Interagency Flood Risk Management (InFRM)

Watershed Hydrology Assessment for the Nueces River Basin

Appendix A:
Statistical Hydrology

March 2025

InFRM
INTERAGENCY FLOOD RISK MANAGEMENT

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1 Statistical Hydrology

Statistical analysis of the observational record from U.S. Geological Survey (USGS) streamgages and other historical information provides an informative means of estimating flood flow frequency. The USGS contributed to the InFRM team's efforts by performing the statistical analysis of the gaged period of record and authored this Appendix to the Nueces River Basin Watershed Hydrology Assessment. Flood flow frequency is defined by values or quantiles of streamflow for selected annual exceedance probabilities (AEPs) (England and others, 2019). Annual peak-streamflow data collected as part of systematic operation of a streamgage provides the foundation for a detailed analysis of peak streamflow, but additional historical information pertaining to peak streamflow are also used in the analysis when available. An annual peak streamflow is defined as the maximum instantaneous streamflow for a streamgage for a given water year, and annual peak streamflow data for USGS streamgages can be acquired through the USGS National Water Information System (NWIS) database (USGS, 2021). The statistical analyses are based on water-year increments, which is the 12-month period from October 1 of a given year through September 30 of the following year designated by the calendar year in which it ends.

For the statistical hydrology portion of the multi-faceted analysis, InFRM team members from the USGS analyzed annual peak streamflow records for the 21 USGS streamgages in the Nueces River Basin listed in Table A.1. The locations of these USGS streamgages are also shown on Figure A.1. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

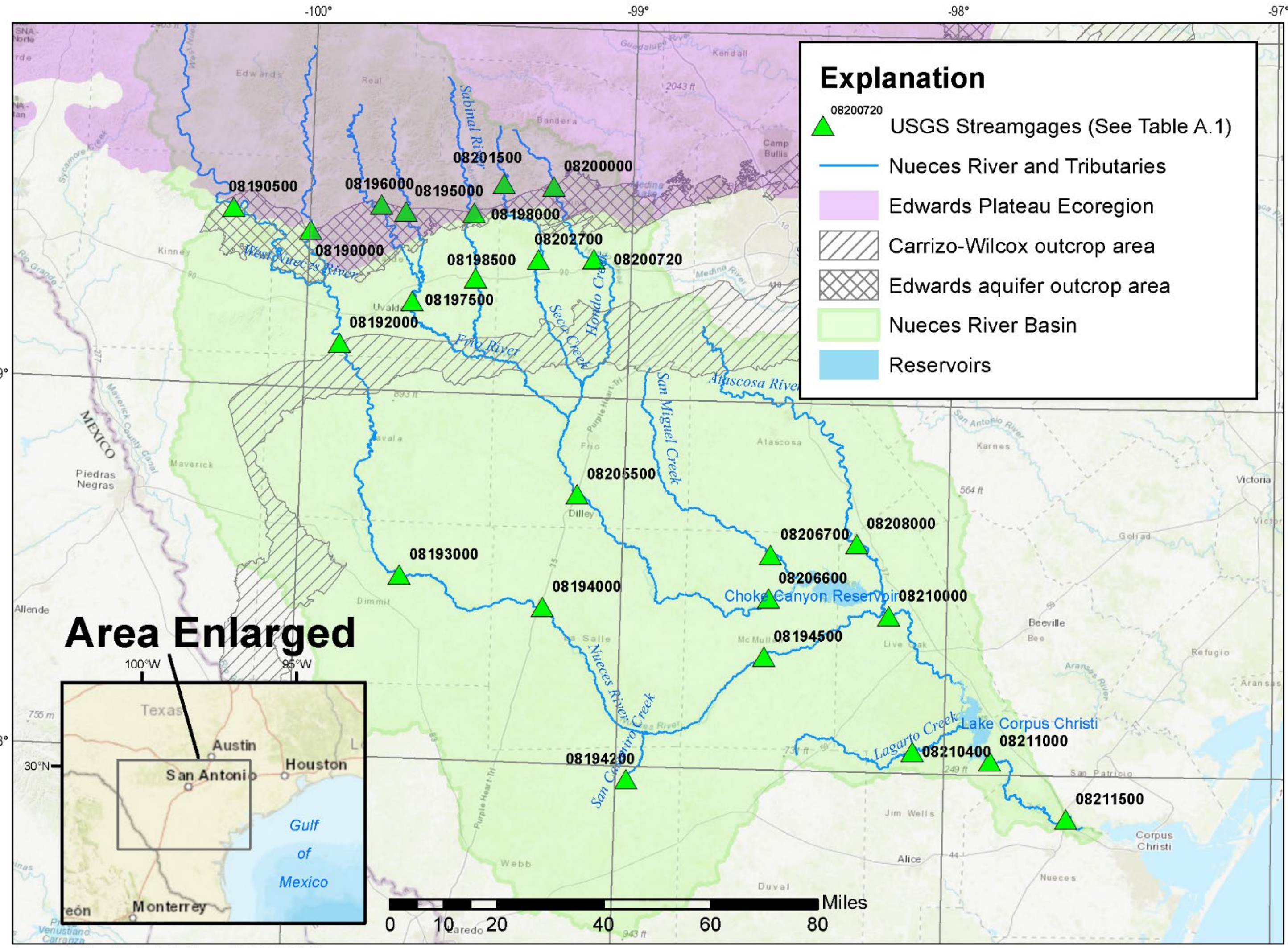


Figure A.1: Map of U.S. Geological Survey (USGS) Streamgages included in the Statistical Analysis

Table A.1: Summary of the Twenty-Five Analyses for U.S. Geological Survey Streamgaging Stations in the Nueces River Basin Study Area, Texas with Ancillary Information Concerning Statistical Analyses

[mi^2, square miles; ft/mi, feet per mile; *p*-value, probability value; <, less than; --, not applicable]

USGS Streamgage number	USGS Streamgage name	Latitude	Longitude	Period of available annual peak streamflow	Period of analyzed annual peak streamflow	Contri-buting drainage area (mi^2)	Station Skew (dimen sion-less)	Regional skew (Asquith and others, 2021) (dimensi on-less)	Stream slope (Asquith and Slade, 1997) (ft/mi)	Kendall's *tau* of analyzed annual peak streamflow (dimension -less)	Kendall's tau *p*-value of analyzed annual peak streamflow (dimension -less)	Kendall's *tau* Trend (*p*-value < 0.05, downward -, upward +) (dimension -less)	Change in Time Analysis (dimensi on-less)	Pettitt Test Change Point (*p*-value < 0.05) (water year)	Pettitt Test *p*-value of full peak streamflow record (dimension-less)
08190000	Nueces River at Laguna, Tex.	29.4283	-99.9969	1913–2020	1913–2020	737	-0.64	-0.46	17.21	-0.059	0.390	None	Yes	--	0.436
08192000	Nueces River below Uvalde, Tex.	29.1236	-99.8944	1928–2020	1928–2020	1,861	-0.74	-0.43	15.62	-0.102	0.149	None	Yes	--	0.185
08193000	Nueces River near Asherton, Tex.	28.5000	-99.6817	1940–2020	1940–2020	4,082	0.12	-0.33	10.70	-0.086	0.262	None	Yes	--	0.190
08194000	Nueces River at Cotulla, Tex.	28.4261	-99.2397	1924–2020	1924–2020	5,171	-0.22	-0.29	9.15	-0.163	0.019	-	Yes	1982	0.014
08194500	Nueces River near Tilden, Tex.	28.3086	-98.5569	1935–2020	1935–2020	8,093	-0.51	-0.22	7.44	-0.209	0.007	-	Yes	1983	0.001
08210000	Nueces River near Three Rivers, Tex.	28.4272	-98.1778	1916–2020	1983–2020	15,247	-0.53	-0.19	6.88	0.018	0.880	None	Yes	1984	<0.001
08211000	Nueces River near Mathis, Tex.	28.0381	-97.8600	1919–2020	1983–2020	16,503	0.22	-0.09	NA	-0.018	0.880	None	No	1982	<0.001
08211500	Nueces River at Calallen, Tex.	27.8828	-97.6250	1983–2020	1983–2020	16,684	0.48	-0.04	NA	0.042	0.733	None	Yes	--	0.653
08194200	San Casimiro Creek near Freer, Tex.	27.9647	-98.9667	1954–2020	1954–2020	469	0.17	-0.19	9.03	-0.175	0.053	None	No	1988	0.044
08190500	West Nueces River near Brackettville, Tex.	29.4811	-100.2392	1900–2020	1900–2020	694	-0.87	-0.45	15.15	-0.059	0.463	None	No	--	0.565
08196000	Dry Frio River near Reagan Wells, Tex.	29.5044	-99.7811	1932–2020	1932–2020	126	-0.90	-0.47	26.70	-0.095	0.250	None	No	--	0.363
08195000	Frio River at Concan, Tex.	29.4883	-99.7044	1923–2020	1923–2020	389	-0.50	-0.47	22.73	0.030	0.667	None	Yes	--	0.386
08197500	Frio River below Dry Frio River near Uvalde, Tex.	29.2456	-99.6742	1894–2020	1894–2020	631	-1.05	-0.45	20.94	0.044	0.644	None	Yes	--	0.197
08205500	Frio River near Derby, Tex.	28.7364	-99.1444	1916–2020	1916–2020	3,429	0.11	-0.35	13.22	-0.088	0.184	None	No	--	0.426

Table A.1: Summary of the Twenty Five Analyses for U.S. Geological Survey Streamgages and Reservoir Stations in the Nueces River Basin Study Area, Texas with Ancillary Information Concerning Statistical Analyses (continued)

USGS Streamgage number	USGS Streamgage name	Latitude	Longitude	Period of available annual peak streamflow	Period of analyzed annual peak streamflow	Contri-buting drainage area (mi²)	Station Skew (dimension-less)	Regional skew (Asquith and others, 2021) (dimension-less)	Stream slope (Asquith and Slade, 1997) (ft/mi)	Kendall's *tau* of analyzed annual peak streamflow (dimension-less)	Kendall's tau *p*-value of analyzed annual peak streamflow (dimension-less)	Kendall's *tau* Trend (*p*-value < 0.05, downward -, upward +) (dimension-less)	Change in Time Analysis (dimension-less)	Pettitt Test Change Point (*p*-value < 0.05) (water year)	Pettitt Test *p*-value of full peak streamflow record (dimension-less)
08206600	Frio River at Tilden, Tex.	28.4672	-98.5472	1979–2020	1979–2020	4,493	-0.57	-0.24	10.11	-0.192	0.076	None	Yes	--	0.087
08206600	Frio River at Tilden, Tex. (*alternative analysis*)	28.4672	-98.5472	1979–2020	1925–2020	4,493	-0.06	-0.24	10.11	-0.175	0.012	-	Yes	--	0.087
08206700	San Miguel Creek near Tilden, Tex.	28.5872	-98.5456	1925–2020	1925–2020	783	-0.49	-0.27	8.05	-0.270	0.003	-	No	1994	0.001
08198000	Sabinal River near Sabinal, Tex.	29.4908	-99.4925	1932–2020	1932–2020	206	-0.02	-0.48	28.28	-0.020	0.796	None	No	--	0.412
08198500	Sabinal River at Sabinal, Tex.	29.3143	-99.4805	1932–2020	1932–2020	241	-0.17	-0.46	23.00	-0.070	0.400	None	Yes	--	0.411
08201500	Seco Creek at Miller Ranch near Utopia, Tex.	29.5731	-99.4028	1958–2020	1958–2020	45	-0.77	-0.49	40.29	-0.087	0.163	None	No	--	0.130
08202700	Seco Creek at Rowe Ranch near D'Hanis, Tex.	29.3706	-99.2875	1961–2020	1961–2020	168	-1.00	-0.46	24.79	0.195	0.050	None	No	--	0.337
08200000	Hondo Creek near Tarpley, Tex.	29.5700	-99.2477	1932–2020	1932–2020	96	-0.78	-0.48	41.84	-0.155	0.063	None	No	--	0.076
08200720	Hondo Creek at S.H. 173 near Hondo, Tex.	29.3761	-99.1167	2007–2020	1961–2020	157	1.06	-0.46	--	-0.118	0.226	None	No	--	0.301
08208000	Atascosa River at Whitsett, Tex.	28.6219	-98.2811	1919–2020	1919–2020	1,171	-0.01	-0.24	6.33	-0.113	0.116	None	Yes	--	0.111
08210400	Lagarto Creek near George West, Tex.	28.0594	-98.0967	1971–2020	1971–2020	155	0.15	-0.12	12.15	-0.271	0.041	-	No	--	0.141

The remainder of this chapter is organized as follows: Section 1.1 provides a brief overview of the study area including but not limited to: underlying geology, channel morphology, and land use, Section 1.2 provides a brief review of statistical methods, Section 1.3 provides statistical flood flow frequency (FFQ) results for the streamgages based on the methods presented in Section 1.2, and Section 1.4 provides estimates of changes to FFQ results over time.

1.1 SITE DESCRIPTION

The Nueces River and many of its tributaries (which include the west Nueces River, Frio and Dry Frio Rivers, Sabinal River, Seco Creek, and Hondo Creek) originate in the southern part of the Edwards Plateau (Figure A.1). The region is described as a region of rocky hills and steep canyons with shallow soils underlain by limestone (TPWD, 2021). Streamgages in this portion of the basin have relatively steep channel slopes, ranging from approximately 15 to 48 ft/mi. (Table A.1; Asquith and Slade, 1997). The steep, rocky terrain of the southern Edwards Plateau, combined with intense 100-year 24-hour precipitation estimates of as much as 13 inches, result in extremely large storm streamflows exiting the Edwards Plateau (NOAA, 2018). It is not uncommon for floods on these streams to exceed 100,000 cubic feet per second (cfs) with several flood peaks measured in excess of 300,000 cfs (USGS, 2021).

Upon exiting the Edwards Plateau, the Nueces River and its tributaries transition into the South Texas Plains ecoregion, where stream channel and floodplains widen and transition into low sinuosity, meandering streams consisting of primarily gravel and coarse bed material (Gustavson, 1978). On its course towards its mouth at Corpus Christi, the Nueces River and its tributaries cross the Edwards and Carrizo-Wilcox aquifer outcrops (Figure A.1; Barnes, 1982).

This relatively abrupt transition from steep, hilly terrain with shallow soils to broad plains with meandering streams with more permeable gravel lobes and coarse bed material results in remarkable streamflow losses, and peak streamflow events may virtually disappear in this transition. In 1997 the peak of 201,000 cfs for the Nueces River below Uvalde, Tex. lost more than 90 percent of its streamflow on its way to Asherton, Tex., where the peak streamflow was only 12,900 cfs. A 1983 study by Massey and Reeves found that storm runoff losses ranged from 32 to 59 percent between Cotulla, Tex. and Tilden, Tex. Streamflow losses along the stretch averaged 174,000 acre-feet per year for the study period (1942 through 1980; Massey and Reeves, 1983). A recent (2012) watershed model for the middle Nueces River (extending from upstream from the Carrizo-Wilcox outcrop to Lake Corpus Christi) estimated that, on average (from 1961 through 2008), approximately 93 percent of annual precipitation was lost to evapotranspiration, 6 percent was lost to groundwater recharge to surficial hydrogeologic units that contain the Carrizo-Wilcox aquifer and approximately 2 percent resulted in surface runoff (Dietsch and Wehmeyer, 2012).

1.2 STATISTICAL METHODS

The statistical methods in this Appendix describe the fitting of a log-Pearson type III probability distribution (LPIII) to the annual peak streamflow data for the Nueces River Basin. The general purpose of fitting a probability distribution is to provide an objective mechanism to extrapolate to hazard levels (as represented by AEPs and equivalently expressed as annual recurrence interval or recurrence interval measured in years) beyond those represented by the sample size of annual peak streamflow data for a given streamgage. The LPIII distribution was fit to the logarithm (base-10) of the annual peak streamflow data. The USGS-PeakFQ software version 7.2 (Veilleux and others, 2013; USGS, 2014) provides the foundation for the results of the flood flow frequency estimates that are specified by average annual recurrence intervals computed and extracted from software output at 2, 5, 10, 25, 50, 100, 200, and 500 year recurrence intervals or respective AEPs of 0.500, 0.200, 0.100, 0.040, 0.020, 0.010, 0.005, and 0.002 along with the accompanying 95-percent confidence limits. The flood flow frequency graphs in this appendix were exported from PeakFQ (USGS, 2014) and depict the relation between annual peak streamflow and AEP for each streamgage. The terms “flow,” “streamflow,” and “discharge” are synonymous and used interchangeably in this report. All three terms refer to the volume of water that passes a given point within a given period of time; all are expressed in units of cubic feet per second (cfs) (Rantz and others, 1982).

A complementary statistical technique used for initial data analysis included the non-parametric rank-based Pettitt test (Pettitt, 1979). The Pettitt test is a commonly used statistical test for identifying an abrupt shift in a data series, such as annual peak streamflow data (Mallakpour and Villarini, 2016; Ryberg and others, 2020). For this analysis, the Pettitt test was used to aid in the determination of the point in time when a new reservoir or other climatic or hydrologic changes upstream from a streamgage began to have an effect on peak streamflow, referred to as the “change point” (Ryberg and others, 2020). The Pettitt test was used to identify the water year of the change point and provide measure of its statistical significance; a statistically significant change point was determined when the *p*-value for the Pettitt test at a given streamgage was less than 0.05. Considered in combination with a visual inspection of the plotted annual peak streamflow series, an analysis of the type and extent of the upstream reservoir (or reservoirs), and the size of the intervening drainage area between the upstream reservoir and streamgage among other considerations, the Pettitt test is a powerful tool for determining whether the NWIS code ‘6’ designation (discharge affected by regulation or diversion) has a measurable or statistically significant effect on streamflows at the gaged location (Ryberg and others, 2020). Table A.1 lists the *p*-values of the Pettitt test for the streamflow records at each streamgage. These values and the specific change point indicated by the Pettitt test are discussed further in the next section with the flood flow frequency results for each streamgage.

A second statistical technique used for data evaluation included the nonparametric Kendall's *tau* (correlation) test, which is a popular statistic technique for quantifying the presence of monotonic changes in the central tendency of streamflow data in time. The Kendall's *tau* test (Hollander and Wolfe, 1973; Helsel and others, 2020) was used through the USGS-PeakFQ software to detect for the presence of monotonic trends (upward or downward changes over time in the annual peak streamflow data). The test was only applied to the peak streamflow data used in the analysis. For example, if a portion of the annual peak streamflow record was removed because it represents a period of record prior to reservoir impoundment (that is, the completion of reservoir construction and deliberate impoundment of water), then the test was only applied to the annual peak streamflow record after reservoir construction. The *p*-values of the Kendall's *tau* test results are listed in Table A.1, and a trend in annual peak streamflow was detected at many of the streamgages at a 0.1 significance level (probability value [*p*-value] of 0.10). Because the Kendall's *tau* test is a two-tailed test, the *p*-value must be divided by two to determine whether the identified trend is a statistically significant upward or downward trend (Helsel and others, 2020). Therefore, a *p*-value of 0.05 was used as the threshold for determining whether there was an upward or downward trend in annual peak streamflow at the streamgages in the Nueces River basin; a statistically significant downward trend in annual peak streamflow was detected for 5 of these 21 streamgages as indicated by the negative *tau* values (no upward trends in annual peak streamflow were detected). A *p*-value greater than 0.05 indicates that any upward or downward changes in streamflow were not statistically significant.

Flood flow frequency analyses were made for the period of record through 2020 for the streamgages included in this study by using the annual peak streamflow data from the USGS NWIS database (USGS, 2021) augmented by historical observations of large flood events, which are also stored in NWIS. The Interagency Advisory Committee on Water Data (IACWD, 1982) describes the updated Bulletin 17C method (B17C) to conduct the frequency analysis (England and others, 2019) for the streamgages in the Nueces River Basin. Bulletin 17C includes improvements over the previous guidelines and methodologies; in particular, the expected moments algorithm (EMA) was used in the flood flow frequency analysis of all streamgage records during this study (England and others, 2019; USGS, 2014). The expected moments algorithm enables sophisticated interpretations of the historical record intended to enhance the estimates of peak streamflow, especially for the rare frequency events such as the 100-year streamflow (AEP of 0.01). Estimates of streamflow can be inferred from historical peak stages by using a present-day streamflow-discharge rating curve at a nearby USGS streamgage. In each flood frequency analysis in Section 1.3 in which the rating curve was used to estimate a historical streamflow, the most recently available rating curve at the time of data collection was used. Although the present stage-discharge relationship represented in the rating curve is almost certainly different than the relationship was during the historical event, the rating curve is used as a simple and efficient means of providing an estimate of streamflow for the historical event, albeit a rough estimate with very high uncertainty. The expected moments algorithm also permits inclusion of nonstandard information such as data censoring. For example, an annual peak streamflow might be known to be less than a specified streamflow threshold. The expected moments algorithm can also be used to accommodate time varying streamflow thresholds by assigning a streamflow threshold, otherwise known as a perception threshold, as a "highest since" value within discrete intervals of time. England and others, 2019, p. 56 explain a perception threshold is "the stage or flow above which it is estimated a source would provide information on the flood peak in any given year." Nonstandard information such as historical peak streamflows, perception thresholds, and special-use NWIS codes (refer to section 1.3) collectively can be thought of as a framework fostering record extension. Nonstandard information regarding rare frequency flood events was not available for all streamgages.

Low outliers within a time series of peak streamflow, such as zero or low flow annual peak streamflow that were likely caused by hydrometeorological processes that are unique from the processes that create the floods of interest for these flood frequency analyses, often need special consideration during the analysis that is done by using a form of conditional probability adjustment (England and others, 2019). PeakFQ and HEC-SSP incorporate the Multiple Grubbs Beck Test (MGBT) to detect potentially influential low floods (Cohn and others, 2013). The MGBT was used to identify and partially exclude potentially influential low floods from the analysis (the potentially influential low floods retain their plotting position but are not used in the fitting of the flood flow frequency curve). Within PeakFQ, those peaks identified as potentially influential low floods are recoded as less than a threshold streamflow and treated as interval data in the expected moments algorithm because potentially influential low floods do not convey meaningful information about the magnitude of floods with low AEPs (0.01 or less); but if retained in the analysis, they can influence the frequency estimates of very low AEP floods. Refer to appendix 7 of Bulletin 17C (England and others, 2019) for more information on the treatment of potentially influential low floods in the expected moments algorithm. For streamgage-specific reasons, the analyst can manually specify a low-outlier threshold. Low-outlier threshold values for each streamgage are identified and discussed further in the individual writeups for each streamgage that follow in this section. Although the ultimate decision for specifying a low-outlier threshold to identify influential low floods is based on engineering judgment, Bulletin 17C provides some general guidelines for choosing an appropriate threshold (England and others, 2019). For each flood frequency analysis, the computed flood frequency curve is evaluated for its fit to the data. If the data appear to have a clear inflection point or shift in the ordered peaks that was not identified by applying the MGBT, then the low outlier may be adjusted (England and others, 2019).

Skew is an expression of the curvature or shape of the LPIII distribution intended to mimic that of the data (Asquith, 2011a, 2011b). The importance of a regional skew is stressed in England and others (2019) to mitigate the sensitivity of modest streamgage record lengths to extreme events (Griffis and

Stedinger, 2007). A substantial motivation for a regional skew is to compensate for inefficient estimation of the product moment skew for highly variable and skewed data such as annual peak streamflow. The generalized skew coefficient is a built-in feature of the USGS-PeakFQ software but can be overridden by the user. Asquith and others (2021) developed generalized skew coefficients throughout Texas, and these estimates may be considered contemporary, and therefore valid, for this study.

Asquith and others (2021) developed generalized skew coefficients throughout Texas that were used for selected streamgage records in conjunction with the station skew coefficient obtained from the PeakFQ software if the period of record was (1) too short, (2) truncated because a substantial number of low outliers were removed, or (3) influenced considerably by a single extreme event (Griffis and Stedinger, 2007; England and others, 2019). The period of record for remaining streamgages was deemed sufficient to use the station skew computed by PeakFQ. Where the period was relatively short, truncated, or influenced by regulation or natural processes, the computed PeakFQ skew was weighted with regional skew values from Asquith and others (2021). In order to use the regional skew values, the weighted-skew option in USGS-PeakFQ software was required in conjunction with manual entry of skew information (USGS, 2014). The Asquith and others (2021) regional skew values used are listed in Table A.1. The choice of weighted or station skew is discussed below in the FFQ analysis description for each streamgage.

At each site, a cursory sensitivity analysis was done to determine the effects of the selected low-outlier threshold and selected skew on the flood frequency curve. For the low-outlier threshold, it was considered whether the threshold could be adjusted to improve the station skew, and if the threshold could be adjusted to bring the estimates more in line with flood frequency curves from upstream and downstream streamgages. These factors along with others are considered for the low-outlier threshold for each gaged location analyzed. Low-outlier threshold values for each streamgage are identified in Section 1.3. The sensitivity analysis considered (1) if the station skew value deviated appreciably from published regional skew values, (2) if the calculated flood frequency curve did not appear to fit the ordered peak floods well, or (3) if the calculated flood frequency curve produced estimates inconsistent with flood frequency estimates at upstream and downstream streamgages. Although a station skew value calculated by using PeakFQ that differs greatly from the regional skew estimate is cause for further investigation, it is not necessarily justification for weighting by the regional skew value. This is because the gaged location may have site-specific hydrological characteristics that differ from regional hydrological characteristics (Asquith, 2021). If a weighted skew value was used at a given streamgage, the details of how the weighted skew was determined as well as the selection of the low-outlier threshold are discussed in the analysis section for that streamgage (Section 1.3).

Confidence limits of flood flow frequency can be informative to decision makers that need to know the probability of an event as well as that probability's associated error. The lower and upper limits of 95-

percent confidence intervals were computed for this study. Confidence intervals can be expected to encompass the true value 95 percent of the time (Good and Hardin, 2006).

Input data are plotted on a probability scale along with the computed frequency curve and confidence limits using plotting positions. Plotting positions do not have any influence on the computed frequency distribution but are an important tool in assessing the fitted frequency distribution. The Hirsch-Stedinger plotting position was used in this analysis, which is the recommended method in Bulletin 17C because of its correct interpretation of historical information conveyed by historical flood data, the recognition of the limited precision of the exceedance probability estimates for historical floods, and noted the relative imprecision of estimators (Hirsch and Stedinger, 1984; England and others, 2018).

1.3 U.S. GEOLOGICAL SURVEY STREAMGAGE DATA AND STATISTICAL FLOOD FLOW FREQUENCY RESULTS

08190000 Nueces River at Laguna, Texas

The period of record for USGS streamgage 08190000 Nueces River at Laguna, Tex. (hereinafter referred to as the "Nueces River at Laguna streamgage") was from 1924 through 2020. Two historical peaks of 210,000 cfs and 160,000 cfs were recorded in 1913 and 1923, respectively and were included in the analysis. A perception threshold of 160,000 cfs was set for the time period between the 1913 and 1923 historical peak streamflows. Beginning in water year 1962, streamflow is qualified with peak code 5 in NWIS, indicating "streamflow [is] affected to [an] unknown degree by regulation or diversion" (USGS, 2021). There are many small diversions for irrigation upstream from the streamgage. As explained in section 1.2 of Appendix A, the Pettitt test was used to determine if there was a significant change point in the annual peak streamflow record and the Kendall's *tau* test was used to determine if there was a significant trend in the annual peak streamflow record. Neither a statistically significant change point nor a trend in the annual peak streamflow record were identified (Table A.1). No statistically significant differences in peak streamflows before and after the 1962 water year were detected.

The largest peak in the gaged period of record is the 1955 peak streamflow of 307,000 cfs at a stage of 32.70 feet (ft). A log-normal plot of the peak streamflows for each water year at the Nueces Rivera at Laguna streamgage is presented in Figure A.2, and the flood flow frequency is presented in Figure A.3. The low-outlier threshold was computed as 3,360 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 29 low outliers were identified.

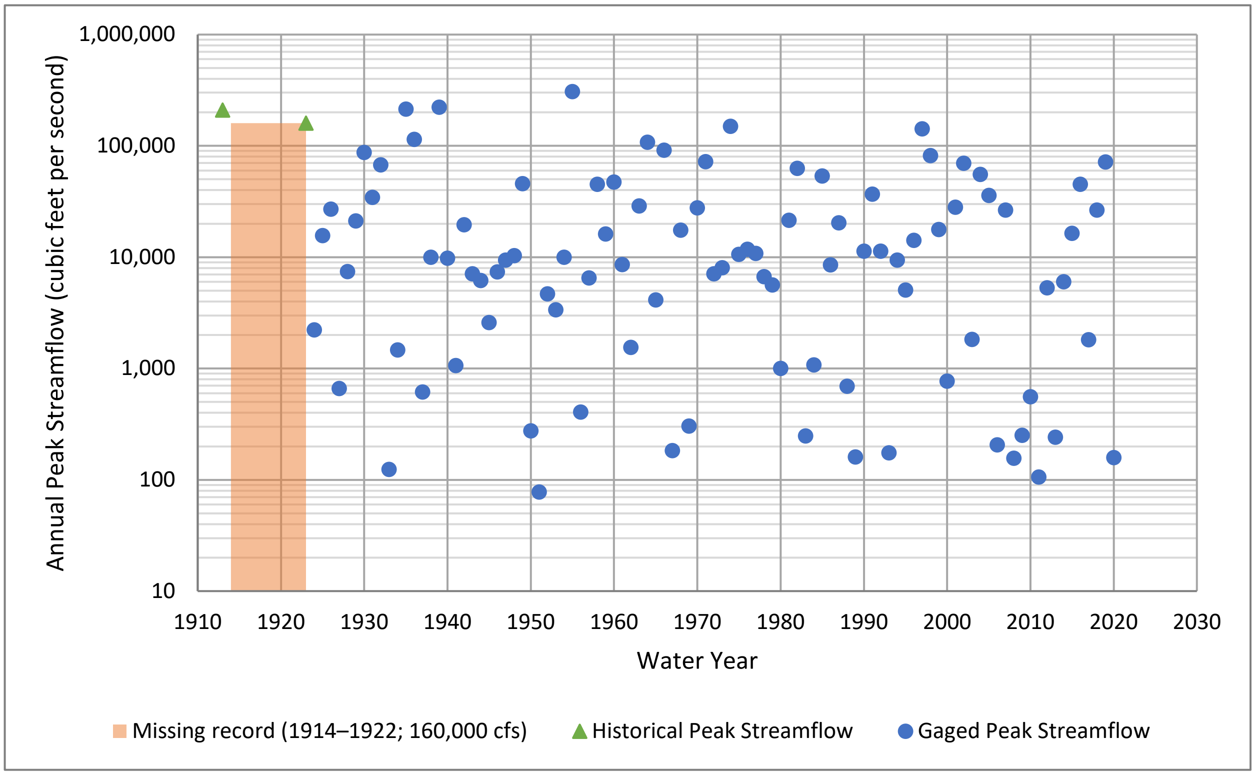


Figure A.2: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08190000 Nueces River at Laguna, Texas.

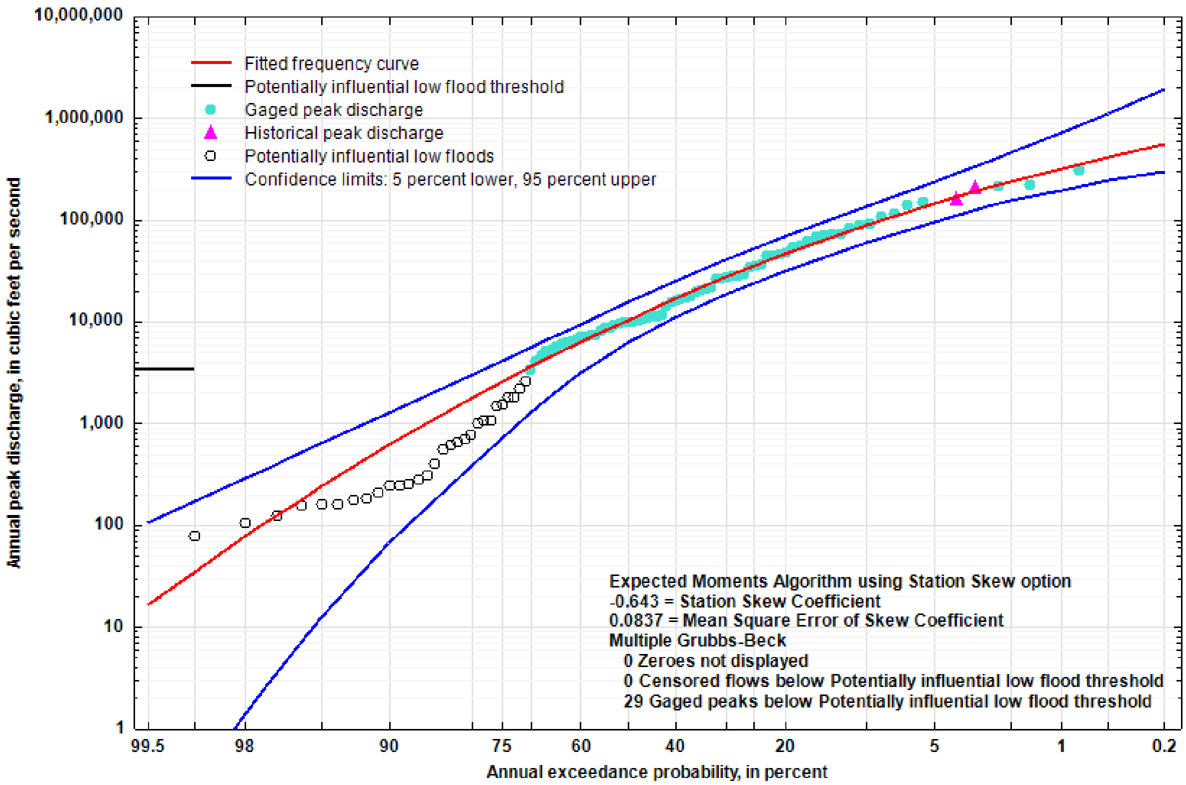


Figure A.3: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08190000 Nueces River at Laguna, Texas.

08192000 Nueces River below Uvalde, Texas

The period of record at USGS streamgage 08192000 Nueces River below Uvalde, Tex. (hereinafter referred to as the "Nueces River below Uvalde streamgage") was from 1928 through 2020. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1). Beginning in water year 1962, streamflow is qualified with peak code 5 in NWIS, indicating "streamflow [is] affected to [an] unknown degree by regulation or diversion" (USGS, 2021). No statistically significant differences in peak streamflows before and after the 1962 water year were detected.

The largest peak in the gaged period of record is the 1935 peak streamflow of 616,000 cfs at a stage of 40.40 ft. A log-normal plot of the peak streamflows for each water year at the Nueces River below Uvalde streamgage is presented in Figure A.4, and the flood flow frequency is presented in Figure A.4. The low-outlier threshold was computed as 4,490 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 1 zero-flow outlier and 34 low outliers were identified.

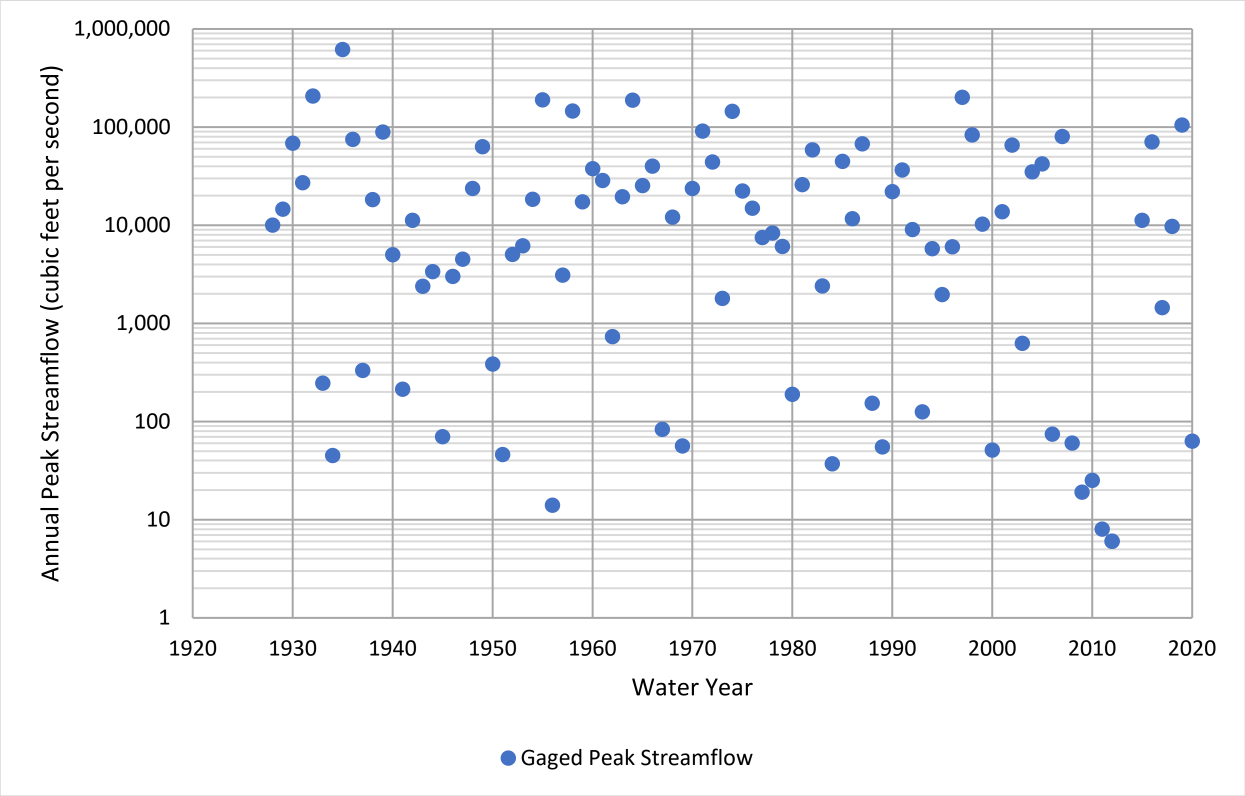


Figure A.4: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08192000 Nueces River below Uvalde, Texas.

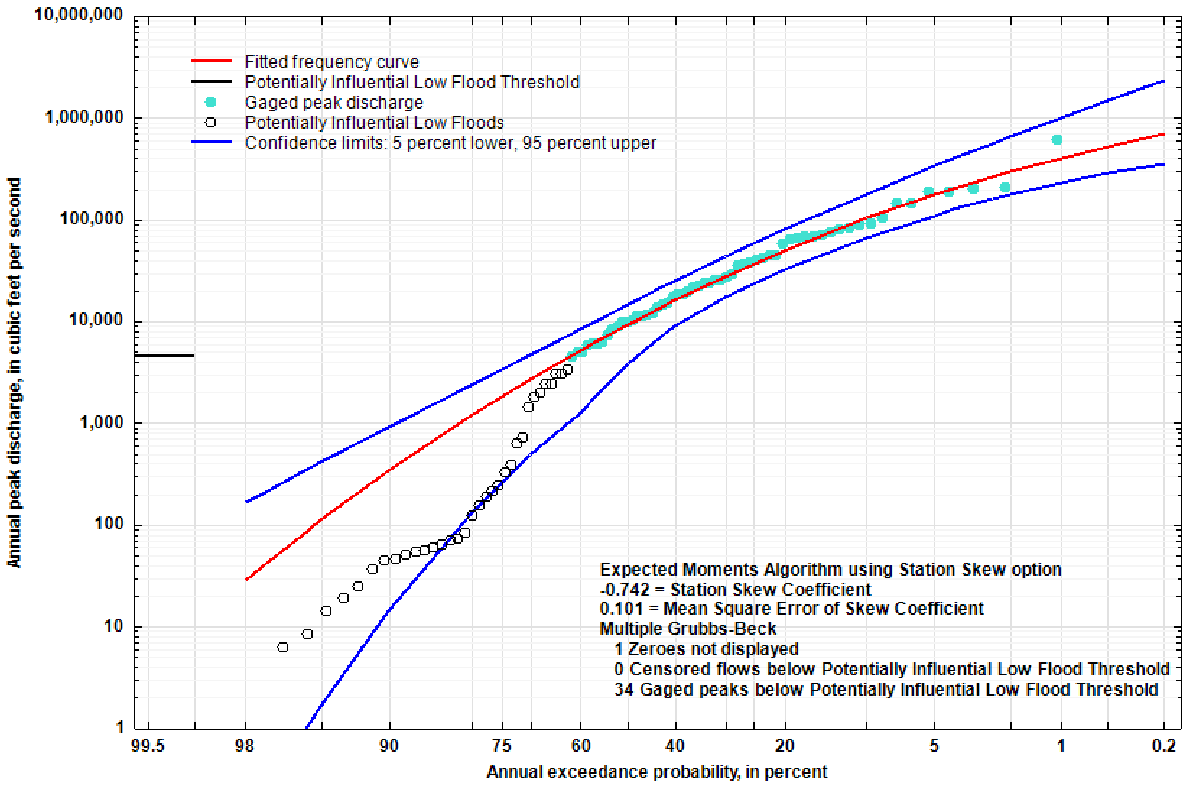


Figure A.5: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08192000 Nueces River below Uvalde, Texas.

08193000 Nueces River near Asherton, Texas

The period of record at USGS streamgage 08193000 Nueces River near Asherton, Tex. (hereinafter referred to as the "Nueces River near Asherton streamgage") was from 1940 through 2020. Two historical peak stages of 33 ft were recorded in 1913 and 1935. Using the rating curve, an interval estimate of 45,000 to 75,000 cfs were set for the 1913 event. Although the 1935 flood reached the same stage, previous storm modeling has revealed additional information about this flooding event (InFRM, 2024). The majority of the rainfall that fell in the Nueces River basin in 1935 fell above the Uvalde gage, suggesting that streamflow decreased moving downstream from Uvalde to Asherton to Cotulla. Therefore, it is unlikely that the 1935 peak streamflow would have been much lower than the 83,600 cfs observed at Cotulla. However, it is still possible for streamflow to increase between Asherton and Cotulla despite the known losses in the basin. In fact, for the seven largest storms to be observed at all three gages, five saw decreases from Asherton to Cotulla while two saw increases moving downstream between the two gages. Therefore, an interval was estimated for the 1935 event by applying the mean and maximum percent decreases between Uvalde and Asherton for these seven largest events. By applying these fractions to the 616,000 cfs observed at Uvalde, an interval estimate of 75,000 to 125,000 cfs was estimated for the 1935 flood at Asherton.

Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1). Beginning in water year 1949, streamflow is qualified with peak code 6 in NWIS, indicating "streamflow [is] affected by regulation or diversion" (USGS, 2021). No statistically significant differences in peak streamflows before and after the 1949 water year were detected.

The largest peak in the gaged period of record is the 1960 peak streamflow of 28,500 cfs at a stage of 30.88 ft. There are large streamflow losses between the Nueces River below Uvalde and Nueces River near Asherton streamgages that vary depending on stream stage (Land and others, 1983). Although streamflow losses during storm events have not been quantified, the July 2002 storm event on the Nueces River decreased from 65,200 cfs at the Nueces River below Uvalde gage to just 12,600 cfs at the Nueces River near Asherton gage (USGS, 2021). More information on potential causes of these losses is provided in the site description in Section A.1. A log-normal plot of the peak streamflows for each water year at the Nueces River near Asherton streamgage is presented in Figure A.6, and the flood flow frequency is presented in Figure A.7. The low-outlier threshold was computed as 3,740 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 2 zero-flow values and 26 low outliers were identified.

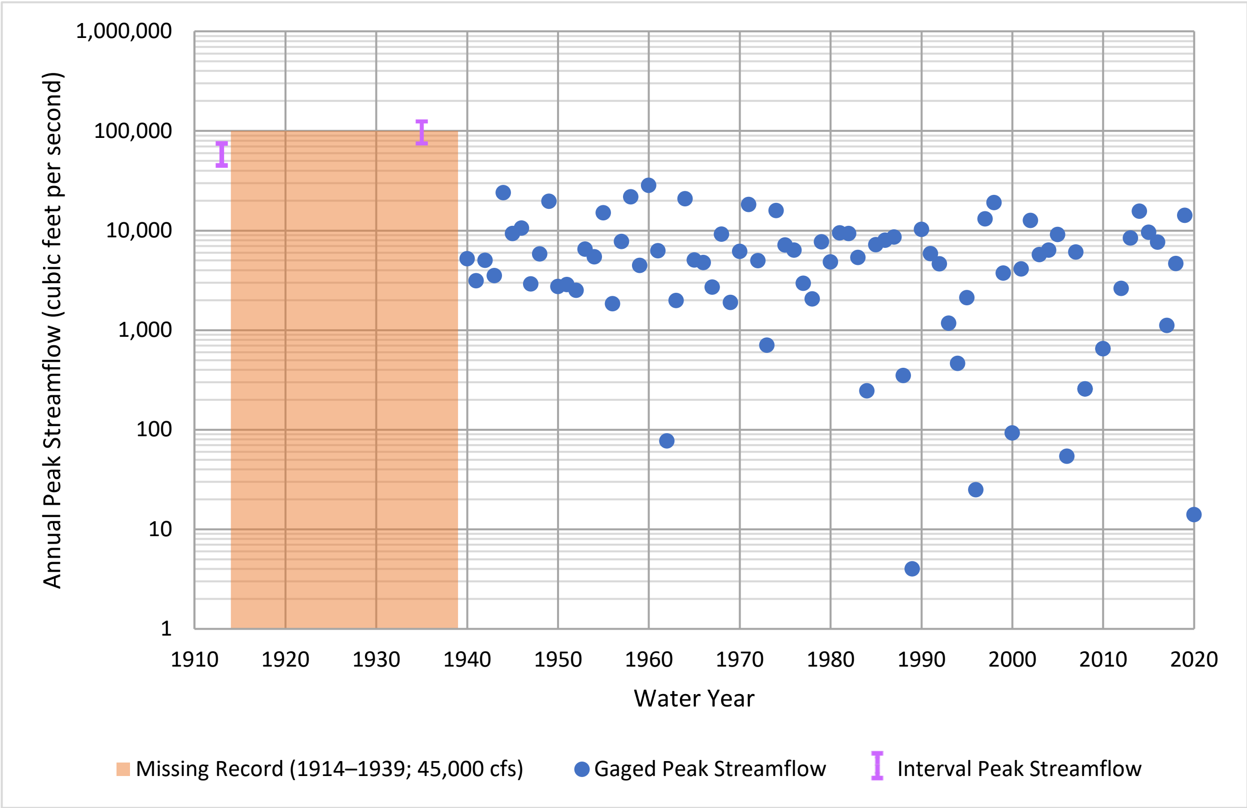


Figure A.6: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08193000 Nueces River near Asherton, Texas.

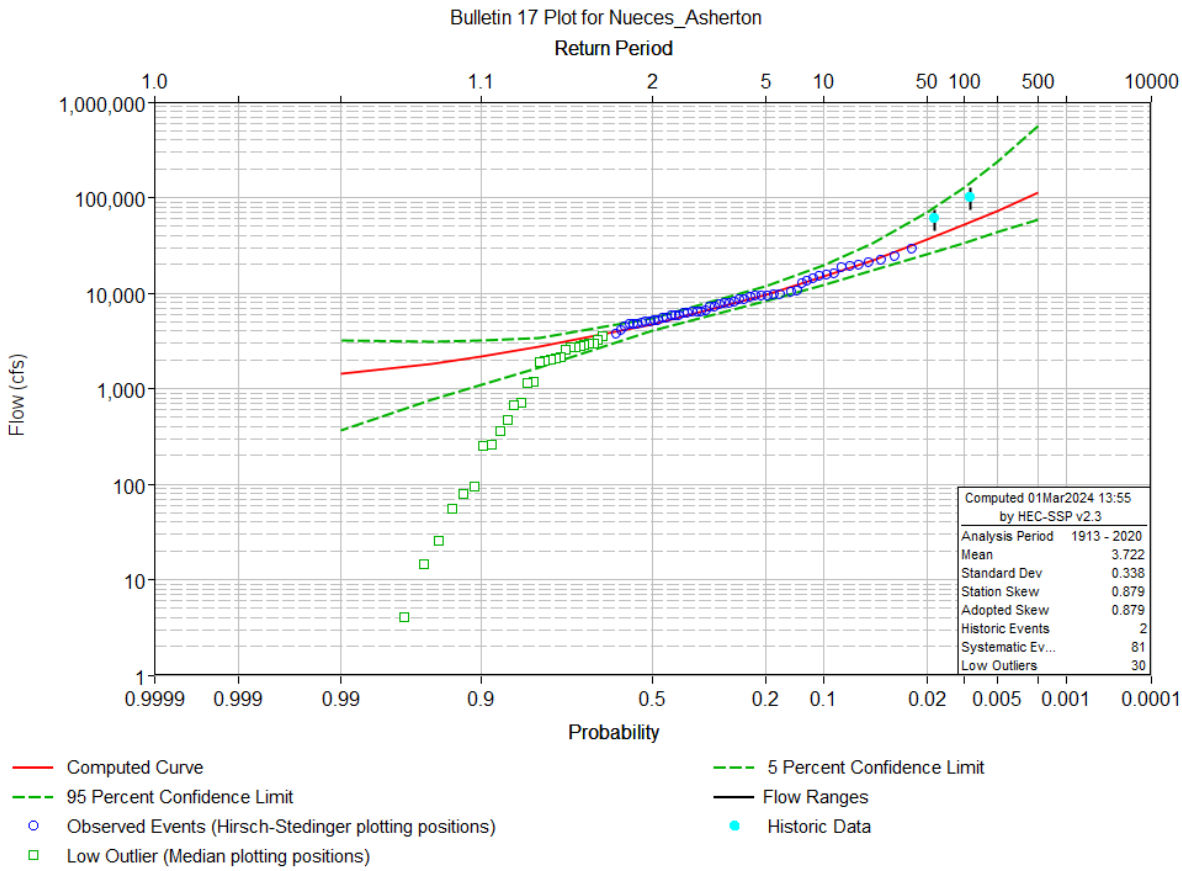


Figure A.7: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08193000 Nueces River near Asherton, Texas.

08194000 Nueces River at Cotulla, Texas

The period of record at USGS streamgage 08194000 Nueces River at Cotulla, Tex. (hereinafter referred to as the "Nueces River at Cotulla streamgage") was from 1924 through 2020. Historical documentation includes a peak stage in 1899 of 29.7 ft (Dalrymple, 1939) at the streamgage location, which ranks as the second largest peak on record through 2020. By extrapolating the 2021 USGS rating curve for the location, the peak from 1899 was estimated between 54,000 and 60,000 cfs, and an interval peak was added to the analysis for that year. Beginning in water year 1949, streamflow is qualified with peak code 6 in NWIS, indicating "streamflow [is] affected by regulation or diversion" (USGS, 2021). No statistically significant differences in peak streamflows before and after the 1949 water year were detected. A significant change point in water year 1982 that does not appear to be associated with reservoir construction was determined by applying the Pettitt test. Furthermore, a significant downward trend in the annual peak streamflow record was identified by applying the Kendall's *tau* test (Table A.1).

The largest peak in the gaged period of record is the 1935 peak streamflow of 82,600 cfs at a stage of 32.40 ft. A log-normal plot of the peak streamflows for each water year at the Nueces River at Cotulla streamgage is presented in Figure A.8, and the flood flow frequency is presented in Figure A.9. The low-outlier threshold was computed as 2,130 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 1 zero-flow and 19 low outliers were identified.

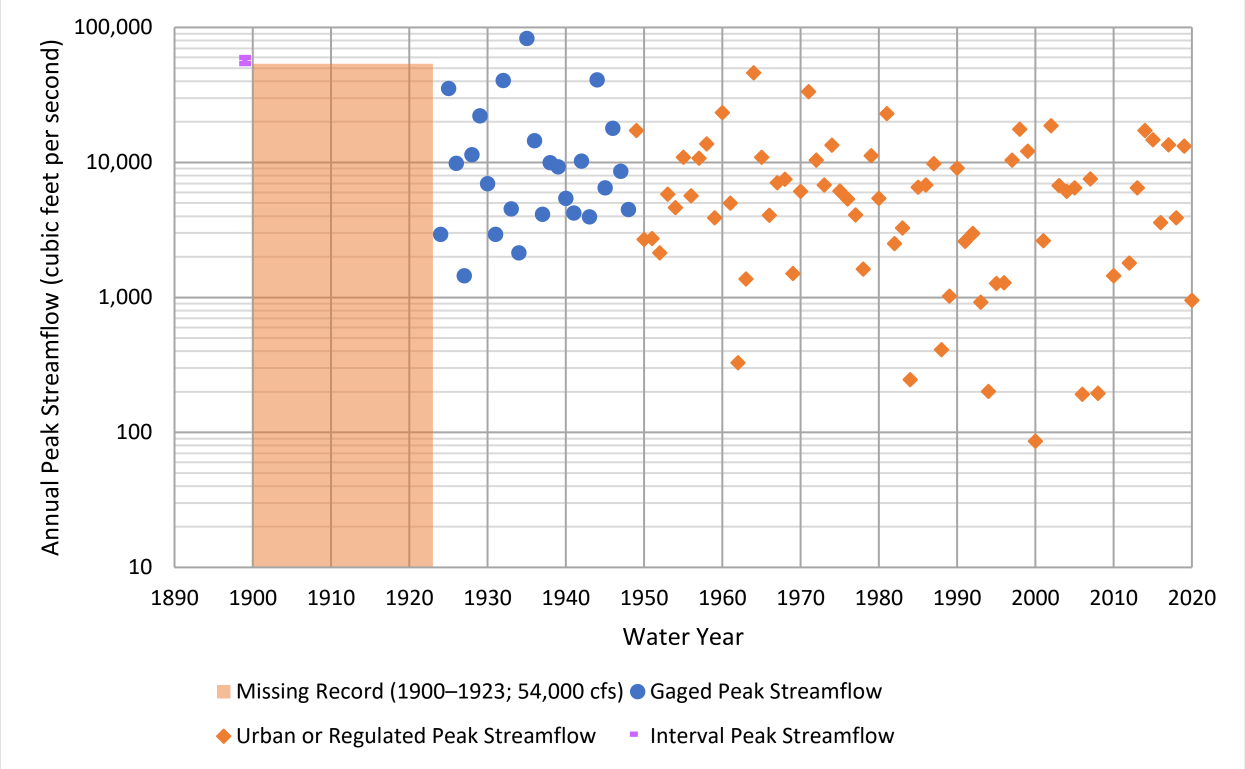


Figure A.8: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08194000 Nueces River at Cotulla, Texas.

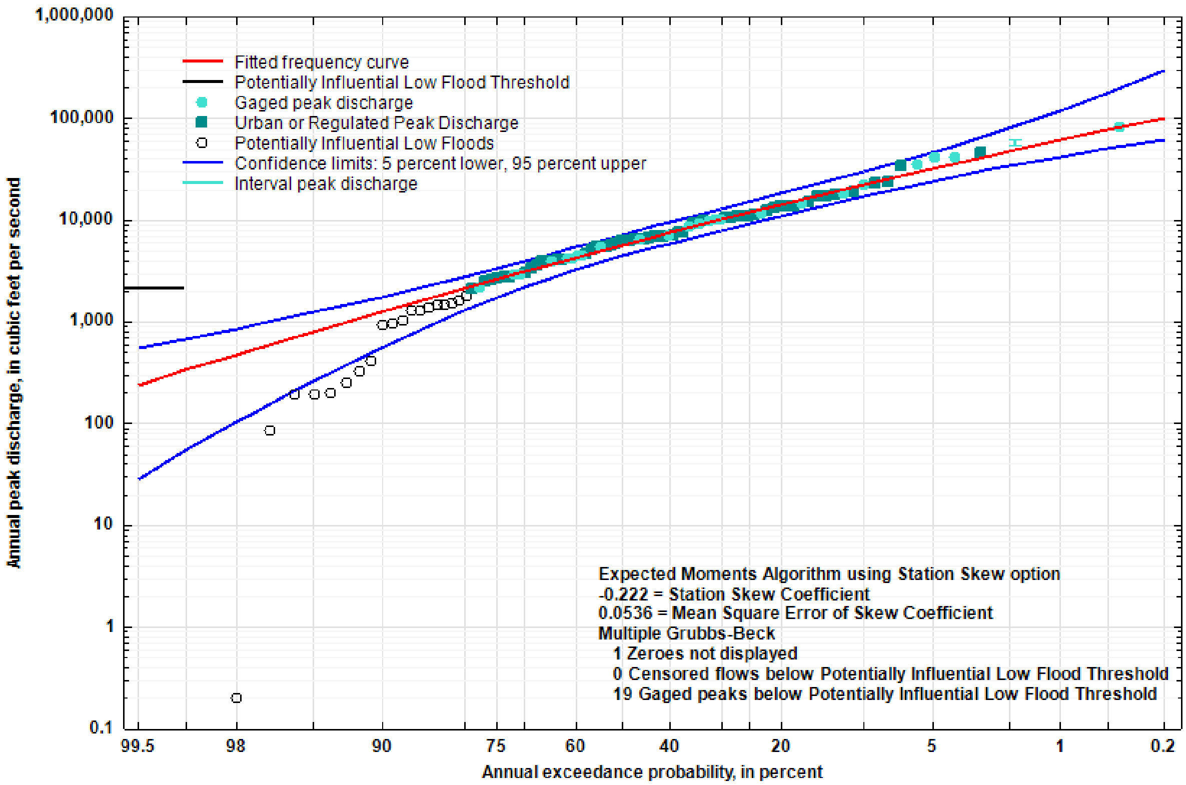


Figure A.9: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08194000 Nueces River at Cotulla, Texas.

08194500 Nueces River near Tilden, Texas

The period of record at USGS streamgage 08194500 Nueces River near Tilden, Tex. (hereinafter referred to as the "Nueces River near Tilden streamgage") was from 1943 through 2020. Two historical peaks of 38,000 and 22,600 cfs were recorded in 1935 and 1942 respectively and were included in the analysis. Beginning in water year 1949, streamflow is qualified with peak code 6 in NWIS, indicating "streamflow [is] affected by regulation or diversion" (USGS, 2021). No statistically significant differences in peak streamflows before and after the 1949 water year were detected. However, a statistically significant change point in water year 1983 was identified by applying the Petit test that does not appear to be associated with reservoir construction. A statistically significant downward trend in the annual peak streamflow record was also identified by applying the Kendall's *tau* test (Table A.1).

The largest peak in the gaged period of record is the 1967 peak streamflow of 76,500 cfs at a stage of 26.57 ft. A log-normal plot of the peak streamflows for each water year at the Nueces River near Tilden streamgage is presented in Figure A.10, and the flood flow frequency is presented in Figure A.11. The low-outlier threshold was manually set at 500 cfs, and five low outliers were identified. This was done to obtain a better fit to the data and adjust the skew closer to regional estimates.

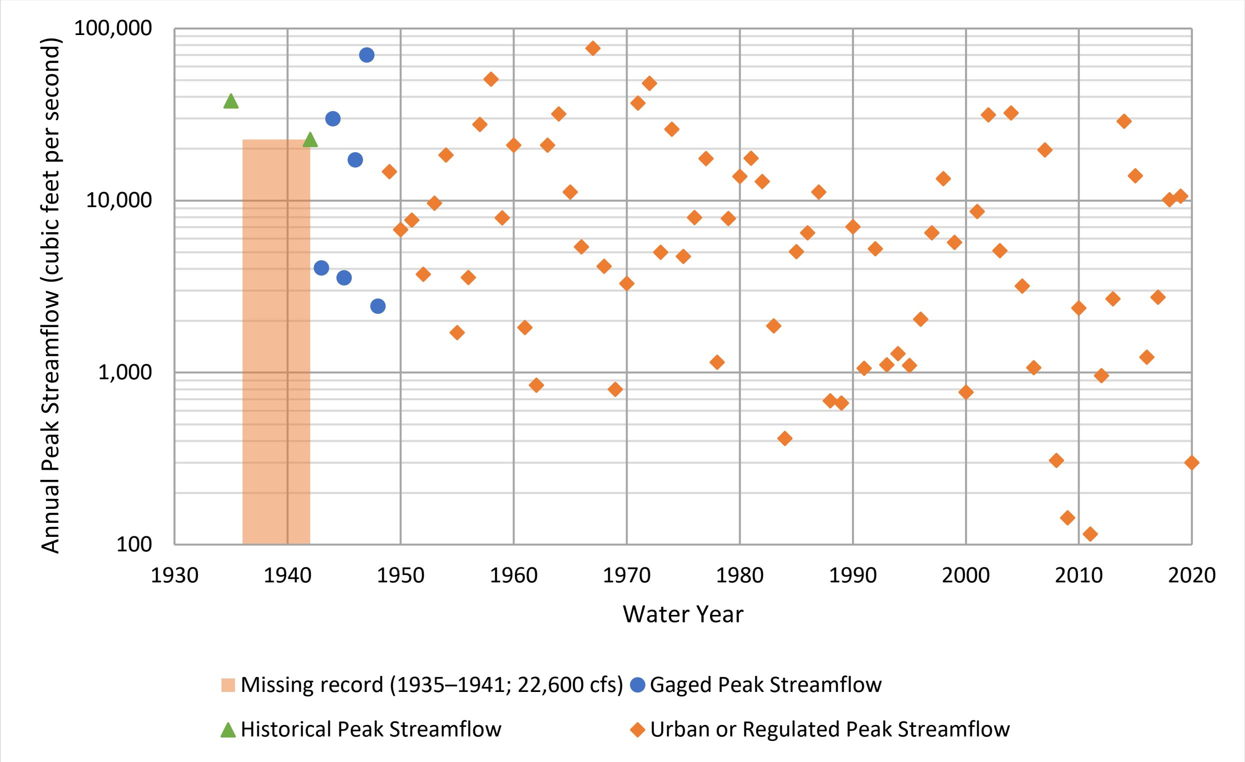


Figure A.10: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08194500 Nueces River near Tilden, Texas.

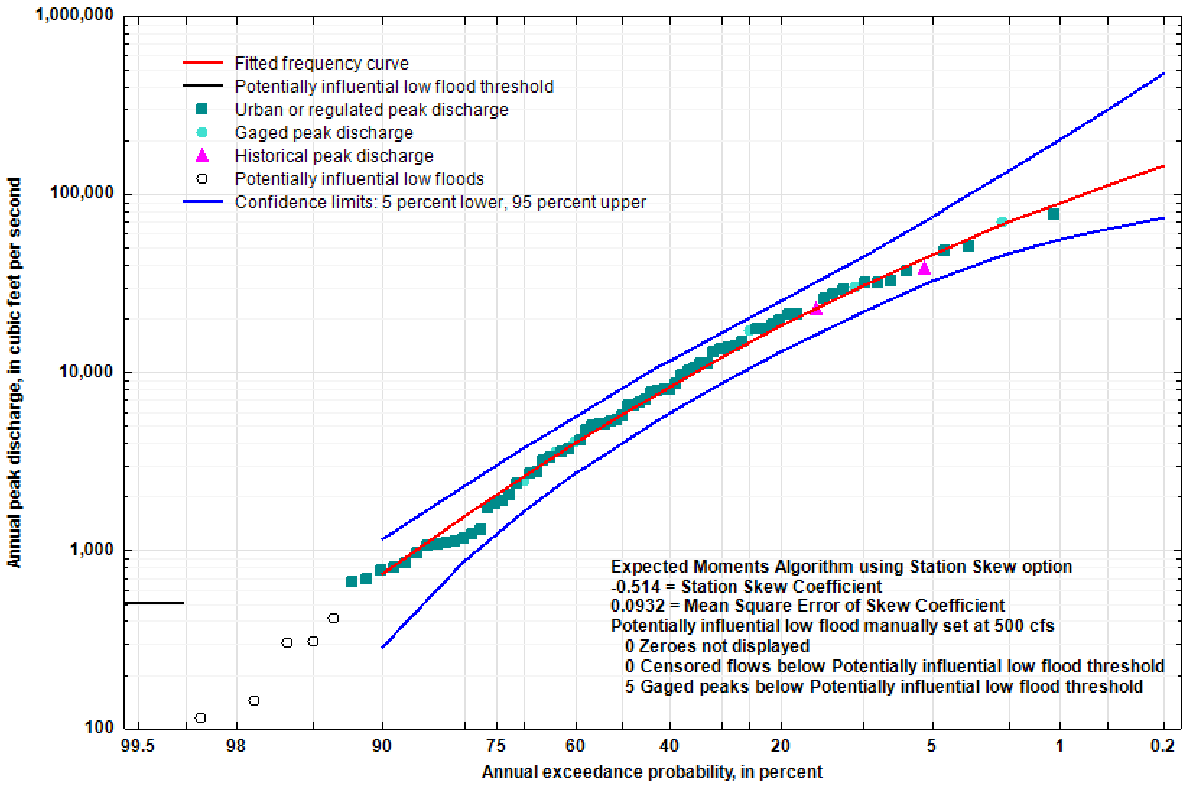


Figure A.11: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08194500 Nueces River near Tilden, Texas.

08210000 Nueces River near Three Rivers, Texas

The period of record at USGS streamgage 08210000 Nueces River near Three Rivers, Tex. (hereinafter referred to as the “Nueces River near Three Rivers streamgage”) was from 1916 through 2020. Beginning in water year 1949, streamflow is qualified with peak code 6 in NWIS, indicating “streamflow [is] affected by regulation or diversion” (USGS, 2021). No statistically significant differences in peak streamflows before and after the 1949 water year were detected. However, the Pettitt test identified a statistically significant change point in water year 1984 corresponding approximately to the construction of Choke Canyon Reservoir in 1982 (TWDB, 2022; Table A.1). Peaks prior to 1983 were removed from the analysis to account for streamflow regulation caused by the reservoir. After record truncation, applying the Kendall’s *tau* test did not identify a significant trend in the annual peak streamflow record (Table A.1).

The largest peak in the analyzed period of record (after removing peaks prior to 1983) is the 2002 peak streamflow of 48,500 cfs at a stage of 44.45 ft. A log-normal plot of the peak streamflows for each water year at the Nueces River near Three Rivers streamgage is presented in Figure A.12, and the flood flow frequency is presented in Figure A.13. After truncating the record to account for reservoir construction in 1982, the skew was weighted by a regional value from Asquith and others (2021) (Table A.1). The low-outlier threshold was manually set at 500 cfs, and one low outlier was identified. Although no low outliers were identified by applying the MGBT, it was determined that the lowest peak of record was incongruent with the remainder of the peak streamflow record and therefore was classified as a low outlier.

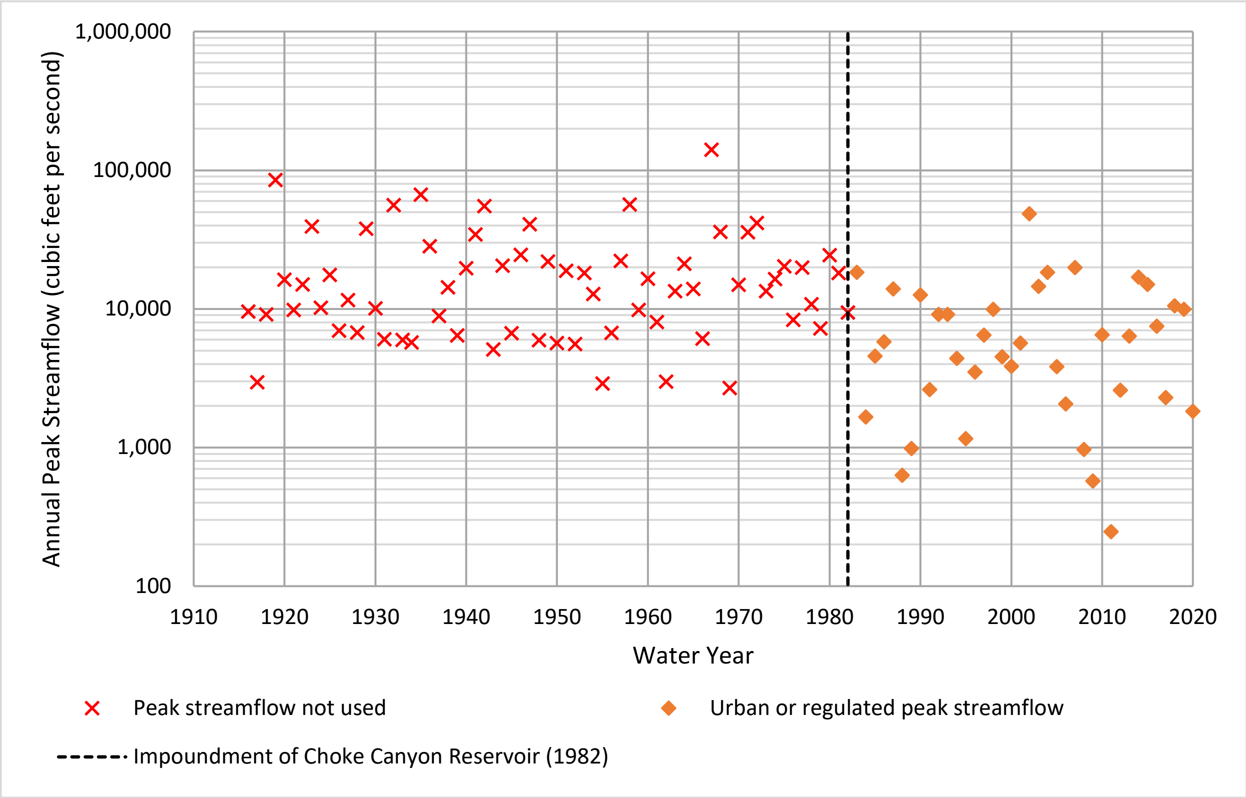


Figure A.12: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08210000 Nueces River near Three Rivers, Texas.

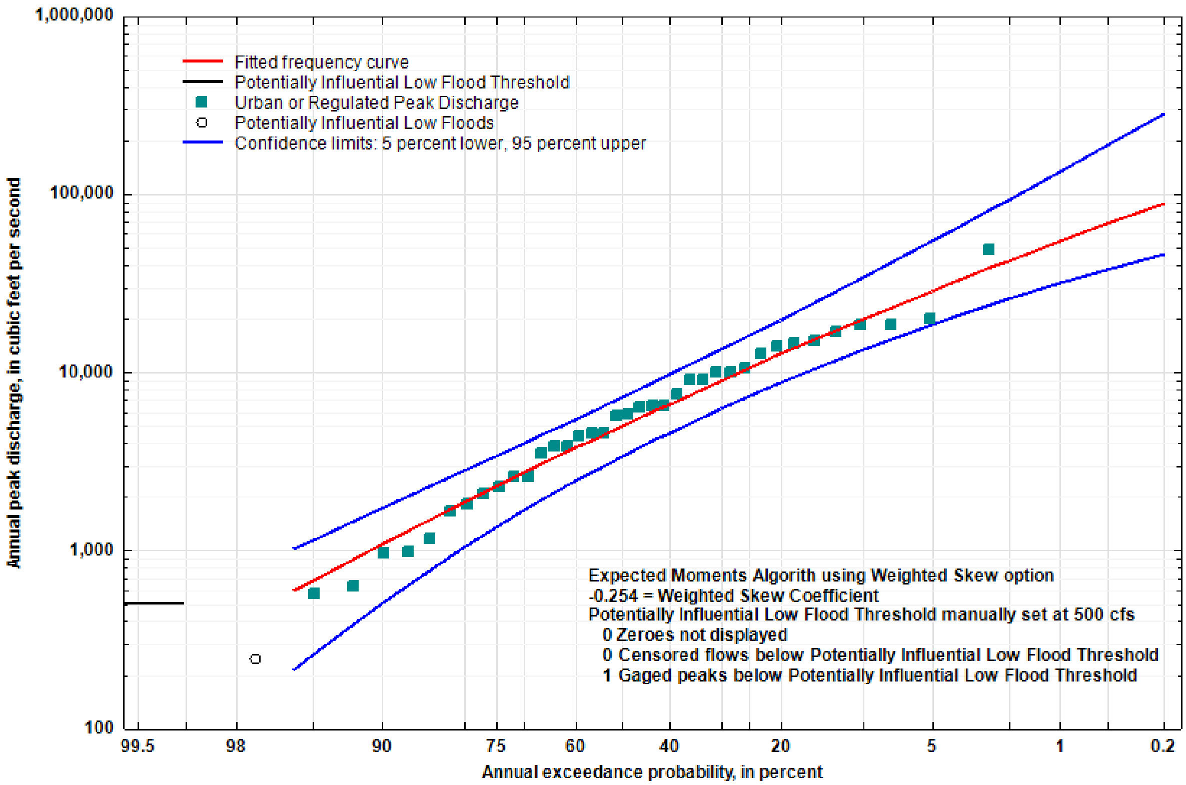


Figure A.13: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08210000 Nueces River near Three Rivers, Texas.

08211000 Nueces River near Mathis, Texas

The period of record at USGS streamgage 08211000 Nueces River near Mathis, Tex. (hereinafter referred to as the "Nueces River near Mathis streamgage") was from 1940 through 2020. Historical peaks are available in 1919, 1931, 1932, and 1935. Beginning in water year 1940, streamflow is qualified with peak code 6 in NWIS, indicating "streamflow [is] affected by regulation or diversion" as a result of the construction of Lake Corpus Christi (TWDB, 2022; USGS, 2021). However, the Pettitt test identified a significant change point in water year 1982 corresponding to the construction of Choke Canyon Reservoir upstream in 1982 (Table A.1). Peaks prior to 1983 were removed from the analysis to account for streamflow regulation caused by Choke Canyon Reservoir. After record truncation, applying the Kendall's *tau* test did not identify a significant trend in the annual peak streamflow record (Table A.1).

The largest peak in the analyzed period of record (after removing peaks prior to 1983) is the 2002 peak streamflow of 53,900 cfs at a stage of 39.23 ft. A log-normal plot of the peak streamflows for each water year at the Nueces River near Mathis streamgage is presented in Figure A.14, and the flood flow frequency is presented in Figure A.15.The skew was weighted by a regional value from Asquith and others (2021) (Table A.1). No low outliers were identified by applying the MGBT.

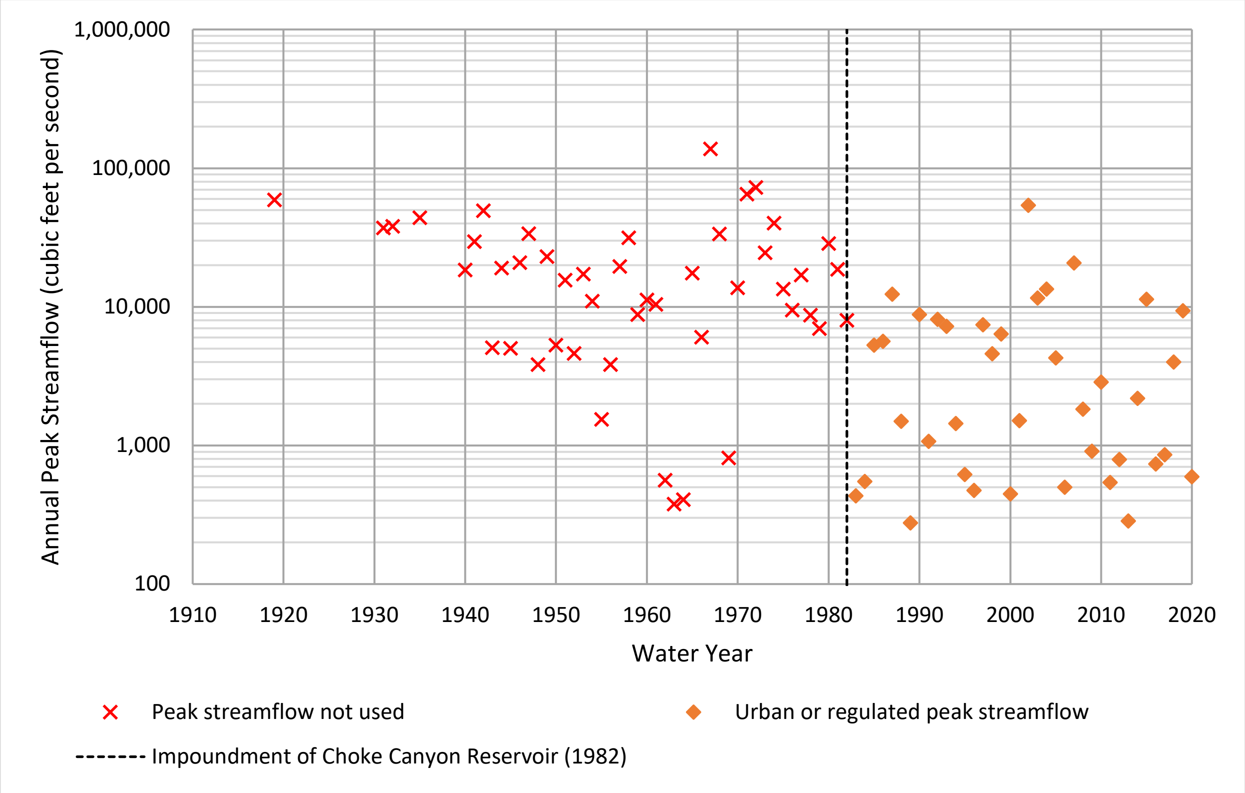


Figure A.14: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08211000 Nueces River near Mathis, Texas

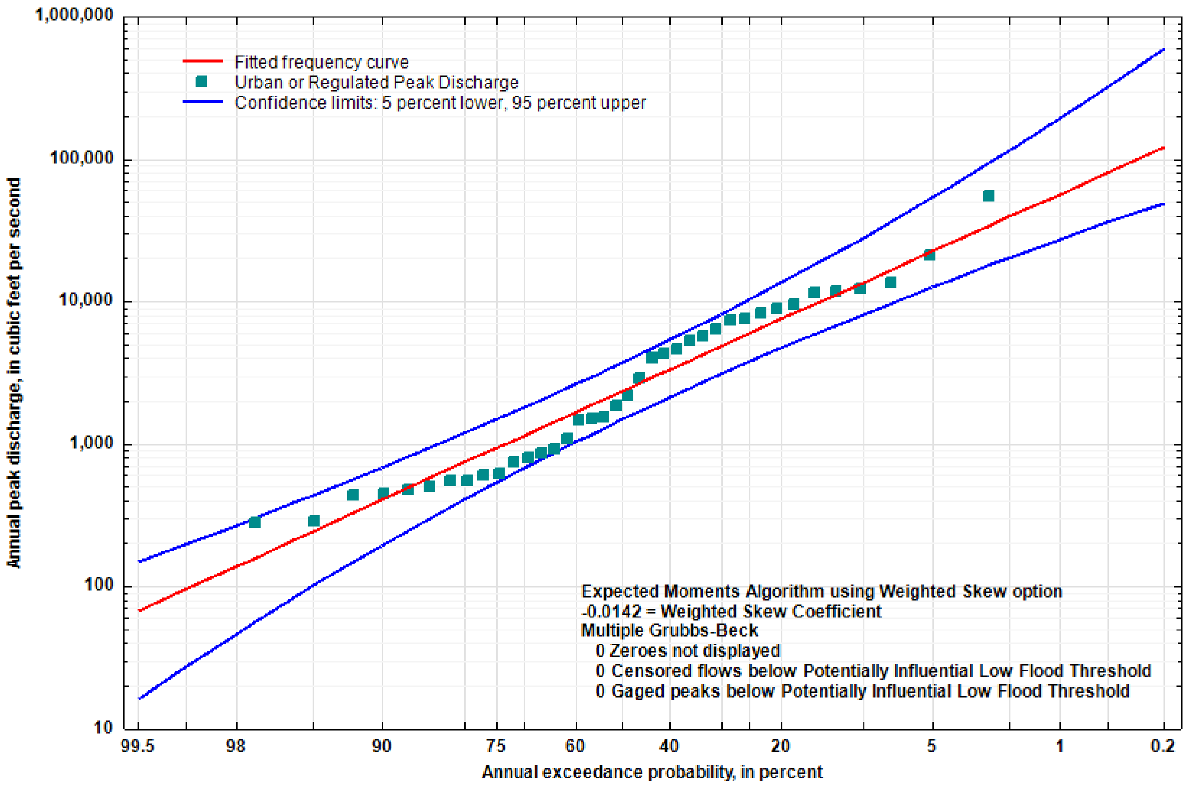


Figure A.15: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08211000 Nueces River near Mathis, Texas

08211500 Nueces River at Calallen, Texas

The period of record at USGS streamgage 08211500 Nueces River at Calallen, Tex. (hereinafter referred to as the "Nueces River at Calallen streamgage") was from 1983 through 2020. All peak streamflow is qualified with peak code 6 in NWIS, indicating "streamflow [is] affected by regulation or diversion" (USGS, 2021). Annual peak streamflow is missing for water years 1990, 1992, and 2012. Using available peak stages, the USGS rating curve, and estimates of streamflow from upstream streamgages, perception thresholds of 12,000, 12,000, and 1,000 cfs were set for those three missing years respectively. Applying the Pettitt test did not identify a statistically significant change point because the period of record begins in 1983— after the construction in 1982 of Choke Canyon Reservoir upstream from this streamgage (TWDB, 2022; Table A.1). A statistically significant trend in the annual peak streamflow record was not identified by applying the Kendall's *tau* test (Table A.1).

The largest peak in the analyzed period of record is the 2002 peak streamflow of 49,000 cfs at a stage of 13.21 ft. A log-normal plot of the peak streamflows for each water year at the Nueces River at Calallen streamgage is presented in Figure A.16, and the flood flow frequency is presented in Figure A.17. The skew was set to the station skew. The low-outlier threshold was manually set at 200 cfs, and one low outlier was identified.

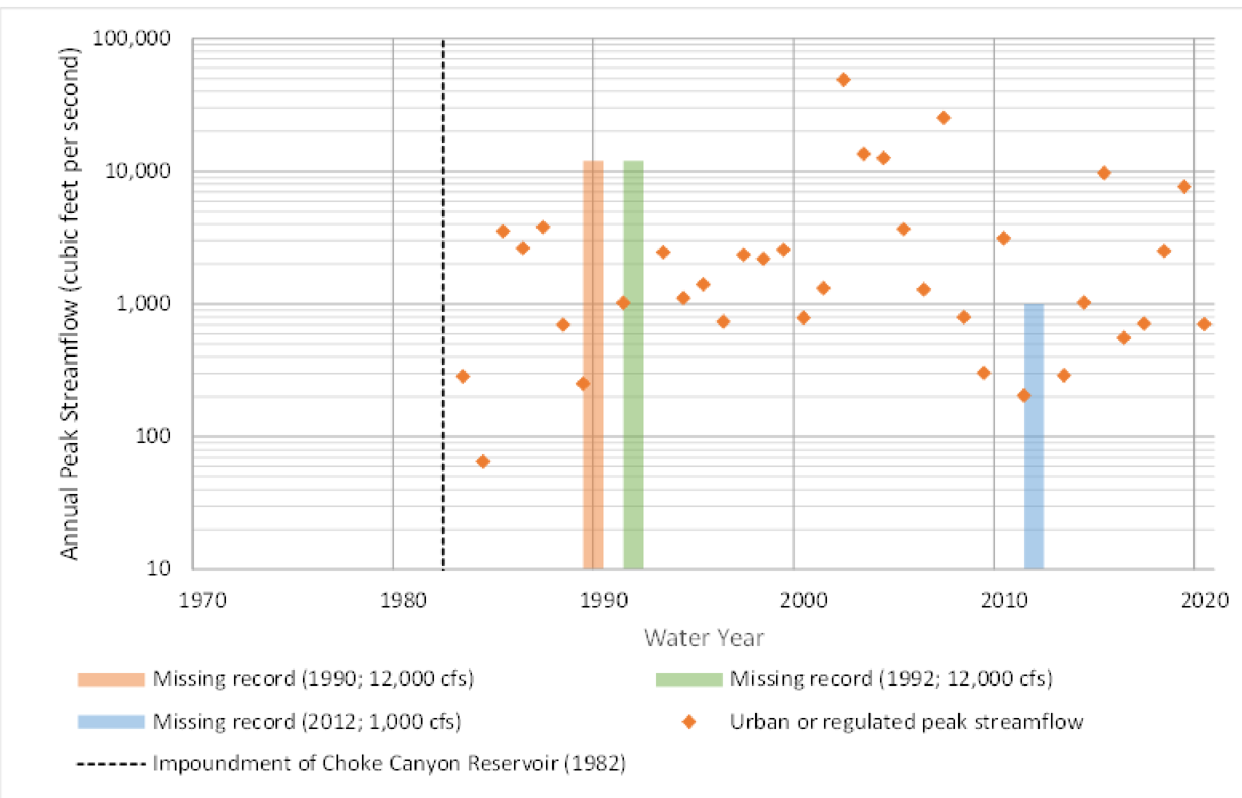


Figure A.16: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08211500 Nueces River at Calallen, Texas

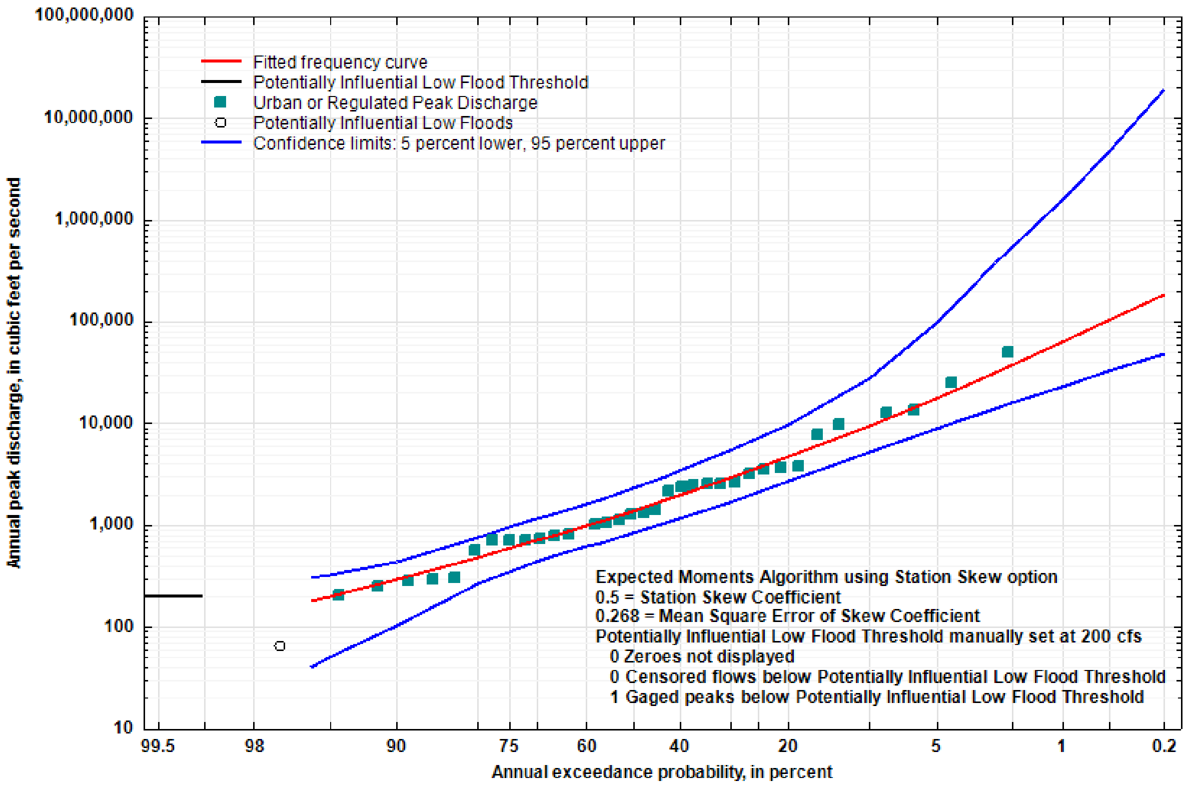


Figure A.17: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08211500 Nueces River at Calallen, Texas

08194200 San Casimiro Creek near Freer, Texas

The period of record at USGS streamgage 08194200 San Casimiro Creek near Freer, Tex. (hereinafter referred to as the "San Casimiro Creek near Freer streamgage") was from 1962 through 2020. A historical peak of 65,200 cfs was recorded in 1954, and a perception threshold of 65,200 cfs was set for the missing record between the historical peak and the start of the gaged peak record in 1962. Applying the Pettitt test identified a significant change point in water year 1988, and applying the Kendall's *tau* test identified a significant downward trend in the annual peak streamflow record (Table A.1). Annual peak streamflow is missing in water years 2018, and a perception threshold of 20,000 cfs was set for that missing year.

The largest peak in the gaged period of record is the 1972 peak streamflow of 82,000 cfs at a stage of 26.87 ft. A log-normal plot of the peak streamflows for each water year at the San Casimiro Creek near Freer streamgage is presented in Figure A.18, and the flood flow frequency is presented in Figure A.19.The skew was set to station skew. The low-outlier threshold was computed as 150 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold two low outliers were identified.

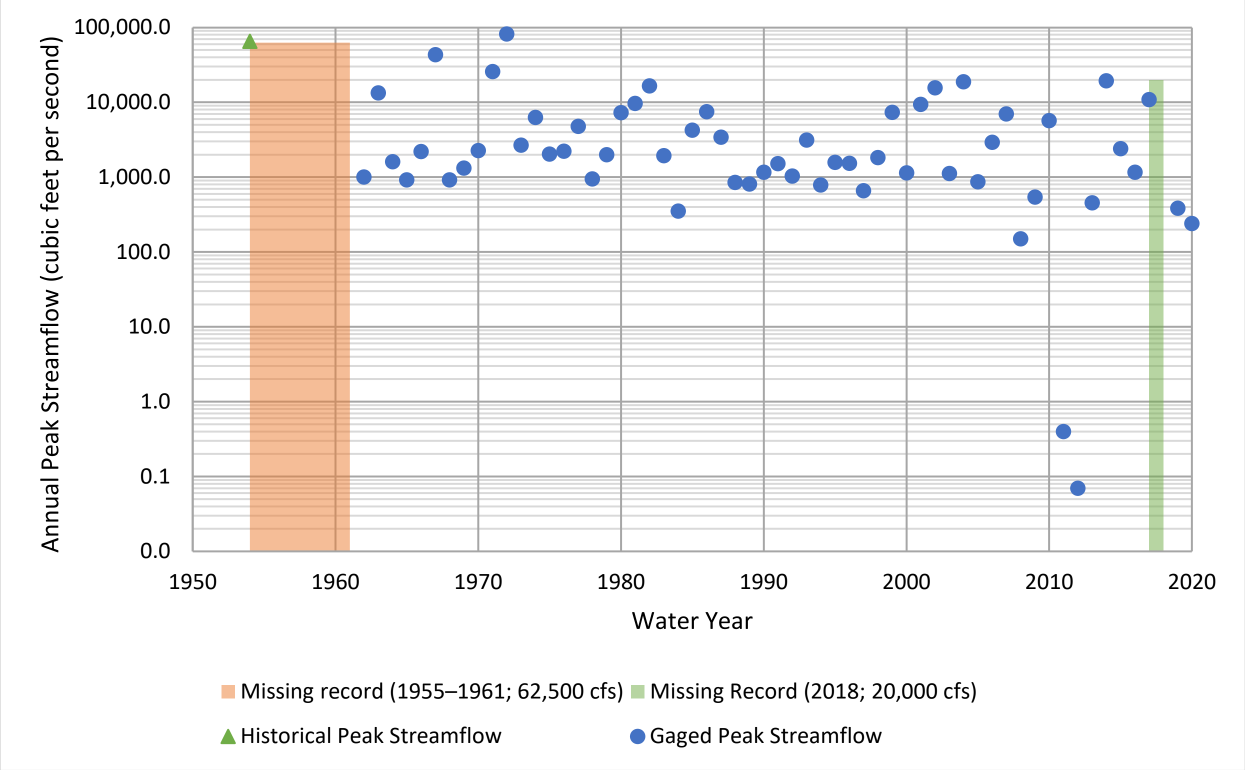


Figure A.18: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08194200 San Casimiro Creek near Freer, Texas

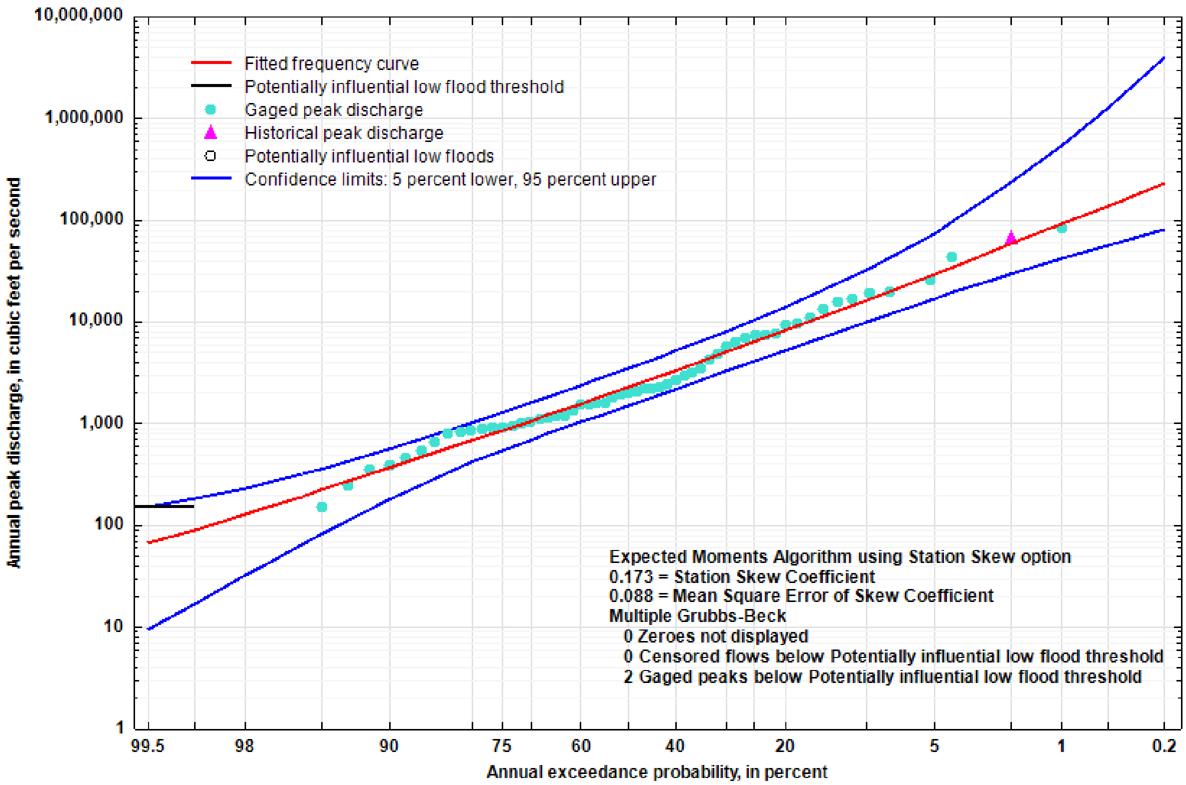


Figure A.19: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08194200 San Casimiro Creek near Freer, Texas

08190500 West Nueces River near Brackettville, Texas

The period of record at USGS streamgage 08190500 West Nueces River near Brackettville, Tex. (hereinafter referred to as the "West Nueces River near Brackettville streamgage") was from 1940 through 2020. Two historical peak streamflows of 550,000 and 150,000 cfs were recorded in 1935 and 1955 respectively and were included in the analysis. A historical peak stage of 34.5 ft was observed in 1900 at the West Nueces River near Brackettville streamgage; using the USGS rating curve for the streamgage, a rough estimate for this peak of 330,000 cfs and was also included in the analysis. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 1935 historical peak streamflow of 550,000 cfs at a stage of 40.00 ft. A log-normal plot of the peak streamflows for each water year at the West Nueces River near Brackettville streamgage is presented in Figure A.20, and the flood flow frequency is presented in Figure A.21. The low-outlier threshold was computed as 3,130 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 2 zero-flow and 33 low outliers were identified.

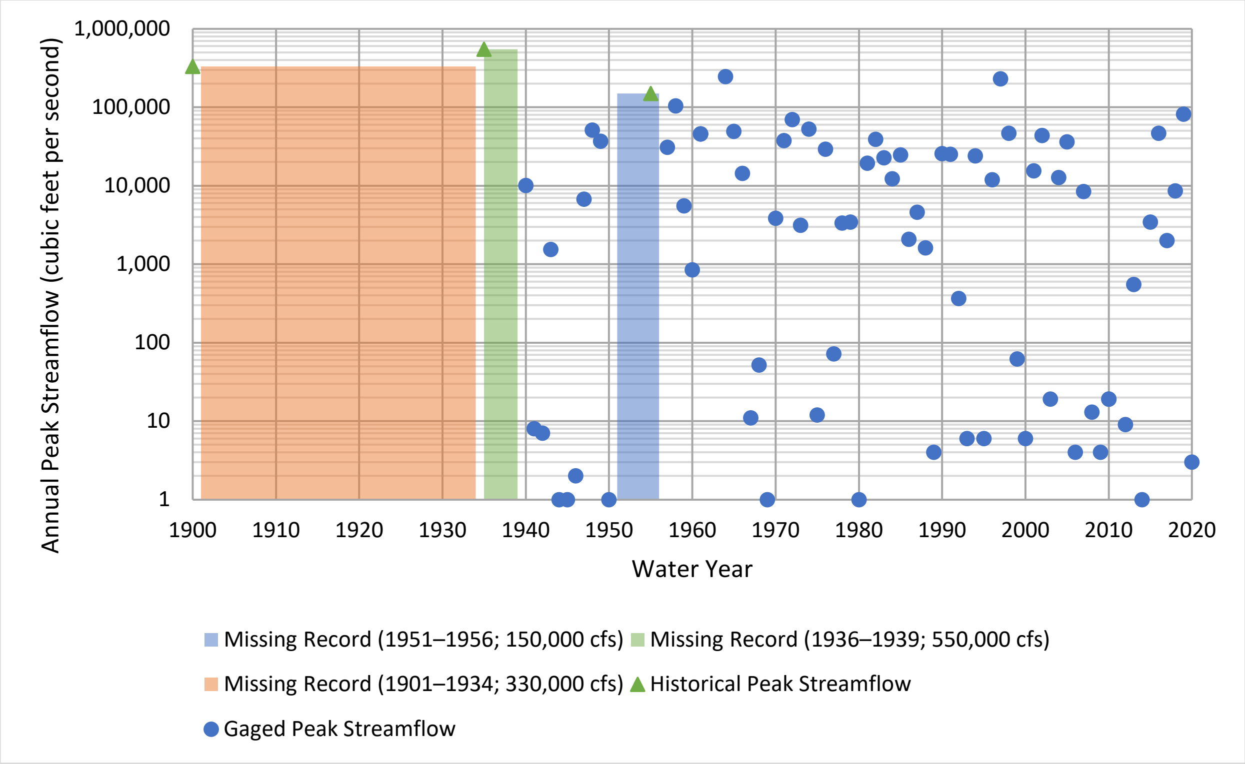


Figure A.20: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08190500 West Nueces River near Brackettville, Texas

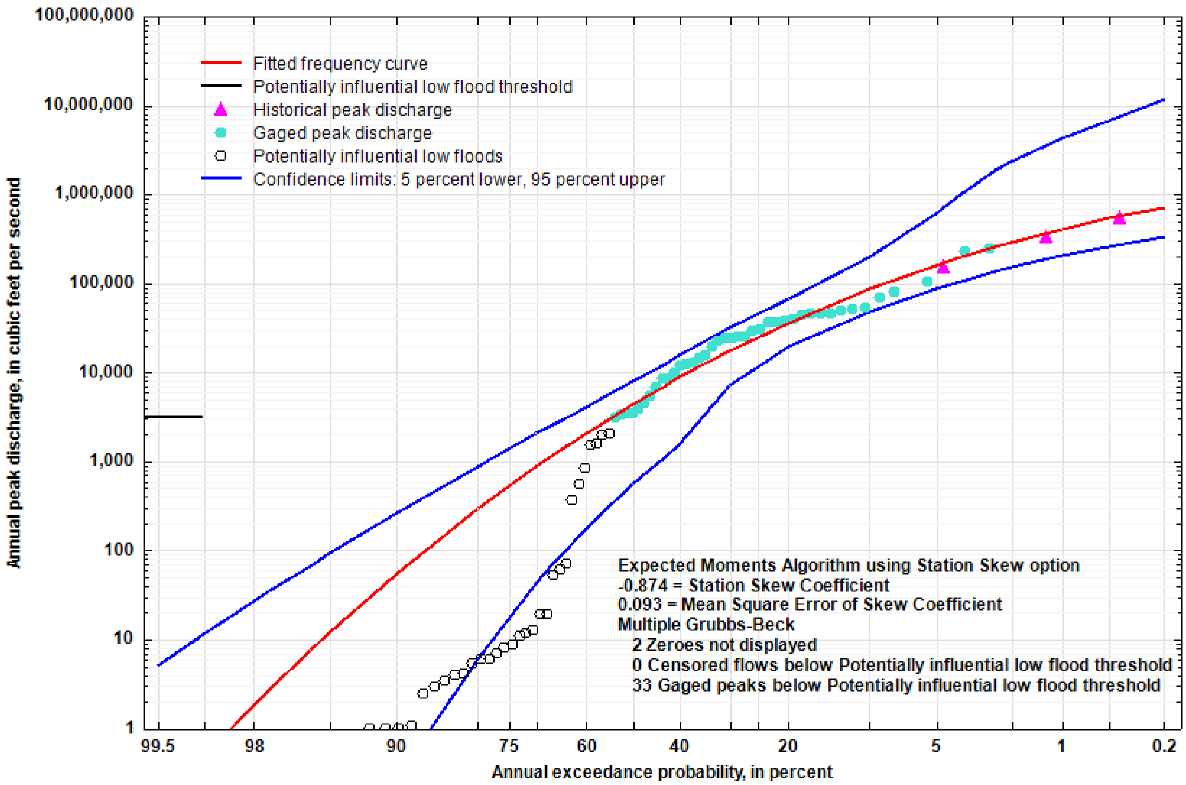


Figure A.21: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08190500 West Nueces River near Brackettville, Texas

08196000 Dry Frio River near Reagan Wells, Texas

The period of record at USGS streamgage 08196000 Dry Frio River near Reagan Wells, Tex. (hereinafter referred to as the “Dry Frio River near Reagan Wells streamgage”) was from 1953 through 2020. Two historical peaks of 30,700 and 64,700 cfs were recorded in 1932 and 1935 respectively and were included in the analysis. A historical peak stage of approximately 33 ft was noted in 1880. This peak is nearly 5 ft above the next highest recorded stage at the streamgage and well beyond the extrapolation limits of the rating curve. With little else known about this historical event, the event was set to a value greater than the largest peak in the observed record at 150,000 cfs and qualified with a peak code of 8 (peak streamflow is greater than the stated value). A peak code of 8 indicates that the streamflow is known to be greater than a certain value but could not be measured for reasons such as a streamgage being destroyed during a flood event or high-water marks not being available. In this case, a high-water mark was available, but it was recorded so long ago that the rating curve could not be used to provide a reasonable estimate. The missing record between 1880 and 1932 was set to the historical peak of 64,700 cfs as records indicate that no flooding greater than this occurred during that time frame. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 1966 peak streamflow of 123,000 cfs at a stage of 27.60 ft. A log-normal plot of the peak streamflows for each water year at the Dry Frio River near Reagan Wells streamgage is presented in Figure A.22, and the flood flow frequency is presented in Figure A.23. The skew was weighted by a regional value from Asquith and others (2021) (Table A.1). The low-outlier threshold was computed at 2,710 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 32 low outliers were identified.

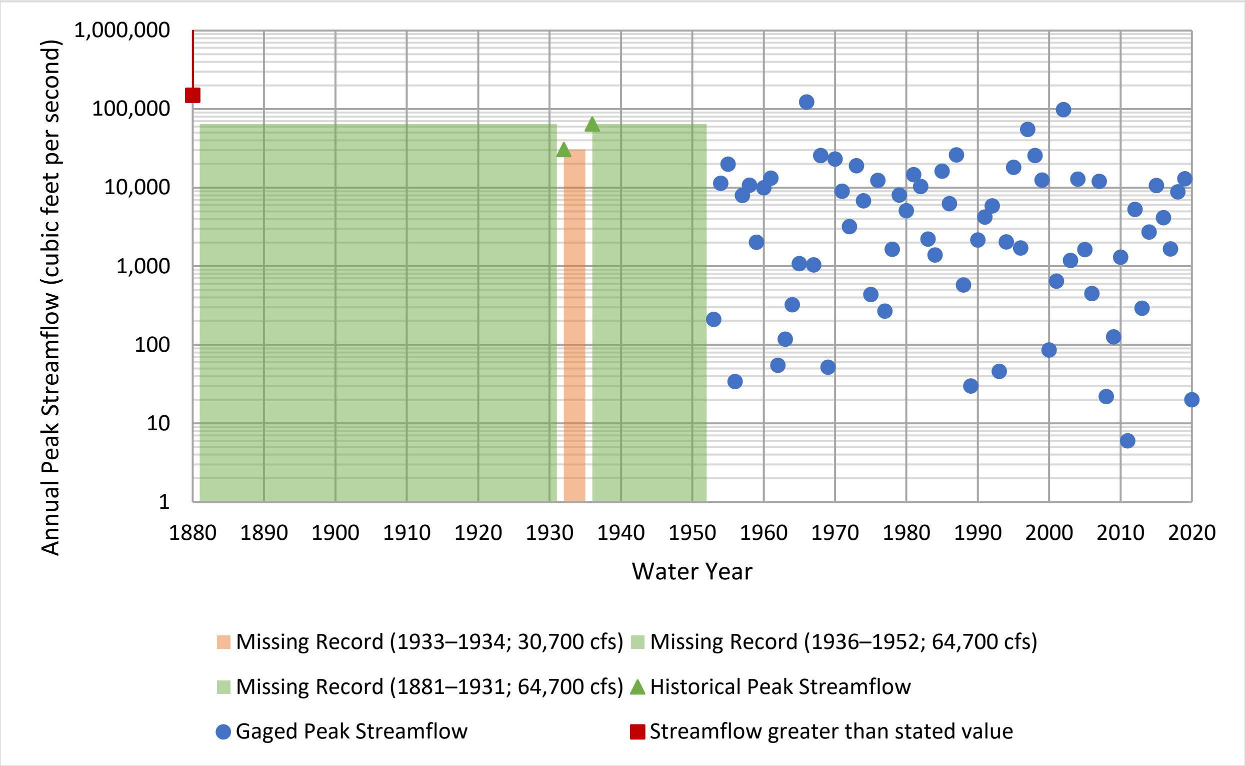


Figure A.22: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08196000 Dry Frio River near Reagan Wells, Texas

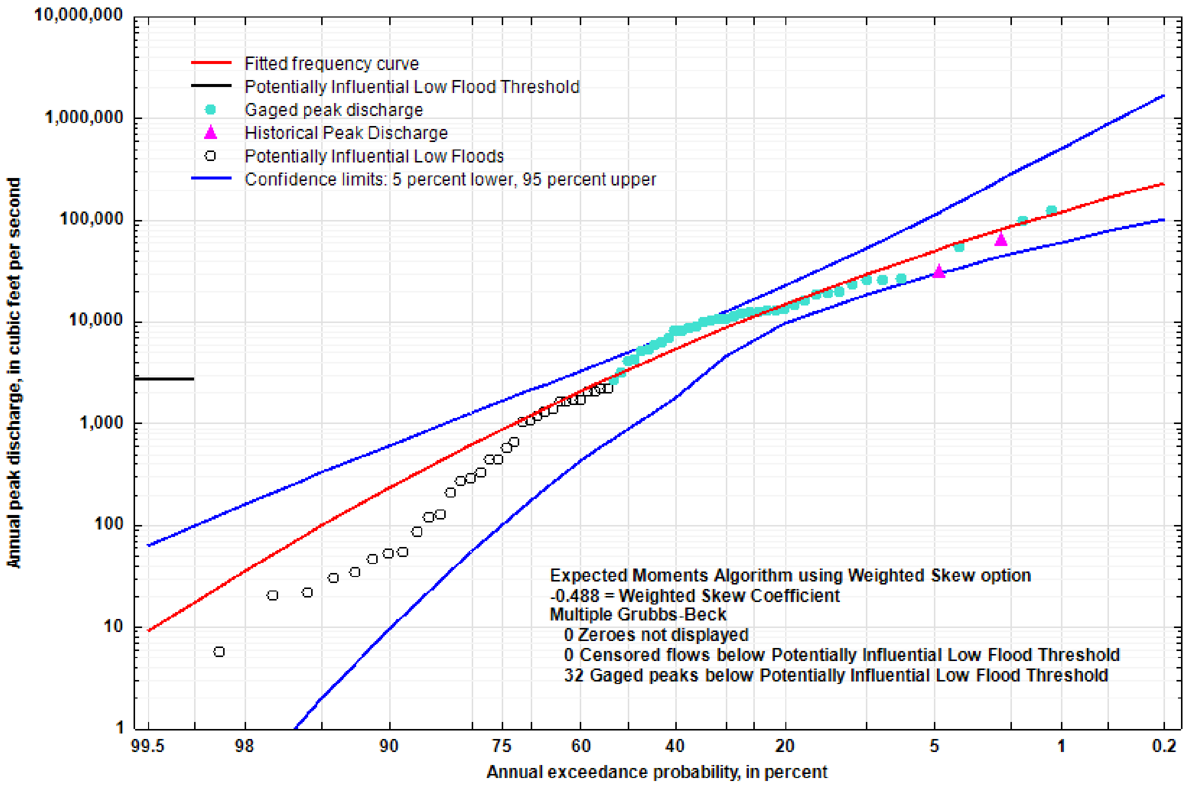


Figure A.23: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08196000 Dry Frio River near Reagan Wells, Texas

08195000 Frio River at Concan, Texas

The period of record at USGS streamgage 08195000 Frio River at Concan, Tex. (hereinafter referred to as the "Frio River at Concan streamgage") was from 1923 through 2020. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 1932 peak streamflow of 162,000 cfs at a stage of 34.44 ft. A log-normal plot of the peak streamflows for each water year at the Frio River at Concan streamgage is presented in Figure A.24, and the flood flow frequency is presented in Figure A.25. In order to obtain a better fit to the data and bring the skew closer to regional estimates, the skew was weighted by a regional value from Asquith and others (2021) (Table A.1). The low-outlier threshold was computed as 5,260 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold, 40 low outliers were identified.

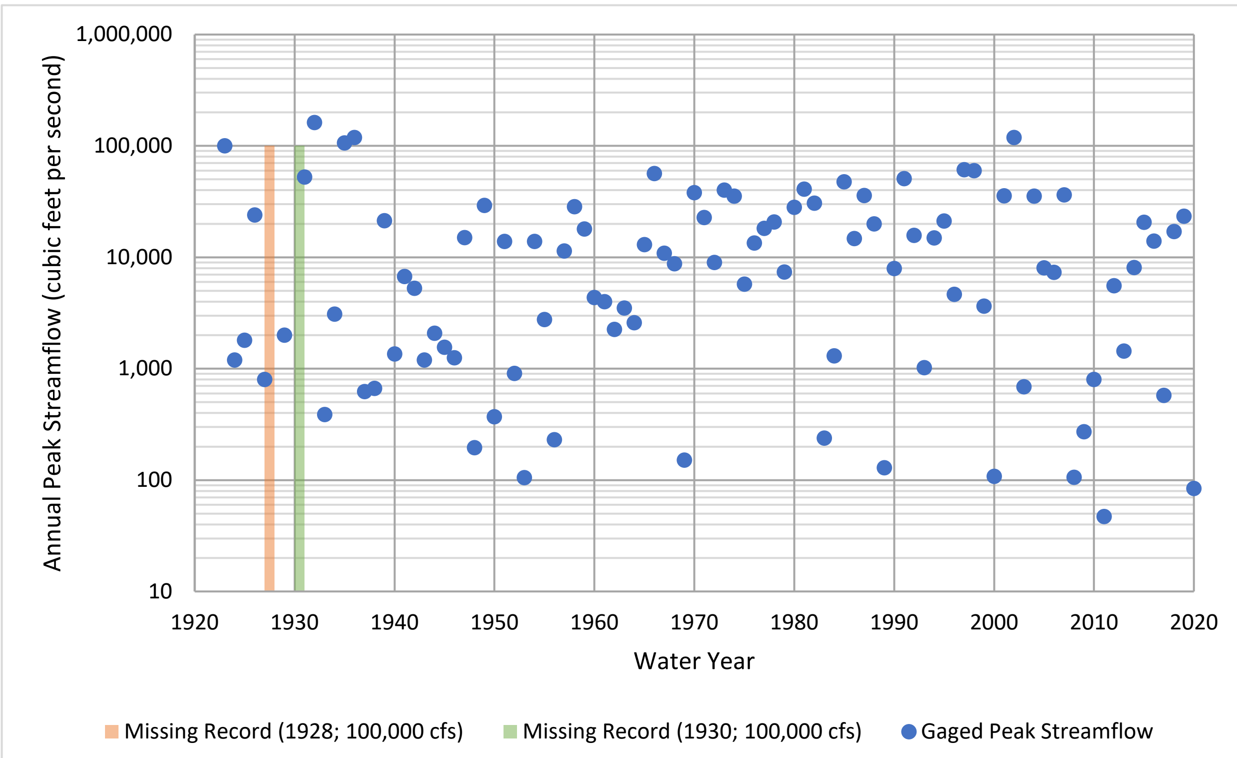


Figure A.24: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08195000 Frio River at Concan, Texas.

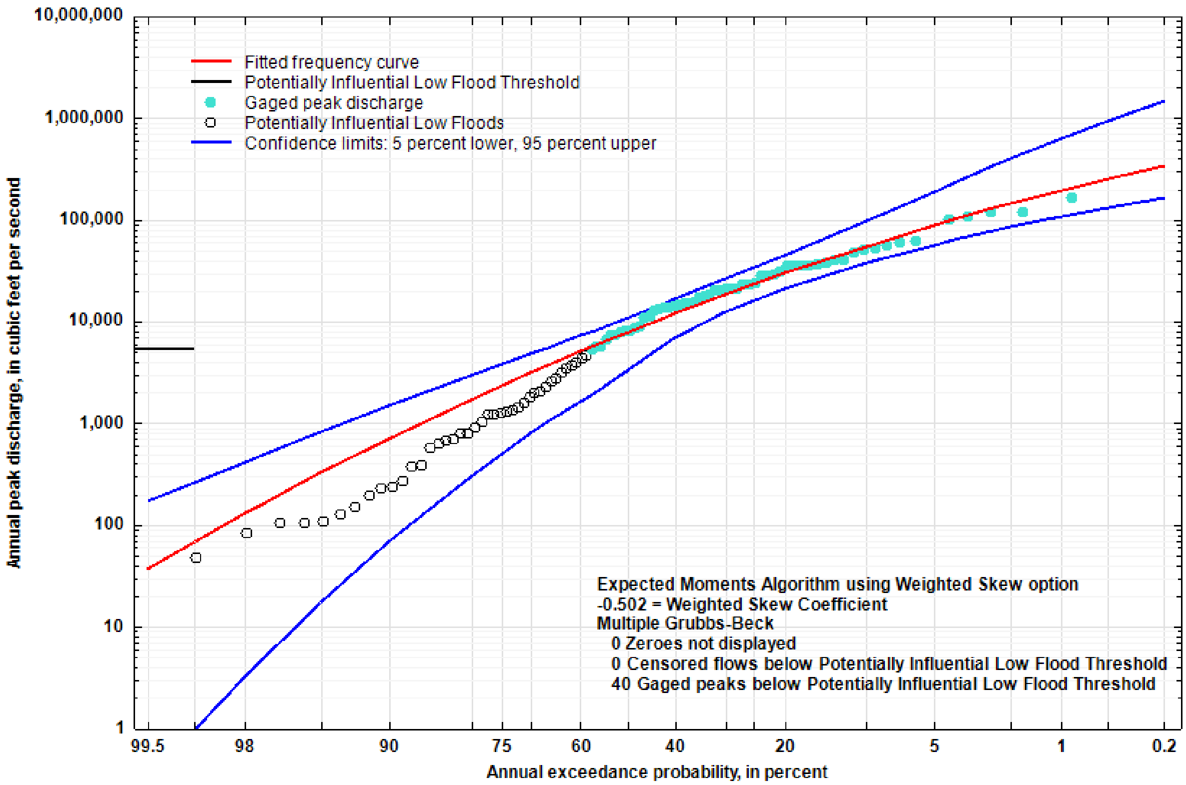


Figure A.25: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08195000 Frio River at Concan, Texas.

08197500 Frio River below Dry Frio River near Uvalde, Texas

The period of record at USGS streamgage 08197500 Frio River below Dry Frio River near Uvalde, Tex. (hereinafter referred to as the "Frio River near Uvalde streamgage") was from 1952 through 2020. Historical peak stages are available in 1894 and 1932. The USGS rating curve was used to provide estimates of these historical peaks and add them to the statistical analysis. The 1894 historical peak of 35 ft was estimated at 191,000 cfs, and the 1932 peak of 30 ft was estimated at 143,000 cfs. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 2002 peak streamflow of 189,000 cfs at a stage of 34.82 ft. A log-normal plot of the peak streamflows for each water year at the Frio River near Uvalde streamgage is presented in Figure A.26, and the flood flow frequency is presented in Figure A.27. The low-outlier threshold was computed as 3,660 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 15 zero-flow and 10 low outliers were identified.

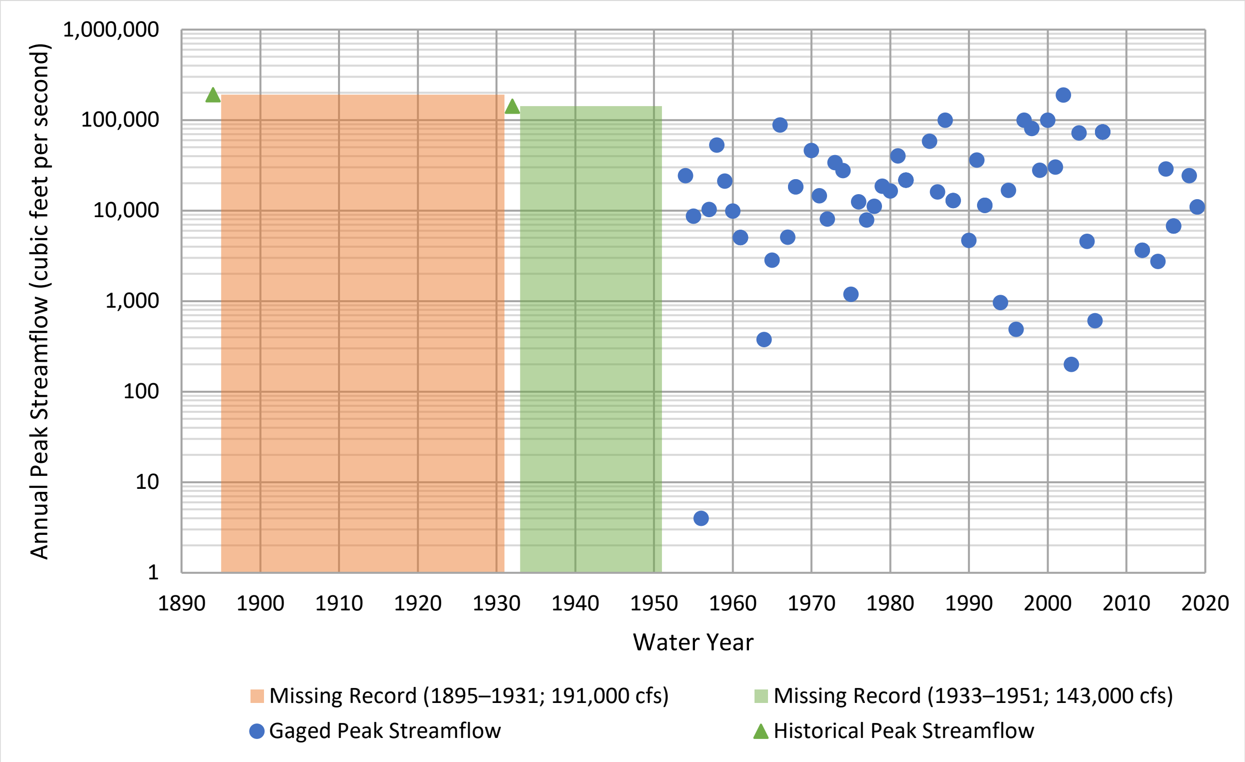


Figure A.26: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08197500 Frio River below Dry Frio River near Uvalde, Texas.

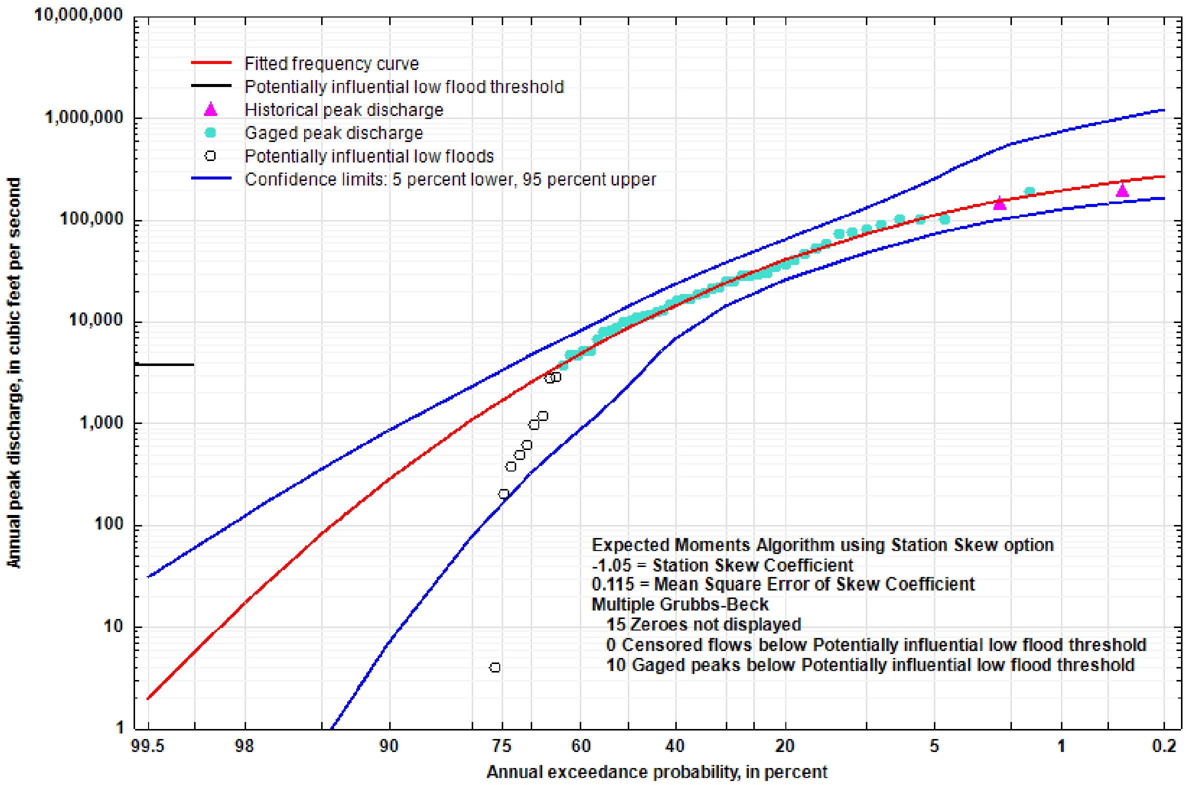


Figure A.27: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08197500 Frio River below Dry Frio River near Uvalde, Texas.

08205500 Frio River near Derby, Texas

The period of record at USGS streamgage 08205500 Frio River near Derby, Tex. (hereinafter referred to as the “Frio River near Derby streamgage”) was from 1916 through 2020. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 1932 peak streamflow of 230,000 cfs at a stage of 29.45 ft. A log-normal plot of the peak streamflows for each water year at the Frio River near Derby streamgage is presented in Figure A.28, and the flood flow frequency is presented in Figure A.29. The low-outlier threshold was manually set at 3,000 cfs, and 39 low outliers were identified.

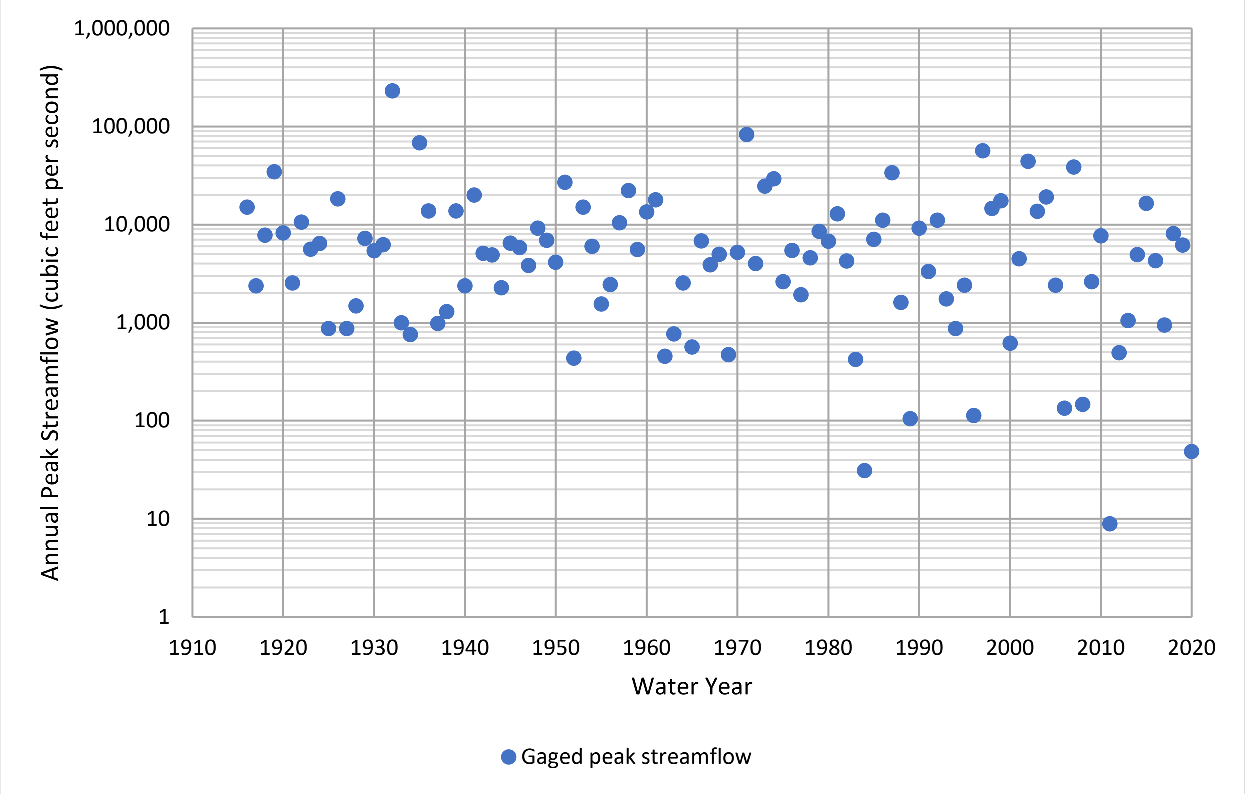


Figure A.28: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08205500 Frio River near Derby, Texas.

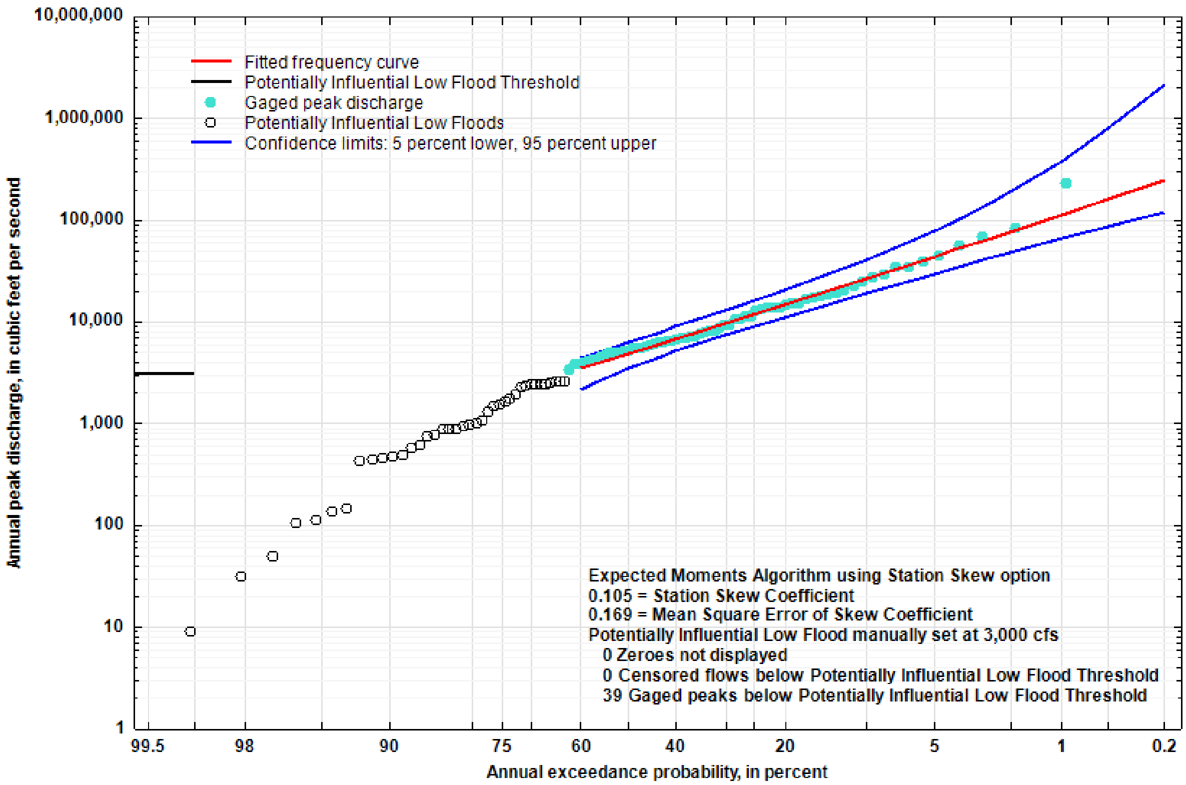


Figure A.29: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08205500 Frio River near Derby, Texas.

08206600 Frio River at Tilden, Texas

The period of record at USGS streamgage 08206600 Frio River at Tilden, Tex. (hereinafter referred to as the “Frio River at Tilden streamgage”) was from 1979 through 2020. A significant change point in the data was not identified. However, by applying the Kendall’s *tau* test a significant downward trend in the annual peak streamflow record was identified (Table A.1).

The largest peak in the gaged period of record is the 2002 peak streamflow of 33,000 cfs at a stage of 30.29 ft. A log-normal plot of the peak streamflows for each water year at the Frio River at Tilden streamgage is presented in Figure A.30, and the flood flow frequency is presented in Figure A.31. The low-outlier threshold was computed as 476 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold five low outliers were identified.

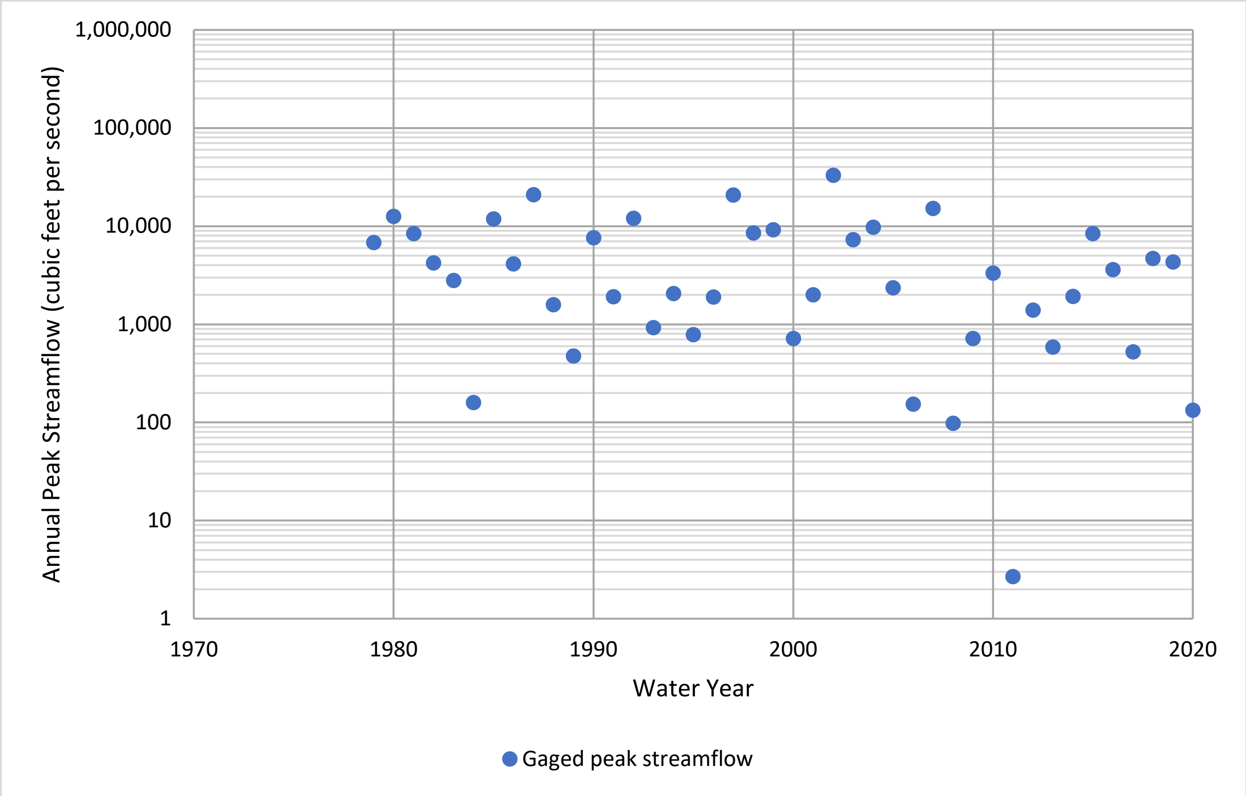


Figure A.30: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08206600 Frio River at Tilden, Texas.

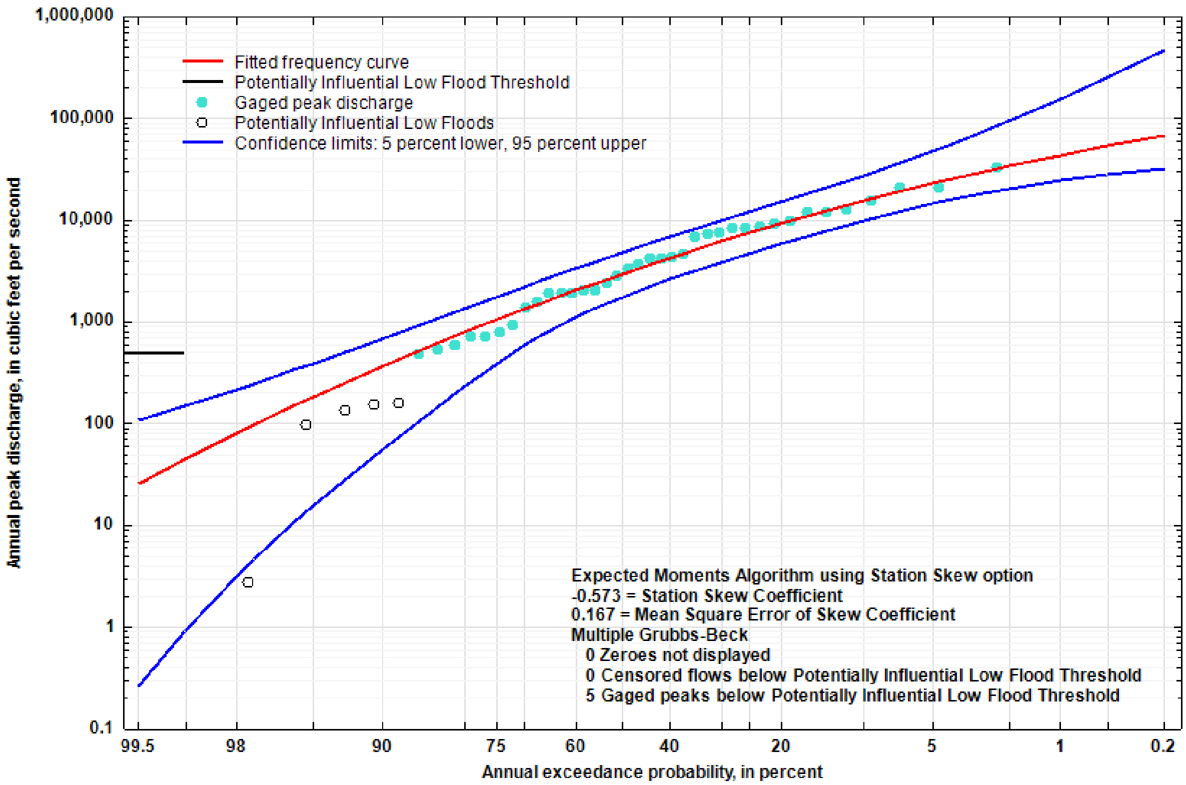


Figure A.31: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08206600 Frio River at Tilden, Texas.

08206600 Frio River at Tilden, Texas (alternative analysis)

In 1932, a peak stage of 38.44 ft was measured at the Frio River at Tilden streamgage. However, this peak is 8 ft greater than the next-highest recorded peak in 2002, and the rating curve at the streamgage (which terminates at 31 ft and 40,000 cfs) cannot be used to estimate the streamflow from this stage. To use the notable peak stage in 1932 and increase the reliability of the estimates at the Frio River at Tilden streamgage, record extension was performed with the MOVE.1 method (Hirsch, 1982; Hirsch and Gilroy, 1984; Vogel and Stedinger, 1985) using the USGS Streamflow Record Extension Facilitator (SREF) software (Granato, 2008). Two index stations were used: the upstream streamgage of 08205500 Frio River at Derby, Tex., and the streamgage downstream decommissioned as a result of the construction of Choke Canyon Reservoir, 08207000 Frio River at Calliham, Tex. The Frio River at Calliham streamgage was downstream from San Miguel Creek. Two other streamgages were considered as input for record extension but were not included because of poor correlation to the Frio River at Tilden streamgage. These were the Atascosa River at Whitsett streamgage and the Nueces River near Tilden streamgage. The extended period of record for the alternative analysis at the Frio River at Tilden was from 1925 through 2020.

Two Maintenance of Variance for Record Extension (MOVE) techniques were considered for extending records. Ultimately, the MOVE.1 method was chosen over MOVE.3 method (Vogel and Stedinger, 1985) for two reasons. First, because the MOVE.1 method provided higher streamflow estimates, which in turn should provide more conservative return interval estimates. Second, while both techniques can estimate records when the short-record site is missing data, the MOVE.1 method produces estimators from data sampled only during the concurrent period of record, while the MOVE.3 method uses the entire periods of record from both sites to produce estimators. In this analysis, only two index streamgages were used due to the lack of appropriate index streamgages nearby, and MOVE.1 was chosen to avoid using estimators from only one index streamgage. A simple drainage area ratio was applied to the Frio River at Calliham to estimate peak streamflow at the Nueces River at Tilden streamgage as well. However, the MOVE.1 methodology was considered to be more robust in this instance because it incorporates data from two streamgages instead of one and because of the unknown influence of San Miguel Creek, which enters between the two streamgages and only has records going back to 1964. Ultimately though, the two estimates produced similar results except for the 1932 peak of record, for which the two methods produced widely different estimates. This is most likely because of the unique characteristics of the 1932 flood. The flood of 1932 originated in early July of 1932 from heavy precipitation in the steeply sloped upstream part of the Nueces River watershed, which resulted in a flood wave that decreased in magnitude as it migrated downstream. The Frio River, Dry Frio River, Sabinal River, Seco Creek, and Hondo Creek all recorded noteworthy annual peak streamflows on either July 1 or July 2, 1932. On July 4, 1932, a peak streamflow of 230,000 cfs was recorded at the Frio River near Derby streamgage. Two days later, a peak of 80,200 cfs was recorded at the now defunct Frio River at Calliham streamgage.

Therefore, the 1932 peak streamflow at Tilden was highly likely to be somewhere between these two values. Because the Tilden streamgage is approximately halfway between the Derby and Calliham streamgages (1,064 square mile [sq. mi.] increase in drainage area from Derby to Tilden; 998 sq. mi. drainage area increase from Tilden to Calliham), a simple average of the peak streamflows from the two streamgages was used to provide an estimate at Tilden. To accommodate this uncertainty, an interval peak streamflow was input into PeakFQ for the 1932 peak streamflow spanning the average estimate of 155,000 cfs to the MOVE.1 estimate of 162,000 cfs.

A log-normal plot of the peak streamflows for each water year at the Frio River at Tilden streamgage is presented in Figure A.32, and the flood flow frequency is presented in Figure A.33. The low-outlier threshold was computed as 1,375 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 17 low outliers were identified. The alternative analysis maintains the original analysis' statistically significant downward trend.

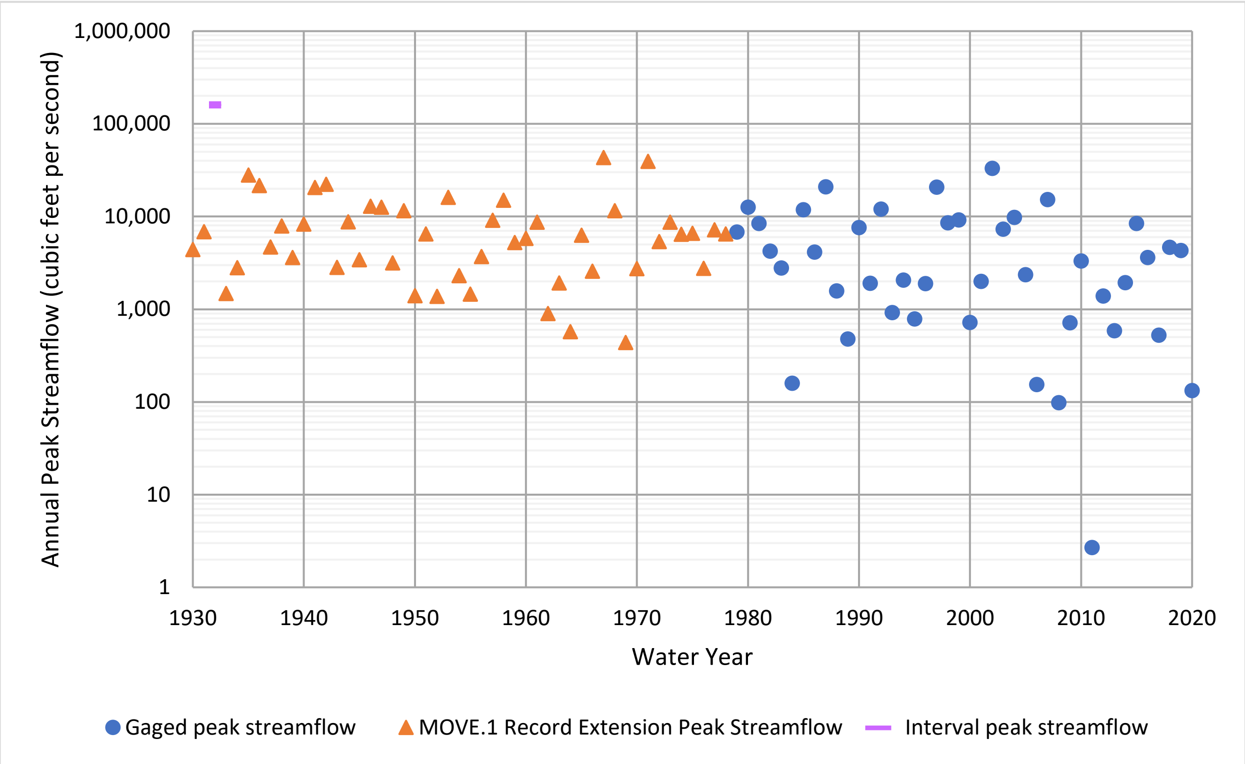


Figure A.32: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08206600 Frio River at Tilden, Texas (alternative analysis).

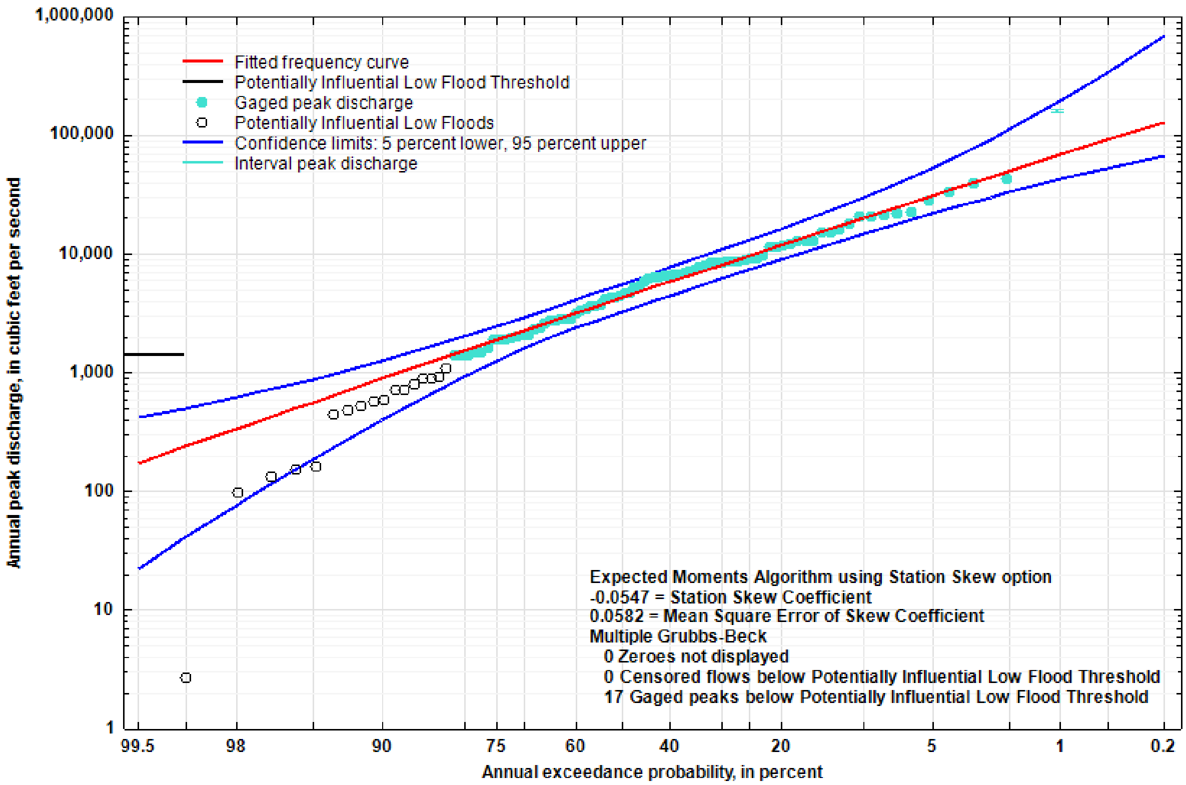


Figure A.33: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08206600 Frio River at Tilden, Texas (alternative analysis).

08206700 San Miguel Creek near Tilden, Texas

The period of record at USGS streamgage 08206700 San Miguel Creek near Tilden, Tex. (hereinafter referred to as the "San Miguel Creek near Tilden streamgage") was from 1964 through 2020. All peak streamflow is qualified with peak code 5 in NWIS, indicating "streamflow [is] affected to [an] unknown degree by regulation or diversion" (USGS, 2021). Five historical peak stages are available in 1925, 1942, 1946, 1956, and 1958. The 1946, 1956, and 1958 historical stages were converted to streamflow estimates of 19,500, 13,400, and 4,310 cfs respectively using the rating curve. The 1925 and 1942 peak stages used extrapolated rating curve values, which inherently contain greater uncertainty. Therefore, the peak stages from 1925 and 1942 were converted to interval peaks streamflow values of 43,700 to 52,900 cfs and 40,500 to 46,400 cfs, respectively.

A significant change point in water year 1994 was identified by applying the Pettitt test, but this change point does not appear to coincide with any known streamflow event or reservoir construction. A significant downward trend in the annual peak streamflow record was identified by applying the Kendall's *tau* test (Table A.1).

The largest peak in the gaged period of record is the 2002 peak streamflow of 29,500 cfs at a stage of 31.64 ft. A log-normal plot of the peak streamflows for each water year at the San Miguel Creek near Tilden streamgage is presented in Figure A.34, and the flood flow frequency is presented in Figure A.35. The low-outlier threshold was computed as 126 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold one low outlier was identified.

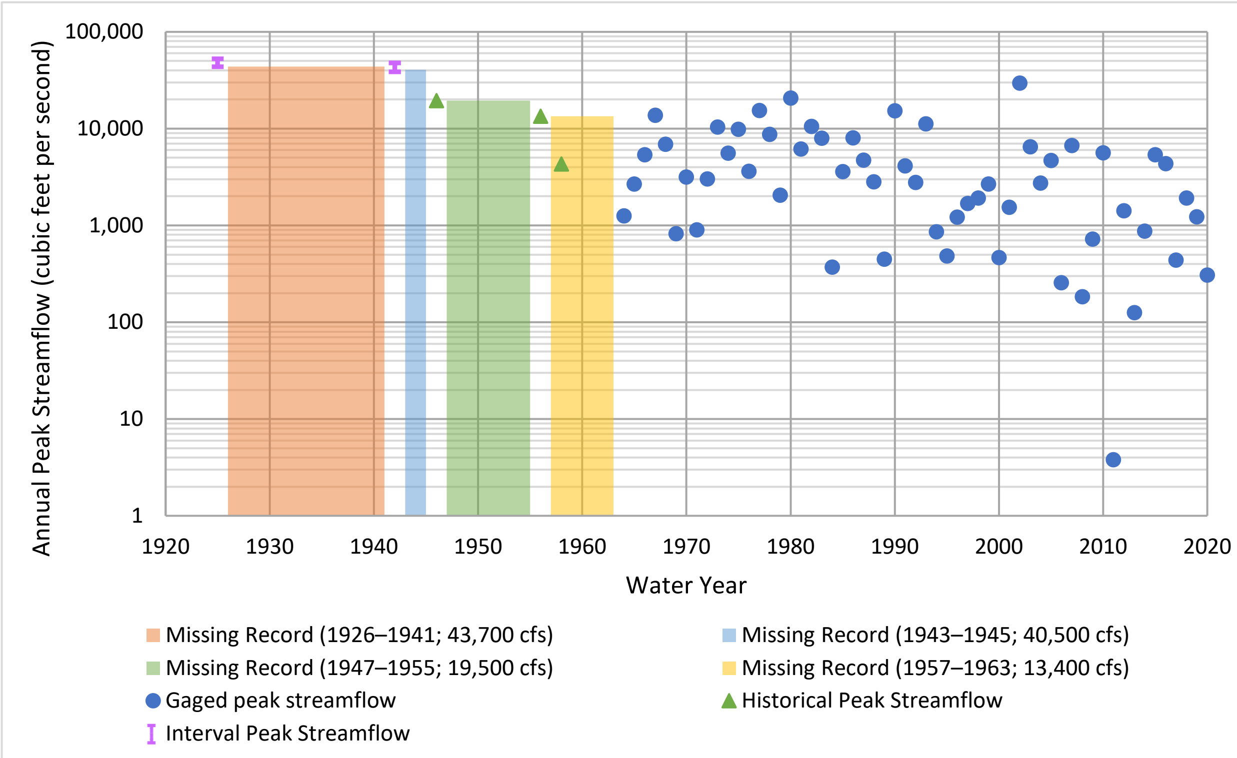


Figure A.34: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08206700 San Miguel Creek near Tilden, Texas.

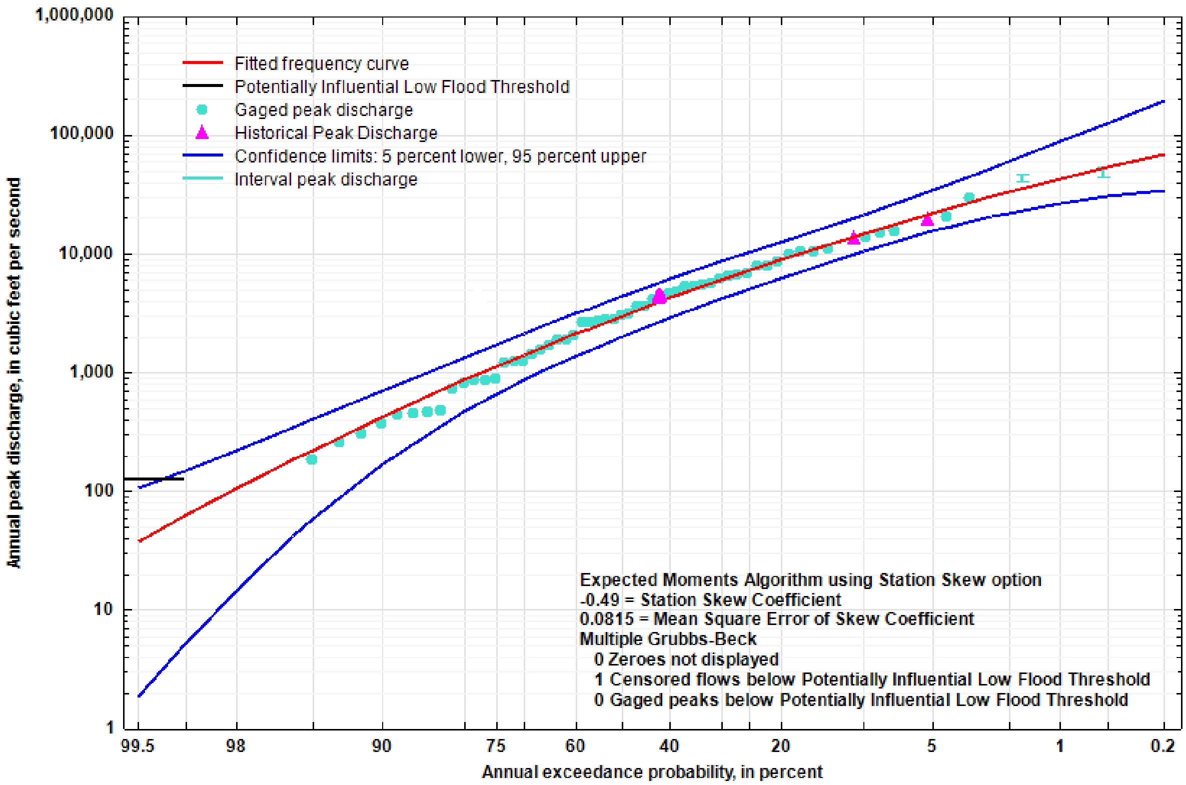


Figure A.35: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08206700 San Miguel Creek near Tilden, Texas.

08198000 Sabinal River near Sabinal, Texas

The period of record at USGS streamgage 08198000 Sabinal River near Sabinal, Tex. (hereinafter referred to as the "Sabinal River near Sabinal streamgage") was from 1943 through 2020. A historical peak stage of 29 ft was observed at the old streamgage location in 1932, and the USGS rating curve was used to provide a streamflow estimate of 59,000 cfs which was used in the analysis. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 2002 peak streamflow of 108,000 cfs at a stage of 33.74 ft. A log-normal plot of the peak streamflows for each water year at the Sabinal River near Sabinal streamgage is presented in Figure A.36, and the flood flow frequency is presented in Figure A.37. The low-outlier threshold was computed as 5,320 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 35 low outliers were identified.

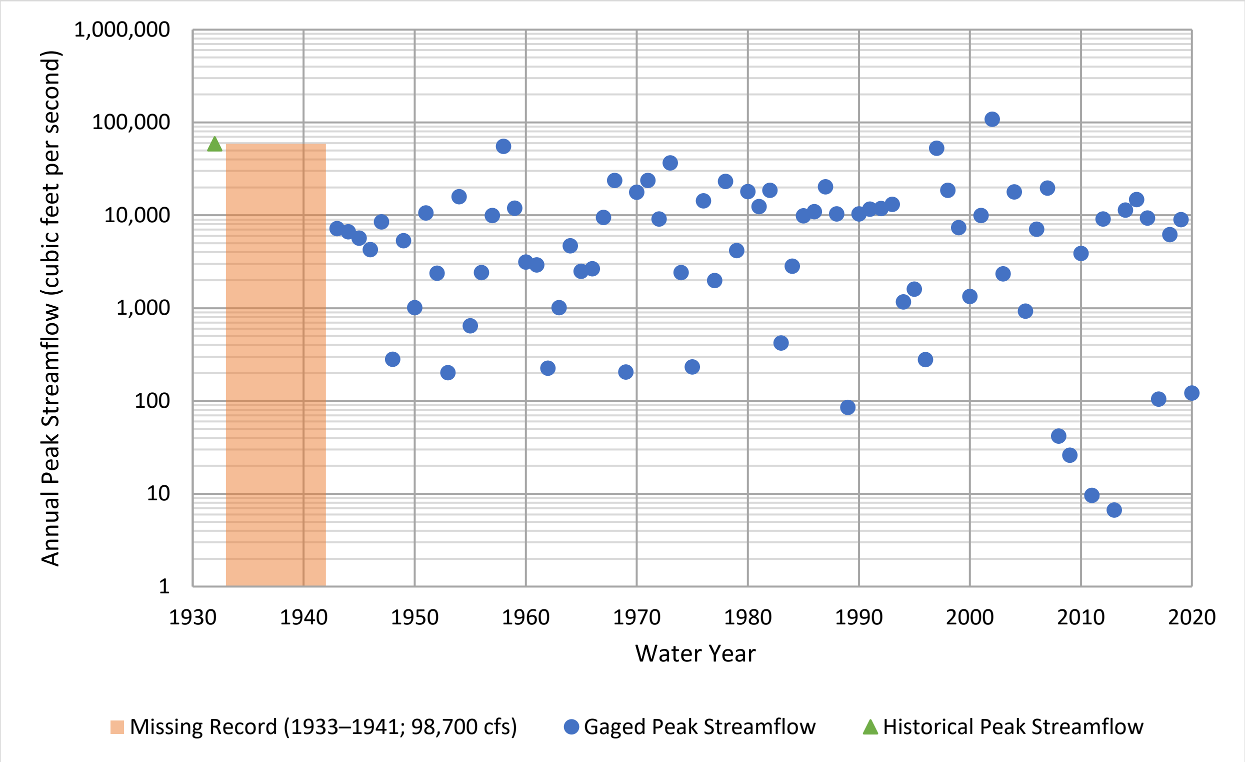


Figure A.36: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08198000 Sabinal River near Sabinal, Texas.

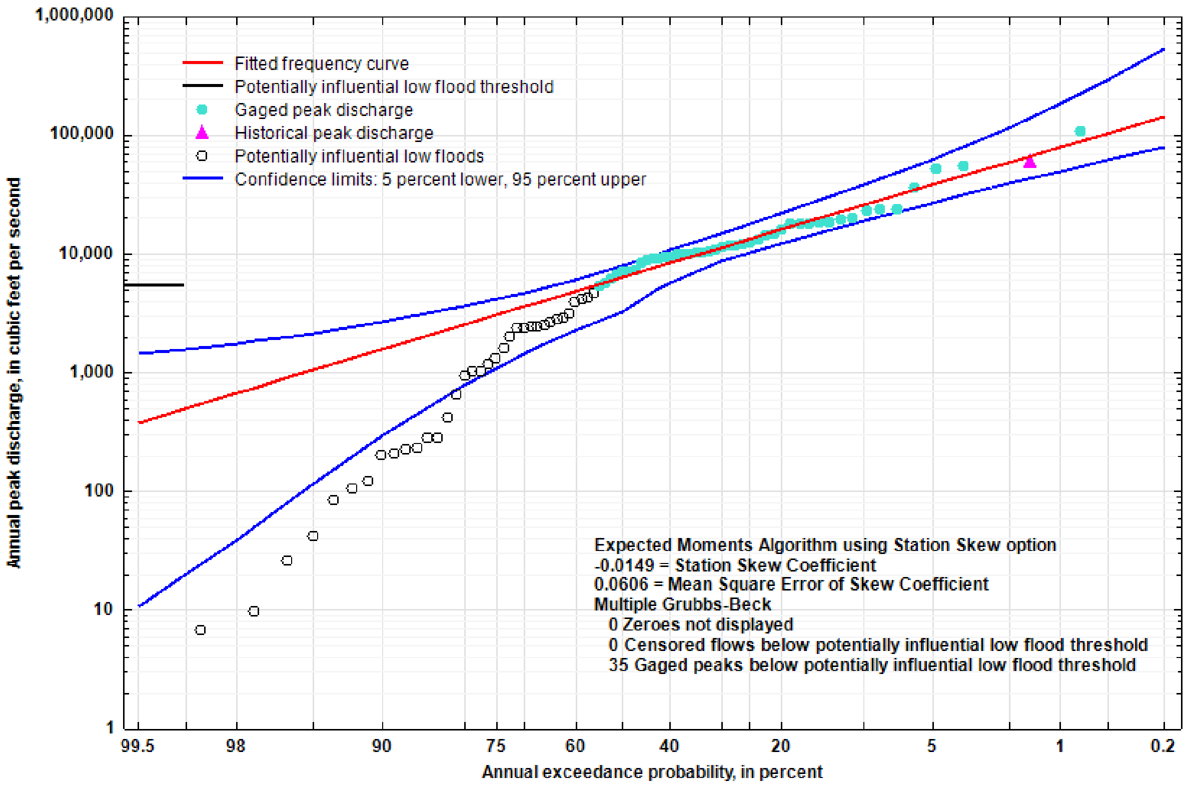


Figure A.37: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08198000 Sabinal River near Sabinal, Texas.

08198500 Sabinal River at Sabinal, Texas

The period of record at USGS streamgage 08198500 Sabinal River at Sabinal, Tex. (hereinafter referred to as the "Sabinal River at Sabinal streamgage") was from 1953 through 2020. A historical peak of 60,000 cfs was recorded in 1932 and was included in the analysis. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 2002 peak streamflow of 119,000 cfs at a stage of 39.00 ft. A log-normal plot of the peak streamflows for each water year at the Sabinal River at Sabinal streamgage is presented in Figure A.38, and the flood flow frequency is presented in Figure A.39. The skew was weighted by a regional value from Asquith and others (2021) (Table A.1). It was determined that the MGBT choice of low-outlier threshold (3,380 cfs) missed a clear inflection point at approximately, 6,000 cfs. Therefore, the low-outlier threshold was manually set at 6,000 cfs, and 34 low outliers were identified.

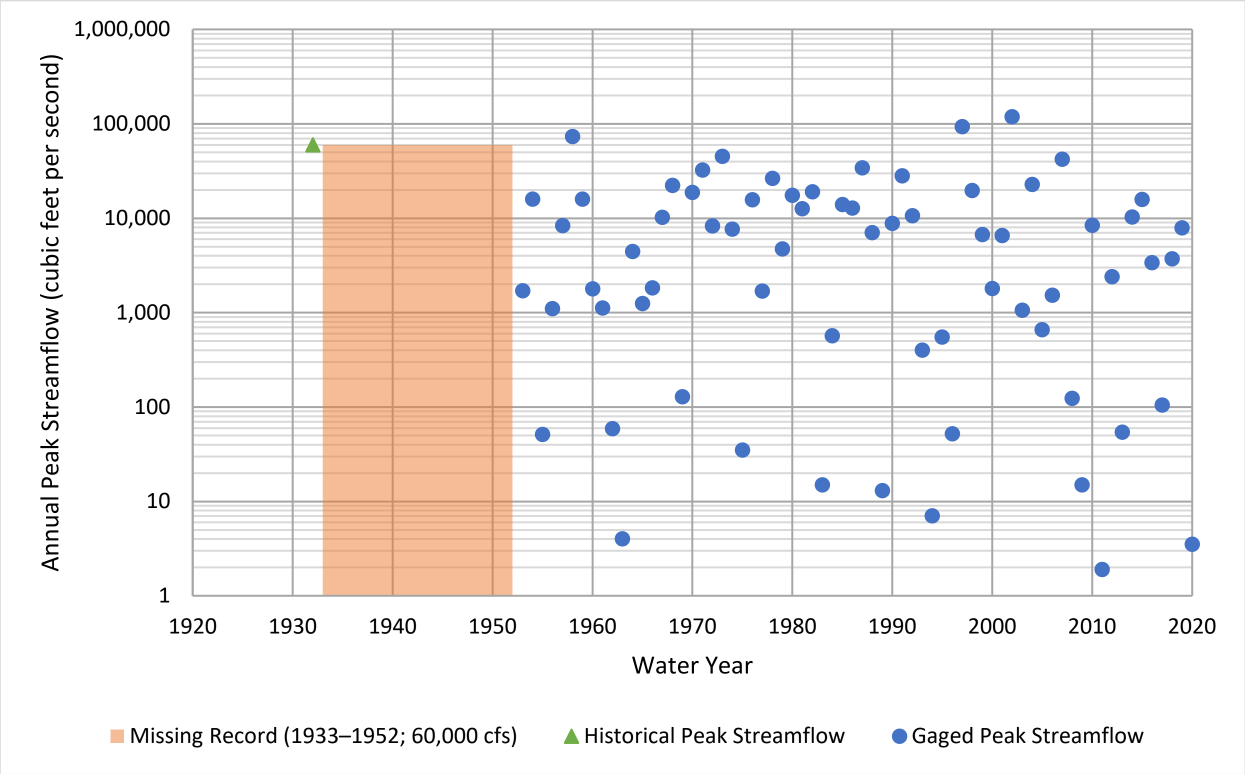


Figure A.38: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08198500 Sabinal River at Sabinal, Texas.

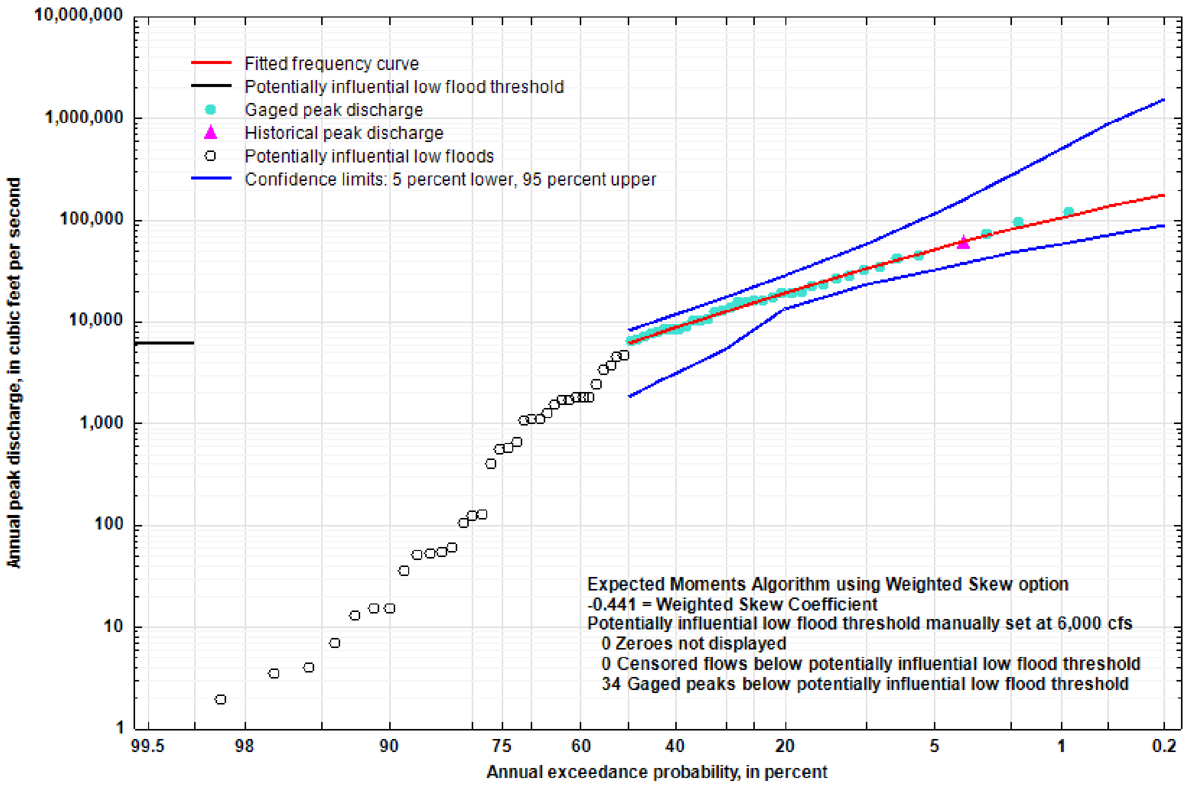


Figure A.39: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08198500 Sabinal River at Sabinal, Texas.

08201500 Seco Creek at Miller Ranch near Utopia, Texas

The period of record at USGS streamgage 08201500 Seco Creek at Miller Ranch near Utopia, Tex. (hereinafter referred to as the "Seco Creek near Utopia streamgage") was from 1962 through 2020. A historical peak of 52,600 cfs was recorded in 1958 and was included in the analysis. The annual peak streamflow of 11,800 cfs for water year 2016 is qualified with code 8 in NWIS, indicating "discharge [is] actually greater than indicated value" (USGS, 2021). A peak code of 8 indicates that the streamflow is known to be greater than a certain value but could not be measured for reasons such as a streamgage being destroyed during a flood event or high-water marks not being available. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 1997 peak streamflow of 64,900 cfs at a stage of 17.70 ft. A log-normal plot of the peak streamflows for each water year at the Seco Creek near Utopia streamgage is presented in Figure A.40, and the flood flow frequency is presented in Figure A.41. The low-outlier threshold was computed as 1,220 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 23 low outliers were identified.

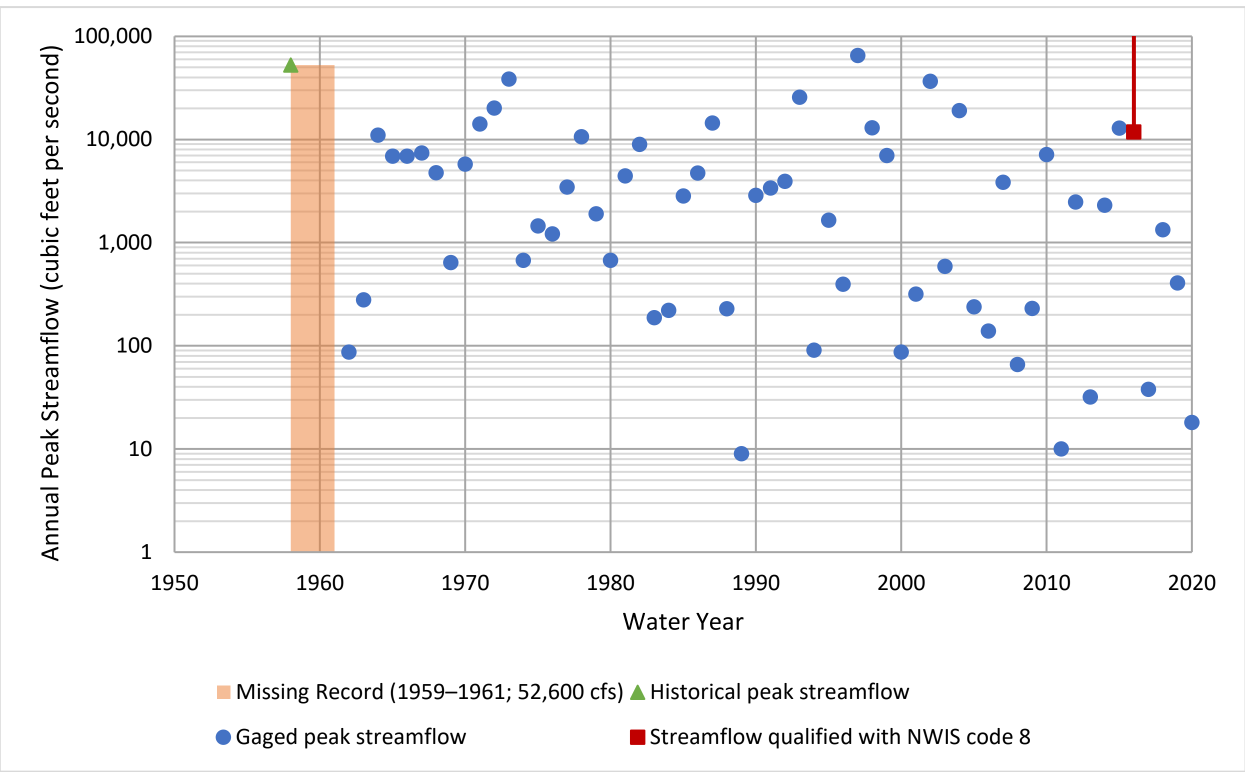


Figure A.40: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08201500 Seco Creek at Miller Ranch near Utopia, Texas. Streamflow qualified with NWIS code 8 indicates "streamflow [is] actually greater than indicated value" (USGS, 2021).

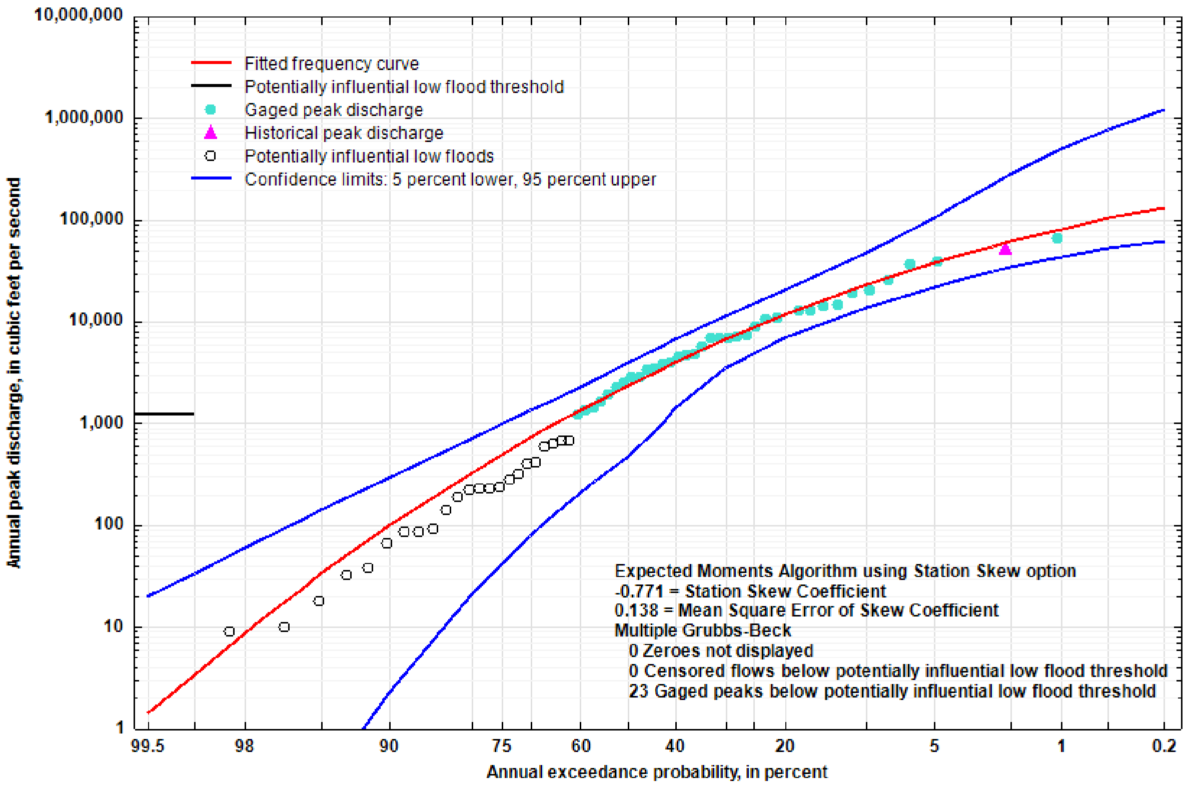


Figure A.41: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08201500 Seco Creek at Miller Ranch near Utopia, Texas.

08202700 Seco Creek at Rowe Ranch near D'Hanis, Texas

The period of record at USGS streamgage 08202700 Seco Creek at Rowe Ranch near D'Hanis, Tex. (hereinafter referred to as the "Seco Creek near D'Hanis streamgage") was from 1961 through 2020. A historical peak of 35,800 cfs was recorded in 1932 and was included in the analysis. Additionally, four peak stages of 33, 28, 35.7, and 32.4 ft with no associated streamflow were recorded at the streamgage in 1894, 1919, 1935, and 1958 respectively. The rating curve for the streamgage was used to provide streamflows of 35,600 and 51,300 cfs for the 1919 and 1958 historical peaks respectively. Additionally, the rating curve was extrapolated to provide an estimate of 53,600 cfs for the 1894 historical peak. Although the stage from the 1935 historical peak is listed in NWIS as only 3 ft greater than the stage for the 1894 peak, the peak streamflow for the 1935 flooding event was computed as 230,000 cfs by Dalrymple (1939)—more than four times the peak streamflow estimated for the 1894 flooding event.

Despite the absence of a statistically significant change point in the data, a statistically significant positive (upward) trend in the annual peak streamflow record was identified (Table A.1). The largest peak in the gaged period of record is the 2007 peak streamflow of 52,200 cfs at a stage of 32.64 ft. A log-normal plot of the peak streamflows for each water year at the Seco Creek near D'Hanis streamgage is presented in Figure A.42, and the flood flow frequency is presented in Figure A.43. The low-outlier threshold was computed as 2,180 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 10 low outliers were identified as well as 18 zero-flow years.

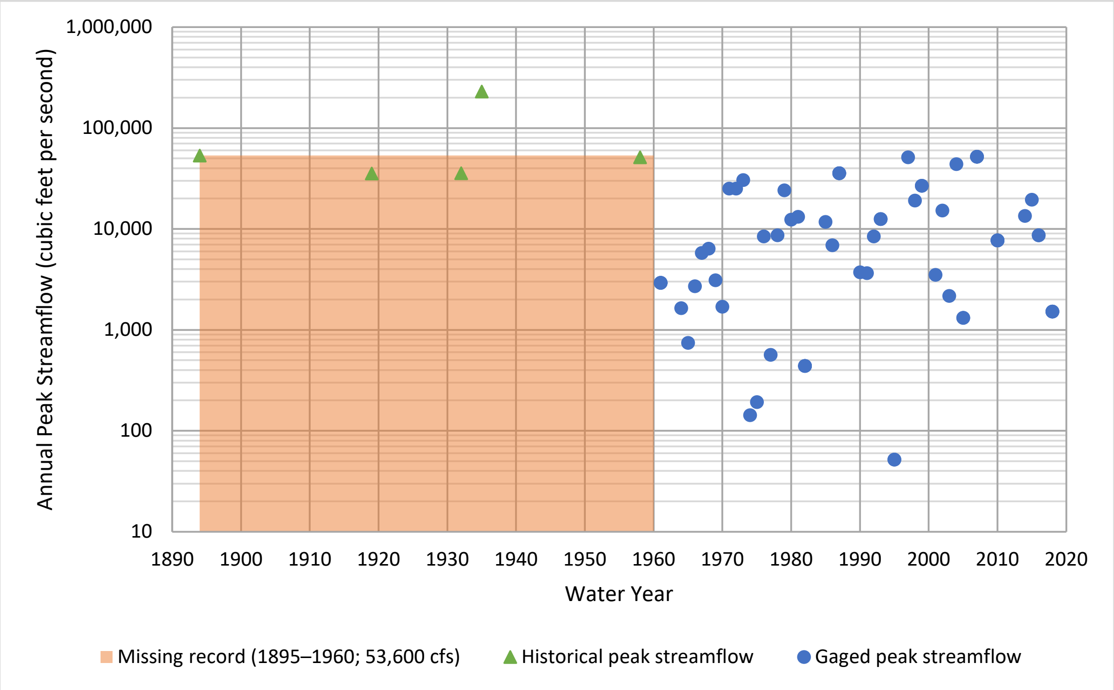


Figure A.42: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08202700 Seco Creek at Rowe Ranch near D'Hanis, Texas.

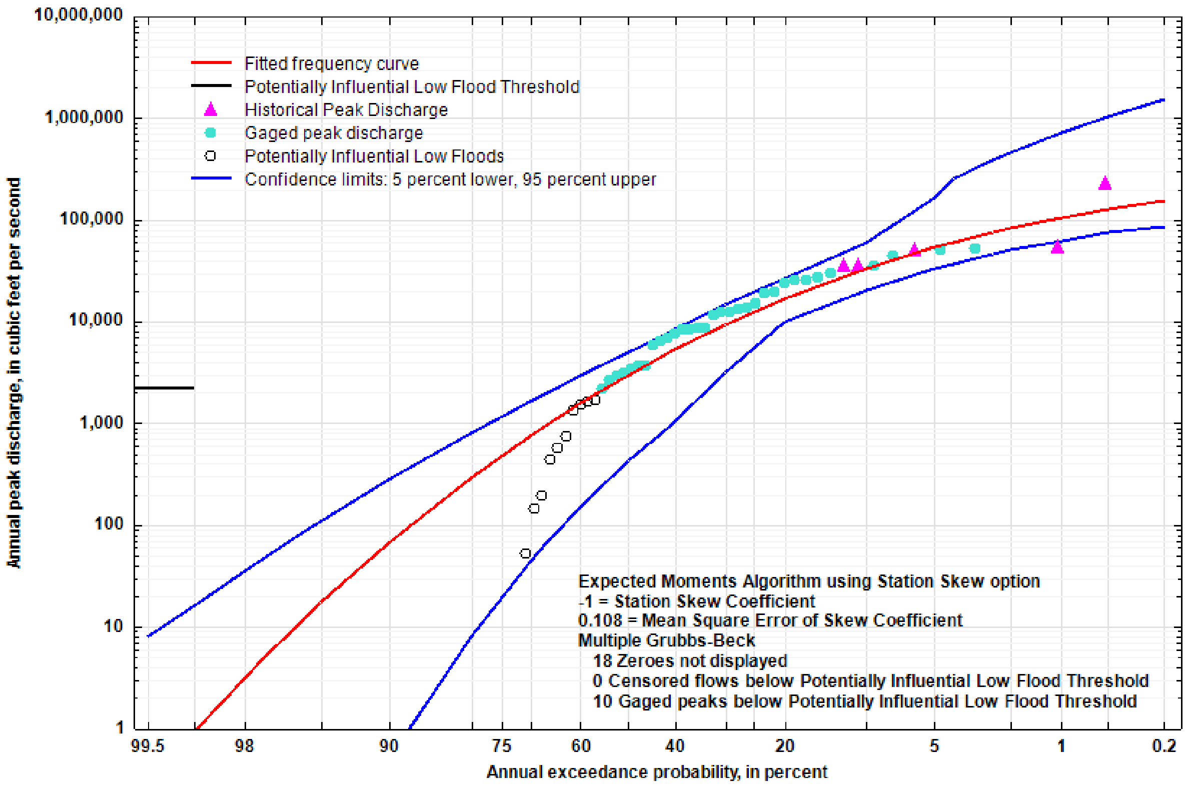


Figure A.43: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08202700 Seco Creek at Rowe Ranch near D'Hanis, Texas.

08200000 Hondo Creek near Tarpley, Texas

The period of record at USGS streamgage 08200000 Hondo Creek near Tarpley, Tex. (hereinafter referred to as the "Hondo Creek near Tarpley streamgage") was from 1953 through 2020. A historical peak of 58,500 cfs was recorded in 1932 and was included in the analysis. Neither a statistically significant change point nor a trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the gaged period of record is the 1997 peak streamflow of 76,900 cfs at a stage of 29.64 ft. A log-normal plot of the peak streamflows for each water year at the Hondo Creek near Tarpley streamgage is presented in Figure A.44, and the flood flow frequency is presented in Figure A.45. The low-outlier threshold was computed as 1,020 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold 15 low outliers were identified.

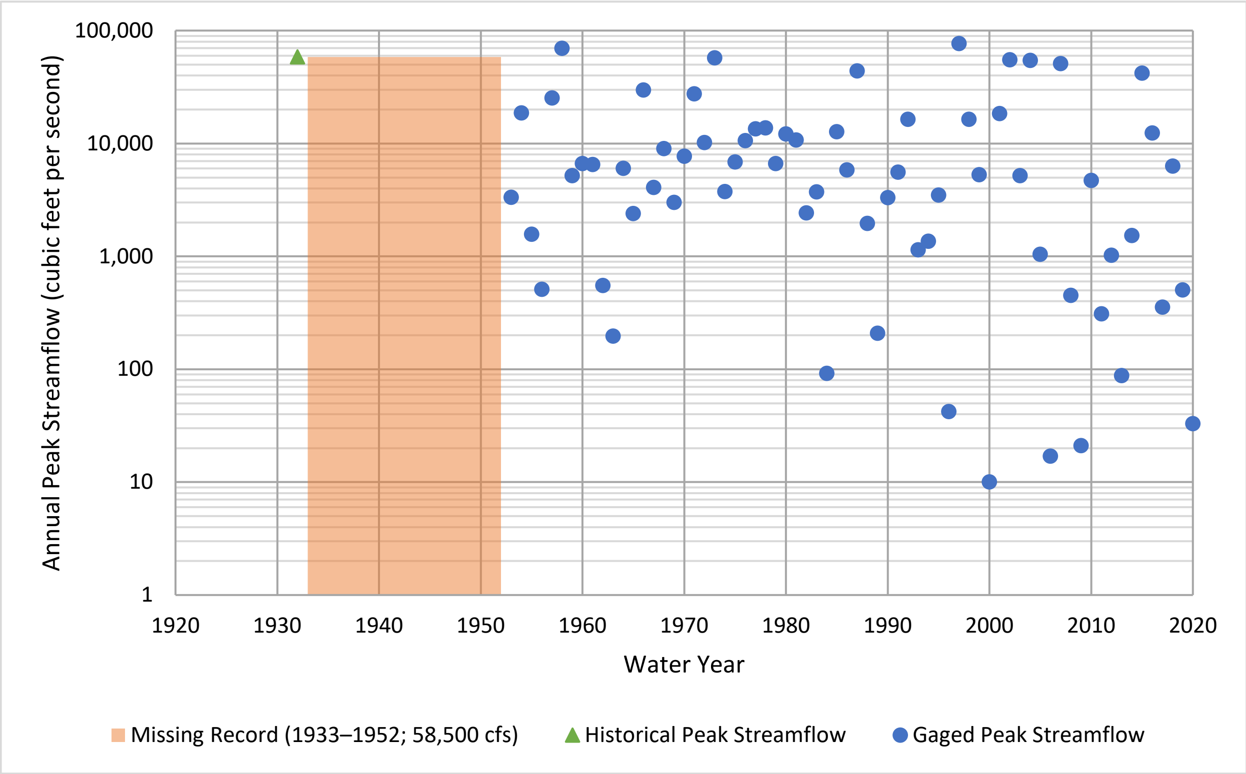


Figure A.44: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08200000 Hondo Creek near Tarpley, Texas.

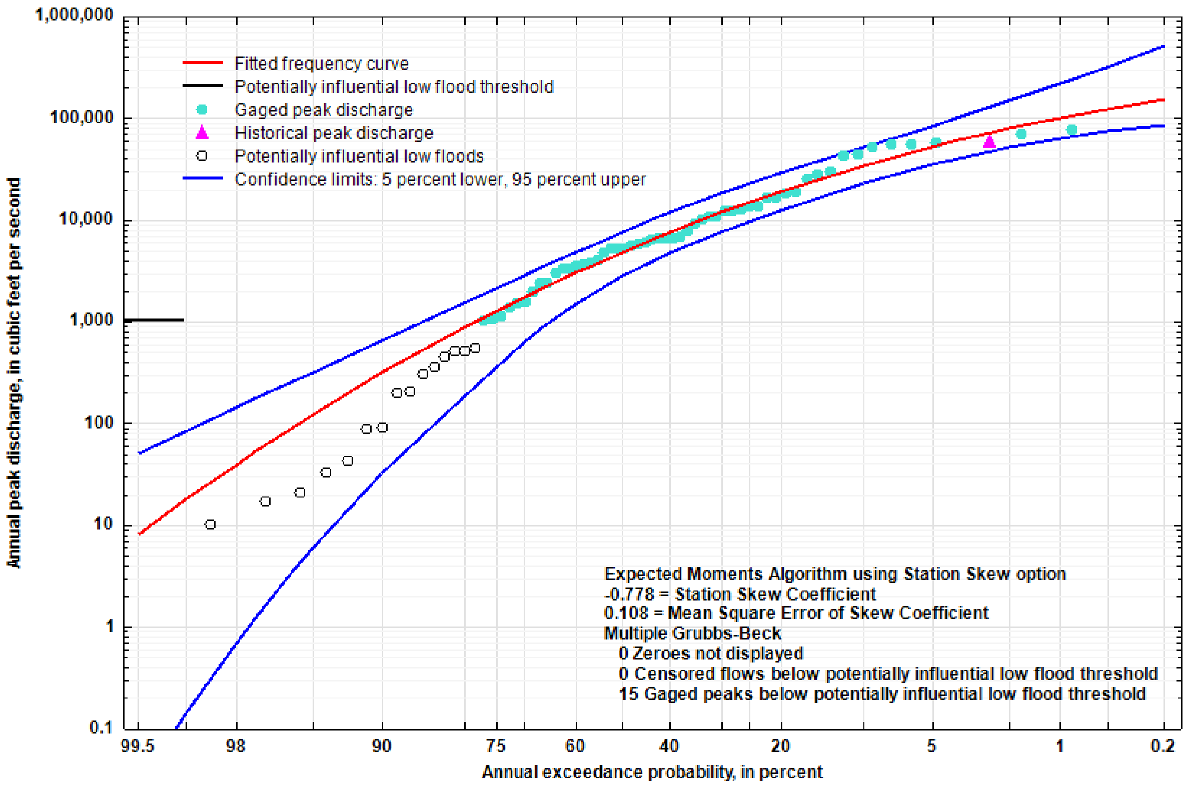


Figure A.45: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08200000 Hondo Creek near Tarpley, Texas.

08200720 Hondo Creek at S.H. 173 near Hondo, Texas

The period of record at USGS streamgage 08200720 Hondo Creek at S.H. 173 near Hondo, Tex. (hereinafter referred to as the "Hondo Creek near Hondo streamgage") was from 1961 through 2005. An older streamgage upstream (08200700 Hondo Creek at King Waterhole near Hondo, Tex.) was decommissioned in 2005 and re-established as the Hondo Creek near Hondo streamgage in 2007, 3.3 miles downstream. Because the difference in contributing drainage area between the two streamgages is only 7 sq. mi., a simple drainage area ratio was used to convert the peaks at the old streamgage to estimates at the new. Neither a statistically significant change point nor trend in the annual peak streamflow record were identified (Table A.1).

The largest peak in the record since 1960 occurred in 1997 and again in 2000 when peak streamflows of 63,600 cfs at a stage of 18.96 ft were measured. A log-normal plot of the peak streamflows for each water year at the Hondo Creek near Hondo streamgage is presented in Figure A.46, and the flood flow frequency is presented in Figure A.47. The skew was weighted by a regional value from Asquith and others (2021) (Table A.1). The low-outlier threshold was manually set at 6,000 cfs, and 8 zero-flows and 21 low outliers were identified.

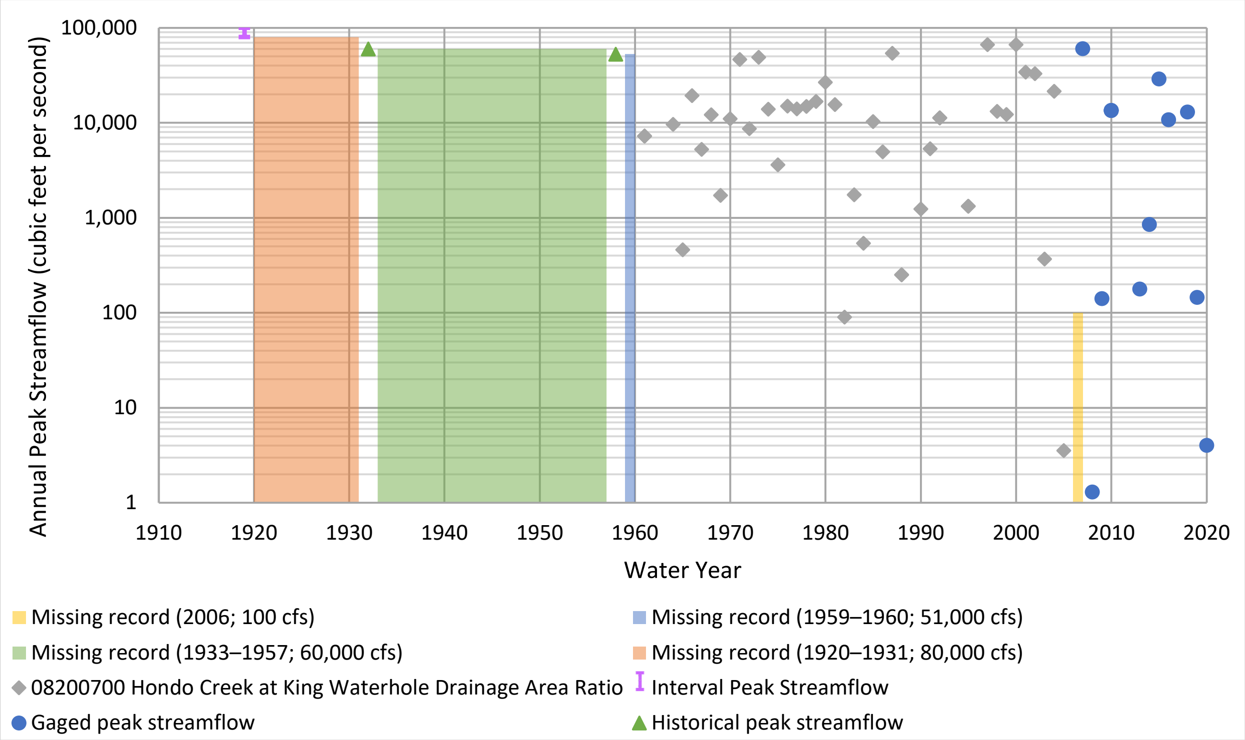


Figure A.46: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08200720 Hondo Creek at S.H. 173 near Hondo, Texas.

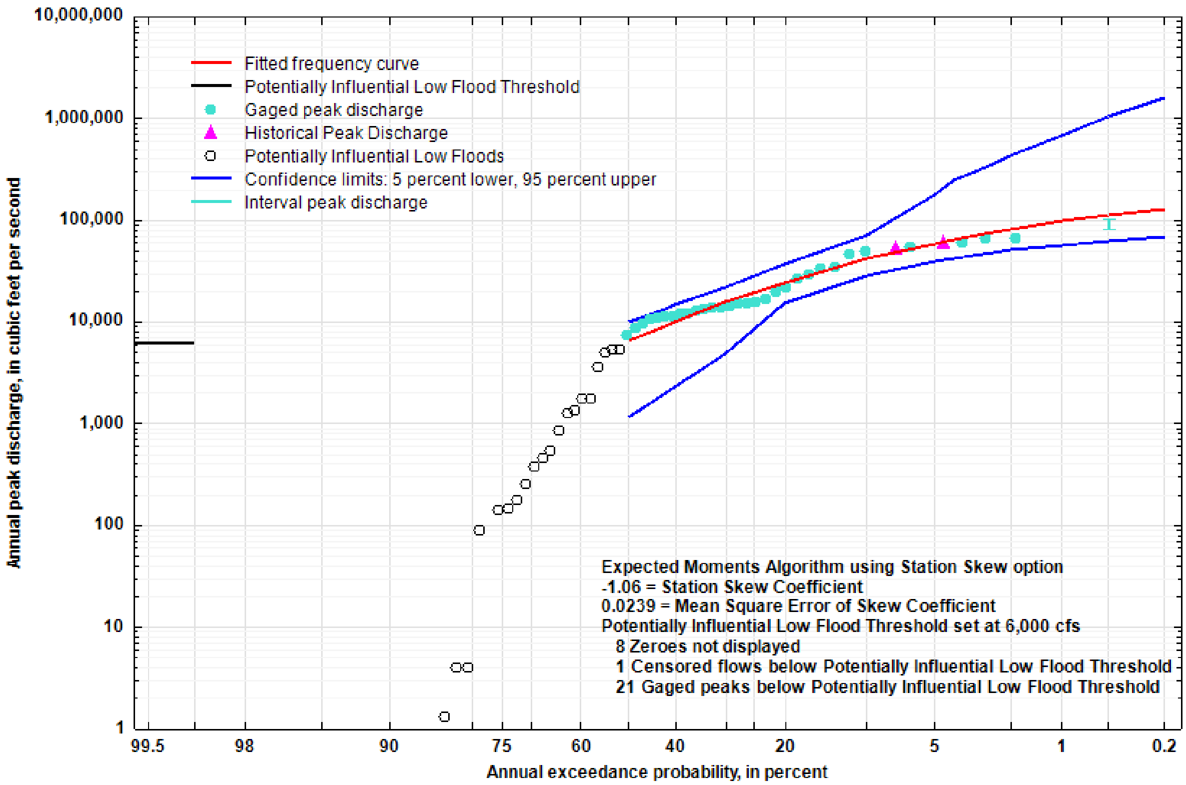


Figure A.47: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08200720 Hondo Creek at S.H. 173 near Hondo, Texas.

08208000 Atascosa River at Whitsett, Texas

The period of record at USGS streamgage 08208000 Atascosa River at Whitsett, Tex. (hereinafter referred to as the “Atascosa River at Whitsett streamgage”) was from 1925 through 2020. A historical peak streamflow of 106,000 cfs was recorded in 1919 and was included in the analysis. The Pettitt test does not identify a significant change point in the data, nor does the Kendall’s *tau* test identify a significant trend in the annual peak streamflow record (Table A.1).

The largest peak in the gaged period of record is the 1967 peak streamflow of 121,000 cfs at a stage of 41.30 ft. A log-normal plot of the peak streamflows for each water year at the Atascosa River near Whitsett streamgage is presented in Figure A.48, and the flood flow frequency is presented in Figure A.49.The low-outlier threshold was manually set at 300 cfs, and three low outliers were identified.

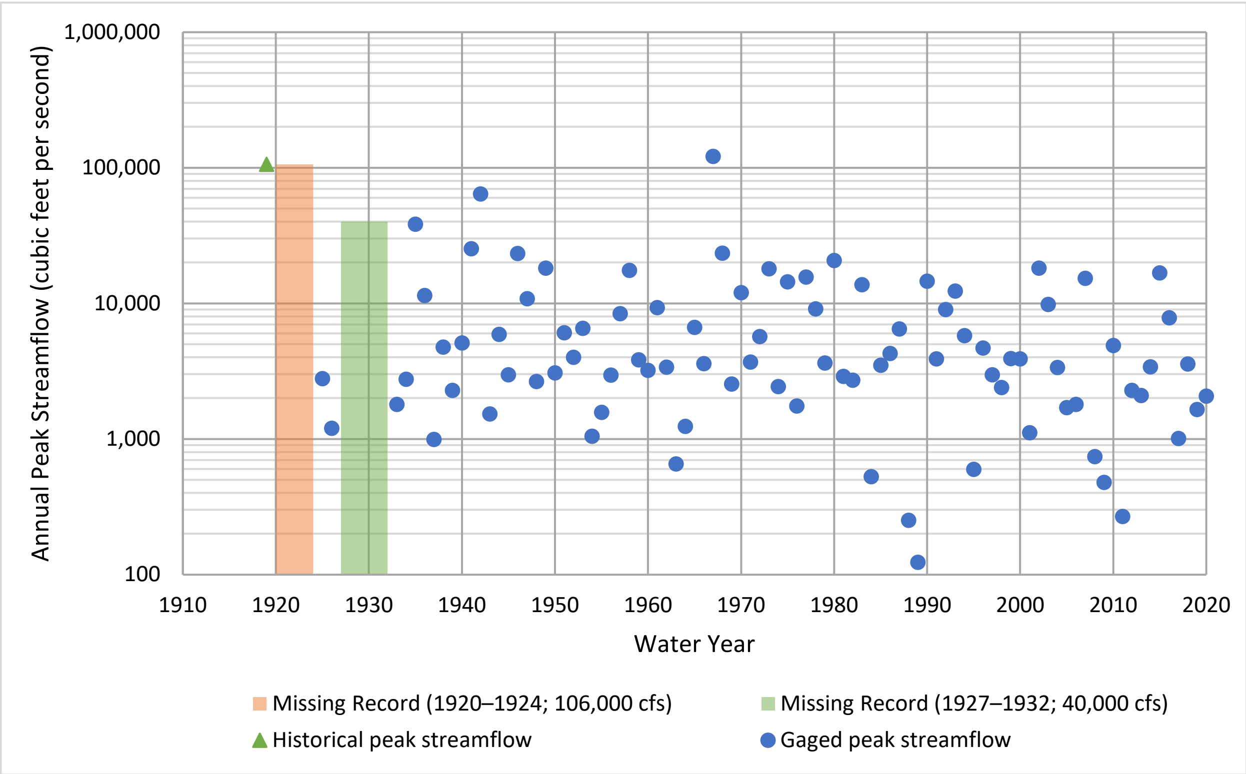


Figure A.48: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08208000 Atascosa River at Whitsett, Texas.

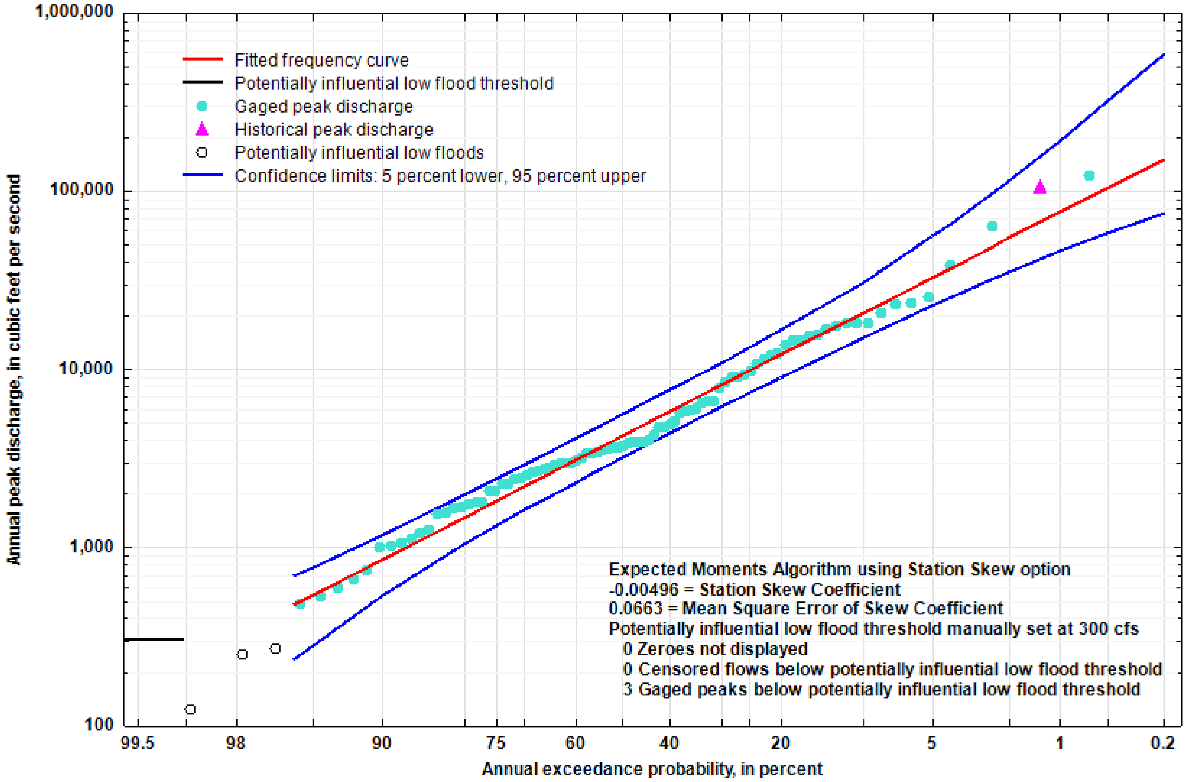


Figure A.49: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08208000 Atascosa River at Whitsett, Texas.

08210400 Lagarto Creek near George West, Texas

The period of record at USGS streamgage 08210400 Lagarto Creek near George West, Tex. (hereinafter referred to as the "Lagarto Creek near George West streamgage") was from 1971 through 2020. Record is missing from 1990 through 2002, and using the capabilities of the expected moments algorithm, a perception threshold of 5,000 cfs was set for that time period. Lagarto Creek appears to be an ephemeral stream at the gaged location, and many years of the gaged period of record have annual peak streamflow values of zero. The Pettitt test does not identify a significant change point in the data, though the Kendall's *tau* test identifies a significant downward trend in the annual peak streamflow record (Table A.1).

The largest peak in the gaged period of record is the 1972 peak streamflow of 33,500 cfs at a stage of 25.10 ft. A log-normal plot of the peak streamflows for each water year at the Lagarto Creek near George West streamgage is presented in Figure A.50, and the flood flow frequency is presented in Figure A.51. The low-outlier threshold was computed as 7 cfs by applying the MGBT in PeakFQ. During the computation of the low-outlier threshold one low outlier was identified along with eight zero-flow years.

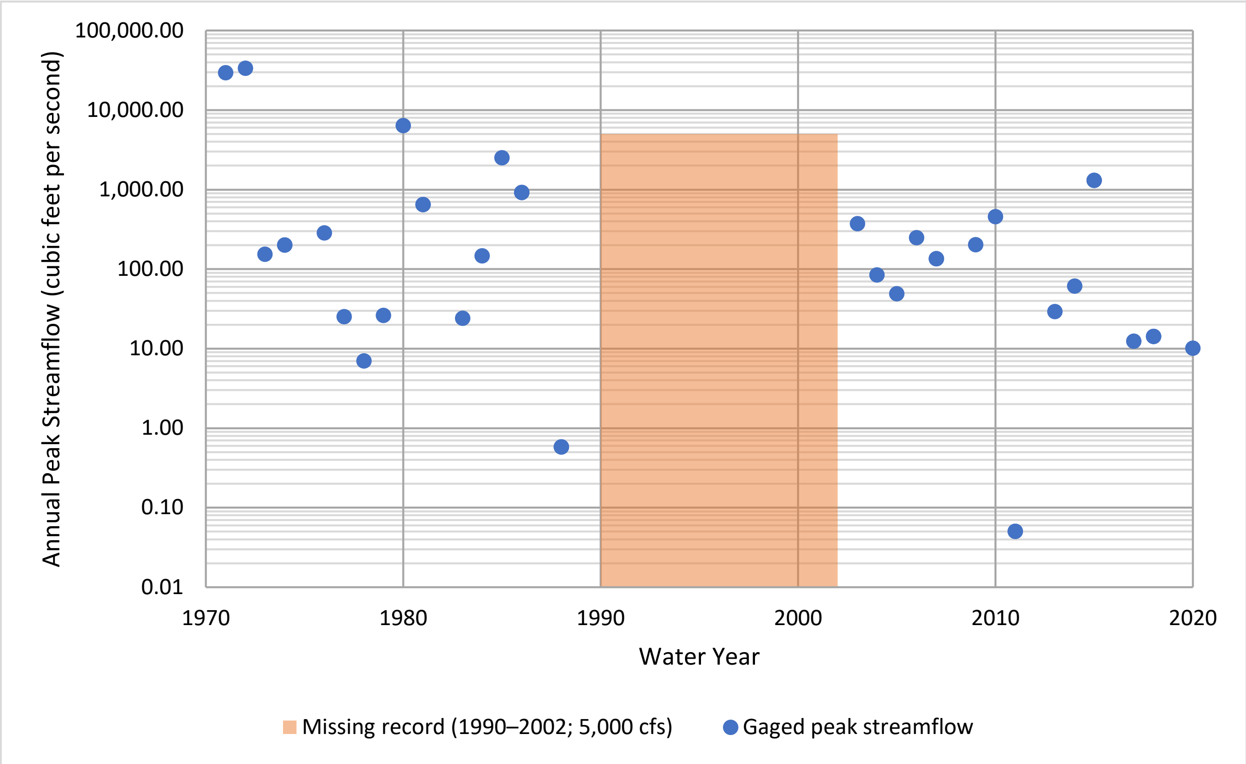


Figure A.50: Annual Peak Streamflow Data for U.S. Geological Survey Streamgage 08210400 Lagarto Creek near George West, Texas.

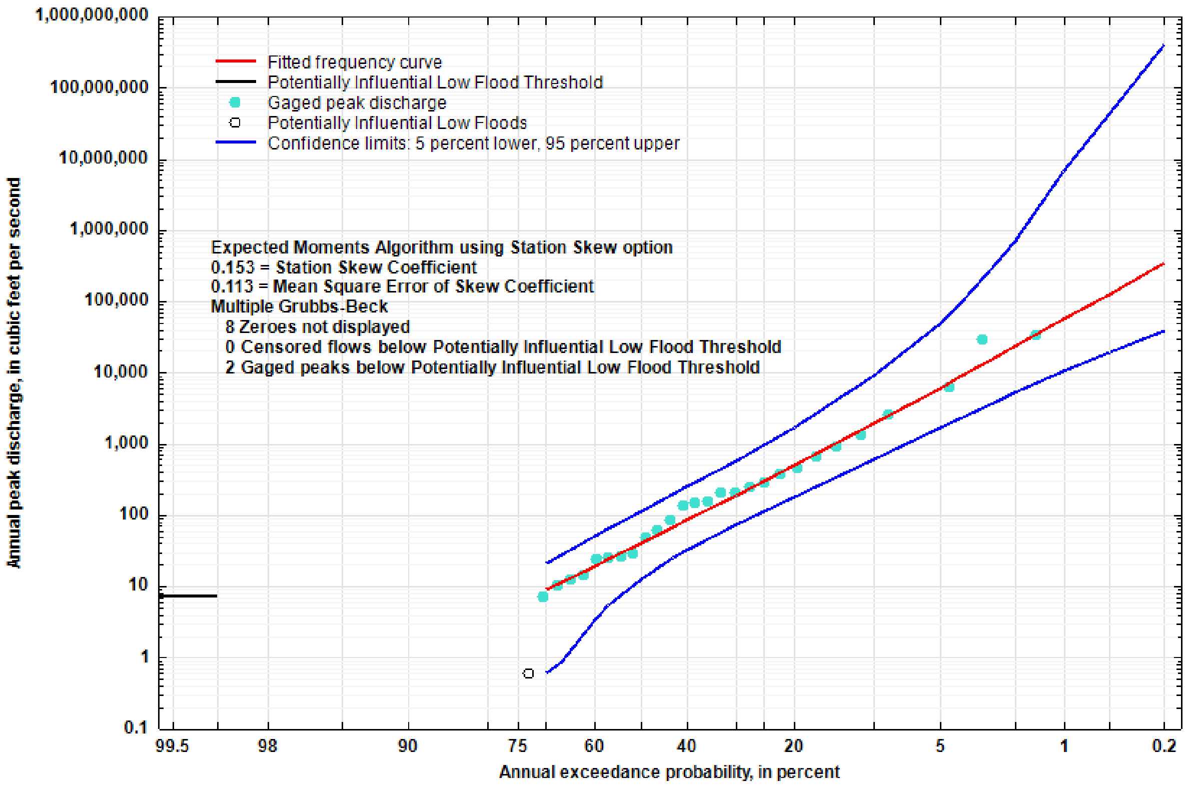


Figure A.51: Flood Flow Frequency Curve for U.S. Geological Survey Streamgage 08210400 Lagarto Creek near George West, Texas.

The wide confidence intervals for the Lagarto Creek near George West streamgage may be attributed to the large variance in observed peak streamflows at the streamgage. It also highlights the difficulty in providing reliable flood frequency estimates for lower exceedance probabilities when over one-fifth of the observed record are zero-flow years.

Table A.2: Statistically Estimated Annual Flood flow frequency Results and Confidence Intervals for Twenty Five Analyses of the U.S. Geological Survey (USGS) Streamgages in the Nueces River basin, Texas. The estimates were determined by using USGS-PeakFQ Software.

[USGS, U.S. Geological Survey; cfs, cubic feet per second; %, percent; CI, confidence interval; Note, table contents derived from EXP file (file extension name) of USGS-PeakFQ software output (USGS, 2014). The estimates are of primary interest and are accentuated using a bold typeface.]

USGS Station number and name	Flood flow frequency by corresponding average return period (recurrence interval) in years							
	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)
08190000 Nueces River at Laguna, Tex.								
Lower 95%-CI	6,170	30,700	59,300	109,000	153,000	197,000	240,000	293,000
Estimate	**10,300**	**45,300**	**87,800**	**164,000**	**237,000**	**320,000**	**412,000**	**546,000**
Upper 95%-CI	15,400	67,400	134,000	277,000	450,000	712,000	1,100,000	1,920,000
08192000 Nueces River below Uvalde, Tex.								
Lower 95%-CI	3,780	32,000	65,400	125,000	177,000	232,000	285,000	350,000
Estimate	**9,310**	**49,500**	**103,000**	**201,000**	**294,000**	**401,000**	**519,000**	**686,000**
Upper 95%-CI	14,500	79,900	177,000	398,000	651,000	994,000	1,460,000	2,350,000
08193000 Nueces River near Asherton, Tex.								
Lower 95%-CI	3,990	8,200	12,200	19,000	25,500	33,500	43,100	58,800
Estimate	**4,710**	**9,590**	**14,900**	**25,200**	**36,500**	**51,900**	**73,100**	**113,000**
Upper 95%-CI	5,380	11,800	19,700	39,700	70,000	128,000	238,000	561,000
08194000 Nueces River at Cotulla, Tex.								
Lower 95%-CI	4,380	10,900	16,900	26,100	33,800	41,700	49,800	60,400
Estimate	**5,610**	**14,000**	**22,000**	**35,000**	**46,900**	**60,600**	**76,300**	**100,000**
Upper 95%-CI	7,130	18,100	29,400	52,100	79,200	119,000	176,000	292,000
08194500 Nueces River near Tilden, Tex.								
Lower 95%-CI	4,020	12,900	22,000	35,800	46,100	55,400	63,700	73,100
Estimate	**5,770**	**18,000**	**30,500**	**51,000**	**69,200**	**89,600**	**112,000**	**144,000**
Upper 95%-CI	8,140	25,000	44,400	86,500	135,000	202,000	296,000	477,000
08210000 Nueces River near Three Rivers, Tex.								
Lower 95%-CI	3,370	8,680	13,300	20,200	25,800	31,700	37,900	46,200
Estimate	**5,010**	**12,600**	**19,900**	**31,600**	**42,300**	**54,500**	**68,400**	**89,400**
Upper 95%-CI	7,230	19,700	34,000	62,200	92,600	133,000	187,000	282,000
08211000 Nueces River near Mathis, Tex.								
Lower 95%-CI	1,470	4,630	8,080	14,200	20,100	27,200	35,600	48,700
Estimate	**2,340**	**7,420**	**13,600**	**25,700**	**38,900**	**56,300**	**79,100**	**119,000**
Upper 95%-CI	3,700	13,300	27,800	64,000	113,000	192,000	317,000	592,000
08211500 Nueces River at Calallen, Tex.								
Lower 95%-CI	828	2,680	5,170	10,200	15,800	23,000	32,300	48,400
Estimate	**1,380**	**4,690**	**9,510**	**21,300**	**37,000**	**62,000**	**101,000**	**187,000**
Upper 95%-CI	2,310	9,700	27,800	151,000	527,000	1,560,000	4,600,000	19,300,000
08190500 West Nueces River near Brackettville, Tex.								
Lower 95%-CI	556	19,700	47,600	100,000	150,000	205,000	260,000	330,000
Estimate	**4,370**	**35,800**	**86,100**	**189,000**	**291,000**	**408,000**	**537,000**	**717,000**
Upper 95%-CI	7,920	66,800	198,000	909,000	2,340,000	4,170,000	6,770,000	11,600,000

Table A.2 (continued): Statistically Estimated Annual Flood flow frequency Results and Confidence Intervals for Twenty Five Analyses of the U.S. Geological Survey (USGS) Streamgages in the Nueces River basin, Texas. The estimates were determined by using USGS-PeakFQ Software.

USGS Station number and name	Flood flow frequency by corresponding average return period (recurrence interval) in years							
	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)
08194200 San Casimiro Creek near Freer, Tex.								
Lower 95%-CI	1,480	5,200	9,940	19,300	29,100	41,500	56,600	81,100
Estimate	**2,250**	**8,100**	**16,200**	**34,600**	**57,000**	**89,900**	**137,000**	**231,000**
Upper 95%-CI	3,430	13,500	31,600	97,200	230,000	543,000	1,270,000	3,880,000
08196000 Dry Frio River near Reagan Wells, Tex.								
Lower 95%-CI	885	9,550	18,300	32,500	45,600	60,300	76,400	99,500
Estimate	**3,340**	**14,600**	**29,100**	**57,100**	**85,600**	**121,000**	**162,000**	**227,000**
Upper 95%-CI	4,970	22,500	51,800	140,000	275,000	507,000	877,000	1,670,000
08195000 Frio River at Concan, Tex.								
Lower 95%-CI	2,580	22,600	39,600	63,400	80,500	95,400	108,000	121,000
Estimate	**8,030**	**32,000**	**55,800**	**89,900**	**116,000**	**140,000**	**163,000**	**190,000**
Upper 95%-CI	11,600	47,000	92,000	197,000	314,000	437,000	541,000	653,000
08197500 Frio River below Dry Frio River near Uvalde, Tex.								
Lower 95%-CI	2,370	25,100	46,900	80,000	105,000	127,000	145,000	164,000
Estimate	**8,560**	**39,800**	**72,900**	**122,000**	**159,000**	**195,000**	**228,000**	**266,000**
Upper 95%-CI	14,000	64,600	132,000	313,000	560,000	745,000	941,000	1,210,000
08205500 Frio River near Derby, Tex.								
Lower 95%-CI	3,430	10,900	18,800	33,300	47,700	65,200	85,800	118,000
Estimate	**4,740**	**14,400**	**26,200**	**49,900**	**76,100**	**112,000**	**159,000**	**245,000**
Upper 95%-CI	6,190	20,400	40,200	94,600	185,000	376,000	783,000	2,130,000
08206600 Frio River at Tilden, Tex.								
Lower 95%-CI	1,740	5,770	9,710	15,700	20,100	24,100	27,500	31,300
Estimate	**2,950**	**9,150**	**15,300**	**25,200**	**33,700**	**43,000**	**53,000**	**67,000**
Upper 95%-CI	4,800	14,700	26,800	55,800	94,000	154,000	249,000	471,000
08206600 Frio River at Tilden, Tex. (alternative analysis)								
Lower 95%-CI	3,260	8,900	14,700	24,300	32,900	42,400	52,600	67,100
Estimate	**4,260**	**11,800**	**19,900**	**34,600**	**49,500**	**68,000**	**90,900**	**129,000**
Upper 95%-CI	5,570	16,000	29,200	62,300	110,000	193,000	333,000	679,000
08206700 San Miguel Creek near Tilden, Tex.								
Lower 95%-CI	2,010	6,240	10,500	17,000	21,900	26,400	30,200	34,500
Estimate	**3,000**	**8,940**	**14,900**	**24,500**	**33,000**	**42,400**	**52,800**	**67,700**
Upper 95%-CI	4,400	12,600	21,300	39,300	59,600	87,300	125,000	195,000
08198000 Sabinal River near Sabinal, Tex.								
Lower 95%-CI	3,250	12,200	18,800	29,300	38,700	49,400	61,100	78,300
Estimate	**6,320**	**15,800**	**25,400**	**42,100**	**58,400**	**78,400**	**103,000**	**142,000**
Upper 95%-CI	7,900	21,700	37,800	72,400	115,000	181,000	287,000	532,000

Table A.2 (continued): Statistically Estimated Annual Flood flow frequency Results and Confidence Intervals for Twenty Five Analyses of the U.S. Geological Survey (USGS) Streamgages in the Nueces River basin, Texas. The estimates were determined by using USGS-PeakFQ Software.

USGS Station number and name	Flood flow frequency by corresponding average return period (recurrence interval) in years							
	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)
08198500 Sabinal River at Sabinal, Tex.								
Lower 95%-C	1,810	13,200	22,900	35,900	46,800	58,600	71,000	88,300
Estimate	**5,990**	**19,200**	**33,200**	**57,100**	**79,300**	**105,000**	**134,000**	**177,000**
Upper 95%-CI	8,250	28,500	57,700	141,000	268,000	494,000	878,000	1,510,000
08201500 Seco Creek at Miller Ranch near Utopia, Tex.								
Lower 95%-CI	468	6,820	13,500	24,500	33,700	43,000	51,800	62,400
Estimate	**2,340**	**11,500**	**22,800**	**42,700**	**60,800**	**81,000**	**103,000**	**132,000**
Upper 95%-CI	3,890	20,400	47,500	135,000	276,000	494,000	777,000	1,230,000
08202700 Seco Creek at Rowe Ranch near D'Hanis, Tex.								
Lower 95%-CI	424	9,810	20,500	37,000	50,100	62,600	73,900	86,600
Estimate	**2,940**	**16,600**	**33,100**	**60,200**	**82,600**	**105,000**	**127,000**	**154,000**
Upper 95%-CI	4,970	26,100	60,000	255,000	458,000	716,000	1,030,000	1,540,000
08200000 Hondo Creek near Tarpley, Tex.								
Lower 95%-CI	2,780	12,400	22,500	38,800	51,700	63,500	73,800	84,900
Estimate	**4,820**	**18,900**	**33,900**	**58,100**	**78,600**	**100,000**	**123,000**	**152,000**
Upper 95%-CI	7,590	28,400	51,100	95,700	146,000	218,000	317,000	513,000
08200720 Hondo Creek at S.H. 173 near Hondo, Tex.								
Lower 95%-CI	1,140	15,200	28,200	41,500	50,000	56,800	62,200	68,200
Estimate	**6,370**	**24,200**	**41,100**	**64,200**	**81,000**	**96,500**	**110,000**	**126,000**
Upper 95%-CI	9,770	36,400	71,500	240,000	419,000	680,000	1,040,000	1,580,000
08208000 Atascosa River at Whitsett, Tex.								
Lower 95%-CI	3,160	8,960	15,100	25,500	35,000	45,800	57,700	75,000
Estimate	**4,190**	**12,000**	**20,700**	**37,200**	**54,200**	**76,000**	**104,000**	**151,000**
Upper 95%-CI	5,550	16,500	30,800	66,100	114,000	191,000	314,000	590,000
08210400 Lagarto Creek near George West, Tex.								
Lower 95%-CI	13	176	603	2,240	5,090	10,300	19,200	39,100
Estimate	**40**	**494**	**1,920**	**8,470**	**22,500**	**54,700**	**125,000**	**343,000**
Upper 95%-CI	113	1,660	8,830	89,700	666,000	6,520,000	41,900,000	399,000,000

1.4 CHANGES TO FLOOD FLOW FREQUENCY ESTIMATES OVER TIME

Statistically based flood flow frequency estimates are dependent on observational data and historical information (England and others, 2019). Examples of changes to flood flow frequency estimates over time are provided for 12 streamgages in the Nueces River basin (Table A.1). Collectively, these are shown in Figures A.52–A.63. The annual recurrence intervals of interest here are 2, 10, 100, and 500 years, which correspond to AEPs of 0.500, 0.100, 0.010, and 0.002, respectively.

Each of these examples is intended to illustrate that there is substantial variation in the statistical estimates over time especially for the rare frequencies. Peak streamflows outside the period of record are not shown. For example, peak streamflow prior to 1983 at the Nueces River near Three Rivers streamgage is not shown in Figure A.57 as the analyzed streamgage record begins in 1983 (Figure A.12). Because the data used to plot the values of the 2, 10, 100, and 500-year streamflow estimates in a given year are dependent on all data before that year, in general there is less variation in the annual chance exceedance estimates during the latter years of a given record (Figures A52–A63). This decrease in the variation associated with annual chance exceedance occurs because the total sample size as a measure of information content of flood flows increases at a proportionally smaller rate with each additional year of data. For example, one more year of data for a sample of 10 years represents a 10-percent increase in information, whereas one more year of data for a sample of 50 years is only a 2-percent increase in information. In other words, as the record length increases given other factors remaining relatively constant (land use for example), the annual chance exceedance estimates are expected to vary year-to-year to a lesser degree for the simple reason that proportionally less information is included with each successive year.

Flood flow frequency estimates over time computations are performed in HEC-SSP and incorporate the Bulletin 17C analysis into a variable time window (England and others, 2019; USACE, 2023). Each analysis utilized an expanding time window with a minimum time period of 10 years and increments of 1 year. Therefore, the flood frequency estimates over time shown in the figures below begin 10 years after the availability of systematic record and provide estimates for each subsequent year through the present analysis (2020).

08190000 Nueces River at Laguna, Tex.

The relative effects of record length and magnitudes of substantial floods for the Nueces River at Laguna streamgage are shown in Figure A.52. In general, the return intervals associated with the different annual exceedance probabilities (expressed as percent annual chance exceedance [ACE]) appear to decrease over time. In addition to the natural tendency for variation in the return intervals to decrease as the number of years of record increases, this decrease in the associated annual chance exceedance estimates over time may be a result of the high concentration of peak streamflows of more than 100,000 cfs in the early part of the gaged record. Three historical peaks of more than 100,000 cfs occurred between 1930 and 1939, followed by the order of magnitude larger estimated peak of record in 1955 of 307,000 cfs. Since 1955 there have only been two more peaks of more than 100,000 cfs—one peak streamflow of more than 100,000 cfs in the 1970s and one more in the 1990s, which may explain the gradual decline of the small annual chance exceedance values (rare frequency flood events). The 1-percent annual chance exceedance event decreases from 451,000 cfs in 2000 to 320,000 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases from 92,500 cfs to 87,800 cfs.

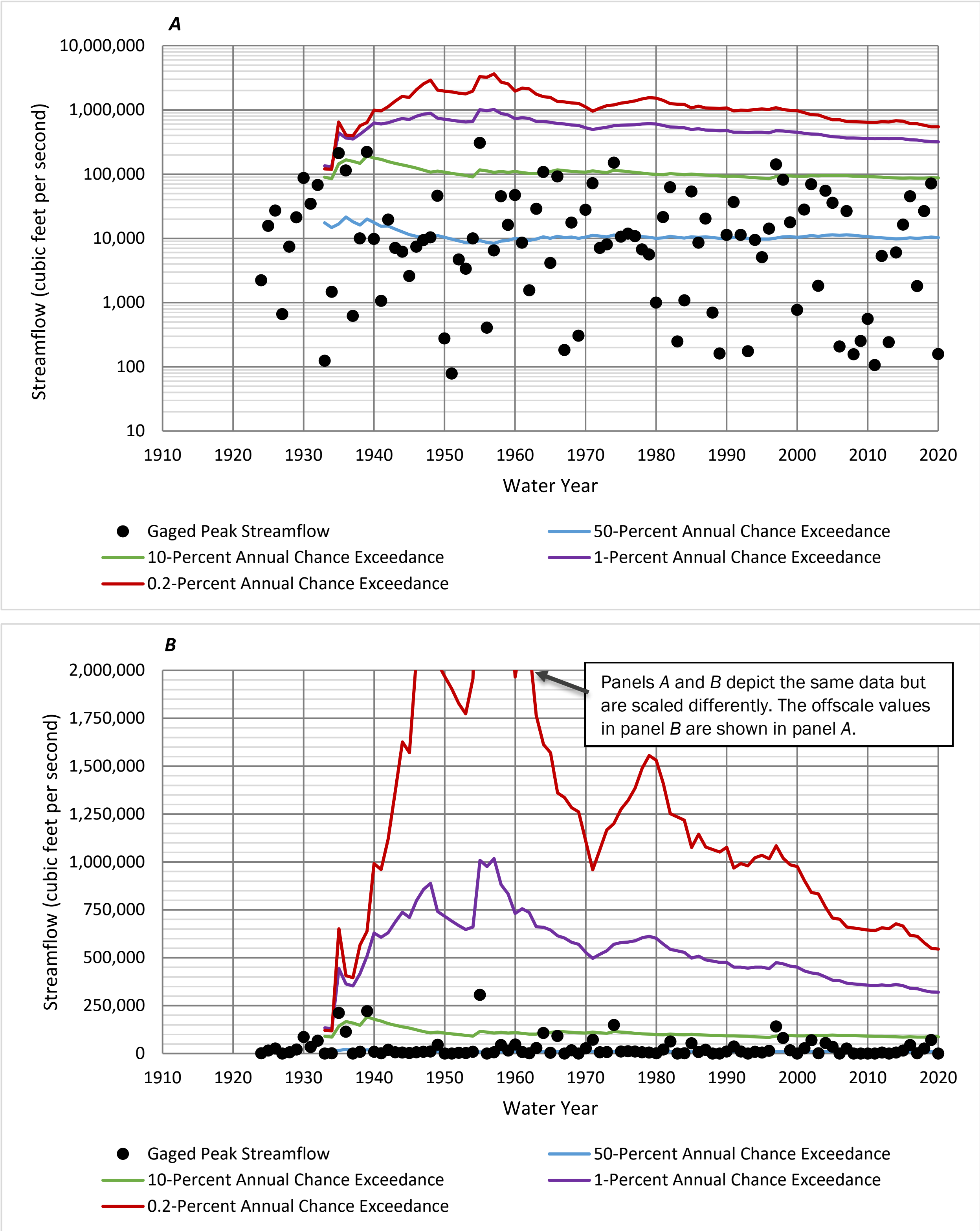
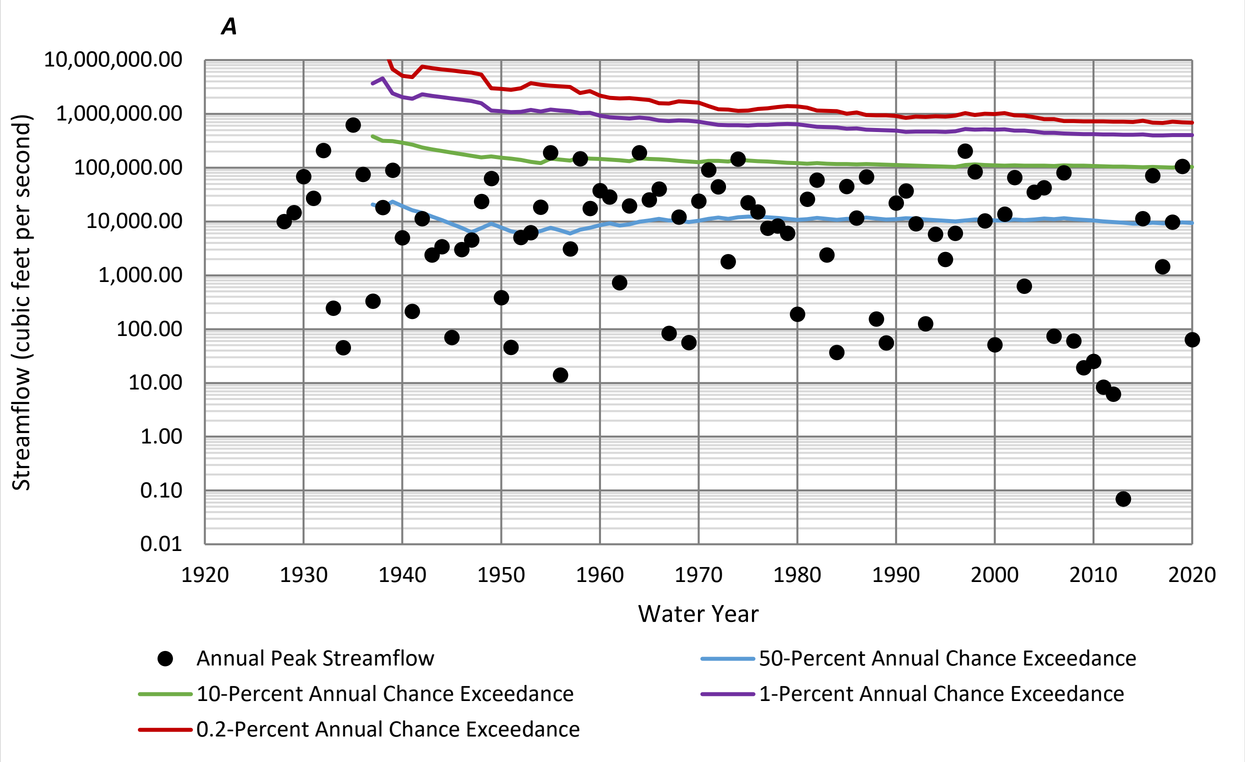


Figure A.52: Statistical Frequency Flow Estimates versus Time in *A,* log y-axis and *B,* linear y-axis for U.S. Geological Survey Streamgage 08190000 Nueces River at Laguna, Texas.

08192000 Nueces River below Uvalde, Tex.

The relative effects of record length and magnitudes of substantial floods for the Nueces River below Uvalde streamgage are shown in Figure A.53. In general, all return intervals appear to decrease over time similar to the Nueces River at Laguna streamgage. Again, this may be a result of an early abundance of peaks observed over 100,000 cfs, especially a 616,000 cfs event observed in water year 1935. Estimates appear to have stabilized somewhat in the last 15 years that were analyzed (2006–20), although the 1-percent annual chance exceedance estimate decreases from 422,000 cfs in 2005 to 401,000 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases from 109,000 cfs to 103,000 cfs.



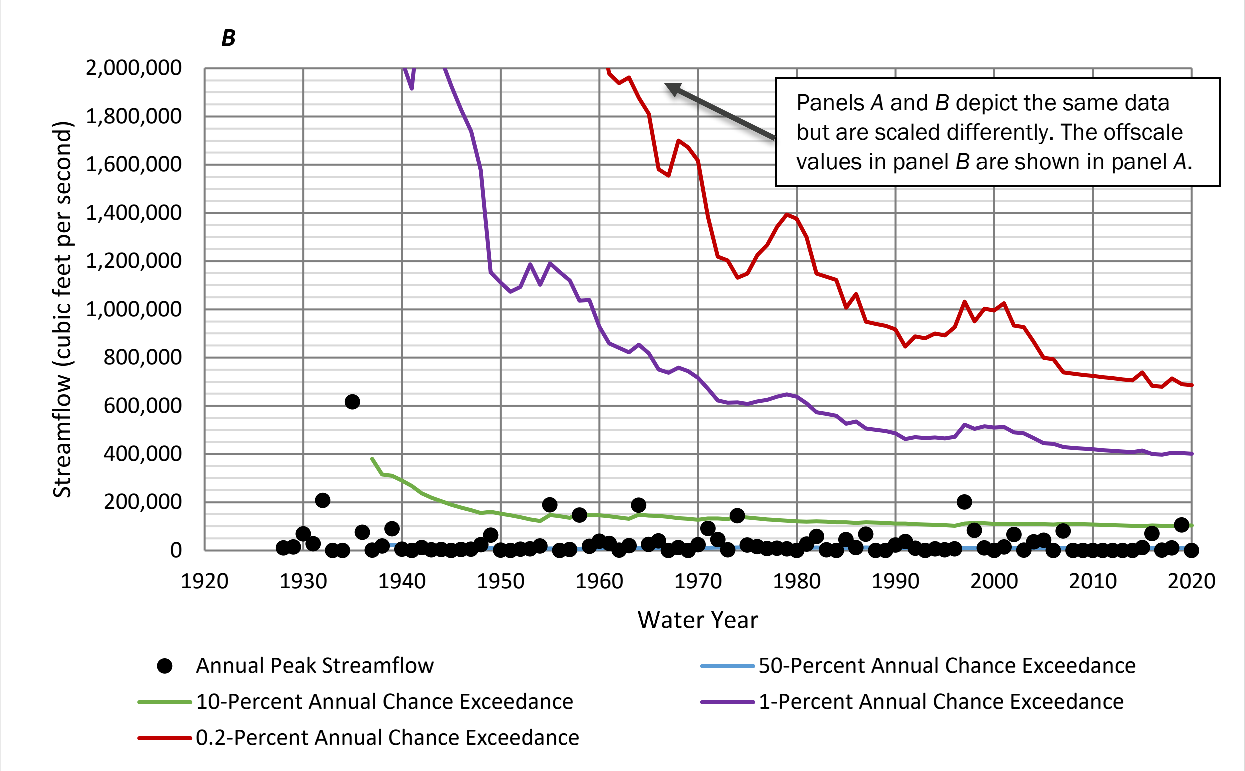


Figure A.53: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08192000 Nueces River below Uvalde, Texas.

08193000 Nueces River near Asherton, Tex.

The relative effects of record length and magnitudes of substantial floods for the Nueces River near Asherton streamgage are shown in Figure A.54. In general, all return intervals appear to decrease over time similar to what is observed at upstream streamgages. Estimates appear to continue to decline through 2021 except for the 50-percent annual chance exceedance and 10-percent annual chance exceedance, which appear to have stabilized somewhat. The 1-percent annual chance exceedance estimate decreases from 53,800 cfs in 2000 to 46,100 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases only from 17,700 cfs to 16,800 cfs.

Although a statistically significant downward trend in annual peak streamflow was not detected with the Kendall's *tau* test for the Nueces River near Asherton streamgage, an increase in the number of peak streamflow values less than 1,000 cfs is apparent beginning in the 1980s. During the aforementioned 2000 through 2020-time span, the 50-percent annual chance exceedance estimate decreases only slightly from 5,210 cfs to 5,170 cfs. However, the 1980 50-percent annual chance exceedance estimate is 5,330 cfs, which represents a relatively small decrease of approximately 7 percent over four decades. Although the 50-percent annual chance exceedance estimate appears to have stabilized, this stabilization likely occurred after a hydrologic change sometime in the 1980s or later.

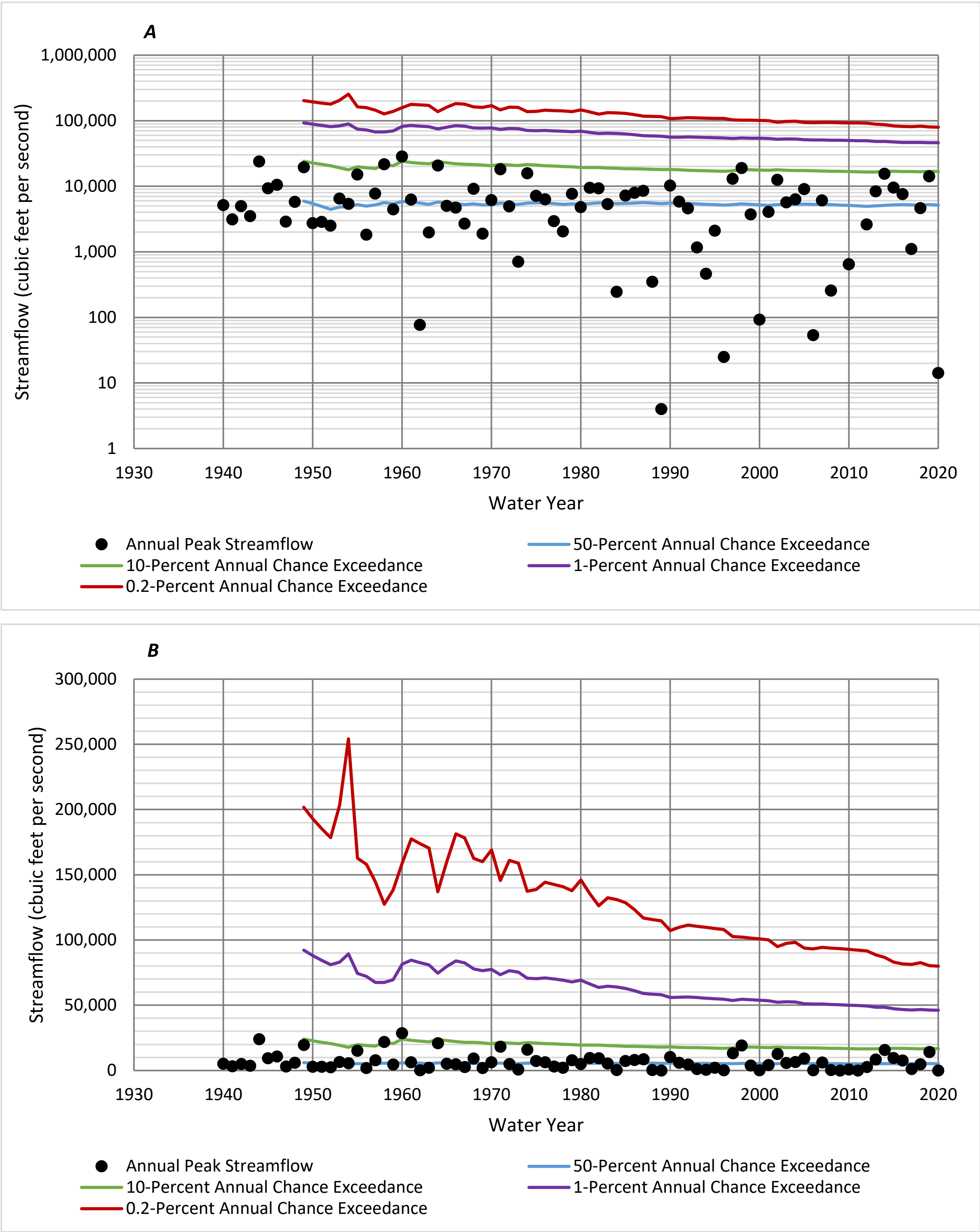


Figure A.54: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08193000 Nueces River near Asherton, Texas.

08194000 Nueces River at Cotulla, Tex.

The relative effects of record length and magnitudes of substantial floods for the Nueces River at Cotulla streamgage are shown in Figure A.55. In general, all return intervals appear to decrease over time similar to what is observed at upstream streamgages. A statistically significant change point was detected in water year 1982 (Table A.1), and an increase in events less than 1,000 cfs is visually apparent beginning in the 1980s as well as a decrease in events greater than 20,000 cfs. The Kendall's *tau* test identified a statistically significant decrease in annual peak streamflow at the gaged location. Estimates of the annual chance exceedance appeared to continue to decline through 2021 except for the 50-percent annual chance exceedance and 10-percent annual chance exceedance estimates, which appear to have stabilized somewhat since about 1980. The 1-percent annual chance exceedance event decreases from 71,700 cfs in 2000 to 60,600 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases only from 23,700 cfs to 22,000 cfs, and the 50-percent annual chance exceedance estimate decreases only from 5,820 cfs to 5,610 cfs. However, prior to the observed increase in peak streamflow, less than 1,000 cfs the 50-percent annual chance exceedance estimate in 1980 is 6,490 cfs, which represents an approximately 14 percent decrease over four decades.

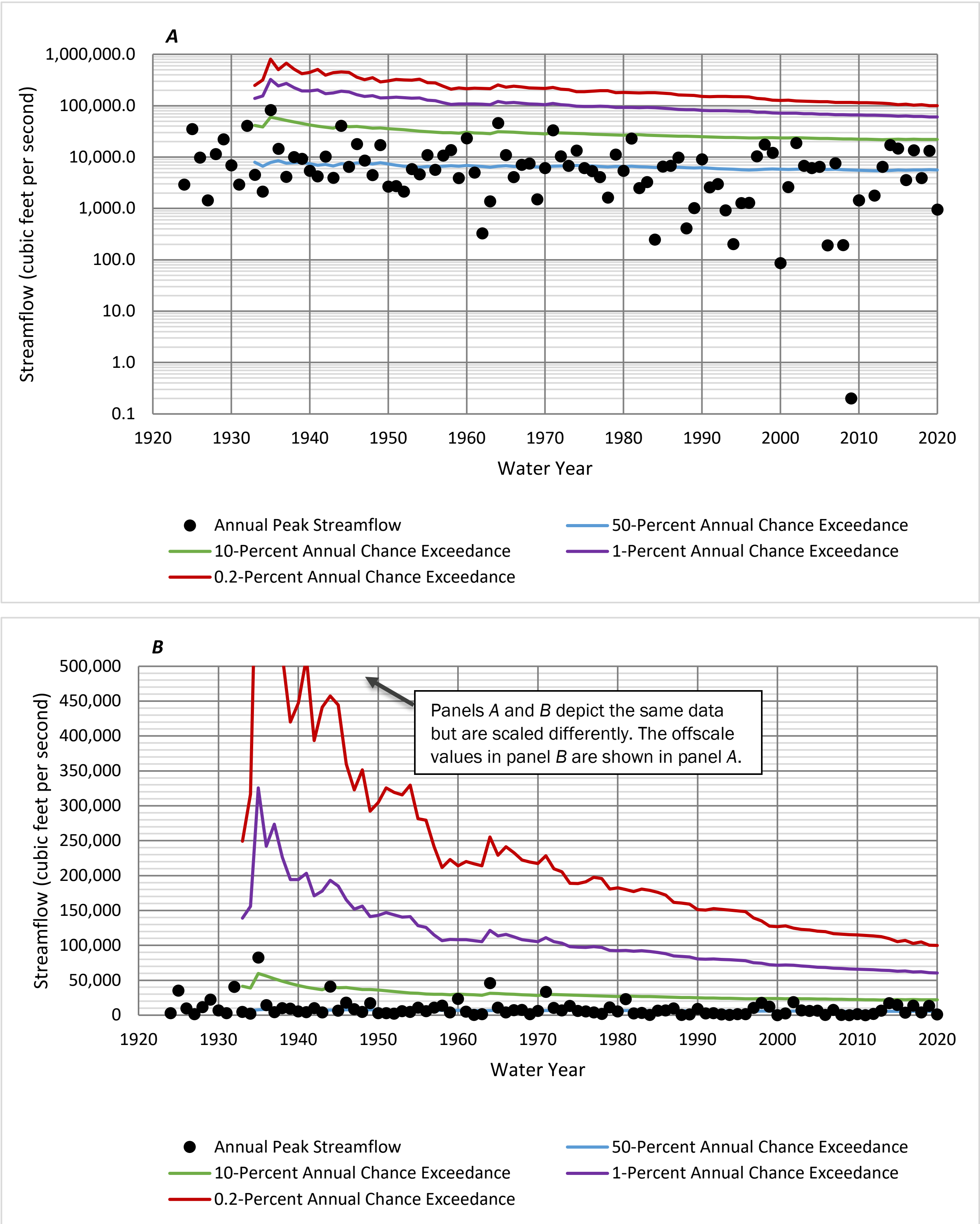
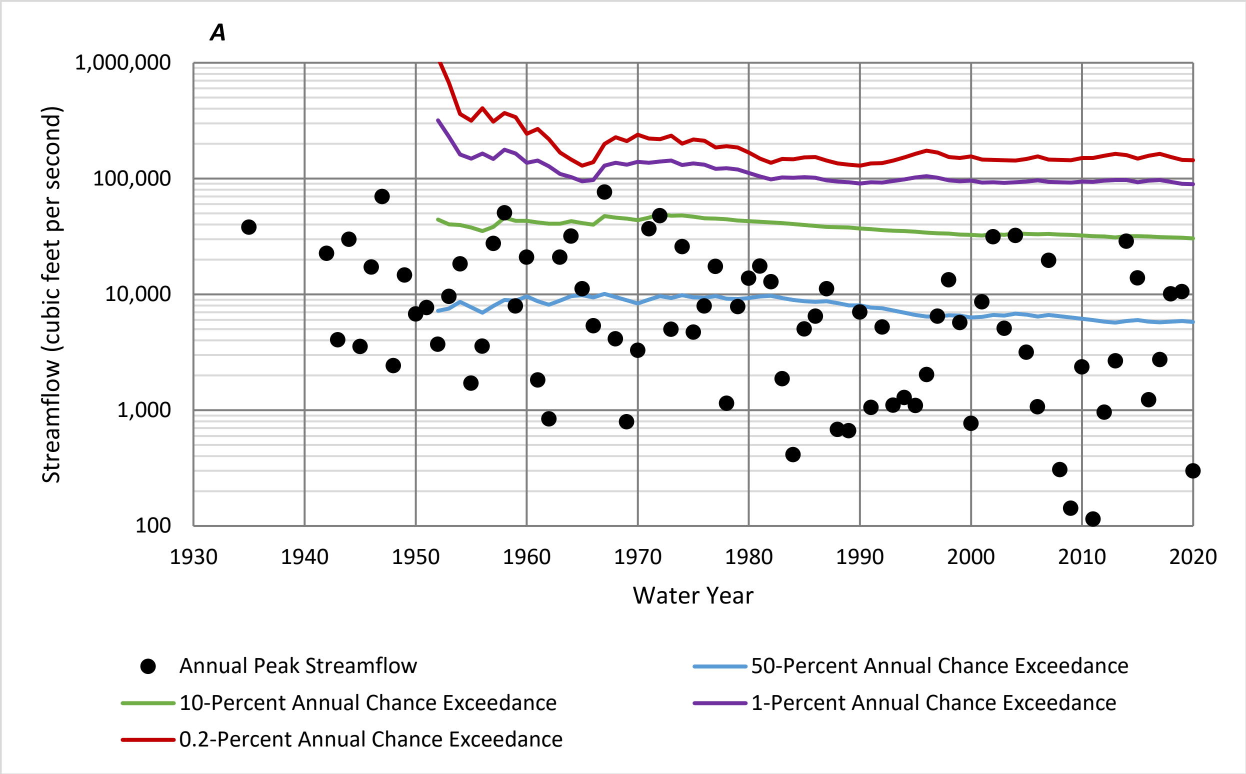


Figure A.55: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08194000 Nueces River at Cotulla, Texas.

08194500 Nueces River near Tilden, Tex.

The relative effects of record length and magnitudes of substantial floods for the Nueces River near Tilden streamgage are shown in Figure A.56. A statistically significant decrease in annual peak streamflow at the gaged location was identified by the Kendall's *tau* test. However, all estimates appear to have mostly stabilized with only small declines. The 1-percent annual chance exceedance estimate decreases only from 96,100 cfs in 2000 to 89,600 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases from 32,600 cfs to 30,500 cfs.



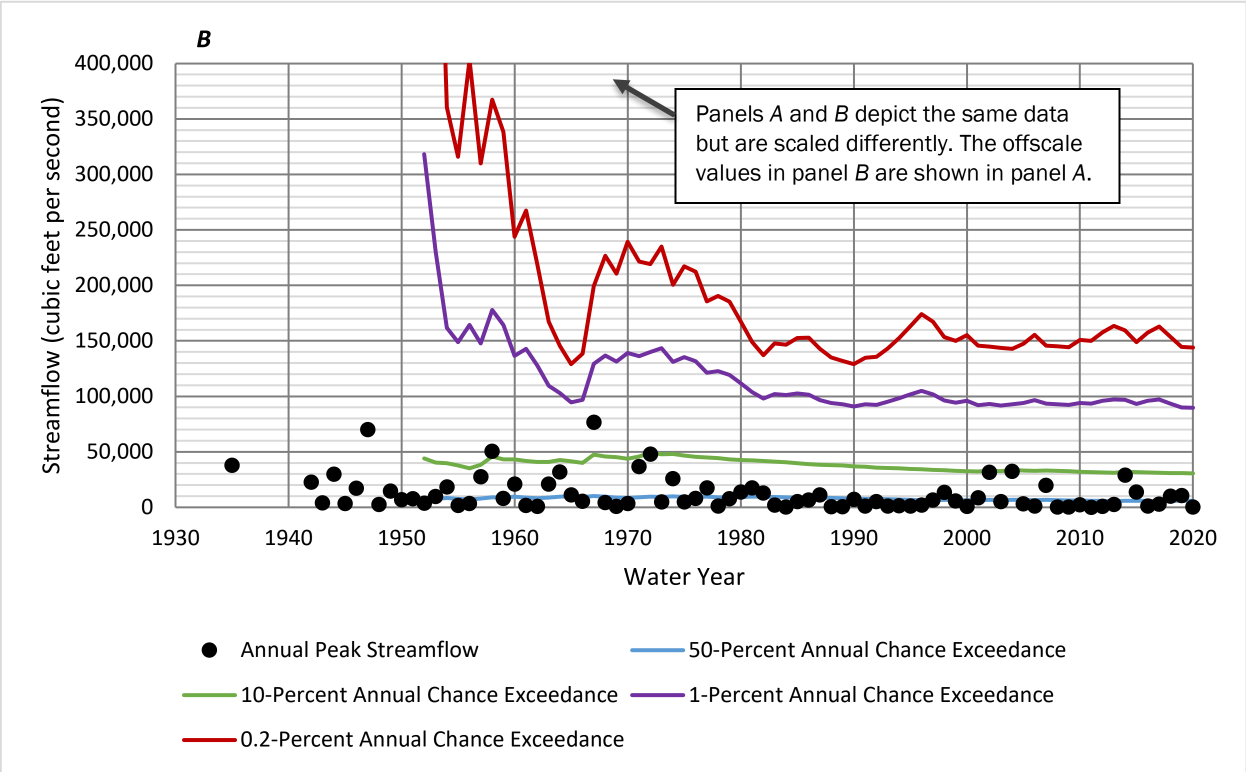
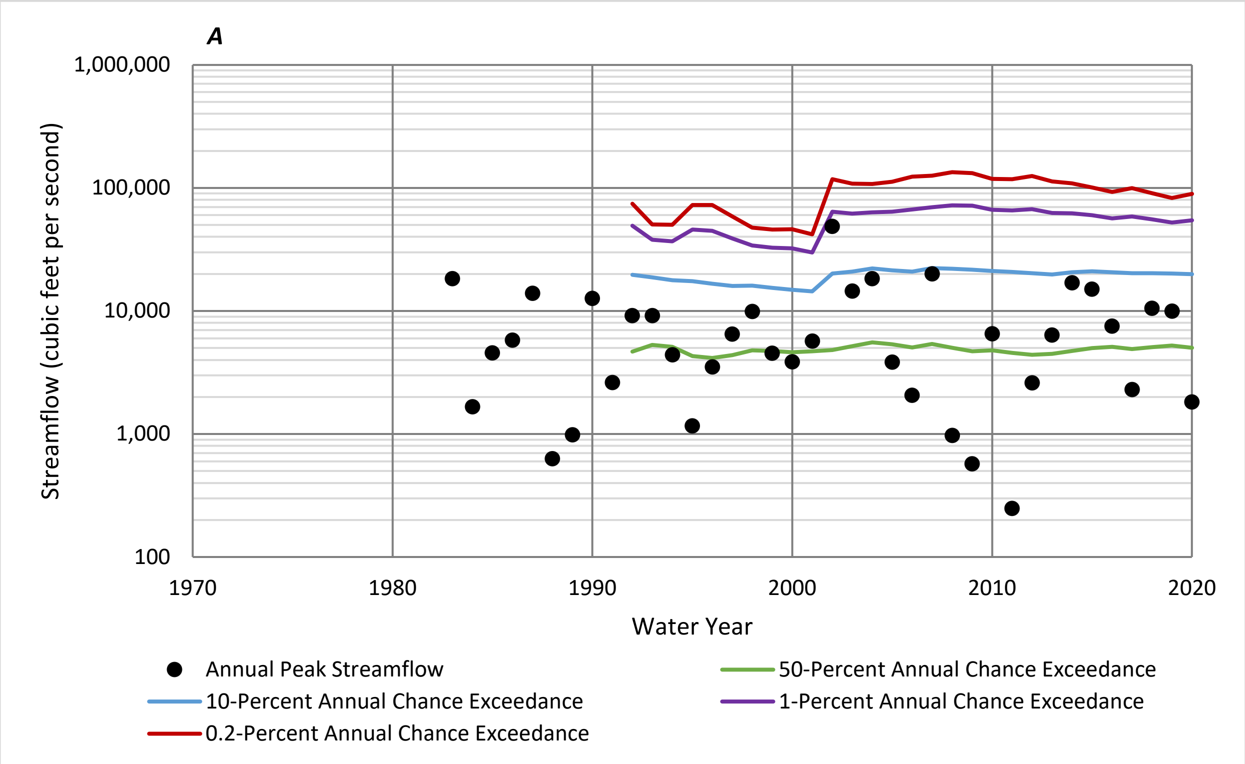


Figure A.56: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08194500 Nueces River near Tilden, Texas.

08210000 Nueces River near Three Rivers, Tex.

The relative effects of record length and magnitudes of substantial floods for the Nueces River near Three Rivers streamgage are shown in Figure A.57. The 2002 annual peak streamflow of 48,500 cfs results in an increase in all estimates except the 50-percent annual chance exceedance. After the 2002 event, the 1-percent annual chance exceedance and 0.2-percent annual chance exceedance events have declined slightly, and it is difficult to determine whether they have stabilized during the 18 years of record after the 2002 event that were considered for this analysis (2003–20). The 1-percent annual chance exceedance event decreases from 66,400 cfs in 2010 to 54,500 cfs in 2020. During the same time span, the 0.2-percent annual chance exceedance decreases from 119,000 cfs to 89,400 cfs, and the 10-percent annual chance exceedance estimate only decreases from 21,100 cfs to 19,900 cfs.



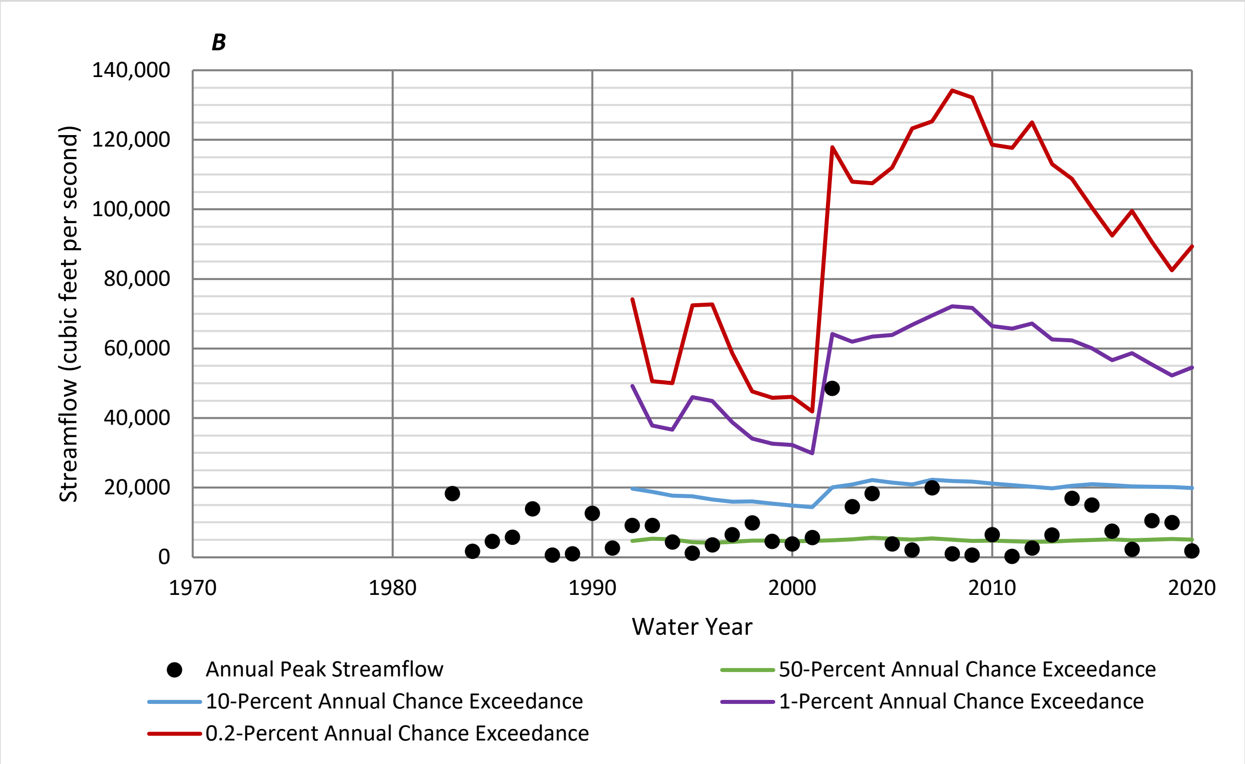
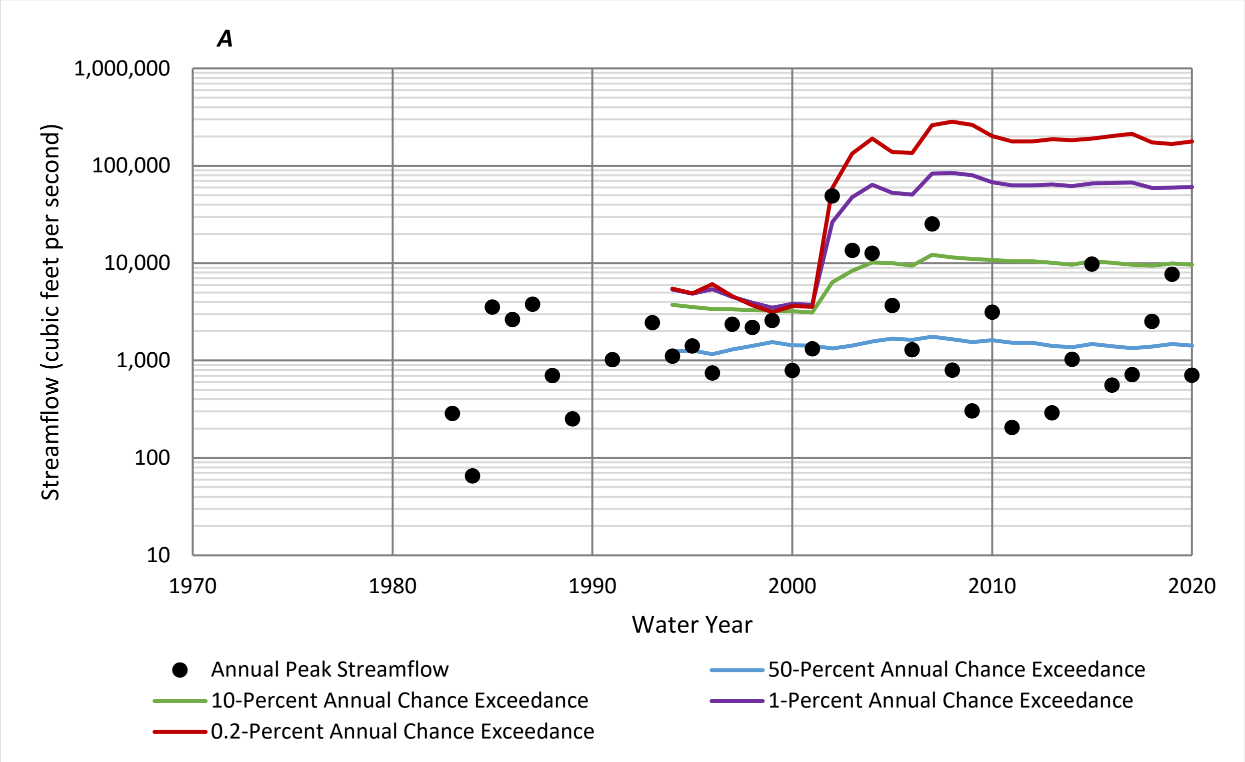


Figure A.57: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08210000 Nueces River near Three Rivers, Texas.

08211500 Nueces River at Calallen, Tex.

The relative effects of record length and magnitudes of substantial floods for the Nueces River at Calallen streamgage are shown in Figure A.58. The 2002 annual peak streamflow of 49,000 cfs results in an increase in all estimates except the 50-percent annual chance exceedance. After the 2002 event, the 10-percent annual chance exceedance and 50-percent annual chance exceedance events have declined, and it is difficult to determine whether they have stabilized during the 18 years of record after the 2002 event that were considered for this analysis (2003–20). However, the 1-percent annual chance exceedance estimate appears relatively stable since water year 2010. The 1-percent annual chance exceedance event decreases from 63,100 cfs in 2011 to 60,600 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases slightly from 10,500 cfs to 9,620 cfs, and the 50-percent annual chance exceedance estimate also decreases slightly from 1,620 cfs to 1,420 cfs.



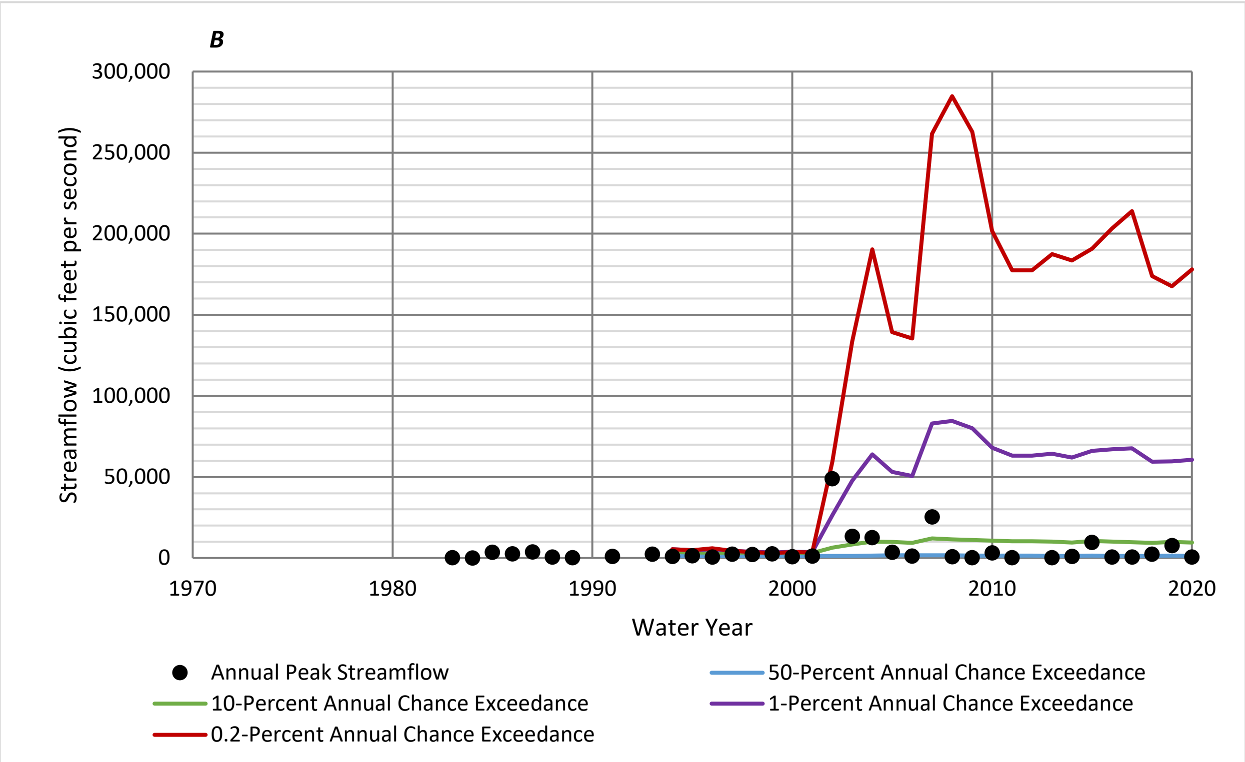


Figure A.58: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08211500 Nueces River at Calallen, Texas.

08195000 Frio River at Concan, Tex.

The relative effects of record length and magnitudes of substantial floods for the Frio River at Concan streamgage are shown in Figure A.59. After approximately 60 years of variable annual chance exceedance estimates from about 1930 to 1990, all annual chance exceedance estimates appear to somewhat stabilize. No streamflows greater than 25,000 cfs have been observed since 2007, and this lack of relatively large streamflow events has resulted in a slight decline in all annual chance exceedance estimates. The 1-percent annual chance exceedance event decreases from 151,000 cfs in 1990 to 140,000 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate remains essentially the same, only slightly decreasing from 56,700 cfs to 55,800 cfs.

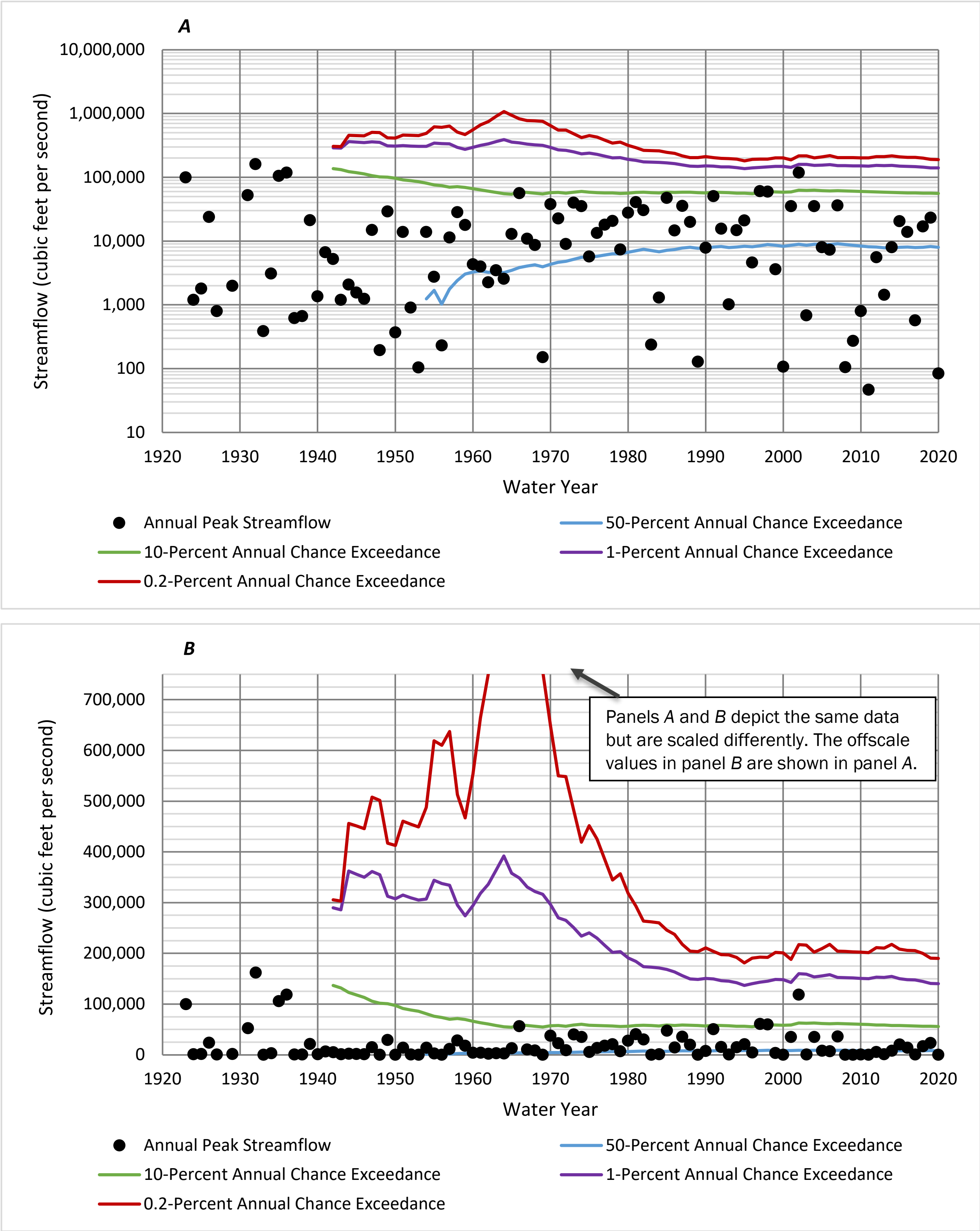


Figure A.59: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08195000 Frio River at Concan, Texas.

08197500 Frio River below Dry Frio River near Uvalde, Tex.

The relative effects of record length and magnitudes of substantial floods for the Frio River near Uvalde streamgage are shown in Figure A.60. The 2002 extreme annual peak streamflow of 189,000 cfs results in an increase in all annual chance exceedance estimates compared to those for the years prior to this flood event. After the 2002 flood event, all annual chance exceedance estimates decreased, although it is difficult to determine whether they have stabilized given there were only 18 years of record (2003–20) since the 2002 event. The 1-percent annual chance exceedance event decreased from 212,000 cfs in 2010 to 195,000 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreased from 81,200 cfs to 72,900 cfs.

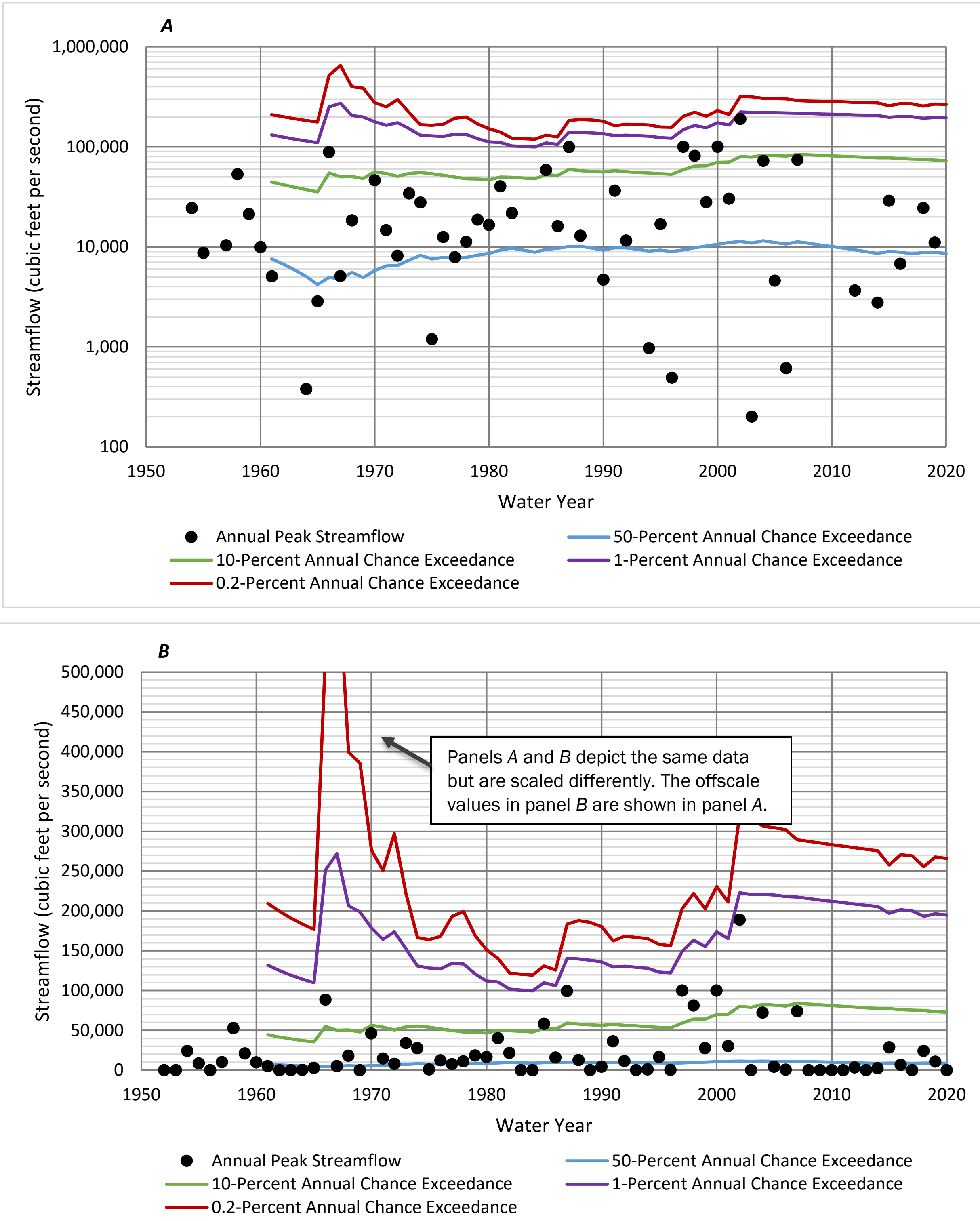
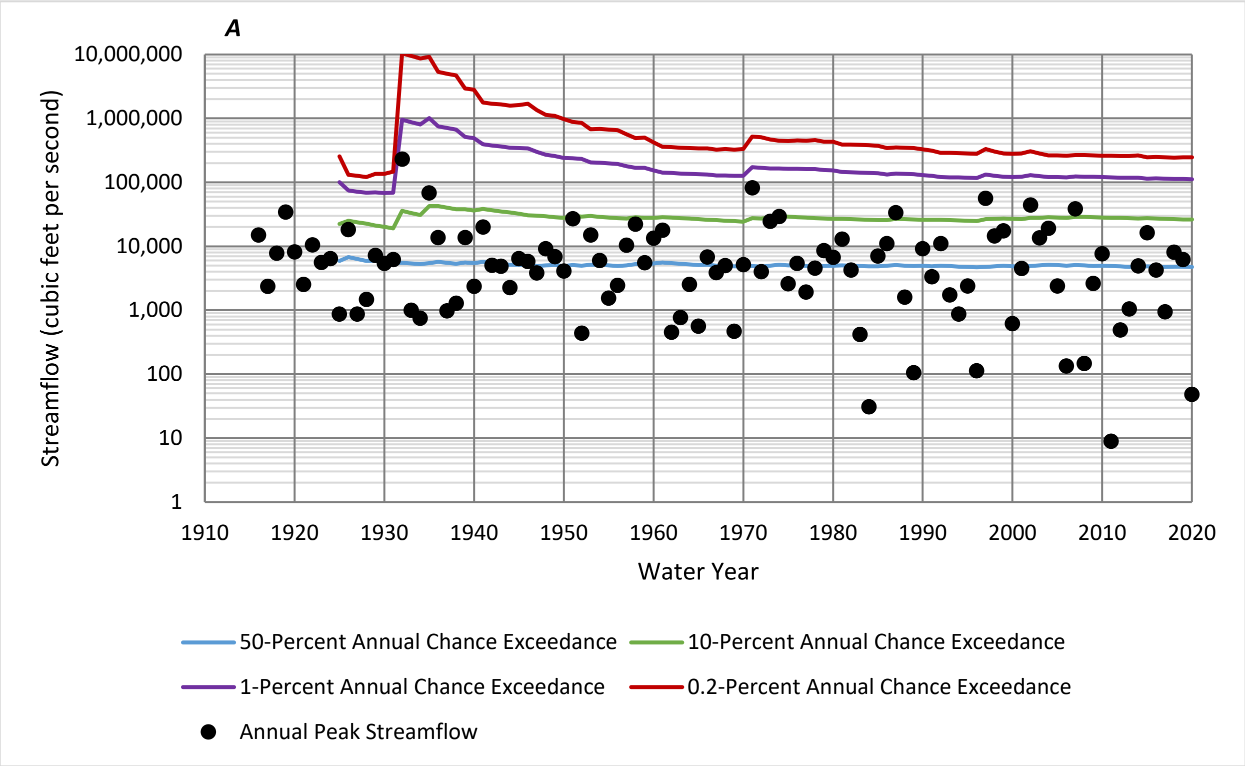


Figure A.60: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08197500 Frio River below Dry Frio River near Uvalde, Texas. Note: zero-flow values plotted in panel B (linear scale) are missing from panel A (log scale) because the logarithm of zero cannot be defined.

08205500 Frio River near Derby, Tex.

The relative effects of record length and magnitudes of substantial floods for the Frio River near Derby streamgage are shown in Figure A.61. Annual chance exceedance estimates reach a maximum in 1932 corresponding with the 230,000 cfs peak of record which occurred the same year. Estimates then gradually decrease through 2020 with slight increases corresponding to peaks above approximately 40,000 cfs. The 1-percent annual chance exceedance estimate decreases from 121,000 cfs in 2010 to 112,000 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases from 28,200 cfs to 26,200 cfs. Although no significant trend in annual peak streamflow was identified, from 2010 through 2020, the 50-percent annual chance exceedance estimate decreases steadily from 4,980 cfs to 4,740 cfs.



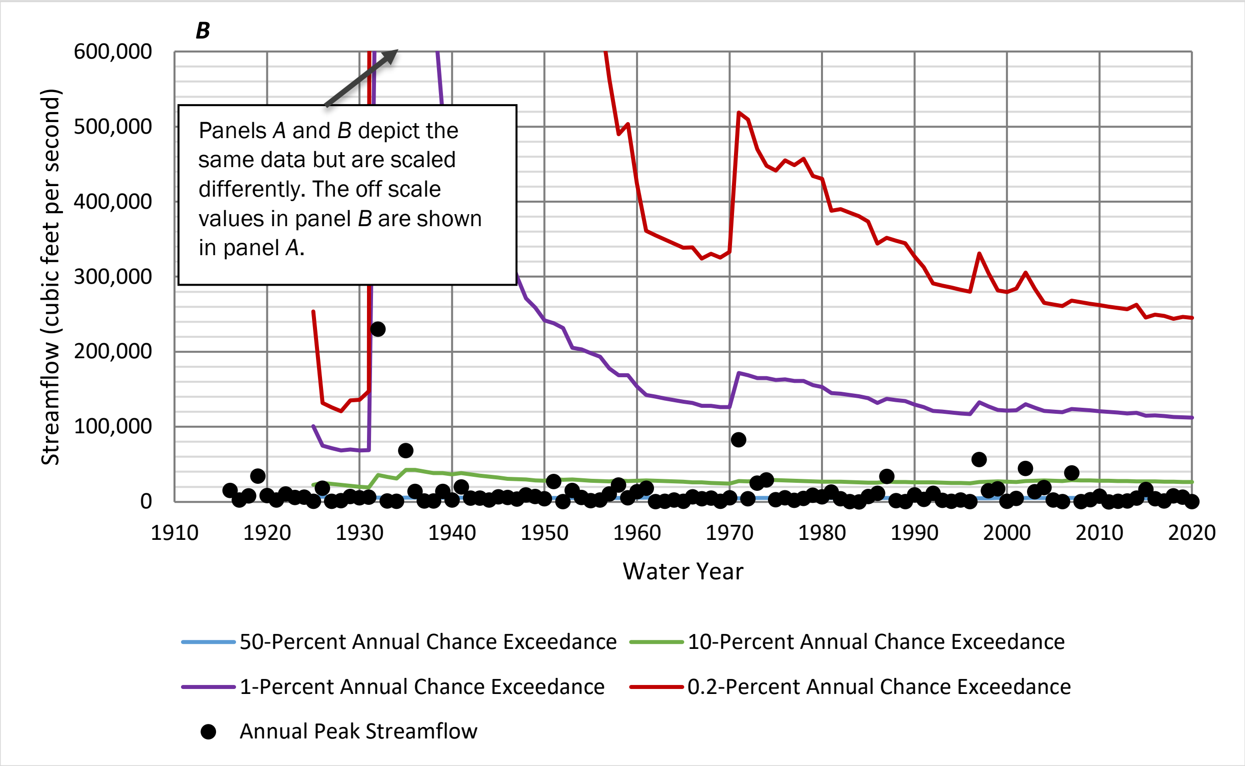
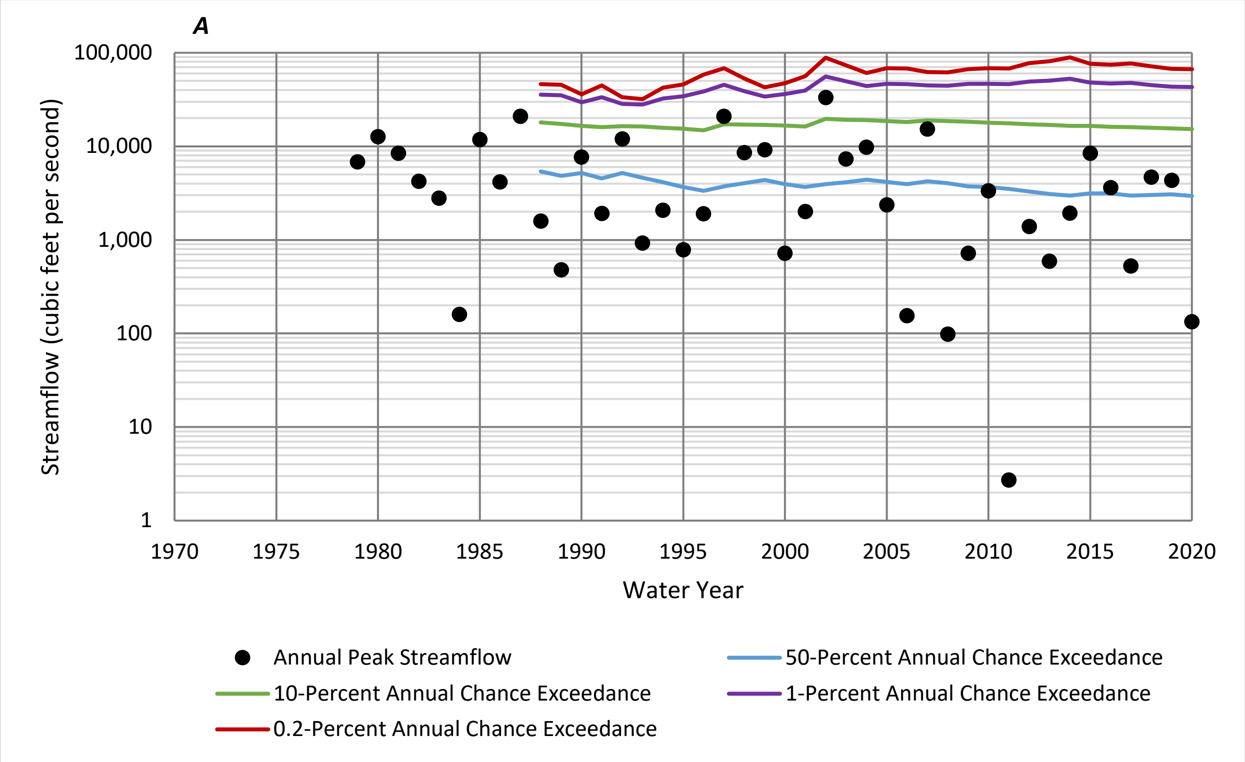


Figure A.61: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08205500 Frio River near Derby, Texas.

08206600 Frio River at Tilden, Tex.

The relative effects of record length and magnitudes of substantial floods for the Frio River at Tilden streamgage are shown in Figure A.62. After a slight increase associated with the 2002 event, all estimates appear to decline only slightly, although it is difficult to determine whether they have stabilized with only 18 years of record after the 2002 event. The 1-percent annual chance exceedance (ACE) event decreases from 46,500 cfs in 2010 to 43,000 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases from 17,900 cfs to 15,300 cfs.



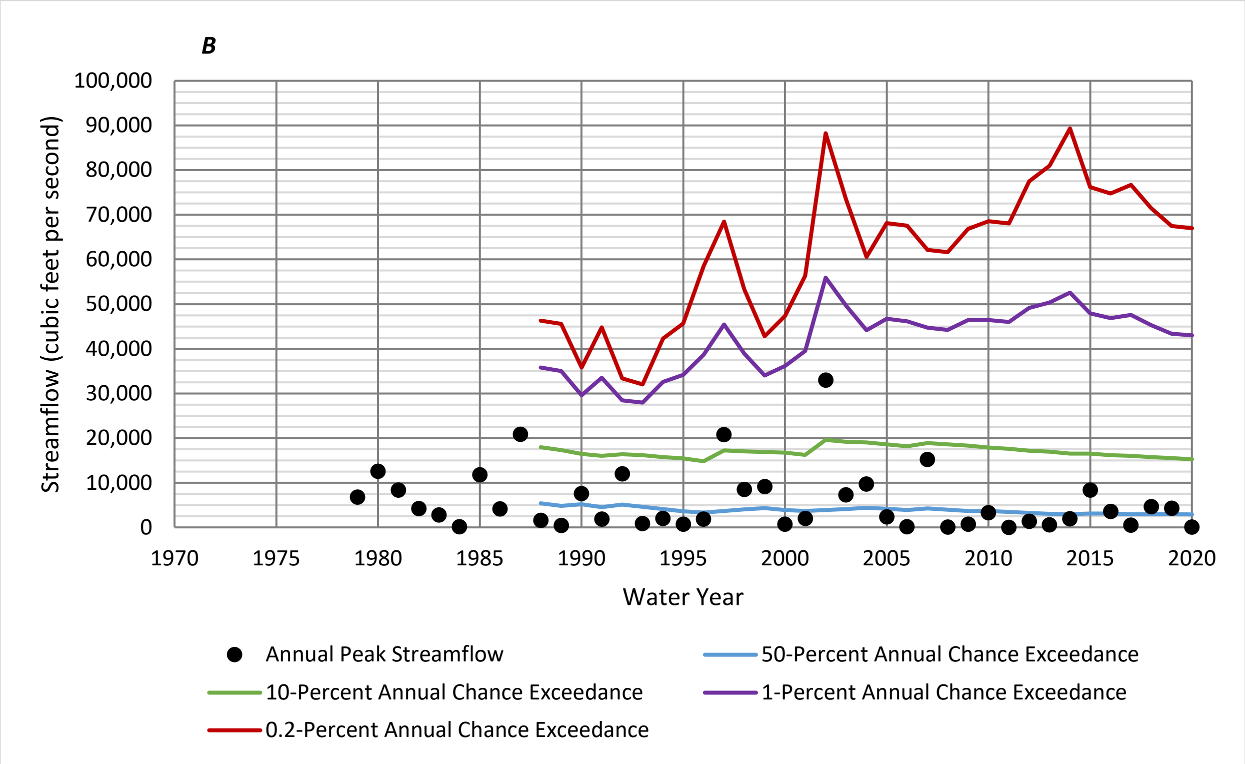


Figure A.62: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08206600 Frio River at Tilden, Texas.

08198500 Sabinal River at Sabinal, Tex.

The relative effects of record length and magnitudes of substantial floods for the Sabinal River at Sabinal streamgage are shown in Figure A.63. After marked increases in the 1-percent and 0.2-percent annual chance exceedance events following the notable 1997 and 2002 events, all estimates appear to have stabilized, although it is difficult to determine whether they have stabilized with only 18 years of record (2003–20) since the 2002 event. The 1-percent annual chance exceedance (ACE) event decreases from 114,000 cfs in 2010 to 105,000 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases from 37,400 cfs to 33,200 cfs.

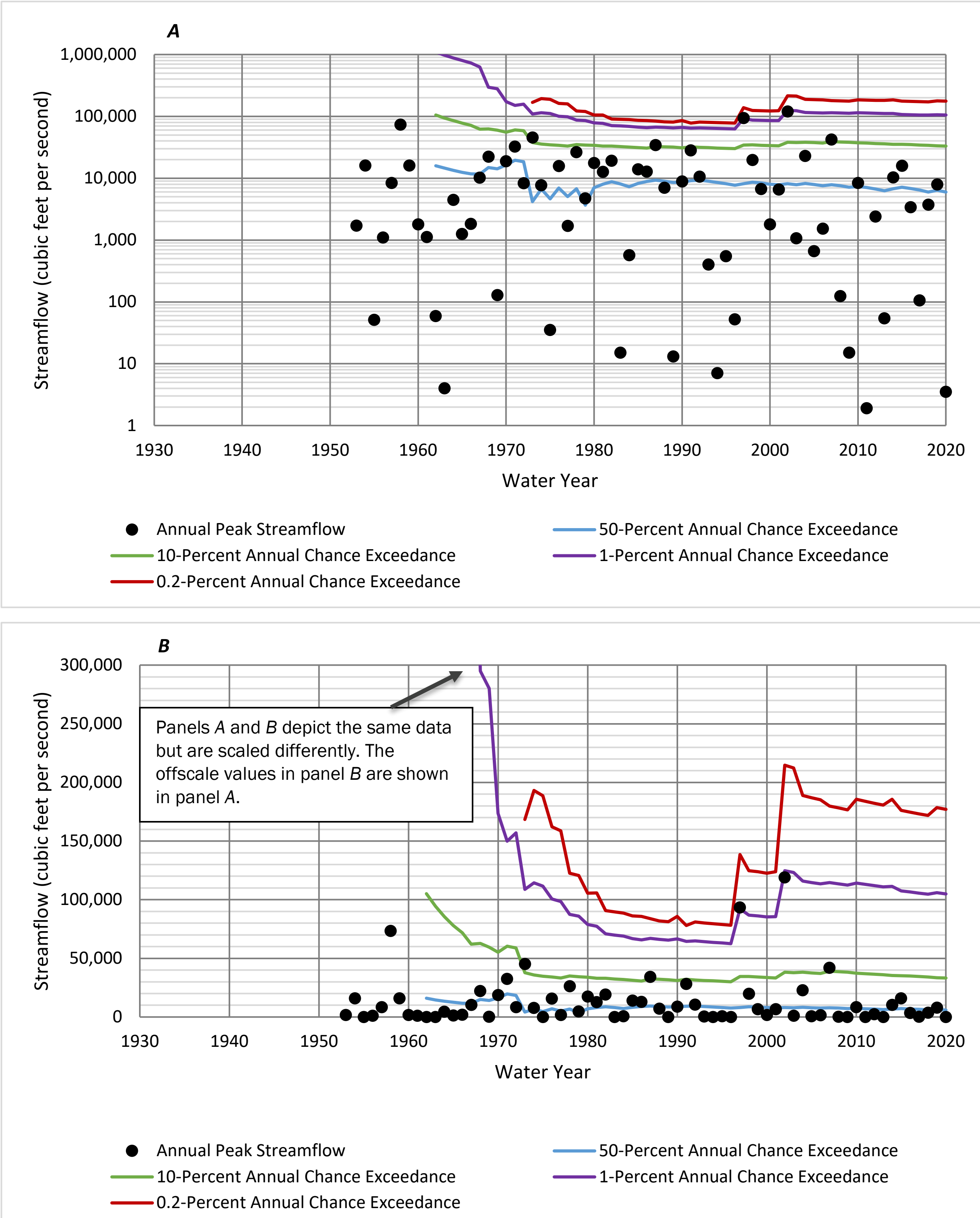


Figure A.63: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08198500 Sabinal River at Sabinal, Texas.

08208000 Atascosa River at Whitsett, Tex.

The relative effects of record length and magnitudes of substantial floods for the Atascosa River at Whitsett streamgage are shown in Figure A.64. After high estimates at the beginning of the period of record, all estimates appear to have stabilized in recent years. The 1-percent annual chance exceedance (ACE) event only decreases from 77,900 cfs in 2010 to 76,000 cfs in 2020. During the same time span, the 10-percent annual chance exceedance estimate decreases from 22,100 cfs to 20,700 cfs.

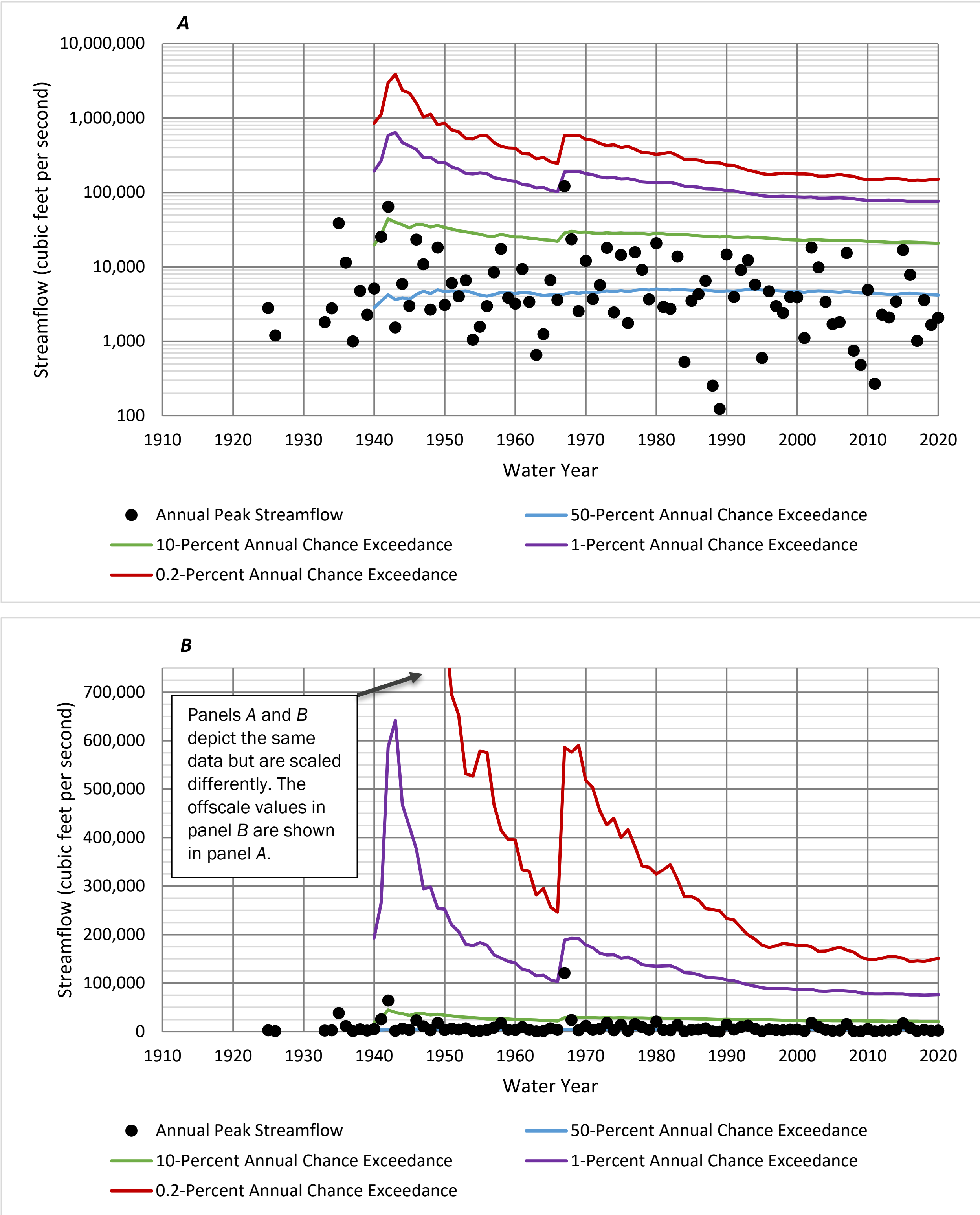


Figure A.64: Statistical Frequency Flow Estimates versus Time in *A*, log y-axis and *B*, linear y-axis for U.S. Geological Survey Streamgage 08208000 Atascosa River at Whitsett, Texas.

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