



Dodge City Technical Assistance Hydrology Study

Hydrologic Analysis of Gage Data in
Western Kansas: A Case Study of
Dodge City, Kansas

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FINAL

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EXECUTIVE SUMMARY

The objective of this mitigation planning technical assistance is to evaluate available hydrologic analysis methodologies and recommend an approach to estimate the 1% annual chance discharge for streams in western Kansas where low flows or zero flows are observed in the stream gage peak flow records.

Stantec evaluated three different approaches to estimate the 1% annual chance discharge for Arkansas River at Dodge City, Kansas in this technical assistance study.

Stantec reviewed methodologies in USGS Scientific Investigations Report 2017-5063 (SIR 2017-5063) and methodologies implemented in the flow frequency analysis of the Arkansas River at Dodge City, KS performed by the United States Army Corps of Engineers (USACE) in 2009. Stantec performed four different analyses to evaluate appropriate methodology to estimate peak stream flow in Western Kansas. Updated stream gage analyses using additional years of gage data with Bulletin 17B and Bulletin 17C methodology. These updated analyses are reported as Approach 1 and Approach 2 respectively in this study. These approaches followed the analysis methodology used in 2009 USACE study. The 1% annual chance discharge for Arkansas River at Dodge City, KS estimated from Approach 1 and Approach 2 are 28,141 ft³/s and 29,190 ft³/s, respectively. Flow estimate based on the United States Geological Survey (USGS) methodology recommended in SIR 2017-5063 using regression equation for streams in hydrologic region 2 in western Kansas is reported as Approach 3. This approach estimates the stream flows using Bulletin 17C methodology using the post 1978 (post-irrigation) flows and then weights the Bulletin 17C estimate using regression equation estimate to adjust the annual exceedance probability flows. The 1% annual chance discharge estimate in Approach 3 is 21,405 ft³/s.

Approach 4 is the mixed distribution method using the Bulletin 17C based analysis of the entire peak flow record dataset for Arkansas River at Dodge City. Approach 4 utilized the continuous gage record from 1942 and omitted the 82,000 ft³/s peak flow measured in 1965. It is considered a high outlier. However, low flows in the gage records are accounted by assuming the probability of the entire peak flow record dataset as a mixed probability distribution. High frequency flows (low and zero flows) are considered to follow a discrete probability distribution and the low frequency flows (high flows) are considered to follow a continuous distribution. The Log Pearson III (LPIII) distribution was fitted using Bulletin 17C methodology with the low outlier censored dataset. USACE HEC-SSP 2.2 is used for the analysis. The quantile functional of the fitted continuous distribution is then shifted using the argument relationship $P_{E_fit} = \frac{P_{E_mix}}{1-P(low\ outlier)}$ to give the weight to the low flows. The quantiles of the mixed continuous distribution at each exceedance probability P_{E_mix} can be estimated from the fitted continuous distribution at corresponding exceedance probability P_{E_fit} which is equal to $\frac{P_{E_mix}}{1-P(low\ outlier)}$. The estimated 1% annual chance discharge for Arkansas River at Dodge City, Kansas using Approach 4 is 23,694 ft³/s.

The results of all four approaches, the 2009 USACE study, and the effective discharge for the Arkansas River at Dodge City as reported in FEMA's Flood Insurance Study (FIS) for Ford County are summarized in the table below.



Table 1 Summary of Results for the Hydrologic Study of the Arkansas River Gage at Dodge City, Kansas

	Description	1% annual chance discharge (ft ³ /s)	Difference (%)
Effective Study	Effective FIS for Ford County Kansas and Incorporated Areas. All records during 1903-1991 using Bulletin 17B	49,900	Reference
USACE (2009)*	Continuous record since 1942, omission 82,000 ft ³ /s in 1965, inclusion of 1921-1941 records extension from Syracuse Kansas using Bulletin 17B	33,190	-33.5
Approach 1	Continuous record since 1942, omission 82,000 ft ³ /s in 1965 inclusion of 1921-1941, 2008-2017 records extension from Syracuse Kansas using Bulletin 17B: USACE (2009) update	28,141	-43.6
Approach 2	Continuous record since 1942, omission 82,000 ft ³ /s in 1965 inclusion of 1921-1941, 2008-2017 records extension from Syracuse Kansas using Bulletin 17C	29,190	-41.5
Approach 3	SIR 2017-5063: Weighted post 1978 gage analysis flow with RRE estimate	21,405	-57.1
Approach 4	Continuous record since 1942, omission 82,000 ft ³ /s in 1965 using Bulletin 17C, then shifted to weight the low flows (mixed distribution)	23,692	-52.5

*Stantec was not able to replicate analysis

The mixed distribution methodology used in Approach 4 captured the low and zero flows in the peak flow records of Arkansas River at Dodge City, Kansas. Based on these evaluations this methodology is the recommended hydrologic flow frequency analysis methodology to estimate low frequency flows for the streams in western Kansas. This continuous section of mixed distribution is not applicable to estimate the high frequency flows.



DODGE CITY TECHNICAL ASSISTANCE HYDROLOGY STUDY

Introduction

1.0 INTRODUCTION

The Arkansas River at Dodge City, Kansas is affected by regulation by an upstream reservoir (John Martin Reservoir) and irrigation in western Kansas. This gage has observed several low and zero flows in recent years. There are multiple years where the annual peak flow is zero flow. Several publications have attributed this to excessive irrigation, depletion of Ogallala aquifer and increase in ground water recharge. Current methodologies for gage analysis fitting the log-Pearson Type III distribution and regression equation analysis in western Kansas are developed to estimate the annual peak flows for unregulated streams. These analyses approaches may not be an appropriate approach to estimate the flow frequencies for the Arkansas River at Dodge City and streams in western Kansas in general.

As part of the Federal Emergency Management Agency (FEMA) Flood Insurance Program, the State of Kansas Department of Agriculture - Division of Water Resources(KDA-DWR) have contracted Stantec Consulting Services Inc. to provide a technical assistance to perform a hydrologic study on the Arkansas River at Dodge City, Kansas that includes estimating the 1% annual chance event discharge for Arkansas River at Dodge City, Kansas through various methodologies and recommending a hydrologic flow frequency analysis methodology that can be applied in western Kansas. The Dodge City case study will also perform a 1% annual chance hydraulic analysis of Arkansas River at Dodge City along the Dodge City Levee North Side and Dodge City Levee South Side levees to evaluate the hydrologic methodologies and the corresponding effect on base flood elevations (BFEs).

This study does not attempt to identify the cause of low flows in streams in Arkansas River at Dodge City or western Kansas. This study evaluates and identifies an appropriate methodology to estimate the 1% annual chance event discharge for Arkansas River at Dodge City and gaged streams in western Kansas with zero flows.

1.1 STUDY AREA

Dodge City, Kansas is a community of approximately 27,340 people located along the Arkansas River in the High Plains region of the Great Plains (KDOT 2003). The city sits above one of the world's largest underground water systems, the Ogallala Aquifer (University of Kansas, 2011). Located at the intersection of U.S. Routes 50, 56, and 283 in southwestern Kansas, Dodge City is west of Wichita, northeast of Amarillo, and southeast of Denver. The study area is Arkansas River at Dodge City, Kansas which is shown in Figure 1.

The Arkansas River begins as a steep mountain stream near Leadville, Colorado. It transitions to a shallow channel with a wide floodplain near Pueblo, Colorado. The river has been regulated in eastern Colorado since 1948 with the construction of John Martin Reservoir. Once the Arkansas River reaches Dodge City, it is not uncommon for the channel to remain dry during the course of an entire water year. Even when large runoff events occur upstream, the wide, flat flood plain – characterized by well-drained alluvial soils – significantly attenuates the discharge. Additionally, the significant groundwater withdrawals caused by irrigation use produce large infiltration losses and attenuation of the discharge.



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Introduction

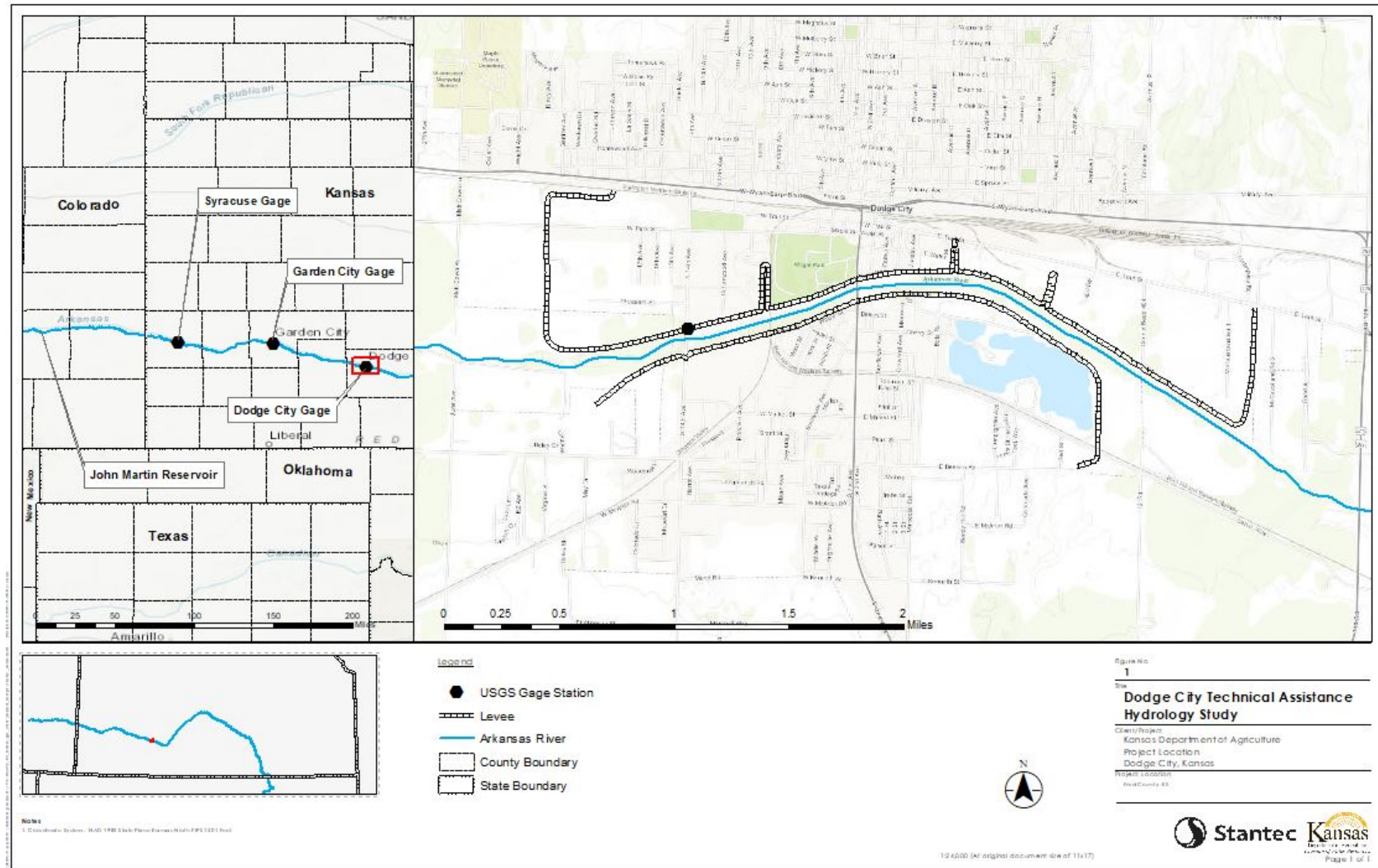


Figure 1 Study Area Map

DODGE CITY TECHNICAL ASSISTANCE HYDROLOGY STUDY

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The gage evaluated in this study is the United State Geological Survey (USGS) stream gage 07139500 Arkansas River at Dodge City, Kansas. This station is operated by the USGS and funded by the U.S. Army Corps of Engineers (USACE) Tulsa District. This gage is currently, and has been throughout its record, affected by regulation or diversion. The Water Year summary noted the maximum discharge of 82,000 ft³/s in 1965 and historical discharge estimation was 21,000 ft³/s in 1942. The annual peak stream flow data for USGS 07139500 spans the water years 1903-1906, followed by a 36-year gap and a continuous record beginning in 1942 to 2007, see Table 1.

Table 2 Summary of Peak Flows of Arkansas River at Dodge City, Kansas

Gage	Contributing Drainage Area (sq mi)	Available Data	Number of Peak Events Recorded
USGS 07139500 Arkansas River at Dodge City, Kansas	25,017	06/13/1903-07/18/1906 04/28/1942* 02/06/1945-10/01/2006	67

*The flow in 1942 was the estimated flow for historical event.

The gage at Arkansas River at Dodge City, Kansas is within the irrigation-affected area; the annual peak flow records for this gage have low peak stream flows and zero peak streamflow values. These low and zero annual peak values have a significant effect on the flow frequency distribution. Therefore, a hydrology gage analysis methodology that is suitable for stream gages with zero and low flows is necessary for Arkansas River at Dodge City, KS.

1.2 HISTORICAL FLOODS

The highest recorded stream flow at USGS gage Arkansas River at Dodge City, KS (07139500) was in the summer of 1965. According to the Flood Insurance Study (FIS) for Ford County, Kansas and Incorporated Areas dated September 25, 2009 (FEMA, 2009) and Flood Report, Arkansas River Basin: Flood of June 1965 (USACE, 1965), the “Superstorm” of 1965 developed on the Front Range of the Colorado and New Mexico Rockies as a slow-moving upper-level storm system developed over Four Corners region. Thunderstorms with heavy rainfall developed on June 13 and continued intermittently through June 17. The stream discharge along the Arkansas River and its tributaries in eastern Colorado and western Kansas were excessively high as a result of the heavy rain that fell during the June 1965 storm event. A peak discharge of 174,000 ft³/s and 82,000 ft³/s were measured along the Arkansas River at Syracuse, Kansas and Dodge City, Kansas, respectively. Major flooding was reported in eastern Colorado and western Kansas, including 220,000 acres of farmland in Kansas alone (USACE, 1965).



2.0 EXISTING METHODOLOGY REVIEW

As a part of this technical assistance, previous studies and methodologies implemented in the flow frequency analysis of the Arkansas River at Dodge City, KS were reviewed. This review involved comparison of the 1% annual event flow estimated from the methodologies reviewed.

2.1 USACE HYDROLOGIC FREQUENCY STUDY

A hydrologic analysis for the Arkansas River at Dodge City was completed by the USACE, Tulsa District in August 2009. This analysis estimated the 1% annual chance event discharge for Arkansas River at Dodge City, KS under four different scenarios. The four scenarios computed by USACE (2009) were: (1) Bulletin 17B analysis of the Dodge City with the inclusion of the 1965 peak event (82,000 ft³/s); (2) Bulletin 17B analysis at the Dodge City with the omission of the 1965 peak event discharge; (3) Bulletin 17B analysis of the Dodge City historical record with the inclusion of the 1921-1941 dataset extension from Syracuse, Kansas and the omission of 1965 peak event. This scenario assumed peak flows at Dodge City are 53% smaller than the peaks at Syracuse; and (4) Bulletin 17B analysis at the Dodge City with the inclusion of the 1921-1941 dataset extension from Syracuse, Kansas (68% reduction applied) and the omission of the 1965 peak event. This scenario assumed peak flows at Dodge city is 68% smaller than the peaks at Syracuse. Frequency estimates on all the scenarios were computed using the HEC-SSP (USACE, 2009a) program developed by USACE. The USACE reported Scenario 4 as a recommended approach for flood frequency analysis at the Arkansas River at Dodge city. The USACE methodology and recommended scenario performed Bulletin 17B analysis with the following modification to the gage record:

The annual peak value of 82,000 ft³/s recorded on 19 June 1965 for Arkansas River at Dodge City was considered an anomalously high outlier and was not included in the gage analysis. The 1921-1941 record gap for the stream gage at Dodge City, Kansas (USGS 07139500) was supplemented using peaks recorded at the nearby stream gage at Syracuse, Kansas (USGS 07138000) to produce a continuous record. Reduction factors estimated based on difference in recorded annual peak flows at these gages was used to extend the gage record at Dodge City.

2.2 USGS SCIENTIFIC INVESTIGATIONS REPORT 2017-5063 METHODOLOGY

The current methods for estimating annual exceedance – probability stream flows for unregulated streams in Kansas is outlined in SIR 2017-5063 (USGS, 2017). According to the SIR 2017-5063 the flow frequency analysis at stream gage locations using the Bulletin 17C involves the following steps:

- 1) Produce flow estimates from gage data using the expected moments algorithm (EMA) procedure with the multiple Grubbs-Beck test (MGB) analysis using the weighted skew option to obtain the at-site flood frequency estimates,



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Existing Methodology Review

- 2) Calculate the annual exceedance percent stream flows at stream gage site using the rural regression equation (RRE),
- 3) Weight the EMA estimate with the RRE estimate to improve the EMA at-site estimate.

The Dodge City, Kansas gage is located in hydrologic region 2 where the decreasing trend in peak stream flows have been observed. According to SIR 2017-5063 this trend is associated with the changes in groundwater withdrawals for irrigation use. The irrigation-affected region boundary was determined based on the spatial data layer depicting the irrigated land cover, the High Plains Aquifer boundary, and the distribution of stream gages with significant decreasing trends in peak stream flows. SIR 2017-5063 had determined the 25-inch mean precipitation contour from the 1981 to 2010 mean precipitation data is a good boundary separating the hydrologic region in Kansas. For the irrigation – affected region a set of generalized skew and regression equations were developed using only the post-irrigation flow record. Based on the reference used in the SIR 2017-5063, the SIR used 1978 as the starting year when the effect of irrigation is observed in the streams of western Kansas (hydrologic region 2).

The rural regression equations for estimating annual exceedance-probability (AEP) stream flows for streams in hydrologic region 2 in Kansas can be found in Table 8 in SIR 2017-5063.

For the irrigation affected region (hydrologic region 2) SIR 2017-5063 recommends calculating at station statistical moments using post-1978 flows and using weighted statistical moments to calculate the EMA based estimates. The regional statistical moments for the irrigation affected region (hydrologic region 2) are also calculated using post-1978 flow records. The details of the EMA and RRE peak discharge estimates weighting can be found in equation 5 in SIR 2017- 5063.



3.0 NEW HYDROLOGIC ANALYSES

Stantec evaluated four different approaches to estimate the 1% annual chance discharge of Arkansas River at Dodge City, Kansas. Three of the analyses performed were an update to methodologies from USACE and from SIR 2017-5053 using additional years of gage record (USACE 2009 and USGS 2017), and the fourth is to produce a modified statistical analysis using a mixed distribution methodology that suits streams in western Kansas. The fourth analysis used a statistical analysis approach to account for the low and zero flows in the annual peak flow record. The evaluated approaches are summarized below, and detailed methodologies are provided in the following sections:

- **Approach 1:** 17B analysis updated 2009 USACE Methodology with more years of supplemented stream gage data
- **Approach 2:** 17C analysis updated 2009 USACE Methodology with more years of supplemented stream gage data
- **Approach 3:** USGS Regression Methodology (SIR 2017-5063) using 17C analysis and post-1978 records weighted with rural regression equation (RRE) estimate
- **Approach 4:** Mixed distribution analysis methodology using the Bulletin 17C based analysis of the entire peak flow record dataset accounting for low flow outliers

3.1 USACE HYDROLOGIC FREQUENCY ANALYSIS METHODOLOGY UPDATES

Stantec's updated analysis only evaluated the recommended scenario from the USACE's 2009 hydrologic frequency analysis. This scenario used the continuous annual peak flow records for the Arkansas River at Dodge City, Kansas with the inclusion of the 1921-1941 annual peak flow extension from the Arkansas River at Syracuse, Kansas (68% reduction) and the omission of the annual peak flow at 1965 as a high outlier.

3.1.1 Reproduction of 2009 USACE 17B Analysis

In order to verify the effect of extending the record of gage data applied to the analysis, Stantec first attempted to recreate the original 2009 USACE 17B analysis. Stantec applied the same assumptions and dataset as reported in the 2009 report for Scenario 4, the preferred scenario:

- Dodge City gage data (continuous since 1942)
- Inclusion of 1921-1941 continuous dataset measured at Syracuse, KS (68% reduction applied)
- Omission of the 82,000 ft³/s peak from 1965
- Station Skew



DODGE CITY TECHNICAL ASSISTANCE HYDROLOGY STUDY

New Hydrologic Analyses

Stantec ran the analysis in HEC-SSP version 2.2 with the assumptions reported but could not produce percent annual chance exceedance discharges that matched the values reported in the 2009 USACE report.

The 2009 USACE study did not include the HEC-SSP report or simulation files in their deliverable (MIP 11-07-1997S), so Stantec was unable compare where the discrepancy in discharges originated.

Table 3 Discrepancy in Results for 2009 USACE 17B Analysis

	Description	1% annual chance discharge (ft ³ /s)
USACE (2009)	Continuous record since 1942, omission 82,000 ft ³ /s in 1965, inclusion of 1921-1941 records extension from Syracuse Kansas using Bulletin 17B	33,190
Stantec	Reproduction of USACE 2009 Analysis	28,015

3.1.2 Approach 1 – Extended 2009 USACE Methodology using 17B Methodology

Stantec's new analysis updated USACE's recommended methodology, USACE Scenario 4, by extending recorded annual peaks to the current period of record. The recorded annual peak flow for Arkansas River at Dodge City, Kansas stops at water year 2007. The updated analysis extended the period of record for Arkansas River at Dodge City, Kansas using peaks from the 2008-2017 observations for Arkansas River at Syracuse, Kansas. To be consistent with USACE's Scenario 4, in this analysis Stantec applied a 68% reduction from the peaks observed at Syracuse to estimate peaks at Dodge City for these water years and used Bulletin 17 B methodology. Stantec reports results from this (Bulletin 17B methodology) scenario as Approach 1.

For Approach 1, the station skew used was applied to match USACE'S 2009 Scenario 4. The low outlier test for the extended peak flow dataset is done using the single Grubbs-Beck method and Weibull plotting position is selected for this analysis. The HEC-SSP Bulletin 17B analysis result is shown in Figure 2. The 1% annual chance discharge estimate from Stantec's updated analysis, Approach 1, is 28,141 ft³/s.

Table 4 Approach 1 Results

	Description	1% annual chance discharge (ft ³ /s)
Approach 1	Continuous record since 1942, omission 82,000 ft ³ /s in 1965 inclusion of 1921-1941, 2008-2017 records extension from Syracuse Kansas using Bulletin 17B: USACE (2009) update	28,141



DODGE CITY TECHNICAL ASSISTANCE HYDROLOGY STUDY

New Hydrologic Analyses

The additional years of low flow data does not significantly affect the 1% annual chance discharge (compared to Stantec's reproduction of the 2009 analysis). The low flows added to the dataset do not fit well with the Log-Pearson Type III (LP III) distribution and fall outside of the 95% confidence interval.

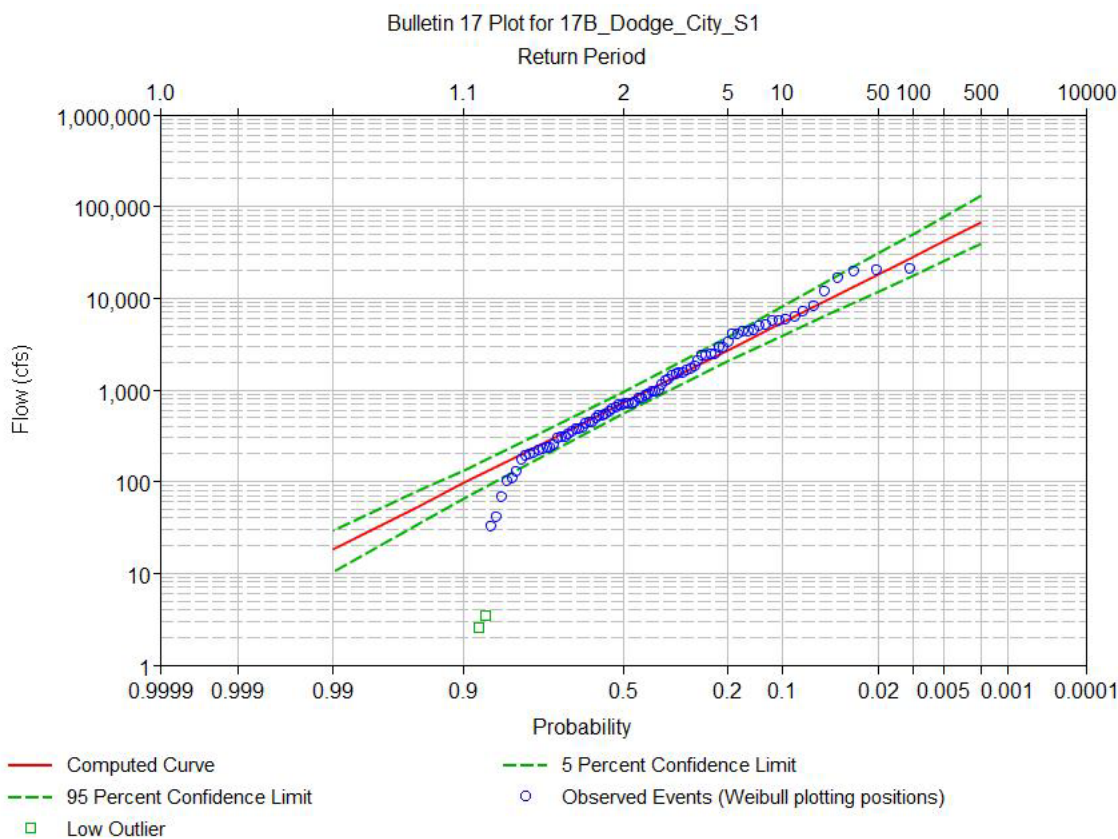


Figure 2 Analysis Result for Arkansas River at Dodge City, Kansas from Approach 1

3.1.3 Approach 2 – Extended 2009 USACE Methodology using 17C Methodology

The current recommended approach to perform flow frequency analysis using gage data is to perform EMA based statistical analysis using methodology outlined in the Bulletin 17C. Therefore, Stantec also updated the USACE's 2009 recommended approach, USACE Scenario 4, using Bulletin 17C methodology. The data set used in this analysis is the same extended records discussed above. Stantec reports results from Bulletin 17C methodology as Approach 2.

In Approach 2, Stantec used a weighted skew and the Hirsch/Stedinger plotting position as recommended in Bulletin 17C guidelines (England et al., 2018). Low outliers are screened using multiple Grubbs-Beck Test (MGBT) per Bulletin 17C guidelines. To be noted that Bulletin 17C guidance (England et al., 2018) recommends employing the Maintenance of Variance Extension (MOVE) technique for



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New Hydrologic Analyses

record extension for sites with short-record using nearby long-record sites along the same stream. This technique is different from the approach used in USACE's 2009 study. To stay consistent with USACE's study Stantec used the approach from USACE's 2009 study for record extension in Approach 2.

The Bulletin 17C analysis result is shown in Figure 3. The computed 1% annual chance discharge from Approach 2 is 29,190 ft³/s.

Table 5 Approach 2 Results

	Description	1% annual chance discharge (ft ³ /s)
Approach 2	Continuous record since 1942, omission 82,000 ft ³ /s in 1965, inclusion of 1921-1941, 2008-2017 records extension from Syracuse Kansas using Bulletin 17C	29,190

Like the 17B analysis, the additional years of low flow data resulted in a slight increase to the flow estimates for low frequency events (compared to Stantec's reproduction of the 2009 analysis). The 17C results in an increase in discharge due to more low flows being censored out from the fitted dataset by the MGBT methodology. Further, Bulletin 17C uses a different fitting method (EMA) resulting in the increase in the 1% annual chance discharge.

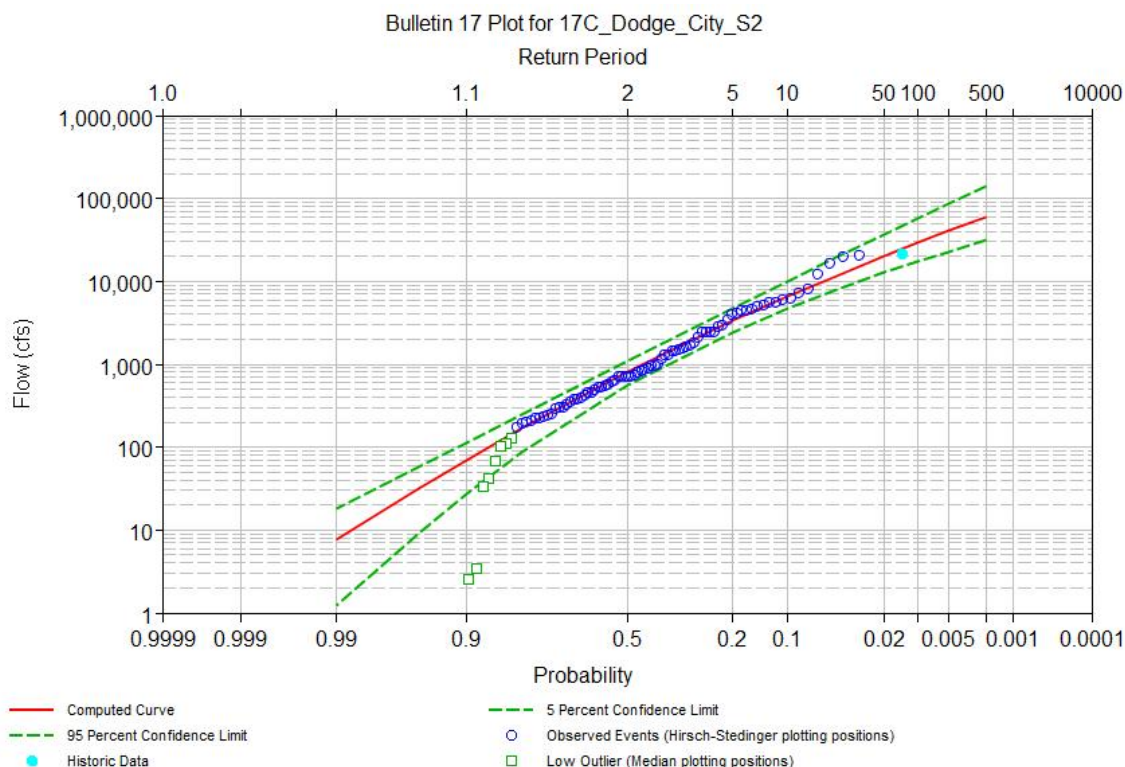


Figure 3 Analysis Results for Arkansas River at Dodge City, Kansas from Approach 2



3.2 USGS RURAL REGRESSION EQUATION METHODOLOGY

Another approach Stantec evaluated is RRE methodology for stream flows in Kansas. Stantec used the RRE for streams in hydrologic region 2 in western Kansas for this approach. This method is reported as Approach 3 in this study.

The methodology outlined in SIR 2017-5063, for application of Regression Models to predict the magnitude and frequency of peak flows at stream gage location is also implemented to evaluate 1% annual chance discharge for western Kansas. This methodology uses Bulletin 17C estimated at-site discharge for gaged streams and then adjusts the Bulletin 17C discharge with the RRE estimated discharge. The Bulletin 17C analysis for this approach only used post-irrigation annual peak flow records at the Arkansas River at Dodge City, Kansas, defined by SIR 2017-0563 as peak flows post 1978. During this period, the highest peak recorded at the Dodge City gage was 2,420 ft³/s in 1999. The low outliers were identified using multiple Grubbs-Beck test. Thirteen low outliers (lower than 109 ft³/s) and zero flows are identified and excluded from the Bulletin 17C analysis. The regional skew for hydrologic region 2 used to calculate weighted skew for this analysis is also developed using post-irrigation flow.

The Bulletin 17C analysis result for post-irrigation records is shown in Figure 4. The Bulletin 17C computed 1% annual chance discharge for Arkansas River at Dodge City, Kansas using only post irrigation annual peaks is 8,968 ft³/s. RRE based estimated 1% annual chance discharge for Arkansas River at Dodge City, Kansas from the Kansas hydrologic region 2 regression equation is 32,839 ft³/s. The weighted 1% annual chance discharge for Arkansas River at Dodge City, Kansas using methodology outlined in SIR 2017-5063 is 21,405 ft³/s. Table 6 shows the flows estimated using USGS RRE methodology.



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New Hydrologic Analyses

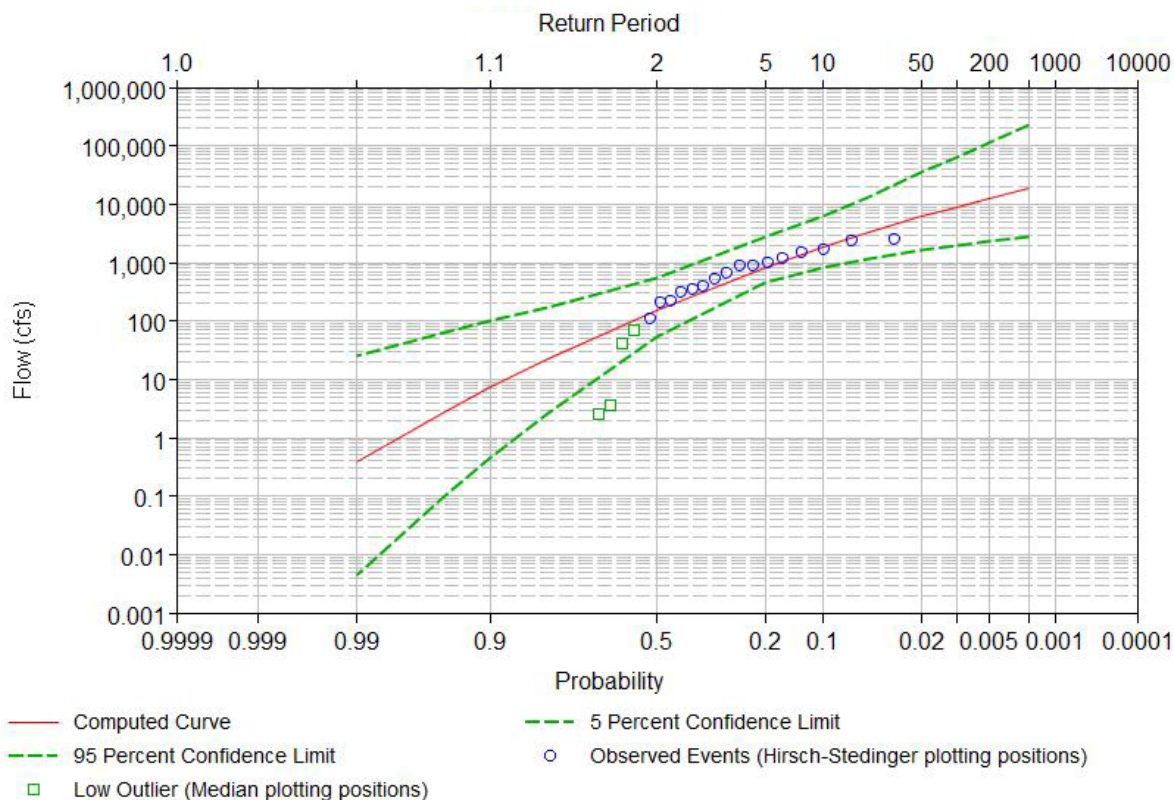


Figure 4 Analysis Results for Arkansas River at Dodge City, Kansas for Approach 3

Table 6 Approach 3 Results

	Description	1% annual chance discharge (ft ³ /s)
Approach 3	Post 1978 records analysis using Bulletin 17C	8,968
	Regression equation estimate	32,839
	Weighted gage analysis flow with RRE estimate	21,405

In cases of gage records where the difference between the regional and station skews is more than 0.5, Bulletin 17C guideline (England et al., 2018) recommends consideration of record length, the largest floods within the gaging record and watershed, and watershed characteristics to evaluate whether greater weight need to be given to the station skew. SIR 2017-5063 however, recommends using weighted skew for Bulletin 17C analysis. Since Approach 3 is the analysis based on USGS RRE methodology, as recommended by SIR 2017-5063, weighted skew is used to estimate the Bulletin 17C based estimate.

The RREs for hydrologic region 2 were developed based on unregulated gage locations with contributing drainage areas between 1.31 to 3,555 mi². The regulated stream gages along the Arkansas River are therefore, not the ideal condition for applying regression equations. In addition, the contributing drainage



area of the Arkansas River at Dodge City is 25,017 mi² which is outside of the range used to develop the regression equations in hydrologic region 2. Applying the RRE to a location outside of the intended contributing drainage area criteria introduces additional uncertainty to the results. Due to these reasons the Arkansas River at Dodge City, Kansas is not an appropriate location for the application of the USGS regression equations.

3.3 MIXED DISTRIBUTION ANALYSIS OF STREAM GAGE DATA

The Arkansas River at Dodge City, Kansas has experienced low and zero peaks in recent years. From the local hydrologic publications and feedback from coordination with stakeholders, these low and zero flows are not from the meteorological changes but are due to the effect of irrigation in western Kansas and other hydrologic features, factors and hydrologic changes in the region in the recent past. Therefore, the low and zero flows should not be ignored when performing flood frequency analysis to estimate peak flows. Stantec performed distribution analyses to develop a flood frequency analysis methodology applicable for the gages in western Kansas that might have observed similar trend in annual peak flows like Arkansas river at Dodge City, Kansas. In these analyses Stantec used the recorded peak flow dataset continuous since 1942 for the Arkansas River at Dodge City with an omission of the 82,000 ft³/s peak flow recorded in 1965.

Several distribution models common in the statistical literature and recommended for flood frequency analysis in many countries (Hassan et al., 2019) were evaluated to check the goodness of fit of the entire recorded peak flows for Arkansas River at Dodge City. The distributions evaluated were three-parameter log-normal (LN) distribution, Gumbel (GUM) distribution, generalized extreme value (GEV), Log Pearson Type III (LP III), and Log-logistic (L-Logis) distribution. To use the log transform to fit the dataset with LN, LP III, and L-Logis distributions, the 0 cfs flow in the dataset was replaced with 0.1 cfs. The goodness-of-fit criteria, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were estimated for these distributions. Stantec's evaluation found that the Log Pearson Type III (LP III) distribution is the best-fit function for the Arkansas River's annual peak flows at the Dodge City, Kansas. The AIC and BIC values for LP III distribution for Arkansas River at Dodge City are 965 and 971. The plot of different distributions for the recorded annual peak stream flows at Arkansas River at Dodge City is shown in Figure 5.



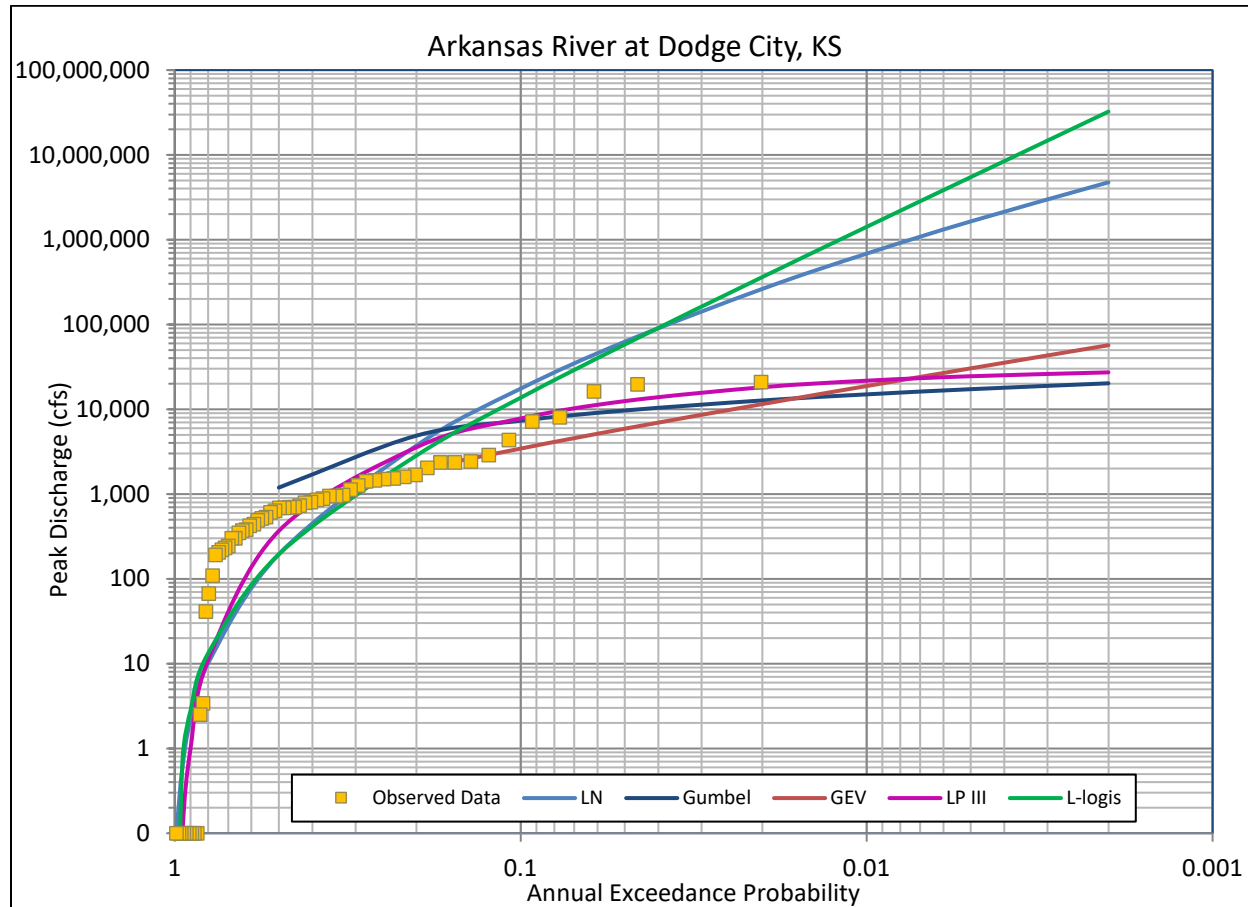


Figure 5 Goodness-of-fit of Different Distributions for Arkansas River at Dodge City, Kansas for Approach 4

From Figure 5 it can be observed, none of the distributions evaluated fit the high frequency flow data very well. Our analysis demonstrated despite upstream flow regulation Log Pearson III (LP III) is the distribution that best fit the Arkansas River at Dodge City peak flow dataset. Contrary to the usual expectation under a regulated flow condition, this distribution does not underestimate extreme events for the gage at the Arkansas River at Dodge City. In addition, the methodology implemented customizes the distribution to best fit the dataset thus, any deviation from the selected distribution due the regulation is also addressed.

To better account for the low and zero flows in the record and improve the distribution fitting performance, a mixed probability distribution was considered to estimate the annual frequency flows for Arkansas River at Dodge City, Kansas.

In Approach 4, Stantec analyzed the annual peak flow dataset to identify a probability distribution that best fit the period of record. Consistent with USACE 2009 study, Stantec used the continuous Dodge City gage record (since 1942) and omitted the peak record 82,000 ft³/s as a high outlier from the analysis. As discussed in the previous section, the data demonstrates a single continuous distribution is not a good predictor for all the flow frequencies. Thus, the flow frequency for the Arkansas River at Dodge City and



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likely other gages with similar flow trend in western Kansas are considered to demonstrate a mixed probability distribution. High frequency flows likely follow some discrete probability distribution. Low frequency flows follow a continuous distribution, as observed from Stantec's distribution analysis.

The mixed distribution approach also captures the effects from the regulation due to the upstream reservoir. The high frequency low flows likely contained by the dam are considered to fit a discrete distribution. The low frequency high flows that are not contained by the dam have its own distribution. Therefore, the respective distributions capture each case. Stantec did not attempt to fit a distribution for high frequency flows since the primary objective of this project is to develop a methodology to estimate 1% annual chance peak flow.

To develop the methodology for low frequency flows, Stantec used HEC-SSP to perform the Bulletin 17C analysis to produce a continuous portion of the distribution. Multiple Grubbs-Beck Test (MGBT) was used to identify the lower outliers from the entire dataset. MGBT identified thirteen outliers, they included low and zero flows which are lower than the critical value of 109 ft³/s. These data points are screened out as low flows and are considered to not follow the continuous probability distribution.

The probability density function (pdf) and cumulative distribution function (CDF) of the mixed distribution were evaluated. The quantile function in terms of the exceedance probability P_E for a mixed distribution is:

$$Q_{P_E} = P_{Q_c}^{-1} \left(\frac{1 - P_E - P(\text{low outlier})}{1 - P(\text{low outlier})} \right)$$

Where $P(\text{low outlier})$ is the non-exceedance probability of flows lower than the critical flow value. This equals to a value obtained by dividing the number years of low flow (number of outliers) by the number of years considered. The domain of the exceedance probability is expressed as:

$$1 - P(\text{low outlier}) \geq P_E \geq 0.$$

The details on probability density function (pdf) and cumulative distribution function (CDF) of the mixed distribution can be found in Appendix A.

As discussed in previous sections, LP III distribution is a good fit to predict extreme events for the Arkansas River at Dodge City. Therefore, to estimate a peak flow for a given exceedance probability for a mixed distribution, a continuous portion of the mixed distribution is developed using HEC-SSP. However, HEC-SSP reports exceedance probability and corresponding discharge estimates by calculating quantile function from the CDF curve that ignores the probabilities of low outliers, see Figure 6. The quantile functional argument for the continuous distribution is expressed as $(1 - P_{E_fit})$. P_{E_fit} is the exceedance probability reported by HEC-SSP based on continuous distribution where probabilities of the outliers are ignored.



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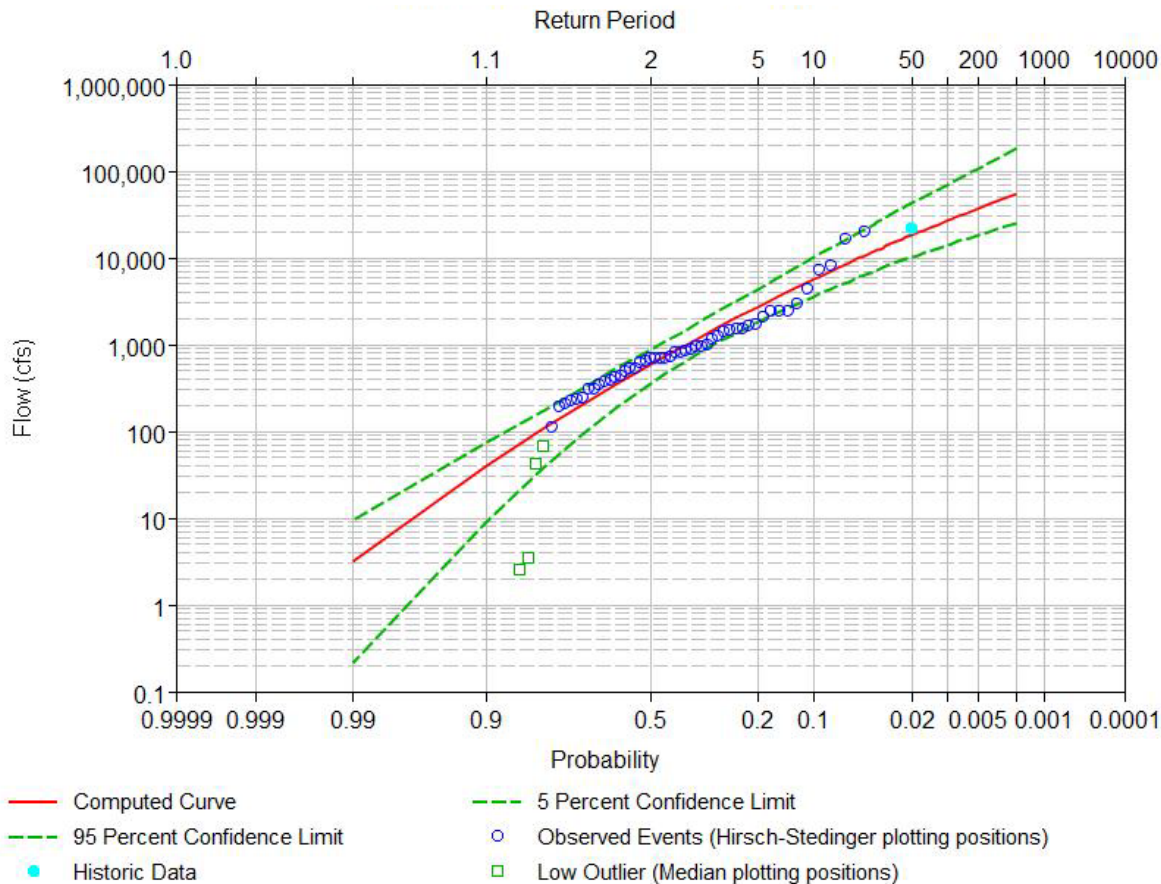


Figure 6 Fitted Continuous Distribution Analysis Results for Arkansas River at Dodge City, Kansas for Approach 4

In order to produce a mixed distribution adjusted CDF curve, the analysis should account for the probabilities of the low outliers. The argument of the continuous segment of the mixed distribution for the uncensored dataset is $\left(\frac{1 - P_{E_{mix}} - P(\text{low outlier})}{1 - P(\text{low outlier})}\right)$. Where $P_{E_{mix}}$ is the exceedance probability of the adjusted CDF (mixed distribution) where probabilities of low outliers are not ignored. HEC-SSP does not report the quantile function of the mixed distribution. In order to continue use of HEC-SSP to produce frequency discharge estimates based on a mixed distribution, Stantec developed an equation to adjust the HEC-SSP output. This can be done by a simple calculation to estimate quantiles of the mix distribution at different annual exceedance probabilities from the adjusted CDF curve.

The HEC-SSP reported quantile function is shifted using the following equation to give the weight to the low flows. The equation was developed based on the relationship of the arguments of the HEC-SSP fitted continuous distribution and mixed continuous distribution

$$1 - P_{E_{fit}} = \frac{1 - P_{E_{mix}} - P(\text{low outlier})}{1 - P(\text{low outlier})}$$



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This equation can be rewritten as:

$$P_{E_fit} = \frac{P_{E_mix}}{1 - P(low\ outlier)}$$

The quantiles (peak discharge estimate) of the mixed continuous distribution with a given exceedance probability P_{E_mix} can be estimated from the fitted continuous distribution at corresponding exceedance probability P_{E_fit} which equal to $\frac{P_{E_mix}}{1 - P(low\ outlier)}$. This low outliers' non-exceedance probability varies by gage. The $P(low\ outlier)$ for Arkansas River at Dodge City, Kansas is 0.210 (13/62). The HEC-SSP fitted and adjusted (mix) distributions are shown in Figure 7. For the 1% annual chance discharge based on the mixed distribution, the P_{E_mix} is 0.01. The corresponding P_{E_fit} for the HEC-SSP reported fitted CDF continuous distribution is 0.01265 calculated using the equation above. This equation can be used to calculate the corresponding P_{E_fit} values for any P_{E_mix} . HEC-SSP "Output Frequency Ordinate" table can be customized to report the select P_{E_fit} values for desired P_{E_mix} values. The 1% annual chance discharge for Arkansas River at Dodge City, Kansas Approach 4, is 23,694 ft³/s.

Table 7 Approach 4 Results

	Description	1% annual chance discharge (ft ³ /s)
Approach 4	Continuous record since 1942, omission 82,000 ft ³ /s in 1965 using Bulletin 17C, then shifted to weight the low flows (mixed distribution)	23,694



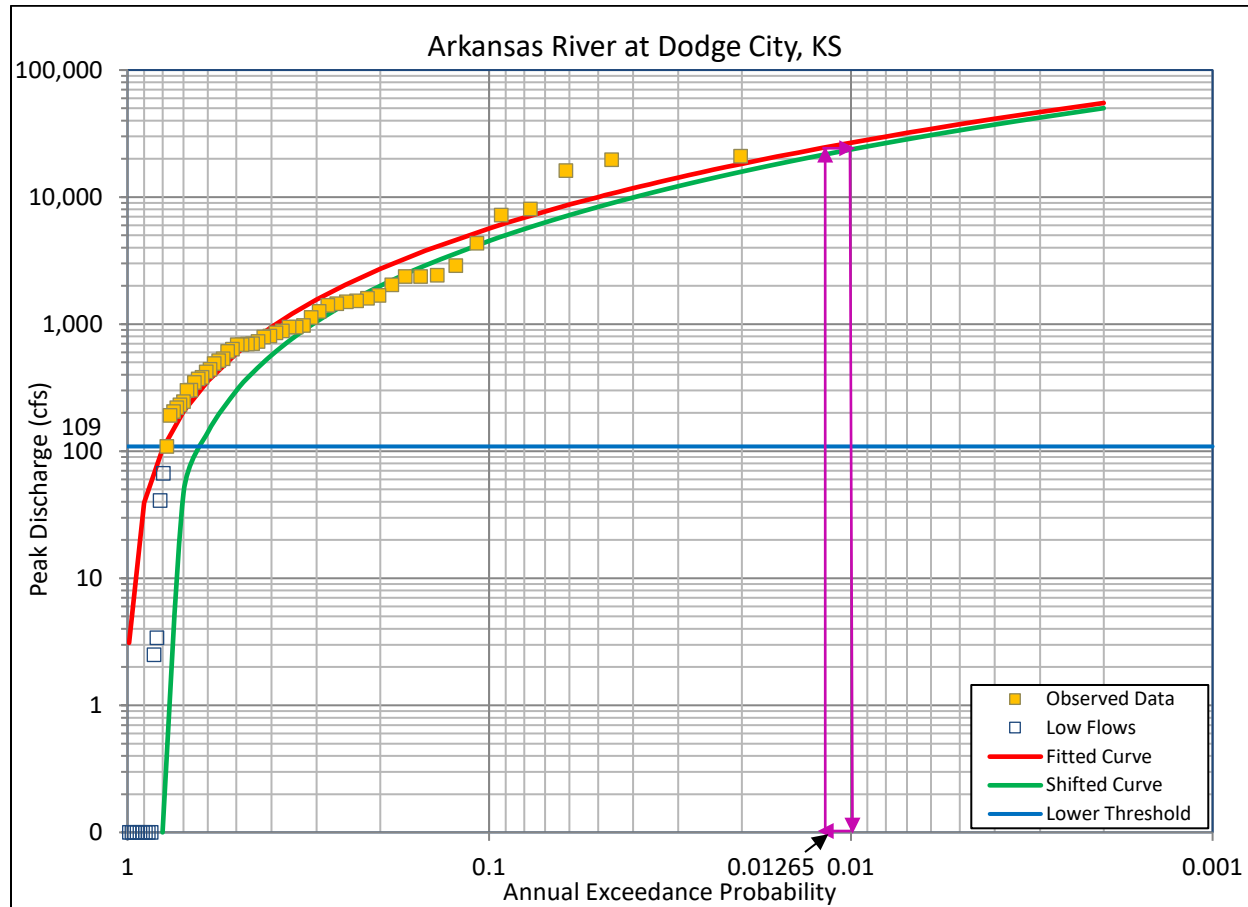


Figure 7 Continuous Distribution Analysis Results for Arkansas River at Dodge City, Kansas for Approach 4

The adjusted (mixed) continuous distribution curve generated using a fitted continuous distribution, that censors the low outliers, is only applicable to estimate the low frequency flows ($P_{E_mix} < P(\text{low outlier})$). The high frequency flows do not fit the continuous distribution and are presumed to have a discrete distribution. For Arkansas River at Dodge City, Kansas the exceedance probability for these high frequency (low outlier) flows is higher than 80%. The maximum lower outliers allowed to be censored in HEC-SSP using Bulletin 17C is flows with 0.5 probability. Thus, for any given gage the discrete distribution is a predictor of flows with frequencies higher than 50%. The objective of the project is not to develop a methodology to estimate high frequency flows. Therefore, this study did not attempt to fit the discrete distribution for low flows.

As discussed in Section 3.2, In cases of gage records where the difference between the regional and station skew is more than 0.5, Bulletin 17C guideline (England et al., 2018) recommends consideration of record length, the largest floods within the gaging record and watershed, and watershed characteristics to evaluate whether greater weight need to be given to the station skew. As discussed in previous sections



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the Arkansas River at Dodge City is heavily affected by regional hydrologic factors that are less likely to be addressed appropriately by statistical moments at a single gage station. In order to account for possible influence from these hydrologic factors, regional skew value was not ignored in the analysis. Thus, the weighted skew value is used in the analyses for Approach 4 despite the difference between the regional skew and station skew for this gage being higher than 0.5.

3.4 EFFECT ON ARKANSAS RIVER BASE FLOOD ELEVATIONS

The results of all four approaches were applied to the 1D, steady-state HEC-RAS model of the Arkansas River developed by AMEC (2013) to evaluate the effect the resulting discharges have on the base flood elevations (BFEs) along the Dodge City Levees. The profile of each approach along the leveed portion of the river are shown below in Figure 8 and reported in Table 8. The water surface elevation grids of the approaches are also included in the deliverable.

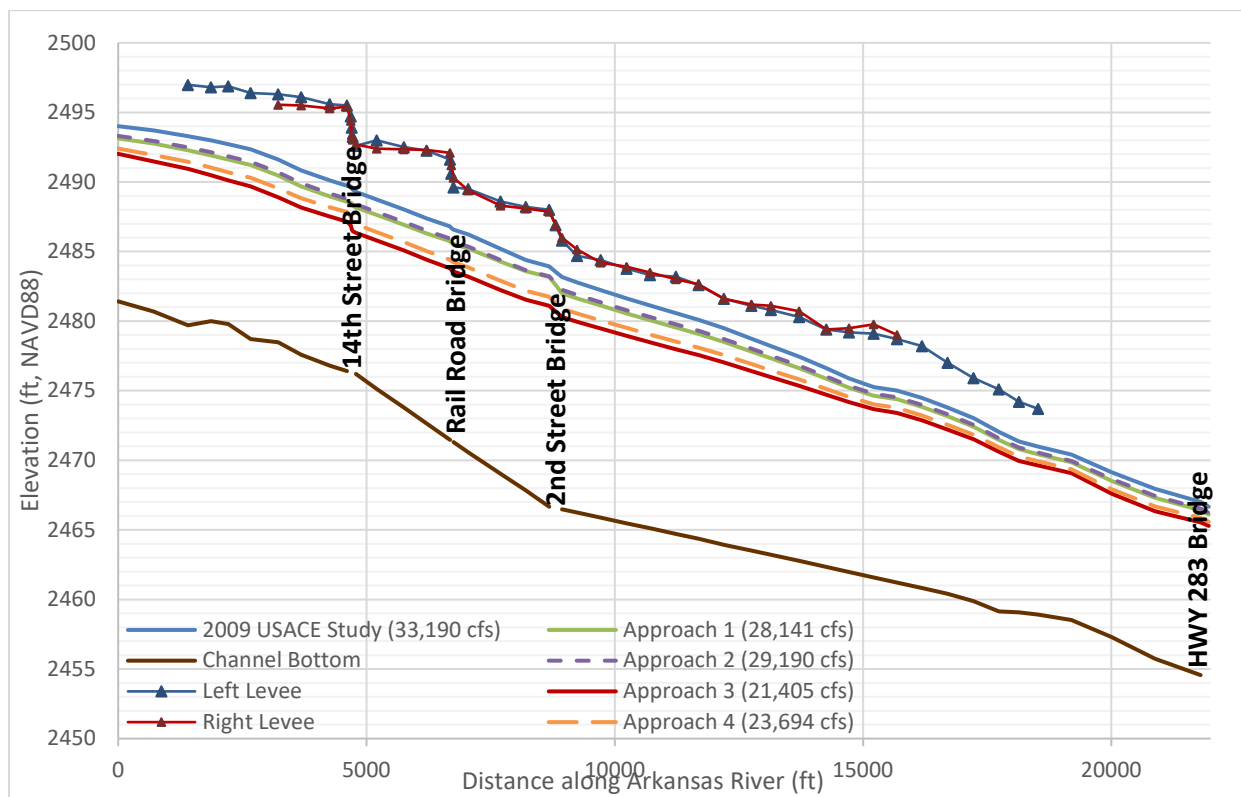


Figure 8 Comparison of Base Flood Elevations along Dodge City Levees for Analyzed Approaches



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Table 8 Comparison of Base Flood Elevations along the Dodge City Levees for Analyzed Approaches

Station Along Arkansas River (ft, Fig 8)	Elevation (ft, NAVD88)						
	2009 USACE Study 33,190 cfs	Approach 1 28,141 cfs	Approach 2 29,190 cfs	Approach 3 21,405 cfs	Approach 4 23,694 cfs	Left Levee	Right Levee
0	2494.0	2493.1	2493.3	2492.0	2492.4	-	-
718	2493.7	2492.8	2493.0	2491.5	2491.9	-	-
1406	2493.3	2492.3	2492.5	2491.0	2491.4	2497.0	-
1868	2493.0	2491.9	2492.1	2490.5	2491.0	2496.8	-
2217	2492.7	2491.6	2491.8	2490.1	2490.7	2496.9	-
2666	2492.4	2491.2	2491.5	2489.7	2490.3	2496.4	-
3220	2491.6	2490.5	2490.7	2488.9	2489.5	2496.3	2495.6
3688	2490.8	2489.7	2489.9	2488.2	2488.8	2496.1	2495.5
4259	2490.1	2489.0	2489.2	2487.5	2488.2	2495.6	2495.3
4608	2489.7	2488.6	2488.8	2487.2	2487.8	2495.5	2495.4
4684	2489.7	2488.5	2488.7	2486.9	2487.5	2494.7	2494.4
4704	2489.6	2488.5	2488.7	2486.6	2487.2	2493.9	2493.4
4721	2489.5	2488.3	2488.5	2486.5	2487.1	2493.3	2493.0
4789	2489.3	2488.2	2488.4	2486.4	2487.0	2492.6	2492.7
5208	2488.7	2487.6	2487.8	2485.8	2486.4	2493.0	2492.4
5754	2488.0	2486.9	2487.1	2485.1	2485.7	2492.5	2492.4
6211	2487.4	2486.3	2486.5	2484.4	2485.0	2492.3	2492.3
6682	2486.8	2485.8	2485.9	2483.8	2484.4	2491.6	2492.1
6712	2486.7	2485.7	2485.8	2483.7	2484.3	2490.6	2491.2
6751	2486.6	2485.6	2485.7	2483.6	2484.2	2489.6	2490.3
7053	2486.2	2485.2	2485.4	2483.2	2483.9	2489.5	2489.4
7704	2485.2	2484.3	2484.4	2482.2	2482.9	2488.6	2488.3
8212	2484.4	2483.6	2483.7	2481.5	2482.2	2488.2	2488.1
8678	2483.9	2483.2	2483.2	2481.1	2481.7	2488.0	2487.9
8813	2483.5	2482.6	2482.7	2480.7	2481.3	2486.9	2486.9
8941	2483.2	2482.0	2482.3	2480.3	2480.9	2485.8	2486.0
9242	2482.8	2481.6	2481.9	2480.0	2480.6	2484.7	2485.2
9718	2482.2	2481.1	2481.4	2479.5	2480.1	2484.4	2484.2
10239	2481.6	2480.6	2480.8	2478.9	2479.5	2483.8	2483.9
10710	2481.1	2480.1	2480.3	2478.5	2479.0	2483.3	2483.5
11235	2480.6	2479.5	2479.8	2478.0	2478.5	2483.2	2483.0
11691	2480.1	2479.1	2479.3	2477.6	2478.1	2482.6	2482.7
12202	2479.5	2478.5	2478.7	2477.0	2477.6	2481.6	2481.6



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Station Along Arkansas River (ft, Fig 8)	Elevation (ft, NAVD88)						
	2009 USACE Study 33,190 cfs	Approach 1 28,141 cfs	Approach 2 29,190 cfs	Approach 3 21,405 cfs	Approach 4 23,694 cfs	Left Levee	Right Levee
12754	2478.7	2477.8	2478.0	2476.4	2476.9	2481.1	2481.2
13146	2478.2	2477.3	2477.5	2476.0	2476.5	2480.8	2481.1
13712	2477.5	2476.6	2476.8	2475.4	2475.8	2480.3	2480.7
14263	2476.6	2475.9	2476.0	2474.7	2475.1	2479.4	2479.4
14721	2475.9	2475.2	2475.4	2474.2	2474.5	2479.2	2479.5
15216	2475.3	2474.6	2474.8	2473.7	2474.0	2479.1	2479.8
15683	2475.0	2474.4	2474.5	2473.4	2473.8	2478.7	2479.0
16188	2474.5	2473.8	2474.0	2472.9	2473.2	2478.2	-
16705	2473.8	2473.2	2473.3	2472.2	2472.6	2477.0	-
17225	2473.0	2472.4	2472.6	2471.5	2471.8	2475.9	-
17737	2472.0	2471.5	2471.6	2470.6	2470.9	2475.1	-
18140	2471.4	2470.8	2470.9	2470.0	2470.3	2474.2	-
18526	2471.0	2470.4	2470.6	2469.6	2469.9	2473.7	-
19200	2470.4	2469.9	2470.0	2469.1	2469.3	-	-
20002	2469.1	2468.5	2468.7	2467.6	2467.9	-	-
20883	2467.9	2467.3	2467.4	2466.3	2466.7	-	-
21799	2467.0	2466.4	2466.5	2465.5	2465.9	-	-
21963	2466.7	2466.1	2466.2	2465.3	2465.9	-	-



3.5 RECOMMENDATION

The 1% annual chance discharge estimates for Arkansas River at Dodge City, Kansas using different methodologies (approaches) evaluated in this study are summarized in Table 9. With considerations of various factors in all four approaches evaluated in this study, Stantec recommends flow frequency analysis using Bulletin 17C methodology to fit a mixed distribution LP III CDF curve (Approach 4) to estimate extreme flows at gages in western Kansas that has observed low and zero flows due to effects from local anthropogenic and hydrologic conditions.

Stantec recommends Approach 4 due to following drawbacks in assumptions in the other approaches.

- 1) In Approaches 1-3 the low and zero flows in the peak flow records are identified as lower outliers and removed from the analysis. These lower outliers are the recorded flows at the gage locations in western Kansas, from review of local publications and feedback from stakeholders streams flow in western Kansas are influenced by effects of irrigation and other hydrologic features which might reduction in stream flow due to ground water recharge. These low flows should be accounted in flow frequency analysis in this region.
- 2) The stream gage analysis in Approaches 1 and 2 does not account for the effect from the reservoir regulation thus, are not appropriate for regulated streams.
- 3) The USGS regression equation method (Approach 3) is only applicable for streams not substantially affected by flow regulation. In addition, USGS regression equations for western Kansas are intended for locations with contributing drainage areas between 1.02 to 3,555 mi². For streams which are affected by regulation and/or with contributing drainage areas outside of the range used to develop the western Kansas regression equation, like the gage at Arkansas River at Dodge City, the method used in Approach 3 is not appropriate. However, the methodologies outlined in SIR 2017-5063 are applicable for sites that are not affected by flow regulation and are within the applicable drainage area range.

Approach 4, the methodology recommended, evaluated various distributions to check the goodness of fit then customized the probability distribution to best fit the data. It assumes a single continuous distribution may not be a good predictor of all flow frequencies. This gives a freedom to define an appropriate distribution for the flow frequency of interest. It accounts for low flows that are likely due to hydrologic conditions in this region rather than instrument malfunction. The possibility to make adjustments to the CDF curve based on observed data addresses unique hydrologic conditions of the stream under evaluation. It is worth noting, though unlikely, different streams may demonstrate a continuous distribution function different from that used for the Arkansas River at Dodge City due to its unique hydrologic conditions. In these situations, Stantec recommends updating the adjustment formula as needed. In most situations, the equation in Section 3.3 of can be used to calculate the exceedance probability for mixed distribution using HEC-SSP Bulletin 17C fitted distribution for low outlier censored data for other gages in western Kansas:

$$P_{E_{fit}} = \frac{P_{E_{mix}}}{1 - P(\text{low outlier})}$$



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While Stantec did not extend the gage record in Approach 4, it is recommended to apply the MOVE technique (as outlined in Bulletin 17C) if gage data extension is used at other sites in western Kansas while using the Approach 4 methodology.

The 1% annual chance flow from Stantec's recommended approach (Approach 4/ mixed distribution) for Arkansas River at Dodge City, Kansas is 23,694 ft³/s.

Table 9 1% Annual Chance Discharge at Dodge City, Kansas for Different Approaches

	Description	1% annual chance discharge (ft ³ /s)	Difference (%)
Effective Study	Effective FIS for Ford County Kansas and Incorporated Areas. All records during 1903-1991 using Bulletin 17B	49,900	Reference
USACE (2009)	Continuous record since 1942, omission 82,000 ft ³ /s in 1965, inclusion of 1921-1941 records extension from Syracuse Kansas using Bulletin 17B	33,190	-33.5
Stantec	Reproduction of 2009 USACE 17B analysis	28,015	-44.9
Approach 1	Continuous record since 1942, omission 82,000 ft ³ /s in 1965, inclusion of 1921-1941, 2008-2017 records extension from Syracuse Kansas using Bulletin 17B: USACE (2009) update	28,141	-43.6
Approach 2	Continuous record since 1942, omission 82,000 ft ³ /s in 1965, inclusion of 1921-1941, 2008-2017 records extension from Syracuse Kansas using Bulletin 17C: USACE (2009) update	29,190	-41.5
Approach 3	SIR 2017-5063: Weighted post 1978 gage analysis flow with RRE estimate	21,405	-57.1
Approach 4	Continuous record since 1942, omission 82,000 ft ³ /s in 1965 using Bulletin 17C, then shifted to weight the low flows (mixed distribution)	23,694	-52.5



4.0 REFERENCES

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APPENDIX A

Mixed Probability Distribution

Appendix A

A.1 MIXED PROBABILITY DISTRIBUTION

In Approach 4 Stantec analyzed the annual peak flow dataset to identify a probability distribution that best fit the period of record. Consistent with USACE 2009 study, Stantec used the continuous record for the gage and omitted the peak record 82,000 ft³/s as a high outlier from the analysis. As discussed in pervious section, the data demonstrates a single continuous distribution is not a good predictor of all the flow frequencies. Thus, the flow frequency for Arkansas River at Dodge City and likely other gages with similar flow trend in western Kansas are considered to demonstrate a mixed probability distribution. High frequency flow likely follows some discrete probability distribution. Low frequency flow follows a continuous distribution, as observed from Stantec's distribution analysis.

Stantec used HEC -SSP to perform the Bulletin 17C analysis to produce a continuous portion of the distribution. Multiple Grubbs-Beck Test (MGBT) was used to identify the lower outliers from the entire dataset. MGBT identified thirteen outliers, they included low and zero flows which are lower than the critical value of 109 ft³/s. These data points are screened out as low flows and are considered to not follow the continuous probability distribution. The continuous distribution of the peak flow, Q_c , where Q_c only has non-outlier flow values (≥ 109 ft³/s) is analyzed. The probability density function (pdf) of Q_c is $p_{Q_c(Q)}$. The cumulative distribution function (CDF) of Q_c is:

$$P(Q \leq q) = P_Q(Q) = \int_0^q p_{Q_c(Q)} dQ$$

The quantile function in terms of the exceedance probability P_E is:

$$Q_{P_E} = P_{Q_c}^{-1}(1 - P_E)$$

In case of a mixed distribution, we analyze the distribution of the annual peak flows included the low and zero flows. The annual peak flows of the mixed distribution is Q , where Q has all flow values. The annual peak flows of the continuous segment of the mixed distribution is Q_c , where Q_c only has non-outlier flow values (≥ 109 ft³/s).

The probability density function (pdf) and cumulative distribution function (CDF) of the mixed distribution were evaluated. The probability density function (pdf) of Q , where Q has all the record flow values, is:

$$p_Q(Q) = \delta(Q)P(\text{low outlier}) + (1 - P(\text{low outlier}))p_{Q_c(Q)}$$

Where $P(\text{low outlier})$ is the non-exceedance probability of flows lower than the critical flow value. This equals to a value obtained by dividing the number years of low flow (number of outliers) by the number of years of considered. This function consists of a discrete probability of lower flow (< 109 ft³/s) $\delta(Q)P(\text{low outlier})$ and plus a continuous distribution of flow for high flow $p_{Q_c(Q)}$.



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The cumulative distribution function (CDF) of Q is:

$$P(Q \leq q) = P_Q(Q) = P(\text{low outlier}) + (1 - P(\text{low outlier})) \int_0^q p_{Q_c(Q)} dQ$$

The quantile function in terms of the exceedance probability P_E is:

$$Q_{P_E} = P_{Q_c}^{-1} \left(\frac{1 - P_E - P(\text{low outlier})}{1 - P(\text{low outlier})} \right)$$

The domain of the exceedance probability is expressed as:

$$1 - P(\text{low outlier}) \geq P_E \geq 0.$$

In order to produce a mixed distribution adjusted CDF curve, the analysis should account for the probabilities of the low outliers. The argument of the continuous segment of the mixed distribution for the uncensored dataset is $\left(\frac{1 - P_{E_{mix}} - P(\text{low outlier})}{1 - P(\text{low outlier})} \right)$. $P_{E_{mix}}$ is the exceedance probability of the adjusted CDF (mixed distribution) where probabilities of low outliers are not ignored. HEC-SSP does not report the quantile function of the mixed distribution. In order to continue use of HEC-SSP to produce frequency discharge estimate based on mixed distribution, Stantec devised an equation to adjust the HEC-SSP output. This can be done by simple calculation to estimate quantiles of the mix distribution at different annual exceedance probabilities from the adjusted CDF curve.

The HEC-SSP reported quantile function is shifted using the following equation to give the weight to the low flows. The equation was developed based on the relationship of the arguments of the HEC-SSP fitted continuous distribution and mixed continuous distribution

$$1 - P_{E_{fit}} = \frac{1 - P_{E_{mix}} - P(\text{low outlier})}{1 - P(\text{low outlier})}$$

This equation can be rewritten as:

$$P_{E_{fit}} = \frac{P_{E_{mix}}}{1 - P(\text{low outlier})}$$

The quantiles (peak discharge estimate) of the mixed continuous distribution with a given exceedance probability $P_{E_{mix}}$ can be estimated from the fitted continuous distribution at corresponding exceedance probability $P_{E_{fit}}$ which equal to $\frac{P_{E_{mix}}}{1 - P(\text{low outlier})}$. This low outliers' non-exceedance probability varies by gage. The $P(\text{low outlier})$ for Arkansas River at Dodge City, Kansas is 0.210 (13/62). For the 1% annual chance discharge based on the mixed distribution, the $P_{E_{mix}}$ is 0.01. The corresponding $P_{E_{fit}}$ for the HEC-SSP reported fitted CDF continuous distribution is 0.01265 calculated using above equation. Above equation can be used to calculate the corresponding $P_{E_{fit}}$ values for any $P_{E_{mix}}$. HEC-SSP "Output Frequency Ordinate" table can be customized to report the select $P_{E_{fit}}$ values for desired $P_{E_{mix}}$ values. The 1% annual chance discharge for Arkansas River at Dodge City, Kansas using this mixed distribution methodology is 23,694 ft³/s.



APPENDIX B

HEC-SSP Results

