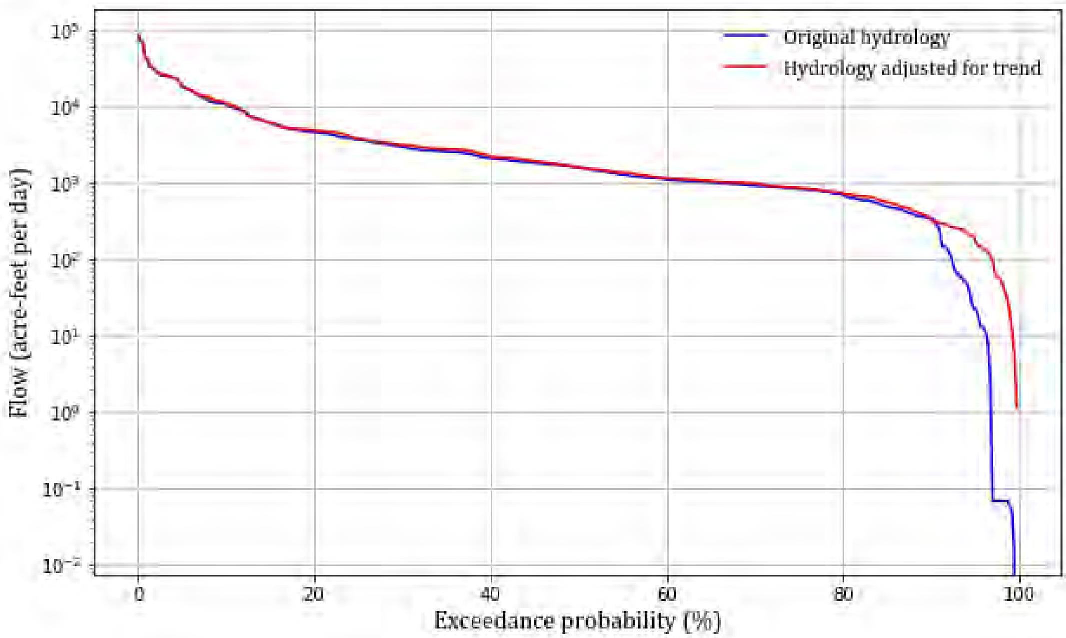
Regulated flow exceedance probability for BRWA41 by original and adjusted hydrology



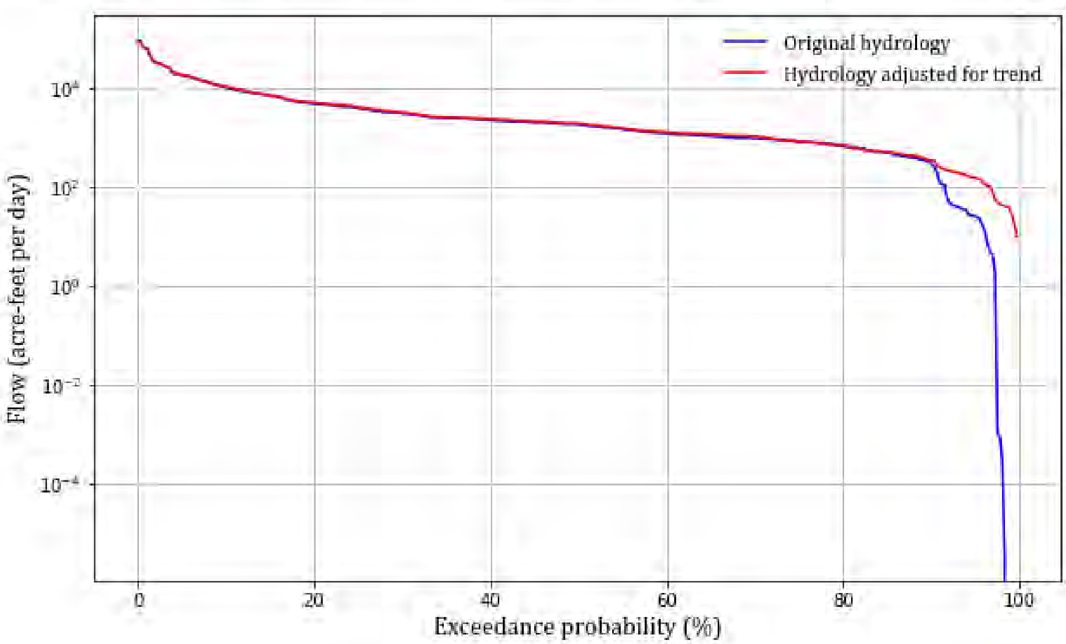
Regulated flow exceedance probability for BRBR59 by original and adjusted hydrology

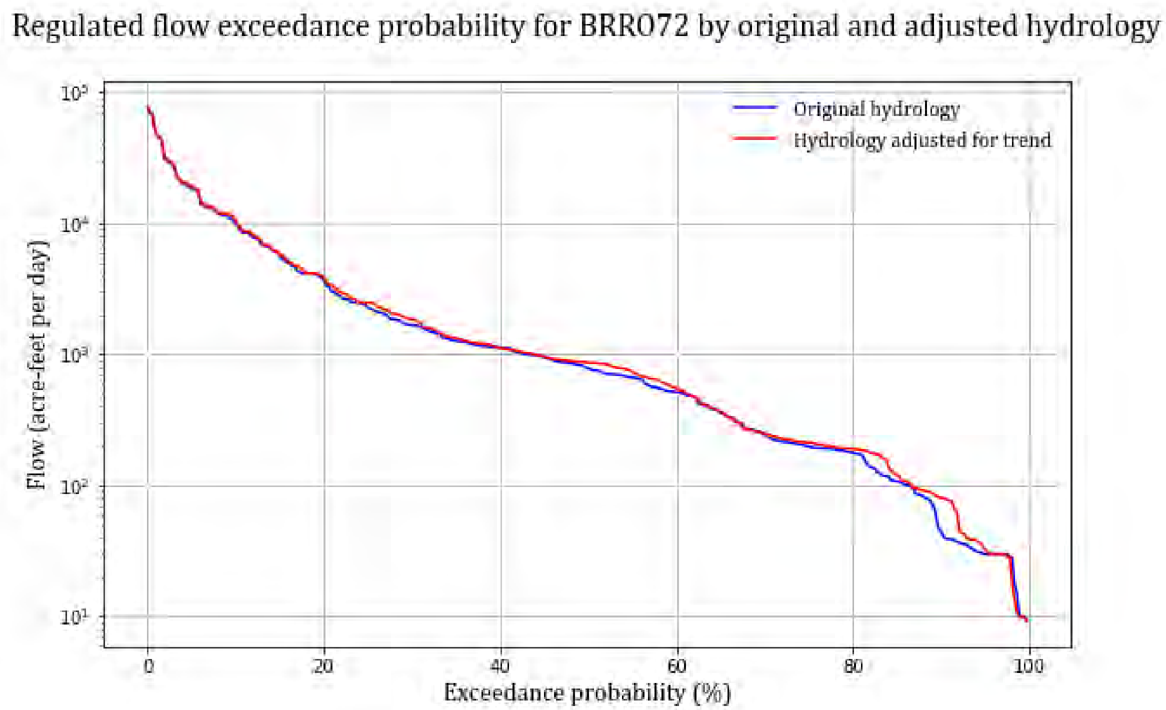


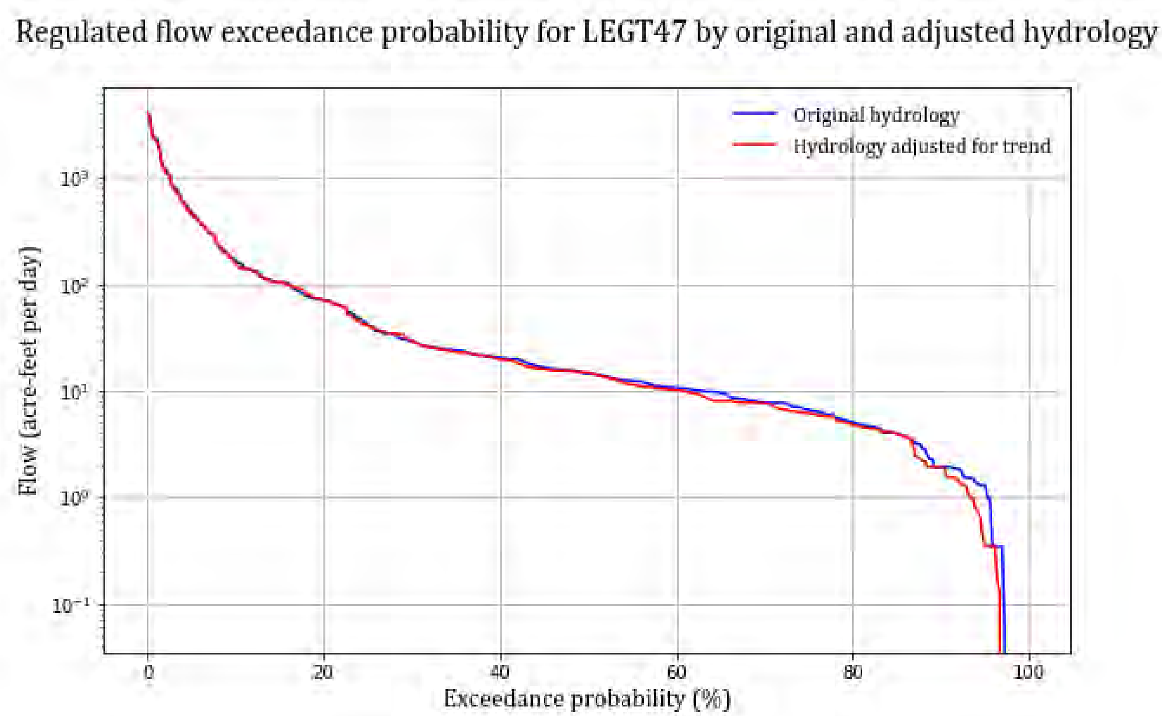
Regulated flow exceedance probability for BRHE68 by original and adjusted hydrology



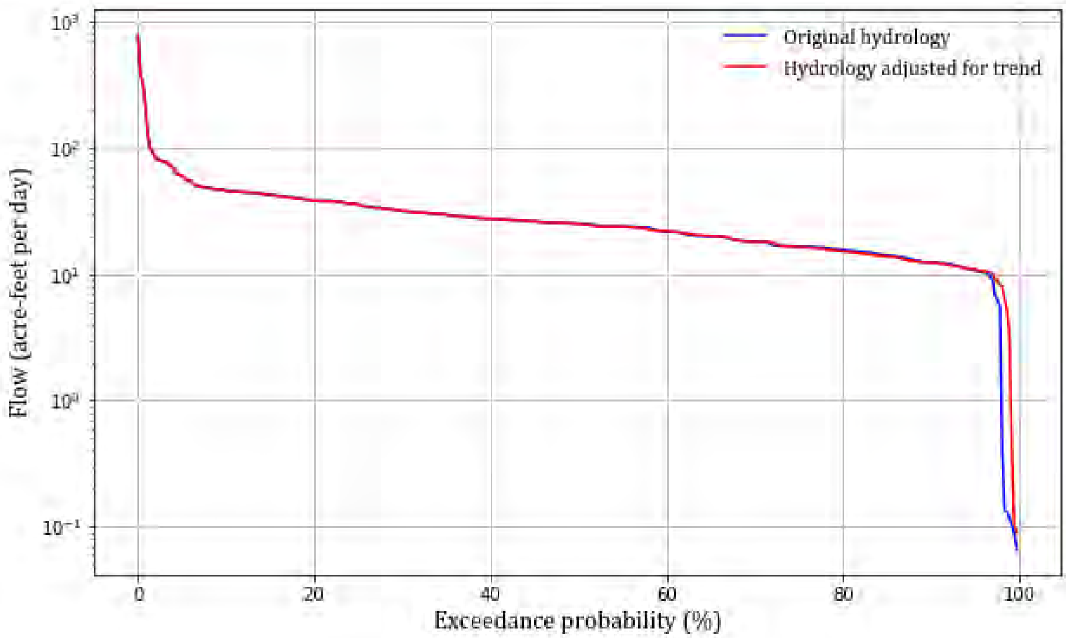
Regulated flow exceedance probability for BRRI70 by original and adjusted hydrology



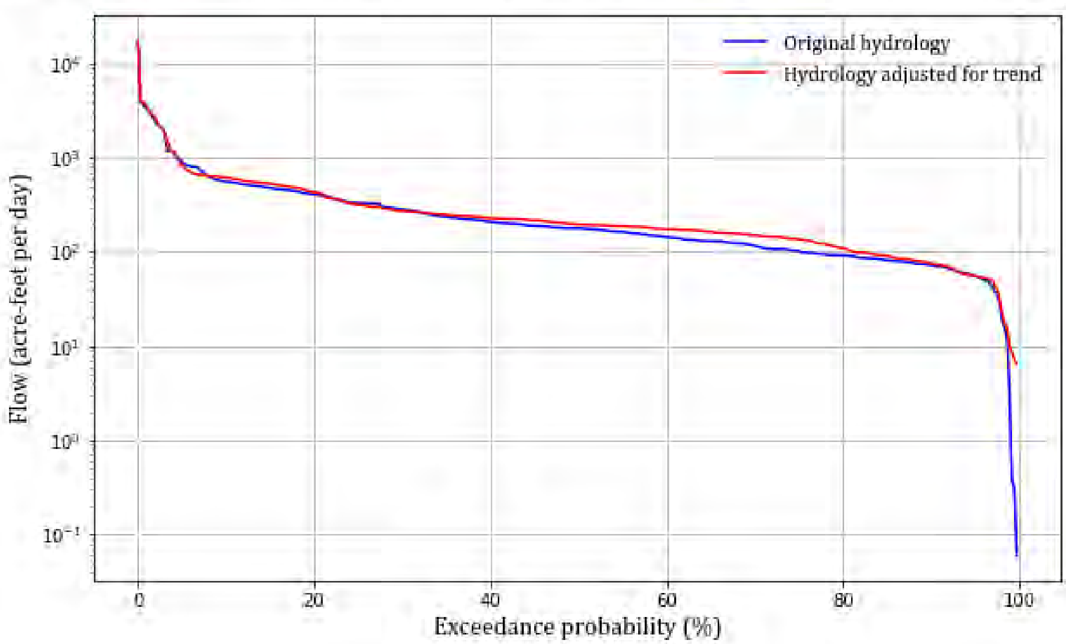

Regulated flow exceedance probability for BRRO72 by original and adjusted hydrology
Original hydrology
Hydrology adjusted for trend
Flow (acre-feet per day)
10^5
10^4
10^3
10^2
10^1
0
20
40
60
80
100
Exceedance probability (%)

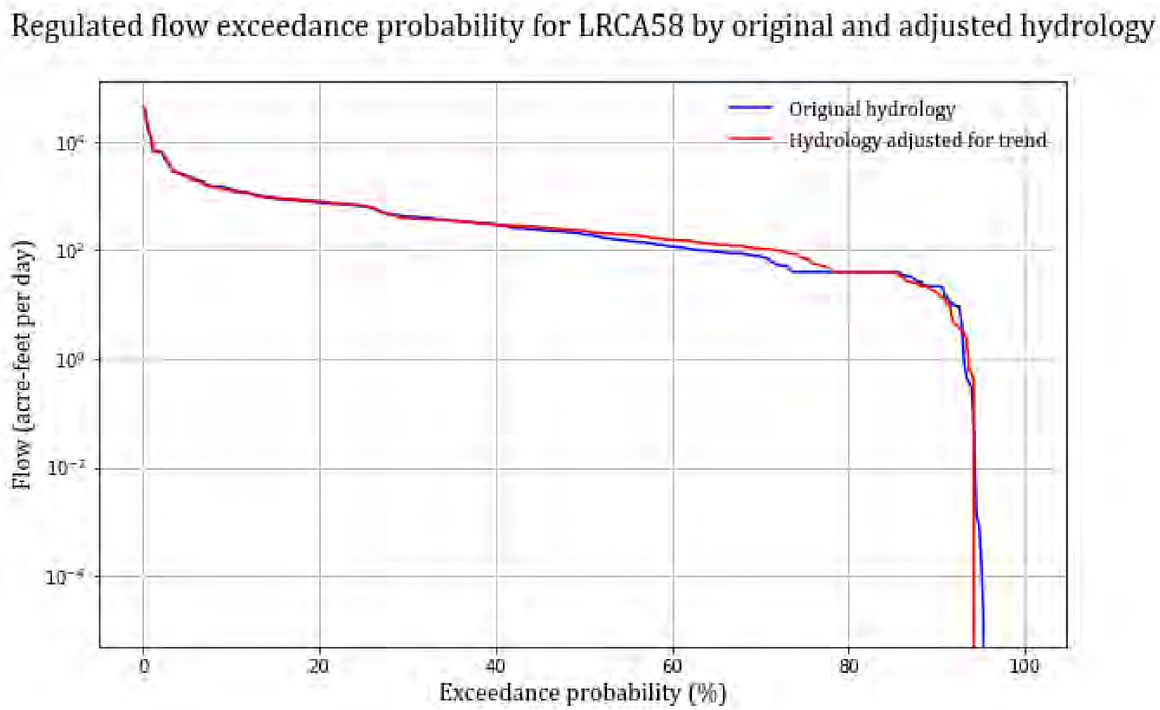

Regulated flow exceedance probability for LEGT47 by original and adjusted hydrology
Original hydrology
Hydrology adjusted for trend
Flow (acre-feet per day)
10^3
10^2
10^1
10^0
10^{-1}
0
20
40
60
80
100
Exceedance probability (%)

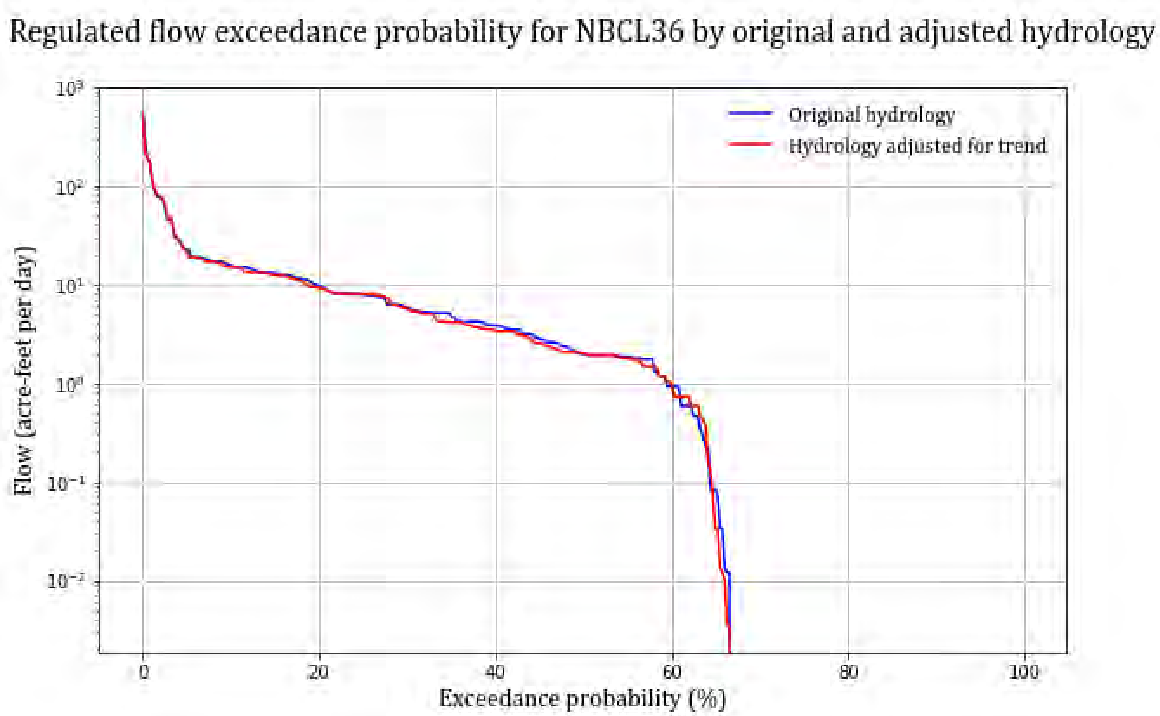
Regulated flow exceedance probability for LAKE50 by original and adjusted hydrology

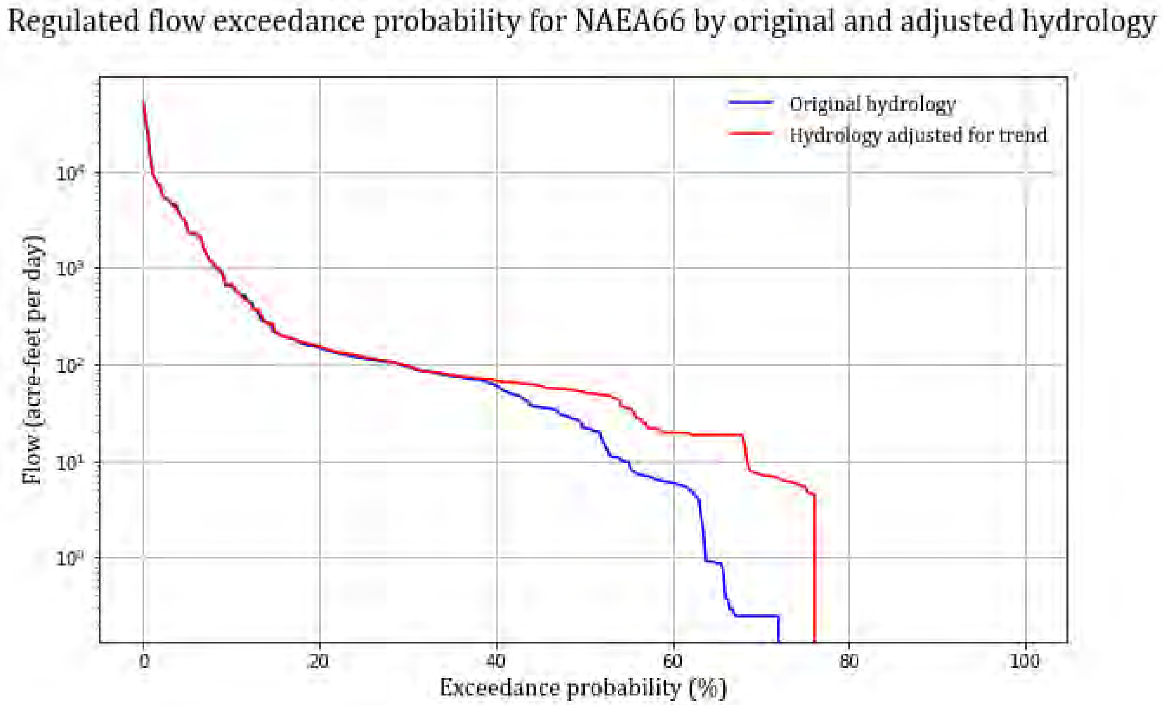


Regulated flow exceedance probability for LRLR53 by original and adjusted hydrology




Regulated flow exceedance probability for LRCA58 by original and adjusted hydrology
Original hydrology
Hydrology adjusted for trend
Flow (acre-feet per day)
Exceedance probability (%)
0
20
40
60
80
100


Regulated flow exceedance probability for NBCL36 by original and adjusted hydrology
Original hydrology
Hydrology adjusted for trend
Flow (acre-feet per day)
Exceedance probability (%)
0
20
40
60
80
100


Regulated flow exceedance probability for NAEA66 by original and adjusted hydrology
Original hydrology
Hydrology adjusted for trend
Flow (acre-feet per day)
Exceedance probability (%)
0
20
40
60
80
100

APPENDIX 3-J: TWDB UPDATES TO THE EXISTING DAILY BRAZOS WAM

All changes and additions are marked/commented with "TWDB". All related input files (.DIS file) are updated too, in addition to .DAT file.

Monthly hydrology inputs are changed from DSS to regular uncompressed. FLO and .EVA files. That is the INEV option of 6 is changed to 0 or blank in JO record field 2 (column 8) and instructs SIMD to read IN and EV records from a regular uncompressed .FLO and .EVA input files. Simulation is limited to 2015 as the original and adjusted hydrologic input is limited to 2015.

BRA System Operation Permit from TCEQ latest version (2018) is added into the daily Brazos WAM obtained from Prof. Wurbs. Associated changes to other water rights are also added. Other items changed include:

1. In DI/IS/IP records, original WHITNY BRA storages are merged into BRAWHT, including changing the rating curve from WHITNY to BRAWHT, and extended the BRAWHT curve to higher elevations from WHITNY's curve.
2. Above Related EV record is also changed, and a new EV record for BELTON is added.
3. Added rating curve (121901) related to Alcoa 12190 SD.
4. Added FD record of 121901, 121902 and 121911 related entry into DIS file.
5. Added FD and WP record of 5165IF into DIS file.
6. Added 1918100 ac-ft for SV and 38000 acres for SA at elevation 658.02 feet into SV/SA rating curve for Lake Belton due to interpolation error – curve is too short. Data are from USACE website.

Water Management Strategies (WMSs) coming online before 2050 are added into daily WAM, based on 2022 Region G Water Plan (https://www.twdb.texas.gov/waterplanning/rwp/plans/2021/index.asp). A total of 8 WMSs are included:

a) Brushy Creek Reservoir – online 2020
b) Cedar Ridge Reservoir – online 2020
c) Coryell County Off-Channel Reservoir (OCR) – online 2020
d) Groesbeck OCR - online 2020
e) Lake Creek Reservoir – online 2020
f) Throckmorton Reservoir – online 2020 - Note: TWDB does not use naturalized flow input for THROCK control point as HDR did in 2021 Region G Water Plan, because the IN data used by HDR only cover the period 1940–1997. As TWDB does not have access to the exact methodology that was used for the construction of fully nationalized flows for the THROCK control point, we could not extend the naturalized data for the period 1998–2018. We used naturalized flow is derived from nearby a primary control point.
g) Turkey Peak Dam–Lake Palo Pinto – online 2020. Add more capacity into Palo Pinto and changed water right as the same as HDR did in 2021 Region G Water Plan.

Reservoir capacity and volume-area rating curves are updated to 2050 condition. Reservoir capacity, inactive pool, and volume-area rating curves are updated to 2050's condition for all major reservoirs that TWDB has the projected rating curves for. TWDB uses the Elevational Sedimentation Rate (ESR) method for projected rating curves (Zhu, et al, 2020).

TL of 17 is entered in JD record field 11 (column 80) to increase the number of entries allowed in the SV/SA record storage-area table to 17 from the default of 12. The SV and SA records are extended as necessary to encompass flood control pools of the nine USACE reservoirs.

a) **Alan Henry** Lake – changed rating curve and permitted capacity from 115,937 ac-ft to projected capacity of 88,546 ac-ft in 2050's condition.
b) **Aquila** Lake – changed rating curve and original permit volume of 52,400 ac-ft to 35,842 ac-ft (left flood control pool unchanged but added additional top point (SV 188322 and SA 7800) by extrapolation to meet the program interpolation need). Also added flood control pool, AQUIFC, as a shared pool per Prof. Wurbs' suggestion (personal communications).
c) **Belton** Lake – changed rating curve and permitted capacity from 445,600 ac-ft to projected capacity of 409,607 ac-ft in 2050's condition. Left flood pool and USACE partial pool unchanged. Also added flood control pool, BELTFC, for the flood control water right, as a shared pool per Prof. Wurbs' suggestion (personal communications).
d) **Granbury** Lake – changed rating curve and permitted capacity from 155,000 ac-ft to projected capacity of 122,483 ac-ft in 2050's condition.
e) **Georgetown** Lake – changed rating curve and permitted capacity from 37,100 ac-ft to projected capacity of 36,428 ac-ft in 2050's condition, but left flood pool unchanged.
f) **Granger** Lake – changed rating curve and original permitted volume from 65,500 ac-ft to 45,667 ac-ft. Left flood control pool of 244,000 ac-ft unchanged.
g) **Hubbard Creek** Reservoir – changed rating curve and permitted capacity from 317,750 ac-ft to projected capacity of 300,375 ac-ft in 2050's condition.
h) **Limestone** Lake – changed rating curve and permitted capacity from 225,400 ac-ft to projected capacity of 176,285 ac-ft in 2050's condition. And changed 217,494 ac-ft to 169,950 ac-ft (proportional to the conservation pool reduction) per the BRA permit.
i) **Possum Kingdom** reservoir – changed rating curve and original permitted volume from 724,739 ac-ft @1000 feet to 2050 condition's capacity of 541,302 ac-ft at the same elevation (note: 520,668 ac-ft @elevation 999 feet). Changed 2 DI-IS-IP records, respectively.
j) **Proctor** Lake – changed rating curve and permitted capacity from 59,400 ac-ft to projected capacity of 47,142 ac-ft in 2050's condition. Left flood pool unchanged.
k) **Somerville** Lake – changed rating curve and permitted capacity from 160,110 ac-ft to projected capacity of 136,322 ac-ft in 2050's condition. Left flood pool unchanged.
l) **Stillhouse Hollow** Lake – changed rating curve and permitted capacity from 235,700 ac-ft to projected capacity of 220,205 ac-ft in 2050's condition. Left flood pool unchanged.
m) **Lake Whitney –** changed volume-area rating curve to 2050 condition and changed capacity of 387,024 ac-ft at elevation 520 feet to 283,785 ac-ft based on the new rating curve. However, did not change the permitted storage (50,000 ac-ft) for BRA. Flood pool volume of 642,180 ac-ft was changed to 557,081 ac-ft. DI/IS/IP was changed according to new volume at elevations, 520, 527, 530, and 533 feet, respectively.
n) **Lake Waco –** changed volume-area rating curve to 2050 condition, However, we did not change any partial capacities, because all partial capacities are much less than the total conservation

pool capacity and those are permit-related. The new rating curve has a dead pool of 89 ac-ft and it is also not added to the partial capacities. Left top of flood pool setup unchanged.

o) **Lake White River –** changed volume-area rating curve to 2050 condition and changed permitted capacities (33,160; 38,232; and largest 44,897 ac-ft), to 4,277; 4,931; 5,791 ac-ft, respectively.
p) **Lake Stamford –** changed volume-area rating curve to 2050 condition and changed permitted capacities from 60,000 ac-ft to 26,709 ac-ft.
q) **Lake Fort Phantom Hill -** changed volume-area rating curve to 2050 condition and changed permitted capacities from 73,960 ac-ft to 69,182 ac-ft.
r) **Lake Mexia -** changed capacity and volume-area rating curve to 2050 condition, and changed capacity from 9,600 ac-ft to 4,313 ac-ft.
s) **Lake Miller Creek** - changed capacity and volume-area rating curve to 2050 condition, and changed capacity from 30,696 ac-ft to 17,312 ac-ft.

Note, no change was made to Allens Creek OCR, because we do not know the sediment condition.

Water right diversion target is kept to the full permitted water use scenario, i.e., full authorization (WAM Run3). Hydrologic input is from 1940 through 2015 (76 years).

Per Dr. Richard Hoffpauir (personal communication, 2021): "The Brazos River basin DAT files contains nine flood control pools. There are no routing control points between Lake Waco and the Brazos River at Waco, control point BRWA41. Accordingly, depletions made by impounding flood waters in Lake Waco arrive within the same time step at BRWA41. This results in occasional low or zero-flow days at BRWA41 when there is mistiming of flood control depletions and the arrival of high flow events at BRWA41. Such depletion of flows because of flood control operations is allowed regardless of downstream water availability constraints. These low or zero-flow days may create baseflow requirement failure days in the analysis of environmental flows when baseflow requirements are controlling at BRWA41 under dry hydrologic conditions at the priority of the standards. In the Brazos River basin, subsistence flow requirements are engaged under dry hydrologic conditions at the priority of the standards. Thus, in the Brazos River basin, no failures of baseflow requirements are expected under dry hydrologic conditions.

To avoid unusual or confusing effects on environmental flow attainment, the field 6 FCDEP option on the Lake Waco flood reservoir FR record was changed from the default value of 2 to a value of 0. The default value allows flood control operations to ignore all downstream control points when determining water availability for making flood control depletions. With FCDEP set to 0, downstream control points are included in water availability calculations. Depletions still occur for flood control operations; however, downstream water availability serves as an additional constraint. This is the only modification made to the Brazos River basin flood control input records developed by Wurbs (2019)."

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CHAPTER 4

Summary of Findings

TWDB Contract Number 2100012466

August 2021

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4.0 SUMMARY OF FINDINGS

4.1 SUMMARY OF TREND ASSESSMENT

Harwell et al. (2020) analyzed trends in streamflow, precipitation, temperature, groundwater level elevation, and flood storage for seven river basins in Texas, including the Brazos Basin. The following sections compare results of this study to trends identified by Harwell et al. (2020). Throughout, references to "Harwell" refer to the authors of that study. Where applicable, results were also compared to other studies discussed in the literature review portion of this study (***Section 1.2.1***).

4.1.1 Temperature

Results

The strongest trend in average air temperature within each climate division was at the annual timescale, with significant increasing trends in temperature being detected in all seven climate divisions. We found the strongest trends when annual trend analysis began in the late 1960s, and we adjusted start years accordingly. We also detected significant increasing trends in most seasons and various seasonal and conditional timescales for each location.

Comparison to Literature

The trends in annual average air temperature identified by this study are consistent with those found in recent literature. Harwell et al. (2020) similarly identified increasing trends in annual mean air temperature in all climate divisions in Texas from 1900 through2017. The mean annual air temperature trends identified by Harwell et al. (2020) are of a lower magnitude than those identified in the current study. This could be due to the differences in the time periods analyzed (late 1960s through 2019 for this study, compared to 1900 through 2017 in Harwell) and the use of periodic functions to assess trends in the Harwell et al. study. The higher magnitude temperature trends used to project forward in this study result in a more conservative estimate of evaporation loss (i.e., higher evaporation) in terms of water supply, compared to lower magnitude trends found in Harwell. The U.S. Bureau of Reclamation (2016) found that temperatures in the western United States have been trending upward since 1900 and especially so since the 1970s. Nielson-Gammon et al. (2020) also found that statewide temperatures in Texas have been increasing and suggested that these increases would continue.

4.1.2 Flow

Results

We identified multiple decreasing trends at various timescales in the upper Brazos Basin, while trends in incremental runoff in the middle and lower basin varied. Many drainage areas in the middle and lower basins did not have any significant trends in incremental runoff. Additionally, some increasing trends and the accumulation of flow in the middle and lower basins generally mitigated the upstream decreases, resulting in adjusted naturalized flows along the main stem of the Brazos River that were slightly greater than the unadjusted flows. Table 4-1 summarizes results at important points on the river and major tributaries.

Table 4-1 – Changes in Flow and Contributing Trends at Ten Primary Control Points

Control Point	Percent Change in Incremental Naturalized Flow (1940-2015)	Percent Change in Total Naturalized Flow (1940-2015)	Trend(s) in incremental flow at this location	Trend(s) in flow applied at contributing upstream points
Brazos River at Seymour (BRSE11)				
BRSE11	-37%	-35%	Annual (-)	**Decreasing:** Annual (-) (multiple locations) **Increasing:** Wet Spring (+) at BSLU07
Clear Fork Brazos River at Eliasville (CFEL22)				
CFEL22	-37%	-22%	Annual (-)	**All Decreasing:** Annual (-) at multiple locations Dry Winter (-), Average Winter (-), Wet Spring (-), Average Summer (-) at CFRO13 Dry Spring (-) at CAST17, CFFG18, and BSBR20
Brazos River at Morris Sheppard Dam near Graford (SHGR26)				
SHGR26	-21%	-26%	Annual (-)	**All Decreasing:** Annual (-) at BRSB23 Winter (-), Dry Spring (-) at MSMN12 Average Summer (-) at CCIV25 *And all trends upstream of and including BRSE11 and CFEL22*

Control Point	Percent Change in Incremental Naturalized Flow (1940-2015)	Percent Change in Total Naturalized Flow (1940-2015)	Trend(s) in incremental flow at this location	Trend(s) in flow applied at contributing upstream points
Brazos River near Aquilla (BRAQ33)				
BRAQ33	118%	6%	Annual (+)	**Decreasing:** Summer (-) at PPSA28 Average Winter (-) at BRDE29, PAGR31, and NRBL32 Dry Spring (-) at PAGR31 Dry Summer (-) at BRGR30 **Increasing:** Dry Winter (+) at BRPP27 and NRBL32 Wet Winter (+) at BRPP27 Average Spring (+) and Wet Spring (+) at BRPP27 *And all trends upstream of and including SHGR26*
Bosque River near Waco (BOWA40)				
BOWA40	0%	-1%	None	**All Decreasing:** Dry Spring (-) at NBHI35 Average Winter (-) at NBHI35 and NBCL36
Little River near Cameron (LRCA58)				
LRCA58	0%	-1%	None	**Decreasing:** Dry Winter (-) at LEHS45 and LABE52 Average Winter (-) at LEDL43, LEHS45, LEGT47, and COPI48 Dry Spring (-) at LEDL43, SADL44, LEHS45 Wet Spring (-) at LEBE49 Average Summer (-) at SADL44 and LEHS45 **Increasing:** Dry Winter (+) at LRLR53 Wet Summer (+) at LEHS45 and LEHM46
Brazos River near Bryan (BRBR59)				
BRBR59	0%	1%	None	**Decreasing:** Wet Spring (-) at AQAQ34 *And all trends upstream of and including BRAQ33, BOWA40, and LRCA58*
Navasota River near Bryan (NABR67)				
NABR67	1%	1%	Dry Summer (+)	**Increasing:** Dry Summer (+) at NAEA66
Brazos River near Rosharon (BRRO72)				
BRRO72	22%	2%	Average Summer (+)	**Decreasing:** Average Spring (-) at MYDB60 **Increasing:** Summer (+) at MYDB60 *And all trends upstream of and including BRBR59 and NABR67*
Brazos River at Gulf of Mexico (BRGM73)				

Control Point	Percent Change in Incremental Naturalized Flow (1940-2015)	Percent Change in Total Naturalized Flow (1940-2015)	Trend(s) in incremental flow at this location	Trend(s) in flow applied at contributing upstream points
BRGM73	0%	2%	None	*All upstream trends assessed in the basin influence BRGM73.*

Comparison to Literature

Harwell et al. (2020) analyzed trends in total historical streamflow on annual, seasonal, and monthly time scales at gages throughout the Brazos River Basin from 1900 through 2017. Vogl and Lopes (2009) quantified significant changes in historical monthly and annual streamflow in the Brazos over the past 60 to 100 years. In comparison, for this study, we analyzed trends in incremental naturalized flow (the naturalized runoff in an incremental watershed between two gages) for annual, seasonal, and seasonal/hydrologic subsets from 1940 through 2015. Differences in the flow data and time scales analyzed likely caused varying results compared to Harwell and Vogl and Lopes (2009); however, we still discovered some parallels in the general directions in total flow between these studies during similar time scales (annual, seasonal) across the Brazos Basin.

In the upper basin (upstream of BRSE11), decreasing trends in incremental runoff and in flow-to-precipitation ratios identified in this study are similar to those found by Harwell at SFAS06 and DMAS09. Some differences in the results may be attributed to trends Harwell identified in specific months of the year that were not apparent in the seasonal analysis performed in this study.

Decreasing trends identified in the Clear Fork subbasin resulted in a total decrease in flow at CFFG18 of 14% by 2070. This aligned with decreasing trends in Q/P identified by Harwell for annual, spring, summer, May through June, and September through October for the total drainage area of CFFG18. Downstream on the main stem of the river at BRSB23, this study found decreasing incremental flow at multiple timescales and seasons, which agrees with the results of the Harwell study, which detected decreasing trends in flow during annual, spring, summer, and May (Harwell Table 8).

Vogl and Lopes (2009) analyzed changes in historical streamflow in the Brazos River Basin. At BRPP27, they found mean annual streamflow decreased, and we also detected a decrease in total naturalized streamflow at this gage.

At BRDE29, we found decreasing trends in incremental flow and Q/P for winter and average winter. Harwell also detected decreasing trends in streamflow during winter months, and a decreasing Q/P trend in winter, September, October, and December.

Harwell also found decreasing trends in total flow and Q/P at BRGR30 for annual, winter, spring, summer, and May through December timescales. We also projected a decrease in total flow at BRGR30 and identified decreasing trends in incremental flow and Q/P during the summer season, which encompasses July through October, but no trends in incremental flow or Q/P on annual, winter, or spring time scales.

Harwell found an increasing streamflow trend in March for LEGT47, and while this study found no significant increasing trends for incremental flow at LEGT47, we project that total flows at LEGT47 would increase by 7 percent by 2070 due to upstream changes. Harwell's study did not detect trends in Q/P, but this study found decreasing trends in both incremental flow and Q/P in average winters (Table 2-C-49). We did not detect any trends in flow or Q/P at LAKE50 (Table 2-C-52), similar to Harwell's study. This control point has no trends in precipitation. LRLR53 has strong increasing trends for incremental flows and Q/P in dry winter for this study (Table 2-C-55). Harwell found no trends in Q/P, and the only streamflow volume trend was an upward trend in August. LRCA58 has no trends for incremental flow, precipitation or Q/P in this study (Table 2-C-60). Harwell found an increasing streamflow trend in August for LRCA58.

For BRWA41, we found no trends in incremental flow, precipitation, or Q/P (Table 2-C-43). In contrast, Harwell et al. found a decreasing trend in historical streamflow for summer. They also found decreasing trends for Q/P at annual, spring, and summer timescales. Vogl and Lopes (2009) found a decrease in historical streamflow at BRWA41, while we found a 3 percent increase in total naturalized flows at that control point.

BRHB42 also had no trends in incremental flow or precipitation in this study (Table 2-C-44). Harwell found a decreasing trend in streamflow volume for August. While no trends in Q/P were found in Harwell, this study detected an increasing trend in Q/P for dry winters in the incremental drainage area.

In this study, NAEA66 has strong increasing trends in dry summer for incremental flow and Q/P only (Table 2-C-68). Harwell found an increasing trend for streamflow volume in August and increasing Q/P trends in August and September.

Control points BRHE68 through BRRO72 have trends in precipitation during certain hydrologic conditions – a decreasing trend in wet summers (MCBL69 and BRRI70), increasing trends in wet springs (BGNE71 and BRRO72), and an increasing trend in dry summer (BRHE68) (Tables C-70 to C-74). At BRHE68, Harwell found decreasing streamflow and Q/P trends in May, whereas this study detected no trends in flow or Q/P (Table 2-C-70). In the incremental drainage area of BRRI70, the precipitation is decreasing and Q/P is increasing, but there are no trends in incremental flow (Table 2-C-72). Harwell also assessed BRRO72 and found no trend in streamflow volume or Q/P. In this study, the projected change in total flow at BRRO72 is minor, only +2 percent. Vogl and Lopes (2009) found similar patterns of increasing streamflow at BRHE68 and BRRI70, which we also found, although the increases we found were minor.

4.1.3 Precipitation

Precipitation trends identified in this study did not align closely to those found by Harwell et al. (2020). In climate divisions 4101 and 4102, this study identified significant increasing precipitation trends in seasons categorized by hydrologic conditions, where Harwell found no trends in seasons or moisture conditions (drought, normal, moist). Meanwhile, Harwell identified an increasing precipitation trend in the month of March in climate division 4103, increasing trends in annual and June and September precipitation in division 4104, and decreasing precipitation in April in division 4106. This study did not identify any significant precipitation trends in these areas. The current study found different precipitation trends (decreasing in wet summers) in climate division 4107 than Harwell's findings (increasing in January and June). In climate division 4108 (Upper Coast), both studies identified increasing precipitation trends, although at separate timescales.

Overall, differences in precipitation trends compared to Harwell et al. (2020) may be due to the variability of precipitation and the impact of the period of analysis: Harwell et al. (2020) analyzed precipitation for a longer period of record (1900 through 2017), while this study assessed precipitation data from 1940 to 2019. Additionally, this study did not assess trends in individual months, while many of the precipitation trends identified by Harwell were for individual months. Harwell et al. (2020) also used Palmer Drought Severity Index (PDSI) data from 1900 to 2017 to define moisture conditions, whereas we used Palmer Hydrologic Drought Index (PHDI) data from 1940 to 2019 to define hydrologic conditions.

Vogl and Lopes (2009) evaluated changes in precipitation from 1935 to 2005. Similar to this study, they found increasing precipitation in the upper basin which they attributed to the prolonged dry period during the 1950s drought, and they did not find any significant annual precipitation changes in the lower basin.

We also did not find any significant annual precipitation trends in the lower basin, but we did find trends when considering seasons categorized by hydrologic condition.

4.1.4 Groundwater

Results

This study assessed groundwater elevation trends within the Brazos Basin in the Blaine, Seymour, Cross Timbers, Paluxy Sand (Trinity), Twin Mountains (Trinity), Brazos River Alluvium, Queen City, Sparta, and Yegua-Jackson Aquifers. We found significant increasing trends in groundwater elevation in five of these aquifers over the 30-year period of analysis (1991 through 2020). We did not identify significant decreasing trends.

Comparison to Literature

Harwell et al. (2020) similarly analyzed annual average groundwater-level elevation in seven major Texas aquifers for trends. This study analyzed trends for two of these seven aquifers, the Seymour Aquifer and the Trinity Aquifer. Both studies used data from TWDB's Groundwater Database and removed years with an insufficient number of groundwater-level measurements to improve the quality of the data. Both studies used Kendall's tau and p value to determine statistical significance and strength of trends in the data. However, Harwell et al. (2020) analyzed the entirety of the Seymour and Trinity Aquifers, whereas this study focused specifically on the area of overlap between the aquifers and the Brazos Basin. This study also constrained the start year of the trend analysis to 1991, whereas Harwell et al. (2020) analyzed trends from the beginning period of the datasets (which varies, but in some instances goes back to 1920).

Both studies found significant positive trends in groundwater levels in the Seymour and Trinity aquifers. This study observed a positive trend in the two pods that were evaluated; Harwell et al. (2020) assessed Seymour Aquifer as a whole and also found an increasing trend. Harwell et al. (2020) observed a downward trend within the Seymour Aquifer for Haskell, Knox, and Baylor Counties, which overlap Pod 7 of the aquifer. However, this study identified an upward trend in Pod 7, although we did not assess trends at the county level.

The Harwell et al. (2020) study also observed an increasing trend in the Trinity Aquifer. This study assessed the Trinity Aquifer in two separate formation groups: the Paluxy Sand and the Twin Mountains Aquifer. There is a positive trend in the Twin Mountains, and there is no trend in the Paluxy Sand. Harwell et al. (2020) mentions that while an overall positive trend was observed in the Trinity Aquifer, a downward trend was observed in Denton, Tarrant, and Johnson Counties. The study area for this analysis did not include Denton and Tarrant counties but did include Johnson County and still observed an overall positive trend, although that trend was at the aquifer-basin scale and was not assessed by county.

4.2 KEY FINDINGS RELATED TO SURFACE WATER SUPPLY AVAILABILITY

Table 4-1 and Table 4-2 summarize the changes to naturalized flow and net reservoir evaporation as a result of adjusting these inputs to reflect extrapolation of trends observed in the historical data.

Table 4-2 – Summary of Climate Trends and Adjustments to Net Reservoir Evaporation

Climate Division	Precipitation		Temperature		Average Annual Change in Net Reservoir Evaporation for 2050 Conditions (ft/yr)	Average Annual Change in Net Reservoir Evaporation for 2070 Conditions (ft/yr)
	Trend Direction [a]	Start Year	Trend Direction [a]	Start Year		
4101[b]	Wet winter (+) Average summer (+)	1940 1940	Annual (+)	1968 1968	0.78	1.01
4102	Dry summer (+)	1940	Annual (+)	1968	0.92	1.19
4103	none	1940	Annual (+)	1968	0.66	0.86
4104	none	1940	Annual (+)	1966	0.49	0.63
4106[c]	none	1940	Annual (+)	1968	none	none
4107	Wet summer (-)	1940	Annual (+)	1968	0.59	0.76
4108	Wet spring (+)	1940	Annual (+)	1966	0.21	0.28

Brazos G

The firm yield of reservoir supplies in the Upper Brazos Basin will decrease if observed trends in streamflow and temperature (and subsequently evaporation) continue in the future. The combined firm yield of reservoirs in the upper basin decreases by 31 percent in 2070 when trends are considered. Although average annual run-of-river diversions in the upper basin decrease substantially when adjusted for trends, the firm availability (minimum annual diversion) of these rights is zero even with no trends applied.

The combined firm yield of reservoirs in the middle basin decreases by less than 1 percent in 2070 when trends are considered, and firm availability of run-of-river rights on the main stem of the Brazos River would increase with trend adjustments. However, several run-of-river rights on tributaries of the Brazos River have decreased minimum annual diversions with trend adjustments.

If current trends continue, the amount of water available to the BRA may decrease slightly. Although the modeling scenario with trend adjustments shows an increase of 19 percent in reliable incremental yield of the BRA System Operations Permit by 2070, this increase is offset by a larger decrease in individual reservoir yields, resulting in a 4 percent net decrease in reliable yield from the system by 2070.

Region H

The increases in flow projected for most of the lower basin resulted in increased minimum annual diversions from large run-of-river rights in Region H. There are no existing reservoir supplies in the Brazos Basin within Region H. However, many water users in Region H rely on contracts with BRA for supply from the BRA System Operations Permit.

4.3 ASSUMPTIONS, LIMITATIONS, AND OTHER CONSIDERATIONS

As was discussed in ***Section 1.4*** of **Chapter 1**, results of this study should be interpreted with an understanding of the underlying assumptions in the methodology that was used and the limitations of this approach. Major limitations and assumptions are discussed here, and the reader is encouraged to review ***Section 1.4***.

1. Attribution of underlying causes of trends was outside the scope of this study. Trends were identified empirically and extrapolated. Some trends may diminish or stabilize over time as the root cause of the impact to streamflow slows or stops. This approach also does not address future changes that may accelerate over time, such as climate change.

2. Adjustments to the methodology may be warranted for river basins with very different hydrological conditions.

3. Trend slopes, and thus the extrapolated future average conditions, are sensitive to the period of analysis. Additionally, although outliers were addressed, the timing of major events within the period of analysis impacts the slope of the trend line.

4. This study adjusts historical hydrology based on climate and flow trends that have been observed to-date rather than using physically based global circulation models. This is an important limitation because future conditions may not follow the pattern of observed trends.

5. Empirical relationships between gross evaporation and air temperature were developed to determine an adjustment factor for gross evaporation based on trends in average air

temperature. This assumes that air temperature directly correlates to gross evaporation and is the only meteorological variable that drives gross evaporation. However, in addition to air temperature, other meteorologic variables, such as wind speed, atmospheric humidity, and solar radiation, can impact evaporative demand (McVicar et al., 2012). Other meteorologic variables, such as shortwave radiation and vapor pressure deficit have been shown to have a stronger correlation to reservoir evaporation rate (Zhao and Gao, 2019). Vapor pressure deficit has been shown to be closely related to temperature and the former has been shown to increase with increasing temperature (Dai et al., 2018).

6. We developed linear trend equations for each identified trend and used these trend line equations to extrapolate future conditions and adjust flow or evaporation. The fit of the trend lines, measured by R-squared, was often poor. However, a low R-squared value is acceptable in this case since the trend lines were only used to predict a future average condition and not to predict variability. We used deviations in the original data (i.e., detrended observations) to maintain variability in the adjusted future time series.

7. This study used a single-scenario modeling approach to determine reliability of surface water supplies. This approach focuses on changes in average conditions, but the pattern of month-to-month variability remained largely the same.

8. This study does not account for the fact that a given hydrologic condition may occur more or less frequently in the future.

9. Adjusting FLO and EVA independently of each other is a simplifying assumption. In reality, trends in temperature, evaporation and precipitation will interact with and influence trends in antecedent moisture conditions and streamflow.

10. Fully naturalized flows in the Brazos Basin were only available through 1997, and the study used "semi-naturalized" flows for the 1998-2015 period.

11. The study made no adjustments to reservoir sedimentation rates based on trends.

12. The study's adjustments to flow and evaporation are similar for all years (or all springs, all summers, or all winters) except when the selected trend for adjustment is based on seasons of a specific hydrologic condition. Trends that continue into the future will likely not impact all years equally.

4.4 ASSESSMENT OF ENVIRONMENTAL FLOW ATTAINMENT FREQUENCIES

In **Chapter 3**, TWDB evaluated changes in environmental flow metrics if current trends were to continue until 2050 for 14 control points on tributaries to the Brazos River and along the main stem. The baseline condition is the 1940-2015 hydrology from the BRA Drought Study, and the naturalized flows and net evaporation rates representing 2050 conditions were developed as discussed in **Chapters 1** and **2** and are included in **Appendix 2-F**. **Chapter 3** uses the daily version of the Brazos WAM updated for 2050 conditions to evaluate the frequency of attainment of environmental flow standards in the Brazos River Basin. The metrics include the frequency with which an applicable environmental standard (subsistence, base, and pulse) is engaged, the amount by which a standard is not met, and metrics characterizing the number of days with zero flow. The metrics are calculated by season (spring, summer, winter) and hydrologic condition (dry, average, and wet). For details, refer to **Appendix 3-A** through **3-J**.

Based on the TWDB simulations, the regulated flows at BRSB23 would decrease if current trends continue, and low flows would increase at other locations in the basin. Changes in regulated flow in the Little River watershed would be minimal or non-existent. The frequency with which subsistence and baseflow targets are met at upstream points (BRSB23-BRGR30) would decrease if current trends continue, while attainment at points downstream of and including BRWA41 would increase or remain the same. The number of engaged pulses was simulated to decrease at BRSB23 but increased at downstream points, with some decreases and increases in the Little River watershed.

4.5 IMPLICATIONS FOR FUTURE SUPPLY SHORTAGES IN REGIONS G AND H

Based on the assumptions in this study, if the observed trends in streamflow, temperature, and precipitation since 1940 continue forward through 2070, the following conclusions warrant consideration by the Brazos G and Region H Water Planning Groups.

Decreases in Supply

Surface water supply reliability in the Upper Brazos Basin and run-of-river supply reliability in the Middle Brazos Basin may decrease substantially. This could warrant consideration of additional water management strategies in the Brazos G Water Planning Area to provide resiliency.

One option for determining the reliable supply from reservoirs subject to decreasing streamflow trends is to use safe yield instead of firm yield. Firm yield is the maximum annual diversion that can be met from a reservoir with no shortages (simulated storage for a reservoir diverting its firm yield is zero or near zero at the lowest point in the simulation). In the case of safe yield, instead of changing the annual diversion amount until the reservoir goes empty, some reserve water supply is left in storage. A reservoir diverting a one-year safe yield, for example, will have an annual diversion amount equal to the amount left in storage at the lowest point in the simulation (i.e., one year's supply of water is left in storage). The Brazos G Water Planning Group currently uses safe yield for planning for many reservoirs in the Upper Brazos Basin and Lake Palo Pinto in the Middle Brazos Basin.

Off-channel storage and aquifer storage and recovery are potential ways to increase the reliability of run-of-river rights subject to decreasing streamflow trends in the Upper and Middle Brazos Basin.

Increases in Supply

This study indicates that minimum annual diversions from large run-of-river rights in Region H may increase if current trends continue. The authors of this study do not recommend that regional water planning groups rely on these results, particularly those indicating increases in supply, to increase supply availability reflected in the regional water plans. However, potential increases in supply could be considered as possible sources to support resiliency and redundancy. In Region H, some water shortages for irrigation water demands are not met by any strategies in the regional water plan, as many irrigators rely on interruptible contracts from BRA and other water providers. The increases in firm supply available from run-of-river rights in Region H could be used to meet some of these shortages, potentially lessening the impacts of drought on agricultural irrigators.

4.6 REFERENCES

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APPENDIX 4-A: RESPONSES TO TWDB COMMENTS ON DRAFT FINAL REPORT

The Texas Water Development Board (TWDB) provided comments to Freese and Nichols (FNI) on the Draft Final Report for the Brazos Trends Study on August 30, 2021. This appendix includes those comments followed by the FNI response in italics. This appendix is organized around the following sections:

- Comments on the Title Page and Executive Summary
- Comments on Chapter 2
- Comments on Chapter 4

Note that TWDB also provided comments on a draft of Chapter 1 on March 9, 2021, which are included with the FNI responses in **Appendix 1-A** and **Appendix 1-B**. TWDB authored Chapter 3 and FNI provided comments to TWDB on a draft of Chapter 3 on August 13, 2021.

Comments on the Title Page and Executive Summary and Responses (shown in *italics*)

1. Please add the following statement to the cover page of the final report: "Pursuant to House Bill 1, as approved by the 86th Texas Legislature, this study report was funded for the purpose of studying environmental flow needs for Texas rivers and estuaries as part of the adaptive management phase of the Senate Bill 3 process for environmental flows established by the 80th Texas Legislature. The views and conclusions expressed herein are those of the author(s) and do not necessarily reflect the views of the Texas Water Development Board."

   Response: *This statement has been added to the cover page.*

2. ES-1: Add in a bullet to cover the fact that while the study found an increasing trend in groundwater elevation, these trends did not correlate with the observed increasing trends in streamflow in the middle and lower basin.

   Response: *We observed increasing trends in aquifers in the upper and lower basins, which was the opposite direction of the decreasing trends in streamflow, but we did not assess correlation between the increasing trends in middle and lower basin streamflow and levels in the Sparta and Yegua-Jackson Aquifers. The following bullet point was added to the Executive Summary:*

"Increasing trends in groundwater elevation were found in portions of the Seymour, Trinity, Sparta, and Yegua-Jackson Aquifers. Decreases in runoff in the Upper Basin do not appear to be the result of falling groundwater levels."

3. ES-2: First paragraph: Mention by how much firm yields of upper basin reservoirs are expected to decrease.

   Response: *Second sentence was revised to read, "If observed trends continue, the firm yields of upper basin reservoirs are expected to decrease by a total of 31 percent in estimated 2070 conditions."*

4. Please add in a paragraph to the Executive Summary that summarizes the implications & conclusions of the study as reported in Chapter 4.

   Response: *The following paragraph was added to the Executive Summary: "If the observed trends in streamflow, temperature, and precipitation since 1940 continue forward through 2070, surface water supply reliability in the Upper Brazos Basin and run-of-river supply reliability in the Middle Brazos Basin may decrease which could warrant consideration of additional water management strategies in the Brazos G Water Planning Area to provide resiliency. Safe yield, which is a more conservative estimate of the reliable supply from a reservoir than firm yield, is currently used by the Brazos G Water Planning Group for planning for many reservoirs in the Upper Brazos Basin and Lake Palo Pinto in the Middle Brazos Basin. Off-channel storage and aquifer storage and recovery are potential ways to increase the reliability of run-of-river rights subject to decreasing streamflow trends in the Upper and Middle Brazos Basin. Potential increases in the reliability of large run-of-river rights in Region H could be considered as possible sources to support resiliency and redundancy.*

Comments on Chapter 2 and Responses (shown in *italics*)

General Comments

1. Throughout the report, please use an n-dash instead of a hyphen when denoting a study period (i.e., 1991–2000 instead of 1991-2000).

   Response: *An n-dash or the word "through" was used rather than a hyphen when denoting year ranges throughout the report.*

2. Page 2-17, Figure 2-8 and all figures that depict drainage areas, please consider including a legend in the map that defines the size of the points used in the figure.

   Response: *A legend was added to all figures depicting the drainage areas (Figure 2-3, Figure 2-5, Figure 2-7, Figure 2-9, Figure 2-11, Figure 2-13, Figure 2-17, Figure 2-19, Figure 2-21) to define the meaning of the colors and sizes of the points.*

3. Please use a consistent tense throughout the report. There are a few places where both the past and present tense have been used.

   Response: *Statements in the draft report that were in future or present tense have been revised to past tense for consistency.*

4. Add figure captions at the bottom of each figure, and align all figure captions to the left, throughout the report.

   Response: *All figure captions were moved to the bottom of each figure and aligned to the left throughout the report.*

5. Align all table captions to the left throughout the report.

   Response: *All table captions have been aligned to the left throughout the report.*

Specific Comments

1. Page 2-9, last section. Please merge the last three sentences into a single paragraph. Suggested rewording: Change “This study did find a decreasing trend…..” to “We found a decreasing trend…”. Change “….for this study match the findings in Harwell et al. (2020)” to “….for this study that corroborate the findings from Harwell et al. (2020)…”.

   Response: *The following changes were made to Page 2-9 (revised, now Page 2-11):*

   - *The last three sentences were merged into a single paragraph.*
   - *The text “This study did find a decreasing trend…” was revised to “We found a decreasing trend”.*
   - *The statement “…for this study match the findings in Harwell et al. (2020)” was revised to “for this study that corroborate the findings from Harwell et al. (2020) …”.*

2. Page 2-10, first paragraph: Please move the text "(The adjustment factor would be zero by 2070.)" to a different location in the text or associate it with a figure caption.

   Response: *The text "The adjustment factor would be zero by 2070" was expanded and moved to Page 2-2, first paragraph as it applies to all control points. The text now reads:*

   "For all control points, the magnitude of adjustments to naturalized flows was greatest in the beginning of the time series and declined to zero by the selected future year (e.g., 2050 or 2070). In other words, the beginning of the time series is furthest from the 2050 or 2070 conditions and therefore requires the largest adjustments to shift it to the future conditions, whereas subsequent years need progressively less adjustments to shift to the future conditions. As described in Section 1.3.2, the purpose of this approach is to produce an adjusted time series of 76 years of hydrology representing conditions in the selected future year (e.g., 2050 or 2070)."

3. Page 2-36, last paragraph, last sentence: Please clarify what is meant by "opposite directions".

   Response: *The following updates were incorporated into Page 2-36, last paragraph, last sentence to clarify the meaning of "opposite directions":*

   "Precipitation trends in climate divisions 4107 and 4108, located along the Gulf Coast, both take place during wet conditions but occur during different seasons and have opposing trend directions, e.g., the precipitation trend is decreasing during wet summers in climate division 4107; whereas the precipitation trend is increasing during wet springs in climate division 4108."

4. Page 2-49, Section 2.3, Trends in Groundwater Levels, last paragraph: Please consider adding a few more details on how the filtering was done to create uniformity.

   Response: *The following details on how the filtering was done were added to the paragraph: "This involved removing groundwater elevation measurements reported as null or N/A by TWDB, and removing measurements from wells screened in multiple aquifers to only include wells in counties that intersect the Brazos Basin. The data was also filtered to include measurements recorded closest to January 1, in order to select measurements taken around a similar time of year, as the bulk of observations were recorded during winter months. Some wells had multiple groundwater elevation measurements reported for one year, of which the measurement closest to January 1 was selected. This provided one observation per well per year that was included in the analysis."*

5. Page 2-52, Section 2.3.3, Seymour Aquifer: Please include a clarification that the "trend" in groundwater elevation refers to the water surface elevation and not depth of the water level from the surface.

   Response: *On Page 2-52, Section 2.3.3, Seymour Aquifer, "groundwater elevation" was revised to "groundwater elevation (feet above sea level)" to clarify that the annual trend refers to the water surface elevation above sea level, rather than the water level depth below the surface.*

6. Page 2-63, Section 2.4.2, Methodology to assess surface water supply availability in the 2021 regional water plans: Please consider clarifying whether it is historical monthly return flow data that is used. Please consider clarifying how the project rates of return flow are derived.

   Response: *The word "monthly" was inserted into the phrase "…historical monthly return flow information…"*

   The following sentence was added to the second bullet point in Section 2.4.2: "More information on how the projected return flows are derived is provided in Section 2.4.3 below and in the Brazos G Regional Water Plan." Note that Section 2.4.3 includes the following statement "Return flows included in the Brazos G WAM were linearly interpolated from 2020 and 2070 levels included in the existing 2020 and 2070 Brazos G WAMs to estimate 2050 return flow levels."

7. Page 2-66, first bullet: Please define "minimum annual diversion" here.

   Response: *On Page 2-66 (revised, now Page 2-68), first bullet, the minimum annual diversion was defined as: "…the smallest volume of water diverted by a run-of-river water right during a single calendar year throughout the WAM period of record."*

8. Page 2-66, third bullet: Please clarify the type (e.g., municipal?) of hypothetical junior water right was added.

   Response: *The sentence was changed to read: "If a reservoir or reservoir system has a firm yield greater than its authorized diversion, a hypothetical junior water right <u>with a uniform use pattern</u> was added to calculate the additional firm yield in excess of the authorized diversion amount" (the underlined part was added).*

9. Page 2-66, Section 2.4.4, Changes to Reservoir Yield Based on Observed Trends. Please clarify whether the 10% reduction in yield in BRA reservoirs is for 2050, 2070, or both 2050 and 2070.

   Response: *On Page 2-66 (revised, now Page 2-68), Section 2.2.4 Changes to Reservoir Yield Based on Observed Trends, first bullet, the text was revised to clarify that 10% reductions in BRA Reservoirs (Possum Kingdom Reservoir, Lake Proctor, and Lake Limestone) occurred in both 2050 and 2070.*

10. Page 2-70, Section 2.5, References: Please add in the Harwell et al. (2020) citation.

    Response: *A citation to Harwell et al. (2020) was added to Page 2-70, Section 2.5, References.*

11. Page 2-A-2, Appendix 2-A, Determination of Start Year: Please change “1948 to 2015” to “1948 through 2015”.

    Response: *The sentence “1948 to 2015” was revised to “1948 through 2015” on Page 2-A-2, Appendix 2-A, Determination of Start Year.*

Suggested Changes

1. Pages 2-61 and 2-62, Section 2.3.10, Summary of Groundwater Trends: Is it possible to plot the Kendall’s Tau values on a map similar to how the change in evaporation is depicted spatially?

   Response: *We added the map in Figure 2-34 that shows changes in incremental flows overlaid on major and minor aquifers that intersect the Brazos River Basin. Although we did not plot the Kendall’s Tau values, we added the Kendall’s Tau values for aquifers that had significant trends to the legend of the map.*

2. Page 2-66, Section 2.4.4: Please consider adding two maps (one for 2050 and one for 2070) that depict reservoir yield changes.

   Response: *Four maps were added to Appendix 2-E in response to this comment: 1) change in reservoir yield in acre-feet per year for 2050 conditions, 2) change in reservoir yield in percent for 2050 conditions, 3) change in reservoir yield in acre-feet per year for 2070 conditions, and 4) change in reservoir yield in percent for 2070 conditions.*

Comments on Chapter 4 and Responses (shown in *italics*)

1. Throughout the report, please use an n-dash instead of a hyphen when denoting a study period (i.e., 1991–2000 instead of 1991-2000).

   Response: *An n-dash or the word "through" was used rather than a hyphen when denoting year ranges in Chapter 4 (and throughout the rest of the report).*

2. Page 4-1, Section 4.1.1, Temperature, Comparison to Literature. Please specify whether the trends identified in Harwell et al. (2020) were trends at the annual scale. Caveat the statement that refers to Harwell et al. (2020) with a note that the trends identified by Harwell et al. are of a lower magnitude than identified in the current study. Mention too that this could be due to the difference in time period and the use of periodic functions to assess trends in the Harwell et al. study.

   Response: *On Page 4-1, Section 4.1.1, Temperature, Comparison to Literature, it was clarified that the trends identified in Harwell et al. (2020) were trends on the annual time scale. Furthermore, the following caveats were added into this section when comparing to the trends identified by Harwell et al. (2020):*

   "The mean annual air temperature trends identified by Harwell et al. (2020) are of a lower magnitude of those identified in the current study. This could be due to the differences in the time periods analyzed (late 1960s to 2019 for this study, compared to 1900 through 2017 in Harwell) and the use of periodic functions to assess trends in the Harwell et al. study. The higher magnitude temperature trends used to project forward in this study result in a more conservative estimate of evaporation loss (i.e., higher evaporation) in terms of water supply, compared to lower magnitude trends found in Harwell."

3. Page 4-4, third paragraph, were the trends found by Harwell et al. (2020) for the same seasons as in the current study? If not, please mention this as a clarification and a potential reason for the findings of the two studies diverging.

   Response: *On Page 4-4, third paragraph (revised, now Page 4-5, second paragraph), it was clarified that this study found "no trends in incremental flow or Q/P on annual, winter, or spring time scales". The following paragraph was added at the beginning of Page 4-4, Section 4.1.2, Flow, Comparison to Literature, to elaborate on why there may be differences in the results between this study and Harwell et al. (2020):*

"Harwell et al. (2020) analyzed trends in total historical streamflow on annual, seasonal, and monthly time scales at gages throughout the Brazos River Basin from 1900 through 2017. Vogl and Lopes (2009) quantified significant changes in historical monthly and annual streamflow in the Brazos over the past 60 to 100 years. In comparison, for this study, we analyzed trends in incremental naturalized flow (the naturalized runoff in an incremental watershed between two gages) for annual, seasonal, and seasonal/hydrologic subsets from 1940 to 2015. Differences in the flow data and time scales analyzed likely caused varying results compared to Harwell and Vogl and Lopes (2009); however, we still discovered some parallels in the general directions in total flow between these studies during similar time scales (annual, seasonal) across the Brazos Basin."

4. Page 4-4, one-before-the-last paragraph: Please consider surmising why there might be differences between the current study and the study by Vogl and Lopes (2009). For example, could it be a difference in study period or the fact that the current study assesses trend on naturalized flow while the Harwell et al. (2020) and Vogl and Lopes (2009) studies used historical streamflow?

   Response: *The following paragraph was incorporated at the beginning of Page 4-4, Section 4.1.2, Flow, Comparison to Literature, to surmise why there might be differences in the results between this study and Vogl and Lopes (2009) and Harwell et al. (2020):*

   "Harwell et al. (2020) analyzed trends in total historical streamflow on annual, seasonal, and monthly time scales at gages throughout the Brazos River Basin from 1900 through 2017. Vogl and Lopes (2009) quantified significant changes in historical monthly and annual streamflow in the Brazos over the past 60 to 100 years. In comparison, for this study, we analyzed trends in incremental naturalized flow (the naturalized runoff in an incremental watershed between two gages) for annual, seasonal, and seasonal/hydrologic subsets from 1940 to 2015. Differences in the flow data and time scales analyzed likely caused varying results compared to Harwell and Vogl and Lopes (2009); however, we still discovered some parallels in the general directions in total flow between these studies during similar time scales (annual, seasonal) across the Brazos Basin."

5. Page 4-5, section 4.1.3, Precipitation: Please mention whether the fact that Harwell et al. (2020) used the full period of record could be a reason for the difference in the trends identified in the current study.

Response: *Paragraph 2 on 4-5 (revised, now Page 4-6), Section 4.1.3, Precipitation was revised to mention that Harwell et al. (2020) used a different period of record than this study, which could be a reason for the difference in the trends identified in this study:*

"Overall, differences in precipitation trends compared to Harwell et al. (2020) may be due to the variability of precipitation and the impact of the period of analysis: Harwell et al. (2020) analyzed precipitation for a longer period of record from (1900 through 2017), while this study assessed precipitation data from 1940 to 2019. Additionally, this study did not assess trends in individual months, while many of the precipitation trends identified by Harwell were for individual months. Harwell et al. (2020) also used Palmer Drought Severity Index (PDSI) data from 1900 to 2017 to define moisture conditions, whereas we used Palmer Hydrologic Drought Index (PHDI) data from 1940 to 2019 to define hydrologic conditions."

6. Page 4-8, Brazos G, last paragraph: Please include the expected net percent decrease in reliable yield from the system.

   Response: *On Page 4-8, Brazos G, last paragraph (revised, now Page 4-9, first paragraph) the expected net percent decrease in reliable yield from the system (4 percent) was incorporated into the text.*

7. Page 4-9, Section 4.3, Assumptions, Limitations and Other Considerations, point 5: Please add a clarification that vapor pressure deficit is closely related to temperature and the former has been shown to increase with increasing temperature (Dai et al., 2018). Add in the following citation to the References section: Dai, A., Zhao, T. and Chen, J., 2018. Climate change and drought: a precipitation and evaporation perspective. *Current Climate Change Reports*, *4*(3), pp.301-312.

   Response: *On Page 4-9, Section 4.3, Assumptions, Limitations, and Other Considerations, point 5, the following statement was incorporated into the text: "Vapor pressure deficit has been shown to be closely related to temperature and the former has been shown to increase with increasing temperature (Dai et al., 2018)." A citation to Dai et al. (2018) was also added to Section 4.6, References.*

8. Page 4-10, first paragraph: Please add "updated for 2050 conditions" after "Brazos WAM". Please add "engaged," after "environmental standard (subsistence, base, and pulse) is". Add "For details refer Appendix 3-A through 3-J" to the end of the paragraph.

Response: *On Page 4-10, first paragraph, the following additions were made in the text:*

- *Added "updated for 2050 conditions" after "Brazos WAM".*
- *Added "engaged" after "environmental standard (subsistence, base, and pulse) is".*
- *Added "For details refer Appendix 3-A through 3-J" to the end of the paragraph.*