Appendix D: Flood Frequency Analysis for Paleoflood Analysis, Mojave River Dam

Introduction

Flood frequency analysis is a statistical method of prediction that consists of studying past flood events that are characteristic of a particular hydrologic process(es) in order to estimate the exceedance probabilities of flood events. When considered in a statistically appropriate manner, paleoflood information can improve the estimation of exceedance probabilities of large, infrequent floods by constraining uncertainties and improving confidence in best estimates in the timing and magnitude of flood flows. Several flood frequency analyses for Mojave River Dam were performed using systematic, historical, and paleoflood data. Subsequent sensitivity analyses were conducted in order to quantify the relative impacts of each data source, including the use of regional skew information, various 1862 flood discharges, and various PSI age interpretations.

All flood frequency analyses in this report were performed using Bulletin 17C (B17C) procedures (England, et al., 2019). Within B17C methodology, the moments/parameters of the Log Pearson Type III (LPIII) distribution are estimated using the Expected Moments Algorithm (EMA), which can incorporate non-standard, censored, and/or historical data simultaneously (Cohn, Lane, & Baier, 1997). The use of B17C methodology also provides improved confidence intervals that incorporate diverse information appropriately as historical data and censored values can impact the uncertainty in the estimated frequency curve (Cohn, Lane, & Stedinger, 2001). When using EMA, every annual peak flow in the analysis period, whether observed or not, is represented by a flow range. Each year within the analysis period also requires a perception threshold. Finally, the Multiple Grubbs-Beck (MGB) test is used to identify low outliers or potentially influential low floods, which require special treatment to prevent exerting excessive influence on the parameterization of the flood frequency distribution. The following sections describe the various sources of data that were used, flood frequency analyses that were performed, and subsequent sensitivity analyses.

Flood Frequency Data

Multiple sources of flow and stage data were investigated for use within this analysis including U.S. Geological Survey (USGS) and USACE stream/reservoir gages in addition to previously published reports. Unless otherwise mentioned, all data is for an instantaneous peak duration.

USGS Stream Gages

The USGS operates multiple stream gages both upstream and downstream of the Mojave River Dam. Additionally, several inactive gages were historically located upstream of Mojave River Dam that are of interest to this study. Pertinent information for these gages is shown within Table D-1 while they are located within Figure D-1.

Table D-1. Pertinent Data for USGS Stream Gages near Mojave River Dam

Gage Number	Gage Name	Begin Date	End Date	Drainage Area (sq mi)
10260500	Deep C Nr Hesperia CA	3/13/1905	Current	134

Gage Number	Gage Name	Begin Date	End Date	Drainage Area (sq mi)
10260550	WF Mojave R Ab Silverwood Lake Nr Hesperia CA	10/1/1995	Current	3
10260700	EF of WF Mojave R Ab Silverwood Lk Nr Hesperia CA	10/1/1995	Current	11
10260820	WF Mojave R Bl Silverwood Lk CA	10/1/1980	Current	34
10260855	Grass Valley Lk Tunnel Outlet A Lake Arrowhead CA	10/1/2008	Current	0
10260950	WF Mojave R Ab Mojave R Forks Res Nr Hesperia CA	3/8/1975	Current	70
10261000	WF Mojave R Nr Hesperia CA	3/5/1907	11/29/1970	70
10261100	Mojave R Bl Forks Res Nr Hesperia CA	10/1/1971	9/29/1997	209
10261500	Mojave R A Lo Narrows Nr Victorville CA	3/1/1899	Current	513

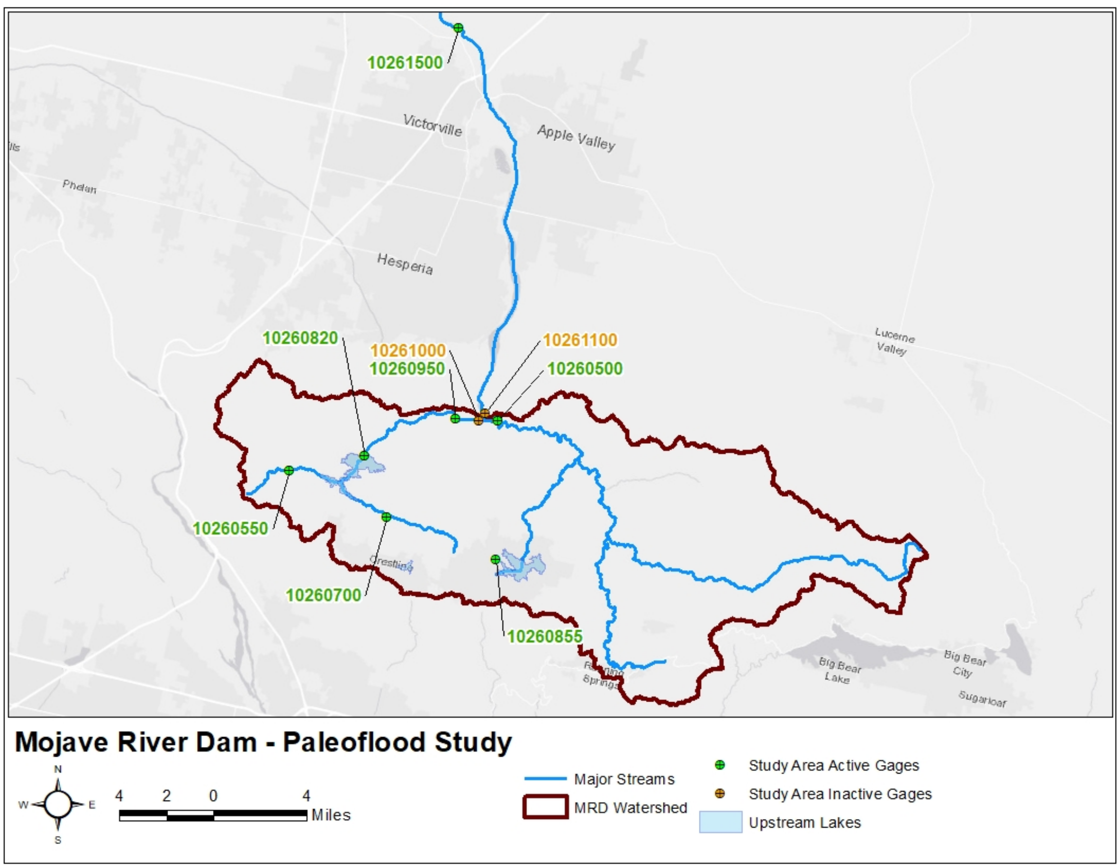

Figure D-1. USGS Stream Gages near Mojave River Dam

Four stream gages of interest either have been or are currently operated by the USGS in the immediate vicinity of Mojave River Dam. These include two gages located along the West Fork Mojave River

(10261000 and 10260950), one located along Deep Creek (10260500), and one previously located immediately downstream of the dam (10261100). These four gages are shown in Figure D-2.

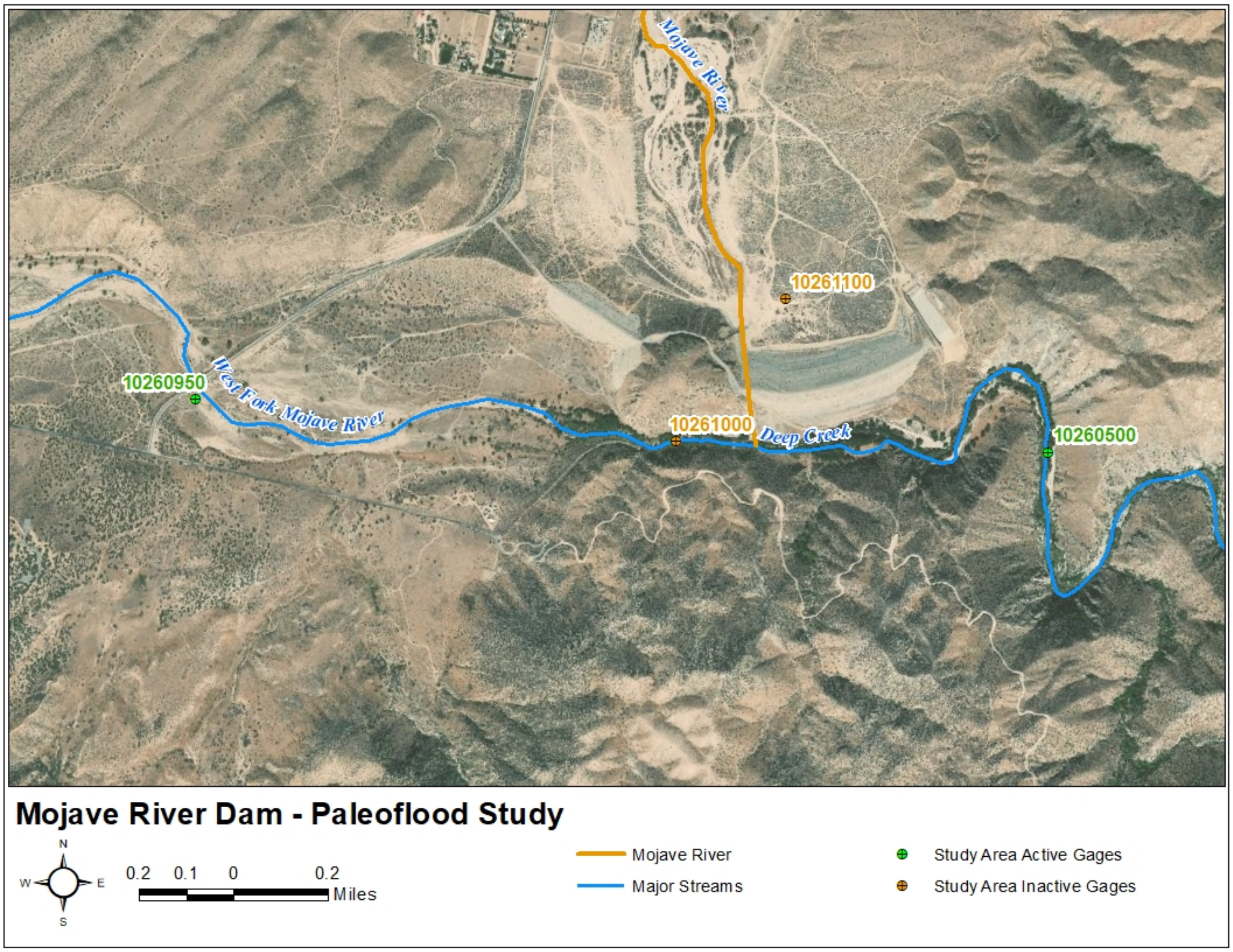

Figure D-2. USGS Stream Gages in the Immediate Vicinity of Mojave River Dam

The most downstream gage along the West Fork Mojave River (10261000) was sited approximately 0.25 miles upstream of Mojave River Dam. To avoid erroneous measurements due to the storage of water within the reservoir formed by the dam, this gage was abandoned, and a new gaging station was established (10260950) approximately 0.75 miles upstream. The travel time between these two gages is negligible as is the difference in contributing drainage area. Therefore, these two records can be combined to create a longer period of record that spans from 1907 to current with several missing periods. Due to its location, the currently operated gage (10260950) can be impacted by both debris blockage and high reservoir pool elevations, as was the case during January 2005 and December 2010.

The gage located along Deep Creek (10260500) has been continuously operated since water year (WY[1]) 1905 with a missing period spanning WY1923 through WY1929. Similar to the currently-operated West Fork Mojave River gage, the Deep Creek gage can also be impacted by high reservoir pool elevations (e.g. January 2005 and December 2010). Due to a lack of observations at high flow rates, backwater effects from high reservoir pool elevations, vegetation growth, and debris impacts, flows in excess of 7000 cfs are believed to be overestimated by as much as 40% (SPL Reservoir Regulation Section, written comm., 03Mar2020) & (United States Geological Survey, 2020). This assertion is based upon reanalysis of reported discharges emanating from Deep Creek, West Fork Mojave River, and computed inflow to Mojave River Dam for a number of large floods. As an example, observed pool elevation (solid black line), computed inflow (solid green line), and computed outflow (solid red line) provided by the USACE Los Angeles District (SPL) Reservoir Regulation Section is compared against a hydrograph computed by summing instantaneous data at the Deep Creek and West Fork Mojave River gages (dashed blue line) within Figure D-3. The pool elevation throughout this time period was continuously recorded and, as such, a complete inflow hydrograph could be constructed. When compared against the inflow hydrograph provided by the SPL Reservoir Regulation Section, the combined Deep Creek and West Fork Mojave River hydrograph overestimates the peak inflow during this time period by approximately 20% while also overestimating the inflow volume.

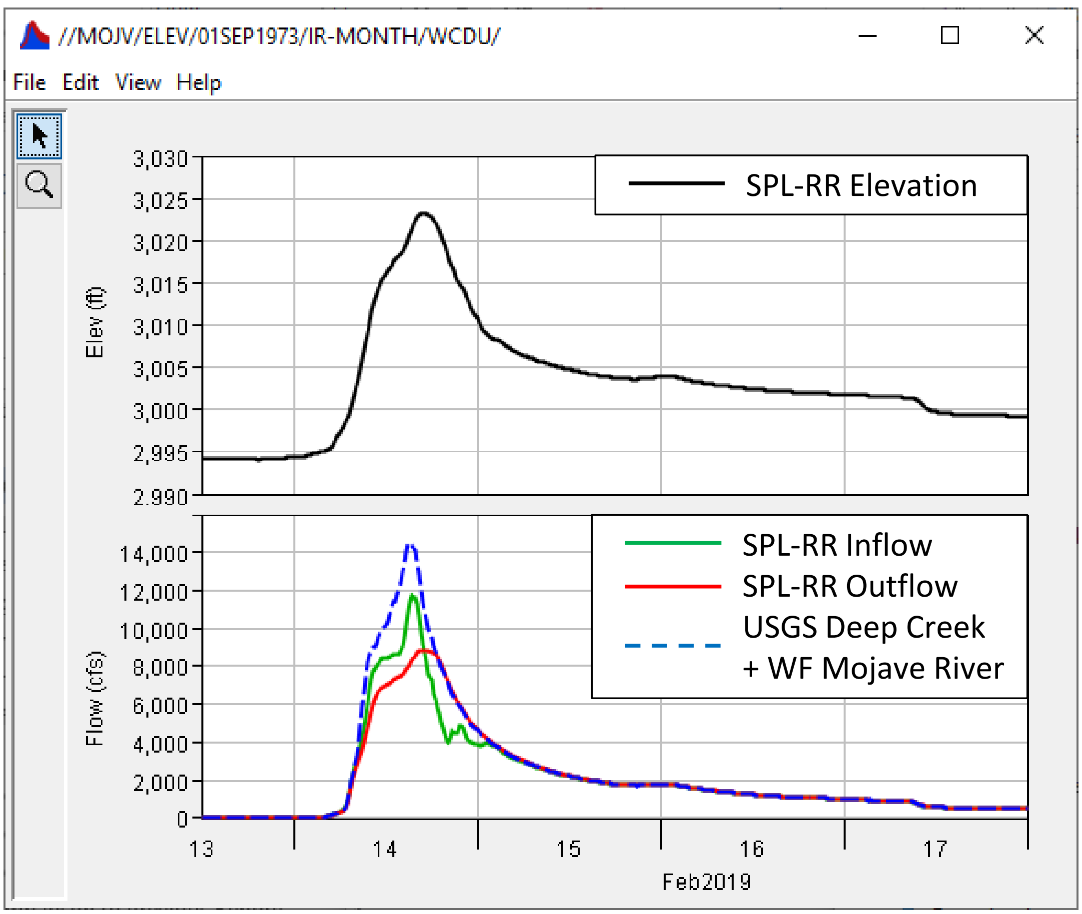

Figure D-3. February 2019 Data

[1] Defined as the period spanning October 1st through September 30th

The accuracy of data obtained at the Mojave River gage located immediately downstream of the dam site was historically hampered by unstable channel geometries and debris blockage. For these reasons, the gage was discontinued at the end of WY1997.

SPL Reservoir Regulation

The SPL Reservoir Regulation Section also operates a water surface recording system which measures the pool elevation within the reservoir formed by Mojave River Dam (U.S. Army Corps of Engineers, 1985). Once the observed pool elevation is converted to storage, the continuity equation can be used to estimate inflow given outflow:

$$I - O = \frac{\Delta S}{\Delta t}$$ Equation 1

where I = inflow to the reservoir, O = outflow from the reservoir, and $\Delta S/\Delta t$ = change in storage during period Δt. However, inflow to Mojave River Dam has historically been difficult to ascertain primarily due to unreliable measured outflow and debris blockage. As was previously mentioned, from the time of construction to the end of WY1997, the USGS operated a stream gage immediately downstream of Mojave River Dam which provided estimates of outflow. However, this gage was abandoned due to an unstable riverbed which negated accuracy. Therefore, elevation-discharge relationships and contributions from the Deep Creek and West Fork Mojave River USGS stream gages have been primarily used to compute inflow to Mojave River Dam. The elevation-storage-area and elevation-discharge relationships for Mojave River Dam are shown in Figure D-4 and Figure D-5, respectively. The original design elevation-discharge relationship was modified in 1991 by the placement of varying amounts of concrete.

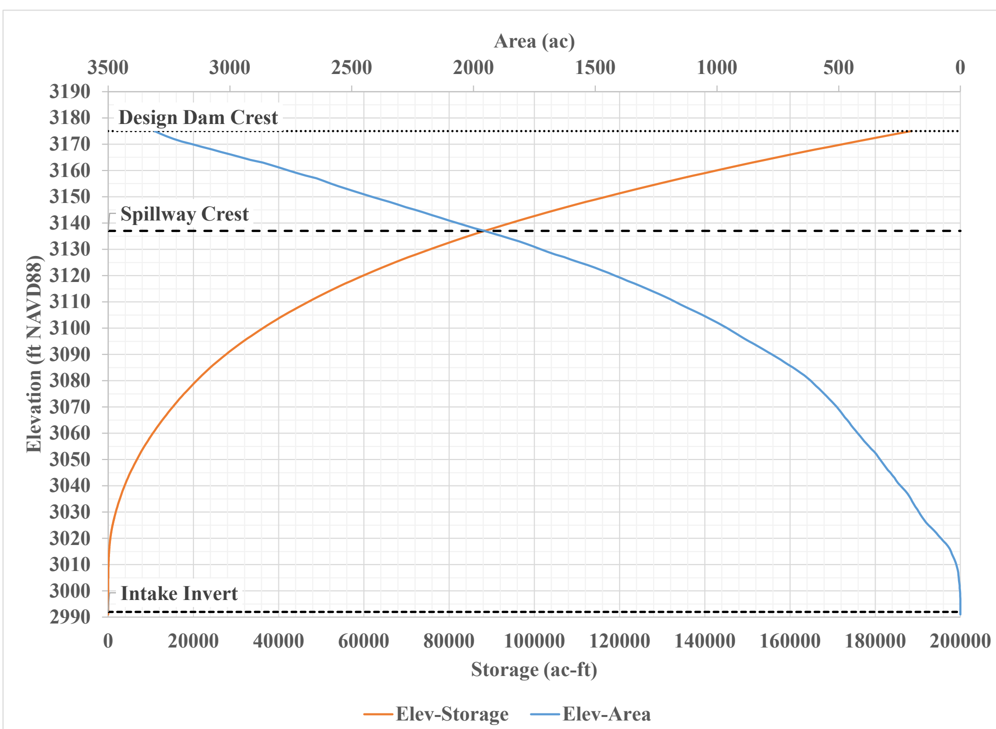

Figure D-4. Elevation-Storage-Area Relationship

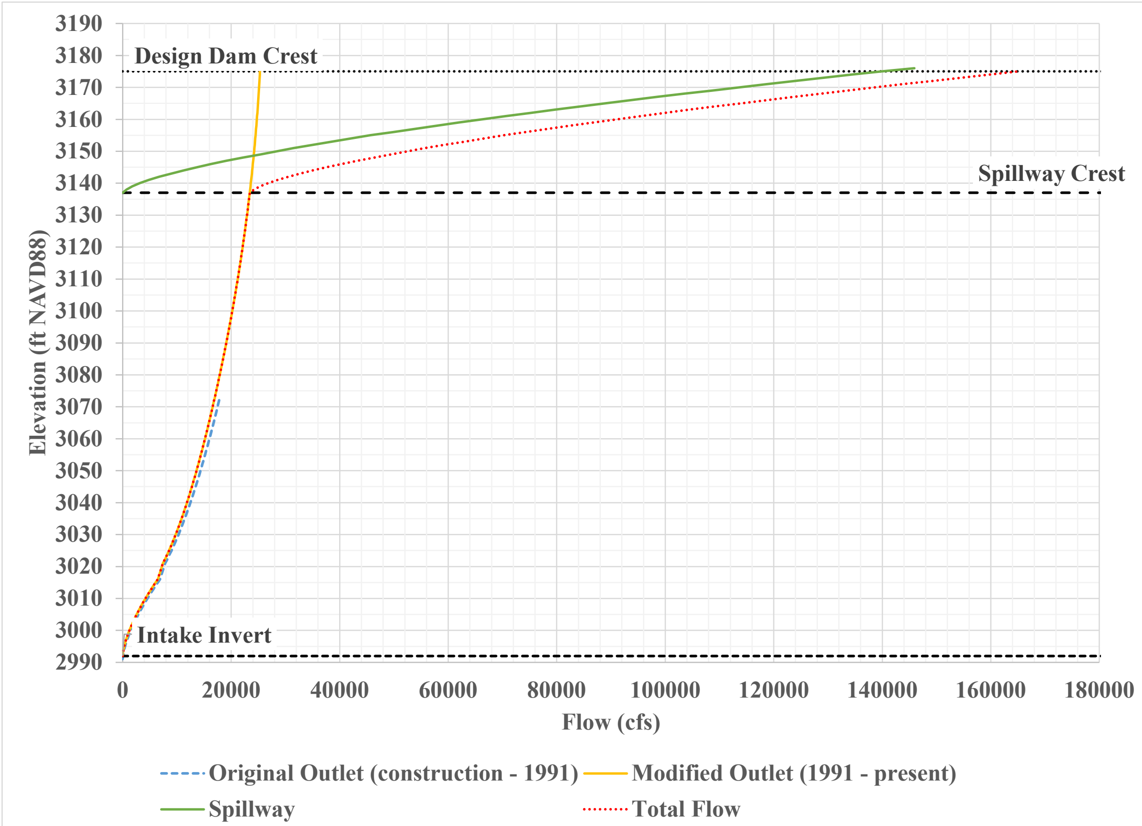

Figure D-5. Elevation-Discharge Relationship

Previous Reports

Report on Survey for Flood Control (1956)

Estimated discharges at the future Mojave River Dam site are presented within the Report on Survey for Flood Control in addition to a flow-frequency relationship (U.S. Army Corps of Engineers, 1956). The estimated discharges at the dam site within this report span from December 1859 to January 1954. The report states that historical references to floods in the Mojave River watershed date from 1852 but records of most floods are available only for the period from 1904 to 1954. However, the magnitude of several floods, for which numerical records were not available, were estimated from historical descriptions and from flood data on nearby streams. Sources of information on floods documented in this report include USGS records, a bulletin on Rainfall and Stream Runoff in Southern California since 1769 (Lynch, 1931), Bulletin No. 5 (California Department of Engineering, 1918), data supplied by officials of the city of San Bernardino, newspaper accounts, and statements by long-time local residents.

This report indicates that at least six major floods greater than 40000 cfs occurred between 1855 and 1956. Available records also indicate that from 1855 to 1956, ten medium to large floods between 20000 and 40000 cfs and at least 40 small to medium events between 4000 to 20000 cfs occurred on the Mojave River. The largest flood since 1855 is reported to have transpired on 22 January 1862. However, a discharge was not reported for the January 1862 flood. The two largest flood events with known magnitudes to have occurred since 1855 include 78000 cfs in WY1868 and 75000 cfs in WY1891. Moreover, the largest major flood of recent times is reported as 72700 cfs in WY1938. An empirical flow-frequency distribution was then fit to the peak flow data using graphical techniques and is shown in Figure D-6.

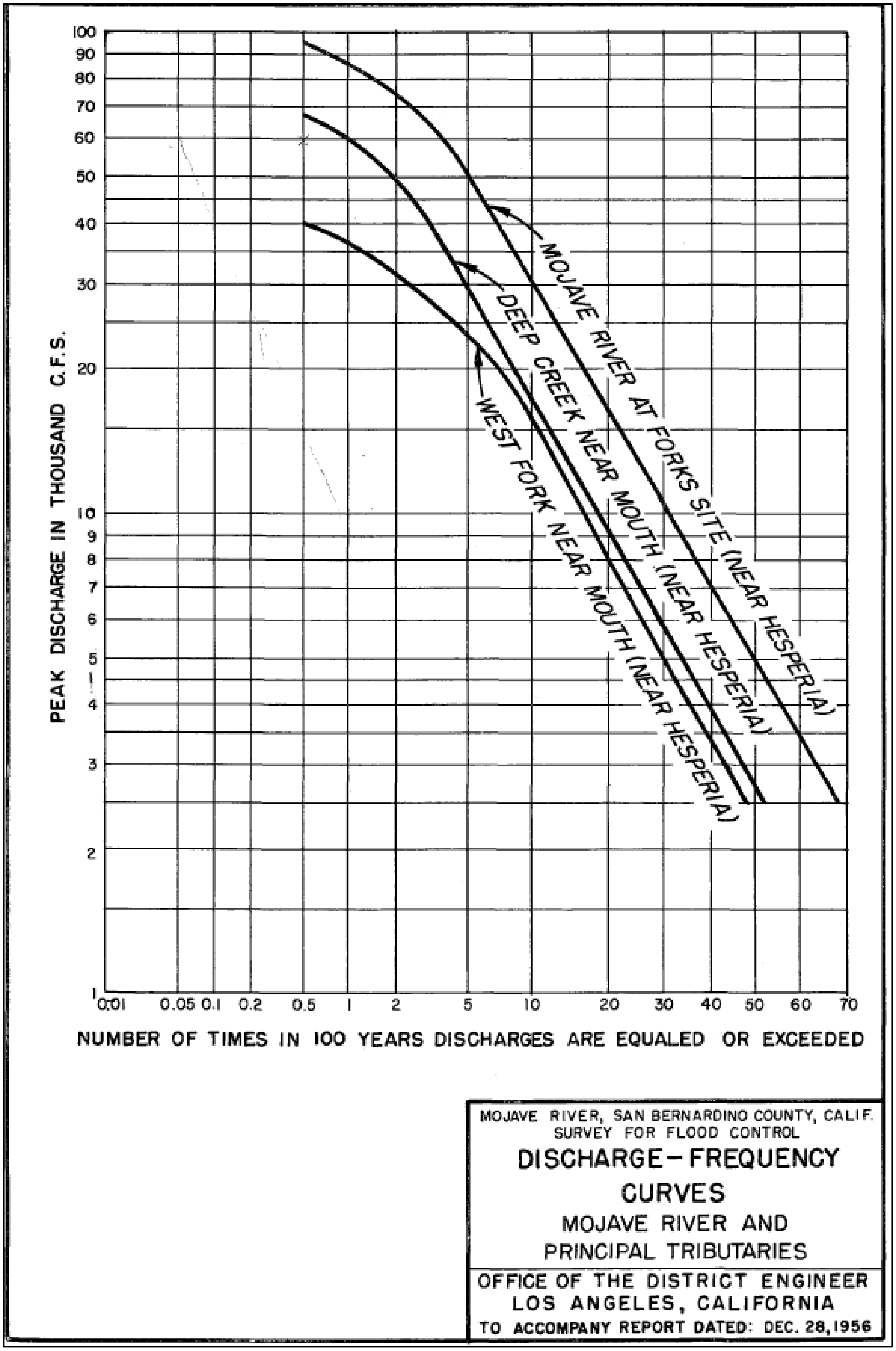

Figure D-6. Report on Survey for Flood Control Flow-Frequency Distribution Reproduced from (U.S. Army Corps of Engineers, 1956)

This analysis used a partial duration series (PDS) instead of an annual maximum series (AMS). AMS refers to a listing of events that are the largest to have occurred within a given year (e.g. water year or calendar year). For instance, if two relatively large events occur within the same year, only the larger of the two events would become part of the AMS. PDS refers to a listing of the largest independent events regardless of whether two or more occurred within the same water year. Typically, flow-frequency distributions created through the use of AMS or PDS produce similar results for relatively infrequency annual exceedance probabilities (AEP); they typically converge between the 1/10 AEP and 1/100 AEP (Langbein, 1949).

Magnitude and Frequency of Floods in the United States, Part 10, Great Basin (1966)

Systematic discharge observations at the Deep Creek and West Fork Mojave River gages through September 1963 are presented within the Magnitude and Frequency of Floods in the United States report (Butler, Reid, & Berwick, 1966). Additionally, years in which moderate to large floods occurred outside of systematic observations are noted for both gages. The oldest flood event is reported to have occurred in December 1859. While no discharge estimates for these historical floods are presented, the report states that none of the historical floods exceeded the magnitude of the WY1938 flood which disagrees with statements made within the Report on Survey for Flood Control (1956).

Evaluation of Proposed Modifications (1985)

The Evaluation of Proposed Modifications report estimated additional discharges at the dam site while also providing an updated flow-frequency relationship (U.S. Army Corps of Engineers, 1985). It should be noted that this analysis demarcated the water year as the period spanning January 1st through December 31st. This conflicts with the natural hydrology of the Mojave River watershed as January 1st is in the middle of the typical flood season. This demarcation can cause discrepancies when comparing multiple AMS.

Peak flow rates at the Deep Creek (10260500) and West Fork Mojave River (10261000) gages were combined in the following manner to estimate peak inflows at Mojave River Dam:

- When the known Deep Creek peak was greater than the known West Fork Mojave River peak, the two values were directly added
- When the known West Fork Mojave River peak exceeded the known Deep Creek peak, the Deep Creek peak was reduced by ten percent before combining with the West Fork Mojave River peak
- When the known peak from one of the streams was unknown, a “base” peak of 500 cfs was added to the known peak
- When the known peak from one of the streams was less than the “base” peak of 500 cfs, the peak (rounded to the next lowest 100 cfs) was added to the known peak from the other stream

The flow data from the Report on Survey for Flood Control (1956) was also analyzed within this report. The reported peak flow rates of 30000 cfs in December 1859, 7700 cfs in February 1874, and 16000 cfs in February 1927 were not used because they were considered “isolated events that were neither systematic nor historic, but rather biased for the record gaps in which they occurred” (U.S. Army Corps of Engineers, 1985). The periods spanning WY1896 to WY1902 and WY1923 to WY1929 were considered to be broken record years and were ignored. Finally, historical data presented in the Report on Survey for Flood Control were considered valid and the three peak flow values of 78000 cfs, 75000 cfs, and 72700 cfs were considered the three highest peaks for a historical period of 120 years spanning WY1863 to WY1982. An analytical flow-frequency distribution was then derived using Bulletin 17B techniques along with a regional skew coefficient of zero (Interagency Advisory Committee on Water Data, 1982). A data source was not presented for the regional skew coefficient. The resulting flow-frequency curve from this analysis is shown in Figure D-7.

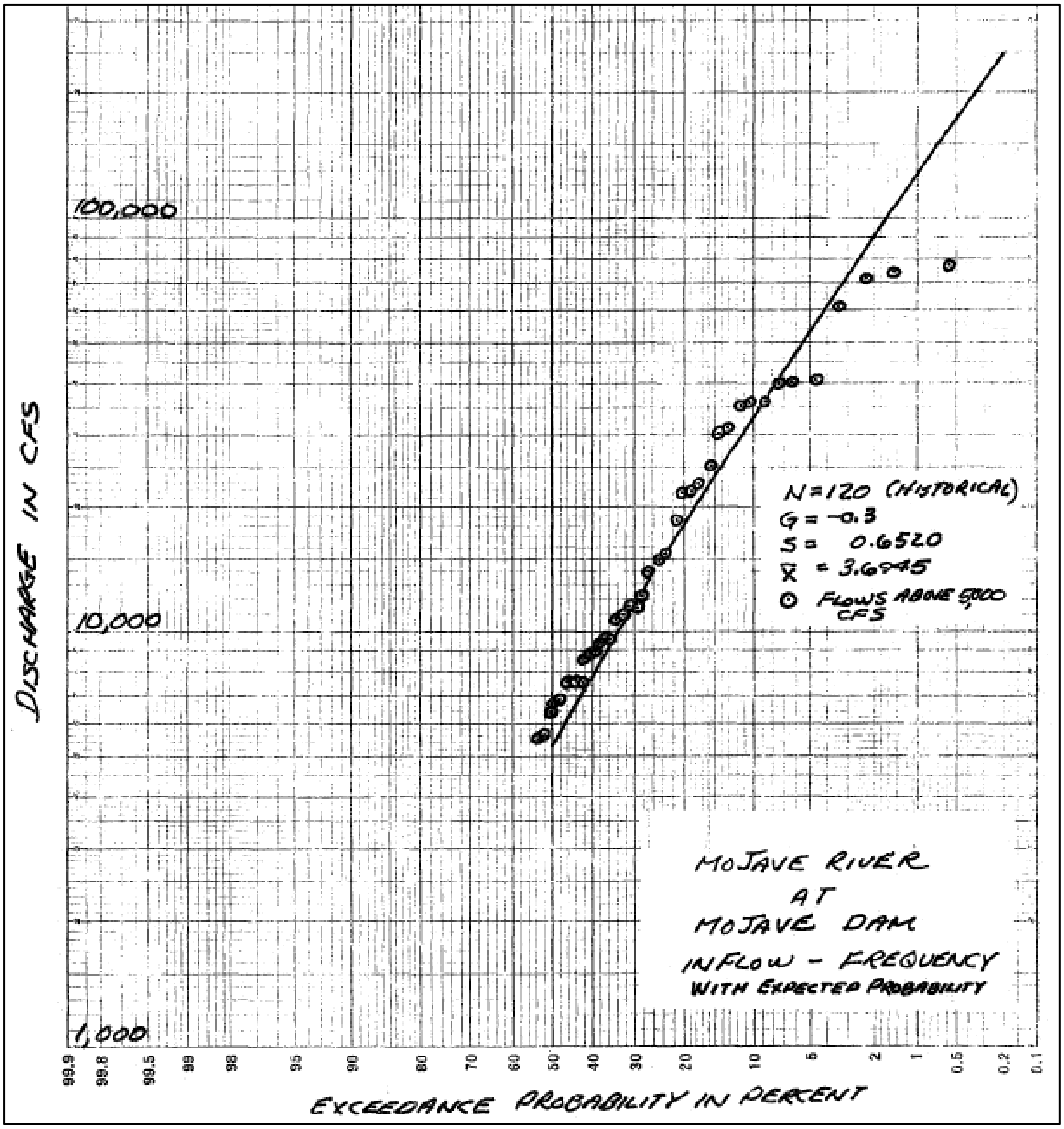

Figure D-7. Evaluation of Proposed Modifications Flow-Frequency Distribution Reproduced from (U.S. Army Corps of Engineers, 1985)

Periodic Assessment #1 (2019)

Periodic Assessment #1 utilized the previously mentioned data presented in the Evaluation of Proposed Modifications report in combination with computed inflow data supplied by the SPL Reservoir Regulation Section to update the flow-frequency relationships at Mojave River Dam. Specifically, computed inflow for WY1997 to WY2017 in addition to a single peak flow rate for WY1978 was added. An analytical flow-frequency distribution was derived using Bulletin 17C techniques. Also, a regional skew coefficient of -0.21 was incorporated (U.S. Army Corps of Engineers, 2019). However, the source of the regional skew coefficient could not be discerned. The flow-frequency distributions developed as part of this effort are shown in Figure D-8.

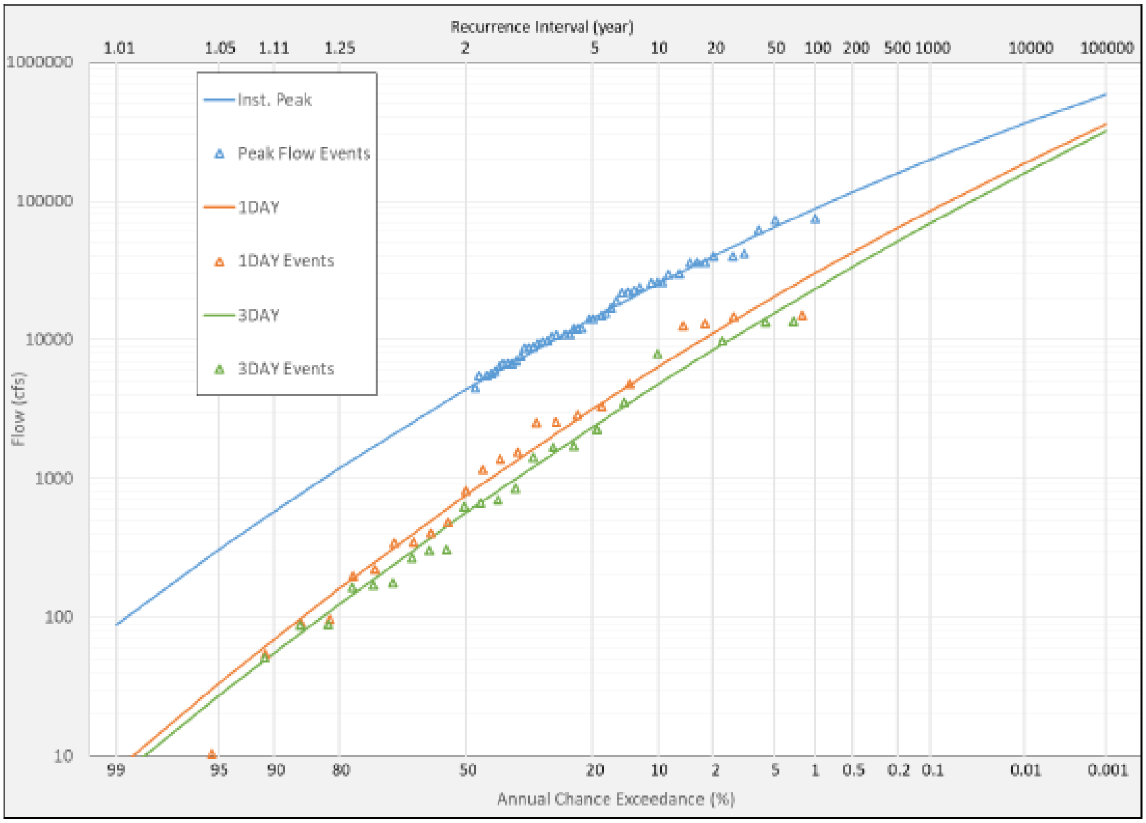

Figure D-8. Periodic Assessment #1 Flow-Frequency Distributions Reproduced from (U.S. Army Corps of Engineers, 2019)

Regional Skew

Regional skew estimates for the Mojave Desert region of California have historically proven difficult to reliably estimate due to small sample sizes, numerous zero/low outliers, and highly variable peak flow data for many stream gages (Parrett, et al., 2010). Within a study of flood frequency in the Southwestern United States, Thomas and others (1997) analyzed more than 1000 gages in desert areas of several states to estimate regional skew and its associated total error (i.e. variance). Several methods for determining regional skew were attempted including multiple regression analysis and kriging. It was concluded that a constant regional skew coefficient of zero with an associated total error of 0.31 log units was the most appropriate choice for use within this region (Thomas, Hjalmarson, & Waltemeyer, 1997).

In an attempt to account for the effects of different at-site record lengths and cross correlation among at-site skew values, an updated regional skew evaluation for California was undertaken by Parrett and others (2010). However, due to a lack of stream gages with sufficient long term peak flow records, an updated regional skew and flood frequency regression equations could not be reliably determined in the hydrologically distinct desert region. Thus, the use of a constant regional skew of zero from Thomas and others (1997) within the Mojave Desert region of California was recommended for use (Parrett, et al., 2010).

Gotvald and others (2012) developed at-site flood frequency and regional regression equations within the Mojave Desert region of California. However, the authors of this study did not reevaluate the constant regional skew of zero from Thomas and others (1997). The authors did reconsider the total error associated with this regional skew and provided an updated estimate of 0.2 log units (Gotvald, Barth, Veilleux, & Parrett, 2012). Finally, it should be mentioned that this study did not include any USGS stream gages within the area of interest when evaluating the regional skew total error or when developing regional flood frequency regression equations.

Systematic Data

Systematic flood data, in the context of this analysis, consists of discharge measurements that are collected at regular, prescribed intervals. The collection of systematic flood data also involves the continuous monitoring of flood properties by hydrologists (England, et al., 2019).

Systematic observations from the Deep Creek (10260500) and West Fork Mojave River (10261000 and 10261100) USGS stream gages, data from previously mentioned reports, and information provided by the SPL Reservoir Regulation Section were used to create an AMS of inflow to Mojave River Dam that spanned WY1905 – WY2019. For the period following construction of Mojave River Dam, additional systematic data was estimated using an approach that was similar to that which was published within the Evaluation of Proposed Modifications report (U.S. Army Corps of Engineers, 1985). Specifically, additional systematic data was estimated in the following manner:

- When the known Deep Creek peak occurred within +/- 2 days (i.e. typical flood event length) of the known West Fork Mojave River peak, the two values were directly added
- When the known Deep Creek peak and known West Fork Mojave River peak did not occur within the same flood event (i.e. difference in occurrence was greater than 2 days), take the maximum of the following:
    - Known Deep Creek peak + West Fork Mojave River daily average (for the same day)
    - Known Deep Creek peak + West Fork Mojave River maximum 15-min flow rate (when available; for the same day)
    - Known West Fork Mojave peak + Deep Creek daily average (for the same day)

As was previously stated, flows in excess of 7000 cfs at the Deep Creek gage are believed to be overestimated by as much as 40%. In order to incorporate this uncertainty, flow ranges were developed for all annual maxima inflow greater than 10000 cfs. The minimum value for these flow ranges was calculated by adding the known West Fork Mojave River peak to the maximum of either the known Deep Creek flow magnitude multiplied by 60% or 7000 cfs. The maximum value for these flow ranges was calculated by adding the known West Fork Mojave River peak to the known Deep Creek peak. Applying these criteria lead to the creation of uncertain flow magnitudes for eight years of systematic data.

The total combined systematic record length includes 108 discrete events spanning 114 years (WY1905 – WY2019). A missing period was found to span WY1923 – WY1929. The systematic data that was created as part of this analysis is tabulated within Table D-2. Unless noted, all other years were assumed to not have any uncertainty in the reported flow magnitude.

Table D-2. Systematic Data

Date	WY	Mid (cfs)	Low (cfs)	High (cfs)	Source
3/14/1905	1905	26000			1
3/13/1906	1906	14000			1
3/5/1907	1907	19000			1
1/25/1908	1908	3800			1
1/22/1909	1909	8800			1
1/1/1910	1910	62000			1
3/9/1911	1911	11000			1
3/11/1912	1912	750			7
4/3/1913	1913	250			7
2/19/1914	1914	26000			1
2/10/1915	1915	12000			1
1/18/1916	1916	36000			1
3/30/1917	1917	325			7
3/7/1918	1918	14000			1
4/3/1919	1919	200			7
2/21/1920	1920	6700			1
3/14/1921	1921	5900			1
12/21/1921	1922	36000			1
3/5/1930	1930	1100			1
4/26/1931	1931	2310			1
2/9/1932	1932	15610			1
4/4/1933	1933	560			1
12/31/1933	1934	3720			1
4/8/1935	1935	4040			1
2/12/1936	1936	2590			1
2/14/1937	1937	8760			1
3/2/1938	1938	72700			1
9/25/1939	1939	2350			2
1/8/1940	1940	4000			1
2/20/1941	1941	6460			1
4/4/1942	1942	800			1
1/23/1943	1943	42000			1
2/22/1944	1944	6750			1
2/2/1945	1945	8700			1
3/30/1946	1946	11900			1
11/13/1946	1947	3920			1
4/4/1948	1948	1340			1
4/14/1949	1949	550			1
2/7/1950	1950	1200			1
5/3/1951	1951	40			1
2/28/1970	1970	960			2
11/29/1970	1971	5520			2
12/25/1971	1972	10000			7
2/12/1973	1973	7500			7
3/3/1974	1974	1100			7
3/9/1975	1975	825			4
9/12/1976	1976	5150			5
5/9/1977	1977	1000			4
3/5/1978	1978	22800	18300	28300	5
3/28/1979	1979	6870			4
2/18/1980	1980	21200	18200	24800	5
1/30/1981	1981	300			6
3/18/1982	1982	3850			6
3/2/1983	1983	18500	15500	22100	4
12/26/1983	1984	5870			4
12/20/1984	1985	1775			4
2/16/1986	1986	5500			4
3/7/1987	1987	1725			4
4/21/1988	1988	775			5
2/11/1989	1989	605			5
2/22/1990	1990	90			6
3/2/1991	1991	9000			4
2/13/1992	1992	12500	10900	14400	4
1/8/1993	1993	14400	11200	18400	5
2/8/1994	1994	4325			5
1/11/1995	1995	12300	10200	14700	4
2/22/1996	1996	7940			4
1/27/1997	1997	6740			4
2/24/1998	1998	19400	15600	24000	4
4/16/1999	1999	110			3
2/22/2000	2000	2560			4
2/14/2001	2001	410			3
11/26/2001	2002	15			3
3/17/2003	2003	6300			4
12/26/2003	2004	9000			4
1/12/2005	2005	29700			3
4/6/2006	2006	12300	9700	15700	5
9/1/2007	2007	91			5
1/28/2008	2008	8140			4
2/17/2009	2009	1610			4

Date	WY	Mid (cfs)	Low (cfs)	High (cfs)	Source
3/15/1952	1952	9400			1
1/7/1953	1953	240			1
1/25/1954	1954	9780			1
2/17/1955	1955	510			2
1/27/1956	1956	7620			2
1/13/1957	1957	12060			2
4/3/1958	1958	22600			2
2/16/1959	1959	9720			2
4/28/1960	1960	960			2
4/4/1961	1961	1780			2
2/11/1962	1962	10790			2
2/10/1963	1963	830			2
4/1/1964	1964	610			2
4/23/1965	1965	1860			2
12/29/1965	1966	39920			2
12/6/1966	1967	21720			2
11/20/1967	1968	1340			2
1/25/1969	1969	36200			2

Date	WY	Mid (cfs)	Low (cfs)	High (cfs)	Source
2/7/2010	2010	9000			8
12/23/2010	2011	24000			3
3/27/2012	2012	360			3
1/26/2013	2013	110			5
3/1/2014	2014	5860			4
12/5/2014	2015	880			3
2/1/2016	2016	2200			4
1/24/2017	2017	5250			4
3/23/2018	2018	1010			5
2/14/2019	2019	11700			3

[1] Report on Survey for Flood Control (1956)

[2] Evaluation of Proposed Modifications (1985)

[3] SPL-Reservoir Regulation Section

[4] Deep Creek peak + WF Mojave River peak

[5] Deep Creek peak w/ daily average WF Mojave River

[6] Deep Creek daily average w/ WF Mojave River peak

[7] Deep Creek peak w/ missing WF Mojave River peak

[8] Deep Creek peak w/ 15-min peak WF Mojave River

A perception threshold of 23500 cfs was inferred for the missing period (WY1923 – WY1929). This magnitude corresponds to the approximate channel capacity of the Mojave River downstream of the dam site (U.S. Army Corps of Engineers, 1956). Local interests historically maintained this approximate channel capacity while, in more recent times, the San Bernardino County Flood Control District has taken over maintenance and regulation of the Mojave River downstream of the dam site. The perception thresholds used in combination with the systematic data are tabulated within Table D-3. The complementary flow range for the missing period along with the systematic data is shown in Figure D-16.

Table D-3. Systematic Data Perception Thresholds

Start Year	End Year	Low Threshold (cfs)	High Threshold (cfs)	Comments
1905	2019	0	inf	Total Record
1923	1929	23500	inf	Approx. Channel Capacity

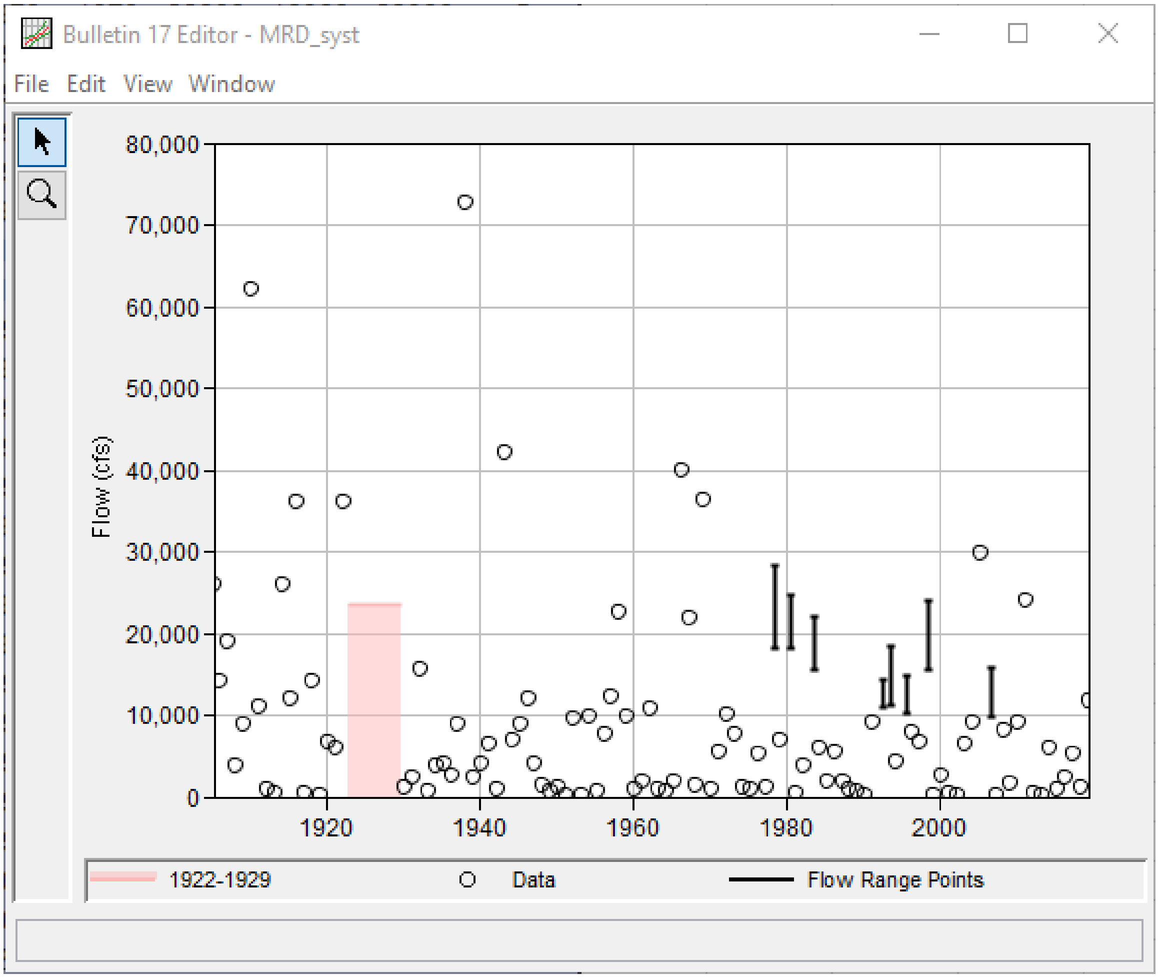

Figure D-9. Systematic EMA Data

Historical Data

Historical flood data consists of discharge measurements or estimates that occurred outside the period of systematic data collection (England, et al., 2019). This can include periods prior to the start of, in between multiple periods, or after periods of systematic data collection. The historical data published within the Report on Survey for Flood Control (1956) was investigated for use. Additionally, the statements made within Magnitude and Frequency of Floods in the Magnitude and Frequency of Floods in the United States, Part 10, Great Basin (1966) and the recommendations from the Evaluation of Proposed Modifications report (1985) were examined.

In this analysis, historical data was found for the period prior to the start of systematic data collection in WY1905 and within the missing period spanning WY1923 – WY1929. The Report on Survey for Flood Control (1956) and Magnitude and Frequency of Floods in the Magnitude and Frequency of Floods in the United States, Part 10, Great Basin (1966) indicate that the first human-made permanent settlements in the area of interest were founded in either 1852, 1855, or 1856. However, Thompson reports that Aaron Lane established the first permanent settlement in 1859 at the Lower Narrows of the Mojave River near present day Oro Grande, CA (Thompson & Thompson, 1995). This date corresponds with the first reported flood discharge in December 1859 (U.S. Army Corps of Engineers, 1956). As such, WY1860 was chosen as the start of the historical period for this analysis.

The Report on Survey for Flood Control (1956) enumerates six major floods greater than 40000 cfs, ten medium to large floods between 20000 and 40000 cfs, and at least 40 small to medium events between 4000 to 20000 cfs since WY1860. As was previously mentioned, the approximate channel capacity of the Mojave River downstream of the dam site is 23500 cfs (U.S. Army Corps of Engineers, 1956). Consequently, only historical events in excess of 23500 cfs (i.e. floods) were included within this analysis. Years within the historical period that did not exceed this magnitude were represented using a perception threshold of 23500 and a complementary flow range of 0 to 23500 cfs.

Also, the Report on Survey for Flood Control posited that the January 1862 flood was the largest flood to have occurred within the area of interest since at least 1860 but did not provide a discharge estimate (U.S. Army Corps of Engineers, 1956). Silver Lake, which is the terminus of Mojave River, was noted to have filled with runoff for the first time in since the establishment of permanent settlements in the area of interest (Cyr, Miller, & Mahan, 2015) & (Thompson & Thompson, 1995). Upon request, San Bernardino County provided a peak discharge estimate of 150000 cfs at the Mojave River dam site for this flood (San Bernardino County, 2018). However, no other evidence alluding to the type of evidence, such as observed stage or debris line, nor discharge estimation technique, such as a slope-area calculation, were provided.

Engstrom reports that the "level of the Mojave River reached at least 5.5 meters above 'an ordinary stage of water' at [Arron] Lane's house" (Engstrom, 1996). As was discussed in Appendix A and Appendix B, a discharge range of 75000 cfs to 150000 cfs was estimated using a hydraulic model to satisfy the quantitative description from Engstrom (1996).

Other sources of evidence alluding to the January 1862 flood were found to be contradictory. For instance, Thompson (1995) provides the following account: "…continuous heavy rain has brought upon this locality a flood such as has not before visited us within the recollection of the present residents. Heretofore, the year 1862 was cited as the year of the flood; this year [WY1868] has outflooded that one". Also, the Magnitude and Frequency of Floods in the Magnitude and Frequency of Floods in the United States, Part 10, Great Basin (1966) states that the WY1938 flood, with a magnitude of 72700 cfs at the dam site, was the largest flood to have occurred since the start of the historical period. However, each source agrees that a flood event did transpire in January 1862.

For this reason, a discrete flood event in WY1862 was included within this analysis. Uncertainty in the flood magnitude was included through the use of an interval spanning 75000 cfs to 150000 cfs. The low magnitude of 75000 cfs signifies that this event was an extreme flood while the high magnitude of 150000 cfs corresponds to the estimate provided by San Bernardino County (San Bernardino County, 2018). This interval also satisfies the quantitative description from Engstrom (1996) in addition to the Report on Survey for Flood Control (U.S. Army Corps of Engineers, 1956). A sensitivity analysis was performed to identify the effects of interpreting different discharge magnitudes for this flood event which can be found within the **January 1862 Flood Event Interpretation** section.

The previously mentioned flow range was compared against estimates for the same flood event at Carbon Canyon Dam (U.S. Army Corps of Engineers, 2020) and Prado Dam (U.S. Army Corps of Enginers, 2019) in addition to a regional envelope curve from USACE (1995) within Figure D-10. These comparisons affirmed that a flow range of 75000 cfs to 150000 cfs was appropriate when compared against other large floods within the region of interest.

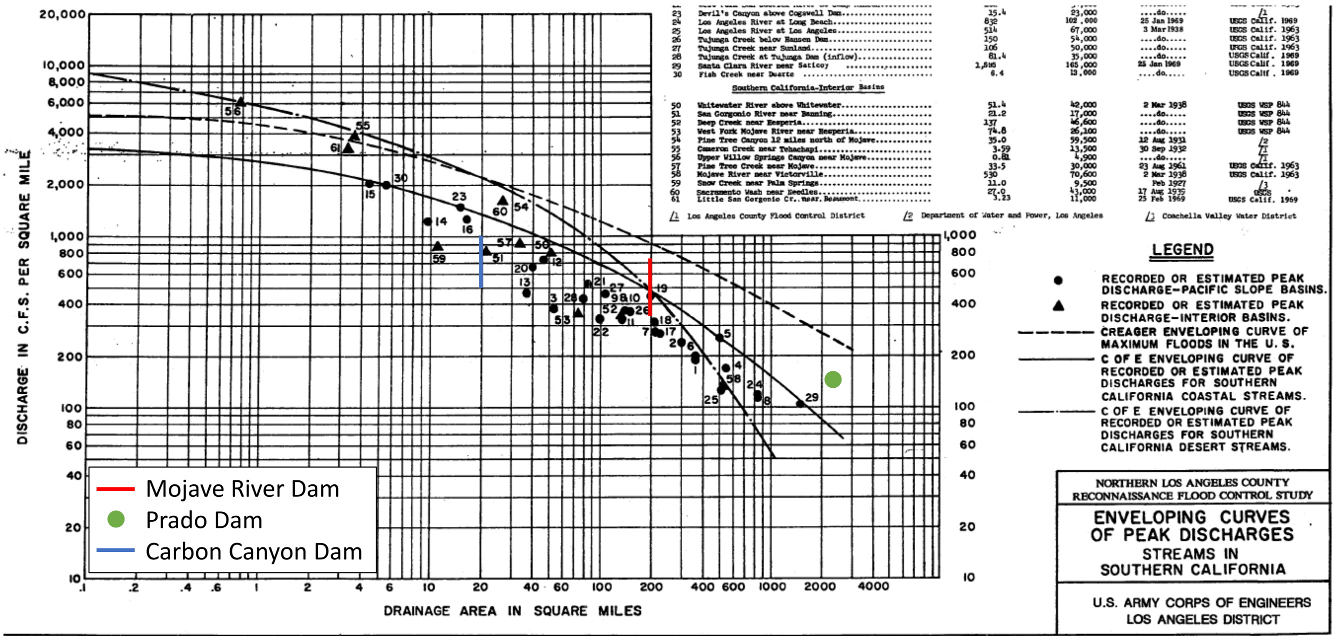

Figure D-10. January 1862 Flood Event Comparison

A total of six historical flood events were identified for inclusion, as shown within Table D-4. Except for WY1862, all years were assumed to have no uncertainty in the peak flow magnitude.

Table D-4. Historical Data

Date	WY	Mid (cfs)	Low (cfs)	High (cfs)	Source
12/1859	1860	30000			1
1/22/1862	1862	106500	75000	150000	1, 2
12/1867	1868	78000			1
3/7/1884	1884	40000			1
2/17/1886	1886	30000			1
2/23/1891	1891	75000			1

[1] Report on Survey for Flood Control (USACE, 1956)
[2] The California Storm of January 1862 (Engstrom, 1996)

A single perception threshold of 23500 cfs was inferred for the missing period between 1860 and the start of the systematic record in WY1905. This magnitude corresponds to the approximate channel capacity of the Mojave River downstream of the dam site (U.S. Army Corps of Engineers, 1956). Local interests historically maintained this approximate channel capacity while, in more recent times, the San Bernardino County Flood Control District has taken over maintenance and regulation of the Mojave River downstream of the dam site. The perception thresholds used in combination with the historical and systematic data are tabulated within Table D-5. The complementary flow ranges for the missing periods along with the historical and systematic data are shown in Figure D-11.

Table D-5. Historical and Systematic Data Perception Thresholds

Start Year	End Year	Low Threshold (cfs)	High Threshold (cfs)	Comments
1860	2019	0	inf	Total Record
1860	1904	23500	inf	Approx. Channel Capacity
1923	1929	23500	inf	Approx. Channel Capacity

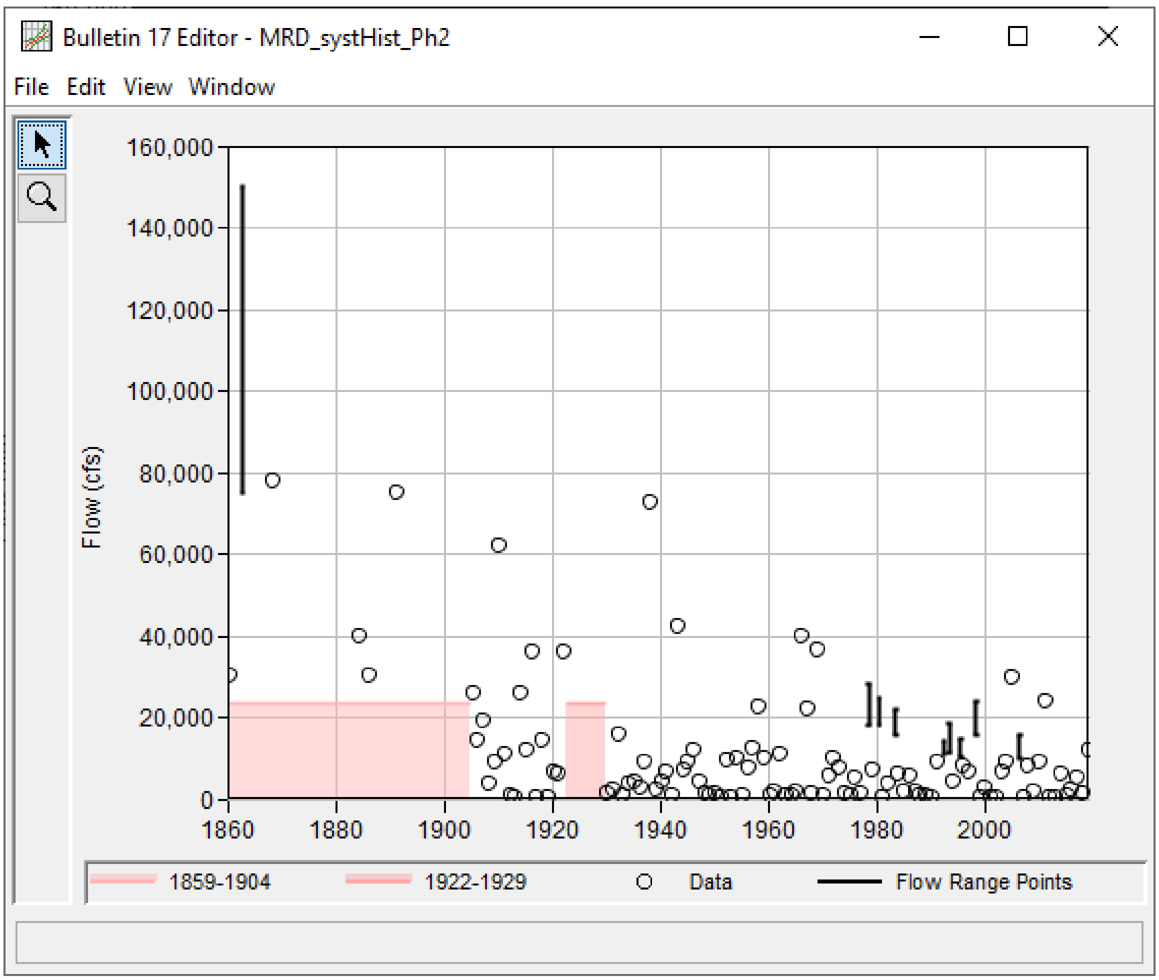

Figure D-11. Historical and Systematic EMA Data

Paleoflood Data

Paleoflood data differs from historical and systematic data in that geologic and physical evidence of past floods provide evidence of paleofloods rather than records based on community memory or referenced by built infrastructure. Paleoflood hydrology focuses on direct evidence of large, rare floods or the absence of such records (England, et al., 2019). Evidence of historic and pre-historic flooding can be provided by flood-related riverine deposits, which are termed Paleostage Indictors (PSI), and/or deposits and landforms that demonstrate an absence of inundation over recent geologic time, which are referred to as Non-Exceedance Bounds (NEB).

In this analysis, a paleoflood PSI was identified for the period prior to the start of historical data in WY1860. **Appendix B** discusses the identification and age dating of this PSI while **Appendix C** details how flow magnitudes were estimated. In summary, the magnitude of the paleoflood PSI ranged from 275000 cfs to 425000 cfs with a best estimate of 375000 cfs. The age of the paleoflood PSI spanned from 1100 years old to 1800 years old with a best estimate age of 1500 years old. All ages are referenced to the date in which the samples were collected (2020). The paleoflood PSI data is summarized within Table D-6.

Table D-6. Paleoflood PSI Data

Geomorphic Datum	Estimated Age (years before 2020)		Estimated Total Inflow Paleodischarge (cfs)	
West Fork Terrace (PSI)	Young	1,100 years	Low	275,000
	Best	**1,500 years**	**Best**	**375,000**
	Old	1,800 years	High	425,000

The paleoflood PSI was compared against multiple design floods which have been estimated for Mojave River Dam since the project's design and construction. The peak flow rate of the original Spillway Design Flood (SDF) is approximately 186000 cfs (U.S. Army Corps of Engineers, 1966). A Probable Maximum Flood (PMF) with a peak flow rate of approximately 287000 cfs was developed as part of Periodic Assessment #1 (U.S. Army Corps of Engineers, 2019). The "1966 SDF" and the "2019 PMF" are compared within the Periodic Assessment #1 report. An updated PMF with a peak flow rate of approximately 400000 cfs, which is currently under review, was developed to support the ongoing Issue Evaluation Study (IES). The "IES PMF" makes use of improved modeling techniques in addition to model calibration/validation to extreme flood events when compared against the 2019 PMF. Furthermore, when comparing the 1966 SDF, 2019 PMF, and IES PMF, an upward trend in the predicted peak flow rate becomes apparent. Between each analysis, improvements were made to meteorologic data, hydrologic and hydraulic modeling techniques, and data availability which resulted in refined estimates of these design floods. Also, the paleoflood PSI low estimate is approximately equivalent to the 2019 PMF peak flow rate while the paleoflood PSI high estimate is approximately equivalent to the IES PMF.

The paleoflood PSI, 1966 SDF, 2019 PMF, and IES PMF were then plotted alongside various regional and nationwide envelope curves. Within Figure D-12, a regional envelope curve developed by USACE (1995) is used. Within Figure D-13, a nationwide envelope curve developed by Crippen & Bue (1977) is used. Finally, within Figure D-14, a regional envelope curve developed by Crippen & Bue (1977) is used. As shown on these figures, the original SDF peak flow rate plots slightly below the various regional and nationwide envelope curves. Conversely, the 2019 PMF peak flow rate, IES PMF peak flow rate, and paleoflood PSI flow range plot slightly above the regional envelope curves shown in Figure D-12 and Figure D-14. However, the 2019 PMF peak flow rate, IES PMF peak flow rate, and paleoflood PSI flow range plot slightly below the nationwide envelope curve as shown within Figure D-13. These comparisons affirmed that a paleoflood PSI of 275000 cfs to 425000 cfs is plausible.

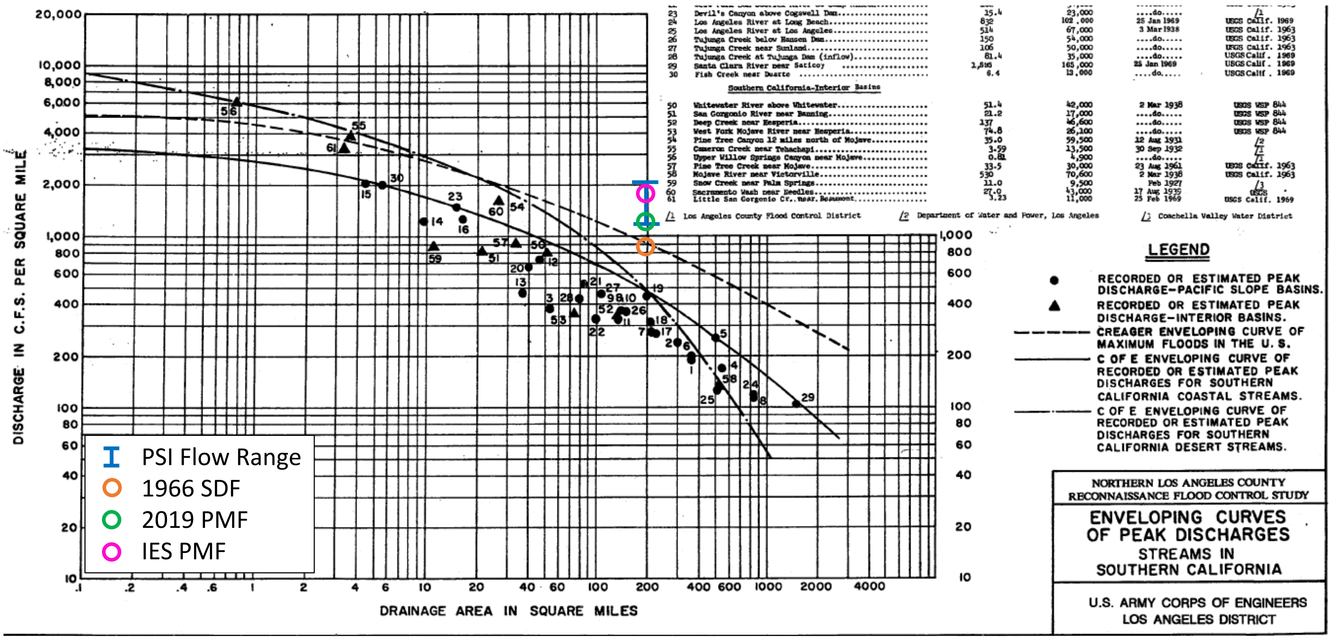

Figure D-12. Paleoflood PSI and Design Flood Comparison using USACE (1995) Regional Envelope Curve

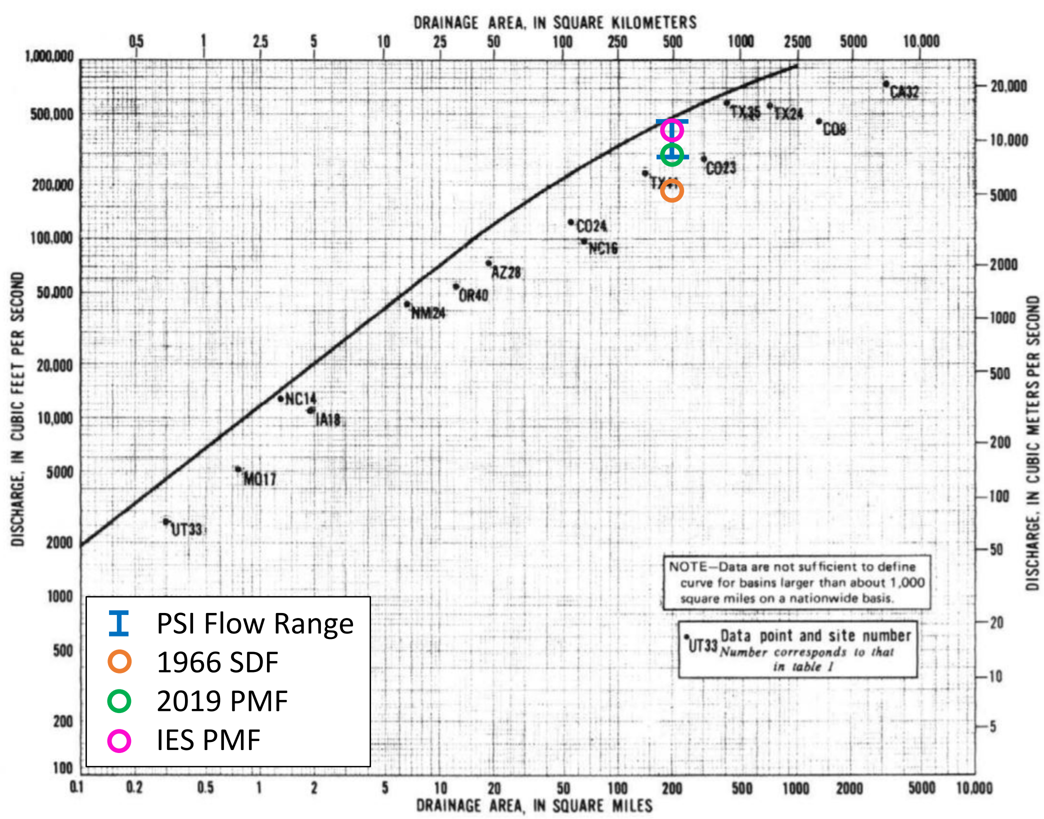

Figure D-13. Paleoflood PSI and Design Flood Comparison using Crippen & Bue (1977) Nationwide Envelope Curve

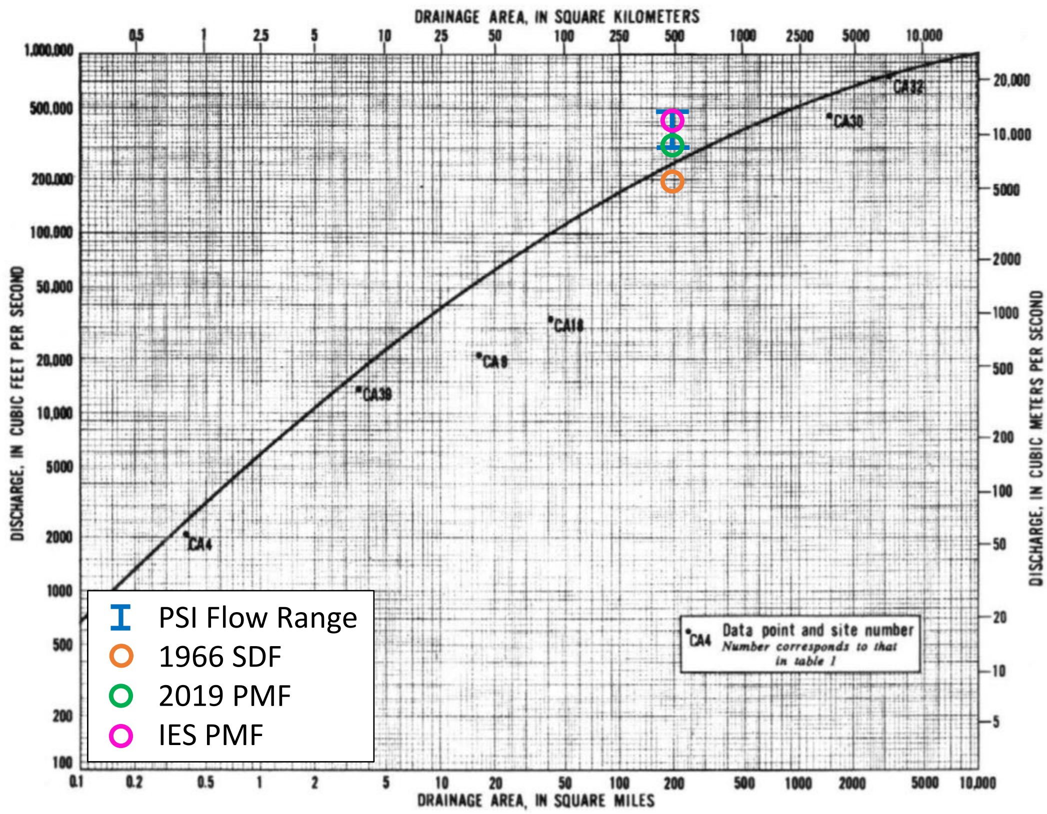

Figure D-14. Paleoflood PSI and Design Flood Comparison using Crippen & Bue (1977) Regional Envelope Curve

A best estimate perception threshold of 340000 cfs was inferred for the period spanning WY520 – WY1859. This perception threshold was estimated using a value that was slightly less than the geometric mean of the low (375000 cfs) and high values (425000 cfs) for the paleoflood PSI. Sensitivity analyses were performed to identify the effects of inferring different ages and/or magnitudes of the PSI. The results of these analyses can be found within the **Paleoflood PSI Age** section. The perception thresholds used in combination with the best estimate paleoflood, historical, and systematic data are tabulated within Table D-7. The complementary flow ranges for the missing periods along with the best estimate paleoflood, historical, and systematic data are shown in Figure D-15.

Table D-7. Best Estimate Paleoflood, Historical, and Systematic Data Perception Thresholds

Start Year	End Year	Low Threshold (cfs)	High Threshold (cfs)	Comments
520	2019	0	inf	Total Record
520	1859	340,000	Inf	Eolian deposit at WF-6, WF-5, WF-3, and WF-2 (PSI)
1860	1904	23,500	inf	Approx. Channel Capacity
1923	1929	23,500	inf	Approx. Channel Capacity

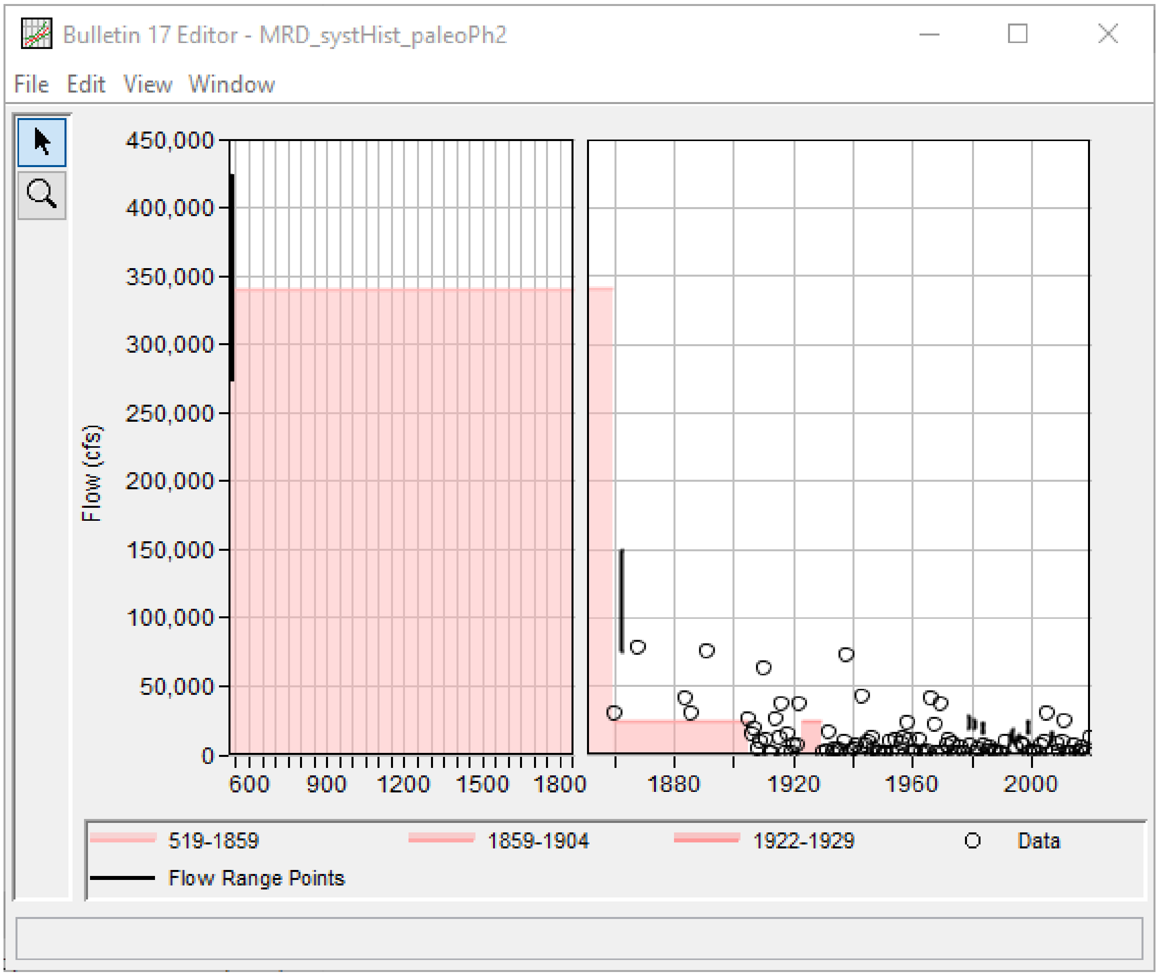

Figure D-15. Best Estimate Paleoflood, Historical, and Systematic EMA Data

Flood Frequency Results and Discussion

The Hydrologic Engineering Center's (HEC) Statistical Software Package (HEC-SSP) version 2.3-beta was used to apply the B17C methodology within this analysis (U.S. Army Corps of Engineers, 2019). HEC-SSP v2.3-beta includes numerous features that are pertinent to paleoflood analyses including the ability to ingest millions of years' worth of data, flood frequency computational enhancements, and data visualization improvements.

Effective Record Length (ERL) quantifies the knowledge uncertainty in a flood hazard curve in terms of an equivalent number of years of known data. Similar terms such as *equivalent record length* can be found in other publications and software (Margo, 2019). ERL is required to utilize a flood frequency distribution within a reservoir stage-frequency analysis such as those performed using HEC's Watershed Analysis Tool (HEC-WAT) or the RMC's Reservoir Frequency Analysis (RMC-RFA) (Smith, Bartles, & Fleming, 2018).

Cohn, Lane, & Baier (1997) proposed an equation to compute ERL using a single quantile. The equation was expanded to compute ERL at multiple quantiles:

$$ERL = \frac{1}{n}\sum_{i=1}^{n} N_S B \frac{Var\left[\hat{X}_i | N_S\right]}{Var\left[\hat{X}_i | N_T\right]}$$ *Equation 2*

where ERL is the effective record length in years, n is the number of quantiles for which the variance is computed, $\hat{X}_i$ is the flood magnitude for a given quantile, Var [] is the variance in flow magnitude for a given quantile and given flood record, N_S is the number of “perfectly known” peaks (those without uncertainty in magnitude), N_T is the total record length, and B is a bias correction factor (Margo, 2019). Within this study, **Equation 2** was used to compute ERL for all quantiles greater than the median (AEP less than 0.2) and then averaged.

Flood Frequency with Systematic Records

An LPIII analytical distribution was parameterized using the systematic data through the use of the previously mentioned B17C methodology. The analysis period spanned 115 years (WY1905 through WY2019) and included 108 systematic events and seven years of missing data. The MGB test identified a critical value of 3720 cfs which automatically censored 43 values.

The computed at-site skew coefficient of -0.449 was found to be significantly different than the recommended regional skew coefficient of 0.0. This may indicate that the flood frequency characteristics of the watershed upstream of Mojave River Dam are appreciably different from those used to develop the regional skew information. When this occurs, it is reasonable to give greater weight to the at-site skew coefficient after due consideration of the data and flood-producing characteristics of the basin (England, et al., 2019). As such, this analysis did not incorporate regional skew information. However, a sensitivity analysis was performed to identify the effects of weighting the at-site skew information with the recommended regional skew information which can be found within the **Use of Regional Skew Information** section.

The mean, standard deviation, and skew for the parameterized LPIII distribution were found to be 3.673, 0.567, and -0.449, respectively with an ERL of approximately 110 years. The plotting positions for the observed data, resultant computed curve, 5- and 95-percent confidence limits, and expected probability curve are shown in Figure D-16.

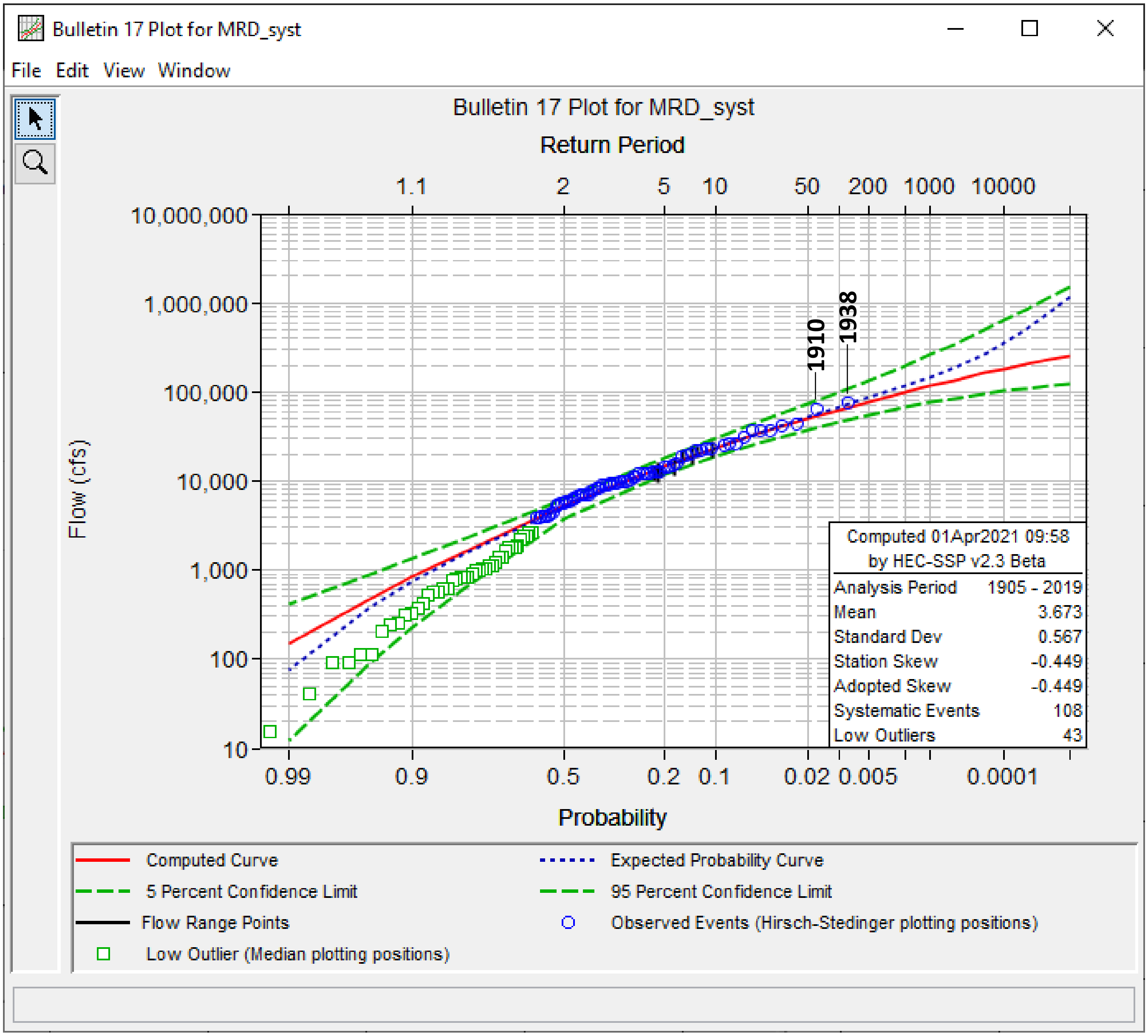

Figure D-16. Flood Frequency Results using Systematic Data

Flood Frequency with Historical Records

An LPIII analytical distribution was parameterized using the historical and systematic data through the use of the previously mentioned B17C methodology. The analysis period spanned 160 years (WY1860 through WY2019) and included 6 historical events, 108 systematic events, and 46 years of missing data. The MGB test identified a critical value of 3720 cfs which automatically censored 43 values.

Similar to the flood frequency results obtained using only systematic data, the computed at-site skew coefficient of -0.21 was found to be significantly different than the recommended regional skew coefficient of 0.0. This may indicate that the flood frequency characteristics of the watershed upstream of Mojave River Dam are appreciably different from those used to develop the regional skew information. When this occurs, it is reasonable to give greater weight to the at-site skew coefficient after due consideration of the data and flood-producing characteristics of the basin (England, et al., 2019). As such, this analysis did not incorporate regional skew information. However, a sensitivity analysis was performed to identify the effects of weighting the at-site skew information with the recommended regional skew information which can be found within the **Use of Regional Skew Information** section.

The mean, standard deviation, and skew for the parameterized LPIII distribution were found to be 3.7, 0.56, and -0.21, respectively with an ERL of approximately 140 years. The plotting positions for the observed data, resultant computed curve, 5- and 95-percent confidence limits, and expected probability curve are shown in Figure D-17.

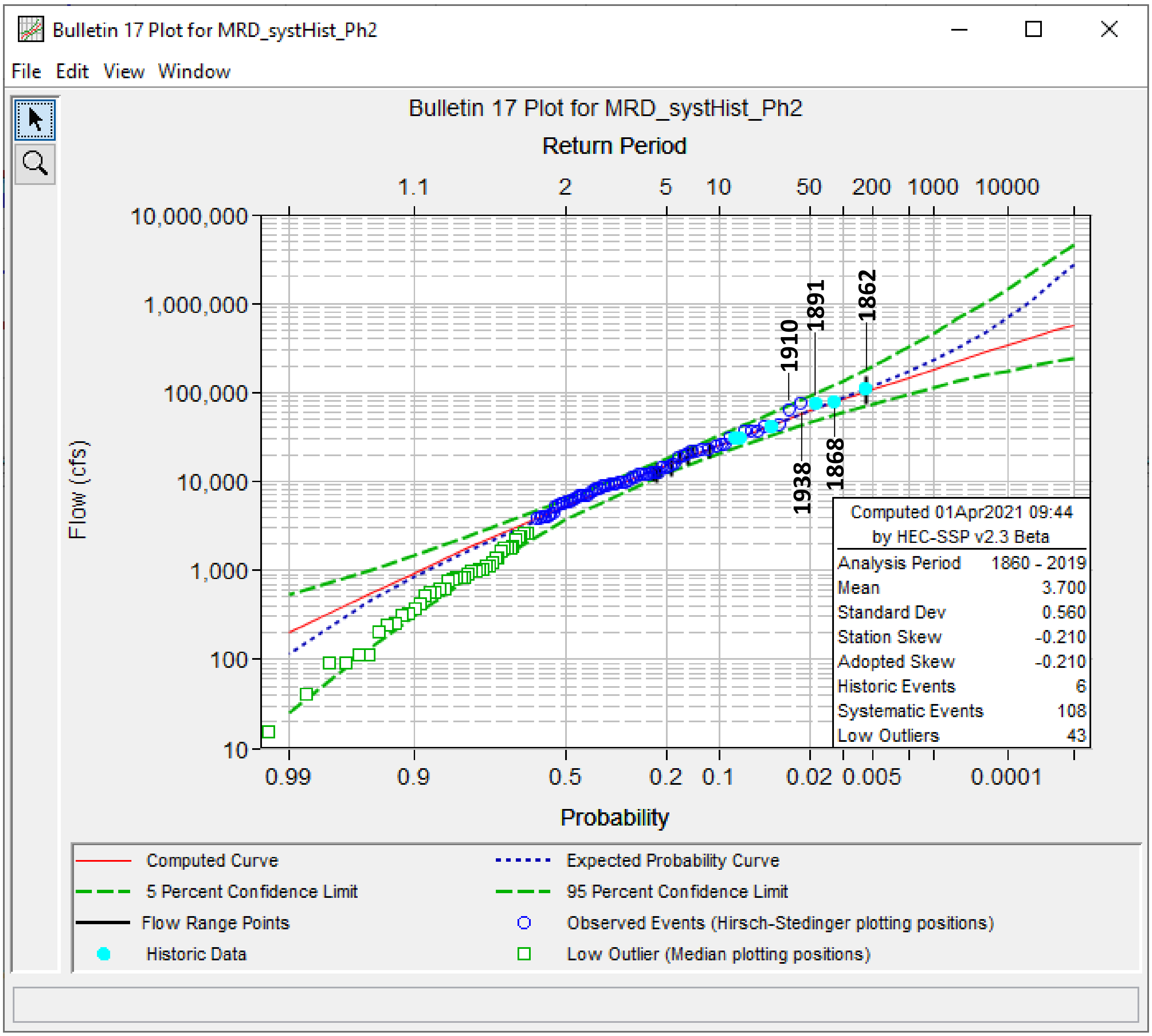

Figure D-17. Flood Frequency Results using Historical and Systematic Data

When compared against the results obtained using only systematic data, the flood frequency curve was found to shift slightly upwards (i.e. increase in the mean) along with a moderate difference in shape (i.e. skew). However, the computed variance at most quantiles was found to decrease when including the historical data. Specifically, by including 6 historical events and lengthening the historical period by 45 years, the ERL increased by approximately 30 years, which indicates that information content was added. The resultant computed curves, 5- and 95-percent confidence limits, and expected probability curves for both analyses are compared in Figure D-18.

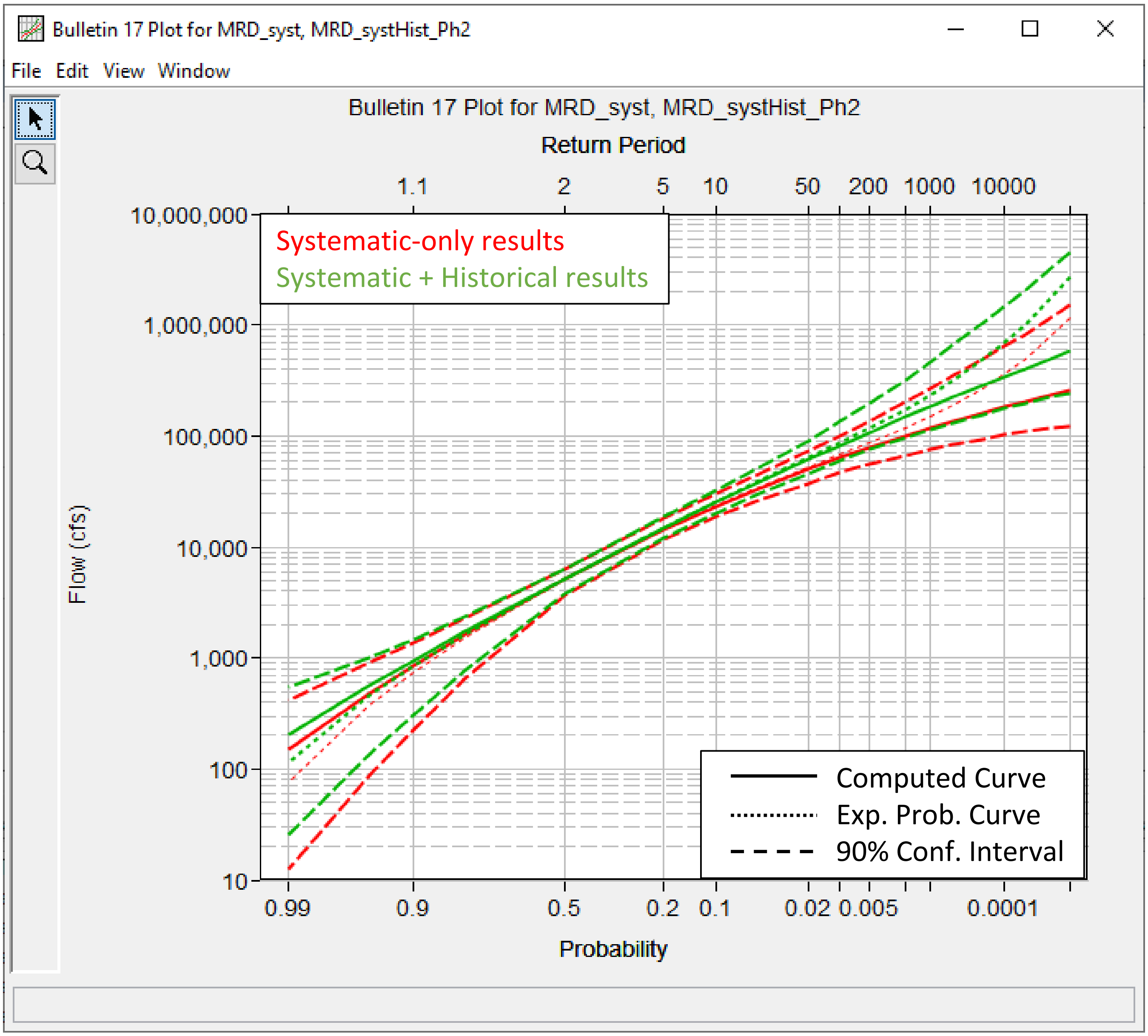

Figure D-18. Flood Frequency Results using Historical and Systematic Data vs. Flood Frequency Results using Only Systematic Data

Flood Frequency with Best Estimate Paleoflood Records

An LPIII analytical distribution was parameterized using the best estimate paleoflood, historical, and systematic data through the use of the previously mentioned B17C methodology. The analysis period spanned 1500 years (WY520 through WY2019) and included 7 historical events, 108 systematic events, and 1385 years of missing data. The MGB test identified a critical value of 3720 cfs which automatically censored 43 values.

Dissimilar to the flood frequency results obtained using only systematic data and/or historical and systematic data, the computed at-site skew coefficient of -0.048 obtained when incorporating the best estimate paleoflood data was found to be comparable to the recommended regional skew coefficient of 0.0. After due consideration of the data, flood-producing characteristics of the basin, and the much larger information content of the at-site skew coefficient when using the best estimate paleoflood data, this analysis did not incorporate regional skew information. However, a sensitivity analysis was performed to identify the effects of weighting the at-site skew information with the recommended regional skew information which can be found within the **Use of Regional Skew Information** section.

The mean, standard deviation, and skew for the parameterized LPIII distribution were found to be 3.714, 0.551, and -0.048, respectively with an ERL of approximately 270 years. The plotting positions for the observed data, resultant computed curve, 5- and 95-percent confidence limits, and expected probability curve are shown in Figure D-19.

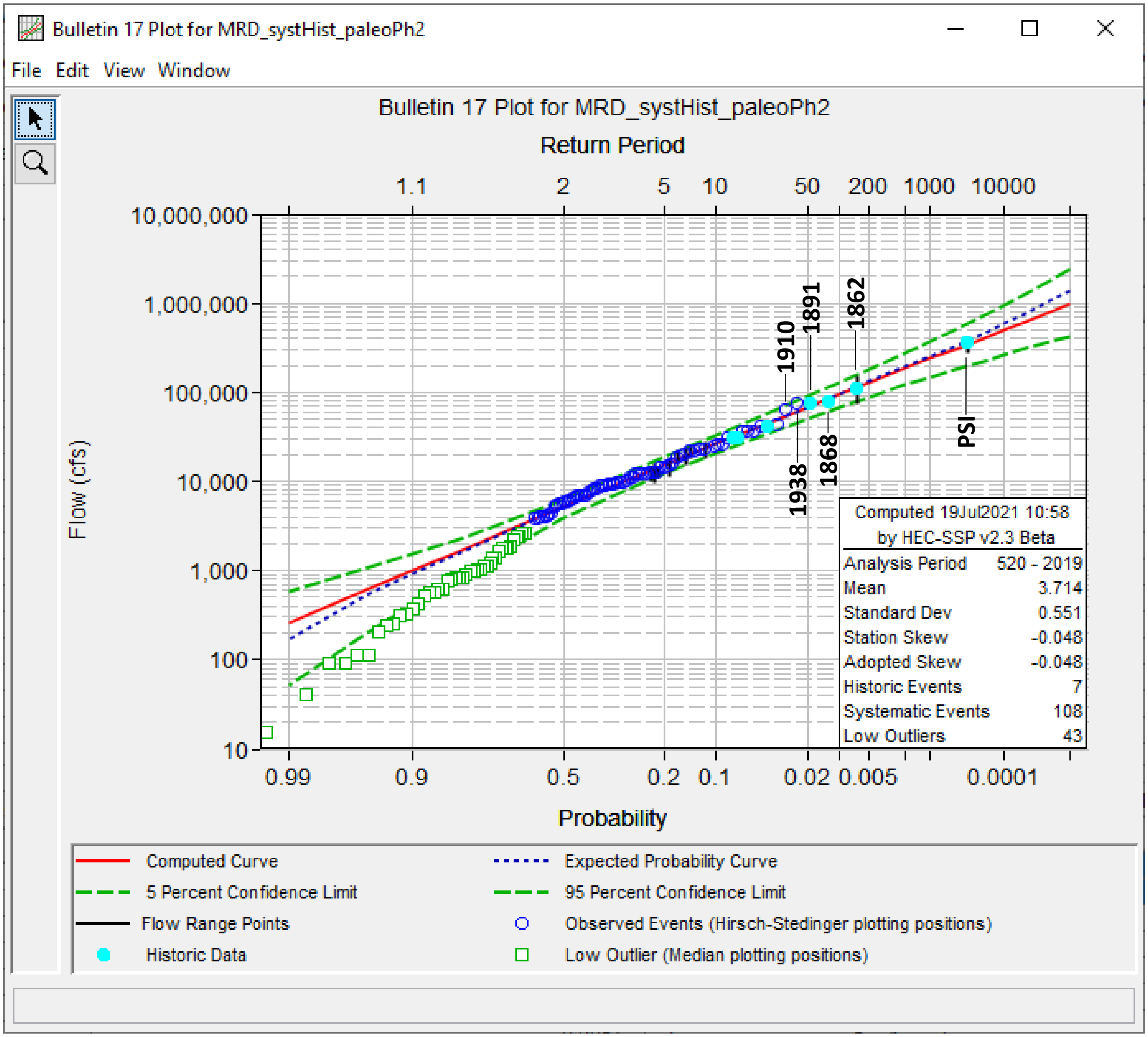

Figure D-19. Flood Frequency Results using Best Estimate Paleoflood, Historical, and Systematic Data

When compared against the results obtained using historical and systematic data, the flood frequency curve was found to shift slightly upwards (i.e. increase in the mean) with a moderate change in shape (i.e. skew). Also, the computed variance at all quantiles was found to decrease when including the best estimate paleoflood data. Specifically, by lengthening the historical period by 1340 years, the ERL increased by approximately 130 years, which indicates that information content was added. The resultant computed curves, 5- and 95-percent confidence limits, and expected probability curves for both analyses are compared in Figure D-20.

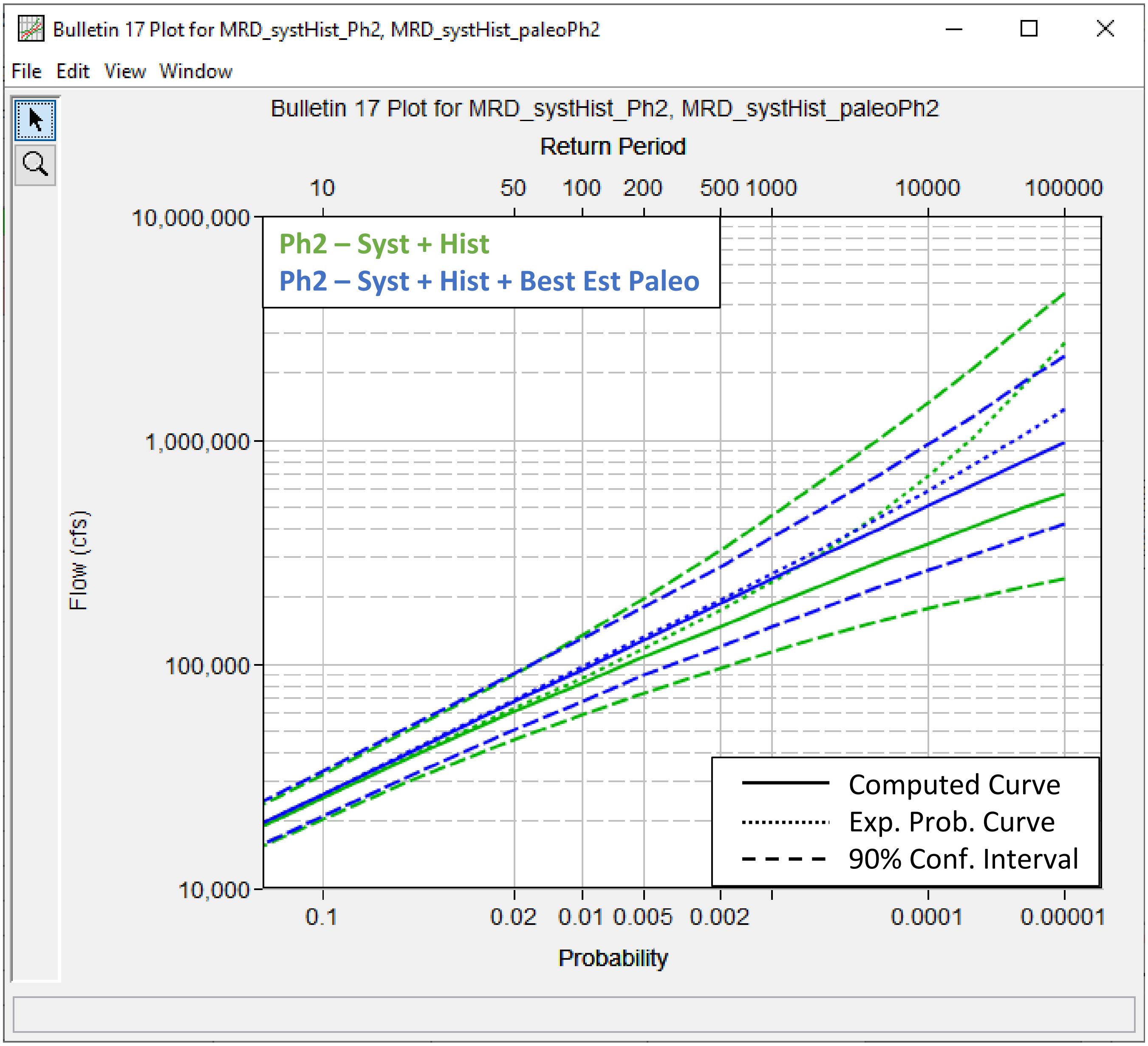

Figure D-20. Flood Frequency Results using Best Estimate Paleoflood, Historical, and Systematic Data vs. Flood Frequency Results using Historical and Systematic Data

Comparison to Previous Reports

The results obtained from this analysis were compared against those presented within the Report on Survey for Flood Control (U.S. Army Corps of Engineers, 1956), the Evaluation of Proposed Modifications report (U.S. Army Corps of Engineers, 1985), and Periodic Assessment #1 (U.S. Army Corps of Engineers, 2019). The flood frequency results from this analysis were found to differ from those published in previous reports. For large floods (peaks between 30000 cfs and 200000 cfs), the results from this analysis are similar to those from Periodic Assessment #1. However, for extremely large floods in excess of 200000 cfs, the results from this analysis indicate that AEPs are greater than those presented in Periodic Assessment #1. These differences are related to several key factors including: 1) incorporating additional systematic and historical data, 2) using uncertain flow magnitudes for eight years of systematic data, and 3) integrating paleoflood data.

Pertinent information from previous reports, in addition to this effort, are tabulated within Table D-8. The resultant computed curves are compared in Figure D-21. It should be noted that an empirical flow-frequency distribution was developed within the Report on Survey for Flood Control while all subsequent reports utilized the LPIII analytical distribution.

Table D-8. Pertinent Information from Previous Reports

Report	Analysis Period	Mean	Standard Deviation	At-Site Skew	Adopted Skew
Survey for Flood Control (1956)	1859 – 1954	-	-	-	-
Evaluation of Proposed Modifications (1985)	1867 – 1971	3.695	0.652	-0.316	-0.300
Periodic Assessment #1 (2019)	1867 – 2017	3.606	0.645	-0.554	-0.335
Best Estimate Paleoflood, Historical, and Systematic Data (2021)	520 – 2019	3.714	0.551	-0.048	-0.048

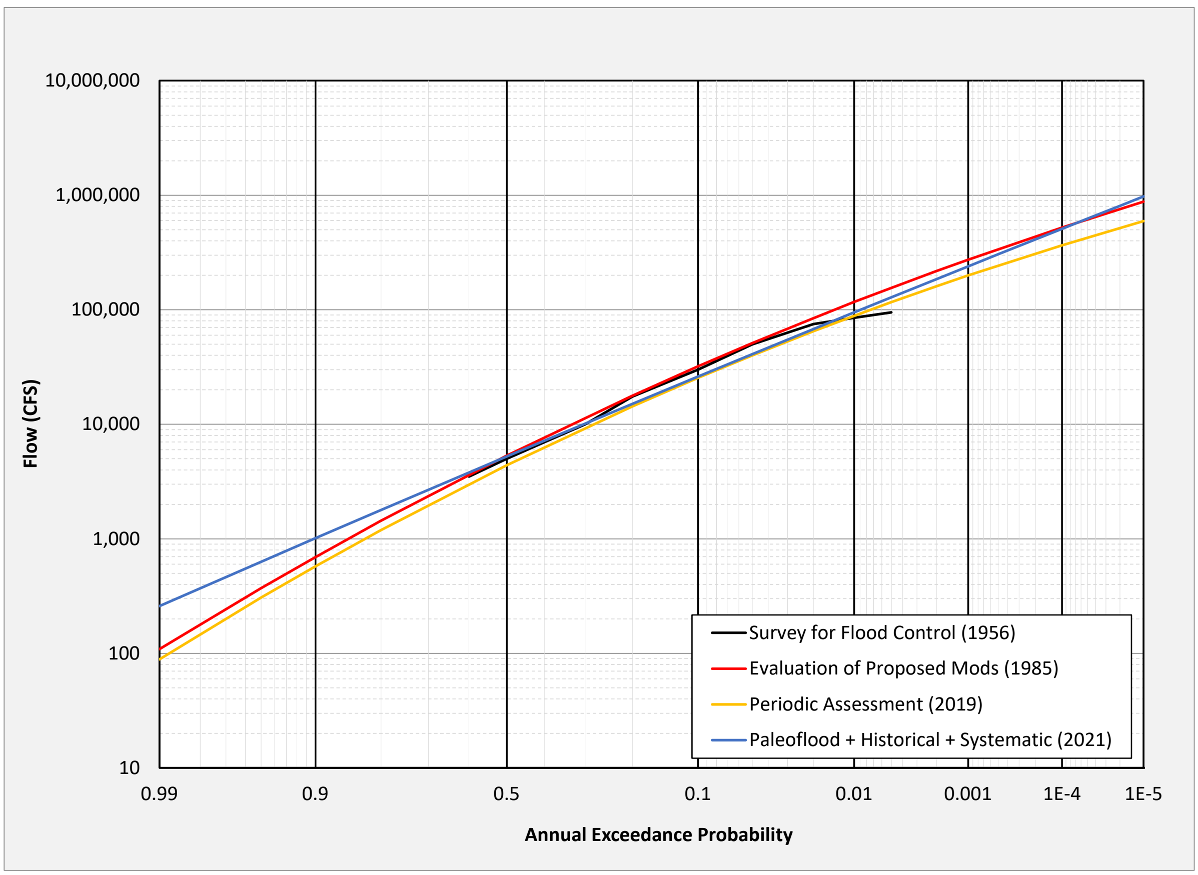

Figure D-21. Flood Frequency Results from Previous Reports

Sensitivity Analyses

Many of the aforementioned sources of data and parameters are uncertain. Sensitivity analyses were used to identify the effects of these uncertain sources of data and parameters upon the computed flood frequency information. The following sections detail these sensitivity analyses and their results. Unless otherwise noted, all sensitivity analyses were compared against the best estimate paleoflood, historical, and systematic data results.

Use of Regional Skew Information

The at-site skew coefficients computed when using historical and/or systematic data were found to be significantly different than the recommended regional skew coefficient of 0.0. This may indicate that the flood frequency characteristics of the watershed upstream of Mojave River Dam are appreciably different from those used to develop the regional skew information. When this occurs, it is reasonable to give greater weight to the at-site skew coefficient after due consideration of the data and flood-producing characteristics of the basin (England, et al., 2019). However, the flood frequency results obtained using paleoflood, historical, and systematic data were found to be comparable to the recommended regional skew coefficient of 0.0.

The physical, hydrological, and meteorological characteristics of the watershed upstream of Mojave River Dam, including overland and channel slopes, infiltration capacity, the availability of floodplain storage, and the spatial distribution of precipitation, can influence the shape or skewness of flood frequency distributions. As previously discussed within **Appendix A**, the average annual precipitation distribution upstream of Mojave River Dam is highly dependent upon elevation. The average annual precipitation throughout the watershed varies from approximately 12 inches at the dam site to approximately 55 inches in the vicinity of Strawberry Peak. Also, while Deep Creek exhibits a relatively uniform slope of 150 ft/mi over its entire length, overland and channel slopes within the West Fork Mojave River watershed decrease with elevation. Specifically, between Silverwood Lake and the Mojave River dam site, the West Fork Mojave River channel slope decreases to approximately 33 ft/mi. Also, within this reach, the West Fork Mojave River valley is underlain by relatively permeable alluvial fan deposits which allow for more rapid infiltration of both precipitation and streamflow. Several ephemeral streams are present within this reach which also suggests relatively large infiltration capacities. Finally, large amounts of floodplain storage are available within this reach of the West Fork Mojave River. When combined, these characteristics are expected to produce a negatively skewed flood frequency distribution which conflicts with the recommended regional skew coefficient of 0.0. As such, the regional skew information was not used in the previously mentioned analyses. However, this sensitivity analysis was performed to quantify the effects of including this regional skew information.

Equation 7-10 within Bulletin 17C was used to directly integrate the regional skew information within each EMA iteration. This ensured that the adjusted mean and standard deviation fit the data (England, et al., 2019). An estimation of the additional years of record for the regional skew coefficient was required to use this equation. A regional skew coefficient of 0.0 and an associated total error of 0.2 equates to approximately 25 years' worth of additional information content (Interagency Advisory Committee on Water Data, 1982). It should be noted that this approach is not currently available within any flood frequency analysis software with the exception of HEC-SSP v2.3-beta.

As expected, when including regional skew information, a resultant weighted skew coefficient was calculated to lie between the at-site skew and regional skew coefficients. However, the LPIII parameterization was found to change to varying degrees depending upon the data that was included. For instance, when using only systematic data, the resultant LPIII parameterization is affected to a greater degree than when using historical and systematic data. In general, as more systematic, historical, and paleoflood data was added to the analysis, the effects of including the regional skew information diminished. This stems from the fact that as more data is added, the information content of the at-site estimators (e.g., such as mean, standard deviation, and skew) increases while the information content of the regional skew information remains the same.

When incorporating regional skew information, the estimated AEP for a flow rate of 250000 cfs is essentially the same as the results presented within the **Flood Frequency with Best Estimate Paleoflood Records** section. Due to the negligible differences, no plots are shown for this sensitivity analysis. However, the LPIII parameterization for all analyses with and without regional skew information are tabulated within Table D-9.

Table D-9. LPIII Parameterization With and Without Regional Skew Information

Data	With Regional Skew?	Mean	Standard Deviation	Weighted Skew
Systematic	No	3.673	0.567	-0.449
	Yes	3.694	0.532	-0.210
Historical + Systematic	No	3.700	0.560	-0.210
	Yes	3.709	0.546	-0.112
Best Estimate Paleoflood + Historical + Systematic	No	3.714	0.551	-0.048
	Yes	3.715	0.548	-0.034

January 1862 Flood Event Interpretation

Various reports which were used for this analysis presented conflicting lines of evidence regarding the January 1862 flood event magnitude, as described within the **Historical Data** section. This sensitivity analysis quantified the effects of interpreting different interval estimates for this flood event. Specifically, four interpretations of the January 1862 flood magnitude were evaluated.

The “Best Estimate” interpretation used a flow range of 75000 cfs – 150000 cfs to represent this event. The low magnitude of 75000 cfs signifies that this event was an extreme flood while the high magnitude of 150000 cfs corresponds to the estimate provided by San Bernardino County (San Bernardino County, 2018). This interval also satisfies the quantitative description from Engstrom (1996) in addition to the Report on Survey for Flood Control (U.S. Army Corps of Engineers, 1956).

The “All Encompassing” interpretation used a flow range of 30000 cfs – 150000 cfs to represent this event. This interpretation encompasses all sources of information regarding this event. The low magnitude of 30000 cfs signifies that this event was at least as large as all other historical flood events while the high magnitude of 150000 corresponds to the estimate provided by San Bernardino County (San Bernardino County, 2018).

The “Butler, et al (1966)” interpretation used a flow range of 30000 cfs – 72700 cfs to represent this event. This interpretation aligns with statements made within the Magnitude and Frequency of Floods in the United States report (Butler, Reid, & Berwick, 1966). The low magnitude of 30000 cfs signifies that this event was at least as large as all other historical flood events while the high magnitude corresponds to the May 1938 flood magnitude.

The “Lane Diary” interpretation used a flow range of 70000 cfs – 78000 cfs to represent this event. This interpretation agrees with diary fragments originally written by Aaron Lane and reproduced within Thompson (1995). The low magnitude of 70000 cfs signifies that this event was an extreme flood while the high magnitude of 78000 cfs corresponds to the December 1867 flood magnitude.

The flood frequency results from this sensitivity analysis were found to slightly differ depending upon the interpretation and flow range that was used to represent the January 1862 flood. The low magnitude of the flow interval was found to exhibit a greater impact on the resultant LPIII parameterization than the high magnitude. As expected, the “Best Estimate” interpretation provided the largest AEP for extreme flow rates, implying they are expected to occur more frequently. Conversely, the “Butler, et al (1966)” interpretation provided the smallest AEP for extreme flow rates, implying they are rarer.

The LPIII parameterization for all analyses are tabulated within Table D-10 while the resultant computed curves, 5- and 95-percent confidence limits, expected probability curves, and 1862 flood intervals are compared in Figure D-22. The 1/100, 1/1000, 1/10000, and 1/100000 AEP results from each interpretation are compared in Figure D-23.

Table D-10. LPIII Parameterization with Different January 1862 Flood Event Interpretations

Analysis	Mean	Standard Deviation	Skew
“Best Estimate” Interpretation	3.714	0.551	-0.048
“All Encompassing” Interpretation	3.714	0.549	-0.067
“Butler, et al (1966)” Interpretation	3.713	0.549	-0.071
“Lane Diary” Interpretation	3.713	0.551	-0.064

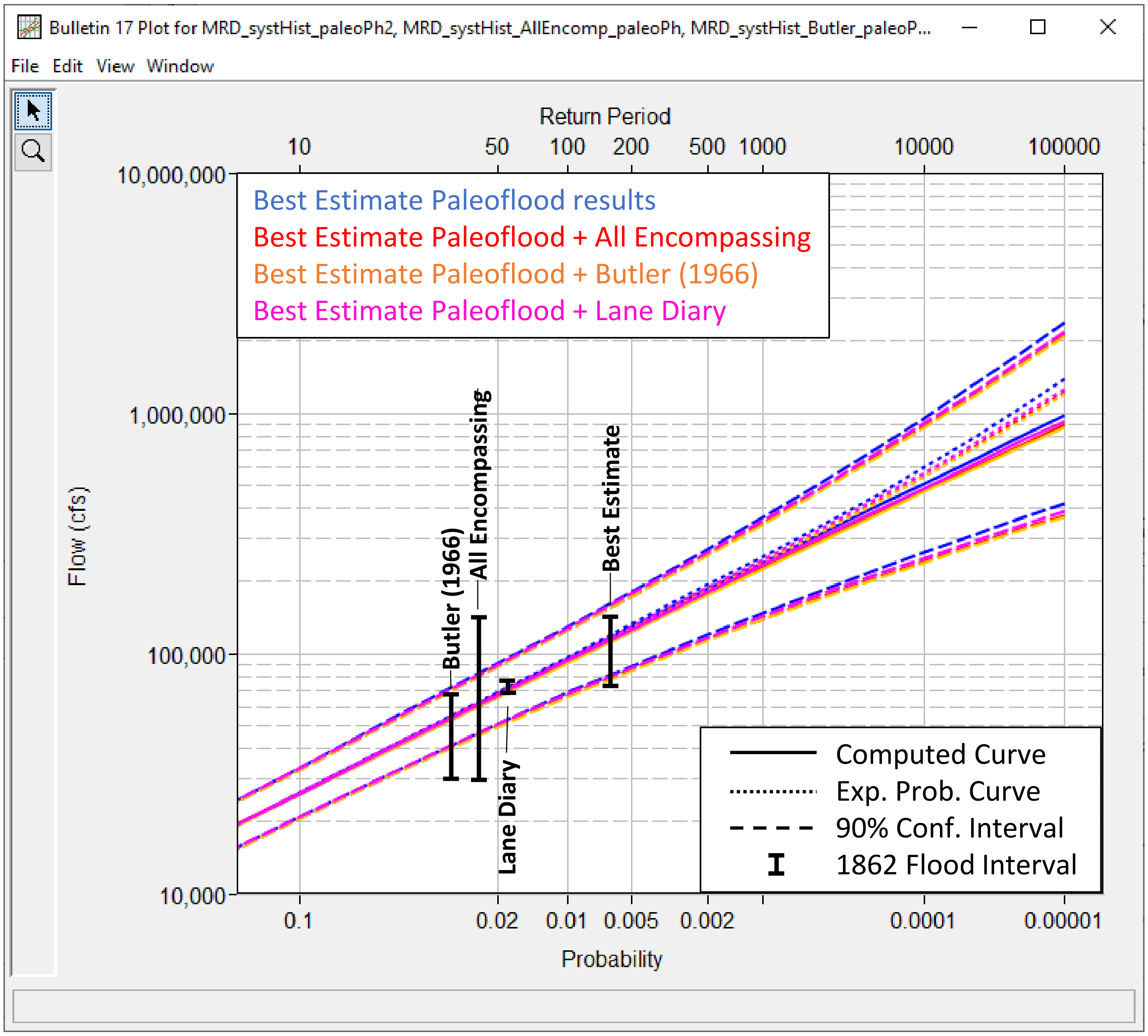

Figure D-22. Flood Frequency Results with Different January 1862 Flood Event Interpretations

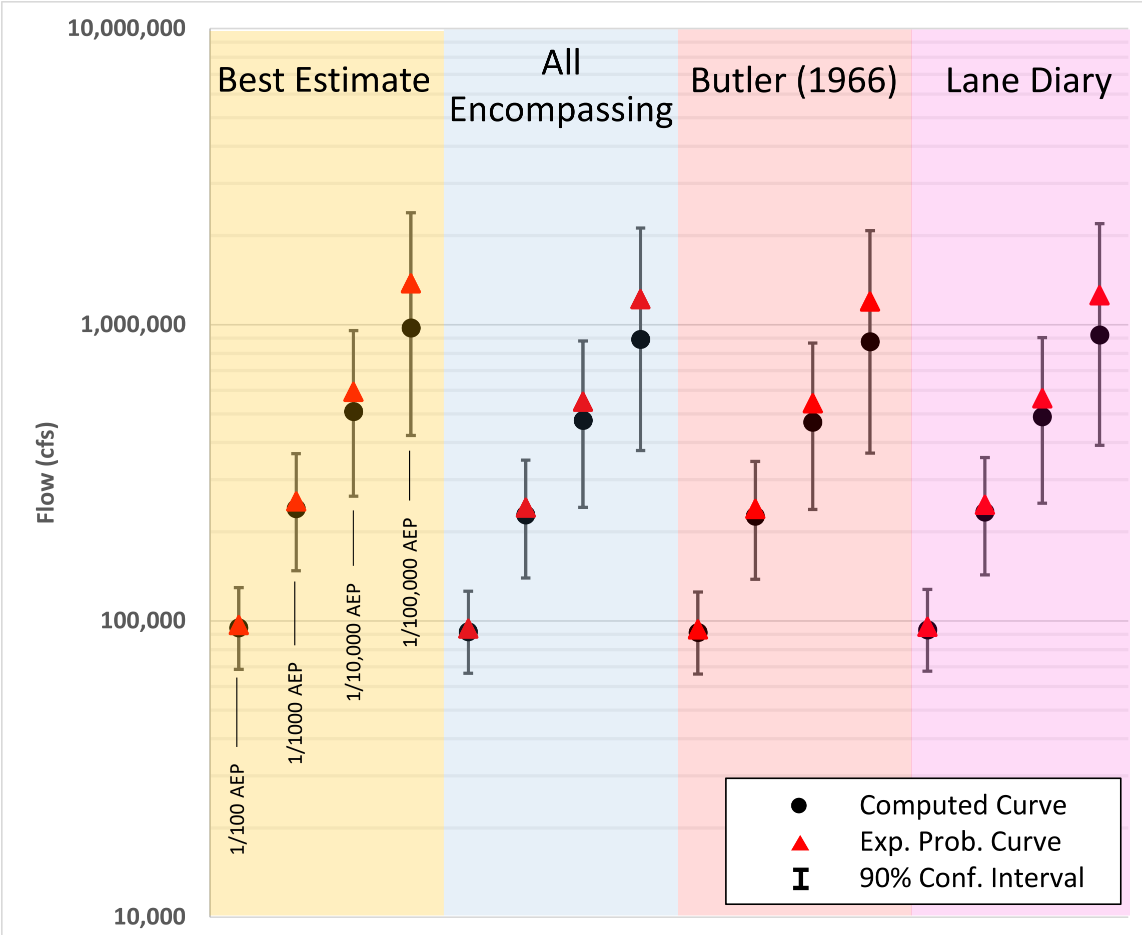

Figure D-23. Comparison of 1/100, 1/1000, 1/10000, and 1/100000 AEP with Different January 1862 Flood Event Interpretations

Paleoflood PSI Age

As was previously mentioned, the age of the paleoflood PSI spanned from 1100 years old to 1800 years old. The results presented within the **Flood Frequency with Best Estimate Paleoflood** Records section used a best estimate age of 1500 years old. This sensitivity analysis quantified the effects of inferring different ages for the paleoflood PSI. Specifically, an age of 1800 years old was analyzed along with an age of 1100 years old, representing “Old” and “Young” interpretations of the paleoflood PSI, respectfully.

Using different age interpretations for the paleoflood PSI resulted in minor differences in LPIII parameterization. For reference, the estimated AEP for a flow rate of 250000 cfs differs by less than +/- ½ order of magnitude when using either the Old, Best Estimate, or Young PSI age interpretations. However, the computed variances at all quantiles were found to be dependent upon the age interpretation. The Old interpretation was found to have the smallest variance which provides the largest information content. Conversely, the Young interpretation exhibited the largest variance which provides the smallest information content. The LPIII parameterization for all analyses are tabulated within Table D-11 while the resultant computed curves are compared in Figure D-24. The results at the 1/100, 1/1000, 1/10000, and 1/100000 AEP are compared in Figure D-25.

Table D-11. LPIII Parameterization for Different PSI Age Interpretations

Analysis	Mean	Standard Deviation	Skew
Best Estimate (1500 years old)	3.714	0.551	-0.048
Old (1800 years old)	3.712	0.553	-0.077
Young (1100 years old)	3.718	0.548	-0.007

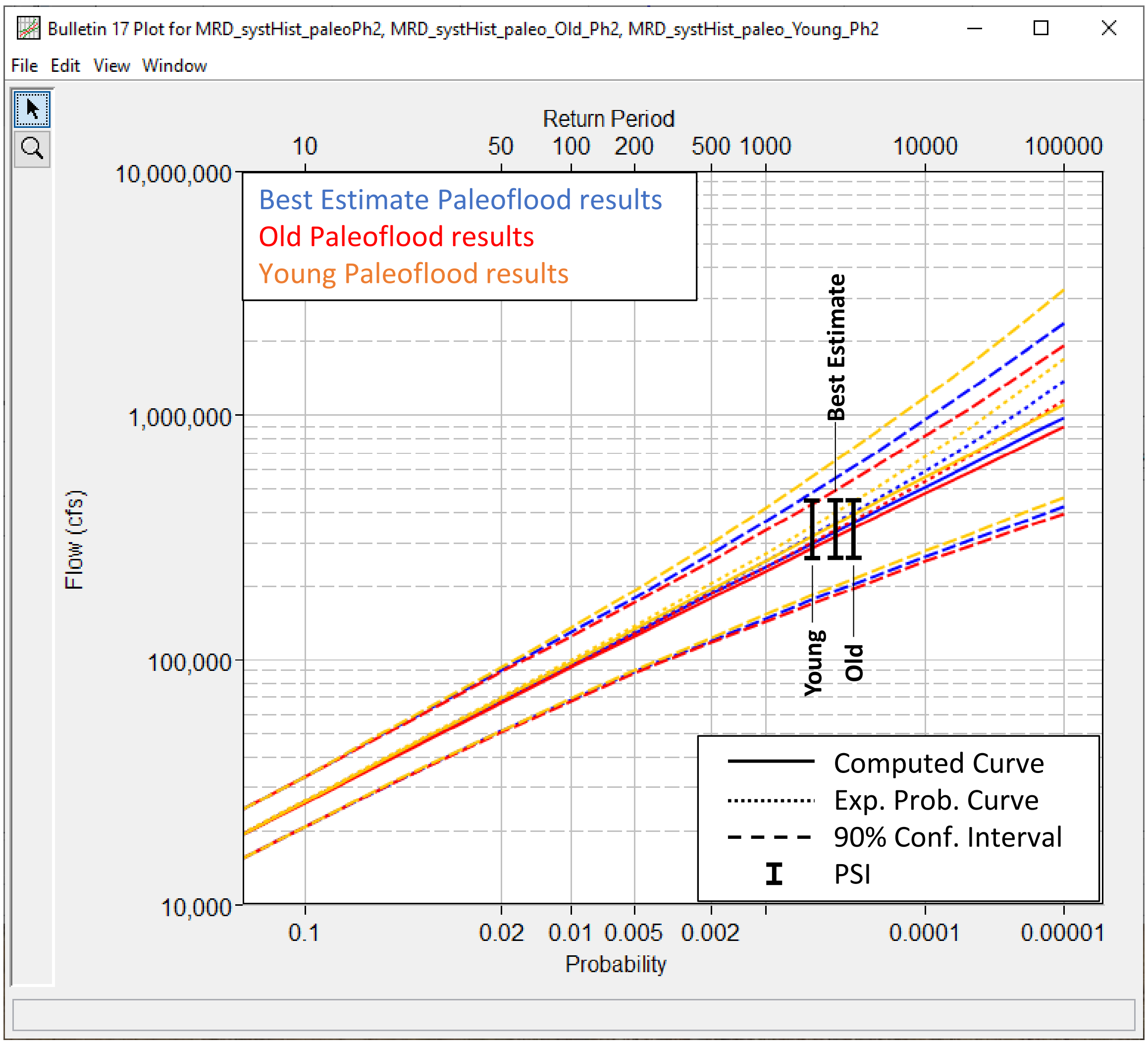

Figure D-24. Flood Frequency Results for Different PSI Age Interpretations

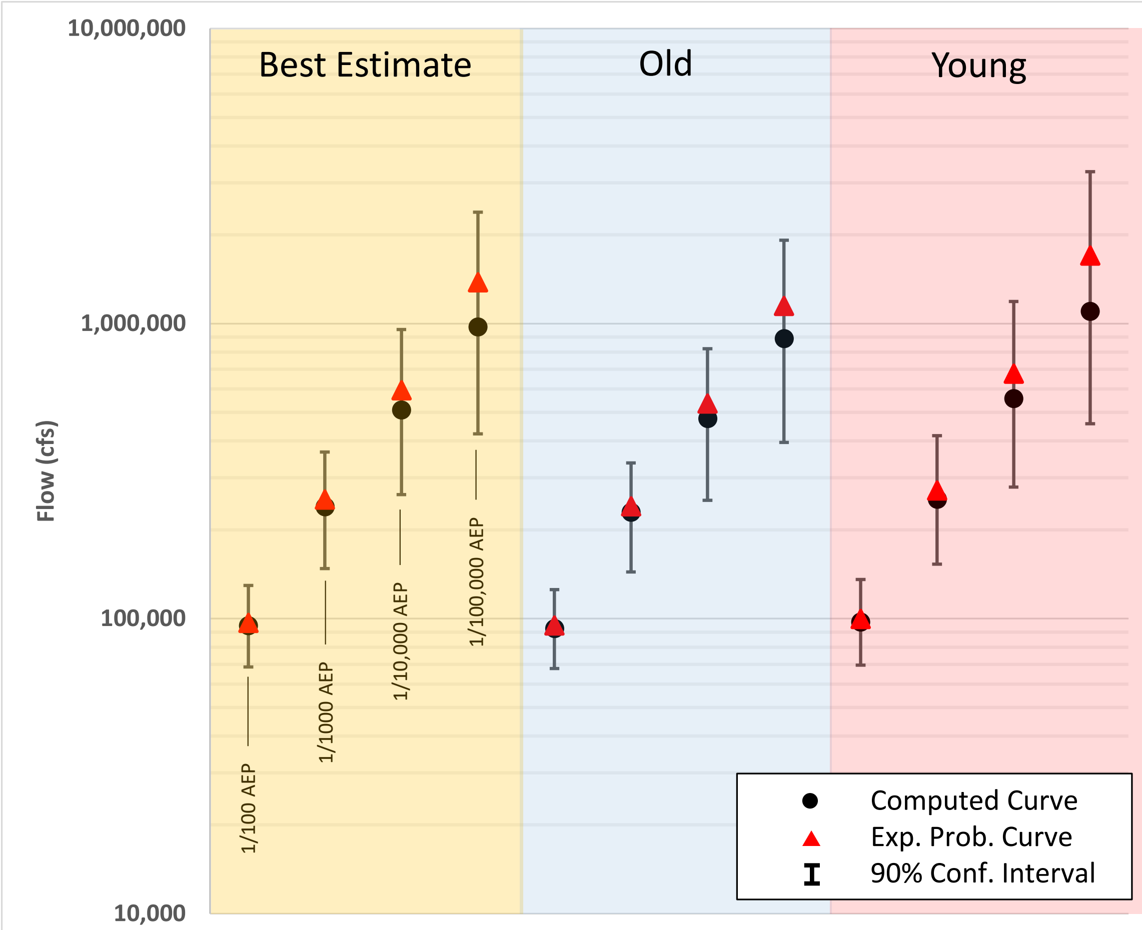

Figure D-25. Comparison of 1/100, 1/1000, 1/10000, and 1/100000 AEP Results for Different PSI Age Interpretations

Paleoflood PSI Magnitude

The results presented within the **Flood Frequency with Best Estimate Paleoflood** Records section used a paleoflood PSI flow range spanning 275000 cfs to 425000 cfs. This sensitivity analysis quantified the effects of inferring a different magnitude for the paleoflood PSI. Specifically, a flow range of 275000 cfs to 375000 cfs was analyzed which represents a "low" magnitude" interpretation of the paleoflood PSI, respectively.

As discussed within Appendix C, depths and velocities vary spatially within the study reach as discharges increase or decrease. A hydraulic model was used to estimate depths and velocities at key locations within the area of interest. The estimated range in paleodischarge presented within Table D-6 considers both the variability in the geomorphic surface elevation and the uncertainty in the hydraulic model. The best-estimate paleodischarge for transporting gravel at site WF-2 corresponds to a total inflow to Mojave River Dam of 375,000 cfs. This discharge results in an estimated inundation of 6 ft and a depth-averaged velocity of 4-5 ft/s at this key location which is needed to transport the gravel of interest. A corresponding low discharge estimate of 275,000 cfs was found to inundate site WF-2 by approximately 1 foot. A discharge any lower than 275,000 cfs would not result in any inundation at this location and could not have mobilized the gravel of interest.

Using different magnitude interpretations for the paleoflood PSI resulted in minor differences in LPIII parameterization. For reference, the estimated AEP for a flow rate of 250,000 cfs differs by less than ± ¼ order of magnitude when using either the Best Estimate or Low PSI magnitude interpretation. Also, the computed variances at all quantiles were found to be independent of the PSI magnitude interpretation. The LPIII parameterizations for the analyses are tabulated within Table D-12, and resultant computed curves are compared in Figure D-26. The results at the 1/100, 1/1000, 1/10000, and 1/100000 AEP are compared in Figure D-27.

Table D-12. LPIII Parameterization for Different PSI Magnitude Interpretations

Analysis	Mean	Standard Deviation	Skew
Best Estimate (275,000 cfs to 425,000 cfs)	3.714	0.551	-0.048
Low Magnitude (275,000 cfs to 375,000 cfs)	3.715	0.552	-0.044

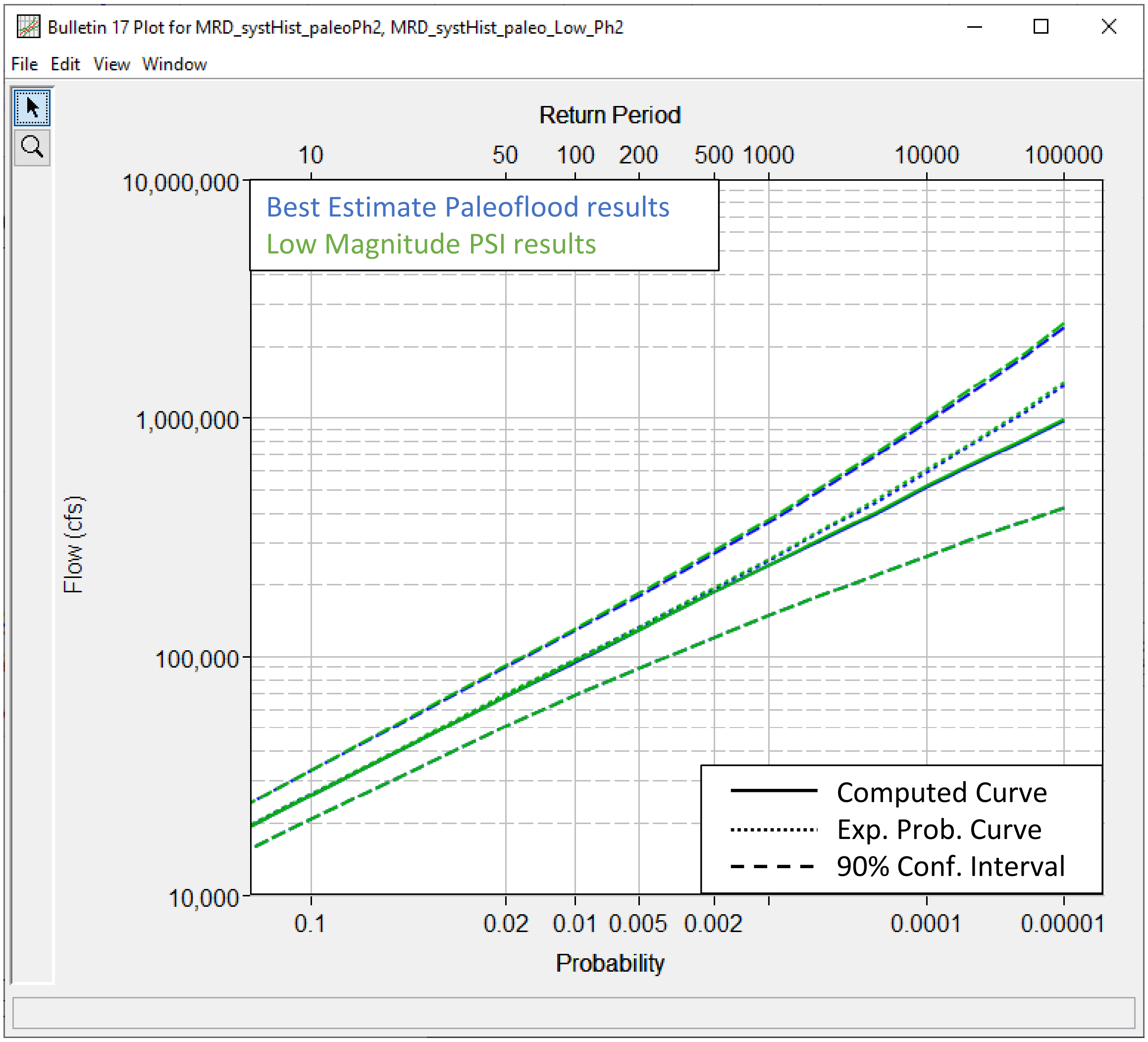

Figure D-26. Flood Frequency Results for Different PSI Magnitude Interpretations

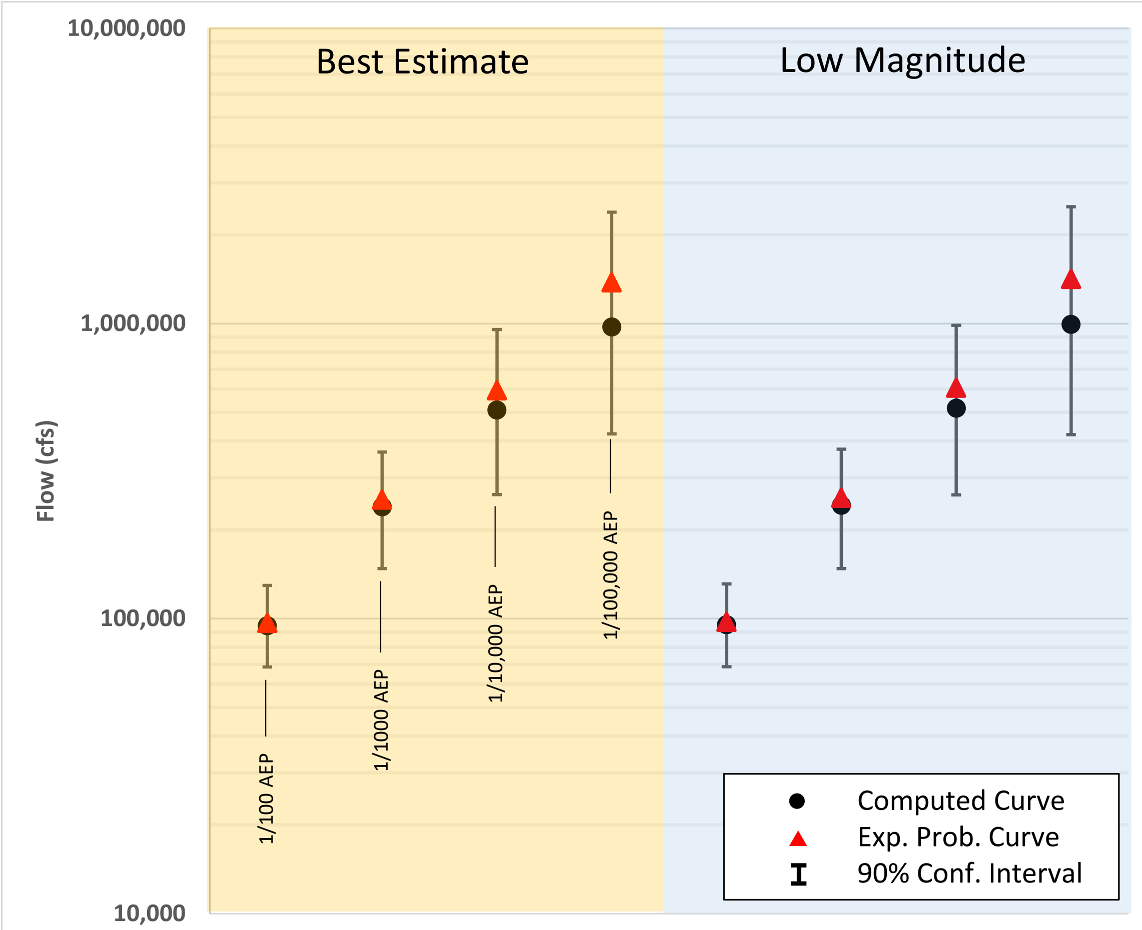

Figure D-27. Comparison of 1/100, 1/1000, 1/10000, and 1/100000 AEP Results for Different PSI Magnitude Interpretations

Flood Frequency Analysis Summary

Multiple sources of flow and stage data were investigated and included within this analysis. These encompassed USGS and USACE stream/reservoir gages in addition to previously published reports. A systematic record was assembled that included 108 discrete events spanning 114 years (WY1905 – WY2019). Historical data was found within a period starting in WY1860 to the start of systematic data collection in WY1905, in addition to a gap in systematic data collection spanning WY1923 – WY1929. Six historical flood events were identified for inclusion. The largest five flood events with reasonably well estimated magnitudes to have occurred since the earliest historical record include 78000 cfs in WY1868, 75000 cfs in WY1891, 72700 cfs in WY1938, 62000 cfs in WY1910, and 40000 cfs in WY1943. A flow interval spanning 75000 cfs to 150000 cfs was used to represent the flood event in WY1862. Paleoflood data, in the form of a PSI, was identified for the period prior to the start of historical data. The magnitude of the paleoflood PSI ranged from 275000 cfs to 475000 cfs with a best estimate of 375000 cfs. The age of the paleoflood PSI spanned from 1100 years old to 1800 years old with a best estimate age of 1500 years old.

HEC-SSP version 2.3-beta was used to parameterize LPIII analytical distributions using various combinations of data and parameters by means of B17C methodology. The at-site skew coefficients computed when using only systematic data and/or historical and systematic data were found to be significantly different than the recommended regional skew coefficient of 0.0. However, when incorporating the best estimate paleoflood data, the computed at-site skew coefficient was found to be comparable to the recommended regional skew coefficient. Due to differences in the flood frequency characteristics of the watershed upstream of Mojave River Dam compared to those used to develop the regional skew information, the regional skew information was not used.

By including the best estimate paleoflood and historical information, the resultant flood frequency distributions indicate that large floods occur more frequently than the systematic data, by itself, would suggest. Also, the inclusion of the best estimate paleoflood PSI and historical information reduces knowledge uncertainty in the resultant flood frequency distributions; the best estimate paleoflood and historical information increased the ERL from approximately 110 to 270 years when compared against the systematic data by itself.

The flood frequency results from this analysis were found to differ from those published in previous reports. For large floods (peaks between 30000 cfs and 200000 cfs), the results from this analysis are similar to those from Periodic Assessment #1. However, for extremely large floods in excess of 200000 cfs, the results from this analysis indicate that AEPs are greater than those presented in Periodic Assessment #1. These differences were due to several key factors including: 1) incorporating additional systematic and historical data, 2) using uncertain flow magnitudes for eight years of systematic data, and 3) integrating paleoflood data.

Multiple sensitivity analyses were used to quantify the effects that uncertain data and parameter values wrought upon the flood frequency results. The sensitivity analyses demonstrated that the estimation of AEP for extreme floods can vary by less than +/- ½ order of magnitude. Future efforts should focus on minimizing sources of uncertainty such as providing more definite ages and associated magnitudes for any paleoflood PSI and identifying additional paleoflood data.

The recommended instantaneous peak flood frequency results using the best estimate paleoflood, historical, and systematic information and at-site skew are shown in Figure D-28.

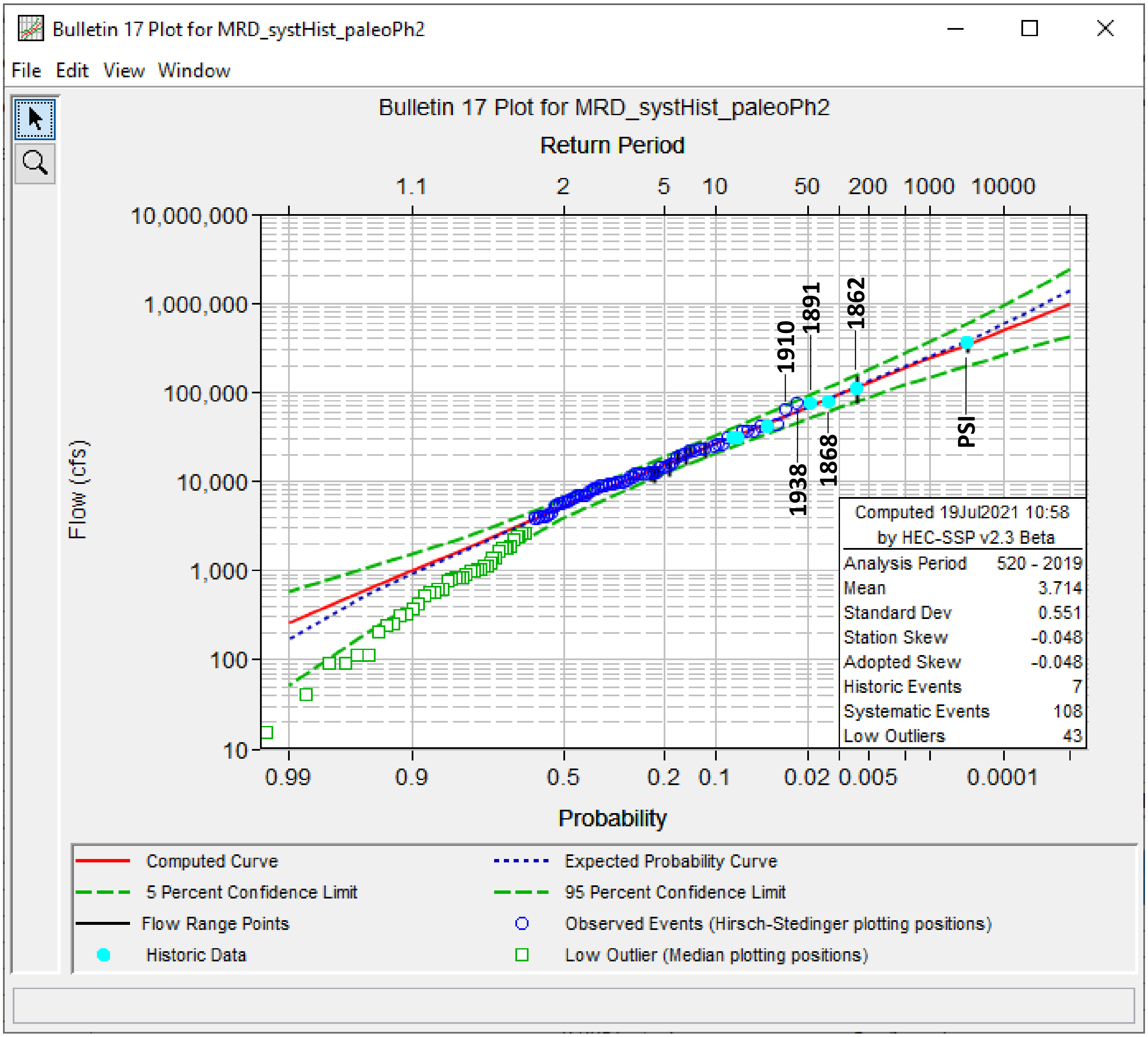

Figure D-28. Recommended Instantaneous Peak Flood Frequency Results using Best Estimate Paleoflood, Historical, and Systematic Data

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