Appendix C. Hydrology and Hydraulics

Draft Kansas River Reservoirs Flood and Sediment Study

October 2023

U.S. Army Corps of Engineers
Kansas City District

HYDROLOGY

IMPACTS OF FLOOD RISK MANAGEMENT INFRASTRUCTURE

Kansas City District

Kansas River Watershed Study

Appendix C: Hydrology

Hydrologic Engineering Branch

Kansas River Hydrology

DRAFT – October 20, 2023 – Not for Public Distribution

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Acronyms

AEP – Annual Exceedance Probability

B17C – Bulletin 17C, Guidelines for Determining Flow Frequency

CWMS – Corps Water Management System

EMA – Expected Moments Algorithm

FIS – Flood Insurance Study

FWOP – Future without Project

HEC-HMS – Hydrologic Engineering Center – Hydrologic Modeling System

HEC-ResSim – Hydrologic Engineering Center – Reservoir Simulation

HEC-SSP – Hydrologic Engineering Center – Statistical Software Package

KC Levees – Kansas City Levees Construction Project

MMC – Mapping, Modeling, and Consequences Program

MRFF – Missouri River Flow Frequency

MSE – Mean Square Error

RMSE – Root Mean Square Error

USGS – U.S. Geological Survey

UMRSFFS – Upper Mississippi River System Flow Frequency Study

USACE - U.S. Army Corps of Engineers

1 Introduction

This report documents the hydrologic analysis for the Kansas River Watershed Study. The purpose of the analysis was to evaluate impacts of flood risk management infrastructure in the Kansas River Basin for existing, future without project (FWOP), and proposed conditions.

2 Data

2.1 Streamflow Data

Systematic streamflow records for the flow-frequency analysis were available from the USGS for the Kansas River and tributary gages listed in Table 2.1. USGS records list several historic floods for the stream gages of interest. A map of the study area is shown in Figure 2.1.

Table 2.1. USGS Streamflow data

USGS Gage ID	Stream	Location	Drainage Area (sq. mi.)	USGS Peak Streamflow Record	Historic Floods (USGS Water Year)	Regulation Start Year (USGS)
Mainstem Kansas River						
06879100	Kansas River	Fort Riley	44,870	1918-1951[a], 1964-2019	1903, 1915	1948
06887500	Kansas River	Wamego	55,280	1902-1903, 1914-2019	1908	1948
06889000	Kansas River	Topeka	56,720	1902-2019	1869, 1877, 1885, 1889, 1897	1948
06891000	Kansas River	Lecompton	58,400	1891-1904, 1929-2019	1908, 1915, 1919	1948
06892350	Kansas River	Desoto	59,756	1917-2019[b]	1903	1948
Kansas River Tributaries below Dams						
06857100	Republican River	Junction City	24,900	1895-1905[c], 1951-2019	1915, 1935	1953, 1957
06887000	Big Blue River	Manhattan	9,640	1918-1960[d], 1955-2019	1903 (stage only), 1951	1960
06890900	Delaware River	Perry	1,141	1922-1968[e], 1969-2019	1865, 1903, 1904, 1908, 1915	1970
06891500	Wakarusa River	Lawrence	425	1930-1972, 1981-2019	1921, 1929	1981

[a]Data 1918-1951 obtained from Ogden USGS gage (06879500)
[b]Data 1917-1973 obtained from Bonner Springs USGS gage (06892500)
[c]Data for 1895-1905, 1951-1963, and 1915, 1935 historic floods taken from Milford, KS USGS gage (06857000).
[d]Data for 1918-1954 (except 1951 flood) taken from Randolph, KS USGS gage (06886000).
[e]Data for 1922-1967 taken from Valley Falls, KS USGS gage (06890500). Peak flow for 1968 taken from Arrington, KS (USGS 06890400).

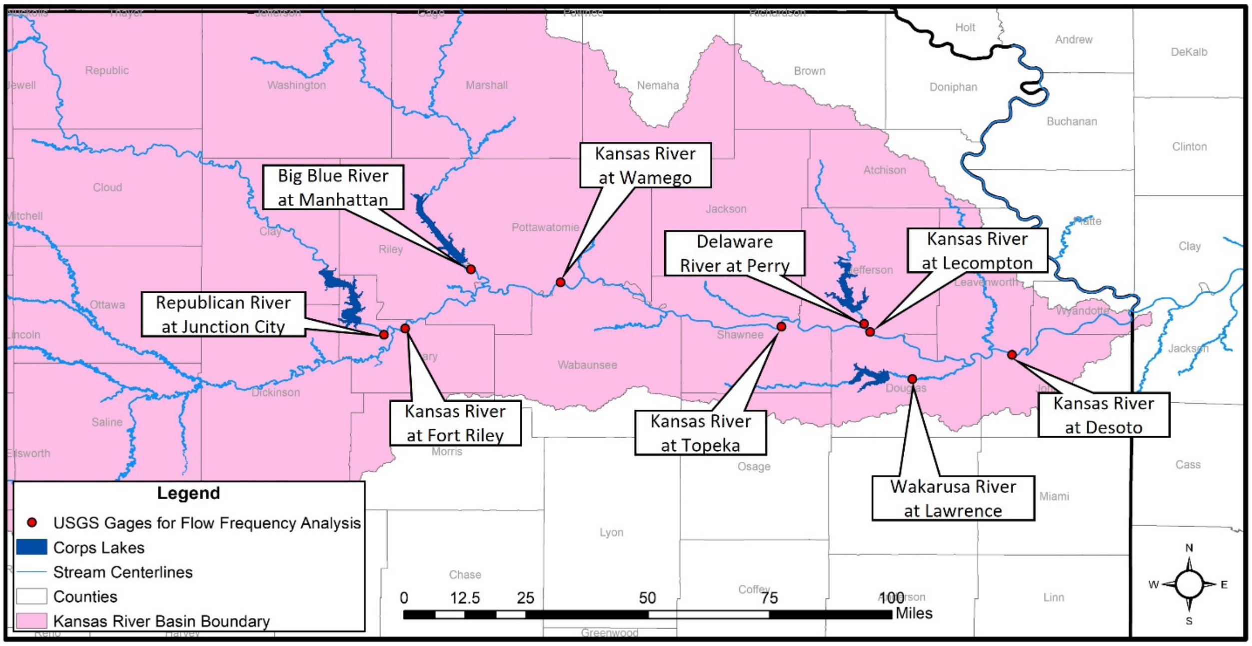

Figure 2.1. Map of the Study Area

2.2 Historic Data

Historic peak flows were gathered from the USGS and other USACE sources and are listed in Table 2.2. The USGS estimates are the annual peak flows with the Qualification Code 7 which represents historic peaks. Additional peak flow estimates for years outside of the USGS record were found in other sources listed in the table.

Table 2.2. Historic Peak Flows

Gage	Water Year	Peak Flow (cfs)	Source
KANSAS RIVER			
Desoto/Bonner Springs	1844	360,000 516,000*	USACE, October 1966 USACE, 2020
	1903	337,000	USGS
	1915	136,000	USACE, 1984
Lecompton	1844	321,000*	USACE, 1935
	1908	230,000	USGS
	1915	110,000	USGS
	1919	78,000	USGS
Topeka	1844	436,700 (345,000 low)	USACE, 2020
	1858	175,000 (175,000 – 225,000)	USACE, 2020
	1869	72,000	USGS
	1877	96,000	USGS

Gage	Water Year	Peak Flow (cfs)	Source
	1885	92,000	USGS
	1889	69,000	USGS
	1897	82,000	USGS
Wamego	1908	160,000	USGS
Fort Riley/Ogden	1903	236,000	USGS
	1915	110,000	USGS
REPUBLICAN RIVER			
Junction City/Milford	1915	130,000	USGS
	1935	171,000 (Milford) 168,000	USGS USGS, 1937
BIG BLUE RIVER			
Manhattan	1903	68,800 93,800 98,000	USACE, 1935 USACE, 2011 USACE, 1973
	1951	93,400	USGS
Randolph	1897	21,900	1944 USGS Letter to District Engineer
	1899	22,200	1944 USGS Letter to District Engineer
	1902	42,000	1944 USGS Letter to District Engineer
	1903	82,500	1944 USGS Letter to District Engineer
	1904	19,900	1944 USGS Letter to District Engineer
	1905	18,000	1944 USGS Letter to District Engineer
	1907	16,200	1944 USGS Letter to District Engineer
	1908	80,500	1944 USGS Letter to District Engineer
	1909	30,400	1944 USGS Letter to District Engineer
	1910	26,500	1944 USGS Letter to District Engineer
	1911	22,200	1944 USGS Letter to District Engineer
	1912	31,200	1944 USGS Letter to District Engineer
DELAWARE RIVER			
Perry/Valley Falls	1865	87,000	USGS
	1903	30,000	USGS
	1904	24,000	USGS
	1908	31,000	USGS
	1915	33,000	USGS
WAKARUSA RIVER			
Lawrence	1921	16,000	USGS
	1929	16,000	USGS

*Peak flows were adjusted in flow frequency analysis. See Table 2.3.

The 1844 and 1858 floods were two of the largest historic floods on the Kansas River. The flow estimates at Topeka were derived using historic flood information documented in the Kansas City Levees Supplemental Hydrology and Hydraulics report (USACE, 2020) and were scaled to the other Kansas River gages using linear regression of the top five largest unregulated flows. The estimates included a range of flow values to account for uncertainty. The Kansas City Levees 1844 low and best estimate flows at Topeka were 345,000 cfs and 436,700 cfs, respectively. The maximum 1844 Kansas River peak flow was estimated to be 555,000 cfs. This was assumed as the high value for Desoto and then scaled to the other gages as well. Greater uncertainty exists at Fort Riley due to a lack of historic flood information at that location. Additionally, Fort Riley is upstream of the Big Blue River, a major tributary to the Kansas River. For these reasons, the 1844 and 1858 flood estimates were not included in the final flow frequency analyses at the Fort Riley gage. The flood estimates are shown in Table 2.3.

Table 2.3. 1844 and 1858 Flood Estimates (cfs)

	Topeka	Desoto	Lecompton	Wamego	Fort Riley
1844 Low	345,000	385,275	365,517	319,737	246,105
1844 Best	436,700	473,609	451,194	389,291	304,394
1844 High	526,802	555,000	530,136	453,377	358,101
1858 Low	125,000	173,349	159,967	152,868	106,263
1858 Best	175,000	221,514	206,683	190,793	138,045
1858 High	225,000	269,679	253,399	228,717	169,828

2.3 Unregulated Data

The USACE Kansas City District Water Management Section produced the unregulated daily flow data for the 5 mainstem Kansas River gages (Fort Riley, Wamego, Topeka, Lecompton, and Desoto) and the 4 tributary gages downstream of USACE dams (Republican River at Junction City, Big Blue River at Manhattan, Delaware River at Perry, and Wakarusa River at Lawrence) for the regulation period. Holdouts from USACE and USBR dams were removed from the period of record data, but other water uses were not considered as they were not significant for large flood peaks. Coefficient routing was used to route the reservoir holdouts downstream; then holdouts were added to the observed daily hydrograph (USGS) to determine the unregulated flow values. Linear regression equations were computed from the observed USGS daily peak data and the USGS annual instantaneous peak data and used to estimate unregulated instantaneous flows. The annual maximums from the USGS daily peak data were computed using the HEC-DSS time function based on water year (Oct 01 to Sept 30). If the computed annual maximums and the USGS instantaneous annual peak flows occurred more than a day apart, that year was removed from the linear regression analysis. The two datasets were then plotted in Excel to compute the linear equation. The plot and linear regression equation for the Desoto gage is shown in Figure 2.2 as an example. Linear regression plots for all the gages are included in Attachment 1.

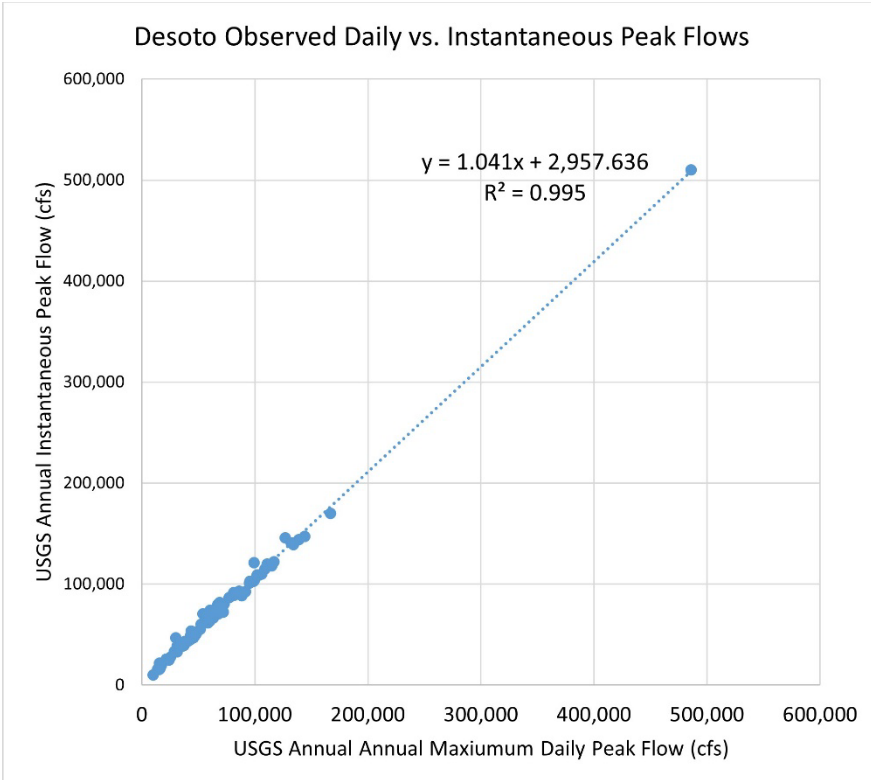

Figure 2.2. Desoto USGS Annual Maximum Daily Peak Flow vs. USGS Annual Instantaneous Peak Flow

The Kansas River unregulated daily peak flow data was combined with USGS daily peak flow data prior to 1948, the beginning of regulation in the Kansas River basin, and the annual maximums were computed using the HEC-DSS time function based on calendar year. The calendar year was used, as it was more representative of independent flood events than the water year. Some of the larger flood events tend to occur in September and October so there was a possibility of double counting the same event if water year was used. For example, Figure 2.3 shows two peaks that occurred at Topeka in September and October of 1973.

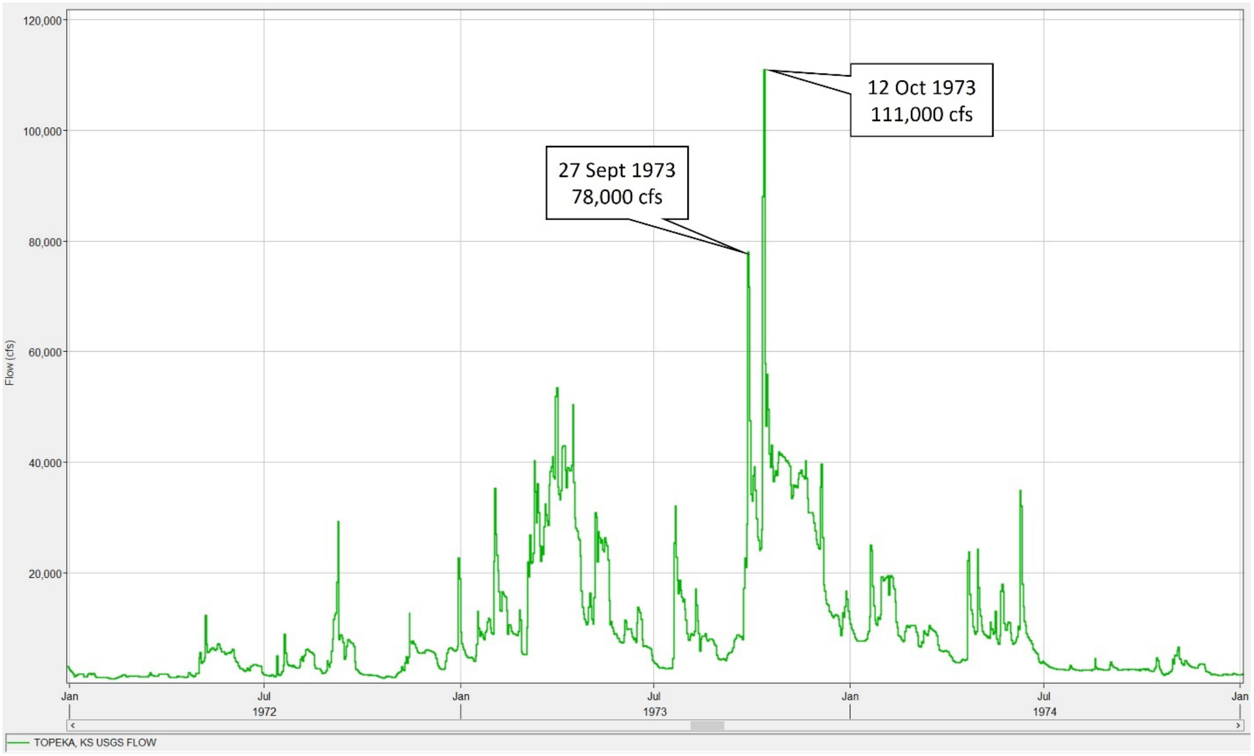

Figure 2.3. USGS Daily Peak Flows for the Kansas River at Topeka, Kansas in 1973

The annual maximums were then converted to instantaneous peak flows using the regression equation for each gage. The unregulated instantaneous data was compared to the Kansas River Hydrology Study (USACE, 2002) unregulated flows without depletions. Figure 2.4 shows the comparison plot for Desoto, and the comparison plots for the other Kansas River gages are included in Attachment 1.

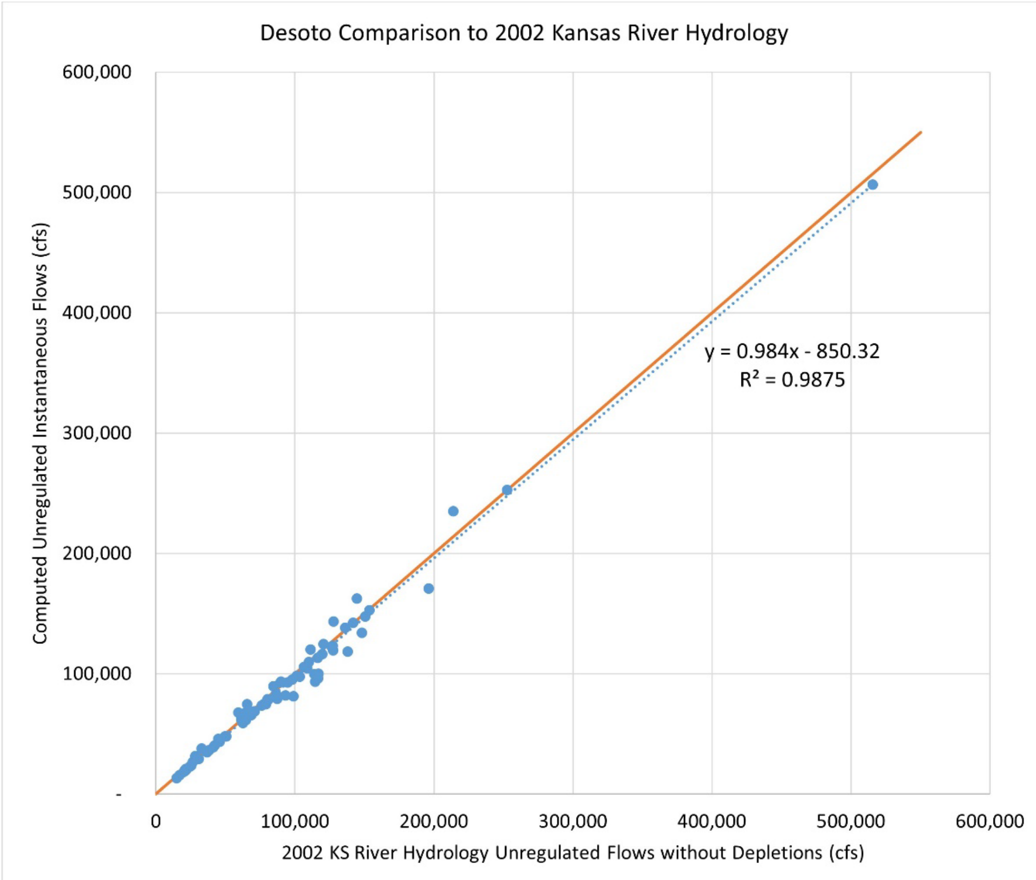

Figure 2.4. Desoto Unregulated Instantaneous Data Compared to KS River Hydrology Study

All the Kansas River gages plotted reasonably well against the Kansas River Hydrology (USACE, 2002) flows except for Fort Riley which is shown in Figure 2.5. It is unknown why the Fort Riley flows from the Kansas River Hydrology Study compared so poorly with the currently developed dataset. The annual maximum unregulated daily peak flow data for Fort Riley was then compared to the Manhattan Feasibility Study unregulated flows. Figure 2.6 shows the comparison to the Manhattan Feasibility Study which plotted much better than the Kansas River Hydrology Study. For the Manhattan Feasibility Study, the unregulated synthetic period of record was developed with a UNET model for the Kansas River assuming no reservoirs were in place. The UNET model was an unsteady flow model developed by the USACE Kansas City District to route daily flows over the period of 1929 to 2002 (USACE, 2011).

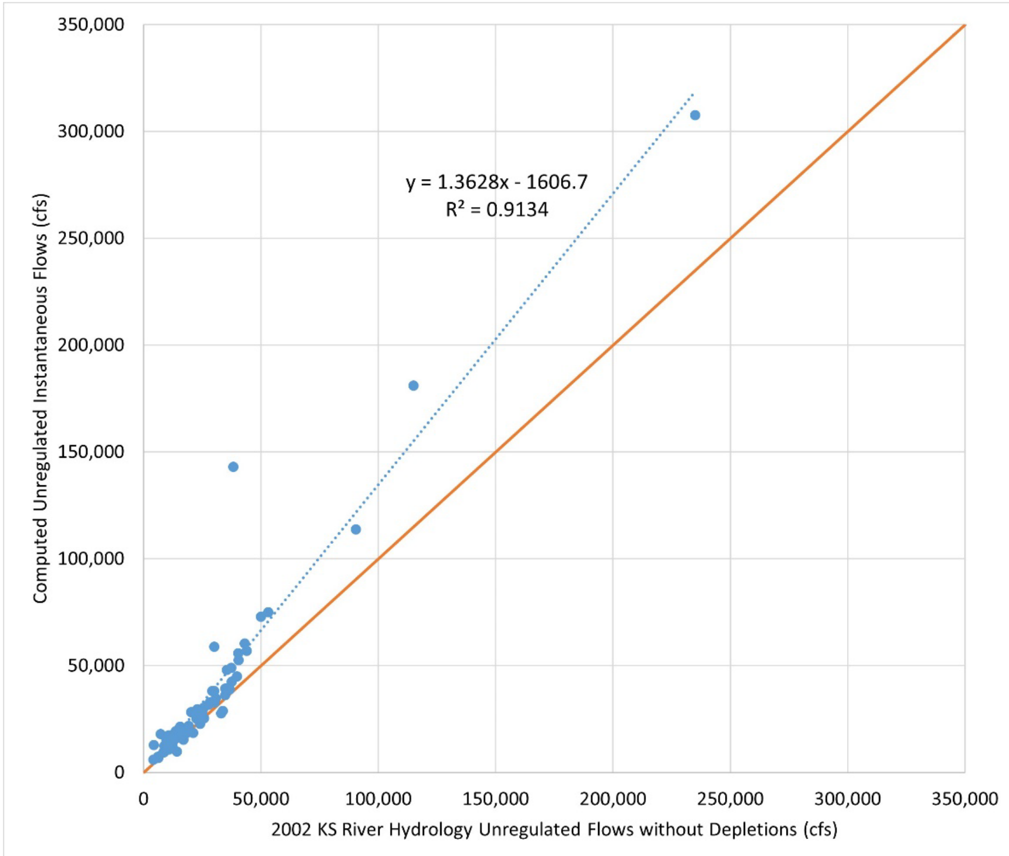

Figure 2.5. Fort Riley Unregulated Instantaneous Data Compared to KS River Hydrology Study

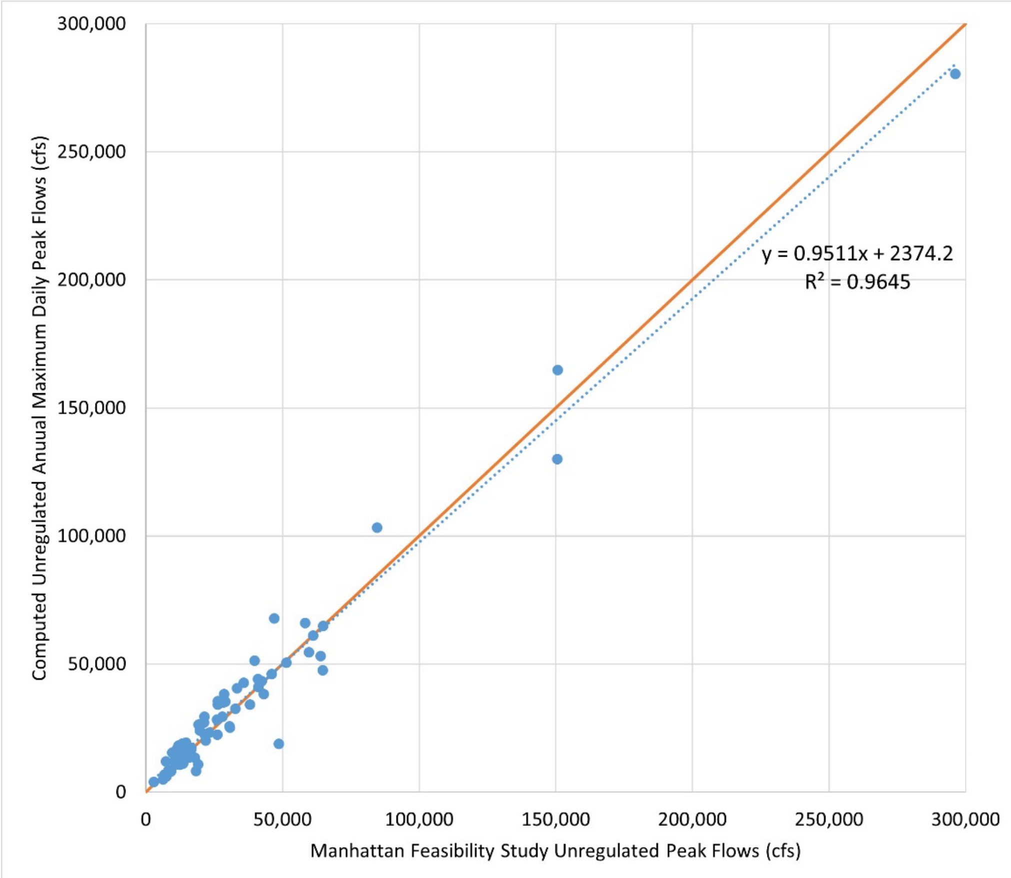

Figure 2.6. Fort Riley Unregulated Annual Maximum Daily Peak Flow Data Compared to Manhattan Feasibility Study

The 1951 natural (unregulated) daily peak flows were found to be less than the observed daily peak flows which suggested the unregulated instantaneous peak flows computed by linear regression were overpredicted. Since this was the largest flood event in the systematic record, the values were adjusted to better correlate with observed data. For each of the Kansas River gages, the 1951 unregulated daily peak flows were multiplied by a ratio of the observed 1951 instantaneous peak to the observed 1951 daily peak. This resulted in unregulated instantaneous peaks that were less than the observed instantaneous peaks. Unregulated peaks for the Kansas River in 1951 were less than the observed values due to releases primarily from Kanopolis Dam that added a small amount of flow to the peak of the flood event.

The unregulated instantaneous data for the tributary gages was developed using the same methodology. For the Junction City gage, the regression equation was computed without the 1903 peak flows to better fit the data. Likewise, the regression equation for Perry was computed without the 1951 peak flows. A polynomial regression equation produced a better fit to the data for Perry, so it was used instead of the linear equation.

2.3.1 Missing Data

The Fort Riley gage did not have peak flow data for the years 1952 through 1963. The peak flow values from the Manhattan Feasibility Study were converted to instantaneous peak flows using the linear regression equation for Fort Riley and were used to fill in the missing years. Use of the maintenance of variance equation 3 (MOVE3) to adjust data for these years from the Wamego gage was also investigated; however, the data from the Manhattan Feasibility Study was adopted. Generally, the Manhattan Feasibility Study peak flows were higher than the computed MOVE3 peak flows and therefore were more conservative.

USGS daily flow data for the Lecompton gage only extends back to 1936; however, annual peaks were available for 1929-1931 and the 1935 flood. An earlier period of peak annual flow also exists as shown in Table 2.1. The Kansas River Hydrology peak flows without depletions were used to fill in missing data from 1920 to 1934.

2.3.2 Final Unregulated Datasets

Three unregulated datasets were developed for each Kansas River gage to use in the flow frequency analysis. The first dataset contains the USGS daily peak flow data converted to annual instantaneous peak flow data prior to 1948 and the computed instantaneous unregulated peak flow data after 1948. Since the USGS instantaneous annual peak flow record extends farther back than the daily record, the USGS instantaneous peak flows were filled in where available.

The second dataset contains the USGS instantaneous annual peak flow data prior to 1948 and the computed instantaneous unregulated peak flow data after 1948. The USGS records annual instantaneous data by water year. So, if two peaks occurred in the same calendar year, the higher of the two was chosen for that year and the computed instantaneous peak from the daily peak flow data was used for the following year (if there was no peak daily flow data for that year, the USGS instantaneous peaks were used for both years).

A third dataset was developed by adding supplemental data to the second dataset. Unregulated streamflow data from nearby USGS gages were transferred to the gages of interest with the MOVE3 which is the recommended method of record extension for Bulletin 17C. Sections 3.1 through 3.9 provide more documentation on supplemental data. Attachment 2 contains the third unregulated datasets which were used in the development of the final frequency flows for each of the gages. The superscripts indicate the source each peak flow came from.

2.4 Regulated Data

The USACE Kansas City District Water Management Section produced the regulated data for the five mainstem Kansas River gages and the four tributary gages using Hydrologic

Engineering Center (HEC) – Reservoir Simulation (ResSim) software. Development of the regulated period of record flows is documented in the Water Management appendix of the Watershed Study report. The regulated flows were plotted against USGS observed daily peak flows post regulation and the plots for the Kansas River gages are shown in Figure 2.7 through Figure 2.11.

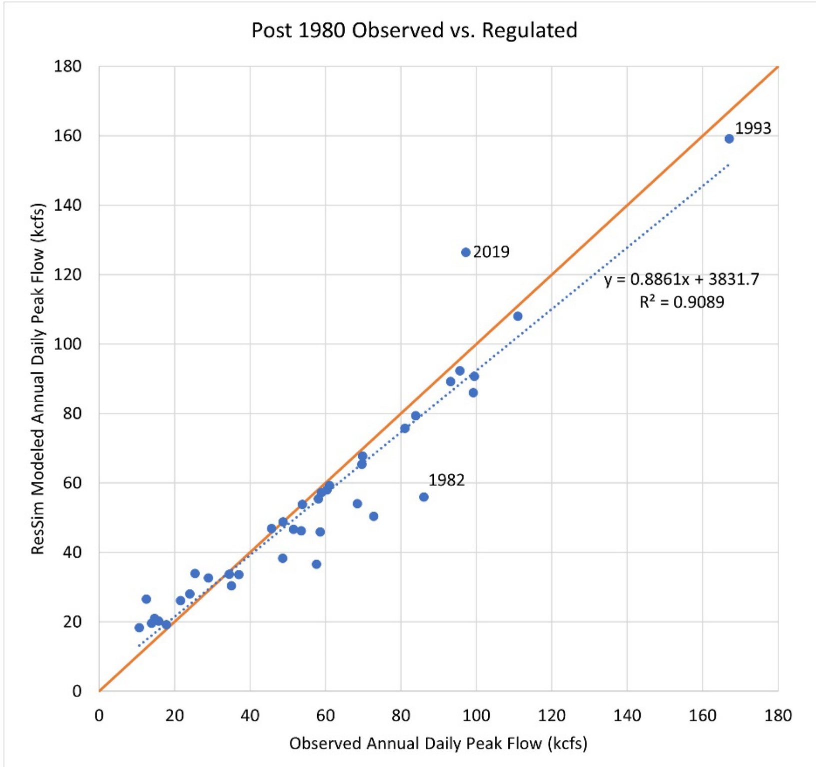

Figure 2.7. Desoto Regulated Data Compared to USGS Observed Data

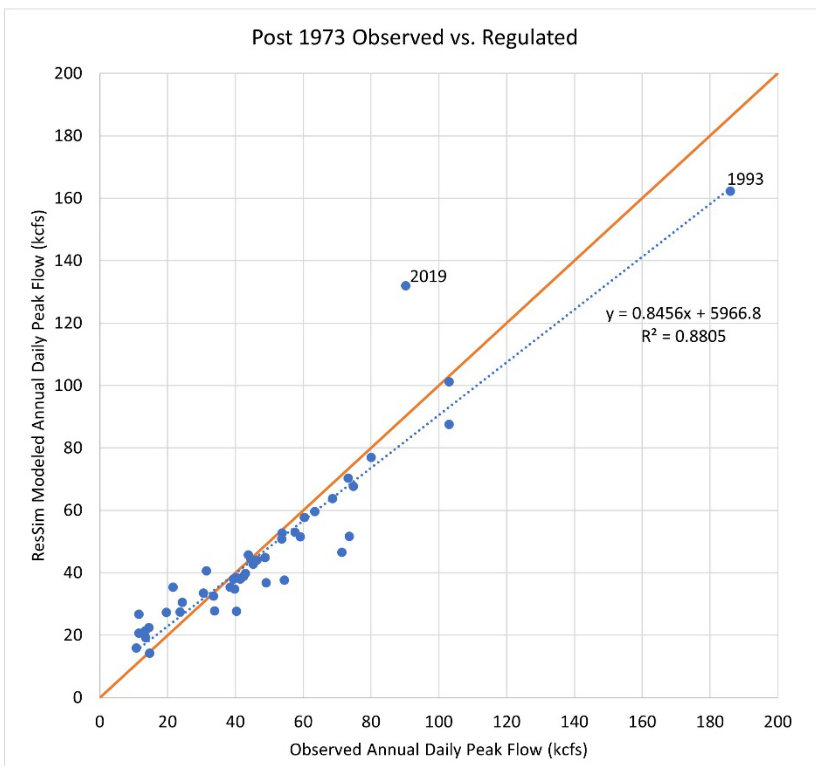

Figure 2.8. Lecompton Regulated Data Compared to USGS Observed Data

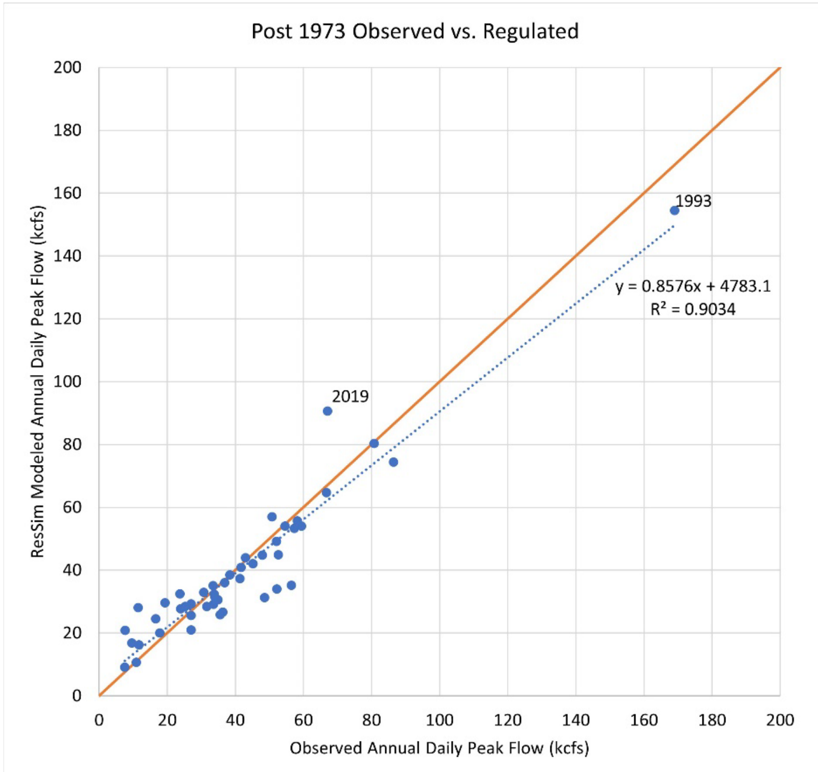

Figure 2.9. Topeka Regulated Data Compared to USGS Observed Data

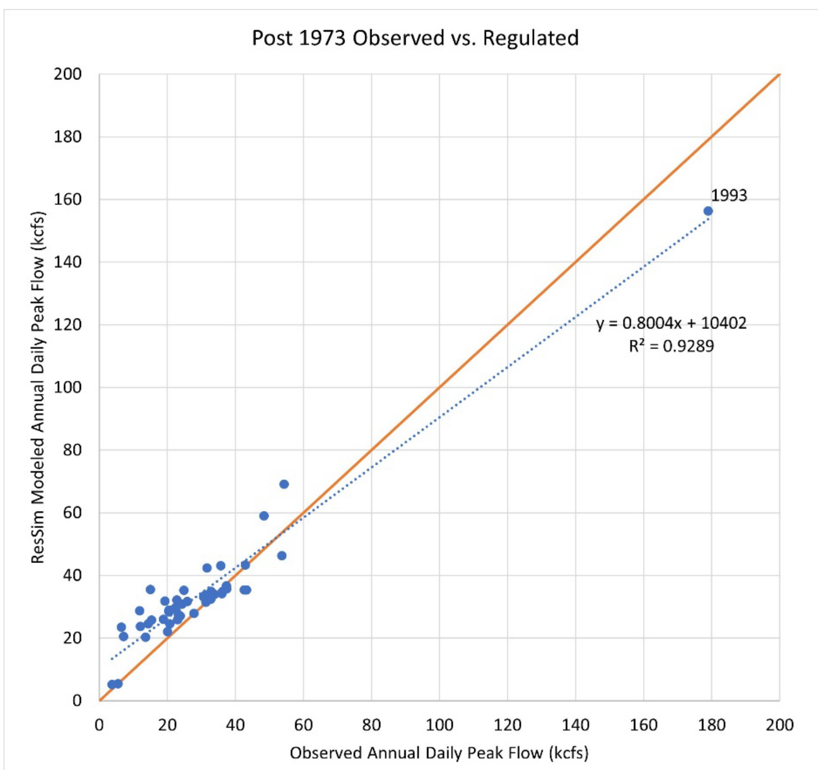

Figure 2.10. Wamego Regulated Data Compared to USGS Observed Data

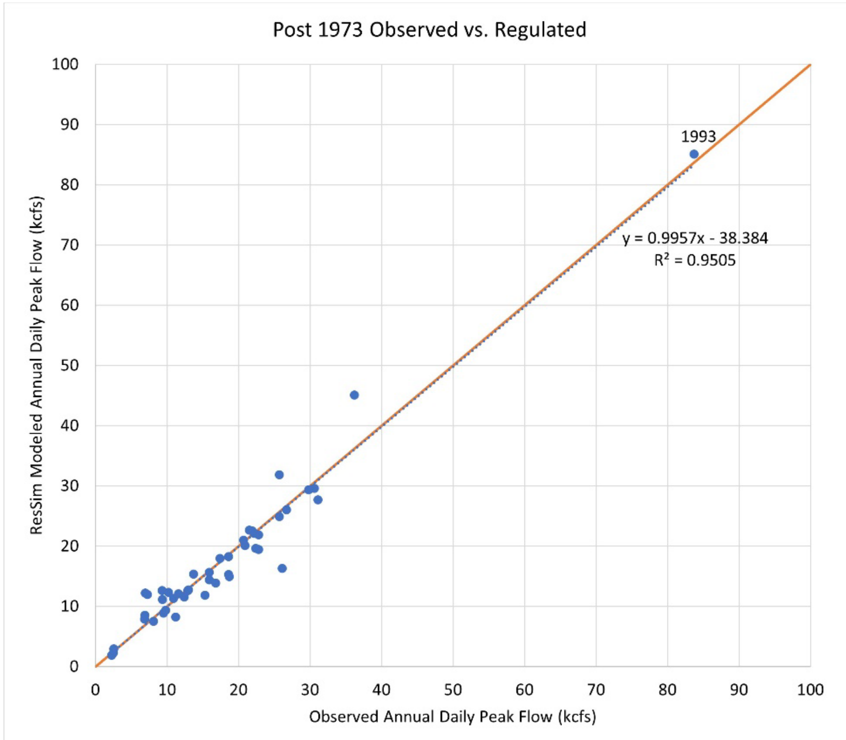

Figure 2.11. Fort Riley Regulated Data Compared to USGS Observed Data

The regulated datasets for the Kansas River gages were then adjusted to create a 1:1 relationship with the observed data. Peak flows were adjusted using the trendline equations for all years except 1951 since the 1951 peak flows were higher than the highest points on the plots.

A similar comparison was made for the tributary gages; however, they did not have a strong correlation. Many of the simulated regulated peak flows were near the maximum Phase 1 release for the upstream reservoir while the observed peak flows were much lower. Therefore, the observed regulated data was adopted for the remainder of the analyses for the tributary gages.

3 Bulletin 17C Analysis

A Bulletin 17C flow frequency analysis was completed for the gages of interest using Hydrologic Engineering Center Statistical Software Package (HEC-SSP) Version 2.3. The unregulated instantaneous datasets were imported into HEC-SSP. The software defaults to water year, so if the day of the peak occurred after September 30th, the date was adjusted to January 1st of that year. The default confidence limits (0.05, 0.95) were selected for the analyses. The station skews were computed for the Kansas River gages using the developed datasets and the results are shown in Table 3.1. The datasets containing USGS annual instantaneous peak data and MOVE3 data were adopted for the flow frequency analyses to reduce uncertainty.

Table 3.1. Computed Station Skews using USGS Daily Peak Data vs. USGS Annual Instantaneous Peak Data Prior to 1948 and the addition of MOVE3 data

Gage	USGS Daily Peak Data	USGS Annual Instantaneous Peak Data	USGS Annual Instantaneous Peak Data and MOVE3 Data
Desoto	-0.150	0.033	-0.020
Lecompton	0.100	0.024	0.101
Topeka	0.336	0.156	0.194
Wamego	0.100	0.117	0.247
Fort Riley	0.411	0.406	0.445

It is recommended that the station skew be weighted with a generalized (or regional) skew to reduce bias caused by modest record lengths. As seen in Table 3.1, the selected dataset significantly impacted the computed station skew, reiterating the importance of regionalizing the skew values. Several methods were considered to determine regional skew. One method commonly used prior to the Bulletin 17C publication was the generalized skew coefficients map on Plate 1 of Bulletin 17B (USGS, 1981). However, according to the Bulletin 17C publication, it is no longer recommended for use in flow frequency studies (USGS, 2019). The skew coefficients for the Kansas River gages based on the map are shown in Table 3.2 for comparison purposes.

Table 3.2. Bulletin 17B Generalized Skew Coefficients Map

Gage	Skew	No. stations to compute average
Desoto	-0.35	3
Lecompton	-0.45	4
Topeka	-0.45	4
Wamego	-0.6	2
Fort Riley	-0.6	2

The USGS developed an equation based on a weighted least squares regression model to estimate the generalized skew coefficient at streamflow gaging stations in Kansas (2000). The variables in the model included streamflow data from 253 gages in Kansas as well as physical and climatic characteristics. The resulting equation had three independent variables: contributing drainage area (CDA), latitude (Lat), and longitude (Lng). The root mean square error (RMSE) for the equation was 0.19. Table 3.3 shows the variables for each Kansas River gage and computed generalized skews (G_g).

Table 3.3. Gage Data and Generalized Skewness Coefficient Computed from WLS Regression Model Equation

Gage	CDA (sq mi)	Lat (decimal degrees)	Lng (decimal degrees)	G_g
Desoto	59,756	38.983	94.964	0.213
Lecompton	58,460	39.051	95.386	0.197
Topeka	56,720	39.067	95.649	0.184
Wamego	55,280	39.198	96.305	0.162
Fort Riley	44,870	39.062	96.766	0.119

The generalized skew coefficients computed from the WLS regression model equation were used in the flow frequency analyses for the Kansas River gages as a sensitivity analysis. However, the USGS states the equation is limited to stations with drainage areas no larger than 9,100 square miles. Therefore, the results are only for comparison purposes.

More recently, the USGS (2017) developed regression models to estimate annual exceedance probability (AEP) streamflows for ungaged sites in Kansas based on streamflow data through water year 2015. As part of the study, regional skews were developed for two hydrologic regions defined by irrigation effects. The eastern region contained the gages of interest in this report. Streamflow data from 120 streamgages in Kansas and surrounding states were used for the analysis. The USGS considered developing an isoline map of station skew coefficients, but there was no geographic correlation of skew for the region when they plotted the station skews. Regression techniques with several basin factors were also considered, but a significant correlation with station skew was not found in this method either. The arithmetic mean of station skew coefficients was the final method for determining regional skew and resulted in a generalized skew coefficient of -0.125 for the eastern region with a standard error of 0.502 and a RMSE of 0.252. The drainage areas of the streamgages used to develop the regression equations ranged from 0.26 to 14,901 square miles in the eastern region.

The drainage areas of the Kansas River gages range from 44,870 square miles at Fort Riley to 59,756 square miles at Desoto. Therefore, an arithmetic mean of station skew coefficients was computed for only the Kansas River gages used in this analysis. According to Engineer Manual (EM) 1110-2-1415, if the arithmetic mean of station skew were used as a regional skew, the mean square error (MSE) could be approximated from the square of the standard deviation (USACE, 1993). The results produced a regional skew of 0.193 and a RMSE of 0.173.

The names and descriptions of all Bulletin 17C analyses completed within HEC-SSP are located in Attachment 3. Short identifiers were assigned to each analysis and are used in the following sections.

3.1 Kansas River at Desoto, KS

The first two weighted skew analyses in HEC-SSP (D2.a and D2.b) included four historic events previously identified in Table 2.2 and Table 2.3. Additional streamflow data was added for the last two analyses (D3.b and D3.c). The MOVE3 was used to scale unregulated streamflow data at Topeka to Desoto by the effective record length (n_e). Record extension using Lecompton data was also investigated, however the extended streamflow values were unreasonably low. For example, the 1915 flow was 107,000 cfs extended with Lecompton and 135,000 cfs extended with Topeka which was much closer to the historic estimate of 136,000 cfs. The results for Desoto are shown in Table 3.4.

Table 3.4. Bulletin 17C Results: Kansas River at Desoto

Annual Exceedance Probability (%)	USGS 2000 WLS (1844, 1858, 1903, 1915, 1917-2019)	USGS 2017 (1844, 1858, 1903, 1915, 1917-2019)	USGS 2017 (1844, 1858, 1902-1909, 1911-2019)	Avg station skew (1844, 1858, 1902-1909, 1911-2019)
0.2	493,000	438,000	450,000	508,000
0.5	398,000	366,000	375,000	409,000
1	334,000	315,000	322,000	342,000
2	277,000	268,000	272,000	283,000
5	210,000	209,000	211,000	214,000
10	165,000	167,000	168,000	167,000
20	124,000	127,000	127,000	125,000
50	73,600	74,600	73,800	72,800
80	44,600	43,300	42,200	43,400
90	34,700	32,500	31,300	33,400
95	28,300	25,500	24,400	27,000
99	19,600	16,100	15,200	18,300
Mean	4.874	4.869	4.864	4.869
Std Dev	0.265	0.277	0.285	0.273
Station Skew	0.033	0.033	-0.020	-0.020
Regional Skew	0.213	-0.125	-0.125	0.193
Adopted Skew	0.175	-0.077	-0.091	0.151
Perception Thresholds	1845-1857: 474kcfs-inf 1859-1902: 222kcfs-inf 1904-1914: 337kcfs-inf 1916: 136kcfs-inf	1845-1857: 474kcfs-inf 1859-1902: 222kcfs-inf 1904-1914: 337kcfs-inf 1916: 136kcfs-inf	1845-1857: 474kcfs-inf 1859-1901: 222kcfs-inf 1910: 100kcfs	1845-1857: 474kcfs-inf 1859-1901: 222kcfs-inf 1910: 100kcfs
Low Outliers	25	25	27	27
Systematic / Historic Events	103 / 4 (1844, 1858, 1903, 1915)	103 / 4 (1844, 1858, 1903, 1915)	115 / 4 (1844, 1858, 1903, 1915)	115 / 4 (1844, 1858, 1903, 1915
Historic Period	176	176	176	176

The final expected moments algorithm (EMA) data for Desoto is shown in Figure 3.1. The circles represent the observed data including historic data and the MOVE3 estimates while the shaded portions represent the perception thresholds. The SSP run with the average station skew (D3.c) was the final selected unregulated flow probability analysis. Figure 3.2 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

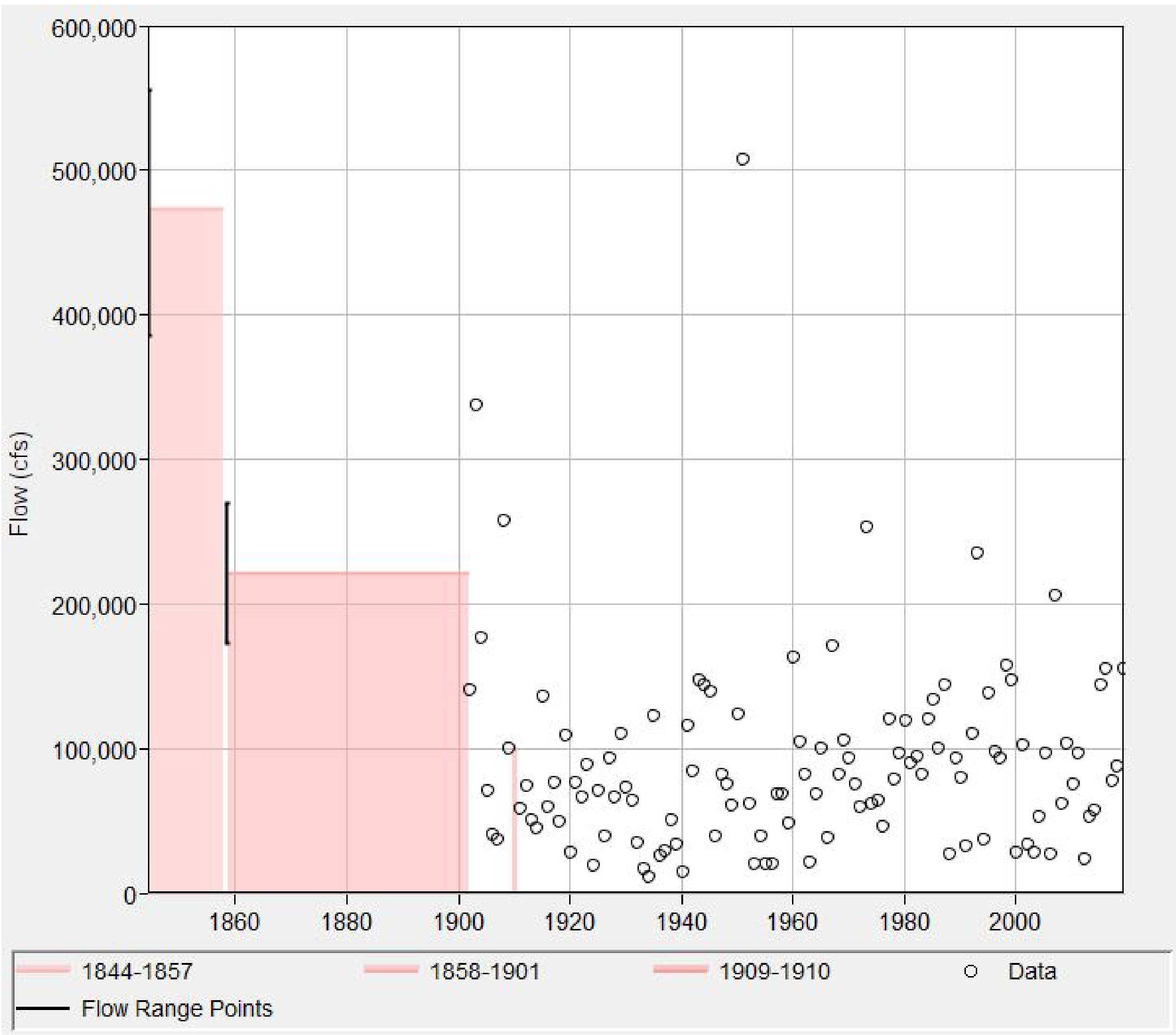

Figure 3.1. Desoto EMA Data

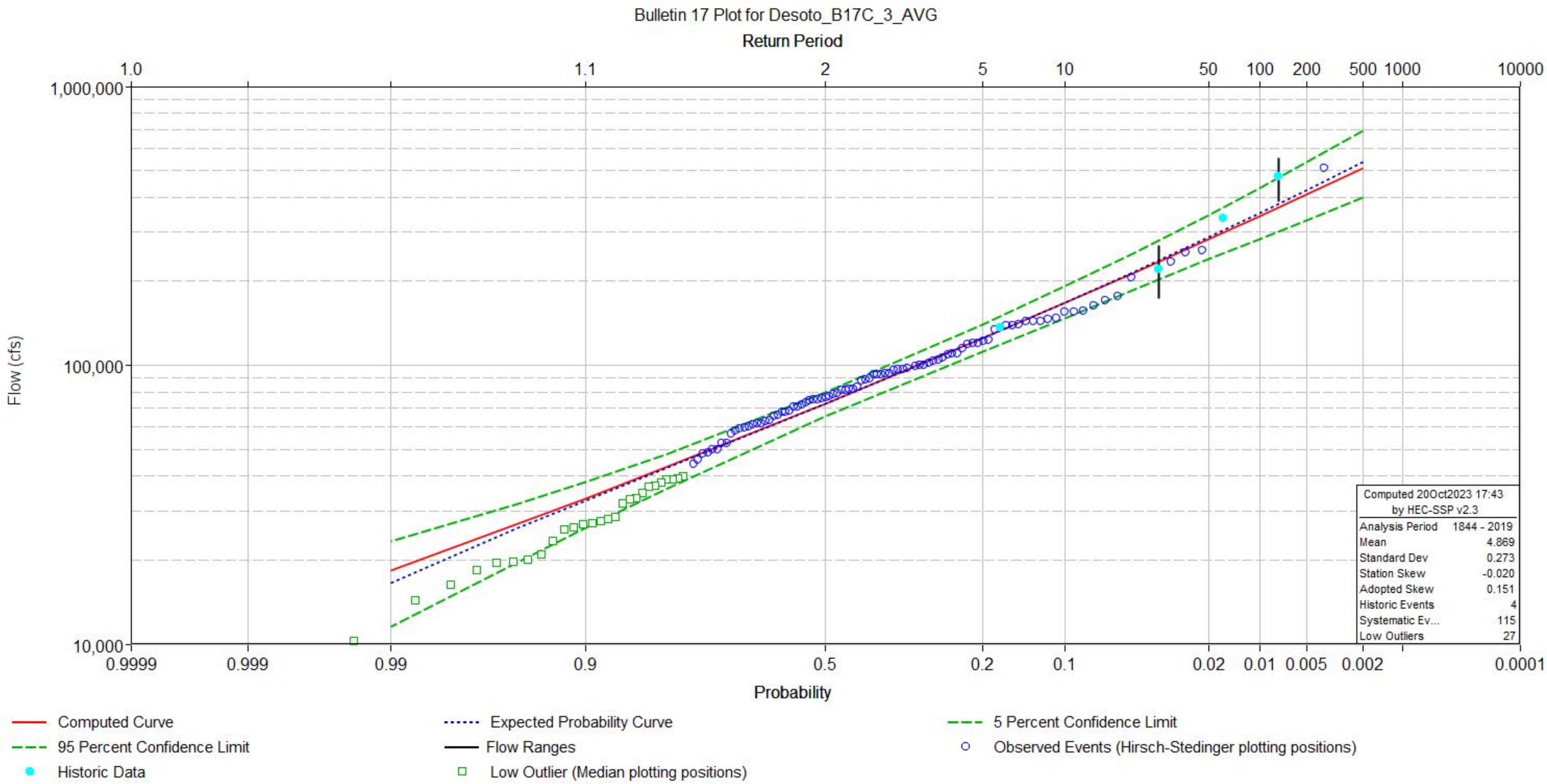

Figure 3.2. Desoto Probability Plot

A sensitivity analysis was completed due to the results of the Nonstationarity and Trend Analyses documented in the Climate Change Assessment. Multiple gage sites on the Kansas River detected nonstationarities with a strong consensus around 1940. The period of data for the final selected unregulated flow probability analysis was shortened to 1941-2019, and the regional skew and MSE were adjusted accordingly. The period of 1930-2019 was also computed to consider impacts of the drought period and to coincide with the period of systematic data adopted for the concurrent Missouri River Flow Frequency Study. The results are compared in Table 3.5 to the final selected analysis results. The full period of record analysis was selected for the study because it produced a probability plot that better matched the more extreme events.

Table 3.5. Desoto Shortened Period of Record Sensitivity Analysis Results

Annual Exceedance Probability (%)	Avg station skew (1844, 1858, 1902-1909, 1911-2019)	Avg station skew (1941-2019)	Avg station skew (1930-2019)
0.2	508,000	432,000	437,000
0.5	409,000	364,000	365,000
1	342,000	315,000	315,000
2	283,000	270,000	267,000
5	214,000	213,000	208,000
10	167,000	173,000	167,000
20	125,000	133,000	127,000
50	72,800	81,100	74,600
80	43,400	49,000	43,300
90	33,400	37,500	32,400
95	27,000	30,000	25,500
99	18,300	19,700	16,100
Mean	4.869	4.907	4.869
Std Dev	0.273	0.259	0.277
Station Skew	-0.020	-0.070	-0.246
Regional Skew	0.193	-0.050	-0.050
Adopted Skew	0.151	-0.051	-0.079
Perception Thresholds	1845-1857: 474kcfs-inf 1859-1901: 222kcfs-inf 1910: 99.6kcfs	N/A	N/A
Low Outliers	27	15	22
Systematic / Historic Events	115 / 4 (1844, 1858, 1903, 1915	79 / 0	90 / 0
Historic Period	176	79	90

The results at Desoto were compared to the Kansas River Hydrology Study (USACE, 2002) Bulletin 17B results as well as the Kansas City Levees (USACE, 2020) Bulletin 17C results which are shown in Table 3.6. The current computed curve was smaller than the 2002 curve for AEP's smaller than 80%. The 2002 study did not include data after 1997 and the skew was not regionalized which likely contributed to the differences. Similar datasets were used for the current study and the Kansas City Levees analysis, however different skew regionalization methods were used. The regional skew for the Kansas City Levees analysis was the USGS (2017) published skew for the eastern Kansas region.

Table 3.6. Desoto Results Compared to Kansas River Hydrology Study and Kansas City Levees Hydrology and Hydraulics Report

Annual Exceedance Probability (%)	Current Study Results		2002 Kansas River Hydrology Study Results	2018 Kansas City Levees Bulletin 17C Expected Probability Results
	Computed Curve	Expected Probability		
0.2	508,000	535,000	523,000	507,000
0.5	409,000	424,000	430,000	405,000
1	342,000	351,000	366,000	337,000
2	283,000	288,000	306,000	277,000
5	214,000	216,000	233,000	208,000
10	167,000	168,000	182,000	161,000
20	125,000	125,000	135,000	119,000
50	72,800	72,800	75,400	66,300
80	43,400	42,900	41,400	--
90	33,400	32,700	30,000	--
95	27,000	26,100	23,000	--
99	18,300	16,500	13,800	--
Mean	4.869	4.869	4.873	4.821
Std Dev	0.273	0.273	0.306	0.301
Station Skew	-0.020	-0.020	-0.092	0.016
Regional Skew	0.193	0.193	--	-0.125
Adopted Skew	0.151	0.151	-0.092	-0.006

3.2 Kansas River at Lecompton, KS

Peak flows reported in the Kansas River Hydrology Study (USACE, 2002) were used for missing data during the period of 1920-1934. The first two weighted skew analyses in HEC-SSP (L2.a and L2.b) included five historic events previously identified in Table 2.2 and Table 2.3. The 1844 peak flow estimate listed in Table 2.2 was assumed to be underestimated based on the 1844 Topeka estimates in the Kansas City Levees report (USACE, 2020). Additional streamflow data was added for the last two analyses (L3.b and L3.c) which included seven historic events. The MOVE3 was used to scale unregulated streamflow data at Topeka to Lecompton by the effective record length (n_e). The results for Lecompton are shown in Table 3.7.

Table 3.7. Bulletin 17C Results: Kansas River at Lecompton

Annual Exceedance Probability (%)	USGS 2000 WLS (1844, 1858, 1891-1904, 1908, 1915, 1919-2019)	USGS 2017 (1844, 1858, 1891-1904, 1908, 1915, 1919-2019)	USGS 2017 (1844, 1858, 1885, 1888, 1891-1909, 1911-2019)	Avg station skew (1844, 1858, 1885, 1888, 1891-1909, 1911-2019)
0.2	504,000	448,000	445,000	496,000
0.5	401,000	366,000	362,000	393,000
1	332,000	310,000	305,000	325,000
2	271,000	259,000	254,000	265,000
5	201,000	196,000	192,000	196,000
10	154,000	154,000	150,000	151,000
20	113,000	114,000	111,000	110,000
50	62,900	64,200	63,100	62,000
80	35,700	35,900	35,800	35,600
90	26,800	26,400	26,600	26,900
95	21,200	20,500	20,800	21,500
99	13,800	12,700	13,200	14,200
Mean	4.805	4.806	4.800	4.800
Std Dev	0.297	0.298	0.293	0.292
Station Skew	0.024	0.024	0.101	0.101
Regional Skew	0.197	-0.125	-0.125	0.193
Adopted Skew	0.119	-0.037	0.012	0.155
Perception Thresholds	1845-1857: 451kcfs-inf 1859-1890: 207kcfs-inf 1905-1907: 130kcfs-inf 1909-1914: 230kcfs-inf 1916-1918: 110kcfs-inf	1845-1857: 451kcfs-inf 1859-1890: 207kcfs-inf 1905-1907: 130kcfs-inf 1909-1914: 230kcfs-inf 1916-1918: 110kcfs-inf	1845-1857: 451kcfs-inf 1859-1884: 207kcfs-inf 1886-1887: 121kcfs-inf 1889-1890: 91kcfs-inf 1910: 90kcfs-inf	1845-1857: 451kcfs-inf 1859-1884: 207kcfs-inf 1886-1887: 121kcfs-inf 1889-1890: 91kcfs-inf 1910: 90kcfs-inf
Low Outliers	0	0	0	0
Systematic / Historic Events	114 / 5 (1844, 1858, 1908, 1915, 1919)	114 / 5 (1844, 1858, 1908, 1915, 1919)	125 / 7 (1844, 1858, 1885, 1888, 1908, 1915, 1919)	125 / 7 (1844, 1858, 1885, 1888, 1908, 1915, 1919)
Historic Period	176	176	176	176

The final EMA data for Lecompton is shown in Figure 3.3. The circles represent the observed data including historic data and the MOVE3 estimates while the shaded portions represent the perception thresholds. The SSP run with the average station skew (L3.c) was the final selected unregulated flow probability analysis. Figure 3.4 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

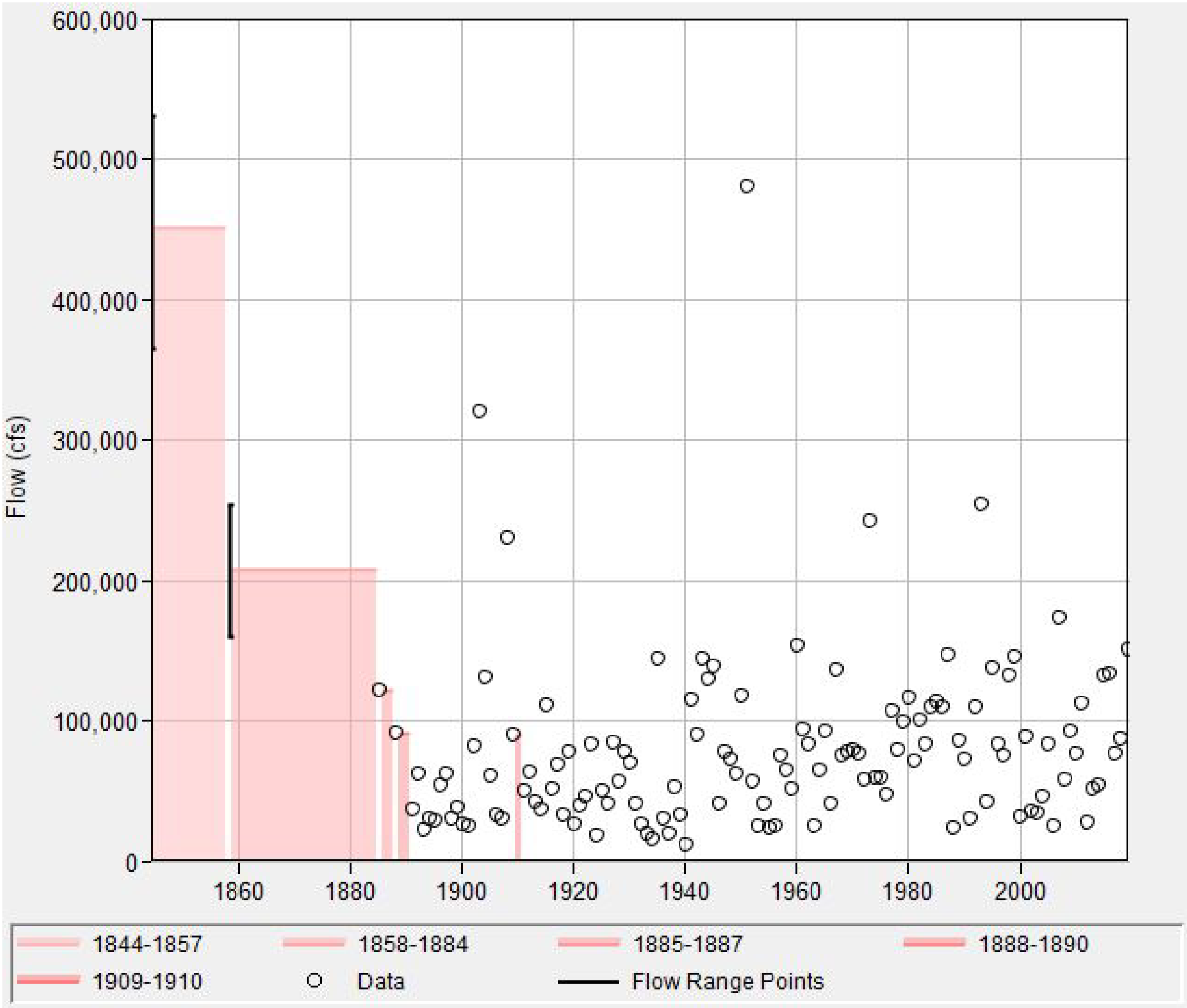

Figure 3.3. Lecompton EMA Data

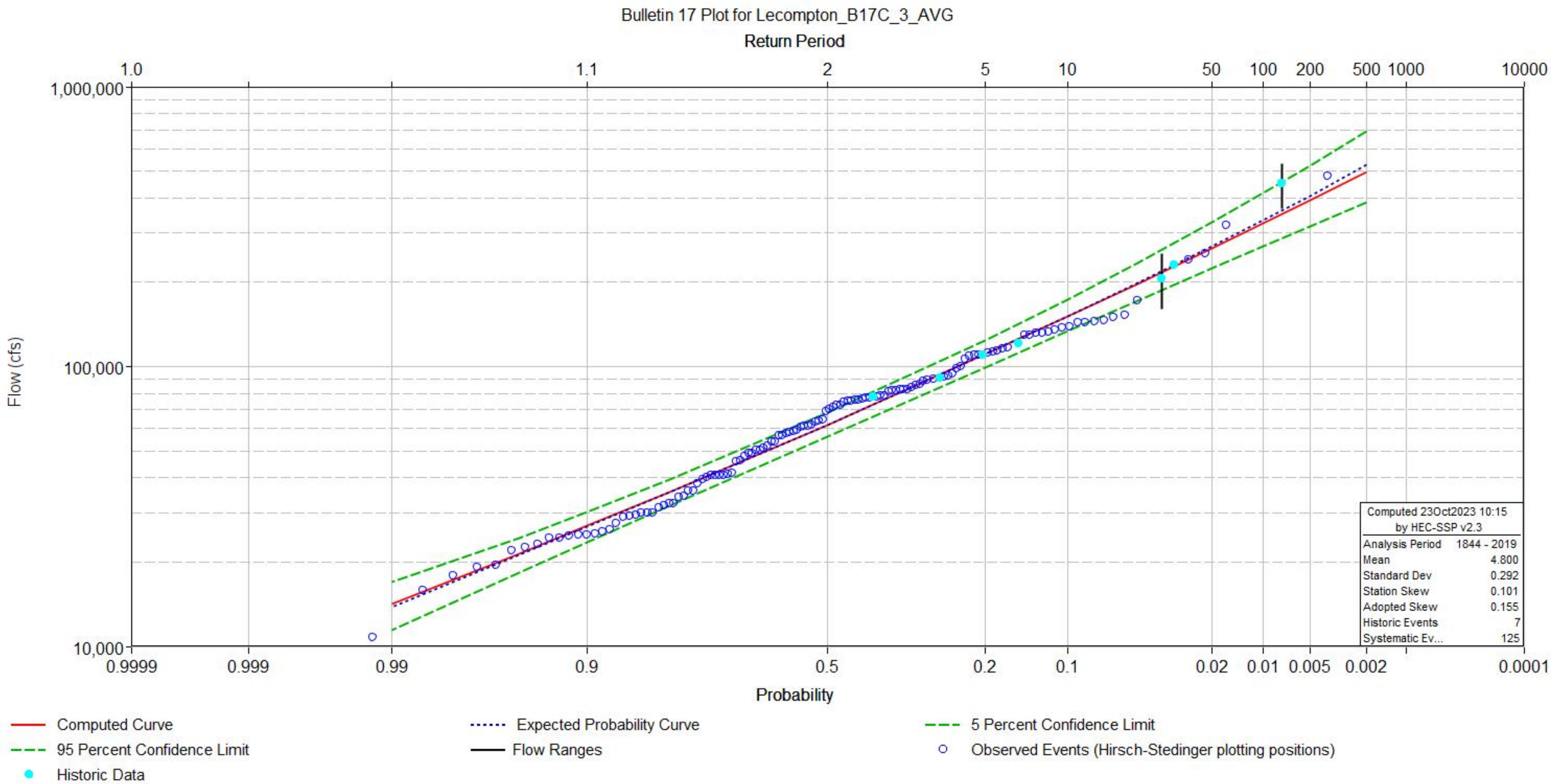

Figure 3.4. Lecompton Probability Plot

A sensitivity analysis was completed due to the results of the Nonstationarity and Trend Analyses documented in the Climate Change Assessment. Multiple gage sites on the Kansas River detected nonstationarities with a strong consensus around 1940. The period of data for the final selected unregulated flow probability analysis was shortened to 1941-2019, and the regional skew and MSE were adjusted accordingly. The results are compared in Table 3.8 to the final selected analysis results. The full period of record analysis was selected for the study because it produced a probability plot that better matched the more extreme events.

Table 3.8. Lecompton Shortened Period of Record Sensitivity Analysis Results

Annual Exceedance Probability (%)	Avg station skew (1844, 1858, 1885, 1888, 1891-1909, 1911-2019)	Avg station skew (1941-2019)
0.2	496,000	409,000
0.5	393,000	344,000
1	325,000	298,000
2	265,000	255,000
5	196,000	201,000
10	151,000	163,000
20	110,000	126,000
50	62,000	76,200
80	35,600	45,900
90	26,900	35,100
95	21,500	28,100
99	14,200	18,500
Mean	4.800	4.880
Std Dev	0.292	0.260
Station Skew	0.101	-0.037
Regional Skew	0.193	-0.050
Adopted Skew	0.155	-0.049
Perception Thresholds	1845-1857: 451kcfs-inf 1859-1884: 207kcfs-inf 1886-1887: 121kcfs-inf 1889-1890: 91kcfs-inf 1910: 90kcfs-inf	N/A
Low Outliers	0	0
Systematic / Historic Events	125 / 7 (1844, 1858, 1885, 1888, 1908, 1915, 1919)	79 / 0
Historic Period	176	79

The results at Lecompton were compared to the Kansas River Hydrology Study (USACE, 2002) Bulletin 17B results which are shown in Table 3.9. The current computed curve was smaller than the 2002 curve for AEP's smaller than 90%. The 2002 study did not include data after 1997 and the skew was not regionalized which likely contributed to the differences.

Table 3.9. Lecompton Results Compared to Kansas River Hydrology Study

Annual Exceedance Probability (%)	Current Study Results		2002 Kansas River Hydrology Study Results
	Computed Curve	Expected Probability	
0.2	496,000	525,000	521,000
0.5	393,000	408,000	424,000
1	325,000	334,000	358,000
2	265,000	270,000	297,000
5	196,000	198,000	224,000
10	151,000	152,000	173,000
20	110,000	111,000	127,000
50	62,000	62,000	69,400
80	35,600	35,500	37,400
90	26,900	26,800	26,900
95	21,500	21,300	20,500
99	14,200	13,800	12,200
Mean	4.800	4.800	4.837
Std Dev	0.292	0.292	0.316
Station Skew	0.101	0.101	-0.076
Regional Skew	0.193	0.193	--
Adopted Skew	0.155	0.155	-0.076

3.3 Kansas River at Topeka, KS

The first two weighted skew analyses in HEC-SSP (T2.a and T2.b) included seven historic events previously identified in Table 2.2 and Table 2.3. Additional streamflow data was added for the last two analyses (T3.b and T3.c). The MOVE3 was used to scale unregulated streamflow data at Lecompton to Topeka by the effective record length (n_e). The results for Topeka are shown in Table 3.10.

Table 3.10. Bulletin 17C Results: Kansas River at Topeka

Annual Exceedance Probability (%)	USGS 2000 WLS (1844, 1858, 1868, 1877, 1885, 1888, 1896, 1902-1909, 1911-2019)	USGS 2017 (1844, 1858, 1868, 1877, 1885, 1888, 1896, 1902-1909, 1911-2019)	USGS 2017 (1844, 1858, 1868, 1877, 1885, 1888, 1891-1909, 1911-2019)	Avg station skew (1844, 1858, 1868, 1877, 1885, 1888, 1891-1909, 1911-2019)
0.2	430,000	388,000	400,000	443,000
0.5	337,000	312,000	319,000	345,000

Annual Exceedance Probability (%)	USGS 2000 WLS (1844, 1858, 1868, 1877, 1885, 1888, 1896, 1902-1909, 1911-2019)	USGS 2017 (1844, 1858, 1868, 1877, 1885, 1888, 1896, 1902-1909, 1911-2019)	USGS 2017 (1844, 1858, 1868, 1877, 1885, 1888, 1891-1909, 1911-2019)	Avg station skew (1844, 1858, 1868, 1877, 1885, 1888, 1891-1909, 1911-2019)
1	277,000	261,000	266,000	282,000
2	224,000	215,000	217,000	227,000
5	164,000	161,000	161,000	165,000
10	125,000	124,000	124,000	125,000
20	90,600	91,300	90,300	89,700
50	50,000	50,800	49,700	49,000
80	28,400	28,400	27,700	27,600
90	21,400	21,000	20,500	20,800
95	17,000	16,400	16,000	16,500
99	11,200	10,400	10,100	10,900
Mean	4.708	4.708	4.700	4.700
Std Dev	0.300	0.301	0.305	0.304
Station Skew	0.156	0.156	0.194	0.194
Regional Skew	0.184	-0.125	-0.125	0.193
Adopted Skew	0.171	0.039	0.065	0.194
Perception Thresholds	1845-1857: 437kcfs-inf 1859-1867: 175kcfs-inf 1869-1876: 72kcfs-inf 1878-1884: 72kcfs-inf 1886-1887: 72kcfs-inf 1889-1895: 69kcfs-inf 1897-1901: 69kcfs-inf 1910: 68kcfs-inf	1845-1857: 437kcfs-inf 1859-1867: 175kcfs-inf 1869-1876: 72kcfs-inf 1878-1884: 72kcfs-inf 1886-1887: 72kcfs-inf 1889-1895: 69kcfs-inf 1897-1901: 69kcfs-inf 1910: 68kcfs-inf	1845-1857: 437kcfs-inf 1859-1867: 175kcfs-inf 1869-1876: 72kcfs-inf 1878-1884: 72kcfs-inf 1886-1887: 72kcfs-inf 1889-1890: 69kcfs-inf 1910: 68kcfs-inf	1845-1857: 437kcfs-inf 1859-1867: 175kcfs-inf 1869-1876: 72kcfs-inf 1878-1884: 72kcfs-inf 1886-1887: 72kcfs-inf 1889-1890: 69kcfs-inf 1910: 68kcfs-inf
Low Outliers	0	0	0	0
Systematic / Historic Events	117 / 7 (1844, 1858, 1868, 1877, 1885, 1888, 1896)	117 / 7 (1844, 1858, 1868, 1877, 1885, 1888, 1896)	127 / 7 (1844, 1858, 1868, 1877, 1885, 1888, 1896)	127 / 7 (1844, 1858, 1868, 1877, 1885, 1888, 1896)
Historic Period	176	176	176	176

The final EMA data for Topeka is shown in Figure **3.5**. The circles represent the observed data including historic data and the MOVE3 estimates while the shaded portions represent the perception thresholds. The SSP run with the average station skew (T3.c) was the final selected unregulated flow probability analysis. Figure 3.6 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

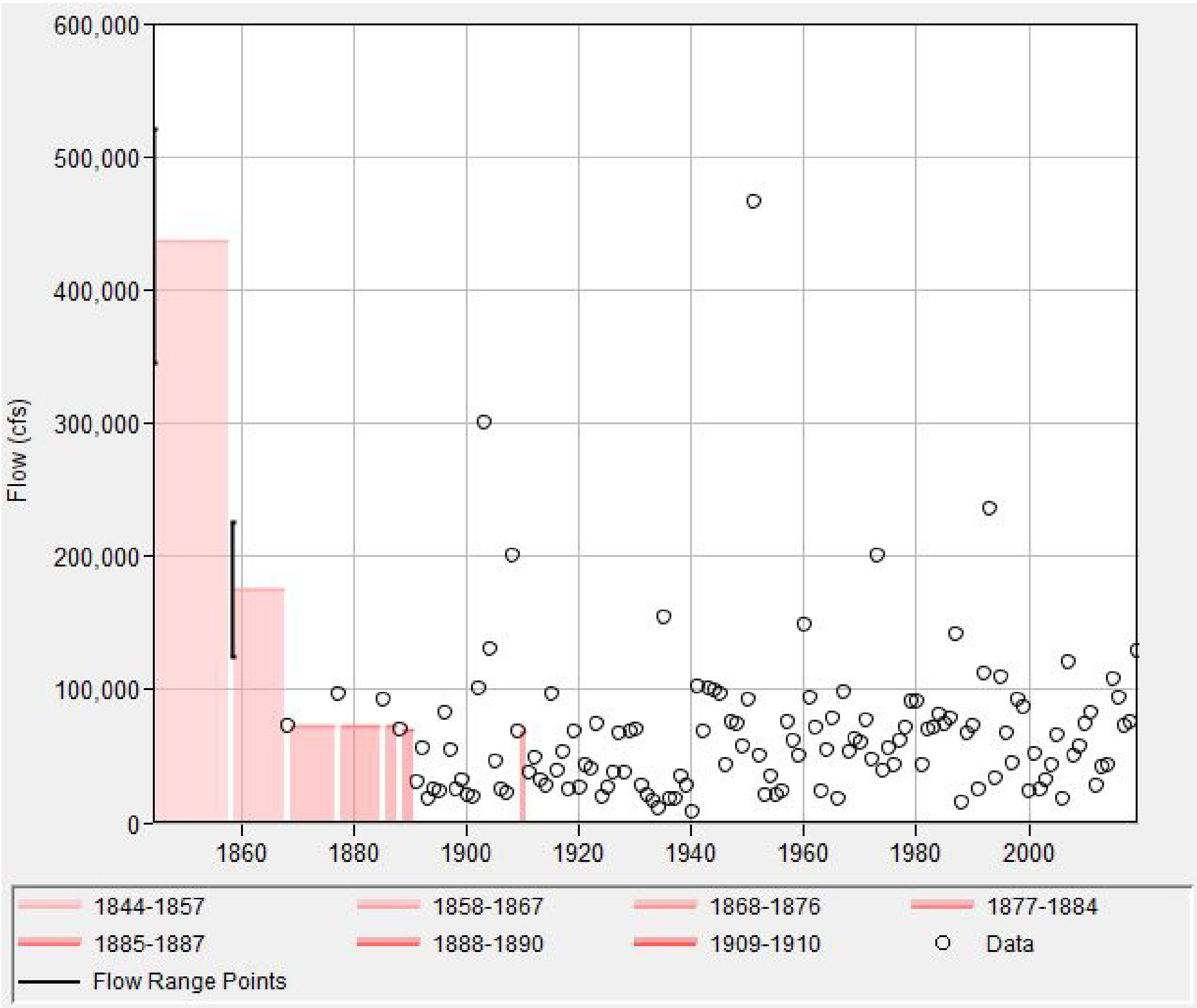

Figure 3.5**. Topeka EMA Data**

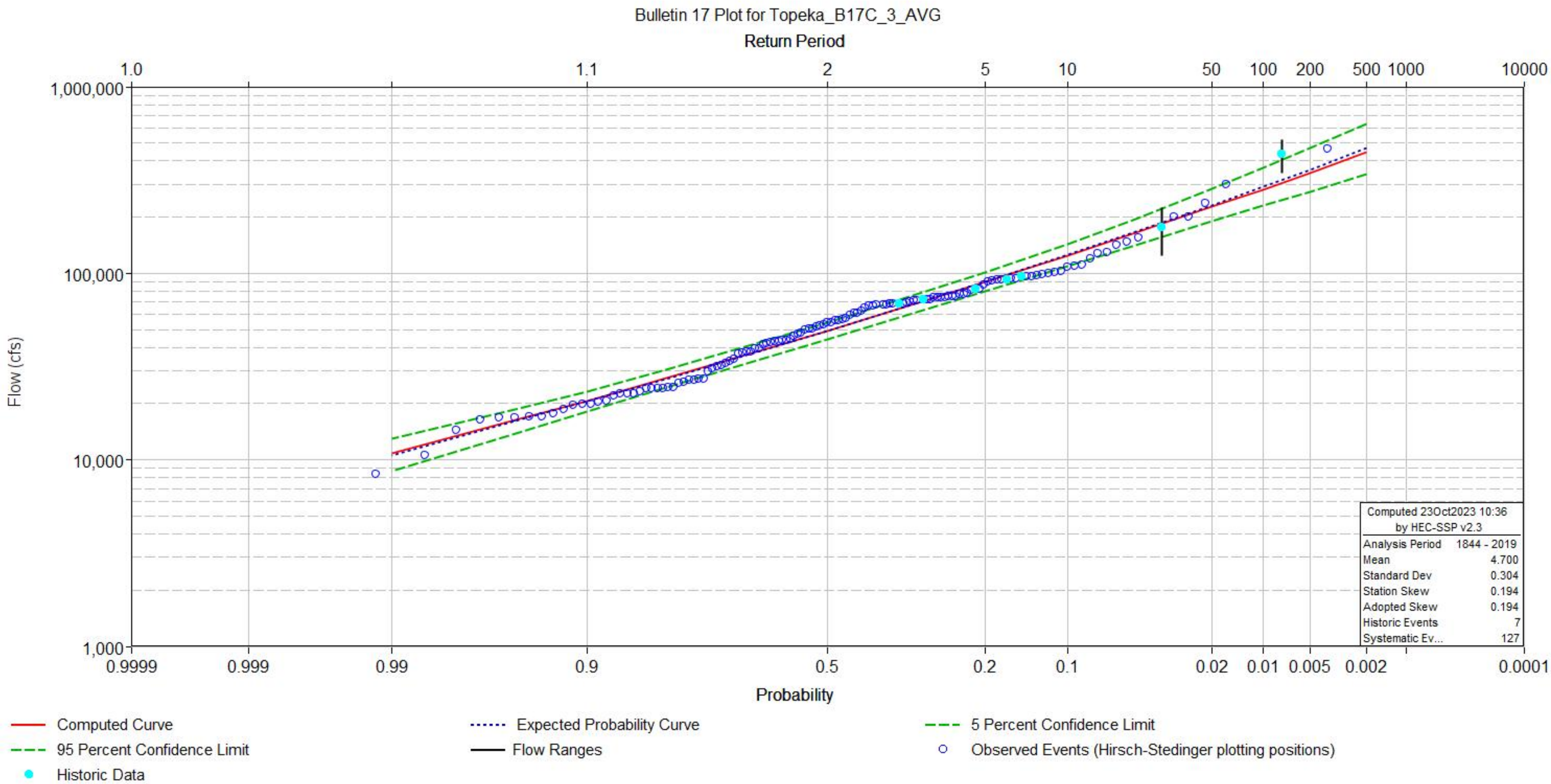

Figure 3.6. Topeka Probability Plot

A sensitivity analysis was completed due to the results of the Nonstationarity and Trend Analyses documented in the Climate Change Assessment. Multiple gage sites on the Kansas River detected nonstationarities with a strong consensus around 1940. The period of data for the final selected unregulated flow probability analysis was shortened to 1941-2019, and the regional skew and MSE were adjusted accordingly. The results are compared in Table 3.11 to the final selected analysis results. The full period of record analysis was selected for the study because it produced a probability plot that better matched the more extreme events.

Table 3.11. Topeka Shortened Period of Record Sensitivity Analysis Results

Annual Exceedance Probability (%)	Avg station skew (1844, 1858, 1868, 1877, 1885, 1888, 1891-1909, 1911-2019)	Avg station skew (1941-2019)
0.2	443,000	350,000
0.5	345,000	293,000
1	282,000	252,000
2	227,000	215,000
5	165,000	168,000
10	125,000	135,000
20	89,700	103,000
50	49,000	61,700
80	27,600	36,500
90	20,800	27,700
95	16,500	22,000
99	10,900	14,200
Mean	4.700	4.788
Std Dev	0.304	0.268
Station Skew	0.194	-0.071
Regional Skew	0.193	-0.050
Adopted Skew	0.194	-0.051
Perception Thresholds	1845-1857: 437kcfs-inf 1859-1867: 175kcfs-inf 1869-1876: 72kcfs-inf 1878-1884: 72kcfs-inf 1886-1887: 72kcfs-inf 1889-1890: 69kcfs-inf 1910: 68kcfs-inf	N/A
Low Outliers	0	10

Systematic / Historic Events	127 / 7 (1844, 1858, 1868, 1877, 1885, 1888, 1896)	79 / 0
Historic Period	176	79

The results at Topeka were compared to the Kansas River Hydrology Study (USACE, 2002) Bulletin 17B results which are shown in Table 3.12. The current computed curve was smaller than the 2002 curve for all AEP's. The 2002 study did not include data after 1997 and the skew was not regionalized which likely contributed to the differences.

Table 3.12. Topeka Results Compared to Kansas River Hydrology Study

Annual Exceedance Probability (%)	Current Study Results		2002 Kansas River Hydrology Study Results
	Computed Curve	Expected Probability	
0.2	443,000	471,000	535,000
0.5	345,000	360,000	409,000
1	282,000	290,000	329,000
2	227,000	231,000	261,000
5	165,000	166,000	186,000
10	125,000	125,000	139,000
20	89,700	90,100	98,800
50	49,000	49,100	53,300
80	27,600	27,600	30,100
90	20,800	20,600	22,700
95	16,500	16,300	18,200
99	10,900	10,500	12,200
Mean	4.700	4.700	4.741
Std Dev	0.304	0.304	0.308
Station Skew	0.194	0.194	0.272
Regional Skew	0.193	0.193	--
Adopted Skew	0.194	0.194	0.272

3.4 Kansas River at Wamego, KS

The first two weighted skew analyses in HEC-SSP (W2.a and W2.b) included three historic events previously identified in Table 2.2 and Table 2.3. Additional streamflow data was added for the last two analyses (W3.b and W3.c) which included five historic events. The MOVE3 was used to scale unregulated streamflow data at Topeka and Lecompton to Wamego by the effective record length (n_e). The results for Wamego are shown in Table 3.13.

Table 3.13. Bulletin 17C Results: Kansas River at Wamego

Annual Exceedance Probability (%)	USGS 2000 WLS (1844, 1858, 1902, 1903, 1908, 1914-2019)	USGS 2017 (1844, 1858, 1902, 1903, 1908, 1914-2019)	USGS 2017 (1844, 1858, 1885, 1888, 1891-1909, 1911-2019)	Avg station skew (1844, 1858, 1885, 1888, 1891-1909. 1911-2019)
0.2	458,000	413,000	417,000	461,000
0.5	355,000	328,000	326,000	352,000
1	288,000	272,000	266,000	282,000
2	230,000	221,000	214,000	223,000
5	165,000	162,000	155,000	158,000
10	123,000	123,000	117,000	117,000
20	87,200	88,200	82,900	82,200
50	45,900	46,800	43,800	43,100
80	24,800	24,900	23,500	23,500
90	18,100	17,900	17,100	17,300
95	14,100	13,600	13,200	13,600
99	8,870	8,210	8,200	8,790
Mean	4.670	4.671	4.647	4.646
Std Dev	0.325	0.327	0.325	0.324
Station Skew	0.117	0.117	0.247	0.247
Regional Skew	0.162	-0.125	-0.125	0.193
Adopted Skew	0.142	0.014	0.095	0.215
Perception Thresholds	1845-1857: 389kcfs-inf 1859-1901: 191kcfs-inf 1904-1907: 280kcfs-inf 1909-1913: 160kcfs-inf	1845-1857: 389kcfs-inf 1859-1901: 191kcfs-inf 1904-1907: 280kcfs-inf 1909-1913: 160kcfs-inf	1845-1857: 389kcfs-inf 1859-1901: 191kcfs-inf 1886-1887: 85kcfs-inf 1889-1890: 64kcfs-inf 1910: 63kcfs-inf	1845-1857: 389kcfs-inf 1859-1901: 191kcfs-inf 1886-1887: 85kcfs-inf 1889-1890: 64kcfs-inf 1910: 63kcfs-inf
Low Outliers	0	0	0	0
Systematic / Historic Events	108 / 3 (1844, 1858, 1908)	108 / 3 (1844, 1858, 1908)	127 / 3 (1885, 1888, 1908)	127 / 5 (1844, 1858, 1885, 1888, 1908)
Historic Period	176	176	176	176

The final EMA data for Wamego is shown in Figure 3.7. The circles represent the observed data including historic data and the MOVE3 estimates. The SSP run with the average station skew (W3.c) was the final selected unregulated flow probability analysis. Figure 3.8 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

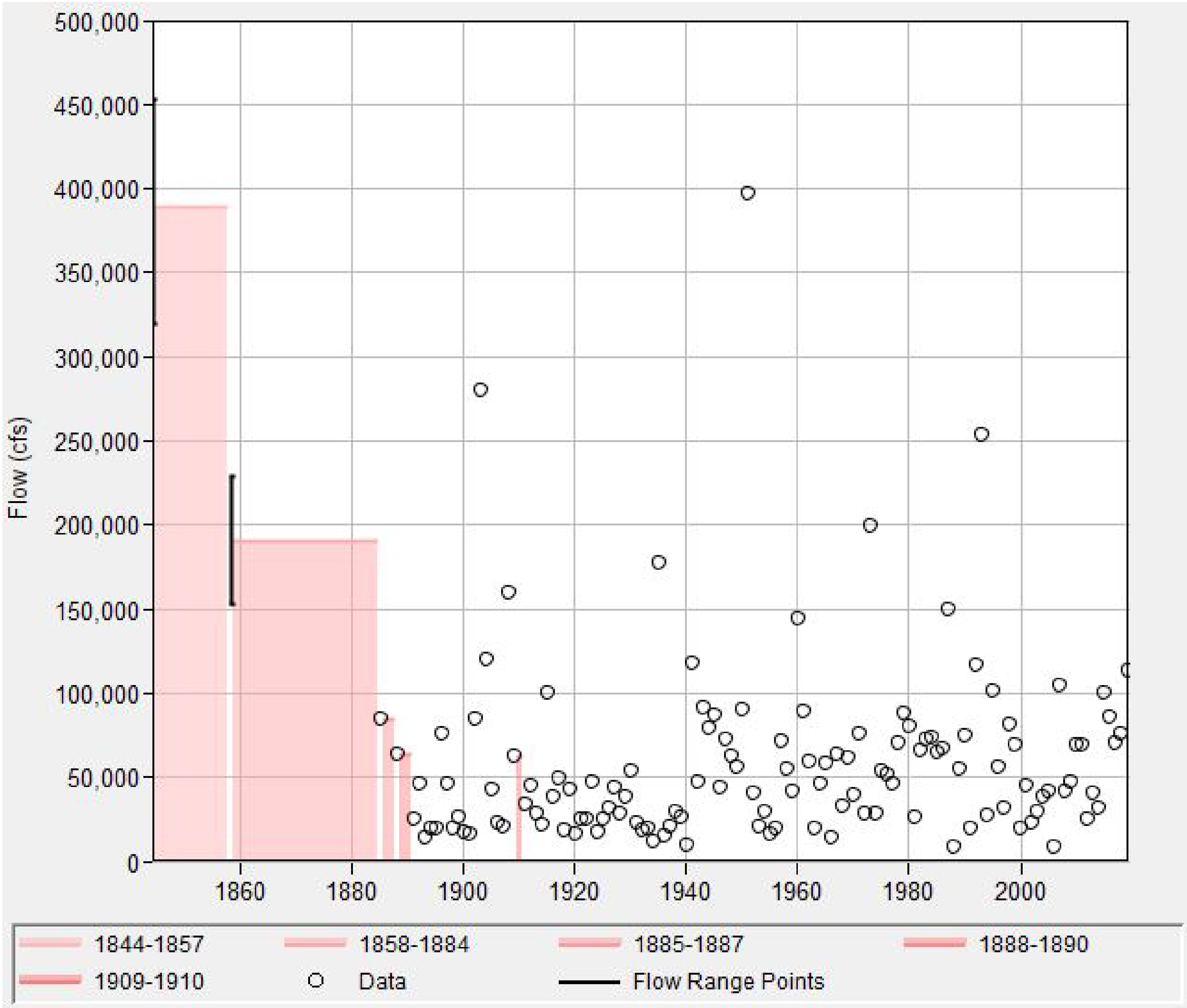

Figure 3.7. Wamego EMA Data

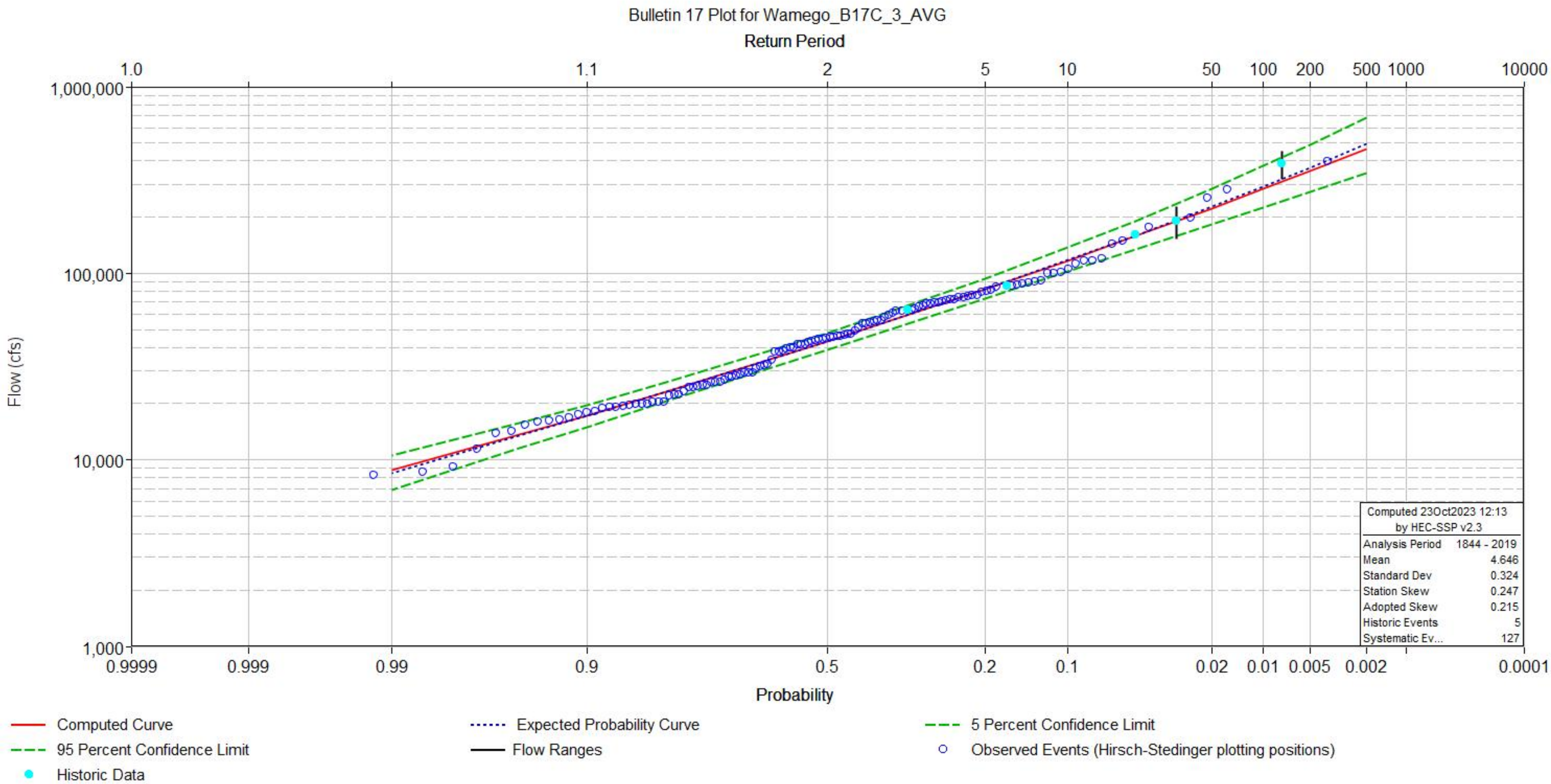

Figure 3.8. Wamego Probability Plot

A sensitivity analysis was completed due to the results of the Nonstationarity and Trend Analyses documented in the Climate Change Assessment. Multiple gage sites on the Kansas River detected nonstationarities with a strong consensus around 1940. The period of data for the final selected unregulated flow probability analysis was shortened to 1941-2019, and the regional skew and MSE were adjusted accordingly. The results are compared in Table 3.14 to the final selected analysis results. The full period of record analysis was selected for the study because it produced a probability plot that better matched the more extreme events.

Table 3.14. Wamego Shortened Period of Record Sensitivity Analysis Results

Annual Exceedance Probability (%)	Avg station skew (1844, 1858, 1885, 1888, 1891-1909. 1911-2019)	Avg station skew (1941-2019)
0.2	461,000	364,000
0.5	352,000	299,000
1	282,000	254,000
2	223,000	212,000
5	158,000	162,000
10	117,000	127,000
20	82,200	94,500
50	43,100	53,200
80	23,500	29,600
90	17,300	21,700
95	13,600	16,800
99	8,790	10,300
Mean	4.646	4.723
Std Dev	0.324	0.299
Station Skew	0.247	-0.165
Regional Skew	0.193	-0.050
Adopted Skew	0.215	-0.062
Perception Thresholds	1845-1857: 389kcfs-inf 1859-1901: 191kcfs-inf 1886-1887: 85kcfs-inf 1889-1890: 64kcfs-inf 1910: 63kcfs-inf	N/A
Low Outliers	0	0
Systematic / Historic Events	127 / 5 (1844, 1858, 1885, 1888, 1908)	79 / 0
Historic Period	176	79

The results at Wamego were compared to the Kansas River Hydrology Study (USACE, 2002) Bulletin 17B results which are shown in Table 3.15. The current computed curve was smaller than the 2002 curve for AEP's smaller than 80%. The 2002 study did not include data after 1997 and the skew was not regionalized which likely contributed to the differences.

Table 3.15. Wamego Results Compared to Kansas River Hydrology Study

Annual Exceedance Probability (%)	Current Study Results		2002 Kansas River Hydrology Study Results
	Computed Curve	Expected Probability	
0.2	461,000	493,000	525,000
0.5	352,000	368,000	393,000
1	282,000	291,000	311,000
2	223,000	228,000	242,000
5	158,000	160,000	168,000
10	117,000	118,000	122,000
20	82,200	82,600	84,600
50	43,100	43,200	43,300
80	23,500	23,400	23,300
90	17,300	17,200	17,100
95	13,600	13,500	13,400
99	8,790	8,480	8,710
Mean	4.646	4.646	4.651
Std Dev	0.324	0.324	0.334
Station Skew	0.247	0.247	0.265
Regional Skew	0.193	0.193	--
Adopted Skew	0.215	0.215	0.265

3.5 Kansas River at Fort Riley, KS

A sensitivity test was completed to determine if using the Manhattan Feasibility Study peak flows in place of the missing data had a significant impact on station skew. The resulting station skew without data between 1951 and 1964 was 0.399. Values were included in the final analysis for the missing data.

The first two weighted skew analyses in HEC-SSP (F2.a and F2.b) included two historic events previously identified in Table 2.2. Additional streamflow data was added for the last two analyses (F3.b and F3.c). The MOVE3 was used to scale unregulated streamflow data at Topeka and Wamego to Fort Riley by the effective record length (n_e). The results for Fort Riley are shown in Table 3.16.

Table 3.16. Bulletin 17C Results: Kansas River at Fort Riley

Annual Exceedance Probability (%)	USGS 2000 WLS (1903, 1915, 1918-2019)	USGS 2017 (1903, 1915, 1918-2019)	USGS 2017 (1903, 1907-	Avg station skew (1903, 1907-1909, 1911-2019

			1909, 1911-2019)	
0.2	308,000	285,000	283,000	314,000
0.5	231,000	218,000	217,000	235,000
1	184,000	176,000	174,000	185,000
2	143,000	139,000	138,000	144,000
5	99,700	98,100	97,500	99,700
10	72,800	72,500	72,100	72,600
20	50,300	50,600	50,400	50,100
50	25,600	25,900	26,000	25,600
80	13,600	13,600	13,800	13,800
90	9,890	9,810	10,000	10,200
95	7,680	7,530	7,770	7,970
99	4,880	4,650	4,860	5,180
Mean	4.421	4.421	4.424	4.424
Std Dev	0.339	0.339	0.334	0.334
Station Skew	0.406	0.406	0.445	0.445
Regional Skew	0.119	-0.125	-0.125	0.193
Adopted Skew	0.222	0.140	0.163	0.275
Perception Thresholds	1904-1914: 236kcfs-inf 1916-1917: 110kcfs-inf	1904-1914: 236kcfs-inf 1916-1917: 110kcfs-inf	1904-1906: 236kcfs-inf 1910: 43kcfs-inf	1904-1906: 236kcfs-inf 1910: 43kcfs-inf
Low Outliers	0	0	0	0
Systematic / Historic Events	102 / 2 (1903, 1915)	102 / 2 (1903, 1915)	111 / 2 (1903, 1915)	111 / 2 (1903, 1915)
Historic Period	117	117	117	117

The final EMA data for Fort Riley is shown in Figure 3.9. The circles represent the observed data including historic data while the shaded portions represent the perception thresholds. The SSP run with the average station skew (F3.c) was the final selected unregulated flow probability analysis. Figure 3.10 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

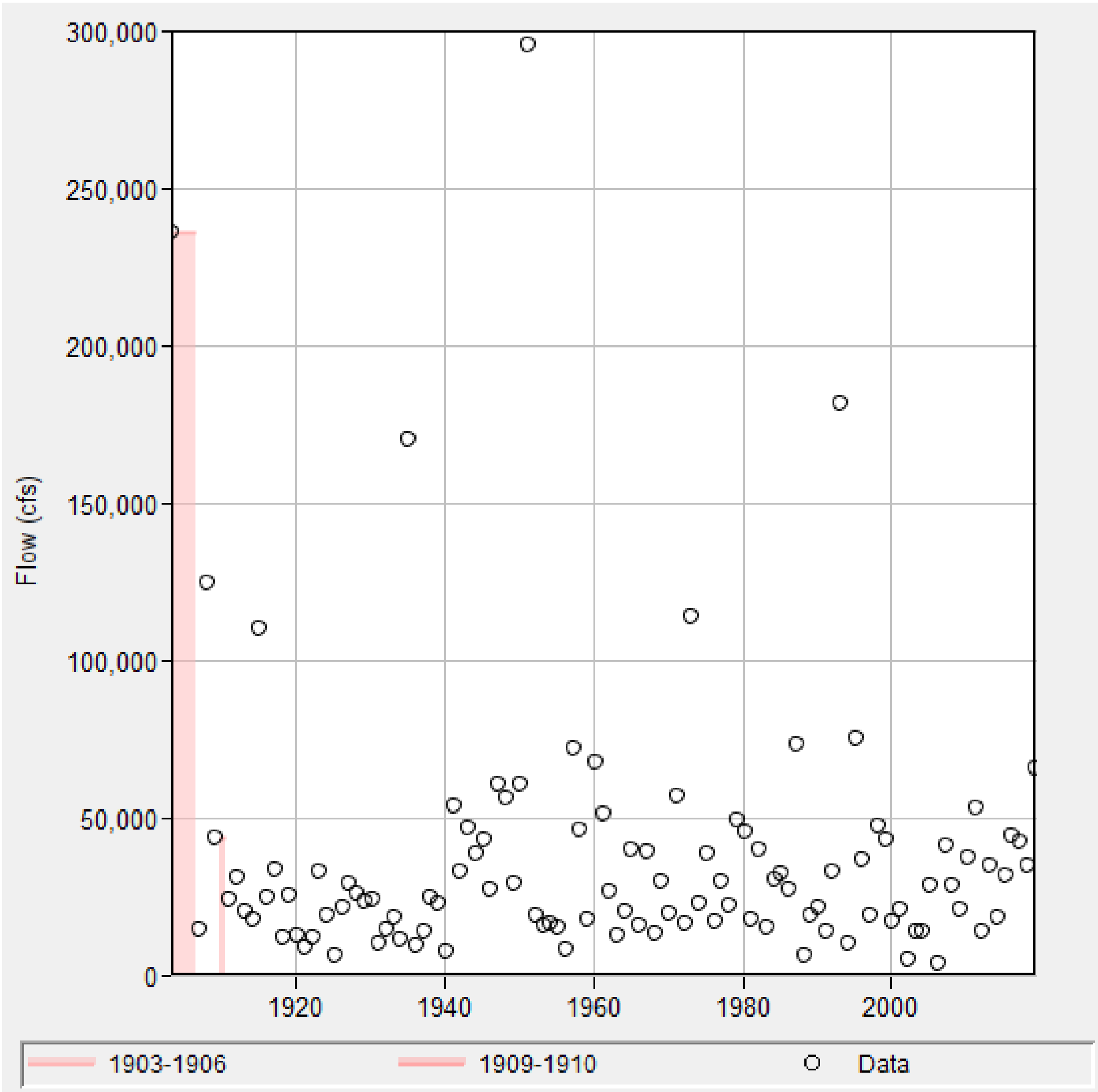

Figure 3.9. Fort Riley EMA Data

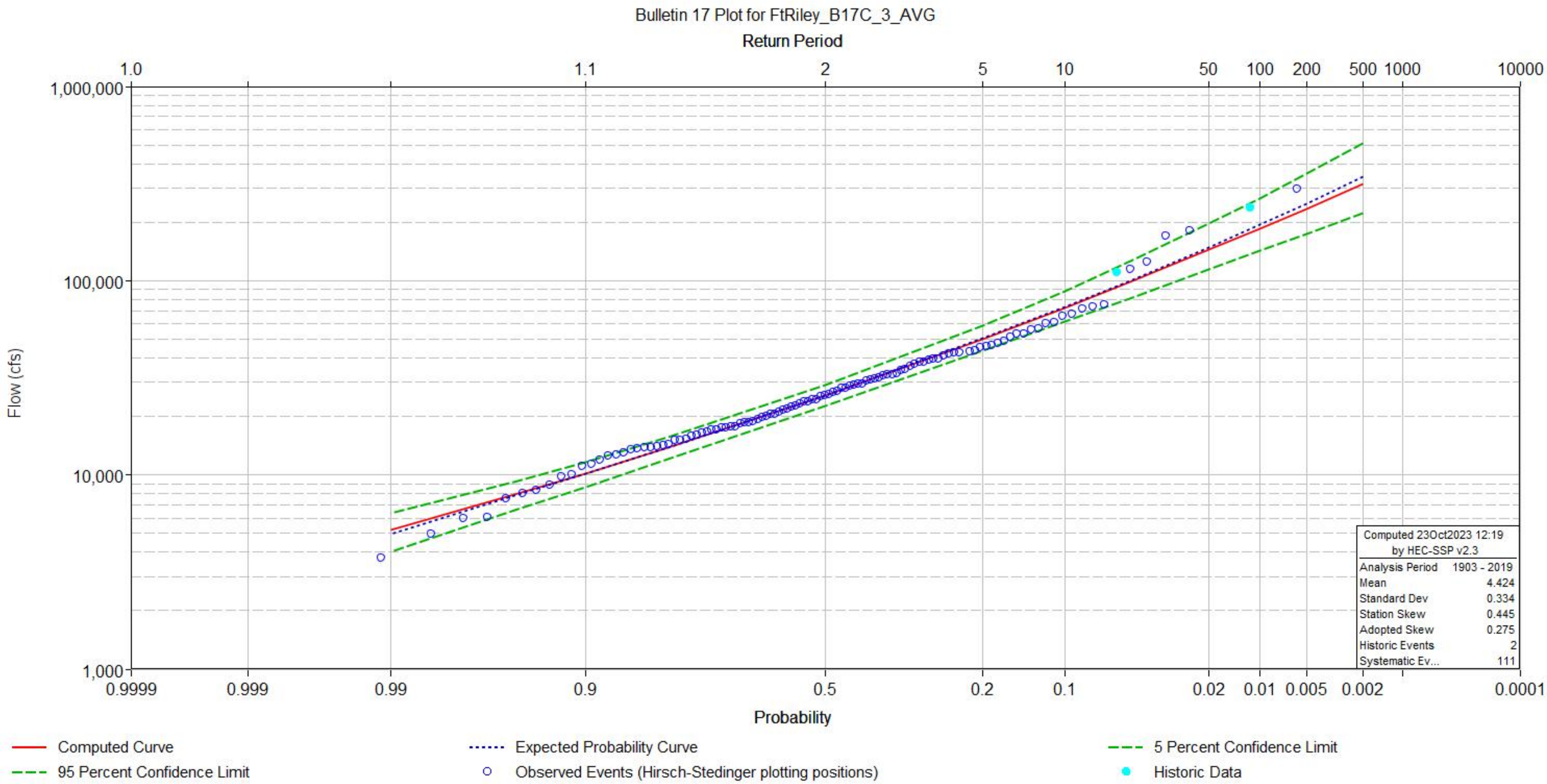

Figure 3.10. Fort Riley Probability Plot

A sensitivity analysis was completed due to the results of the Nonstationarity and Trend Analyses documented in the Climate Change Assessment. Multiple gage sites on the Kansas River detected nonstationarities with a strong consensus around 1940. The period of data for the final selected unregulated flow probability analysis was shortened to 1941-2019, and the regional skew and MSE were adjusted accordingly. The results are compared in Table 3.17 to the final selected analysis results. The full period of record analysis was selected for the study because it produced a probability plot that better matched the more extreme events.

Table 3.17. Fort Riley Shortened Period of Record Sensitivity Analysis Results

Annual Exceedance Probability (%)	Avg station skew (1903, 1907-1909, 1911-2019	Avg station skew (1941-2019)
0.2	314,000	225,000
0.5	235,000	182,000
1	185,000	152,000
2	144,000	126,000
5	99,700	93,900
10	72,600	72,400
20	50,100	52,800
50	25,600	28,700
80	13,800	15,500
90	10,200	11,200
95	7,970	8,590
99	5,180	5,170
Mean	4.424	4.456
Std Dev	0.334	0.316
Station Skew	0.445	0.093
Regional Skew	0.193	-0.050
Adopted Skew	0.275	-0.035
Perception Thresholds	1904-1906: 236kcfs-inf 1910: 43kcfs-inf	N/A
Low Outliers	0	0
Systematic / Historic Events	111 / 2 (1903, 1915)	79 / 0
Historic Period	117	79

3.6 Republican River at Junction City, KS

The regional skew developed by the USGS in 2017 was evaluated for the tributary gages. Republican River at Milford, KS (USGS 06857000) peak instantaneous flow data was used prior to 1950. The reservoir holdouts computed by the Water Management section upstream of Milford were added to the USGS Milford daily peak flow data between 01 October 1950 and 30 September 1963, because the USGS Junction City data was not available until 1964. The resulting peak flows were converted to instantaneous data by linear regression as discussed in section 2.3. However, some of the computed instantaneous peak flows were lower than the observed instantaneous flows. For those years, a ratio of the observed instantaneous peak flow to the observed daily peak flow was multiplied by the natural daily peak flow. MOVE3 could not be used to scale the Milford peak flows due to lack of overlapping data with Junction City. According to the USGS, the two gages have the same contributing drainage area, so the drainage area ratio method could not be used either. Two historic events identified in Table 2.2 were included in the analyses. The results for Junction City for station skew only (J) and weighted skew (J.b) are shown in Table 3.18.

Table 3.18. Bulletin 17C Results: Republican River at Junction City

Annual Exceedance Probability (%)	Station Skew Only (1895-1905, 1915, 1935, 1950-2019)	USGS 2017 (1895-1905, 1915, 1935, 1950-2019)
0.2	184,000	148,000
0.5	135,000	115,000
1	106,000	93,600
2	81,300	74,800
5	55,700	53,700
10	40,300	40,200
20	27,700	28,400
50	14,300	14,800
80	7,880	7,920
90	5,920	5,740
95	4,730	4,430
99	3,200	2,740
Mean	4.176	4.178
Std Dev	0.327	0.330
Station Skew	0.372	0.372
Regional Skew	--	-0.125
Adopted Skew	0.372	0.111
Perception Thresholds	1906-1914: 103kcfs-inf 1916-1934: 103kcfs-inf 1936-1949: 103kcfs-inf	1906-1914: 103kcfs-inf 1916-1934: 103kcfs-inf 1936-1949: 103kcfs-inf
Low Outliers	0	0
Systematic / Historic Events	81 / 2 (1915, 1935)	81 / 2 (1915, 1935)
Historic Period	125	125

The final EMA data for Junction City is shown in Figure 3.11. The circles represent observed data and the shaded areas represent the perception thresholds. The analysis using the station skew was selected for the final results (J). The drainage area at Junction City exceeds the range of values used in developing the regional skew, and station skew provided a better fit to the plotted data. Figure 3.12 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

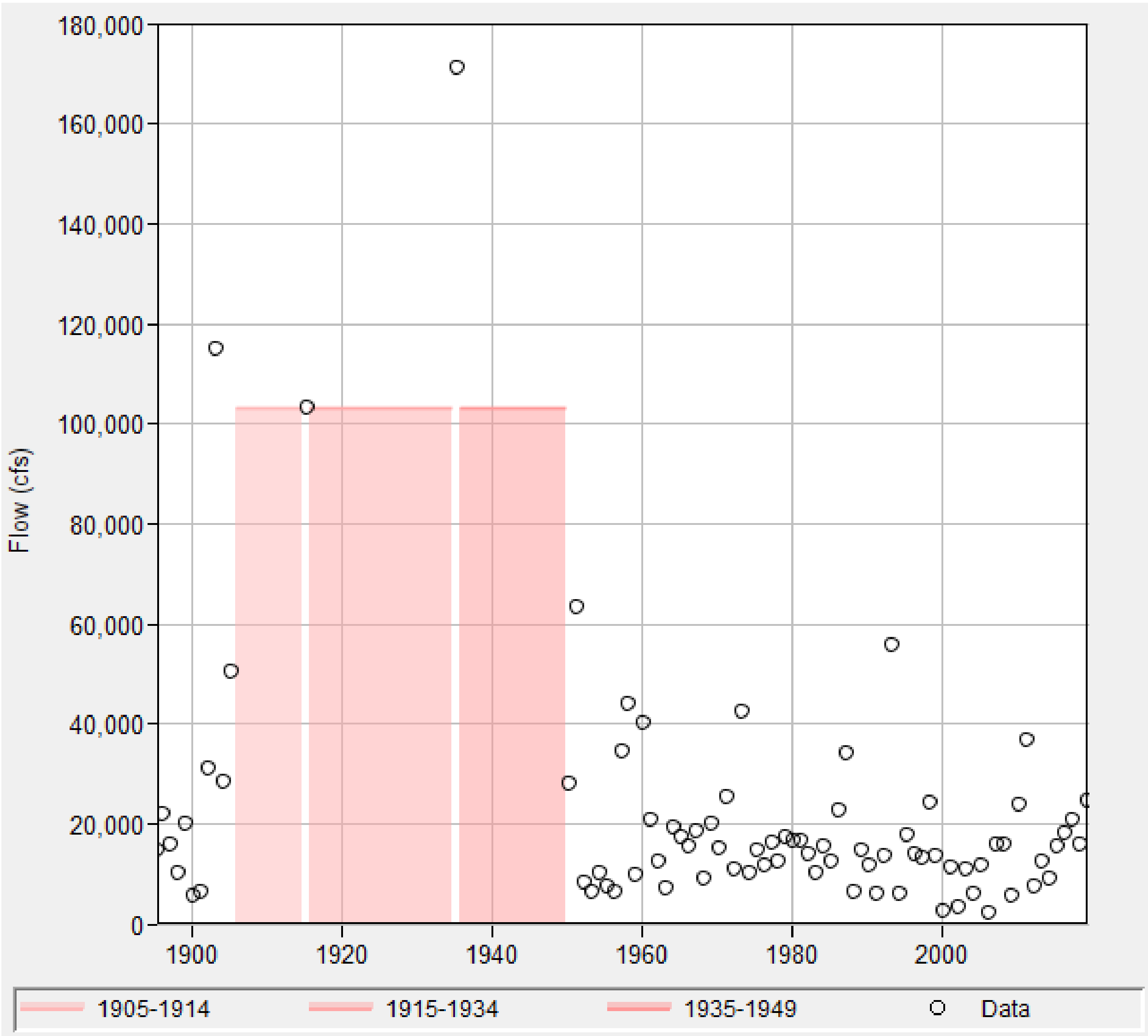

Figure 3.11. Junction City EMA Data

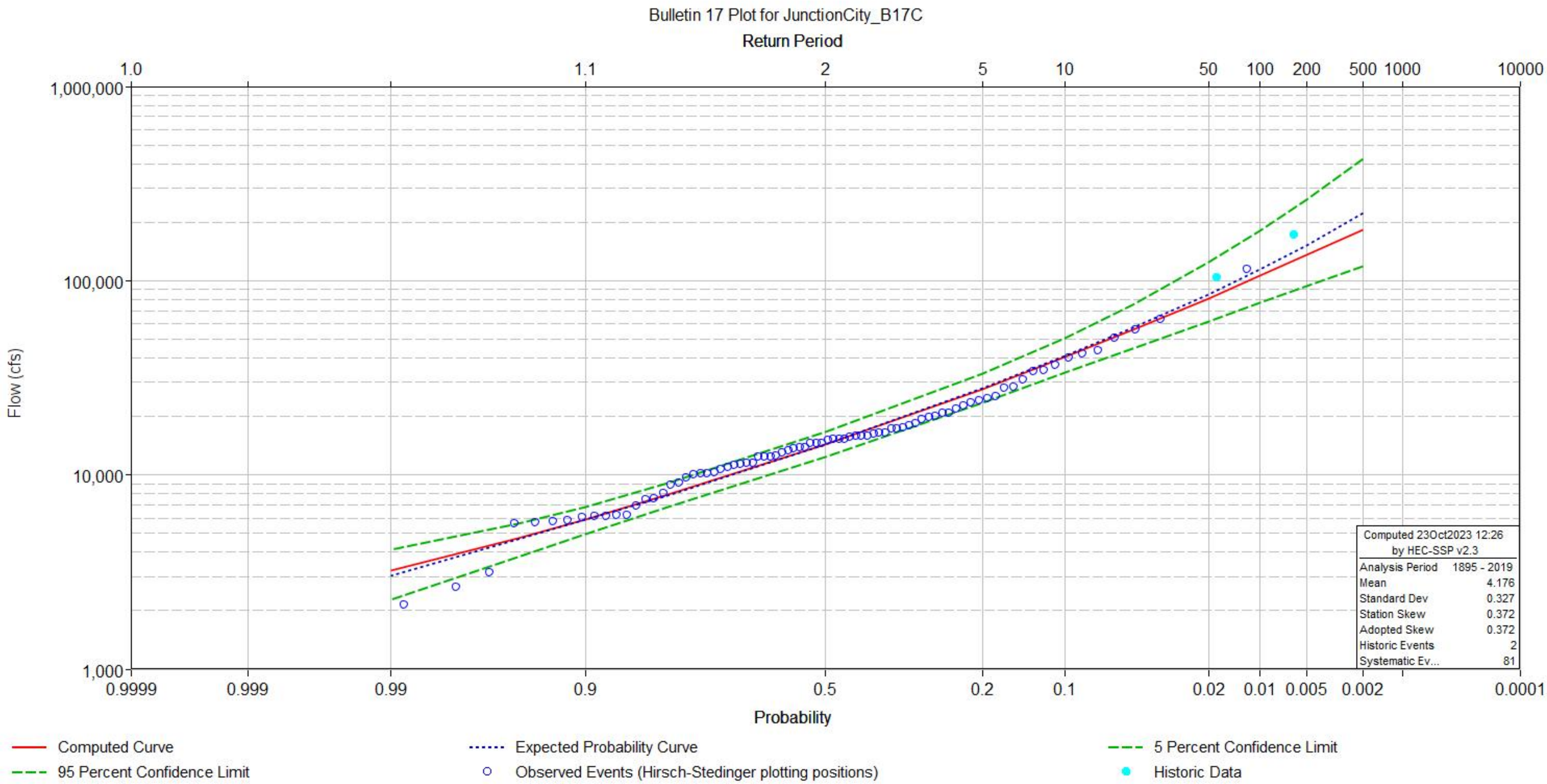

Figure 3.12. Junction City Probability Plot

3.7 Big Blue River at Manhattan, KS

USGS annual peak streamflow data at Randolph (USGS 06886000) was used to supplement the Manhattan data prior to 1955 excluding the 1951 peak flow. Additional streamflow estimates at Randolph (provided in Table 2.2) were obtained from a USGS letter dated August 2, 1944. According to the letter, peak stages recorded by a local resident were adjusted to represent stages at the gage site and a mean rating curve was used to determine the discharges (Spiegel). MOVE3 could not be used to scale the Randolph peak flows to Manhattan because the concurrent record length was less than 10 years. Instead, the drainage area ratio method was used. A range of flows was input for 1903 using the high and low estimates for Manhattan in Table 2.2 and the scaled Randolph flow for the peak value. Peak flow estimates prior to 1918 were set as historic events as well as the 1951 flow. Table 3.19 shows the results for Manhattan for station skew only (M) and weighted skew (M.b).

Table 3.19. Bulletin 17C Results: Big Blue River at Manhattan

Annual Exceedance Probability (%)	Station Skew Only (1897, 1899, 1902-1905, 1907-1912, 1918-2019)	USGS 2017 (1897, 1899, 1902-1905, 1907-1912, 1918-2019)
0.2	161,000	171,000
0.5	138,000	145,000
1	121,000	126,000
2	105,000	107,000
5	83,100	84,400
10	67,300	67,700
20	51,500	51,400
50	29,800	29,600
80	16,500	16,500
90	11,900	12,000
95	8,970	9,130
99	5,160	5,400
Mean	4.460	4.461
Std Dev	0.295	0.294
Station Skew	-0.288	-0.288
Regional Skew	--	-0.125
Adopted Skew	-0.288	-0.208
Perception Thresholds	1898: 23kcfs-inf 1900-1901: 24kcfs-inf 1906: 19kcfs-inf 1913-1917: 33kcfs	1898: 23kcfs-inf 1900-1901: 24kcfs 1906: 19kcfs 1913-1917: 33kcfs
Low Outliers	1	1
Systematic / Historic Events	101 / 13 (1897, 1899, 1902-1905, 1907-1912, 1951)	101 / 13 (1897, 1899, 1902-1905, 1907-1912, 1951)
Historic Period	123	123

The final EMA data for Manhattan is shown in Figure 3.13. The circles represent observed data including historic data and scaled data while the shaded area represents the perception thresholds. The analysis using the weighted skew was selected for the final results (M.b). Figure 3.14 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

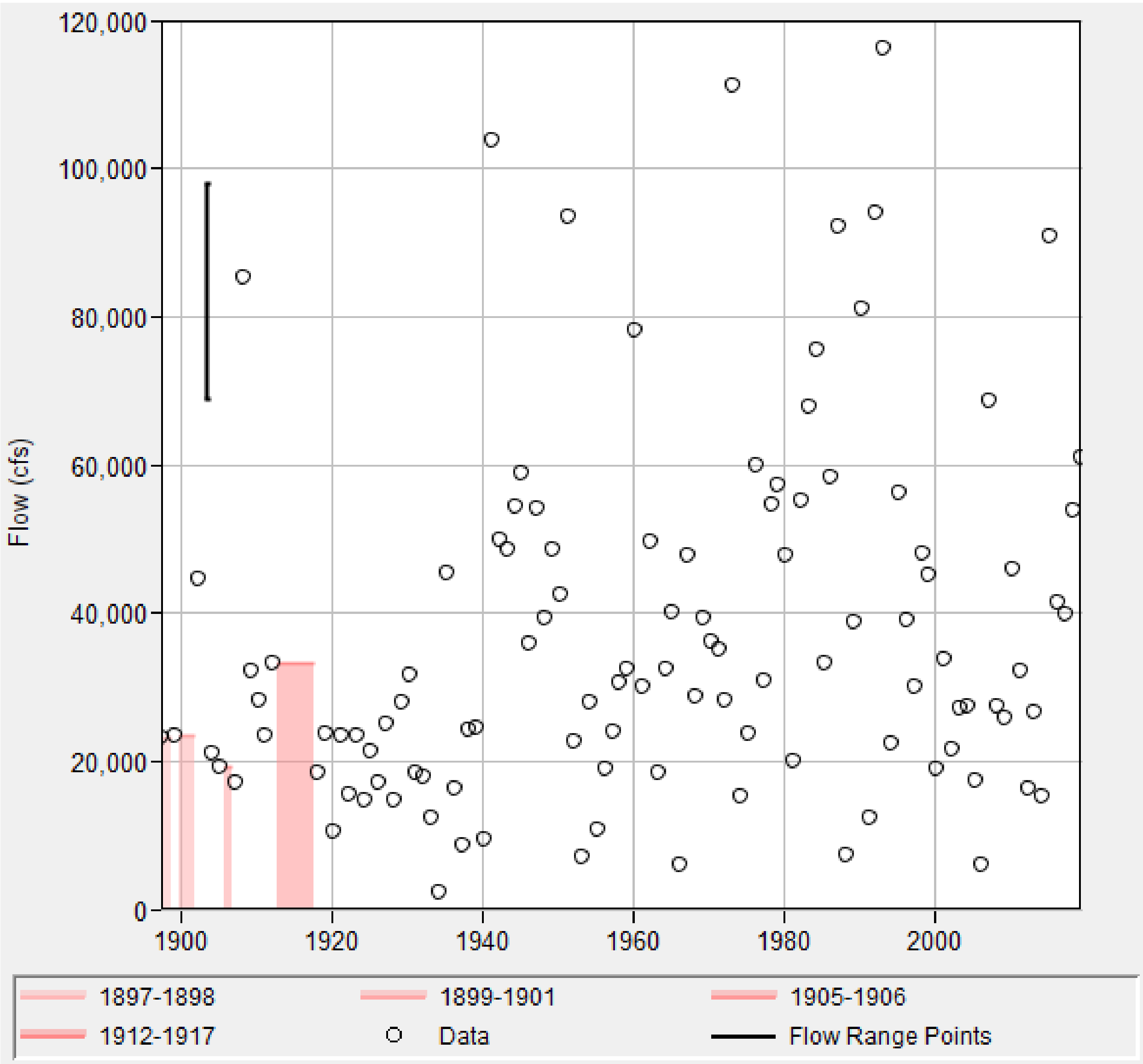

Figure 3.13. Manhattan EMA Data

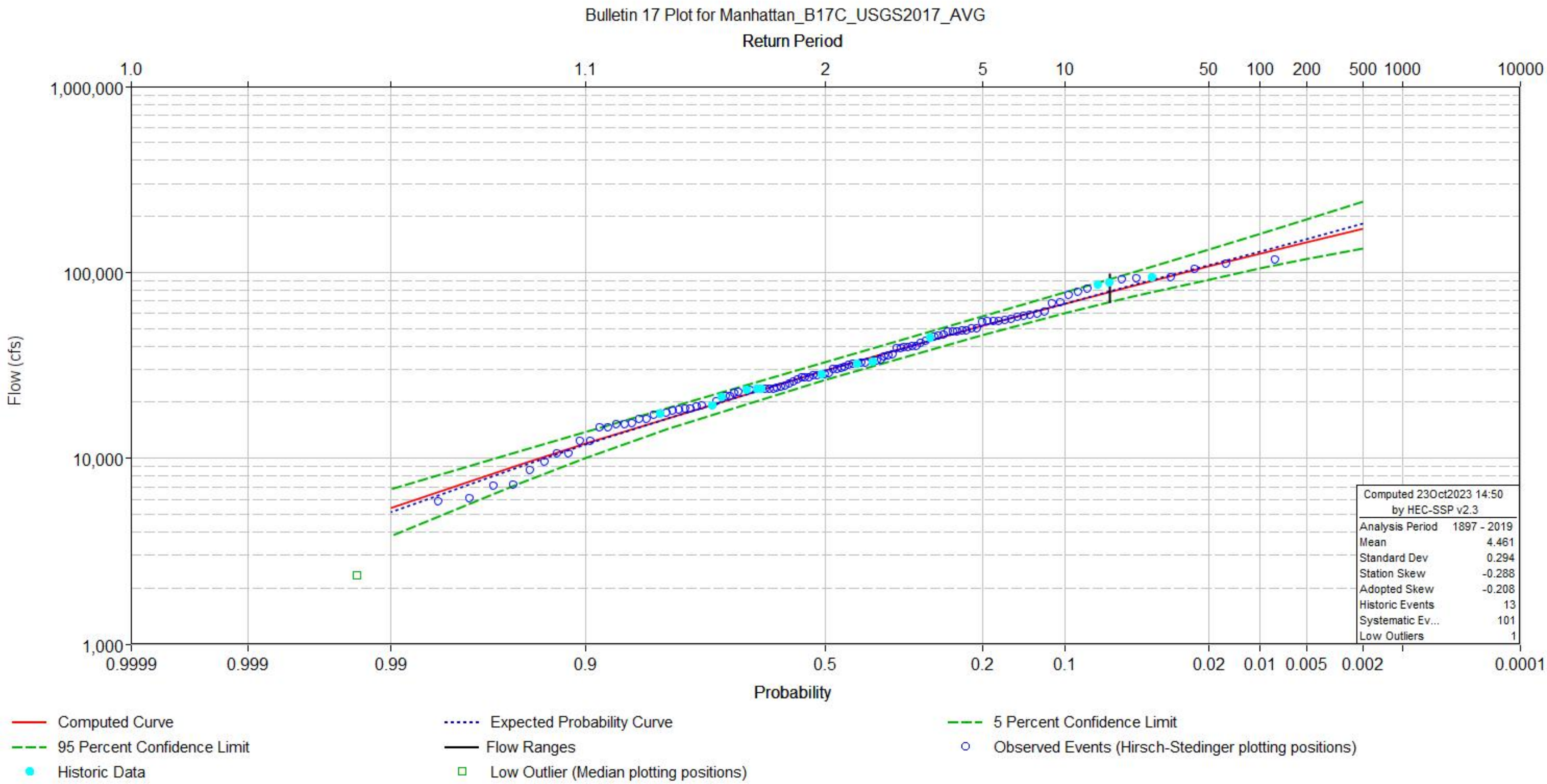

Figure 3.14. Manhattan Probability Plot

The results at Manhattan were compared to the Manhattan Feasibility Study Bulletin 17B results which are shown in Table 3.20. The current expected probability curve was higher than the 2011 curve for all AEP's. The 2011 study did not include data after 2002 and a different regional skew was used which likely contributed to the differences.

Table 3.20. Manhattan Results Compared to Manhattan Feasibility Study

Annual Exceedance Probability (%)	Current Study Results		2011 Manhattan Feasibility Study Results (Expected)
	Computed Curve	Expected Probability	
0.2	171,000	183,000	178,000
0.5	145,000	151,000	147,000
1	126,000	129,000	126,000
2	107,000	110,000	106,000
5	84,400	85,200	N/A
10	67,700	68,000	63,600
20	51,400	51,500	47,200
50	29,600	29,500	26,200
80	16,500	16,400	N/A
90	12,000	11,800	9,890
95	9,130	8,960	N/A
99	5,400	5,110	4,080
Mean	4.461	4.461	4.407
Std Dev	0.294	0.294	0.311
Station Skew	-0.288	-0.288	-0.214
Regional Skew	-0.125	-0.125	-0.200
Adopted Skew	-0.208	-0.208	-0.211

3.8 Delaware River at Perry, KS

USGS annual peak streamflow data at Valley Falls (USGS 06890500) and Arrington (USGS 06890400) was used to supplement the Perry data prior to 1969. The streamflow records at Valley Falls and Arrington do not have a large enough concurrent record with Perry for the MOVE3, so the drainage area ratio method was used to scale peak flows to Perry. The historic peaks in Table 2.2 were input as historic events in the analysis except for water year 1904, because it occurred in the same calendar year as 1903. An additional analysis was performed for Perry to evaluate the effect of using the additional data from Valley Falls and Arrington. The analysis with only at-station data resulted in a much more negative skew value. Adding the other available data likely improved the results. The results for Perry for station skew only (P), weighted skew (P.b), and the sensitivity analysis (P.b.s) are shown in Table 3.21.

Table 3.21. Bulletin 17C Results: Delaware River at Perry

Annual Exceedance Probability (%)	At-Station Data Only w/ USGS 2017 (1969-2019)	Station Skew Only (1864, 1903, 1908, 1915, 1922-2019)	USGS 2017 (1864, 1903, 1908, 1915, 1922-2019)
0.2	146,000	139,000	145,000
0.5	122,000	115,000	119,000
1	105,000	98,600	101,000
2	89,100	82,800	84,100
5	68,700	63,300	63,700
10	54,100	49,400	49,400
20	40,100	36,300	36,200
50	21,900	19,600	19,400
80	11,400	10,100	10,200
90	7,980	7,050	7,150
95	5,880	5,190	5,320
99	3,240	2,860	3,010
Mean	4.326	4.279	4.280
Std Dev	0.325	0.331	0.328
Station Skew	-0.518	-0.221	-0.221
Regional Skew	-0.125	--	-0.125
Adopted Skew	-0.250	-0.221	-0.161
Perception Thresholds	None	1865-1902: 108kcfs-inf 1904-1907: 37kcfs-inf 1909-1914: 37kcfs-inf 1916-1921: 37kcfs-inf	1865-1902: 108kcfs-inf 1904-1907: 37kcfs-inf 1909-1914: 37kcfs-inf 1916-1921: 37kcfs-inf
Low Outliers	0	13	13
Systematic / Historic Events	51/0	98 / 4 (1864, 1903, 1908, 1915)	98 / 4 (1864, 1903, 1908, 1915)
Historic Period	51	156	156

The final EMA data for Perry is shown in Figure 3.15. The circles represent observed data including historic data and scaled data while the shaded areas represent the perception thresholds. The analysis using the weighted skew was selected for the final results (P.b). Figure 3.16 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

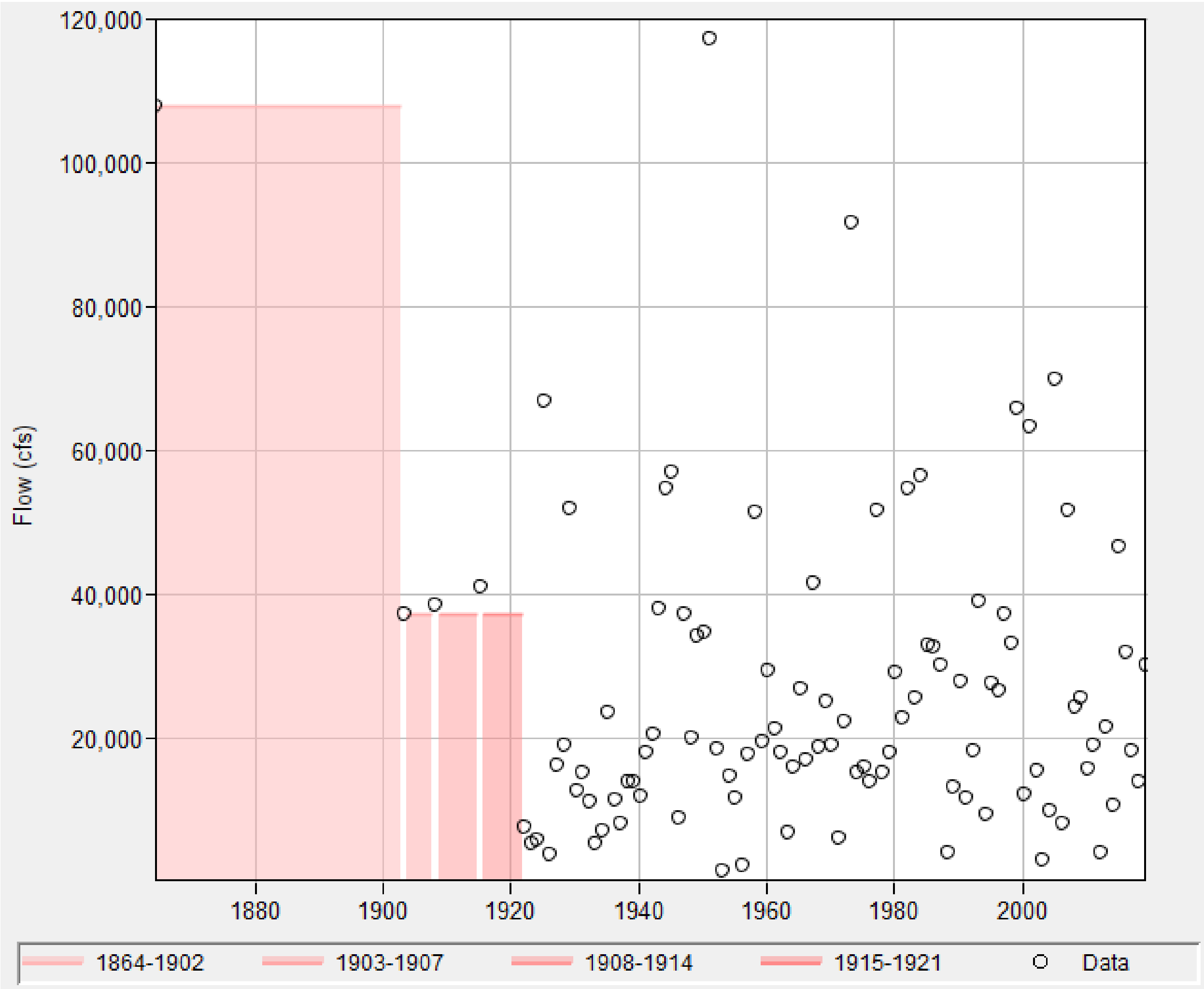

Figure 3.15. Perry EMA Data

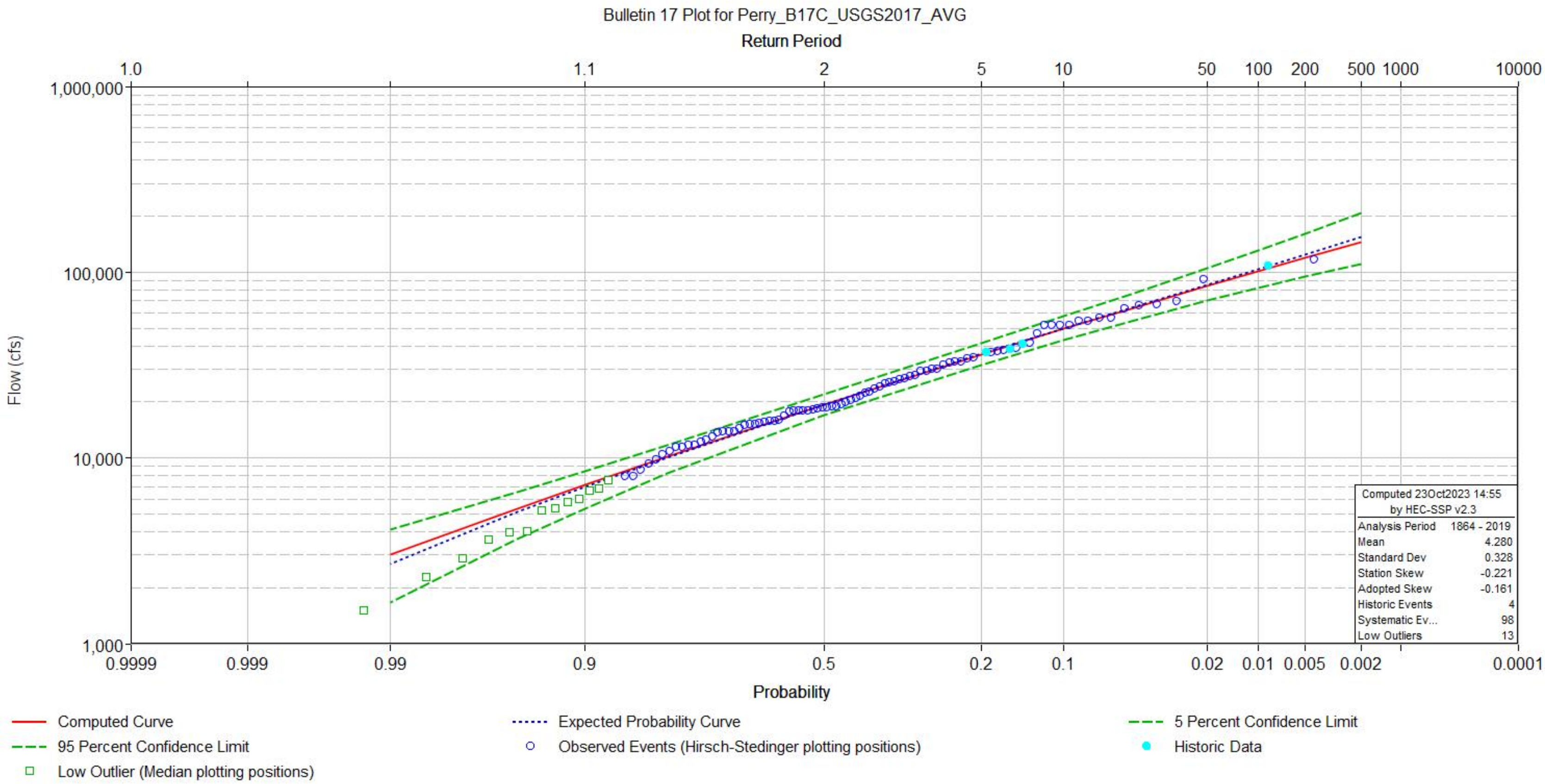

Figure 3.16. Perry Probability Plot

3.9 Wakarusa River at Lawrence, KS

Two historic events identified in Table 2.2 were included in the analyses. Table 3.22 shows the results for Lawrence for station skew only (La) and weighted skew (La.b). The low outlier test initially identified 44 low outliers which was almost 50% of the dataset. A sensitivity run was completed with an override low outlier threshold value of 3,000 cfs. This reduced the number of low outliers to 10 and the computed curve is shown in the right column of Table 3.22 (La.b.s). The AEPs with the largest percent differences from the original weighted skew run were the 80% and higher. The computed curve without the override value produced a better fit to the 50% and smaller AEP plotting positions and was carried forward in the analysis.

Table 3.22. Bulletin 17C Results: Wakarusa River at Lawrence

Annual Exceedance Probability (%)	Station Skew Only (1920, 1928, 1930-2019)	USGS 2017 (1920, 1928, 1930-2019)	USGS 2017 (1920, 1928, 1930-2019), Low Outlier Threshold = 3,000cfs
0.2	32,300	41,200	46,700
0.5	29,700	35,300	39,500
1	27,400	31,000	34,300
2	24,900	26,900	29,200
5	21,200	21,500	22,800
10	17,900	17,600	18,100
20	14,200	13,700	13,600
50	8,230	8,330	7,610
80	4,140	4,930	4,070
90	2,720	3,710	2,880
95	1,870	2,920	2,140
99	845	1,830	1,200
Mean	3.872	3.913	3.868
Std Dev	0.327	0.264	0.313
Station Skew	-0.801	-0.801	-0.597
Regional Skew	--	-0.125	-0.125
Adopted Skew	-0.801	-0.182	-0.263
Perception Thresholds	1921-1927: 16kcfs-inf 1929: 16kcfs-inf	1921-1927: 16kcfs-inf 1929: 16kcfs-inf	1921-1927: 16kcfs-inf 1929: 16kcfs-inf
Low Outliers	44	44	10
Systematic / Historic Events	90 / 2 (1920, 1928)	90 / 2 (1920, 1928)	90 / 2 (1920, 1928)
Historic Period	100	100	100

The final EMA data for Lawrence is shown in Figure 3.17. The circles represent observed data including historic data while the shaded areas represent the perception thresholds. The analysis using the weighted skew was selected for the final results (La.b). Figure 3.18 shows the unregulated data Hirsch-Stedinger plotting positions against the final computed probability curve.

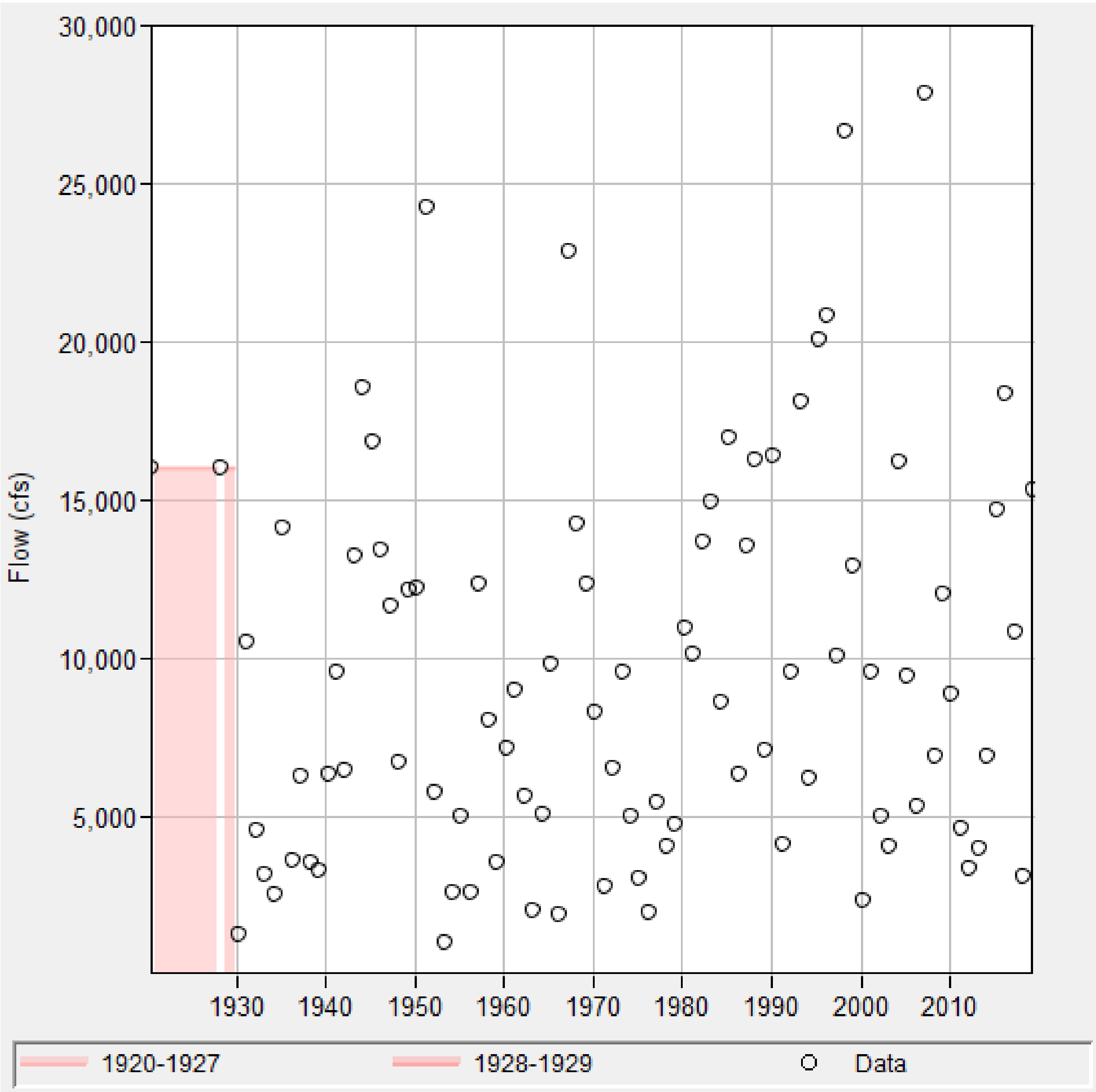

Figure 3.17. Lawrence EMA Data

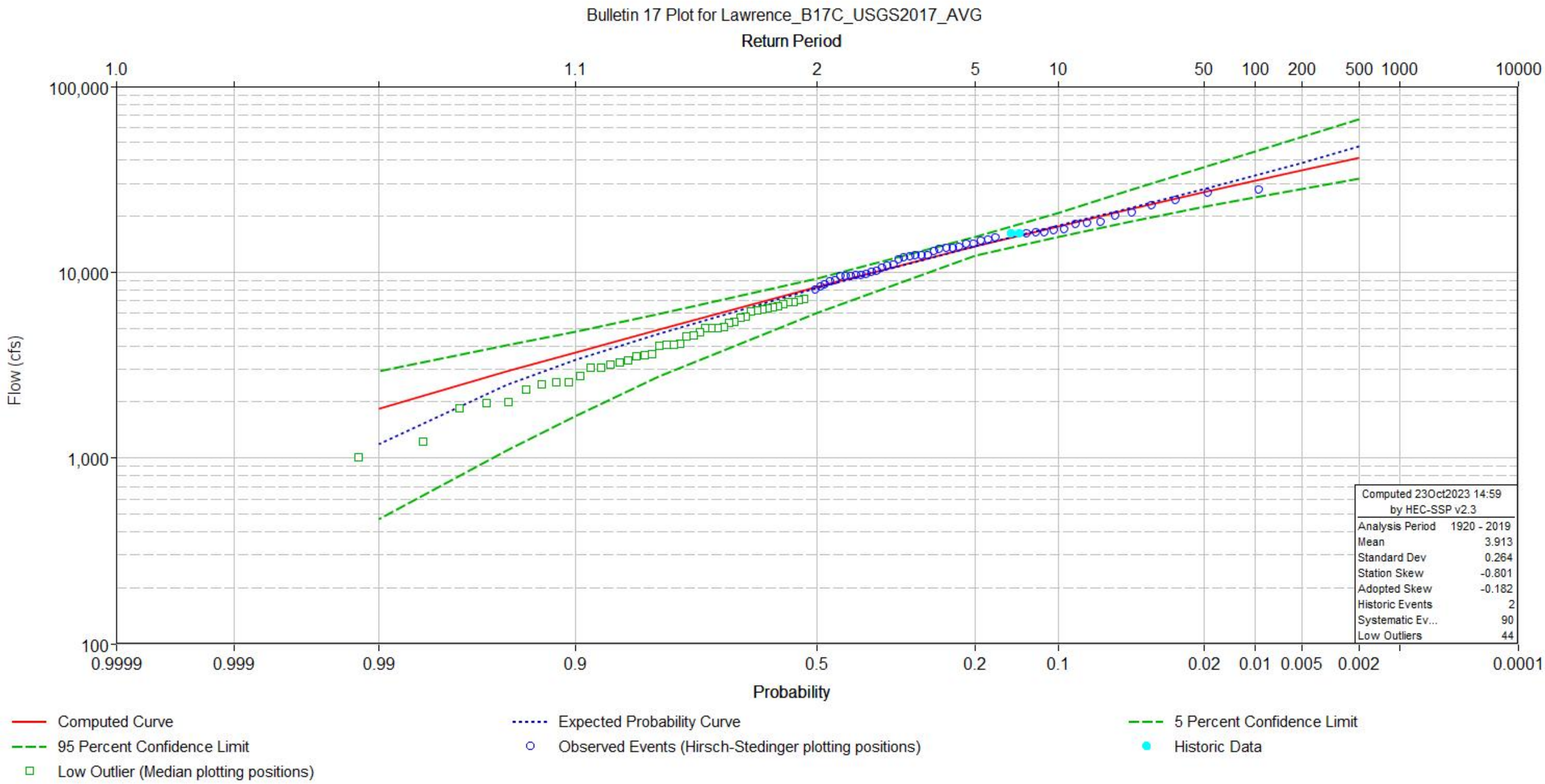

Figure 3.18. Lawrence Probability Plot

3.10 Adopted Unregulated Frequency Flows

The adopted unregulated expected probability flows for the mainstem Kansas River gages and the tributary gages are presented in Table 3.23 and Table 3.24. The results for the Kansas River suggest there may be some attenuation during large events between Wamego and Topeka. This is evident in the observed USGS annual peak flow records shown in Figure 3.19. The Wamego peak flow was larger than Topeka for the 1915, 1935, 1941, and 1993 events.

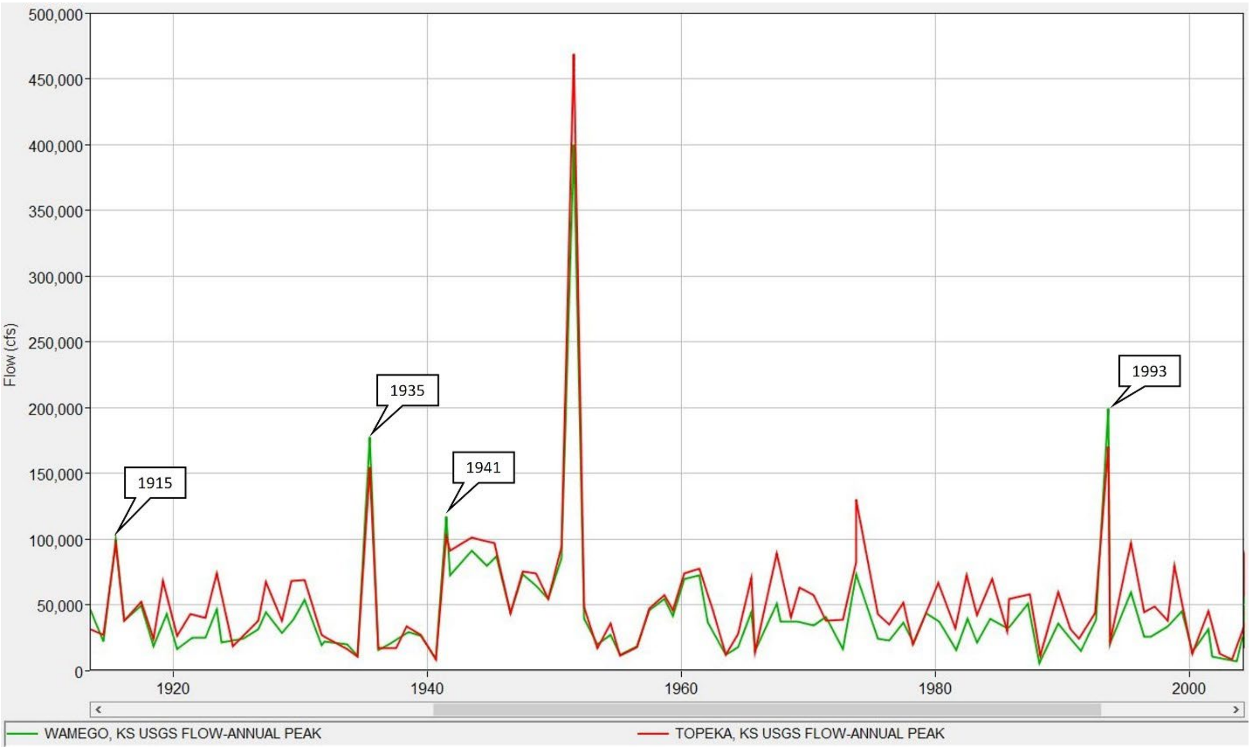

Figure 3.19. USGS Annual Peak Flows at Wamego and Topeka

Table 3.23. Unregulated Expected Probability Flows for the Mainstem Kansas River Gages

Annual Exceedance Probability (%)	Desoto	Lecompton	Topeka	Wamego	Fort Riley
0.2	535,000	525,000	471,000	493,000	345,000
0.5	424,000	408,000	360,000	368,000	250,000
1	351,000	334,000	290,000	291,000	194,000
2	288,000	270,000	231,000	228,000	149,000
5	216,000	198,000	166,000	160,000	101,000
10	168,000	152,000	125,000	118,000	73,400
20	125,000	111,000	90,100	82,600	50,500
50	72,800	62,000	49,100	43,200	25,700

Annual Exceedance Probability (%)	Desoto	Lecompton	Topeka	Wamego	Fort Riley
80	42,900	35,500	27,600	23,400	13,800
90	32,700	26,800	20,600	17,200	10,100
95	26,100	21,300	16,300	13,500	7,890
99	16,500	13,800	10,500	8,480	4,980

Table 3.24. Unregulated Expected Probability Flows for the Tributary Gages

Annual Exceedance Probability (%)	Lawrence	Perry	Manhattan	Junction City
0.2	47,800	155,000	183,000	223,000
0.5	38,900	124,000	151,000	152,000
1	33,100	104,000	129,000	114,000
2	28,000	85,700	110,000	85,200
5	21,900	64,300	85,200	56,900
10	17,800	49,700	68,000	40,800
20	13,800	36,200	51,500	28,000
50	8,170	19,400	29,500	14,400
80	4,670	10,000	16,400	7,870
90	3,360	6,980	11,800	5,870
95	2,470	5,110	8,960	4,670
99	1,190	2,670	5,110	3,020

4 Existing Conditions Frequency Flows

Existing conditions frequency flows were developed following the Bulletin 17C analysis. The expected probability unregulated frequency flows were transformed to regulated (existing conditions) frequency flows.

4.1 Unregulated to Regulated Flow Transform

Initially, the unregulated and regulated annual peak instantaneous flows were plotted for each gage and curves were fit to the data. The 1951 data points defined the upper ends of the curves which created greater uncertainty for larger events. To validate the curves, hypothetical flood events were produced to expand the unregulated-regulated relationships. The Corps Water Management System (CWMS) HEC-Hydrologic Modeling System (HMS) version 4.2 and HEC-ResSim version 3.5 models for the lower Kansas River were used to model excess precipitation and route the probable maximum precipitation (PMP) for several storm centers. The hypothetical storms were produced from Hydrometeorological Reports 51 and 52 (HMR 51/52) and the storm parameters are shown in Table 4.1.

Table 4.1. HMR 51/52 Storm Parameters

Location Description	X-Coordinate (feet, Albers*)	Y-Coordinate (feet, Albers*)	Orientation/ Preferred Orientation (deg)	1-hr to 6-hr Precipitation Ratio	Area (mi^2)
North of Perry Lake	105,182	6,012,098	242	0.301	20,000
13 Miles West of Topeka	36,748	5,854,243	241	0.302	20,000
West of Leavenworth	211,661	5,947,993	242	0.300	20,000
Big Blue River Basin	-188,121	6,081,143	241	0.305	20,000
Republican River Basin	-387,458	6,039,368	240	0.307	20,000
Smoky Hill River Basin	-439,341	5,775,689	238	0.307	20,000

*MMC Standard Projection: USA_Contiguous_Albers_Equal_Area_Conic_USGS_version, North American Datum of 1983

Figure 4.1 shows a map of the modeled subbasins with the storm center locations and the isohyetals for the hypothetical storm center north of Perry Lake. An approximate HEC-HMS model for the Platte River above Agency, Missouri and the Little Platte River CWMS HEC-HMS model were used to feed flow into the Platte River at Sharps Station. An approximate HEC-HMS model for the Missouri River between Nebraska City, Nebraska and St. Joseph, Missouri was used to feed flow into the Missouri River at St. Joseph. The approximate models were developed using loss rates similar to neighboring basins with initial deficits of approximately 1 inch. The Clark parameters were adjusted to obtain reasonable peak flow estimates when compared to precipitation rates for each subbasin. The loss parameters for the CWMS models were kept at the initial calibrated values. An average baseflow of 40,000 cfs was assumed for the Missouri River at St. Joseph, Missouri and a baseflow of 1,000 cfs was assumed for the Platte River. To estimate unregulated flows, reservoir elements were removed from the model. For the first three storm centers in Table 4.1, the reservoir elements for Perry, Clinton, Tuttle Creek, Milford, and Smithville dams were removed and the western dams were neglected since they had minimal upstream precipitation. For the remaining storm centers, all reservoir elements were removed to approximate unregulated flows. As shown in Figure 4.1, the west Kansas Basin was not modeled and therefore the HMR 51/52 estimates may be underpredicted. However, since the hypothetical storms are centered in the eastern part of the basin it is not expected to make a significant impact to the peak flows at the gages of interest.

Factors of 0.75 and 0.5 were applied to the precipitation for several of the storm centers and the models were rerun for both regulated and unregulated conditions. Sensitivity to initial flood storage was checked by running two different scenarios, one with reservoirs starting at multi-purpose pool elevations, and another with reservoirs starting at top of flood control, or top of active storage (TAS), pool elevations. Additionally, the loss parameters for all subbasins for the storm center 13 miles west of Topeka were reduced to an initial deficit of 0.2 inches and a constant rate of 0.05 inches/hour to check loss rate sensitivity.

While the same unregulated model results apply to both regulated runs, in some TAS runs, this yielded higher regulated flows than unregulated flows, which is extremely unlikely. Base flows on the Kansas were much higher when starting the dams full due to the outflow curves of the reservoirs in HEC-HMS. For the without dam case, there would also have to be antecedent runoff to get a condition where the reservoirs are entirely full, so comparing to a without dam model result that only showed very low flows was judged to be unrealistic. While it is uncertain how much flow would be in the Kansas River in the natural conditions, the TAS regulated scenario was essentially starting with a bankfull Kansas River. Based on the flood history for this type of extreme event, near bankfull flows was assumed to be a reasonable starting scenario for the unregulated runs also. Flow was manually added to the unregulated model results to ensure the same model result for a more realistic comparison to a full reservoir, or TAS condition. The regulated HMR51/52 runs for TAS produced an initial discharge on the Kansas River at Desoto of nearly 85,000 cfs, compared to less than 4,000 cfs for without dam runs. Therefore, unregulated values were plotted with 80,000 cfs added as large natural flows would be required to fill the dams. A similar approach was taken for the other Kansas River gages and the tributary gages.

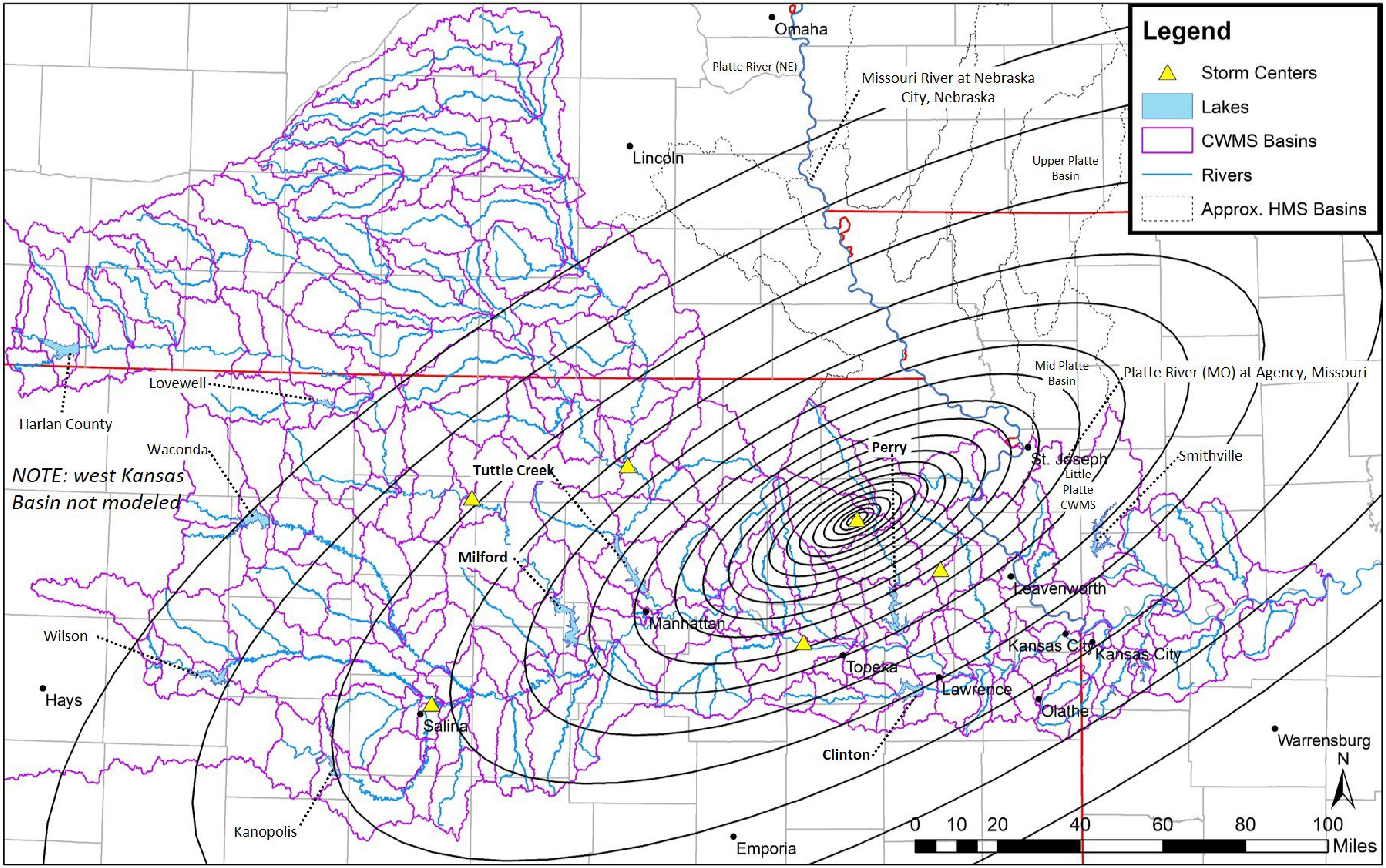

Figure 4.1. Schematic of the CWMS and Approximate HEC-HMS Model Basins and Hypothetical Storm Centering using HMR 52

Results from the HEC-HMS model were input into the CWMS HEC-ResSim model (shown in Figure 4.2) to better estimate regulated peak flows at the gages. Local flow time series were added to the corresponding junctions in HEC-ResSim; however, the Republican River was not modeled upstream of Clay Center. Routing methods included modified puls for the Kansas and Missouri Rivers and Muskingum for the tributaries, and the model was run with an hourly time step. In some cases, the regulated peak flows computed in HEC-ResSim were higher than the unregulated peak flows computed in HEC-HMS, which is unlikely to occur. The HEC-HMS regulated peak flows were used instead if they were close to the HEC-ResSim regulated peak flows. If they were not close, it was assumed to be a model error (such as an unrealistic spike in the reservoir release) and the scenario was not incorporated for that gage. The resulting peak flows for each of the scenarios at the gages are listed in Attachment 4.

A sensitivity analysis was completed to determine if the approximate HEC-HMS models for the Missouri and Platte Rivers had any significant impacts to regulated flows at the gages of interest. Unregulated flow estimates were not impacted because the Missouri River confluence with the Kansas River is at Kansas City which is downstream of the gages. Flow factors of 0.5 and 1.5 were applied to the nodes at St. Joseph and Sharps Station in the HEC-ResSim model to test if reservoir operations would be affected by changes in inflows at these locations. Generally, the mainstem Kansas River gages were not significantly impacted because releases from the reservoirs do not typically increase the downstream peak flows along the Kansas River. However, the peak flows at the tributary gages were affected by changes in reservoir releases. This makes sense because there is a downstream control point on the Missouri River at Waverly, Missouri. The largest differences occurred with the multipurpose starting pool elevations. When a factor of 0.5 was applied, the reservoirs generally released more water and when a factor of 1.5 was applied, the reservoirs typically held more water back. Although there are significant impacts to the tributary peak flows, these events are hypothetical, and many different scenarios were modeled to capture some of the variability. Still, careful consideration should be taken when applying the transform curves that were developed for the tributary gages using the hypothetical events to inform the upper end of the curves. Additional analyses may be required to develop more accurate unregulated-regulated relationships.

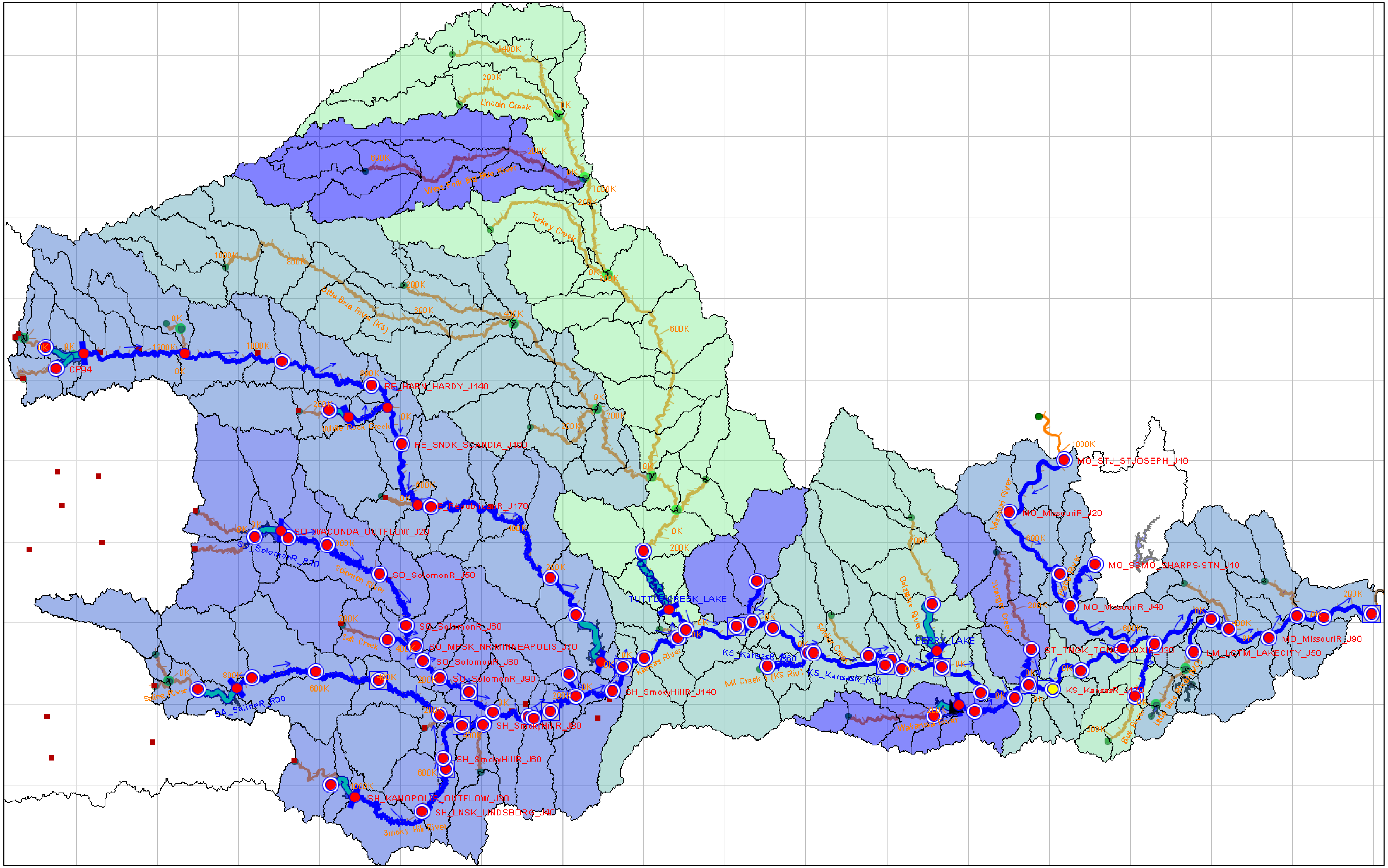

Figure 4.2. CWMS HEC-ResSim Model

Additional hypothetical peak flows from a concurrent USACE study were also incorporated into the transform analyses for the Wamego and Fort Riley gages. In the Missouri River Flow Frequency Study (MRFFS) (USACE, 2022), a combined HEC-ResSim model based on the Kansas River Watershed Study model (1-day time step) was used to produce peak flows from scaled floods on the Kansas and Missouri Rivers. Standard deviation scaling factors of 0.5, 1.0, 1.5, and 2.0 were applied to several floods. The MRFFS peak flow estimates for Wamego and Fort Riley are listed in Attachment 4.

4.1.1 Kansas River at Desoto, KS

Figure 4.3 shows the regulated-unregulated relationship for the Kansas River at Desoto, Kansas. The adjusted regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates. Previous regulated peak flow estimates for 1951 from the Kansas River Hydrology Study (USACE, 2002), Manhattan Feasibility Study (USACE, 2011), and the 1966 Regulation Manual (USACE, December 1966) are also shown. The Kansas City's Project 1962 Modification used a design discharge of 390,000 cfs on the Kansas River with the assumption that three additional dams, Onaga, Woodbine, and Grove, would be built (USACE, October 1966). Without the three dams the discharge on the Kansas River would increase to 432,600 cfs (USACE, October 1977 MRKED-DG memorandum). The design discharge was based on a transposition of the 1951 storm. Other 1951 transpositions, documented in a 1953 USACE report titled "Influence of the 1951 Flood on the Flood Control Program, Kansas River Basin," were adjusted to include Clinton Dam regulation and were also plotted.

The adjusted annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. Also, the rank ordered hypothetical flows greater than the 1973 unregulated flow were combined with the adjusted rank ordered data and a second order polynomial was fit to the combined dataset. 1973 was used as the minimum unregulated flow for the hypothetical floods in the combined curve since it is the second highest value in the period of record. Above the 1973 flow, only the 1951 peak flow exists to define the relationship, therefore hypothetical floods were used to populate this region. Points below 10,000 cfs regulated were dropped to produce a better fit at the 50% AEP line. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.3 and the equation is shown on the plot along with recommended unregulated flow bounds.

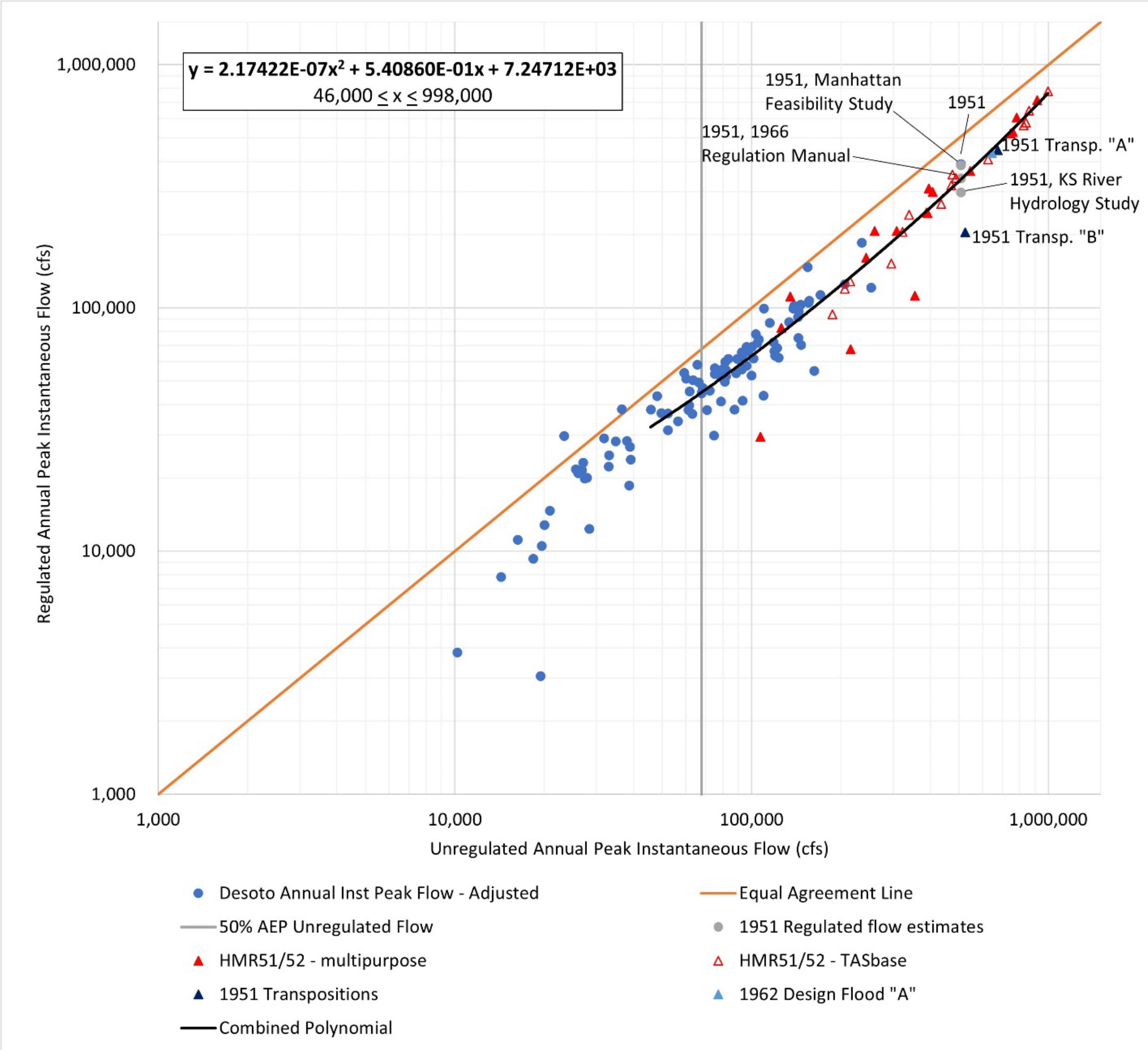

Figure 4.3. Regulated-Unregulated Relationship for the Kansas River at Desoto, Kansas

4.1.2 Kansas River at Lecompton, KS

Figure 4.4 shows the regulated-unregulated relationship for the Kansas River at Lecompton, Kansas. The adjusted regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates. The previously discussed 1951 regulated peak flow estimates and the 1951 transpositions are also shown.

The adjusted annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. The rank ordered hypothetical flows greater than the 1993 unregulated flow of 254,000 cfs were combined with the adjusted rank ordered data and a fourth order polynomial was fit to the combined dataset.

1993 was used as the minimum unregulated flow for the hypothetical floods in the combined curve since it is the second highest value in the period of record. Above the 1993 flow, only the 1951 peak flow exists to define the relationship, therefore hypothetical floods were used to populate this region. Points below 30,000 cfs regulated were dropped to produce a better fit at the 50% AEP line. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.4 and the equation is shown on the plot along with recommended unregulated flow bounds.

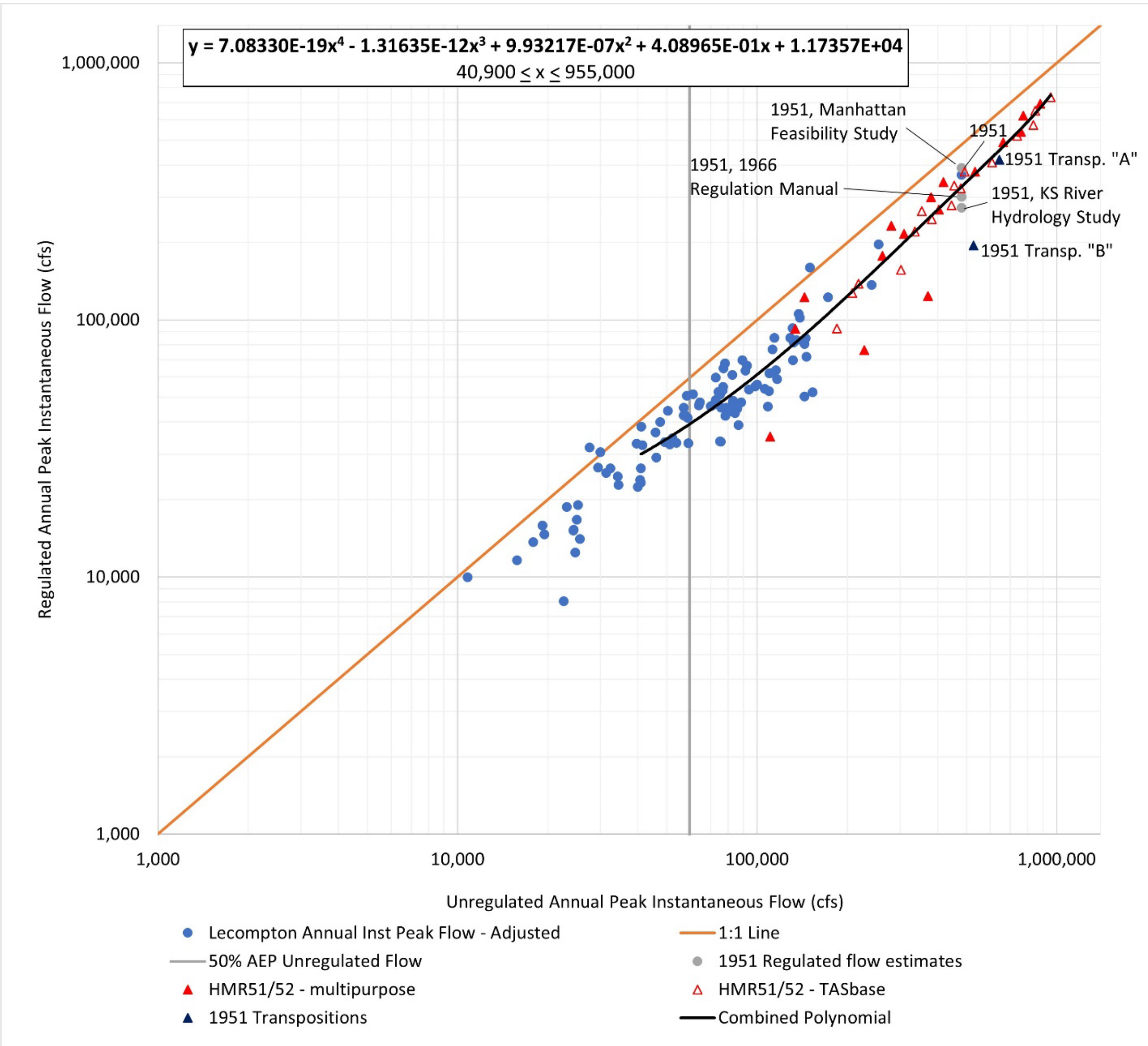

Figure 4.4. Regulated-Unregulated Relationship for the Kansas River at Lecompton, Kansas

4.1.3 Kansas River at Topeka, KS

Figure 4.5 shows the regulated-unregulated relationship for the Kansas River at Topeka, Kansas. The adjusted regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates. The previously discussed 1951 regulated peak flow estimates and the 1951 transpositions are also shown. Many of the HMR51/52 runs plotted near the equal agreement line primarily due to the large amount of unregulated runoff upstream of Topeka. The hypothetical storm centers in the Republican River and Big Blue River basins had the greatest impacts on regulated flow at Topeka.

The adjusted annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. The rank ordered hypothetical flows greater than the 1993 unregulated flow were combined with the adjusted rank ordered data and a second order polynomial was fit to the combined dataset. 1993 was used as the minimum unregulated flow for the hypothetical floods in the combined curve since it is the second highest value in the period of record. Above the 1993 flow, only the 1951 peak flow exists to define the relationship, therefore hypothetical floods were used to populate this region. Points below 12,000 cfs regulated were dropped to produce a better fit at the 50% AEP line. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.5 and the equation is shown on the plot along with recommended unregulated flow bounds.

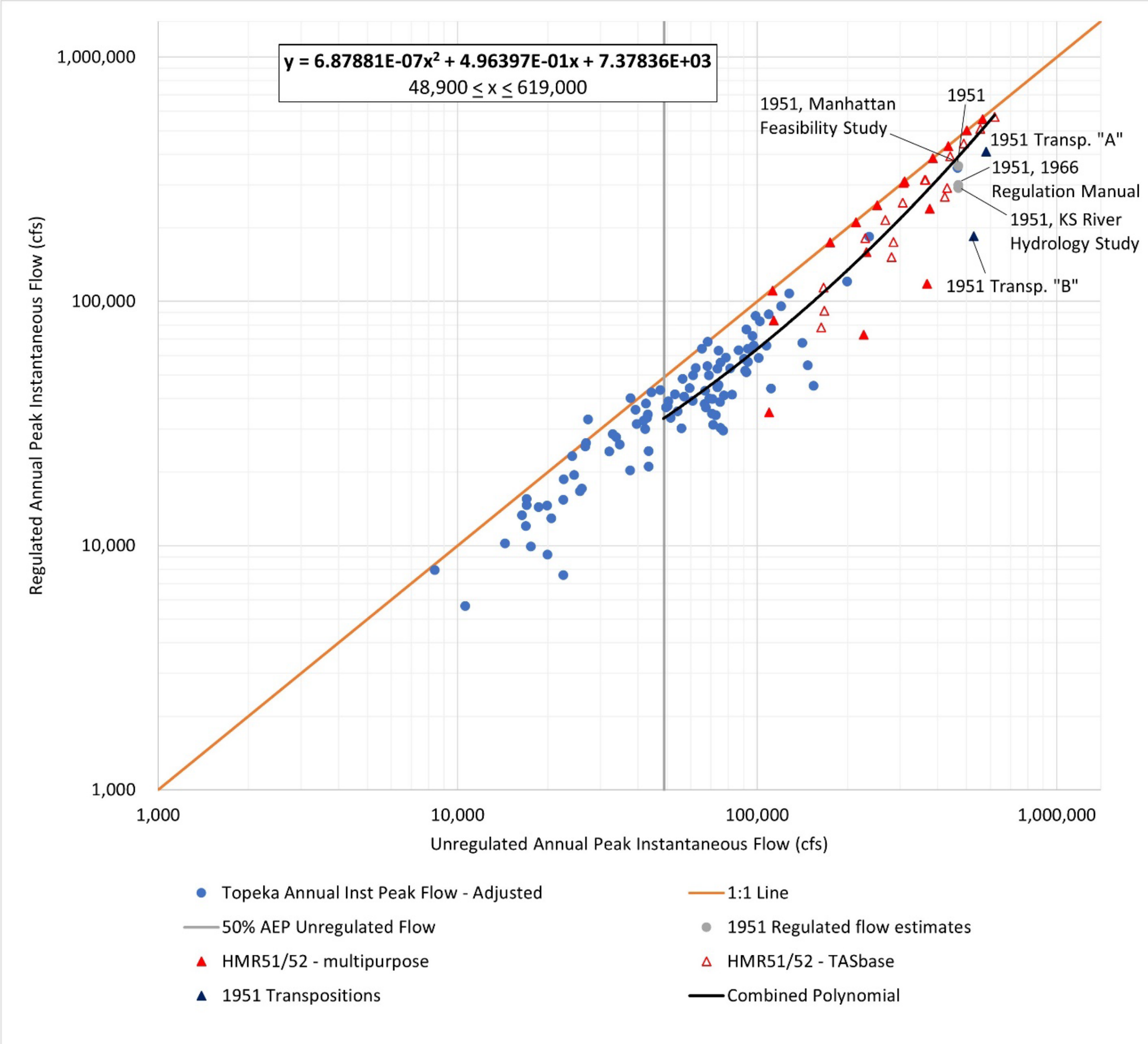

Figure 4.5. Regulated-Unregulated Relationship for the Kansas River at Topeka, Kansas

4.1.4 Kansas River at Wamego, KS

Figure 4.6 shows the regulated-unregulated relationship for the Kansas River at Wamego, Kansas. The adjusted regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates. The rank ordered MRFF scaled floods above 300,000 cfs unregulated were included to supplement the data at the upper end of the curve. The previously discussed 1951 regulated peak flow estimates and the 1951 transpositions are also shown.

The adjusted annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. Two intersection points occurred and were tested as minimum thresholds for the hypothetical data. The first intersection point at 75,000 cfs unregulated was chosen as it produced a slightly more conservative curve when combined with the adjusted rank ordered data. A second order polynomial was also fit to the combined dataset. Points below 16,000 cfs regulated were dropped to produce a better fit at the 50% AEP line. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.6 and the equation is shown on the plot along with recommended unregulated flow bounds.

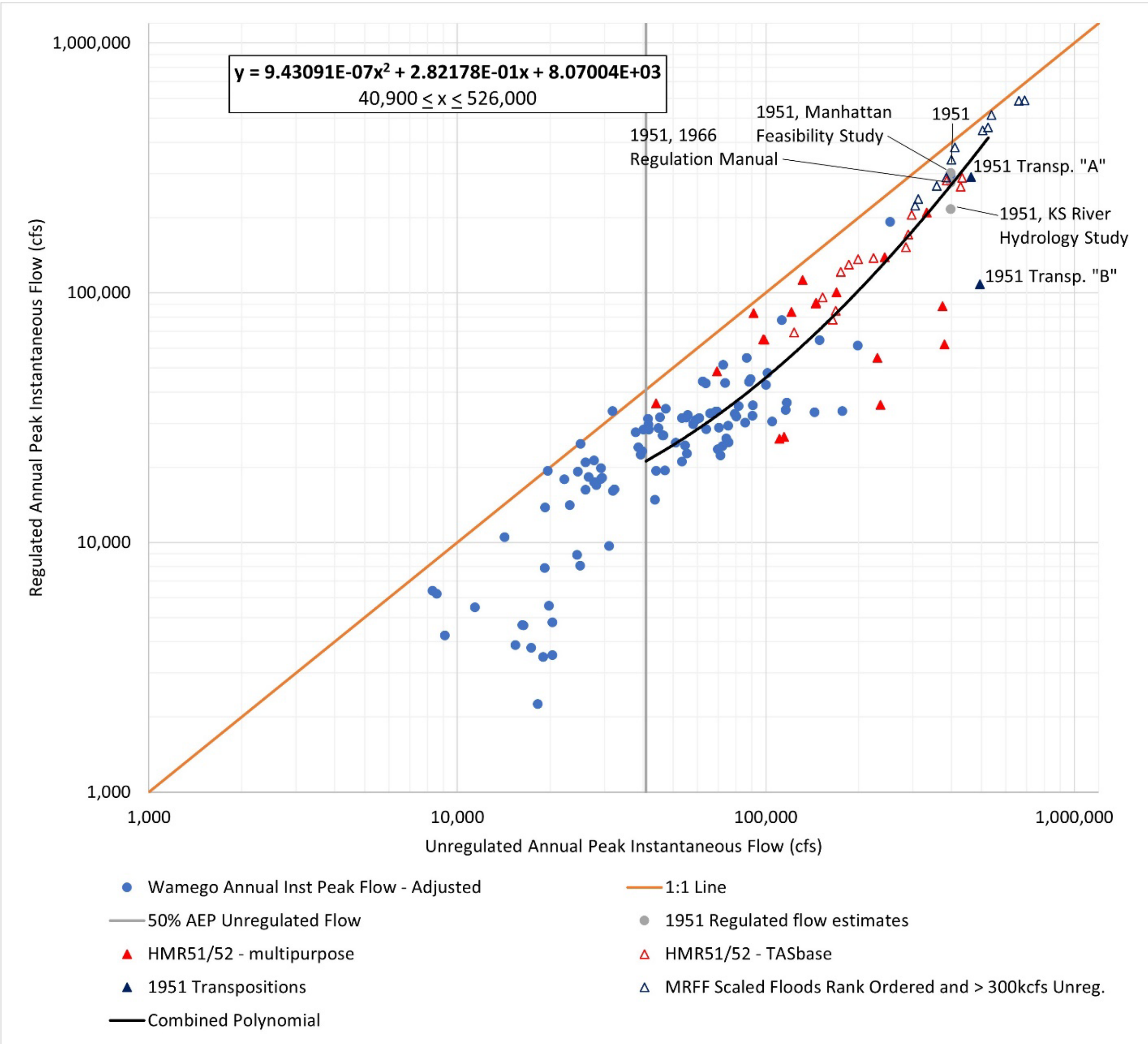

Figure 4.6. Regulated-Unregulated Relationship for the Kansas River at Wamego, Kansas

4.1.5 Kansas River at Fort Riley, KS

Figure 4.7 shows the regulated-unregulated relationship for the Kansas River at Fort Riley, Kansas. The adjusted regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates. The rank ordered MRFF scaled floods above 300,000 cfs unregulated were included to supplement the data at the upper end of the curve. The previously discussed 1951 regulated peak flow estimates and the 1951 transpositions are also shown.

The adjusted annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. The curves intersected near the 1951 data point, so the hypothetical data greater than the unregulated 1951 flow was combined with the adjusted rank ordered data. A third order polynomial was fit to the combined dataset. Points below 13,200 cfs regulated were dropped to produce a better fit at the 50% AEP line. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.7 and the equation is shown on the plot along with recommended unregulated flow bounds.

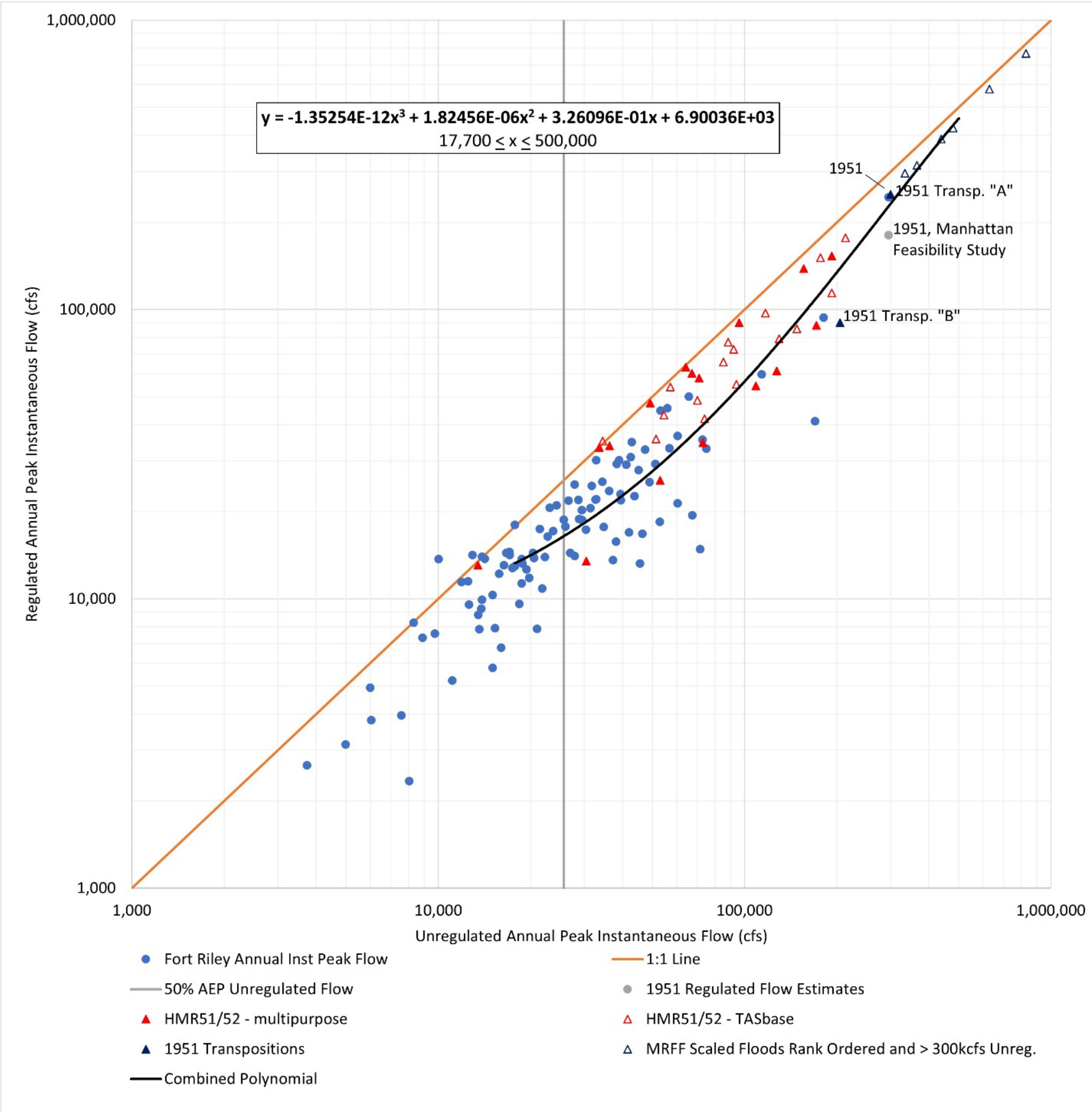

Figure 4.7. Regulated-Unregulated Relationship for the Kansas River at Fort Riley, Kansas

4.1.6 Republican River at Junction City, KS

Figure 4.8 shows the regulated-unregulated relationship for the Republican River at Junction City, Kansas. The regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates. Two additional hypothetical flood scenarios were produced for Junction City to supplement the data at the upper end of the curve. The storm area for the Republican River Basin was reduced to 1,000 square miles and the models were run with TAS and multipurpose starting pool elevations.

The annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. Many of the hypothetical estimates plotted near the maximum phase three release (22,500 cfs) at Milford dam. Hypothetical estimates greater than 1,000 cfs regulated were combined with the rank ordered annual peak flow data to produce a regulated flow frequency curve that had a better fit to the regulated plotting positions. The flow frequency curves and plotting positions are further discussed in Section 4.2. A second order polynomial was fit to the combined dataset. A third order polynomial was also considered which would have brought the curve closer to the 1993 point. However, the resulting regulated flow frequency curve did not fit as well to the regulated plotting positions. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.8 and the equation is shown on the plot along with recommended unregulated flow bounds.

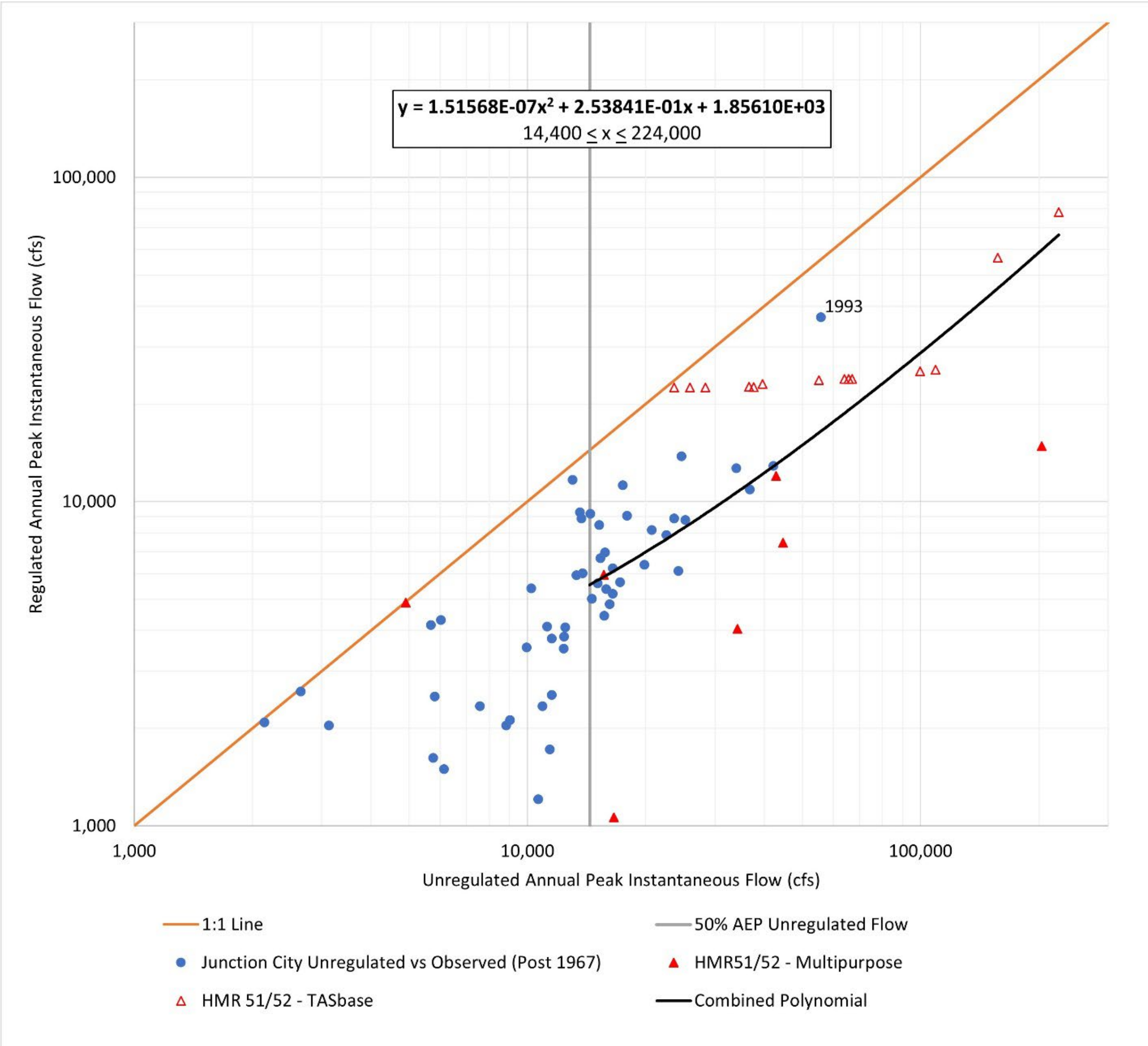

Figure 4.8. Regulated-Unregulated Relationship for the Republican River at Junction City, Kansas

4.1.7 Big Blue River at Manhattan, KS

Figure 4.9 shows the regulated-unregulated relationship for the Big Blue River at Manhattan, Kansas. The regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates.

The annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. Hypothetical estimates starting at Top of Active Storage (TAS) were combined with the rank ordered annual peak flow data and a second order polynomial was fit to the combined dataset. Points below 30,500 cfs unregulated were dropped to produce a regulated flow frequency curve that better fit the regulated plotting positions. The flow frequency curves and plotting positions are further discussed in Section 4.2. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.9 and the equation is shown on the plot along with recommended unregulated flow bounds.

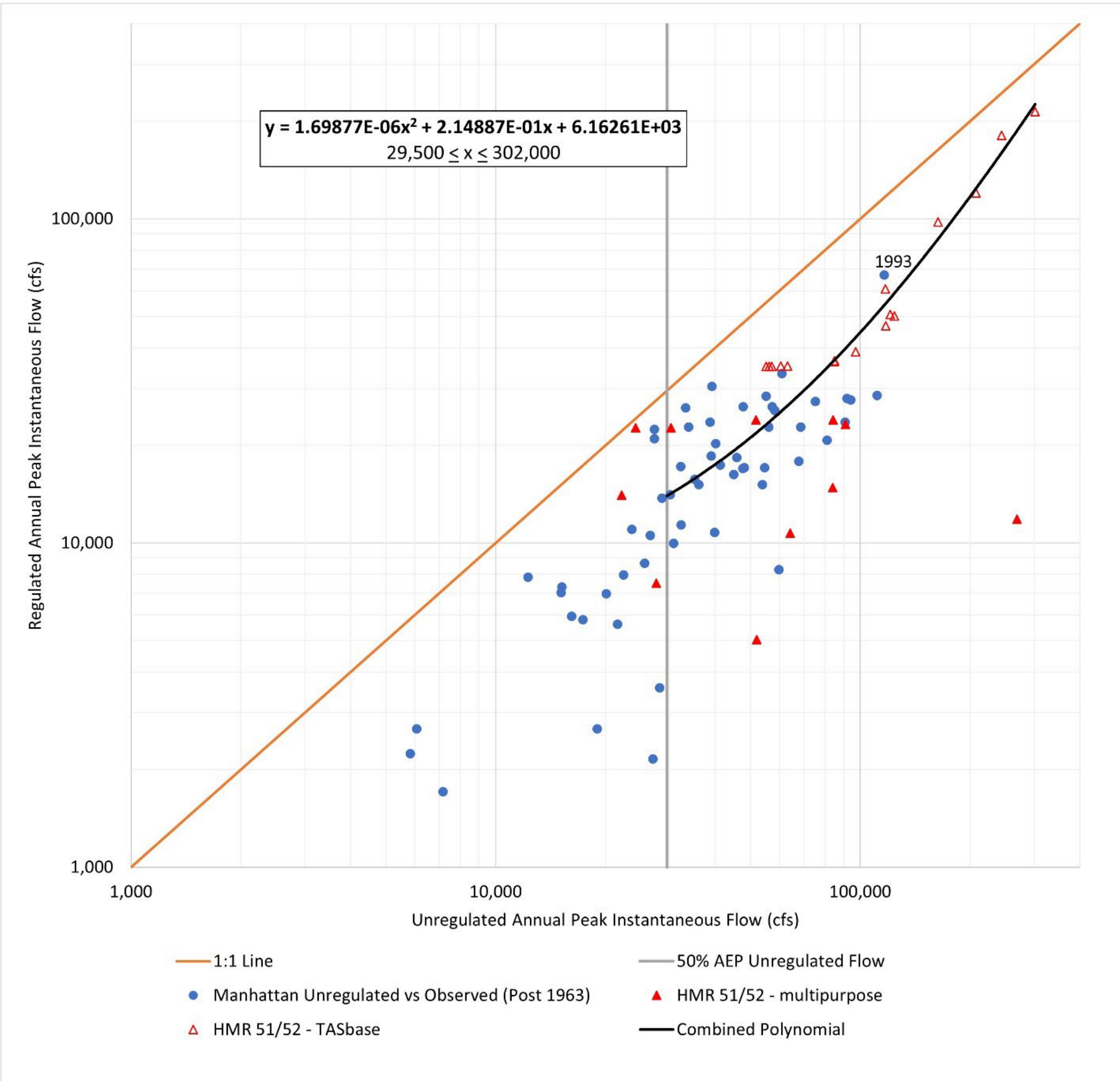

Figure 4.9. Regulated-Unregulated Relationship for the Big Blue River at Manhattan, Kansas

4.1.8 Delaware River at Perry, KS

Figure 4.10 shows the regulated-unregulated relationship for the Delaware River at Perry, Kansas. The regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates.

The annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. The curves intersected at approximately 50,000 cfs unregulated, so the hypothetical estimates greater than 50,000 cfs unregulated were combined with the rank ordered annual peak flow data. A second order polynomial was fit to the combined dataset. Points below 2,000 cfs regulated were dropped to produce a better fit at the 50% AEP line. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.10 and the equation is shown on the plot along with recommended unregulated flow bounds.

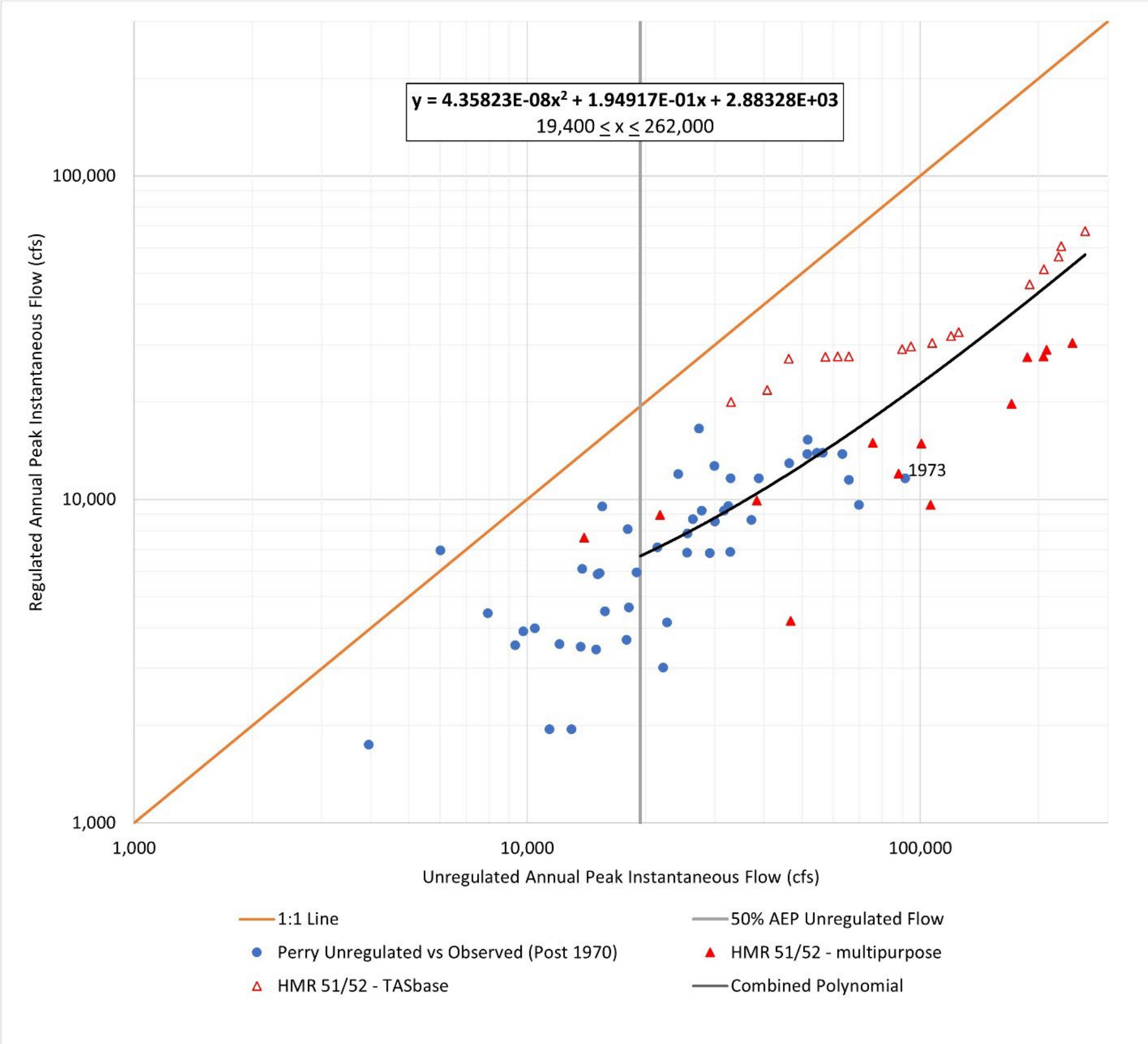

Figure 4.10. Regulated-Unregulated Relationship for the Delaware River at Perry, Kansas

4.1.9 Wakarusa River at Lawrence, KS

Figure 4.11 shows the regulated-unregulated relationship for the Wakarusa River at Lawrence, Kansas. The regulated peak flows, described in Section 2.4, and the unregulated peak flows were plotted on the graph along with the hypothetical flood estimates.

The annual instantaneous peak flow data and the hypothetical data were rank ordered separately and polynomials were fit to both datasets. Hypothetical estimates greater than the largest regulated annual peak flow were combined with the rank ordered annual peak flow data. A second order polynomial was fit to the combined dataset. The three curves are shown in Attachment 5. The final transform curve is labeled as a combined polynomial in Figure 4.11 and the equation is shown on the plot along with recommended unregulated flow bounds. The regulated-unregulated transform could likely be extended by evaluating an HMR 51/52 storm center over the Wakarusa River basin.

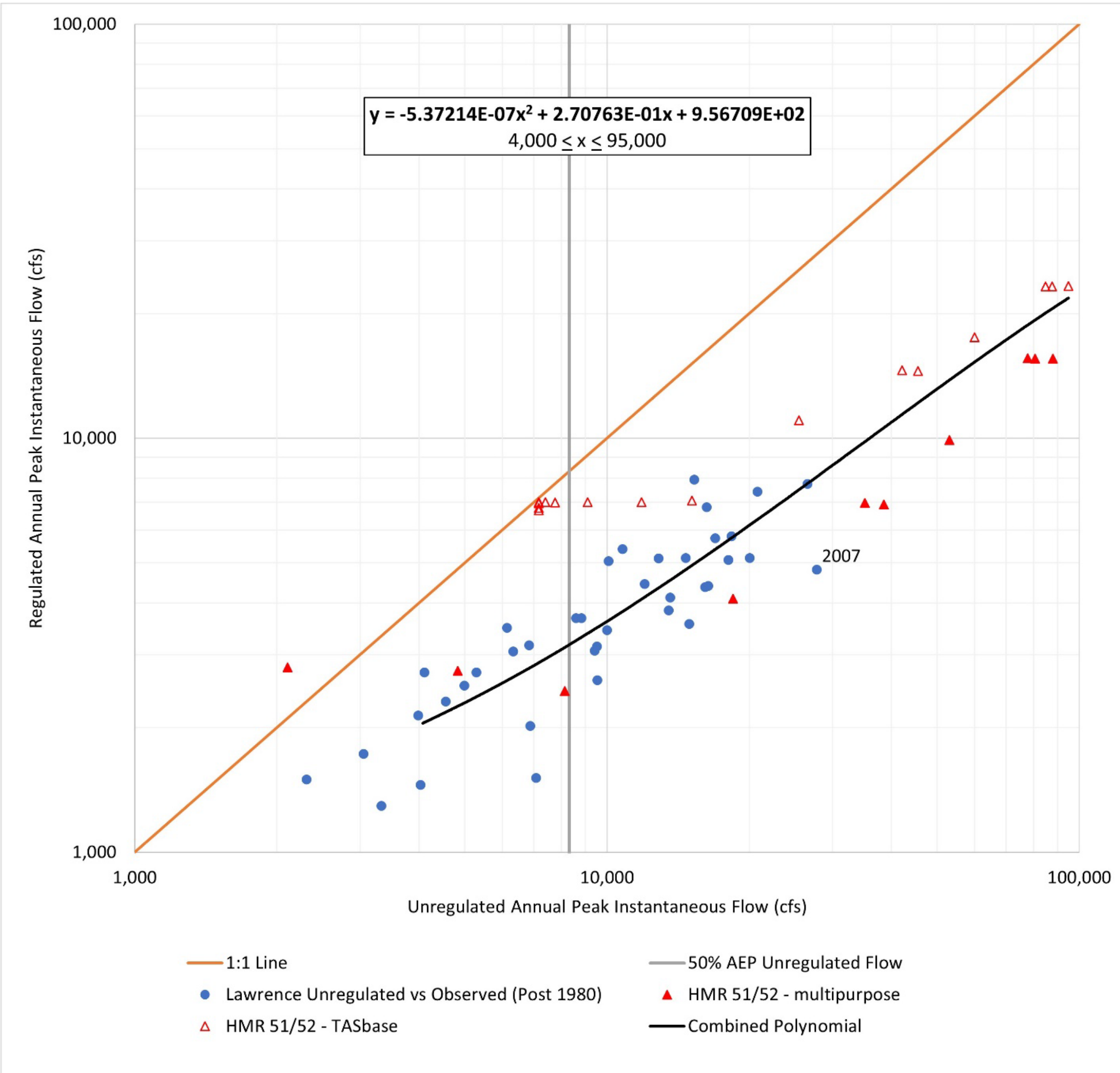

Figure 4.11. Regulated-Unregulated Relationship for the Wakarusa River at Lawrence, Kansas

4.2 Adopted Regulated Frequency Flows

The unregulated expected probability curves computed in HEC-SSP were transformed to regulated frequency flows using the equations discussed in Section 4.1. Results for the current and previous studies are presented in Table 4.2 through Table 4.10. The regulated and unregulated flow frequency curves are presented in Attachment 6. The unregulated

Hirsch-Stedinger plotting positions from HEC-SSP are shown on the plots as well as the computed Weibull regulated plotting positions.

The largest difference in the 1% AEP regulated flow from the Kansas River Hydrology study (USACE, 2002) occurred at Wamego, however the transform curve appears reasonable against the scattered data. Two large floods that diverge from the recommended regulated flow frequency curve are present at Wamego. The adopted regulated flows for Wamego indicate the 1903 observed flow would have an AEP of approximately 0.4% (1/250-yr), while the 1951 flow AEP is approximately 0.2% (1/500-yr).

The 0.2% AEP regulated flows at Topeka and Wamego were larger than the flows at Desoto and Lecompton. This is consistent with the flow estimates produced in the 2002 Kansas River Hydrology Study. The transform curves at Topeka and Wamego have steeper slopes at the upper ends compared to Desoto and Lecompton as shown in Figure 4.12. This suggests that during less frequent events, the existing regulation has a larger impact on flows at Desoto and Lecompton.

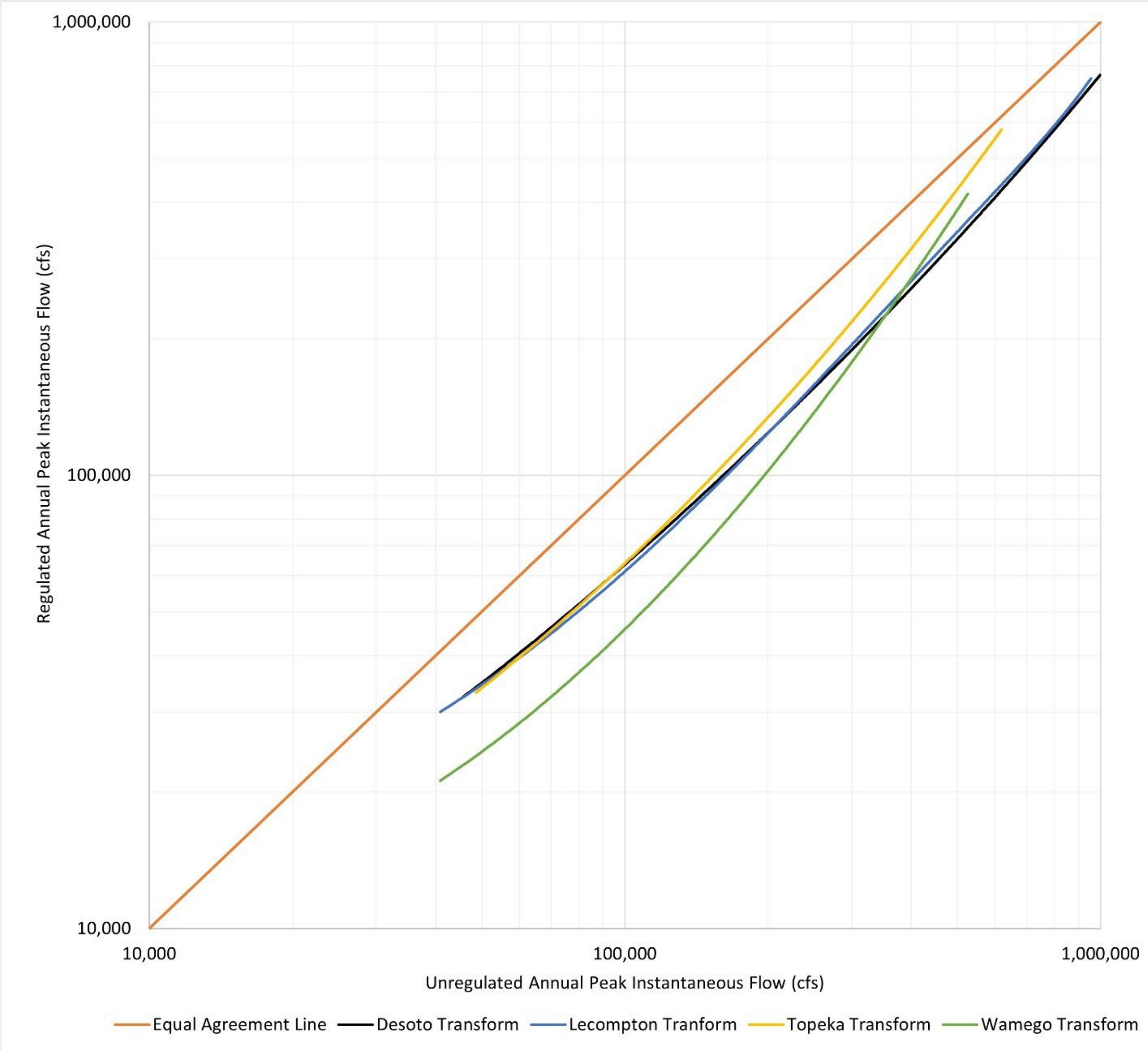

Figure 4.12. Kansas River Transform Curves

The Big Blue River at Manhattan showed a significant change in the 0.2% and 0.5% AEPs compared to the previous study results. According to the Manhattan Feasibility Study Hydrology and Hydraulics Existing Conditions Engineering Appendix, "The data points above the 5% (20-year) annual chance exceedance event are from the 1993 and 1951 spillway discharge flood events and likely are not adequately assigned a probability based on the short period of record. Thus, the graphical analysis of the regulated data was used only for the flow frequency analysis on the Big Blue River for flows up to the 5% (20-year) annual chance exceedance event" (USACE, 2011).

The change in regulated frequency flows for the Delaware River at Perry from the 2010 Jefferson County FIS could be due to several factors such as different methodologies and period of record lengths. For example, the generalized skewness coefficient for the FIS was computed using the USGS 2000 WLS regression model whereas the current study used the more recent USGS 2017 skewness coefficient.

The regulated frequency flows for the Wakarusa River at Lawrence were significantly lower than the 2015 Douglas County FIS. However, the FIS flows were computed further downstream of the gage past a small tributary, which is likely why the flows are larger. Additionally, the flows were computed using the 1993 Kansas regression equations.

Table 4.2. Regulated Frequency Flows for the Kansas River at Desoto, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)		
	Computed Curve	Expected Probability	2022 Watershed Study	2002 KS River Hydrology	2018 Kansas City Levees Update
0.2	508,000	535,000	359,000	344,000	329,000
0.5	409,000	424,000	275,000	282,000	257,000
1	342,000	351,000	224,000	239,000	213,000
2	283,000	288,000	181,000	199,000	175,000
5	214,000	216,000	134,000	152,000	133,000
10	167,000	168,000	104,000	118,000	105,000
20	125,000	125,000	78,500	87,900	80,000
50	72,800	72,800	47,800	49,600	55,500

Table 4.3. Regulated Frequency Flows for the Kansas River at Lecompton, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2002 KS River Hydrology
0.2	496,000	525,000	363,000	343,000
0.5	393,000	408,000	274,000	278,000
1	325,000	334,000	219,000	234,000
2	265,000	270,000	172,000	193,000
5	196,000	198,000	123,000	146,000
10	151,000	152,000	92,500	112,000
20	110,000	111,000	67,600	82,700
50	62,000	62,000	40,600	45,700

Table 4.4. Regulated Frequency Flows for the Kansas River at Topeka, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2002 KS River Hydrology
0.2	443,000	471,000	394,000	352,000
0.5	345,000	360,000	275,000	268,000
1	282,000	290,000	209,000	215,000
2	227,000	231,000	159,000	170,000
5	165,000	166,000	109,000	121,000
10	125,000	125,000	80,400	90,500
20	89,700	90,100	57,700	64,600
50	49,000	49,100	33,400	35,400

Table 4.5. Regulated Frequency Flows for the Kansas River at Wamego, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2002 KS River Hydrology
0.2	461,000	493,000	376,000	345,000
0.5	352,000	368,000	239,000	257,000
1	282,000	291,000	170,000	203,000
2	223,000	228,000	121,000	157,000
5	158,000	160,000	77,200	109,000
10	117,000	118,000	54,400	79,500
20	82,200	82,600	37,800	55,500
50	43,100	43,200	22,000	29,000

Table 4.6. Regulated Frequency Flows for the Kansas River at Fort Riley, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2016 Geary Co. FIS
0.2	314,000	345,000	282,000	201,130
0.5	235,000	250,000	182,000	N/A
1	185,000	194,000	129,000	118,360

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2016 Geary Co. FIS
2	144,000	149,000	91,300	92,290
5	99,700	101,000	57,400	N/A
10	72,600	73,400	40,100	47,370
20	50,100	50,500	27,800	N/A
50	25,600	25,700	16,500	N/A

Table 4.7. Regulated Frequency Flows for the Republican River at Junction City, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2016 Geary Co. FIS
0.2	184,000	223,000	66,100	76,540
0.5	135,000	152,000	43,800	N/A
1	106,000	114,000	32,700	43,800
2	81,300	85,200	24,600	24,320
5	55,700	56,900	16,800	N/A
10	40,300	40,800	12,500	12,470
20	27,700	28,000	9,090	N/A
50	14,300	14,400	5,540	N/A

Table 4.8. Regulated Frequency Flows for the Big Blue River at Manhattan, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2014 Manhattan Feasibility Study
0.2	171,000	183,000	102,000	167,000
0.5	145,000	151,000	77,400	115,800
1	126,000	129,000	62,400	71,600
2	107,000	110,000	50,100	46,200
5	84,400	85,200	36,800	N/A
10	67,700	68,000	28,600	27,000
20	51,400	51,500	21,700	N/A

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2014 Manhattan Feasibility Study
50	29,600	29,500	14,000	N/A

Table 4.9. Regulated Frequency Flows for the Delaware River at Perry, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2010 Jefferson Co. FIS
0.2	145,000	155,000	34,100	40,600
0.5	119,000	124,000	27,700	N/A
1	101,000	104,000	23,600	32,000
2	84,100	85,700	19,900	29,900
5	63,700	64,300	15,600	N/A
10	49,400	49,700	12,700	17,600
20	36,200	36,200	10,000	N/A
50	19,400	19,400	6,680	N/A

Table 4.10. Regulated Frequency Flows for the Wakarusa River at Lawrence, Kansas

Annual Exceedance Probability (%)	Unregulated Flows (cfs)		Regulated Flows (cfs)	
	Computed Curve	Expected Probability	2022 Watershed Study	2015 Douglas Co. FIS
0.2	41,200	47,800	12,700	26,630
0.5	35,300	38,900	10,700	N/A
1	31,000	33,100	9,330	11,910
2	26,900	28,000	8,110	10,180
5	21,500	21,900	6,640	N/A
10	17,600	17,800	5,590	6,540
20	13,700	13,800	4,580	N/A
50	8,330	8,170	3,130	N/A

5 Future without Project

The future without project (FWOP) frequency flows were developed using the same methodology as the existing conditions frequency flows for the mainstem Kansas River gages. FWOP daily flows were developed by Water Management for the period of record with projected sedimentation in the reservoirs for 25, 50, and 100 years into the future. The 100-year scenario was used in the FWOP flow frequency analysis because it was expected to have the largest impact compared to existing conditions. The average percent differences in peak annual daily flows for existing conditions and FWOP 100 year were less than 7% for all the mainstem gages except Wamego which was approximately 11%.

The same adjustment that was used for the existing conditions flows (documented in Section 2.4) was applied to the FWOP flows. The daily data was converted to instantaneous data with the same regression equations used with existing conditions. The hypothetical flood events were re-run in HEC-HMS and HEC-ResSim with the projected storage curves to estimate the supplemental FWOP peak flows. New transform curves were produced for the FWOP 100-year scenario and are presented in Table 5.1 where y is the regulated flow and x is the unregulated flow. The FWOP frequency flows were computed using the transform equations and are shown in Table 5.2. Overall, the FWOP frequency flows were not significantly higher than existing conditions.

Table 5.1. FWOP 100-Year Transform Curves for Mainstem Kansas River Gages

Gage	Transform Curve
Desoto	$y = 2.11643E\text{-}07x^2 + 5.47340E\text{-}01x + 6.90621E{+}03$ $R^2 = 9.97504E\text{-}01$
Lecompton	$y = 7.66827E\text{-}19x^4 - 1.45265E\text{-}12x^3 + 1.08762E\text{-}06x^2 + 3.90376E\text{-}01x +$ $1.25736E{+}04$ $R^2 = 9.96620E\text{-}01$
Topeka	$y = 6.82562E\text{-}07x^2 + 5.04220E\text{-}01x + 6.92451E{+}03$ $R^2 = 9.95976E\text{-}01$
Wamego	$y = 9.35393E\text{-}07x^2 + 2.90669E\text{-}01x + 8.01509E{+}03$ $R^2 = 9.87551E\text{-}01$
Fort Riley	$y = -1.37240E\text{-}12x^3 + 1.83957E\text{-}06x^2 + 3.25977E\text{-}01x + 7.25394E{+}03$ $R^2 = 9.95335E\text{-}01$

Table 5.2. FWOP 100-Year Frequency Flows

Annual Exceedance Probability (%)	Desoto	Lecompton	Topeka	Wamego	Fort Riley
0.2	361,000	365,000	396,000	378,000	283,000
0.5	277,000	276,000	276,000	241,000	183,000
1	225,000	220,000	211,000	172,000	130,000
2	182,000	173,000	160,000	123,000	91,900
5	135,000	123,000	110,000	78,300	57,800
10	105,000	92,200	80,900	55,300	40,600
20	78,900	67,400	57,900	38,400	28,200
50	47,900	40,600	33,300	22,300	16,800

6 With Project Scenarios

Two different hypothetical operational scenarios were modeled by Water Management in HEC-ResSim to estimate how flows might change with different operational rules. The first scenario included the removal of flow targets at the Waverly control point on the Missouri River. The second included releasing 90% of the peak flow after it had peaked at Waverly. The plotting positions of the annual peak flows from these scenarios were compared to the existing conditions regulated plotting positions to visualize how the flow frequency curves might change at the Kansas River gages. The results are shown in Attachment 7. At Desoto, Lecompton, and Topeka, the plotting positions for AEPs less than 0.5 were lower than existing conditions indicating that the flow frequency curves could shift down for the two hypothetical scenarios. At Wamego, the plotting positions were lower than existing conditions for small AEP's and higher for AEPs greater than 0.2. This could cause the upper end of the flow frequency curve to shift down and the lower end to shift up. At Fort Riley, the impacts were smaller but the results indicate the flow frequency curve could potentially shift down.

7 Uncertainty

Uncertainty in the unregulated streamflow data can be attributed to uncertainty in the original streamgage records themselves, as well as uncertainty in the downstream routing of reservoir holdouts. Some marginal improvement in the routing methods may be possible; however, uncertainty in the unregulated flows would remain.

Some level of uncertainty also exists in the simulated streamflow data from HEC-ResSim due to operational decisions; however, efforts were made to reduce it. For example, the simulated regulated flows for the mainstem Kansas River gages were adjusted to better match the observed data. Additionally, observed USGS peak data was used as regulated peak flow for the four tributary gages.

The unregulated to regulated transform method is approximate since there is no true one-to one relationship between regulated and unregulated peak flow. Greater uncertainty in the regulated frequency flows exists where there is minimal data to define the transform relationship. This is especially true for the Junction City gage where there is only one hypothetical data point larger than the expected 0.2% AEP unregulated flow. The uncertainty could be reduced by developing more hypothetical floods that produce larger flows at the gage.

8 Conclusions

Unregulated frequency flows for the five mainstem Kansas River gages (Desoto, Lecompton, Topeka, Wamego, and Fort Riley) and four tributary gages (Junction City, Manhattan, Perry, and Lawrence) were developed using Bulletin 17C analyses. The unregulated datasets included USGS peak flow data, historic peak flows, supplemental peak flows computed with the MOVE3 and ratio method, and unregulated data produced by the Kansas City Water Management section. Peak flows from the Manhattan Feasibility Study and Kansas River Basin Hydrology Study were used to supplement the Fort Riley and Lecompton datasets, respectively. The daily peak flows were converted to instantaneous peak flows using relationships between observed USGS annual maximum daily peak flows and observed USGS annual instantaneous peak flows. The Bulletin 17C analyses were run in HEC-SSP using different datasets (with and without supplemental data) and different regional skew methods to test sensitivity. An average station skew was selected as the regional skew for the Kansas River gages and a regional skew of -0.125 was selected for the tributary gages.

The computed unregulated frequency flows were then transformed to regulated frequency flows using relationships between the regulated and unregulated datasets. Hypothetical flood data were developed to extend the relationships. The relationships were defined to compute frequency flows greater than the 50% AEP unregulated flows. The existing conditions regulated frequency flows are presented in Table 7.1 and Table 7.2.

Table 7.1. Existing Conditions Regulated Frequency Flows for the Mainstem Kansas River Gages

Annual Exceedance Probability (%)	Desoto	Lecompton	Topeka	Wamego	Fort Riley
0.2	359,000	363,000	394,000	376,000	282,000
0.5	275,000	274,000	275,000	239,000	182,000
1	224,000	219,000	209,000	170,000	129,000

Annual Exceedance Probability (%)	Desoto	Lecompton	Topeka	Wamego	Fort Riley
2	181,000	172,000	159,000	121,000	91,300
5	134,000	123,000	109,000	77,200	57,400
10	104,000	92,500	80,400	54,400	40,100
20	78,500	67,600	57,700	37,800	27,800
50	47,800	40,600	33,400	22,000	16,500

Table 7.2. Existing Conditions Regulated Frequency Flows for the Tributary Gages

Annual Exceedance Probability (%)	Lawrence	Perry	Manhattan	Junction City
0.2	12,700	34,100	102,000	66,100
0.5	10,700	27,700	77,400	43,800
1	9,330	23,600	62,400	32,700
2	8,110	19,900	50,100	24,600
5	6,640	15,600	36,800	16,800
10	5,590	12,700	28,600	12,500
20	4,580	10,000	21,700	9,090
50	3,130	6,680	14,000	5,540

9 References

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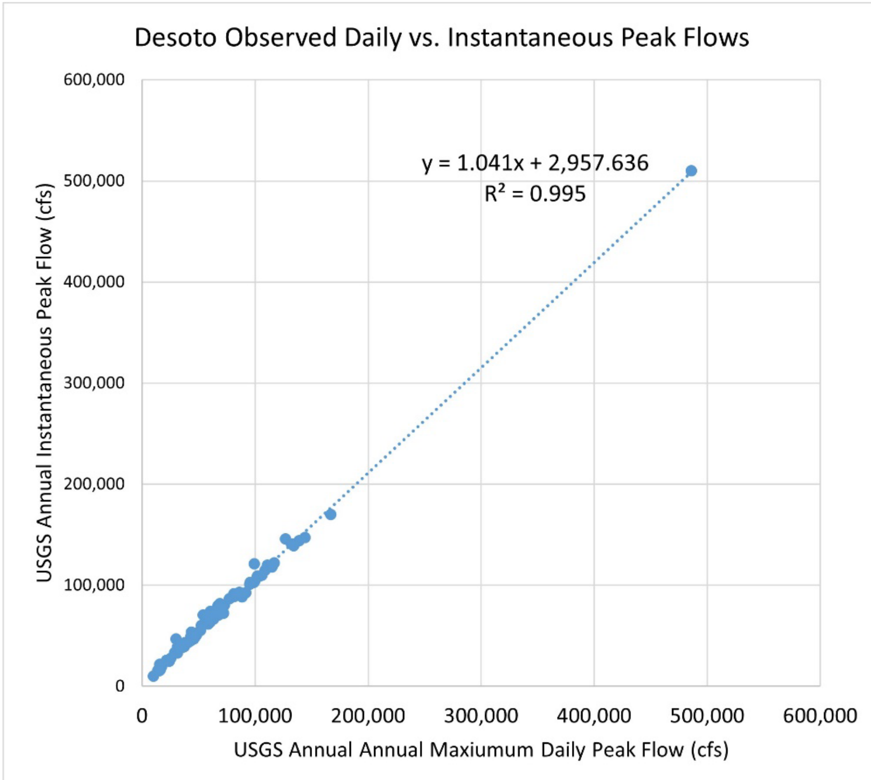
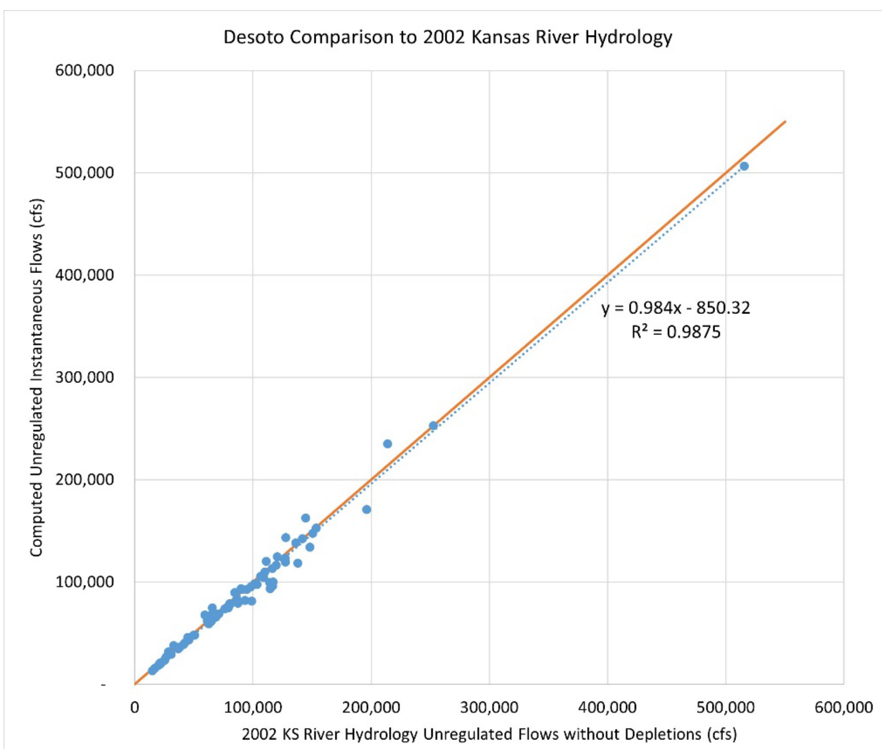
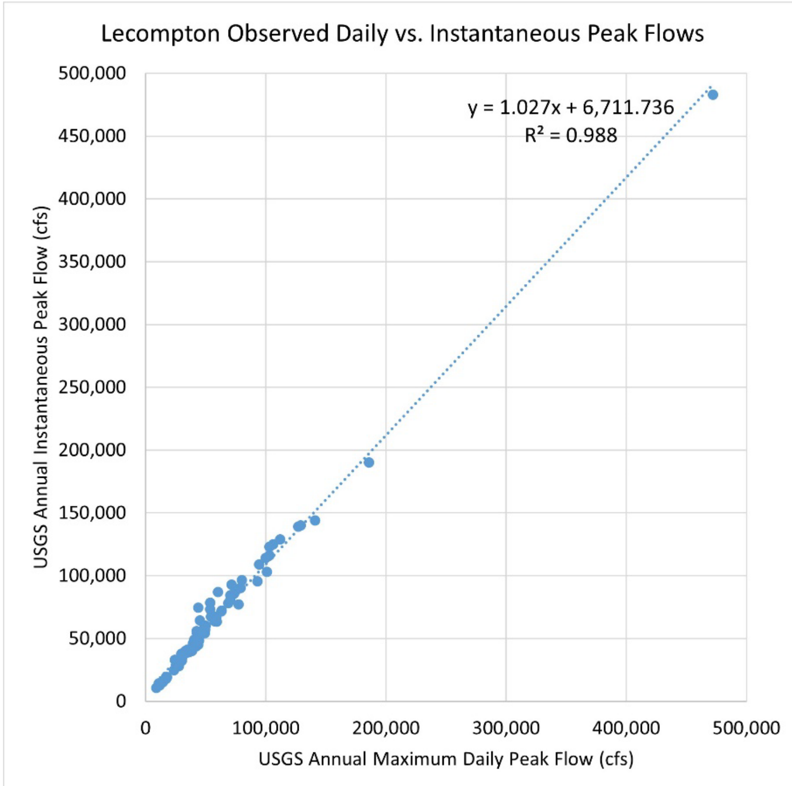
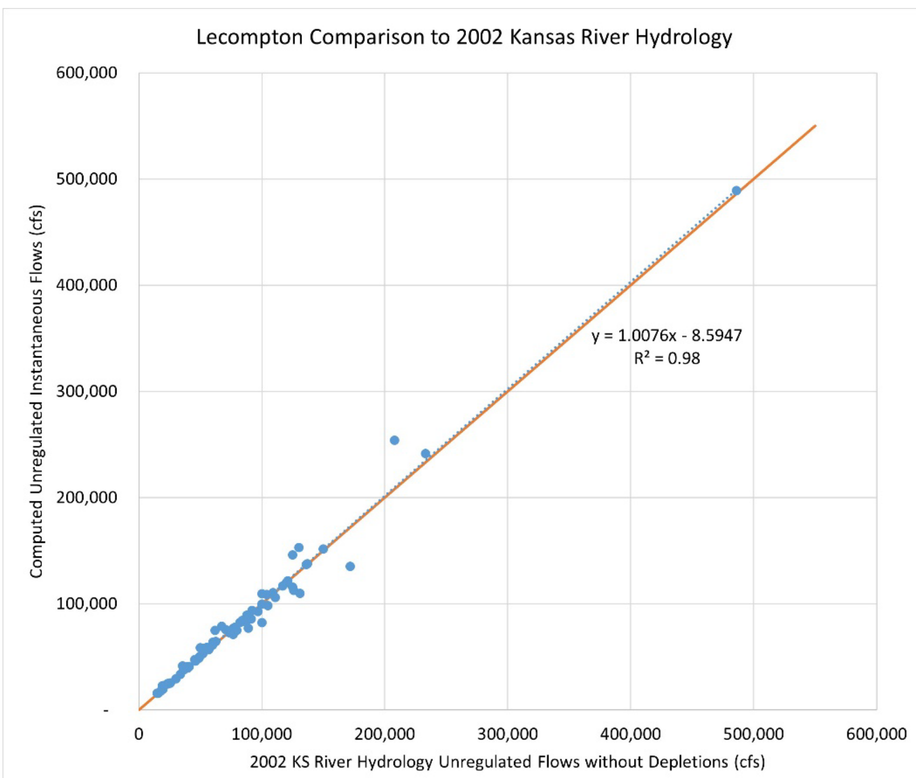
Attachment 1: Unregulated Linear Regression Plots and Comparisons to the Kansas River Hydrology Study (USACE, 2002)



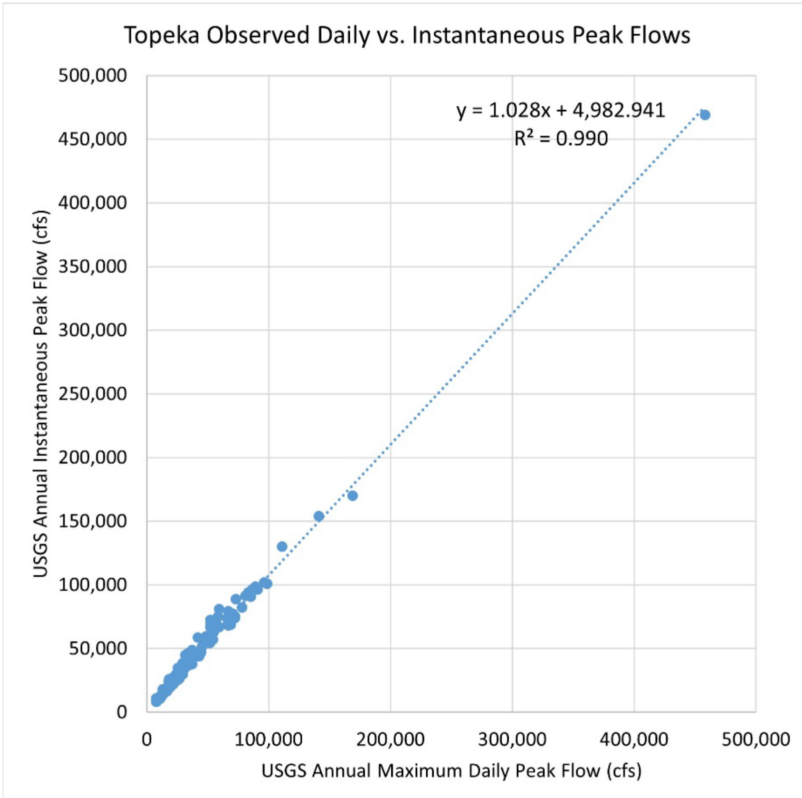




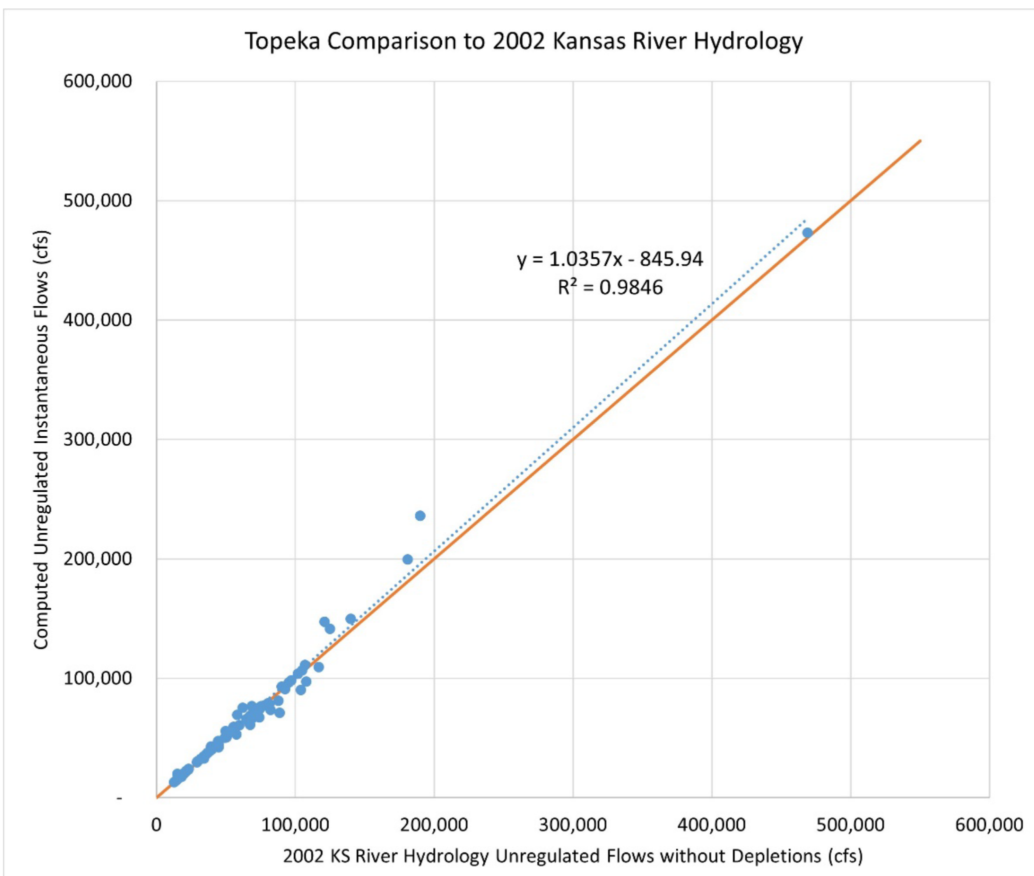
Lecompton Observed Daily vs. Instantaneous Peak Flows
y = 1.027x + 6,711.736
R² = 0.988
USGS Annual Instantaneous Peak Flow (cfs)
USGS Annual Maximum Daily Peak Flow (cfs)
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
400,000
450,000
500,000



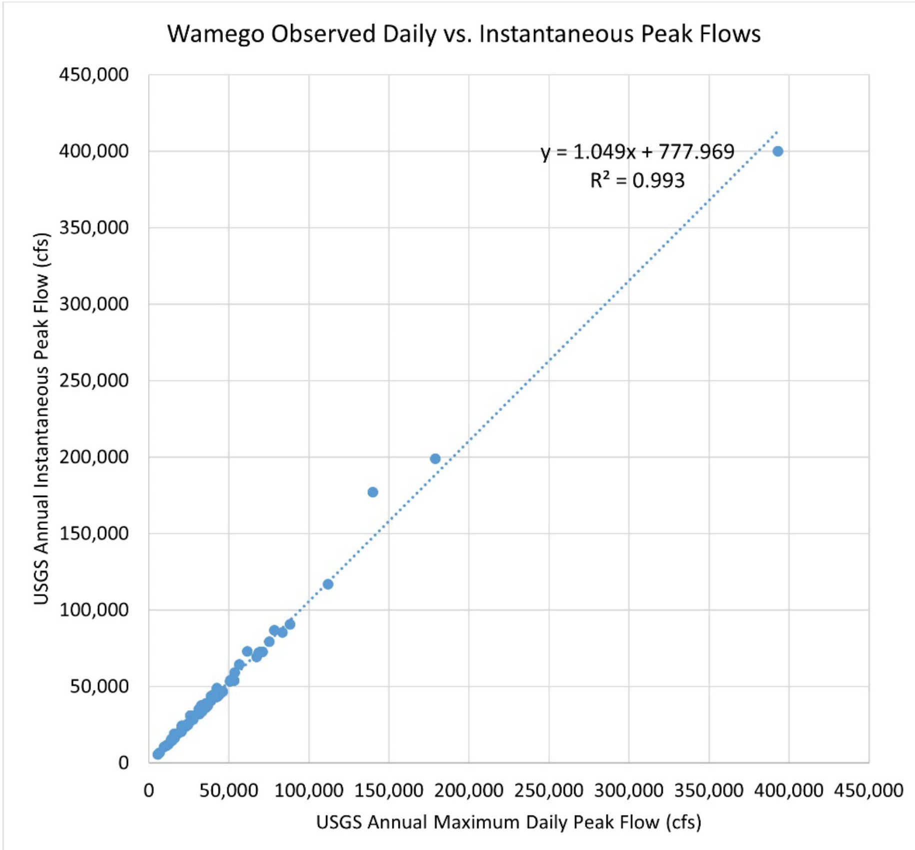
Lecompton Comparison to 2002 Kansas River Hydrology
y = 1.0076x - 8.5947
R² = 0.98
Computed Unregulated Instantaneous Flows (cfs)
2002 KS River Hydrology Unregulated Flows without Depletions (cfs)
-
0
100,000
200,000
300,000
400,000
500,000
600,000



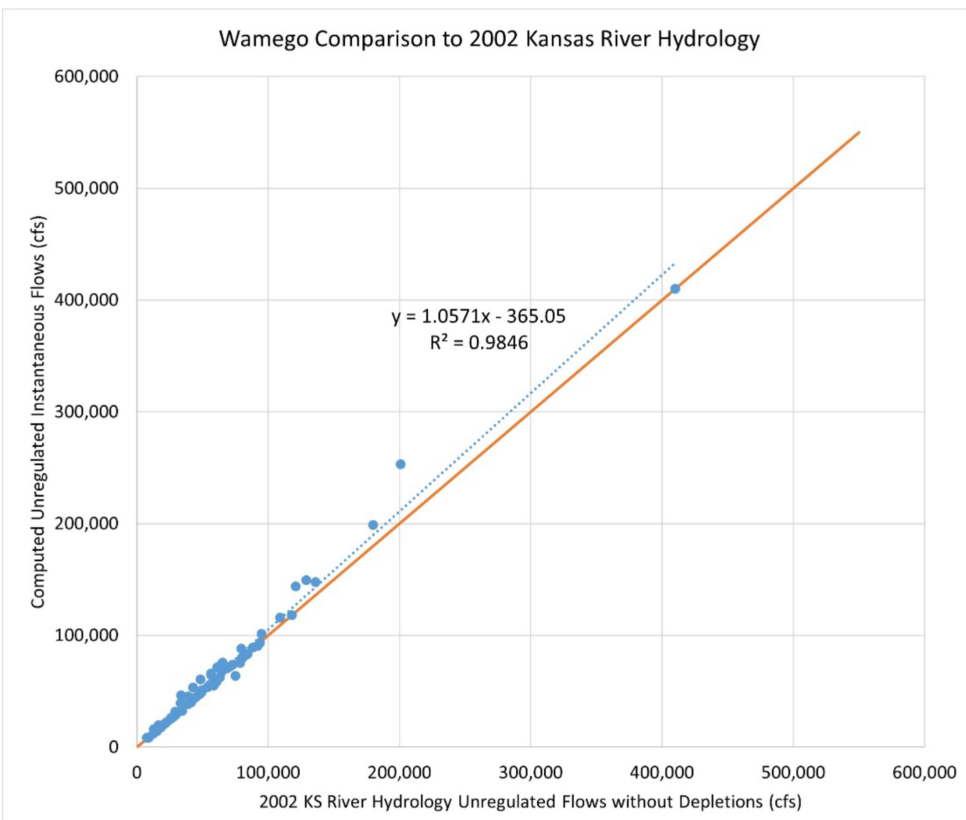
Topeka Observed Daily vs. Instantaneous Peak Flows
y = 1.028x + 4,982.941
R² = 0.990
USGS Annual Instantaneous Peak Flow (cfs)
USGS Annual Maximum Daily Peak Flow (cfs)
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
400,000
450,000
500,000



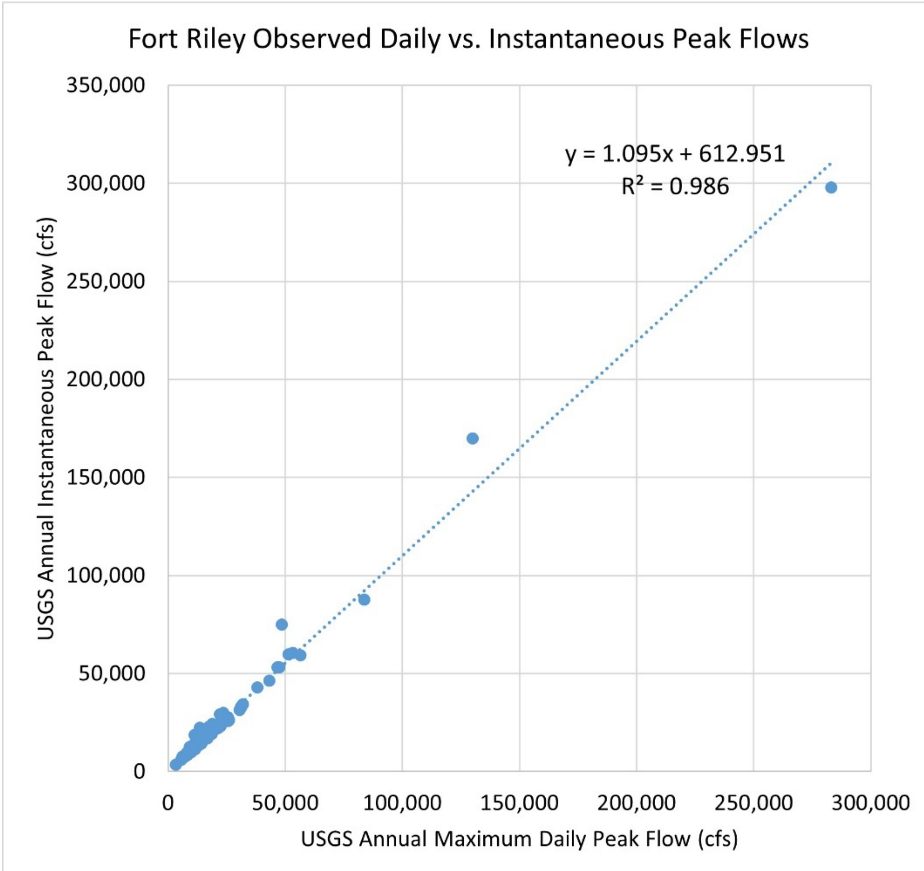
Topeka Comparison to 2002 Kansas River Hydrology
y = 1.0357x - 845.94
R² = 0.9846
Computed Unregulated Instantaneous Flows (cfs)
2002 KS River Hydrology Unregulated Flows without Depletions (cfs)
-
0
100,000
200,000
300,000
400,000
500,000
600,000

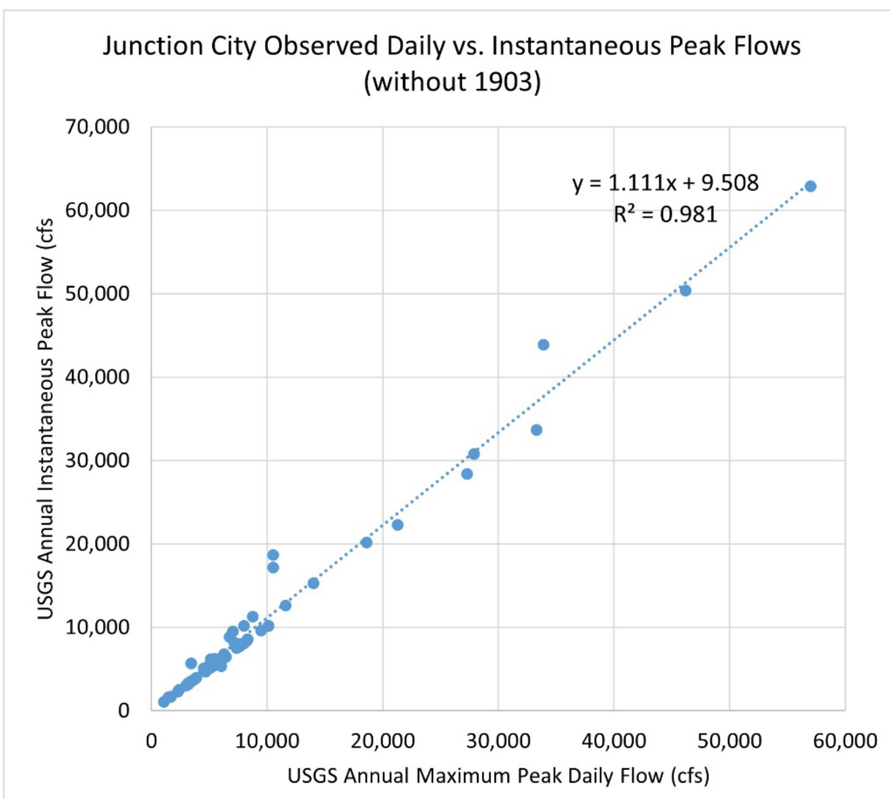


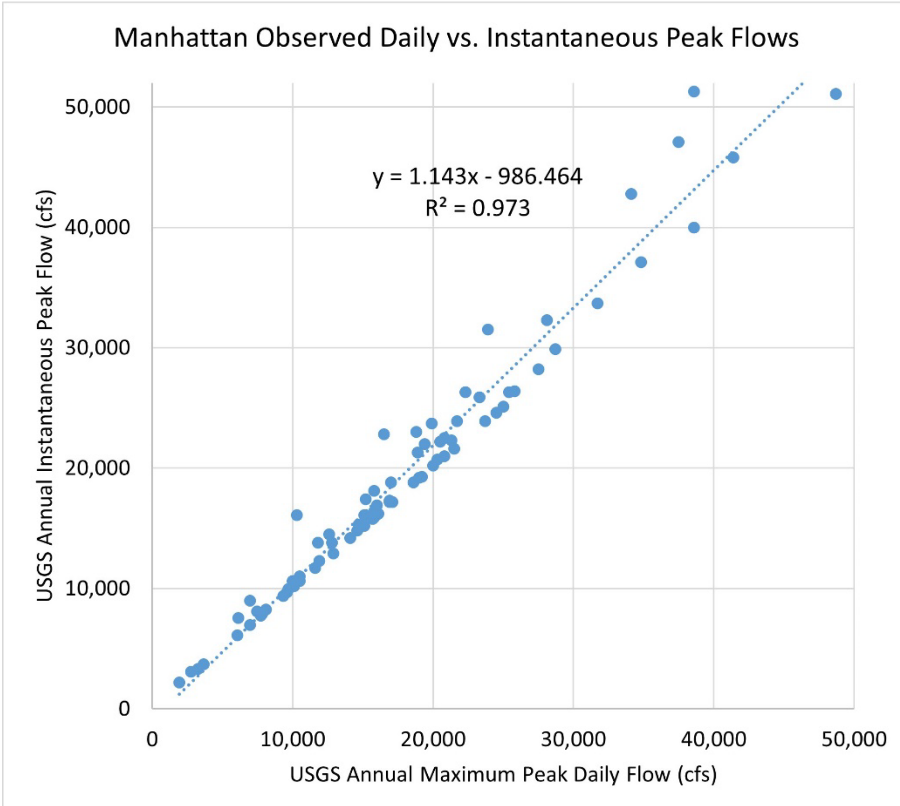
Wamego Observed Daily vs. Instantaneous Peak Flows
y = 1.049x + 777.969
R² = 0.993
USGS Annual Instantaneous Peak Flow (cfs)
USGS Annual Maximum Daily Peak Flow (cfs)
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
400,000
450,000

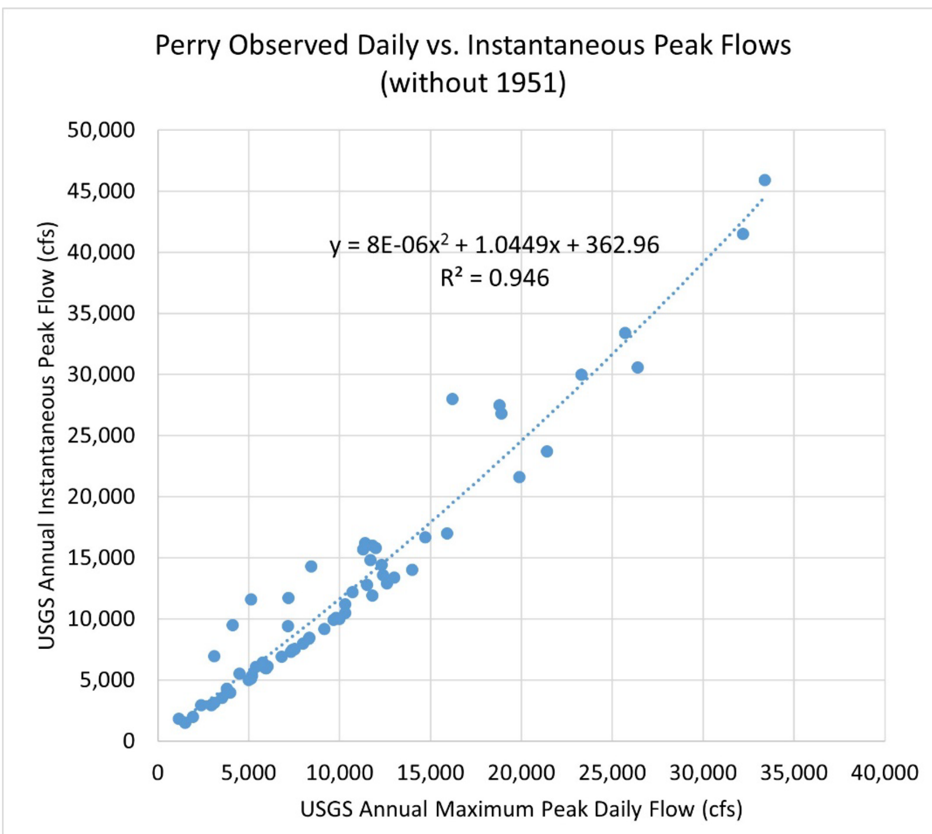


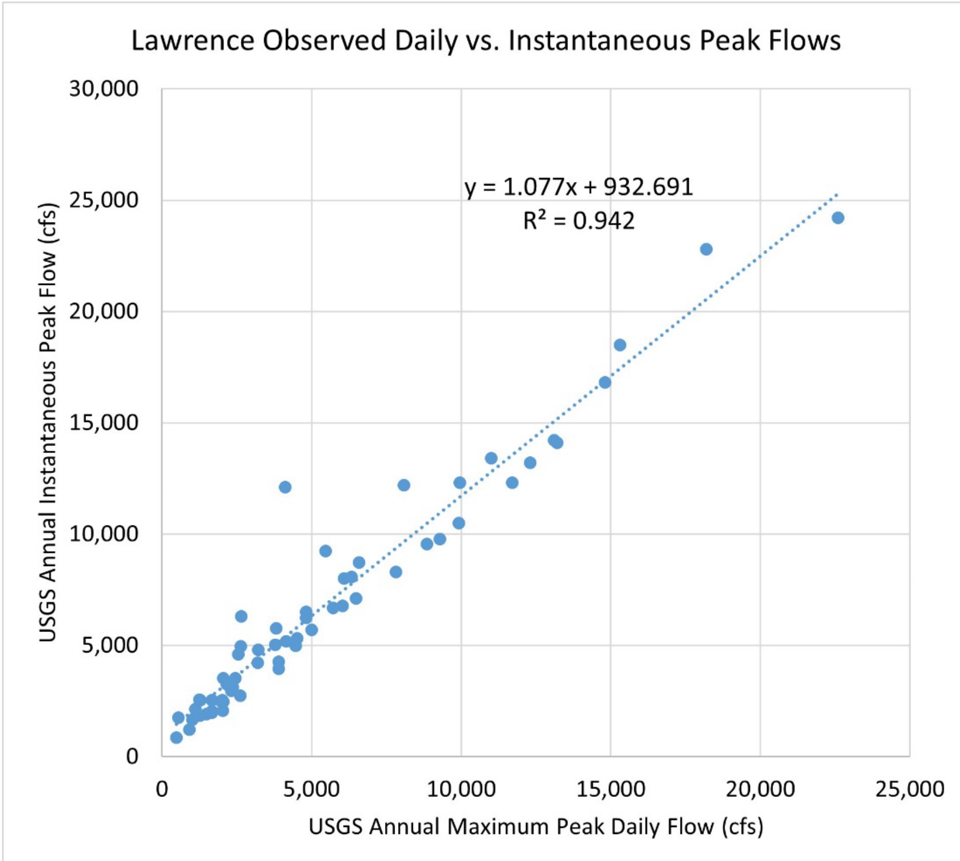
Wamego Comparison to 2002 Kansas River Hydrology
y = 1.0571x - 365.05
R² = 0.9846
Computed Unregulated Instantaneous Flows (cfs)
2002 KS River Hydrology Unregulated Flows without Depletions (cfs)
0
100,000
200,000
300,000
400,000
500,000
600,000


Fort Riley Observed Daily vs. Instantaneous Peak Flows
y = 1.095x + 612.951
R² = 0.986
USGS Annual Instantaneous Peak Flow (cfs)
USGS Annual Maximum Daily Peak Flow (cfs)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0
50,000
100,000
150,000
200,000
250,000
300,000


Junction City Observed Daily vs. Instantaneous Peak Flows (without 1903)
y = 1.111x + 9.508
R² = 0.981
USGS Annual Instantaneous Peak Flow (cfs
USGS Annual Maximum Peak Daily Flow (cfs)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
10,000
20,000
30,000
40,000
50,000
60,000


Manhattan Observed Daily vs. Instantaneous Peak Flows
y = 1.143x - 986.464
R² = 0.973
USGS Annual Instantaneous Peak Flow (cfs)
USGS Annual Maximum Peak Daily Flow (cfs)
0
10,000
20,000
30,000
40,000
50,000


Perry Observed Daily vs. Instantaneous Peak Flows
(without 1951)
y = 8E-06x² + 1.0449x + 362.96
R² = 0.946
USGS Annual Instantaneous Peak Flow (cfs)
USGS Annual Maximum Peak Daily Flow (cfs)
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000


Lawrence Observed Daily vs. Instantaneous Peak Flows
30,000
25,000
20,000
15,000
10,000
5,000
0
USGS Annual Instantaneous Peak Flow (cfs)
y = 1.077x + 932.691
R² = 0.942
0
5,000
10,000
15,000
20,000
25,000
USGS Annual Maximum Peak Daily Flow (cfs)

Attachment 2: Unregulated Datasets

Attachment 3: HEC-SSP Names and Descriptions

Identifier	HEC-SSP Name	Description
D1	Desoto_B17C	1st dataset, station skew only
L1	Lecompton_B17C	1st dataset, station skew only
T1	Topeka_B17C	1st dataset, station skew only
W1	Wamego_B17C	1st dataset, station skew only
F1	FtRiley_B17C	1st dataset, station skew only
D2	Desoto_B17C_2	2nd dataset, station skew only
L2	Lecompton_B17C_2	2nd dataset, station skew only
T2	Topeka_B17C_2	2nd dataset, station skew only
W2	Wamego_B17C_2	2nd dataset, station skew only
F2	FtRiley_B17C_2	2nd dataset, station skew only
F2.s	FtRiley_B17C_2_missing_flows	2nd dataset, station skew only, missing data sensitivity test
D2.a	Desoto_B17C_2_USGS2000_WLS	2nd dataset, Weighted skew used with regional skew computed from USGS equation for generalized skewness coefficient at streamflow gaging stations in Kansas
L2.a	Lecompton_B17C_2_USGS2000_WLS	2nd dataset, Weighted skew used with regional skew computed from USGS equation for generalized skewness coefficient at streamflow gaging stations in Kansas
T2.a	Topeka_B17C_2_USGS2000_WLS	2nd dataset, Weighted skew used with regional skew computed from USGS equation for generalized skewness coefficient at streamflow gaging stations in Kansas
W2.a	Wamego_B17C_2_USGS2000_WLS	2nd dataset, Weighted skew used with regional skew computed from USGS equation for generalized skewness coefficient at streamflow gaging stations in Kansas
F2.a	FtRiley_B17C_2_USGS2000_WLS	2nd dataset, Weighted skew used with regional skew computed from USGS equation for generalized skewness coefficient at streamflow gaging stations in Kansas
D2.b	Desoto_B17C_2_USGS2017_AVG	2nd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
L2.b	Lecompton_B17C_2_USGS2017_AVG	2nd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
T2.b	Topeka_B17C_2_USGS2017_AVG	2nd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication

Identifier	HEC-SSP Name	Description
W2.b	Wamego_B17C_2_USGS2017_AVG	2nd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
F2.b	FtRiley_B17C_2_USGS2017_AVG	2nd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
D3	Desoto_B17C_3	3rd dataset, station skew only
L3	Lecompton_B17C_3	3rd dataset, station skew only
T3	Topeka_B17C_3	3rd dataset, station skew only
W3	Wamego_B17C_3	3rd dataset, station skew only
F3	FtRiley_B17C_3	3rd dataset, station skew only
D3.b	Desoto_B17C_3_USGS2017_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
L3.b	Lecompton_B17C_3_USGS2017_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
T3.b	Topeka_B17C_3_USGS2017_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
W3.b	Wamego_B17C_3_USGS2017_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
F3.b	FtRiley_B17C_3_USGS2017_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
D3.c	Desoto_B17C_3_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP
L3.c	Lecompton_B17C_3_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP
T2.c	Topeka_B17C_3_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP
W3.c	Wamego_B17C_3_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP

Identifier	HEC-SSP Name	Description
F3.c	FtRiley_B17C_3_AVG	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP
D3.c.s	Desoto_B17C_3_AVG_1941-2019	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP, shortened record sensitivity test
L3.c.s	Lecompton_B17C_3_AVG_1941-2019	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP, shortened record sensitivity test
T2.c.s	Topeka_B17C_3_AVG_1941-2019	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP, shortened record sensitivity test
W3.c.s	Wamego_B17C_3_AVG_1941-2019	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP, shortened record sensitivity test
F3.c.s	FtRiley_B17C_3_AVG_1941-2019	3rd dataset, Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in HEC-SSP, shortened record sensitivity test
J	JunctionCity_B17C	Station skew only
M	Manhattan_B17C	Station skew only
La	Lawrence_B17C	Station skew only
P	Perry_B17C	Station skew only
J.b	JunctionCity_B17C_USGS2017_AVG	Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
M.b	Manhattan_B17C_USGS2017_AVG	Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
La.b	Lawrence_B17C_USGS2017_AVG	Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
La.b.s	Lawrence_B17C_USGS2017_AVG_low	Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication, low outlier sensitivity test
P.b	Perry_B17C_USGS2017_AVG	Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication
P.b.s	Perry_B17C_Only_Station_Data	Weighted skew used with regional skew computed from arithmetic mean of station skew coefficients in 2017 USGS publication, station data only sensitivity test

Attachment 4: Hypothetical Flows from HMR51/52 Runs and MRFFS

HMR 51/52 Peak Flow Estimates for Mainstem Kansas River Gages

	Peak Discharge (cfs)														
	Desoto			Lecompton			Topeka			Wamego			Fort Riley		
Scenario	Unreg-HMS	Reg-HMS	Reg-ResSim	Unreg-HMS	Reg-HMS	Reg-ResSim	Unreg-HMS	Reg-HMS	Reg-ResSim	Unreg-HMS	Reg-HMS	Reg-ResSim	Unreg-HMS	Reg-HMS	Reg-ResSim
100% HMR, north of Perry, MP	759,724	537,287	528,129	759,896	541,460	538,887	434,385	431,593	440,784	169,651	101,304	100,428	67,303	60,292	60,115
50% HMR, north of Perry, MP	308,694	212,160	206,694	309,062	217,932	216,198	175,296	174,529	178,778	44,106	32,249	36,061	13,459	12,982	13,056
50% HMR, 13mi west Topeka, MP, Low Losses	407,433	304,490	299,928	380,786	300,762	299,557	251,461	243,923	247,182	121,112	84,774	83,754	71,028	58,625	57,858
75% HMR, north of Perry, MP	545,561	372,299	364,575	534,418	379,715	377,351	307,984	305,166	311,903	98,920	65,205	64,742	36,207	33,727	33,756
100% HMR, west Leavenworth, MP	745,274	529,900	520,404	663,205	493,507	490,490	386,076	385,493	391,976	91,290	83,267	82,837	33,573	33,326	33,370
100% HMR, 13mi west Topeka, MP	781,194	612,070	605,100	773,595	623,901	621,716	501,172	500,505	506,944	131,661	112,952	112,358	64,233	63,129	63,171
100% HMR, 13mi west Topeka, MP low losses	917,579	722,584	713,555	880,538	695,577	692,358	565,462	550,138	556,967	332,007	214,622	209,628	192,603	156,213	152,917
100% HMR, Smoky Hill Basin, MP	395,167	313,466	309,455	418,351	343,677	343,603	310,412	304,338	309,479	242,805	158,282	138,719	155,800	149,301	138,395
75% HMR, Smoky Hill Basin, MP	259,473	209,822	206,995	280,503	232,279	232,327	213,841	207,301	210,727	144,930	100,814	90,682	95,867	95,182	90,130
50% HMR, Smoky Hill Basin, MP	134,972	112,853	111,425	143,877	122,552	122,599	112,539	110,755	112,604	69,409	52,062	48,501	49,141	48,880	47,521
100% HMR, Republican Basin, MP	354,842	149,481	112,292	371,972	150,980	123,690	368,602	146,585	118,225	373,917	146,030	88,444	171,684	121,197	88,210
75% HMR, Republican Basin, MP	215,795	95,204	67,729	227,837	95,840	76,188	226,446	93,107	73,097	230,137	92,448	54,922	108,729	75,519	54,462
50% HMR, Republican Basin, MP	107,026	44,479	29,517	110,345	44,782	35,201	109,650	43,314	35,067	110,740	42,716	26,036	52,985	34,571	25,654
100% HMR, Big Blue Basin, MP	391,502	252,490	245,150	403,782	272,215	268,698	376,643	234,665	238,878	378,949	104,682	62,147	127,290	78,657	61,360
75% HMR, Big Blue Basin, MP	242,871	165,106	160,626	261,778	179,170	177,038	231,139	156,220	159,293	235,420	63,679	35,526	73,025	43,760	34,659
50% HMR, Big Blue Basin, MP	125,893	85,309	82,799	133,946	93,543	92,163	113,576	81,893	83,382	114,725	26,722	26,509	30,423	16,598	13,512
100% HMR, north of Perry, TAS	839,724	591,661	578,160	833,896	581,977	572,530	488,385	462,189	442,996	223,651	142,955	137,959	88,303	73,945	77,091
50% HMR, north of Perry, TAS	388,694	269,162	246,374	383,062	274,347	246,742	229,296	222,035	181,311	98,106	74,198	65,037	34,459	26,776	35,118
50% HMR, 13mi west Topeka, TAS, Low Losses	487,433	361,328	342,256	454,786	354,604	332,500	305,461	285,662	254,005	175,112	125,788	121,099	92,028	71,851	72,765
75% HMR, north of Perry, TAS	625,561	425,501	408,323	608,418	426,721	408,852	361,984	342,942	313,912	152,920	105,386	95,838	57,207	47,524	53,996
100% HMR, west Leavenworth, TAS	825,274	586,624	563,773	737,205	540,688	520,730	440,076	423,253	392,936	145,290	123,583	91,309	54,573	47,202	43,216
100% HMR, 13mi west Topeka, TAS	861,194	668,554	647,066	847,595	667,865	651,996	555,172	532,216	508,104	185,661	154,962	129,572	85,233	76,941	65,915
100% HMR, 13mi west Topeka, TAS low losses	997,579	780,942	776,605	954,538	732,196	734,875	619,462	579,103	570,169	386,007	254,521	281,209	213,603	167,469	176,755
100% HMR, Smoky Hill Basin, TAS	475,167	361,601	352,944	492,351	385,800	376,484	364,412	335,224	314,268	296,805	189,095	204,870	176,800	159,196	151,001
75% HMR, Smoky Hill Basin, TAS	339,473	263,281	241,360	354,503	283,746	264,701	267,841	248,020	215,575	198,930	135,852	136,072	116,867	106,701	97,181
50% HMR, Smoky Hill Basin, TAS	214,972	170,383	128,286	217,877	181,037	138,215	166,539	157,823	113,780	123,409	90,295	69,418	70,141	61,530	48,560
100% HMR, Republican Basin, TAS	434,842	207,489	267,478	445,972	205,025	278,671	422,602	192,010	267,823	427,917	190,920	266,022	192,684	135,909	114,244
75% HMR, Republican Basin, TAS	295,795	130,585	151,857	301,837	134,080	156,663	280,446	118,285	151,652	284,137	115,813	152,052	129,729	83,296	79,166
50% HMR, Republican Basin, TAS	187,026	93,010	93,922	184,345	93,675	92,673	163,650	80,093	78,095	164,740	72,781	78,028	73,985	43,779	41,864
100% HMR, Big Blue Basin, TAS	471,502	302,068	318,391	477,782	315,317	325,006	430,643	269,922	291,460	432,949	163,310	288,710	148,290	86,550	85,681
75% HMR, Big Blue Basin, TAS	322,871	219,569	205,192	335,778	232,773	220,217	285,139	199,521	175,245	289,420	87,408	171,145	94,025	52,734	55,153
50% HMR, Big Blue Basin, TAS	205,893	144,580	119,752	207,946	149,851	127,023	167,576	128,136	91,495	168,725	58,620	84,495	51,423	27,874	35,634

HMR 51/52 Peak Flow Estimates for Tributary Gages

	Peak Discharge (cfs)											
	Junction City			Manhattan			Perry			Lawrence		
Scenario	Unreg-HMS	Reg-HMS	Reg-ResSim	Unreg-HMS	Reg-HMS	Reg-ResSim	Unreg-HMS	Reg-HMS	Reg-ResSim	Unreg-HMS	Reg-HMS	Reg-ResSim
100% HMR, north of Perry, MP	7,379	1,073	12,000	84,298	7,473	24,000	243,513	28,974	30,441	53,021	10,514	9,894
50% HMR, north of Perry, MP	638	206	9,258	24,201	2,249	22,637	100,580	12,084	14,890	18,498	4,386	4,094
50% HMR, 13mi west Topeka, MP, Low Losses	15,644	1,874	5,941	27,542	3,507	7,513	88,115	10,864	12,000	38,524	7,377	6,921
75% HMR, north of Perry, MP	2,624	455	9,036	51,796	4,553	24,000	170,521	14,811	19,725	35,159	7,407	6,974
100% HMR, west Leavenworth, MP	348	25	5,000	23,279	2,319	24,000	205,848	20,814	27,660	77,725	16,353	15,590
100% HMR, 13mi west Topeka, MP	1,371	264	4,269	30,234	3,063	22,666	187,058	17,756	27,525	80,631	16,341	15,560
100% HMR, 13mi west Topeka, MP low losses	42,940	5,892	12,000	84,026	10,315	14,826	209,449	24,901	29,006	87,883	16,588	15,562
100% HMR, Smoky Hill Basin, MP	34,176	4,349	4,049	87,809	8,416	352	75,643	9,936	14,966	8,131	557	2,453
75% HMR, Smoky Hill Basin, MP	16,599	2,165	1,062	51,948	4,977	5,033	46,798	6,001	4,209	4,831	386	2,745
50% HMR, Smoky Hill Basin, MP	4,900	729	4,880	22,187	2,270	14,052	21,780	2,759	8,948	2,106	261	2,795
100% HMR, Republican Basin, MP	136,136	13,256	25	210,933	25,180	100	42,594	5,487	25	175	85	57
75% HMR, Republican Basin, MP	88,215	10,210	25	130,566	16,981	100	27,238	3,321	25	175	85	57
50% HMR, Republican Basin, MP	44,679	4,996	7,470	64,178	7,936	10,716	13,960	1,610	7,609	175	85	57
100% HMR, Big Blue Basin, MP	78,662	9,365	25	268,816	25,887	11,849	106,088	12,483	9,606	759	219	2,058
75% HMR, Big Blue Basin, MP	45,976	5,444	25	174,704	19,403	100	70,800	8,715	25	398	209	57
50% HMR, Big Blue Basin, MP	18,626	2,280	374	91,146	9,416	23,203	38,373	4,466	9,921	175	97	508
100% HMR, north of Perry, TAS	28,379	21,446	22,500	117,298	34,258	46,750	262,513	48,280	67,503	60,021	14,618	17,530
50% HMR, north of Perry, TAS	21,638	21,446	22,500	57,201	34,258	35,006	119,580	19,954	31,969	25,498	7,911	11,057
50% HMR, 13mi west Topeka, TAS, Low Losses	36,644	21,446	22,604	60,542	34,258	35,176	107,115	19,596	30,478	45,524	10,953	14,528
75% HMR, north of Perry, TAS	23,624	21,446	22,500	84,796	34,258	36,289	189,521	33,594	46,211	42,159	10,942	14,575
100% HMR, west Leavenworth, TAS	21,348	21,446	22,500	56,279	34,258	35,074	224,848	40,507	56,336	84,725	21,033	23,268
100% HMR, 13mi west Topeka, TAS	22,371	21,446	22,500	63,234	34,258	35,143	206,058	37,416	51,423	87,631	21,716	23,244
100% HMR, 13mi west Topeka, TAS low losses	63,940	21,446	23,883	117,026	34,258	60,772	228,449	44,285	60,579	94,883	24,665	23,276
100% HMR, Smoky Hill Basin, TAS	55,176	21,446	23,703	120,809	34,258	50,697	94,643	19,596	29,674	15,131	6,979	7,069
75% HMR, Smoky Hill Basin, TAS	37,599	21,446	22,570	84,948	34,258	36,446	65,798	19,596	27,686	11,831	6,979	7,000
50% HMR, Smoky Hill Basin, TAS	25,900	21,446	22,500	55,187	34,258	35,074	40,780	19,596	21,767	9,106	6,979	7,007
100% HMR, Republican Basin, TAS	157,136	39,805	56,564	243,933	83,440	180,873	61,594	19,596	27,634	7,175	6,979	6,957
75% HMR, Republican Basin, TAS	109,215	21,446	25,537	163,566	34,258	97,694	46,238	19,596	27,238	7,175	6,979	6,692
50% HMR, Republican Basin, TAS	65,679	21,446	23,877	97,178	34,258	38,861	32,960	19,596	20,000	7,175	6,979	7,000
100% HMR, Big Blue Basin, TAS	99,662	21,446	25,213	301,816	100,061	213,956	125,088	22,090	32,875	7,759	6,979	6,997
75% HMR, Big Blue Basin, TAS	66,976	21,446	23,884	207,704	34,298	120,266	89,800	19,596	29,107	7,398	6,979	7,000
50% HMR, Big Blue Basin, TAS	39,626	21,446	23,025	124,146	34,258	50,180	57,373	19,596	27,579	7,175	6,979	6,786

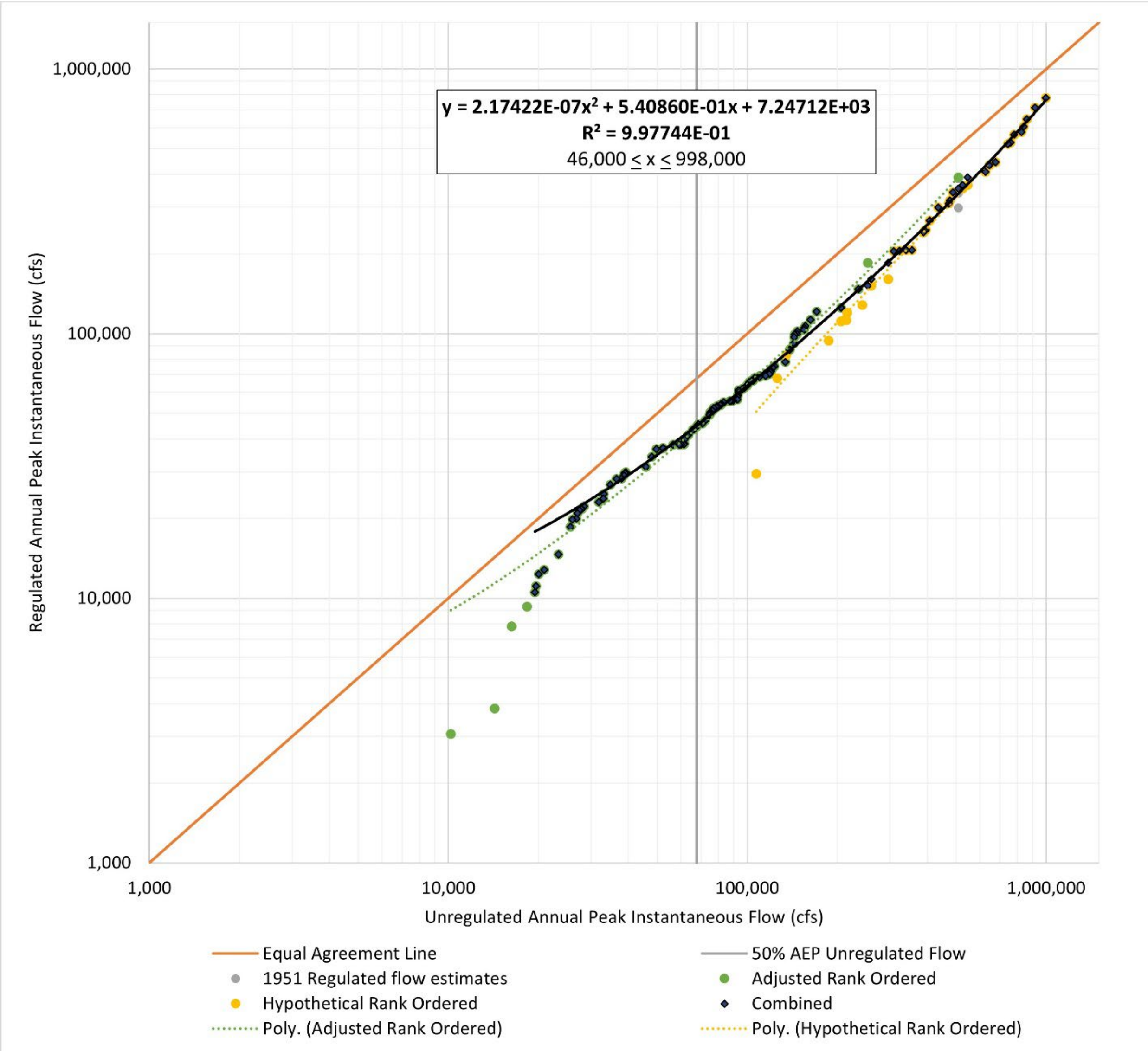
MRFFS Peak Flow Estimates for Wamego and Fort Riley

SD_Scale	Year	Unregulated Peak Daily Flow (cfs)		Regulated Peak Daily Flow (cfs)	
		Wamego	Fort Riley	Wamego	Fort Riley
0.5	1943	114,997	56,579	52,483	23,014
0.5	1944	98,791	44,719	46,275	34,684
0.5	1947	101,733	70,317	46,732	22,800
0.5	1951	503,709	365,332	446,646	314,577
0.5	1952	50,494	23,262	36,090	14,651
0.5	1960	158,037	57,396	49,335	27,116
0.5	1967	86,891	47,082	46,472	32,488
0.5	1973	237,668	126,821	97,940	72,249
0.5	1986	79,853	26,743	35,078	13,554
0.5	1987	169,490	74,481	61,743	38,568
0.5	1993	304,533	193,418	223,219	127,003
0.5	1995	130,125	80,013	60,662	38,848
0.5	2007	130,650	50,654	40,264	34,740
0.5	2008	49,561	23,034	30,262	17,265
0.5	2010	76,755	32,523	36,236	14,411
0.5	2011	89,682	57,347	30,828	21,987
0.5	2013	49,493	43,872	36,292	30,086
0.5	2015	122,998	33,856	40,605	24,017
0.5	2017	79,717	43,020	36,614	19,860
0.5	2019	127,592	73,403	114,898	52,633
1.0	1943	151,073	74,329	55,018	27,817
1.0	1944	129,783	58,748	60,598	45,377
1.0	1947	133,648	92,376	65,282	33,754
1.0	1951	661,729	479,941	587,761	423,559
1.0	1952	66,334	30,560	36,887	18,875
1.0	1960	207,614	75,402	51,729	35,525
1.0	1967	114,150	61,852	56,525	42,664
1.0	1973	312,227	166,607	267,536	108,542
1.0	1986	104,904	35,132	44,394	14,436
1.0	1987	222,661	97,846	112,981	55,207
1.0	1993	400,068	254,095	340,755	215,745
1.0	1995	170,947	105,114	85,671	50,482
1.0	2007	171,637	66,545	52,853	45,622
1.0	2008	65,108	30,260	36,022	17,678
1.0	2010	100,834	42,726	68,050	36,657
1.0	2011	117,816	75,337	39,590	29,874
1.0	2013	65,020	57,635	38,149	37,223
1.0	2015	161,583	44,477	54,260	31,547

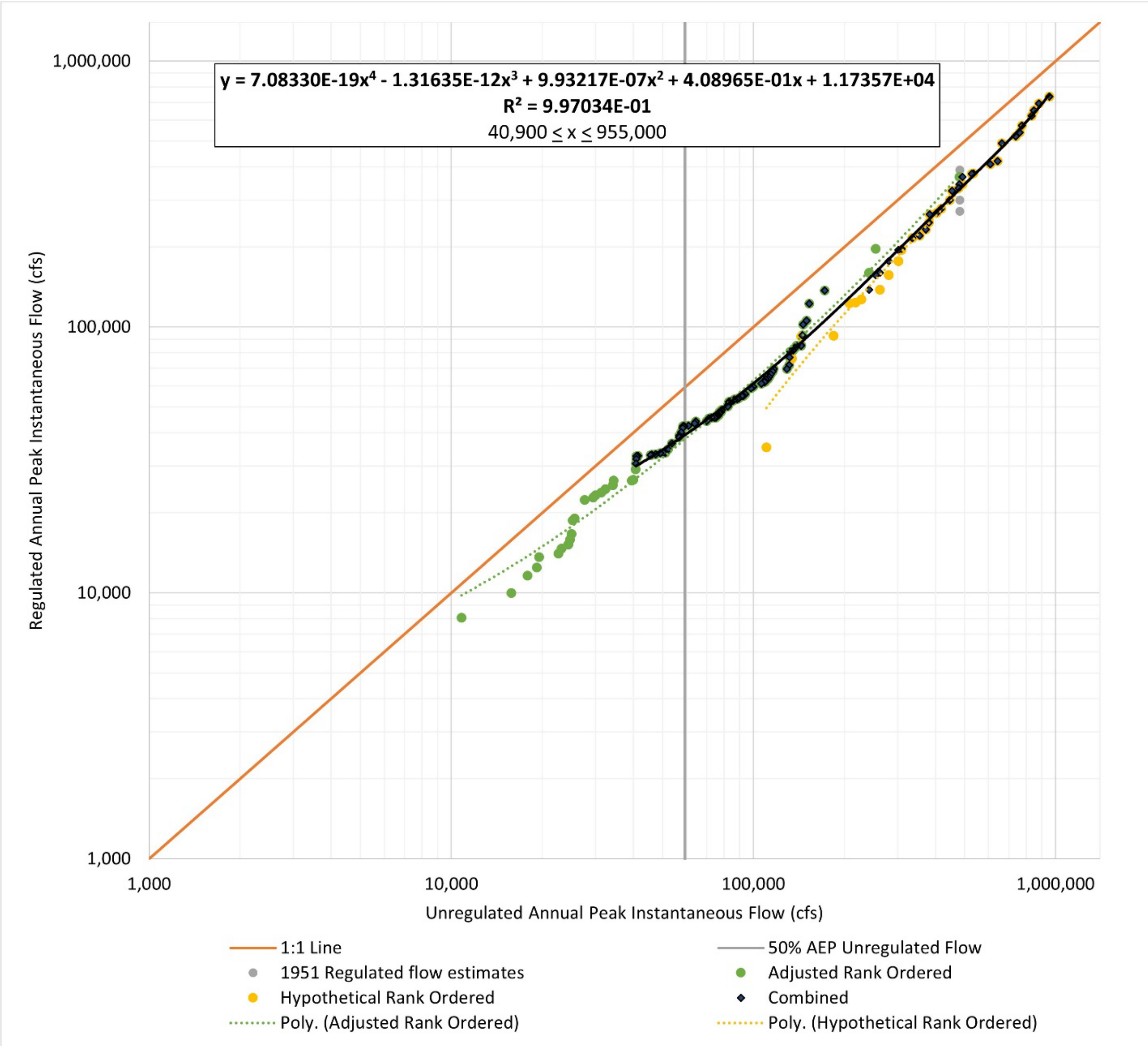
SD_Scale	Year	Unregulated Peak Daily Flow (cfs)		Regulated Peak Daily Flow (cfs)	
		Wamego	Fort Riley	Wamego	Fort Riley
1.0	2017	104,725	56,516	36,058	23,735
1.0	2019	167,619	96,430	168,165	75,632
1.5	1943	198,466	97,646	68,209	37,462
1.5	1944	170,497	77,178	79,700	59,631
1.5	1947	175,575	121,355	133,053	65,332
1.5	1951	869,320	630,504	789,485	578,023
1.5	1952	87,144	40,147	56,417	26,012
1.5	1960	272,745	99,056	59,018	46,590
1.5	1967	149,960	81,256	75,030	56,054
1.5	1973	410,176	218,873	381,434	172,002
1.5	1986	137,813	46,153	123,817	33,907
1.5	1987	292,512	128,542	151,513	75,269
1.5	1993	525,574	333,808	459,261	295,736
1.5	1995	224,575	138,090	147,586	76,619
1.5	2007	225,481	87,421	72,252	59,835
1.5	2008	85,534	39,753	50,400	18,974
1.5	2010	132,466	56,130	116,129	40,644
1.5	2011	154,776	98,971	50,495	50,332
1.5	2013	85,418	75,715	49,468	48,892
1.5	2015	212,274	58,430	118,809	41,481
1.5	2017	137,579	74,246	55,439	30,250
1.5	2019	220,203	126,681	221,968	92,180
2.0	1943	260,727	128,279	186,028	74,381
2.0	1944	223,984	101,390	104,667	78,343
2.0	1947	230,655	159,426	189,723	111,038
2.0	1951	1,142,036	828,301	1,041,422	767,470
2.0	1952	114,482	52,741	57,862	34,782
2.0	1960	358,309	130,131	138,625	61,133
2.0	1967	197,004	106,747	98,130	74,031
2.0	1973	538,853	287,536	514,725	244,287
2.0	1986	181,047	60,632	157,306	42,099
2.0	1987	384,277	168,867	202,472	109,101
2.0	1993	690,453	438,527	590,007	388,854
2.0	1995	295,027	181,410	205,249	106,843
2.0	2007	296,217	114,845	166,128	78,581
2.0	2008	112,367	52,224	75,062	28,634
2.0	2010	174,023	73,739	147,452	47,152
2.0	2011	203,331	130,019	75,456	85,610
2.0	2013	112,214	99,468	64,963	64,231

SD_Scale	Year	Unregulated Peak Daily Flow (cfs)		Regulated Peak Daily Flow (cfs)	
		Wamego	Fort Riley	Wamego	Fort Riley
2.0	2015	278,867	76,760	236,814	54,446
2.0	2017	180,739	97,538	53,639	58,994
2.0	2019	289,283	166,422	289,547	124,250

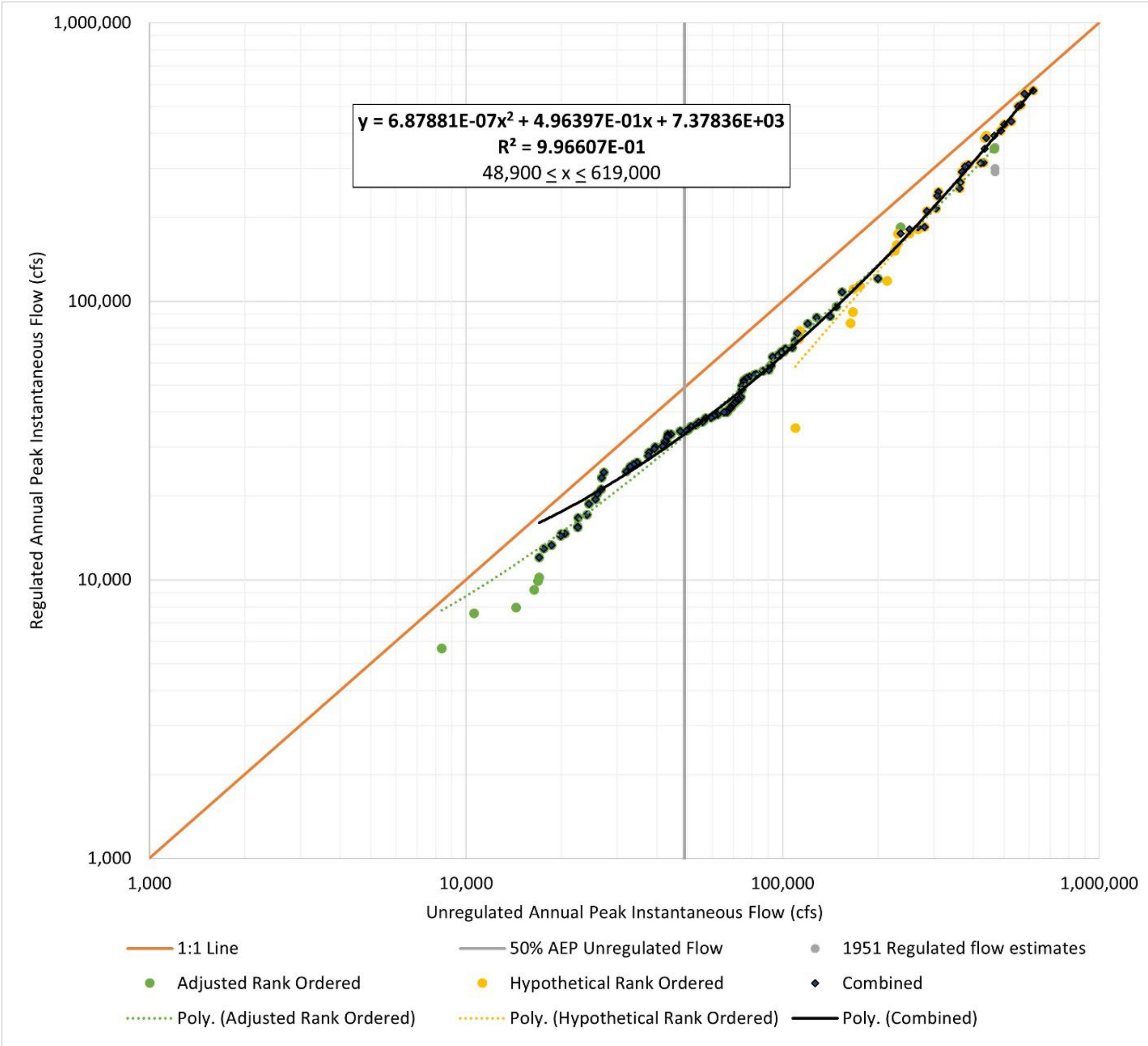
Attachment 5: Transform Curve Development Plots



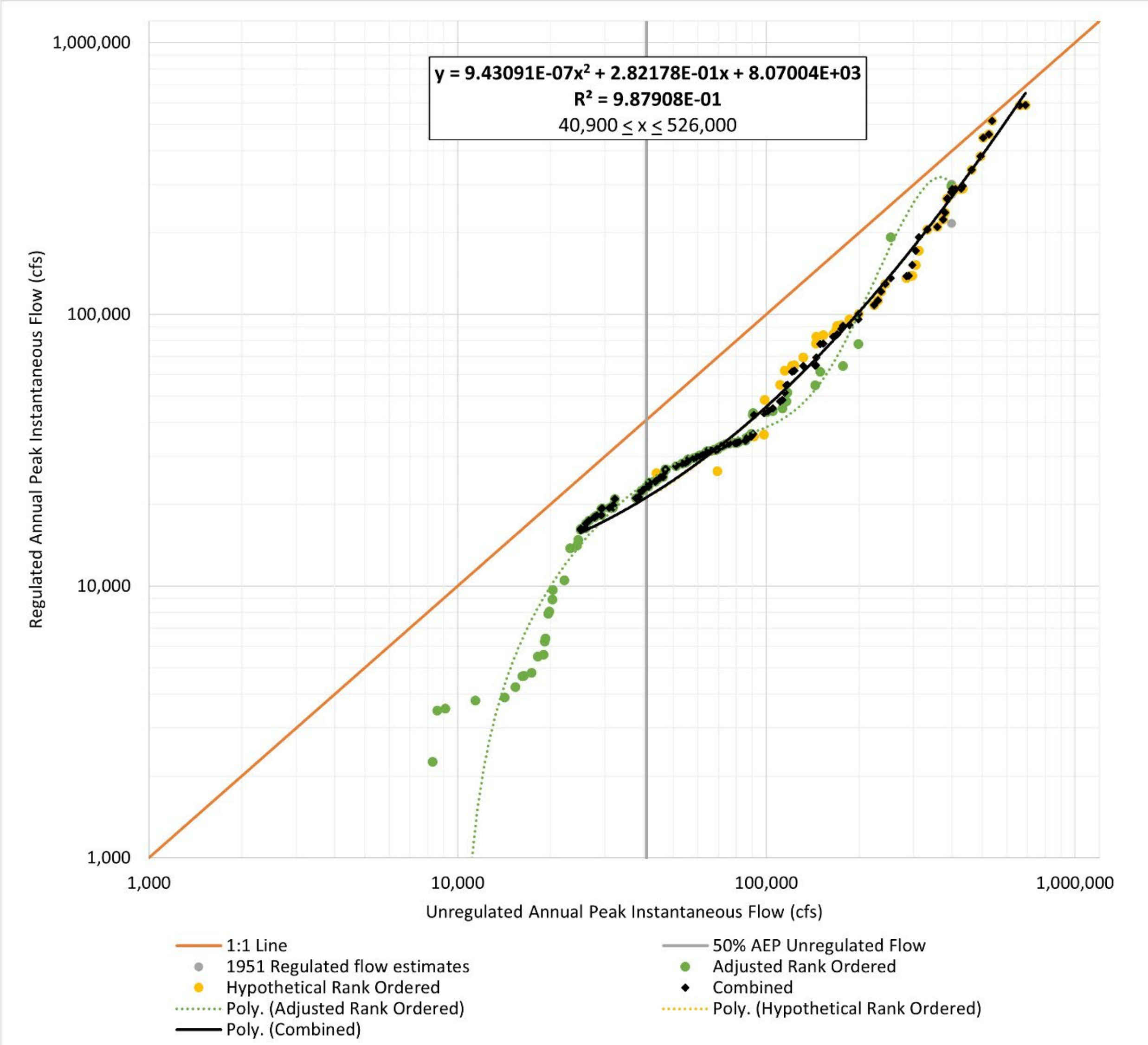
Desoto Transform Curve Development



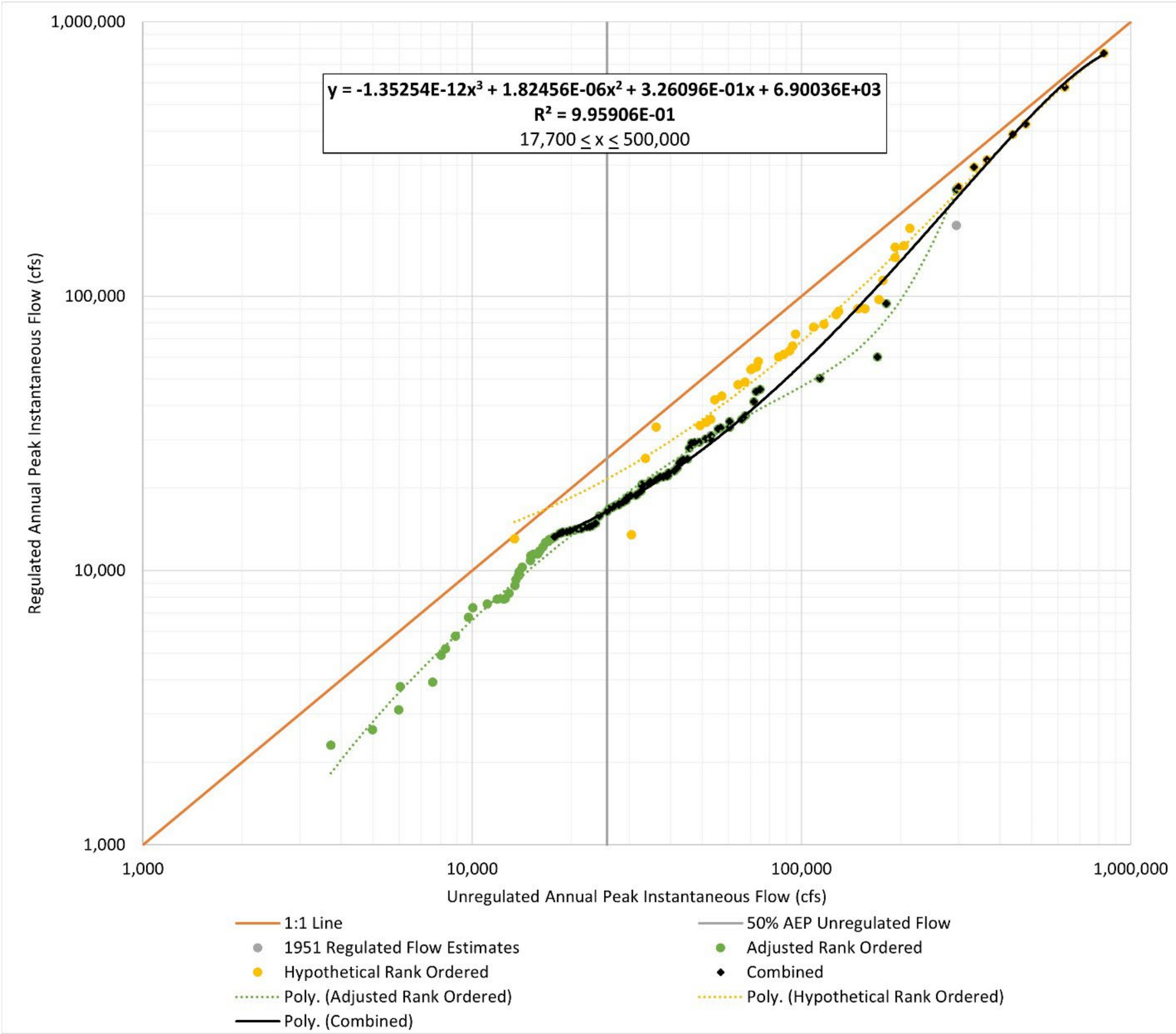
Lecompton Transform Curve Development



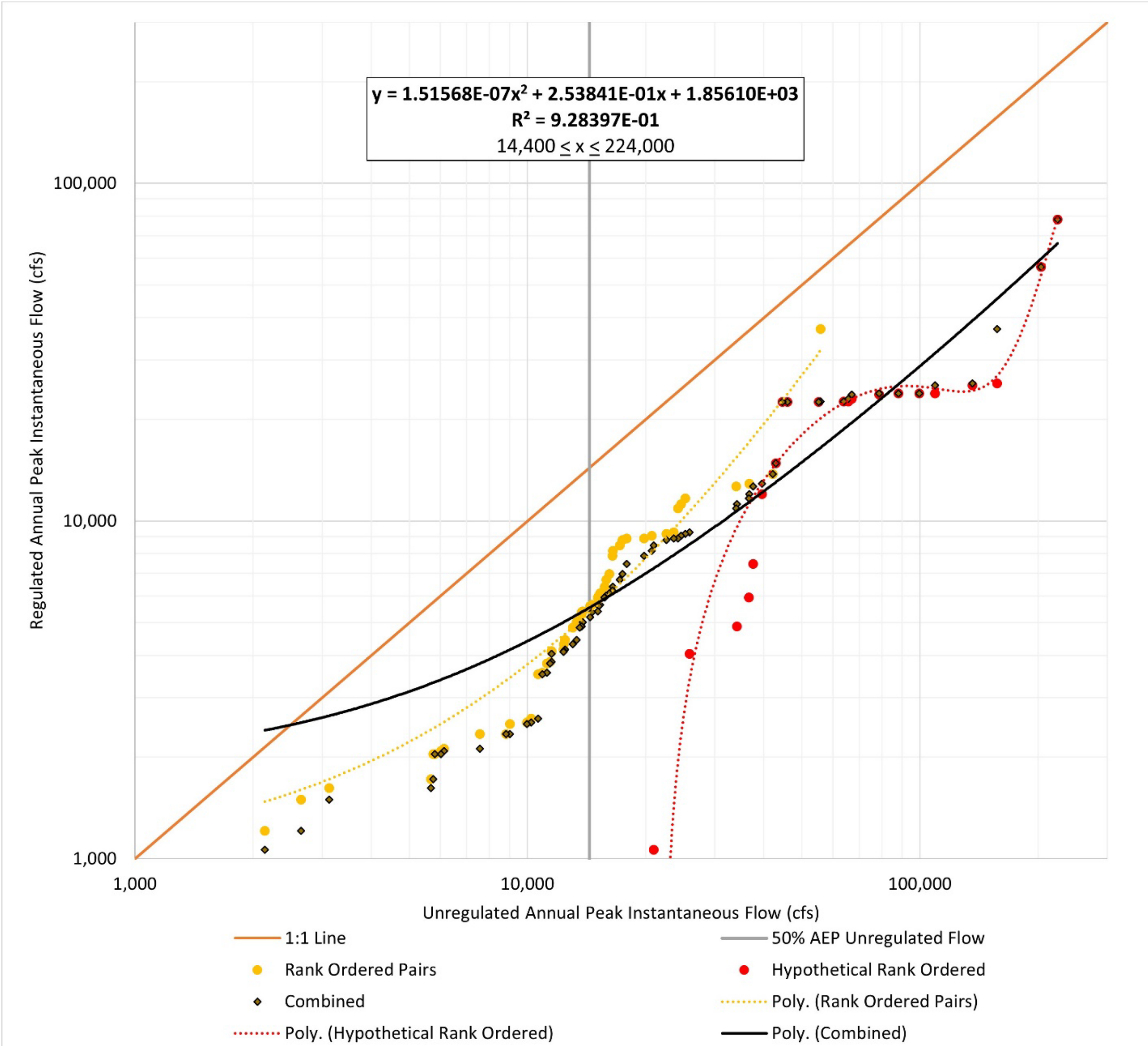
Topeka Transform Curve Development



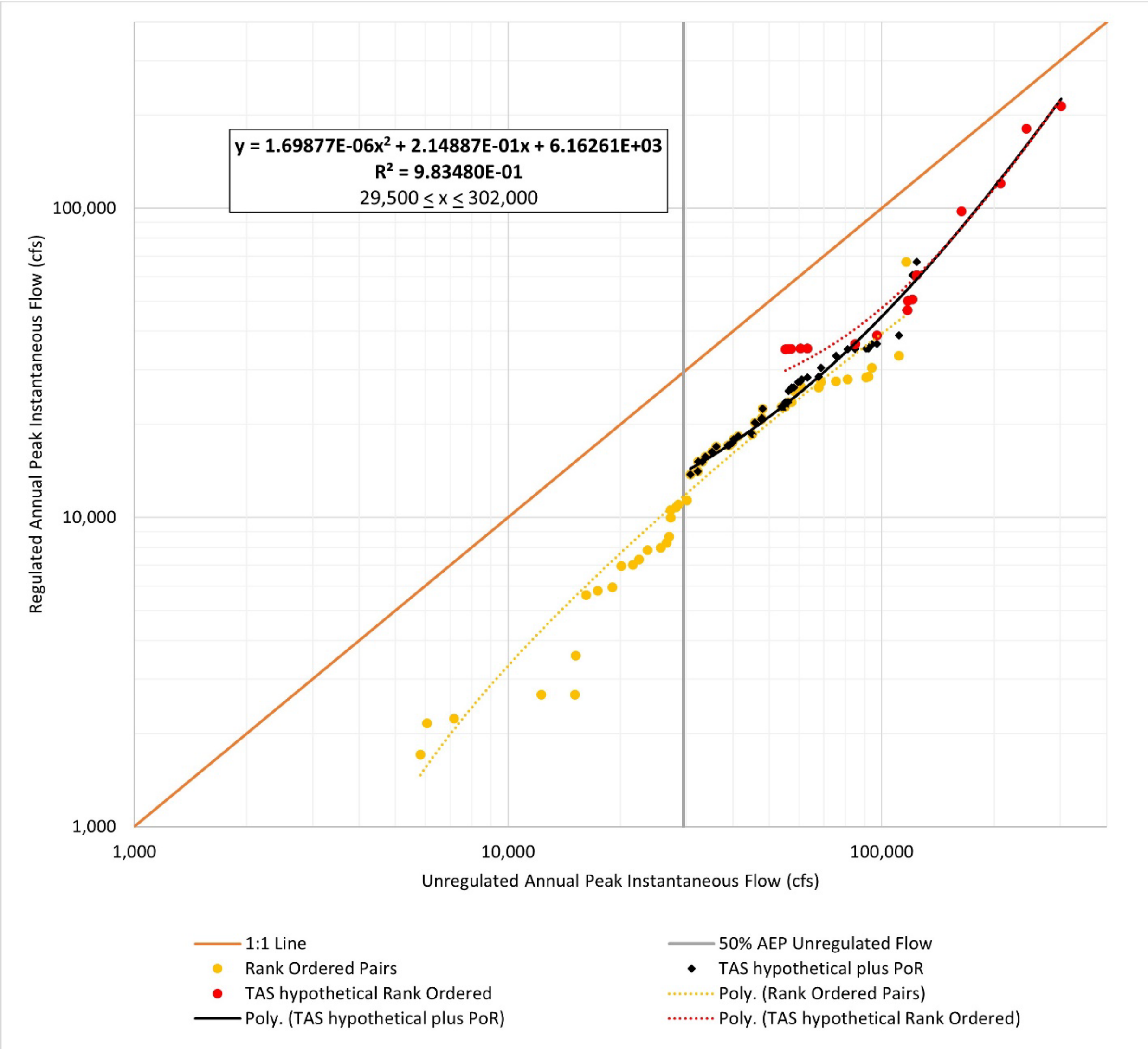
Wamego Transform Curve Development



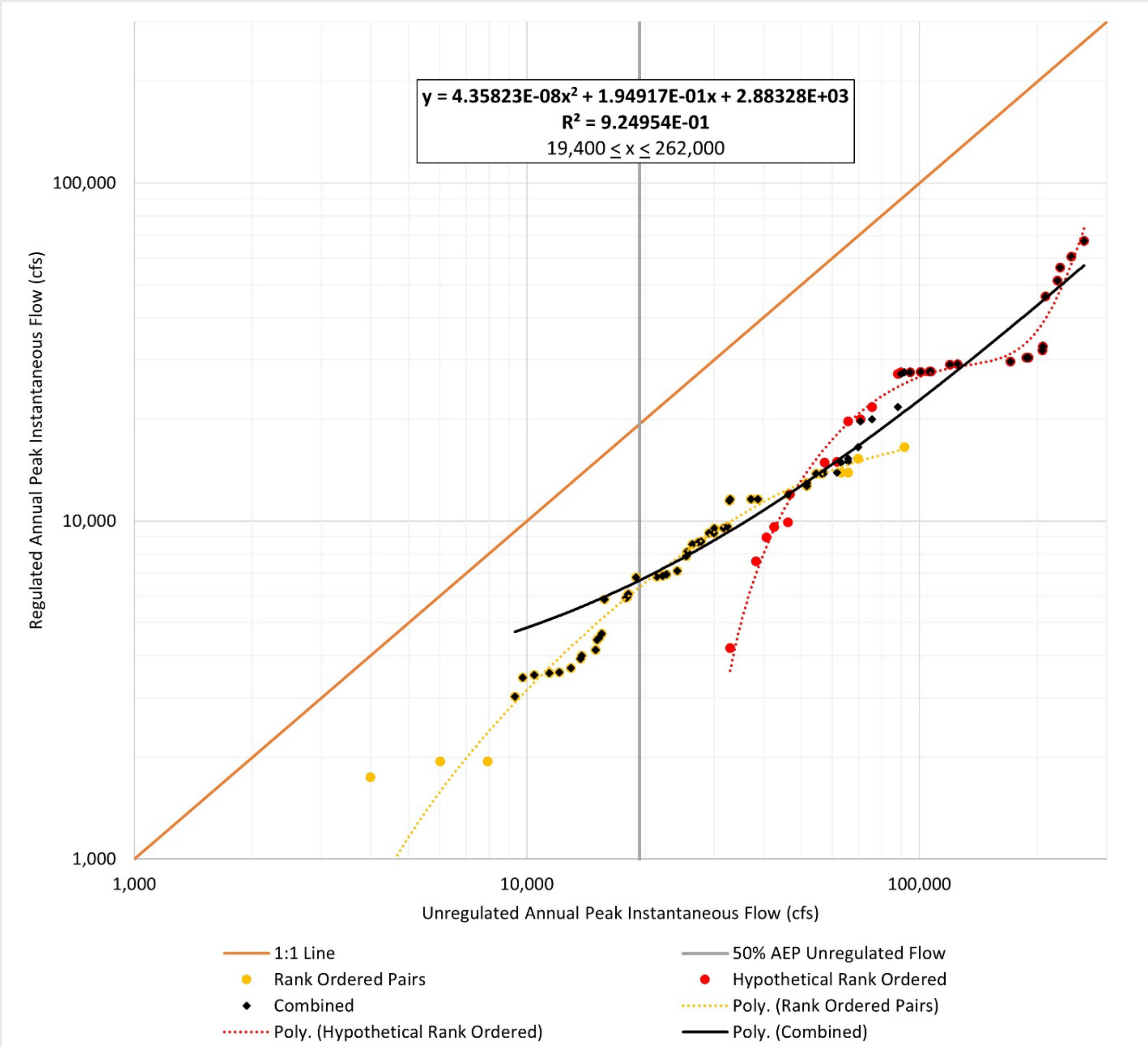
Fort Riley Transform Curve Development



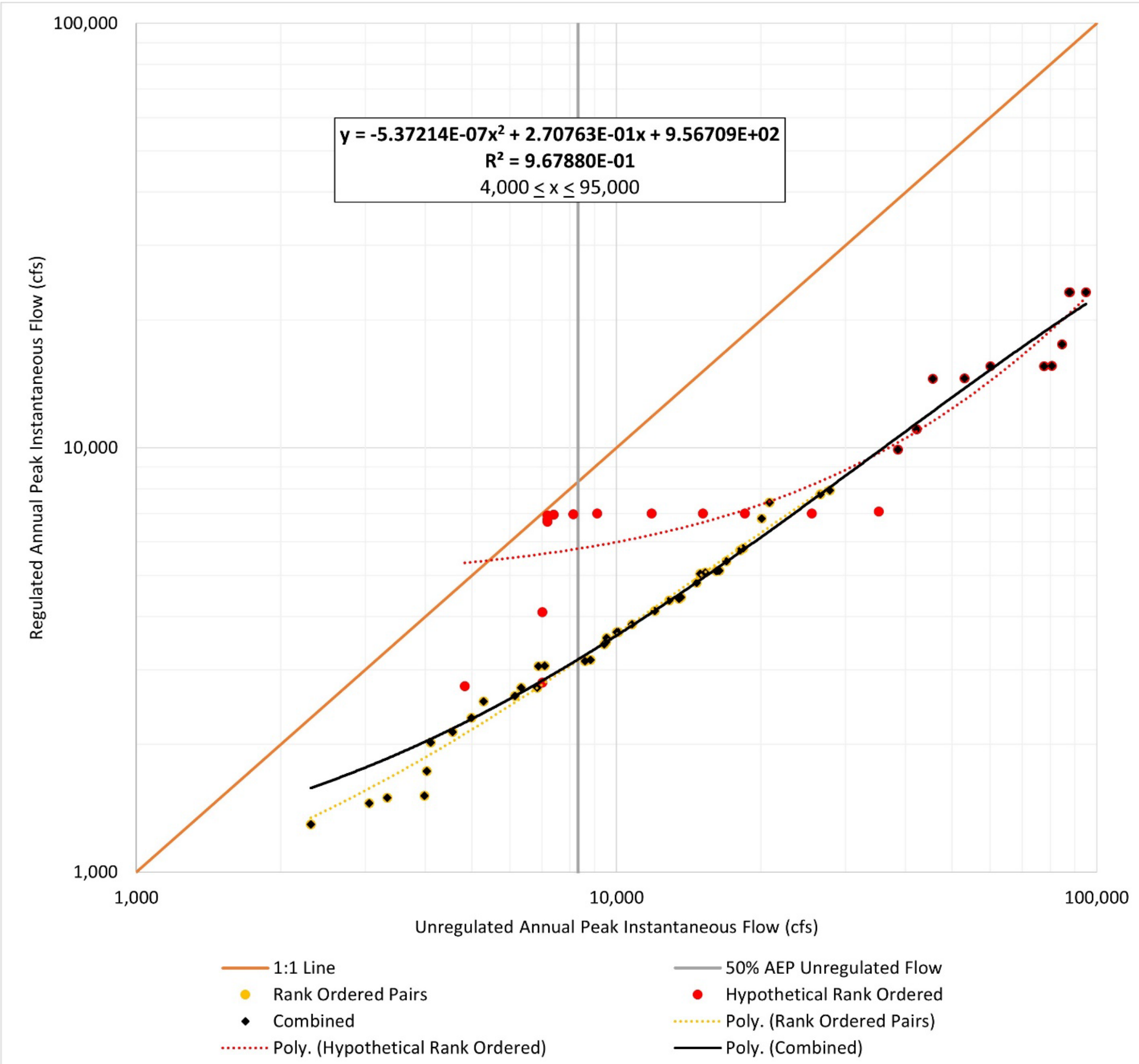
Junction City Transform Curve Development



Manhattan Transform Curve Development

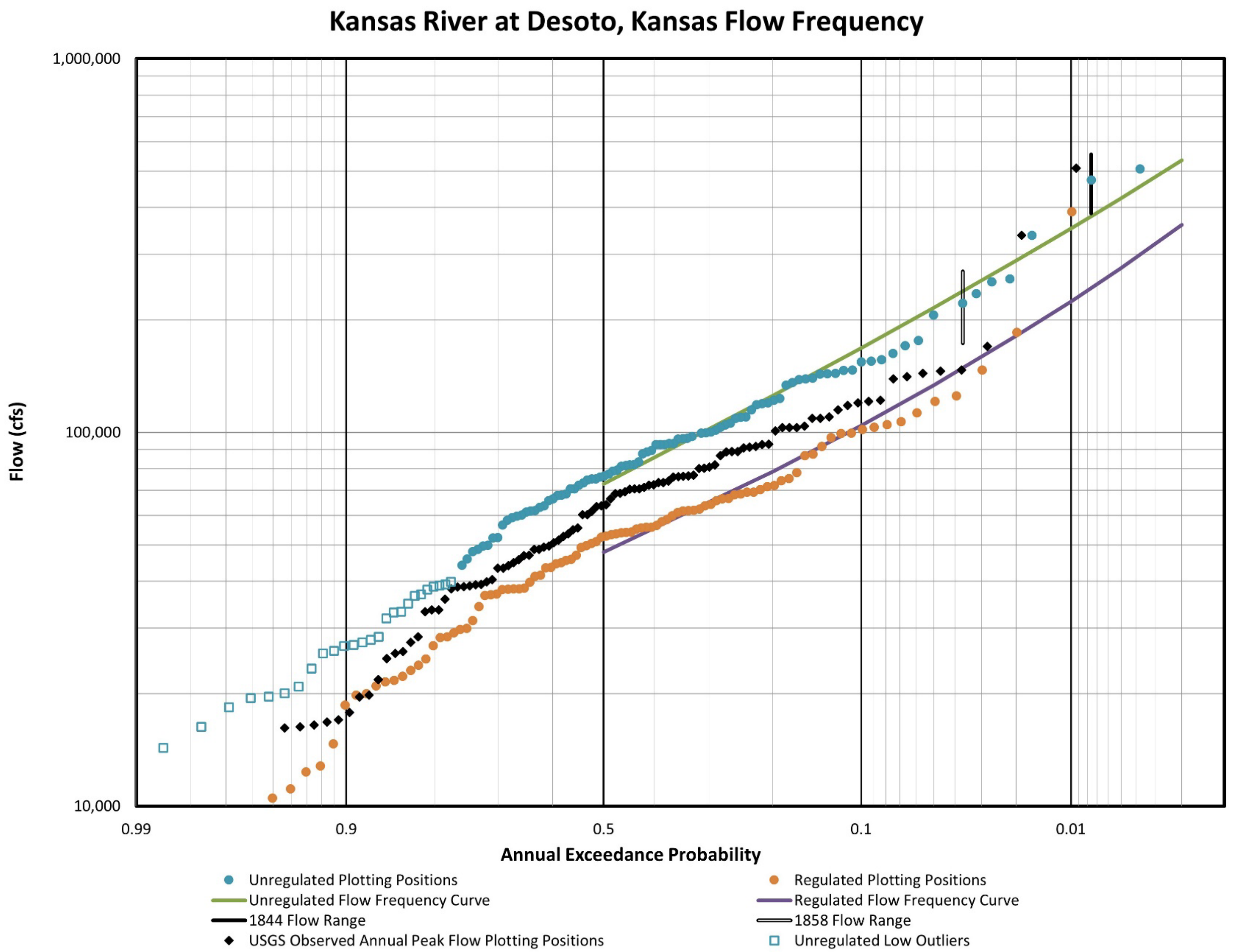


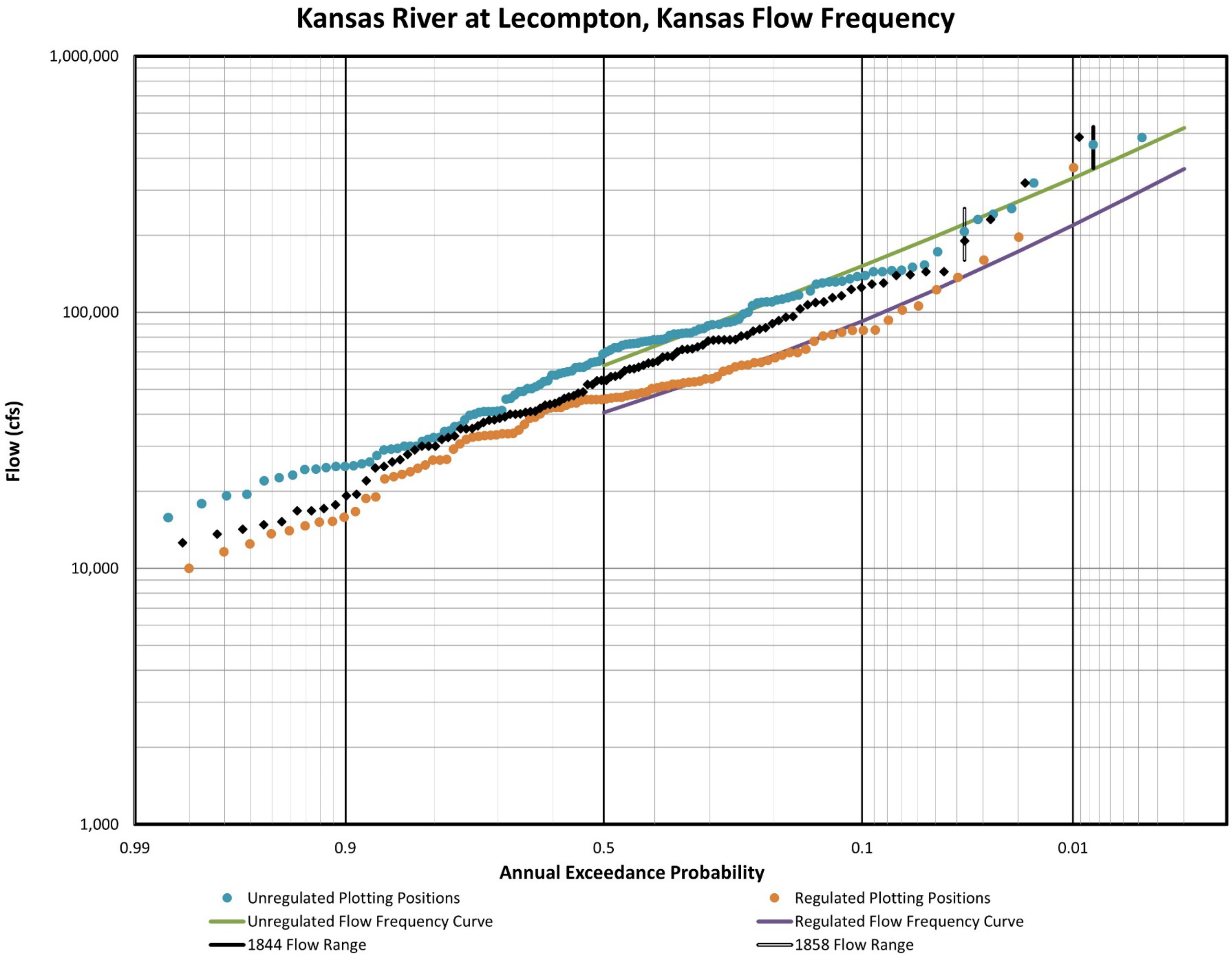
Perry Transform Curve Development



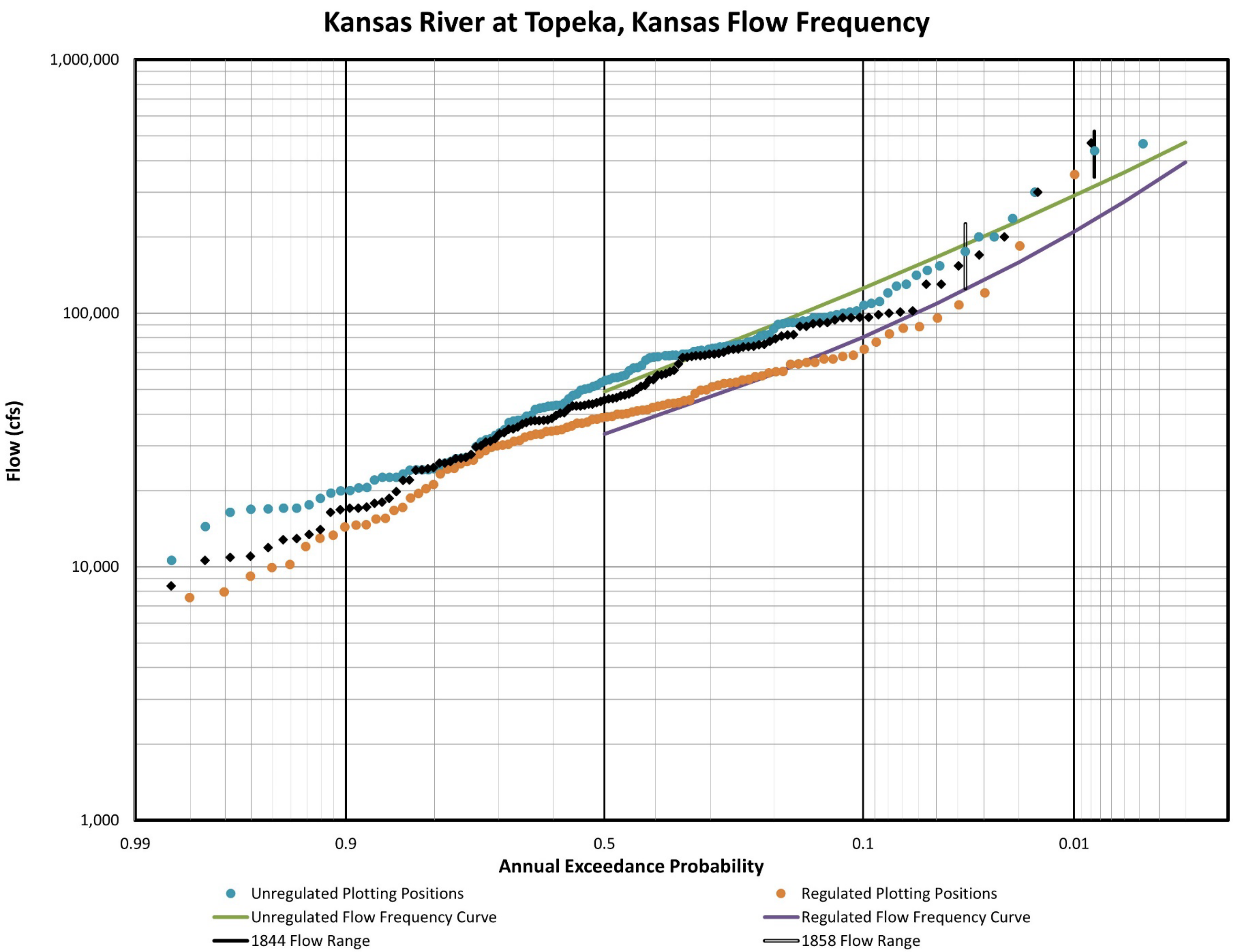
Lawrence Transform Curve Development

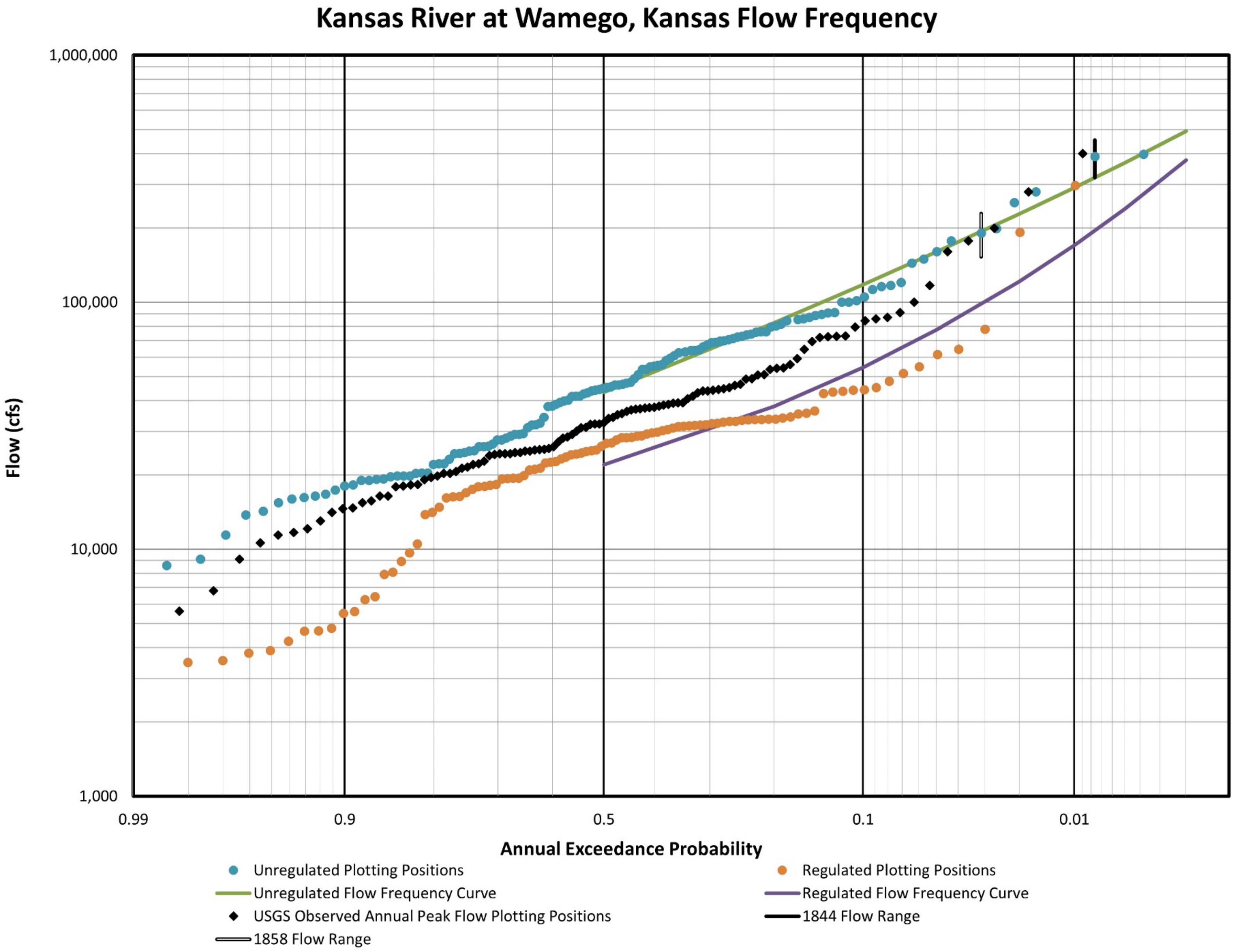
Attachment 6: Regulated and Unregulated Flow Frequency Plots



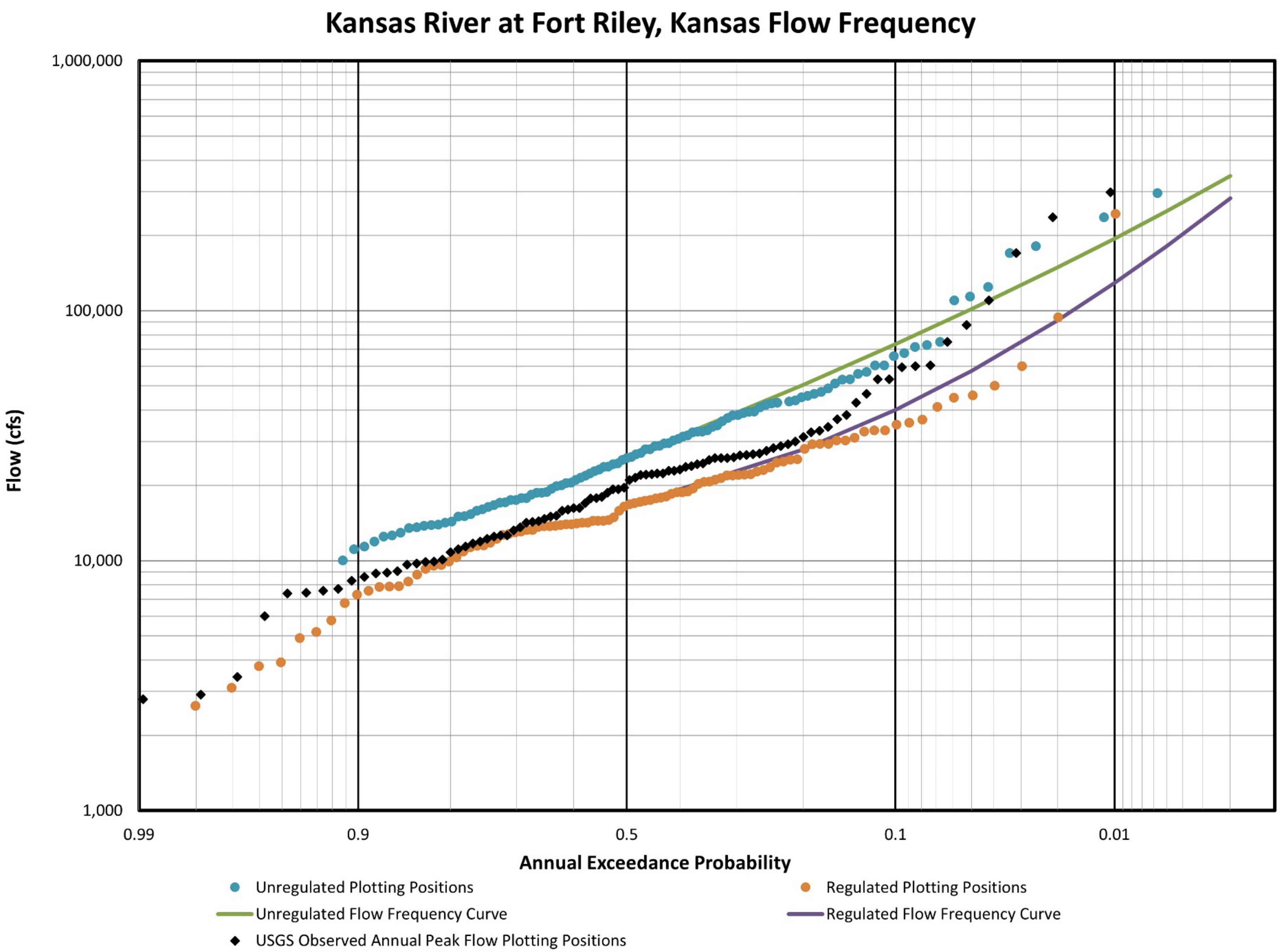


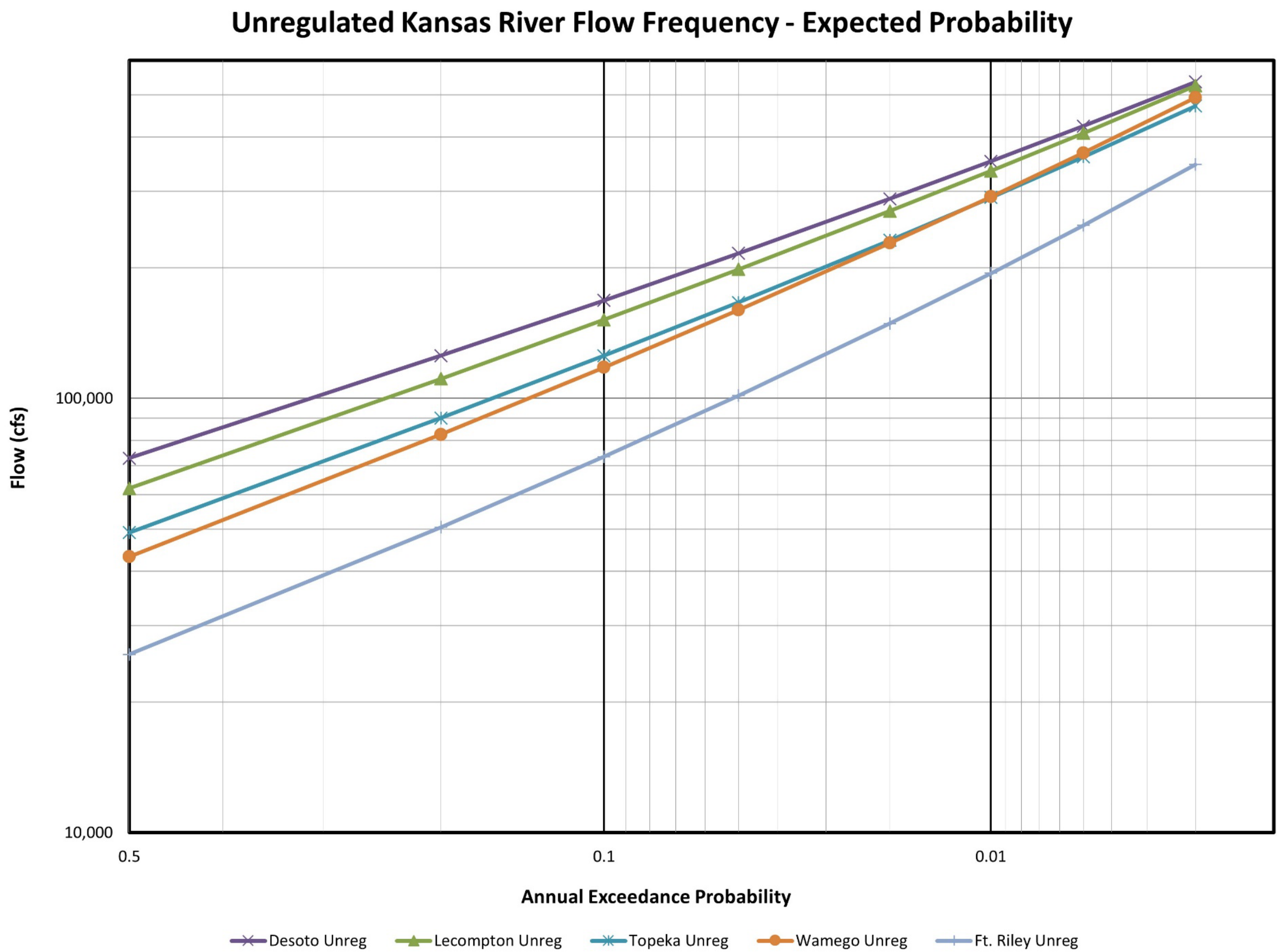
Kansas River at Lecompton, Kansas Flow Frequency
Flow (cfs)
1,000,000
100,000
10,000
1,000
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Unregulated Plotting Positions
Regulated Plotting Positions
Unregulated Flow Frequency Curve
Regulated Flow Frequency Curve
1844 Flow Range
1858 Flow Range

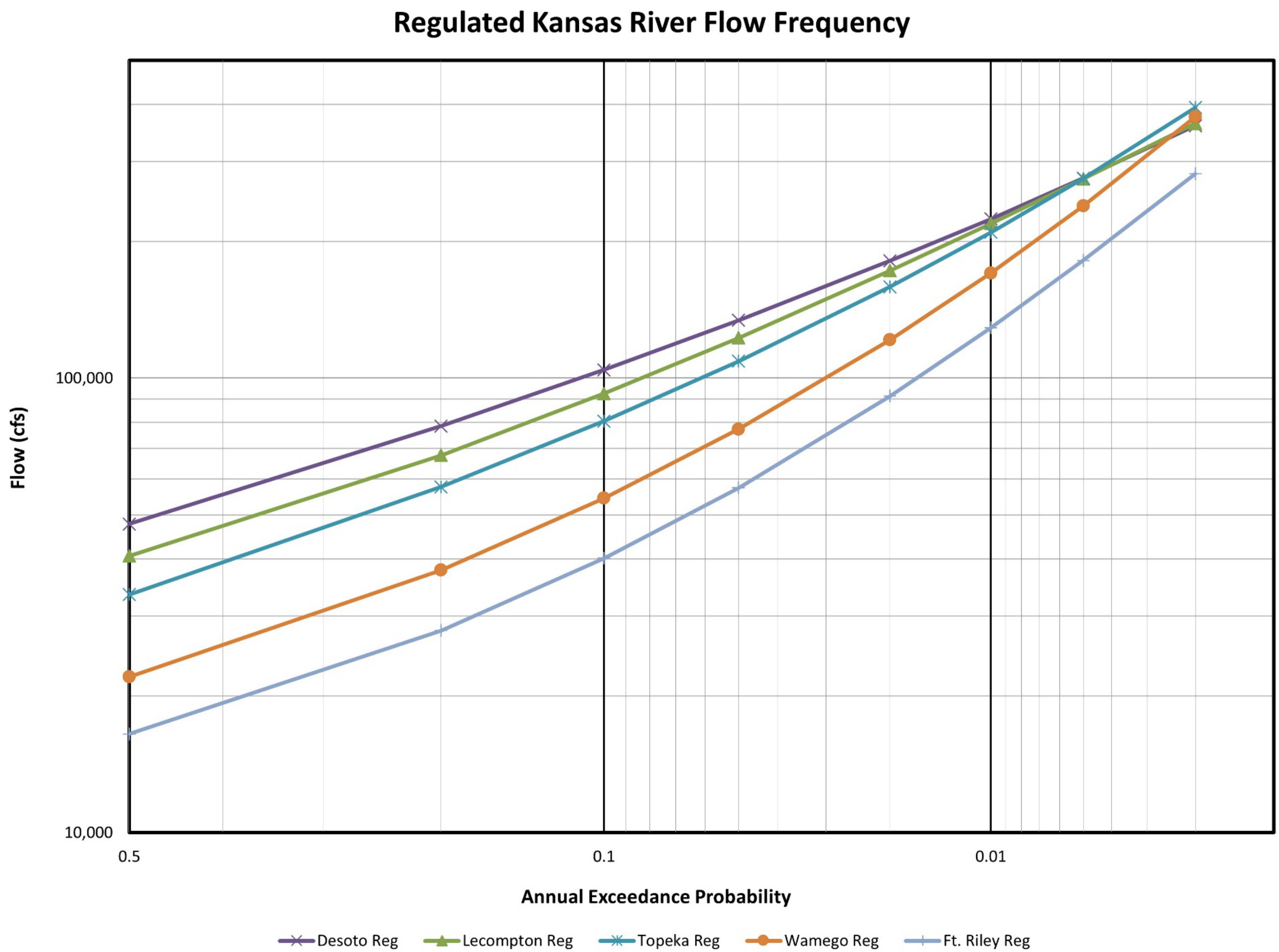

Kansas River at Topeka, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Unregulated Plotting Positions
Unregulated Flow Frequency Curve
1844 Flow Range
Regulated Plotting Positions
Regulated Flow Frequency Curve
1858 Flow Range

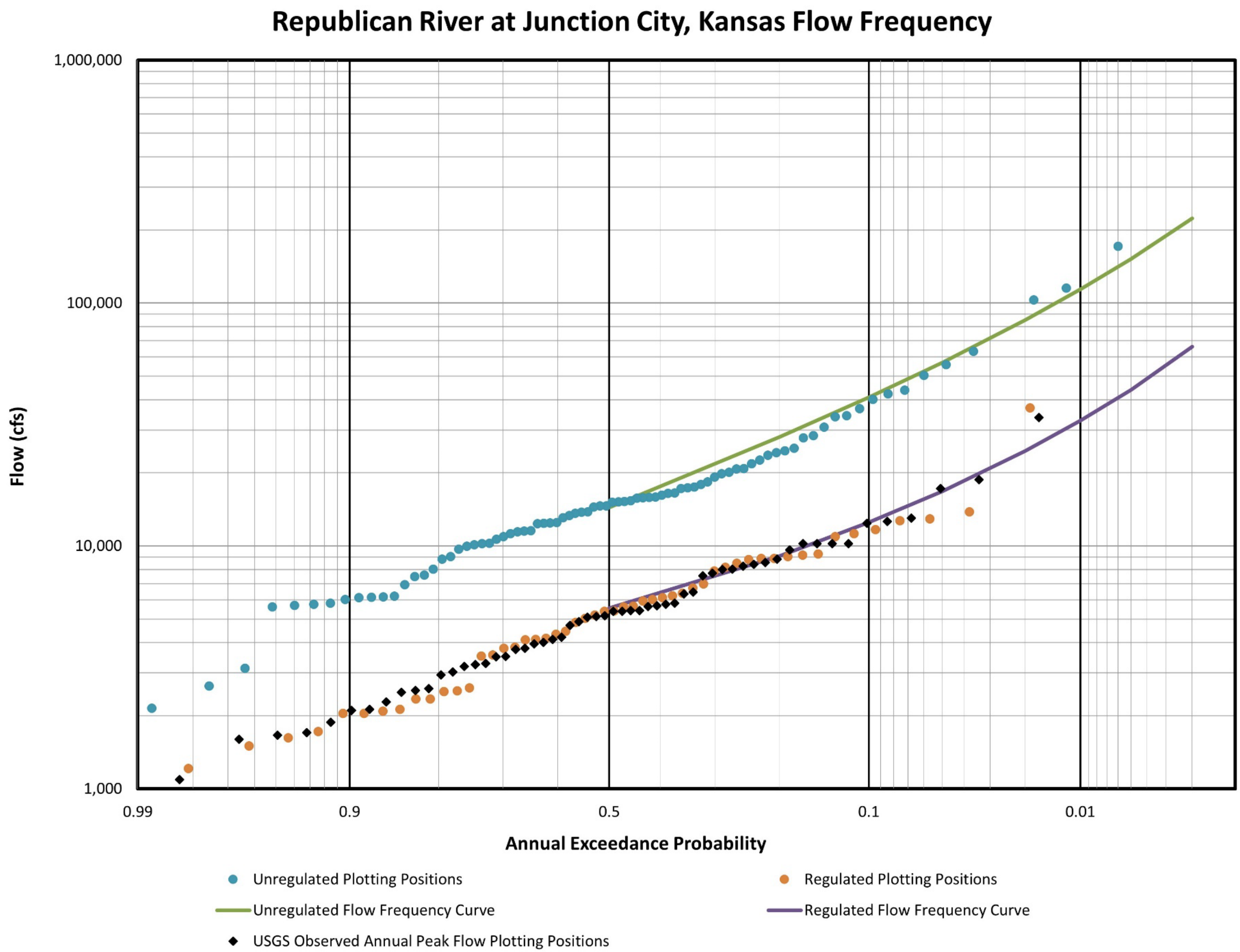


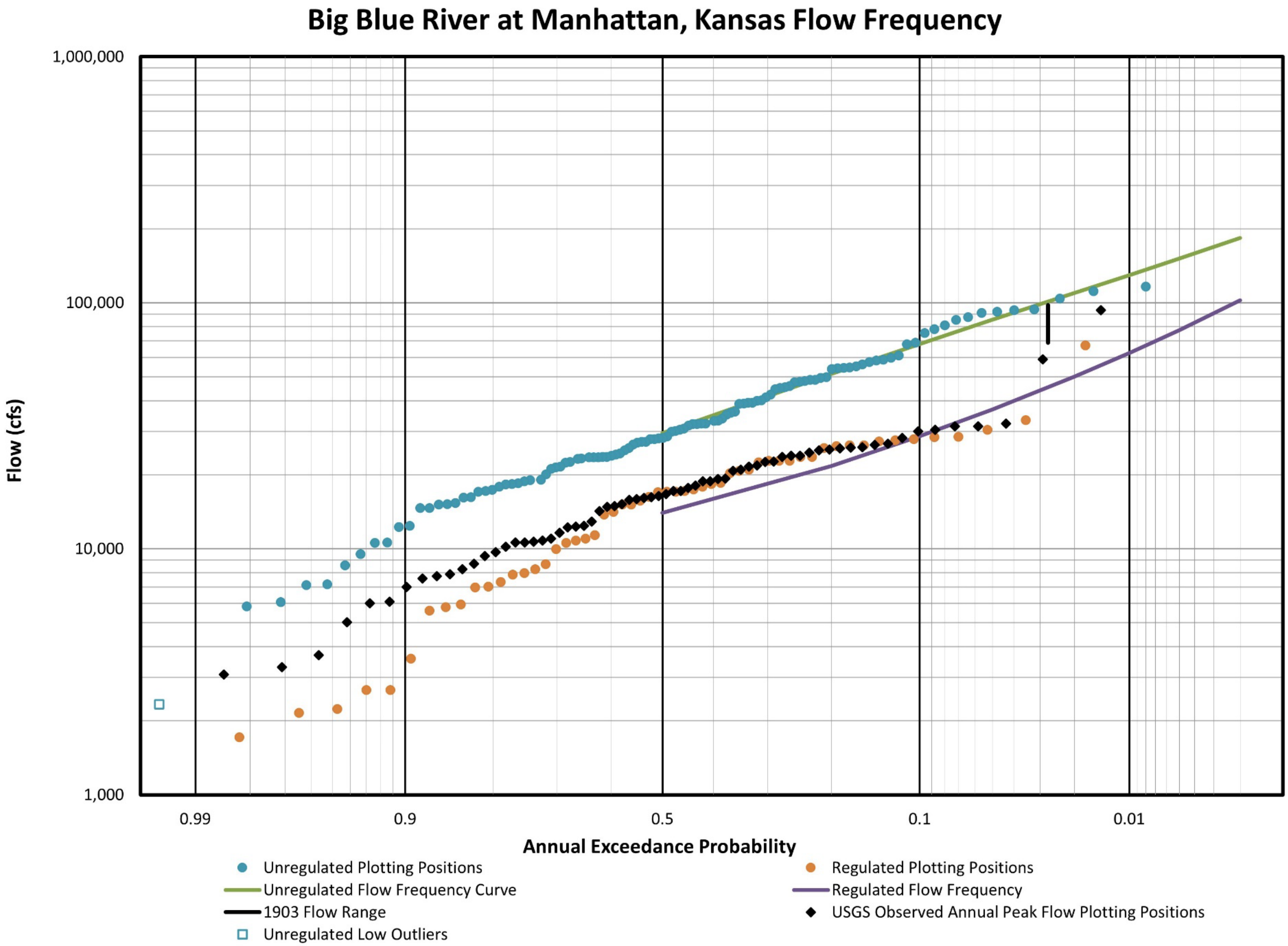
Kansas River at Wamego, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Unregulated Plotting Positions
Regulated Plotting Positions
Unregulated Flow Frequency Curve
Regulated Flow Frequency Curve
USGS Observed Annual Peak Flow Plotting Positions
1844 Flow Range
1858 Flow Range

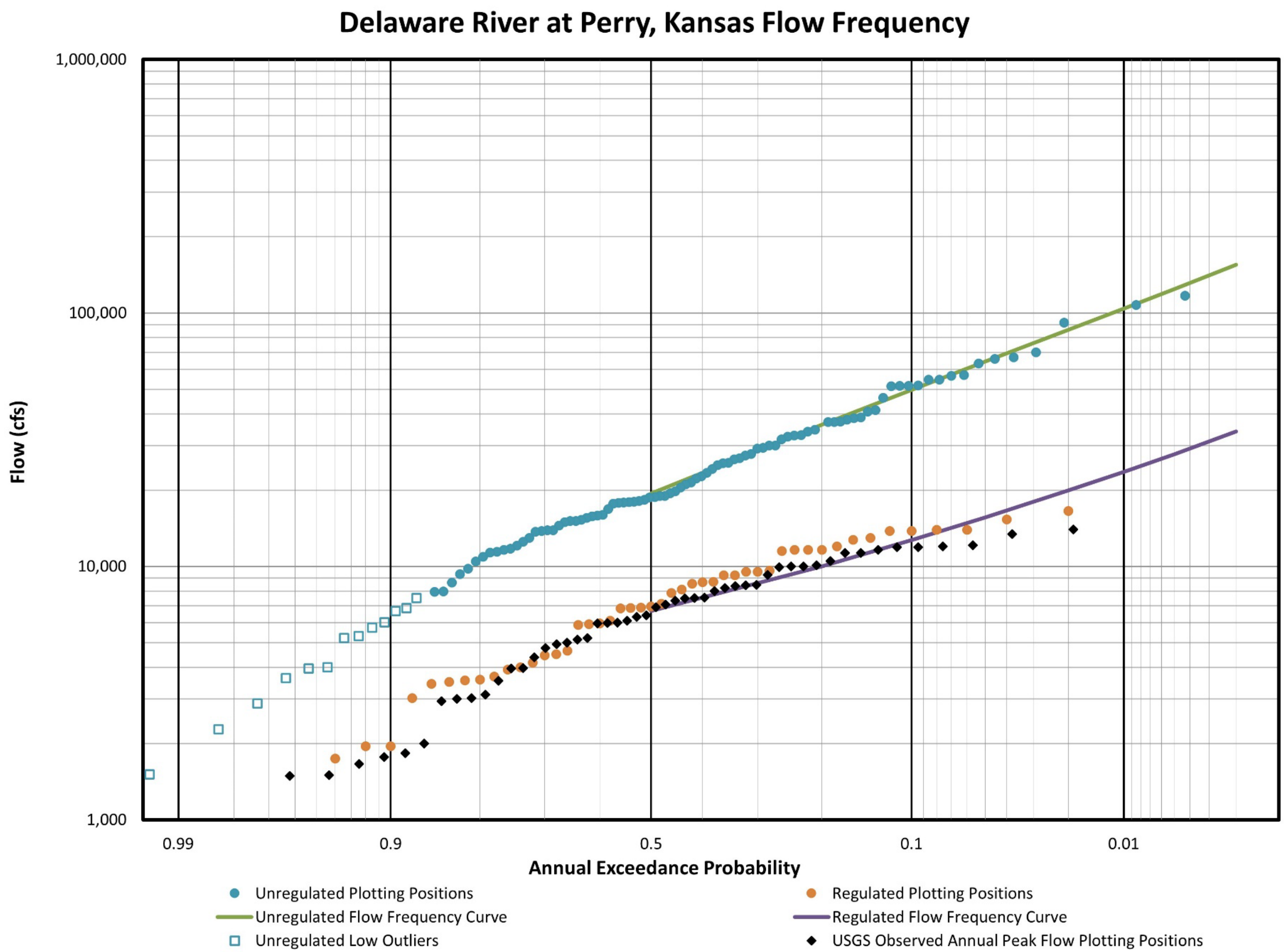

Kansas River at Fort Riley, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Unregulated Plotting Positions
Regulated Plotting Positions
Unregulated Flow Frequency Curve
Regulated Flow Frequency Curve
USGS Observed Annual Peak Flow Plotting Positions

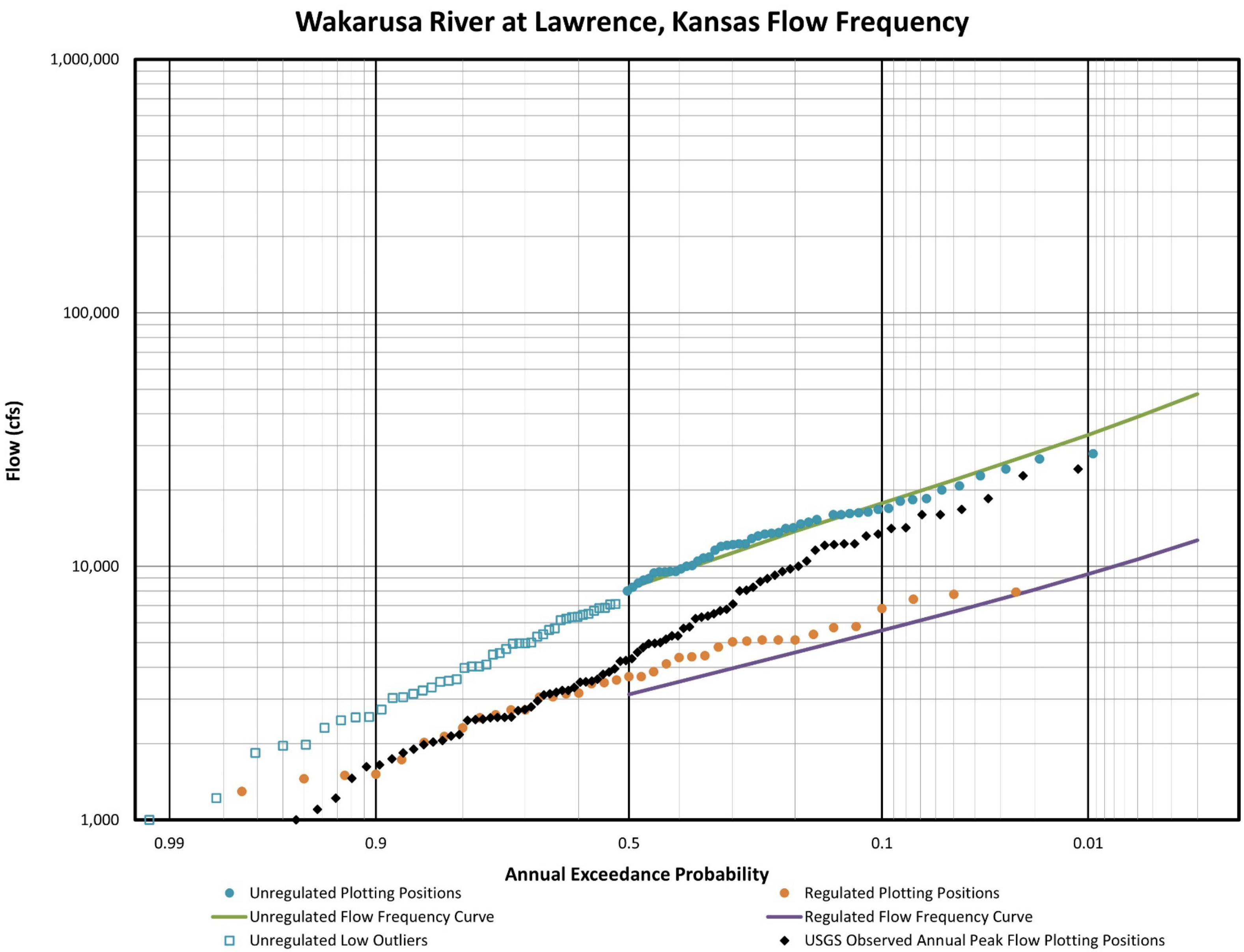

Unregulated Kansas River Flow Frequency - Expected Probability
Flow (cfs)
100,000
10,000
0.5
0.1
0.01
Annual Exceedance Probability
Desoto Unreg
Lecompton Unreg
Topeka Unreg
Wamego Unreg
Ft. Riley Unreg


Regulated Kansas River Flow Frequency
Flow (cfs)
100,000
10,000
0.5
0.1
0.01
Annual Exceedance Probability
Desoto Reg
Lecompton Reg
Topeka Reg
Wamego Reg
Ft. Riley Reg


Republican River at Junction City, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Unregulated Plotting Positions
Regulated Plotting Positions
Unregulated Flow Frequency Curve
Regulated Flow Frequency Curve
USGS Observed Annual Peak Flow Plotting Positions

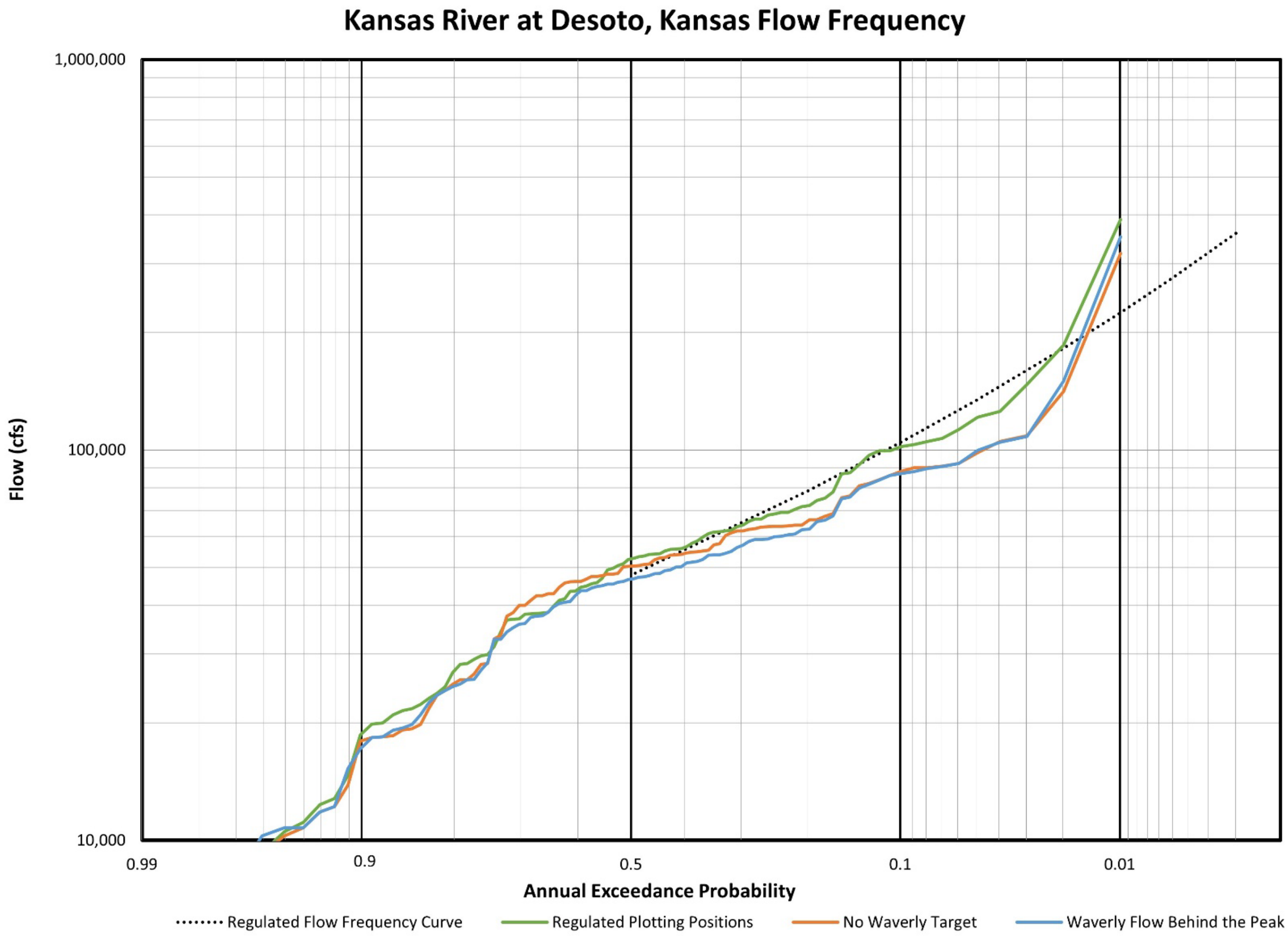

Big Blue River at Manhattan, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Unregulated Plotting Positions
Unregulated Flow Frequency Curve
1903 Flow Range
Unregulated Low Outliers
Regulated Plotting Positions
Regulated Flow Frequency
USGS Observed Annual Peak Flow Plotting Positions

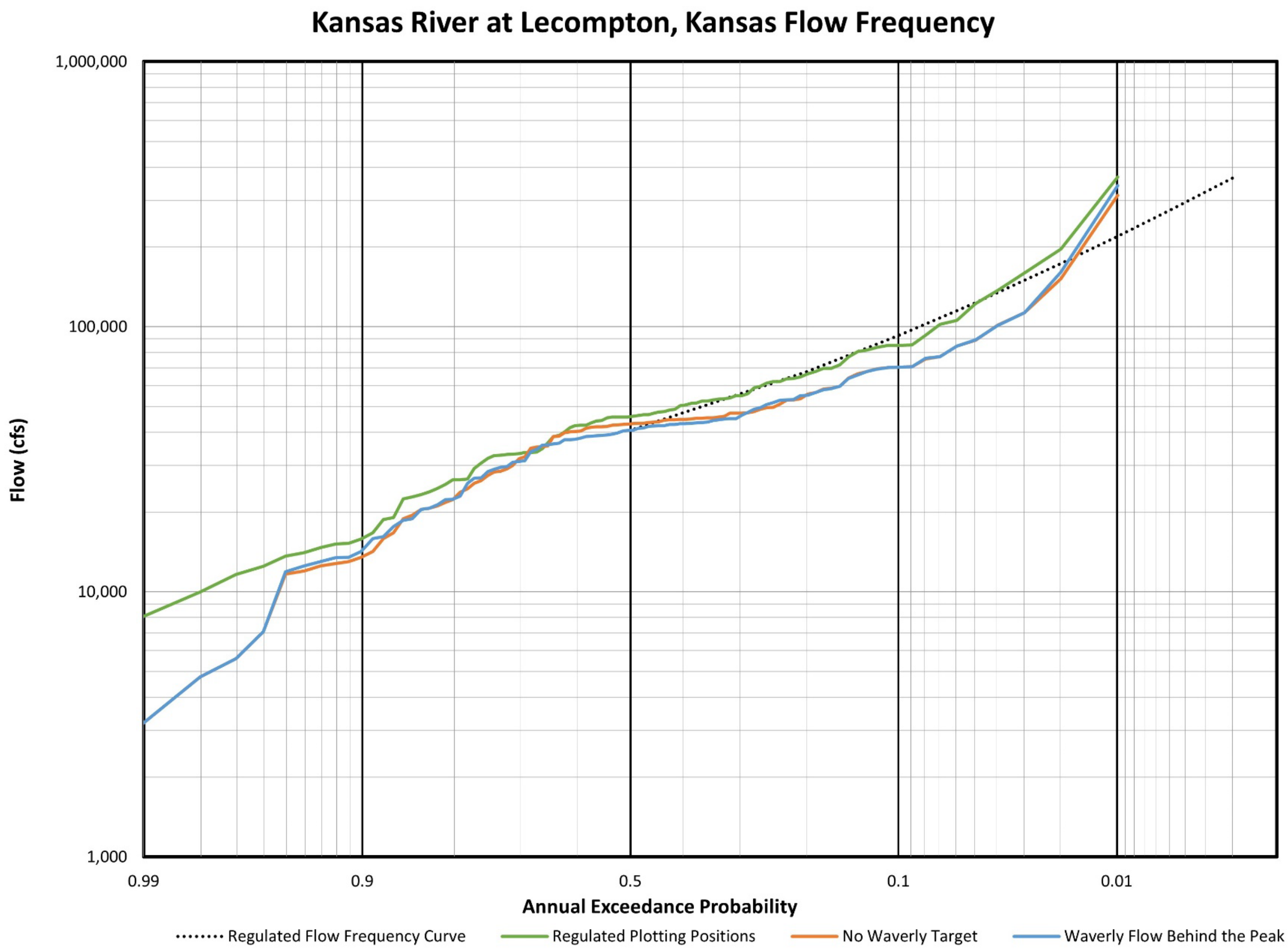

Delaware River at Perry, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Unregulated Plotting Positions
Unregulated Flow Frequency Curve
Unregulated Low Outliers
Regulated Plotting Positions
Regulated Flow Frequency Curve
USGS Observed Annual Peak Flow Plotting Positions

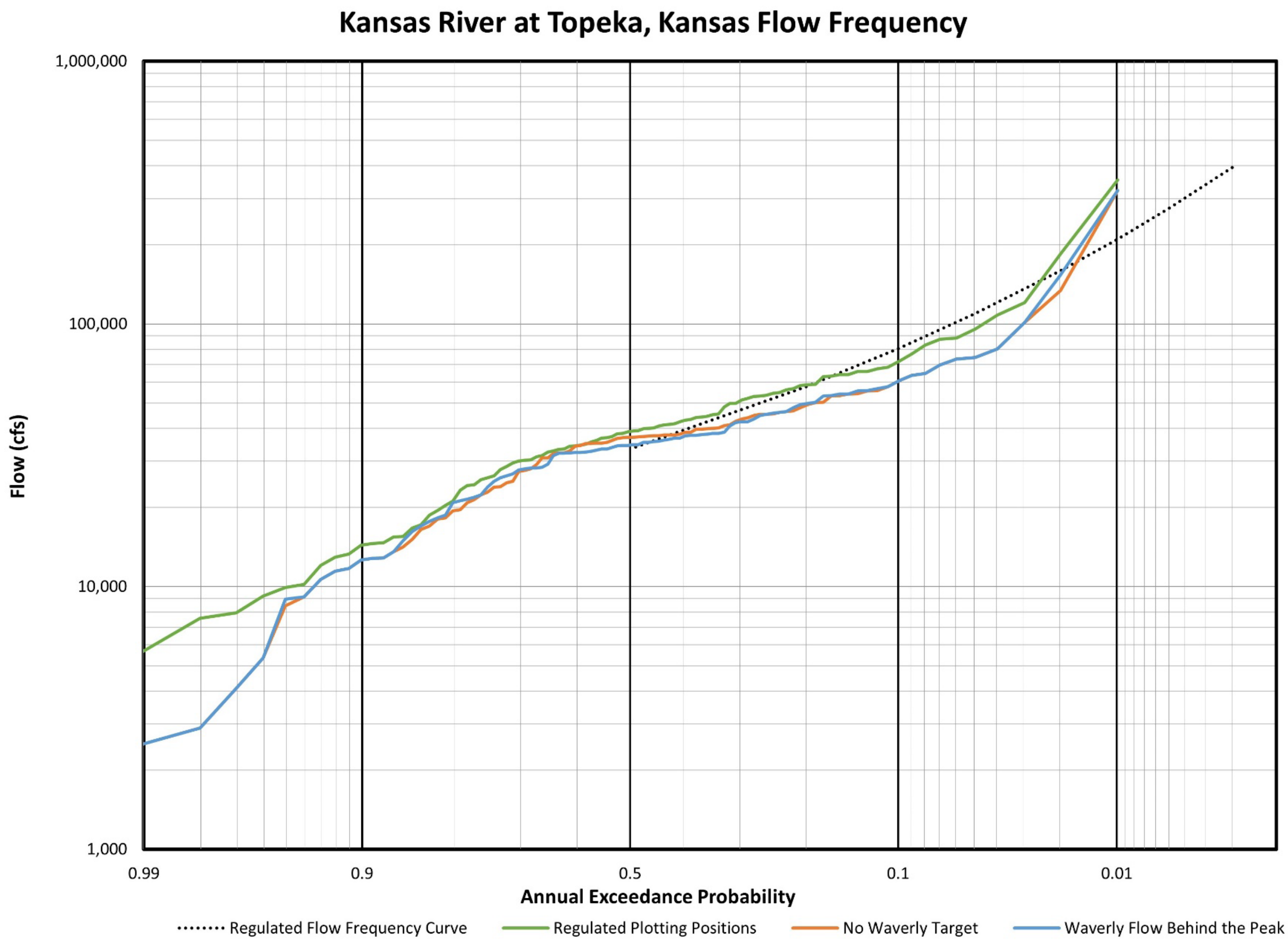


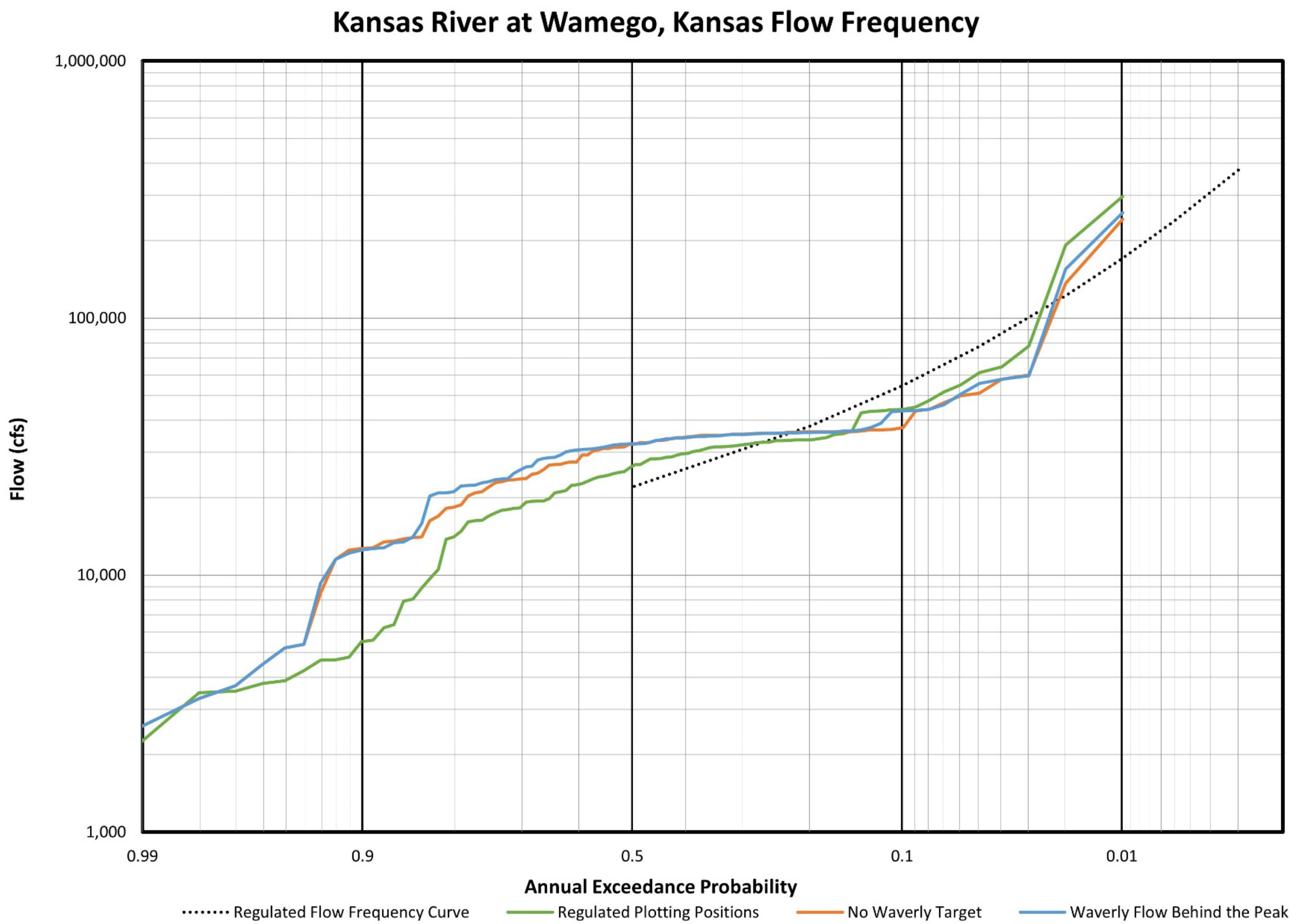
Wakarusa River at Lawrence, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Unregulated Plotting Positions
Unregulated Flow Frequency Curve
Unregulated Low Outliers
Regulated Plotting Positions
Regulated Flow Frequency Curve
USGS Observed Annual Peak Flow Plotting Positions

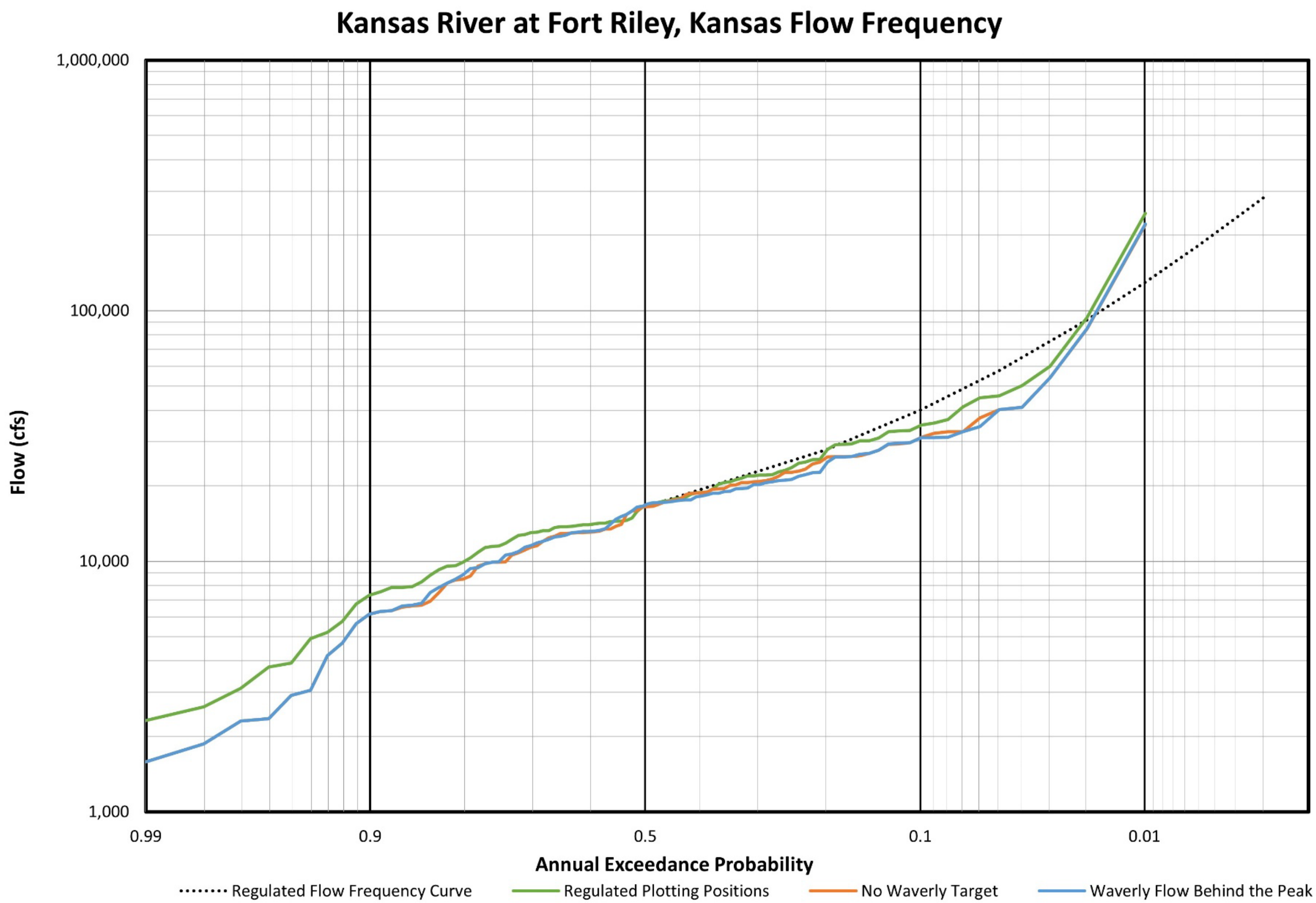
Attachment 7: With Project Plotting Positions




Kansas River at Lecompton, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Regulated Flow Frequency Curve
Regulated Plotting Positions
No Waverly Target
Waverly Flow Behind the Peak


Kansas River at Topeka, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Regulated Flow Frequency Curve
Regulated Plotting Positions
No Waverly Target
Waverly Flow Behind the Peak


Kansas River at Wamego, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Regulated Flow Frequency Curve
Regulated Plotting Positions
No Waverly Target
Waverly Flow Behind the Peak


Kansas River at Fort Riley, Kansas Flow Frequency
1,000,000
100,000
10,000
1,000
Flow (cfs)
0.99
0.9
0.5
0.1
0.01
Annual Exceedance Probability
Regulated Flow Frequency Curve
Regulated Plotting Positions
No Waverly Target
Waverly Flow Behind the Peak

HYDRAULIC ANALYSIS

Kansas River Watershed Study

Appendix C: Hydraulic Analysis

Hydrologic Engineering Branch

US Army Corps of Engineers

Kansas City District

Hydraulic Analysis

October 10, 2023

Table of Contents

1 Introduction

This report documents the hydraulic analysis for the Kansas River Watershed Study. The purpose of this analysis was to estimate the existing conditions (EC) Kansas River Basin flood inundation for the 10-year, 100-year, and 500-year flood events. The 10-year flood event was also evaluated with future without project (FWOP) conditions.

2 Source Model Development

The source one-dimensional, unsteady HEC-RAS model used for this study was developed in version 5.0.3 as part of the 2016 fiscal year Corps Water Management System (CWMS) modeling effort of the Kansas River Basin. See Kansas River Basin Corps Water Management System Report (August 2017) for details.

3 Model Adjustments

3.1 Geometry and Terrain Updates

For this study, the Kansas River Basin CWMS HEC-RAS model was reviewed and updated to HEC-RAS 6.1. A HEC-RAS 5.0.7 model was also created as an alternative user option. The focus was to achieve sufficient model output accuracy when running the desired frequency flows. Listed below are the model updates in response to the review.

3.1.1 Levees (Lateral Structures)

The Kansas Citys Levees (Armourdale, CID, and Argentine) and Manhattan Levee projects planned design stationing, profile, and orientation were incorporated into the model based on the following listed resources. At the time of this study, both projects are pending full implementation.

- Kansas Citys Flood Protection System As Awarded for Construction – Supplemental Hydrology and Hydraulic Analysis and Levee Heights Report dated August 2021.
- Armourdale Unit – Levee Raise Drawings dated April 2021.
- CID Unit – Levee Raise Drawings dated April 2021.
- Kansas City Levees Supplemental HEC-RAS Model dated January 2021.
- Part 4 – 95% Design Efforts Report for Manhattan, Kansas Federal Levee Improvements Design Project dated April 2021.
- Appendix A – 95% Design Report for Manhattan, Kansas Federal Levee Improvements Design Project dated March 2021.
- Manhattan Levee Improvements Design HEC-RAS model dated approx. 2021.

Also, a missing culvert was added to Argentine Levee to allow water to back up Barber Creek and the Santa Fe ditch. Data for the culvert was acquired from the following sources:

- Kansas City Levees supplemental analysis report and HEC-RAS model noted above.
- Argentine Residual Risk HEC-RAS model dated February 2021.

3.1.2 Terrain

The initial terrain associated with the model had several data gaps throughout the Kansas River basin. The best available data to fill these gaps was the most recent 30-meter National Elevation Dataset (NED) data from USGS. These spots of coarse terrain resolution, while somewhat inconsistent with the source terrain, allow for continuous inundation mapping and have minimal impact on the final deliverables for this study. Nearby structures are not impacted by the added data.

The terrain also did not include the new Highway K-18 embankment near Ogden, Kansas that significantly alters the floodplain. The newest and highest resolution LiDAR available (1-meter, 2018 LiDAR collected by USGS) was used to incorporate this feature into the terrain. Features associated with the embankment construction were also added to the terrain, including a large borrow pit and two new constructed channels that go under embankment bridges.

Only these identified outdated spots of the terrain were corrected because the 2018 LiDAR data is inconsistent in elevation against the source terrain (around 1-1.5 feet in most areas). This is because of a variety of factors, including the effect of LiDAR resolution on collection methods and processing. While the elevation differences are within the expected range, incorporating the data more broadly near Ogden would result in abruptly raised terrain by up to two feet. Without model re-calibration efforts, the resultant inundation extents for this study would likely be underestimated. A larger effort to update other portions of the terrain is not required for this study.

3.1.3 Cross Sections and Edge Lines

Select cross sections were re-cut to reflect the new features of the terrain near Ogden (embankment, borrow pit, and constructed channels). Existing bathymetric data was added back into the newly cut cross sections. Ineffective flow areas were placed to account for expected stagnant floodwater.

In multiple locations throughout the model, edge lines were cutting off the full inundation extents. Edge lines were adjusted as necessary to capture all floodwater. Since HEC-RAS sometimes automatically re-computes edge lines incorrectly after changes are made to the model, the correct edge lines are saved as shapefiles within the model folders and should replace the model edge lines when needed.

To capture the maximum water surface elevation of all flood events modeled for this study, the number of cross section computation points was increased to 120 for Wakarusa River and Delaware River.

Several cross sections along the KC Levees were extended to connect with the lateral structures and fully map the 500-year flood event.

3.1.4 Storage Areas

The bottom of the following storage area elevation-volume curves were made less steep to stabilize the model runs for this study:

- MO_bea2 (~2 acre-ft)
- MO_iat (~2 acre-ft)
- KS-088-L Sold2 (~2 acre-ft)
- KS-104-L Tri2 (~20 acre-ft)
- KS-100-L Tri3b (~6 acre-ft)
- KS-086-R Watw (~2 acre-ft)
- KS-085-R Stop (~10 acre-ft)

The following storage area elevation-volume curves were extended (set to higher maximum) to capture the maximum modeled water surface elevation:

- MO_tet1
- MO_tet2
- MO_blu
- MO_mlt
- MO_tet3
- MO_sugt

The following storage area connection rating curves were extended (set to higher maximum) to capture the maximum modeled water surface elevation:

- MO_ebt-blu
- MO_mlt-tet1
- MO_sug1-2
- MO_sug2-3
- MO_tet1-2
- MO_tet1-3
- MO_tet2-3
- chick-wa17
- wa17-16

4 Model Limitations

Several features that may significantly impact the model output were not updated or adapted as they're outside the scope of this study. These include, but are not limited to, the following:

- The model is calibrated based on outdated rating curves at key river gages (circa 2016).
- The cross sections are mostly cut from the original model terrain, which does not reflect the newest elevation data available
- The bathymetric data incorporated into the cross sections has not been re-evaluated since source model creation
- Leveed areas and other high-consequence areas are represented with 1D hydraulics; 2D modeling would improve flood inundation mapping accuracy in areas of concern
- Bridge structures are not included in the model, which would have a significant local impact on the river hydraulics
- Rubber dam operations are not considered for Bowersock Dam in Lawrence, Kansas; it's always deflated in the model, while in practice it's inflated for flood events less than 35,000-cfs

5 Unresolved Issues & Recommendations for Use

See HEC-RAS model description box for items that were not resolved but did not influence the accuracy of the output for this study.

6 Existing Conditions Hydraulics

6.1 Flow Files

The utility of the hydraulic model was to estimate the flood inundation resulting from the flow frequency results of the hydrology study. Three probability events were selected to be modeled: 0.2%, 1%, and 10%. These events were chosen because historical flood events occurred along the Kansas River that approximately reflect these probability flows (1951 event = 0.2% flow, 1993 event = 1% flow, and 2019 = 10% flow). The observed data was scaled to match the assigned flow frequency event.

The structure of the CWMS model flow file was adapted and integrated into separate model plans to simulate the events. The boundary conditions were consolidated, and multipliers were added to distribute the observed gage flow more realistically throughout the model. The flow distribution was based on drainage area ratio.

6.2 Plans

Model plans were created to produce flood inundations with the new flow files. For each probability event, the main stem Kansas River was separated from the tributaries to run the target gage flows based on the study hydrology. It was not possible to use the combined model because the tributary flow raised the downstream Kansas River flow beyond the targets. Each tributary was broken into its own plan for each event.

Furthermore, the 0.2% event for the mainstem Kansas River was broken into an upstream and a downstream part, separated at the Lecompton gage. This was necessary to achieve the target flows for the downstream part. The upstream plan more conservatively estimates the flow between Topeka and Lecompton.

In total, 13 model plans were created to run the target flows from the hydrology study and produce flood inundation maps:

1. 0.2% Mainstem Kansas River (Top of Reach to Topeka)
2. 0.2% Mainstem Kansas River (Lecompton to MO River Confluence)
3. 0.2% Big Blue River
4. 0.2% Delaware River
5. 0.2% Wakarusa River
6. 1% Mainstem Kansas River
7. 1% Big Blue River
8. 1% Delaware River
9. 1% Wakarusa River
10. 10% Mainstem Kansas River
11. 10% Big Blue River
12. 10% Delaware River
13. 10% Wakarusa River

The inundation map for each plan is based on the target flow for the reach of interest and the base observed flows for all other reaches. For example, the 0.2% Mainstem Kansas River (Top of Reach to Topeka) plan is based on the 1951 event flows, which are scaled to the 0.2% AEP flow along the subject reach but not altered anywhere else. Since the historical flood events are similar in magnitude to the respective AEP events, coincident flows for each plan may be realistic, but for the most accurate interpretation of consequences, the reaches should be analyzed independently. At areas of interest where multiple reaches might influence inundation extents, maximum consequences for each AEP would occur when peak flows for all relevant reaches coincide. A new HEC-RAS plan with this scenario would be required to determine full backwater effects near the confluence, as this impact might not be sufficiently captured by a combination of output from the 13 existing model plans.

6.3 Input Data Adjustments

The historic event observed flow data was scaled in HEC-DSS so that the resulting model flow at gages was within the rounding margin of the flow probability targets for the corresponding events. The same scaling factor was used for all inflows between two gages to maintain realistic output over the reach. The flow target matching results are given in Section 6.4.

6.4 Results

The economic analysis, for which this hydraulic analysis was performed, only required the mainstem Kansas River output. The HEC-FIA requirements were not clearly understood until the mainstem river and tributary plans were all completed. Table 6-2, Table 6-3, and Table 6-4 indicate the flow frequency target and final modeled event flows at each gage of interest. The hydrograph peaks were all within the rounding margin of the corresponding probability flows. Note that there are negligible differences between the HEC-RAS 6.1 and HEC-RAS 5.0.7 output.

Table 6-1 lists the locations in the HEC-RAS model at which flow was determined for each mainstem Kansas River gage. The 10% and 1% events were captured by one cross section nearest each gage. Since the 0.2% event overtops the levees at Fort Riley and Topeka, the full flow at each location is captured by model components other than the cross-section gage because it doesn’t extend through the leveed areas.

Table 6-1. Kansas River Gage Locations vs Flow Measurement Locations in HEC-RAS Model.

	Kansas River Gage Location	10% Event Flow Location	1% Event Flow Location	0.2% Event Flow Location
Ft. Riley	Cross-section 166.27	Cross-section 166.27	Cross-section 166.27	Cross-section 167.34
Wamego	Cross-section 126.45	Cross-section 126.45	Cross-section 126.45	Cross-section 126.45
Topeka	Cross-section 82.44	Cross-section 82.44	Cross-section 82.44	Cross-section 87.19 **+** Lateral Structure 'kaw-ntop1' **+** Lateral Structure 'kaw-sold3'
Lecompton	Cross-section 63.20	Cross-section 63.20	Cross-section 63.20	Cross-section 63.20
Desoto	Cross-section 30.52	Cross-section 30.52	Cross-section 30.52	Cross-section 30.52

6.4.1 10-Year Flood Event

Table 6-2. Results of 10-Year Flood Event Analysis (2019 Flows Scaled).

	Modeled	Target
Ft. Riley	40,041	40,100
Wamego	54,474	54,400
Topeka	80,438	80,400
Lecompton	92,409	92,500
Desoto	104,658	104,000

6.4.2 100-Year Flood Event

Table 6-3. Results of 100-Year Flood Event Analysis (1993 Flows Scaled).

	Modeled	Target
Ft. Riley	130,393	130,000
Wamego	170,014	170,000
Topeka	209,743	209,000
Lecompton	218,778	219,000
Desoto	223,921	224,000

6.4.3 500-Year Flood Event

Table 6-4. Results of 500-Year Flood Event Analysis (1951 Flows Scaled),

	Modeled	Target
Ft. Riley	284,514	285,000
Wamego	376,282	376,000
Topeka	394,817	394,000
split of upper and lower plans		
Lecompton	364,554	364,000
Desoto	358,611	359,000

Also note that the 500-year event economic analysis used the upper Kansas River plan (flows matched from top of reach down to Topeka) between Topeka and Lecompton because it provided a more conservative estimate of the flood inundation than the lower Kansas River plan.

7 Future Conditions Hydraulics

The reservoir sedimentation in future conditions analyses does not alter the flow frequency results enough as to notably impact the model hydraulics. The 100-year future without project (FWOP) and existing conditions (EC) peak flows vary by less than 2% at every mainstem Kansas River gage, as shown in Table 7-1. This margin is well within the bounds of assumed HEC-RAS model accuracy for producing depth grids and inundation boundaries.

Table 7-1. Differences between EC and FWOP peak flows.

Annual Exceedance Probability (%)	Desoto Change	Lecompton Change	Topeka Change	Wamego Change	Fort Riley Change
0.2	1000 **(0.3%)**	1000 **(0.3%)**	2000 **(0.5%)**	2000 **(0.5%)**	1000 **(0.4%)**
1	1000 **(0.4%)**	1000 **(0.6%)**	2000 **(1.0%)**	2000 **(1.2%)**	1000 **(0.8%)**
10	1000 **(1.0%)**	-300 **(-0.3%)**	500 **(0.6%)**	900 **(1.6%)**	500 **(1.2%)**

To identify if the flow differences are negligible, the maximum stage change at all mainstem gages except Topeka were estimated for the 500-year event (since the levees around Topeka overtop from the 500-year flow, a single rating could not be easily obtained from the 1D model output used for this analysis). The stage-flow relationships were based on the output rating curves from the stress test plan of the calibrated source HEC-RAS model (Kansas River Basin CWMS). The stress test simulated a scenario with Kanopolis Dam break flows routed downstream along the Kansas River and floodplain. Since the published USGS gage rating curves do not extend to all the 500-year EC and FWOP flows, this stress test plan provided the most useful rating estimates available.

Even though the estimated FWOP 500-year flow was no more than 0.5% larger than EC at each gage, for this analysis the stage change was based on an all-around 2% flow increase as to be conservative with assumptions. Table 7-2 shows the maximum estimated stage difference at each tested gage for the EC and FWOP 500-year event scenarios. Based on the modeled ratings, the average stage increase for a 2% flow increase is 0.21-ft. The largest change is 0.27-ft at Desoto. Since this difference is within the range of HEC-RAS accuracy and would not result in significant additional economic or life loss, future conditions were not included in the hydraulic analysis for this study.

Table 7-2. Maximum FWOP minus EC stages for 500-year event.

Fort Riley	Wamego	Lecompton	Desoto	Average
0.23 ft	0.16 ft	0.19 ft	0.27 ft	0.21 ft

For full confidence that FWOP hydraulics don't need to be modeled, the incipient overtopping flows for two of the major Kansas River levee systems (Topeka Levees and KC Levees) were checked against EC and FWOP flows to determine if the changes might indicate significant flood inundation mapping differences due to levee overtopping. See Table 7-3 and Table 7-4 for the Topeka Levees and KC Levees analyses, respectively. The KC Levees frequency flows were based on the upstream Desoto gage because that was the nearest one to the levees from the hydrology study. Since there are sizeable tributaries between that gage and the KC Levees, the assumed flows at the levees would be larger.

Table 7-3. Topeka Levees design overtopping flows vs EC and FWOP probability flows.

	Design OT	1% EC	1% FWOP	0.2% EC	0.2% FWOP
Auburndale	331,000	209,000	211,000	394,000	396,000
Waterworks	330,000	209,000	211,000	394,000	396,000
Oakland	310,000	209,000	211,000	394,000	396,000
S Topeka	310,000	209,000	211,000	394,000	396,000
N Topeka	299,000	209,000	211,000	394,000	396,000

Table 7-4. KC Levees design overtopping flows vs EC and FWOP probability flows.

	Design OT	1% EC (Desoto)	1% FWOP (Desoto)	0.2% EC (Desoto)	0.2% FWOP (Desoto)
Argentine	358,000	224,000	225,000	359,000	360,000
Armourdale	358,000	224,000	225,000	359,000	360,000
CID-KS	358,000	224,000	225,000	359,000	360,000

None of the Topeka Levee units are close to overtopping at 1% EC and FWOP flows, but all of them overtop by at least 60k cfs at 0.2% EC and FWOP flows. In conjunction with the previous analyses, this supports that there would be no significant difference between EC and FWOP flood maps at Topeka. Similarly, none of the KC Levees units are close to overtopping at 1% EC and FWOP flows, even with tributary inflow downstream of Desoto considered. The 0.2% Desoto flows are just barely larger than the levee overtopping flows, which agrees with the EC model that indicates the levees are overtopped. Since at that gage the 0.2% FWOP flows are larger than the 0.2% EC flows, FWOP hydraulic model output would not change the levee overtopping status. Since the 0.2% Kansas River flows changed very little from EC to FWOP at any gage location, levee overtopping status would not be expected to change for systems along the reach and flood inundation map differences would likely be negligible. Recommendation is to not use project resources to model FWOP hydraulics.

8 Uncertainties

Uncertainty from the associated hydrologic study for determination of probability flows propagates to uncertainty with the HEC-RAS model output. See the 'Uncertainty' section of the hydrologic model report for details.