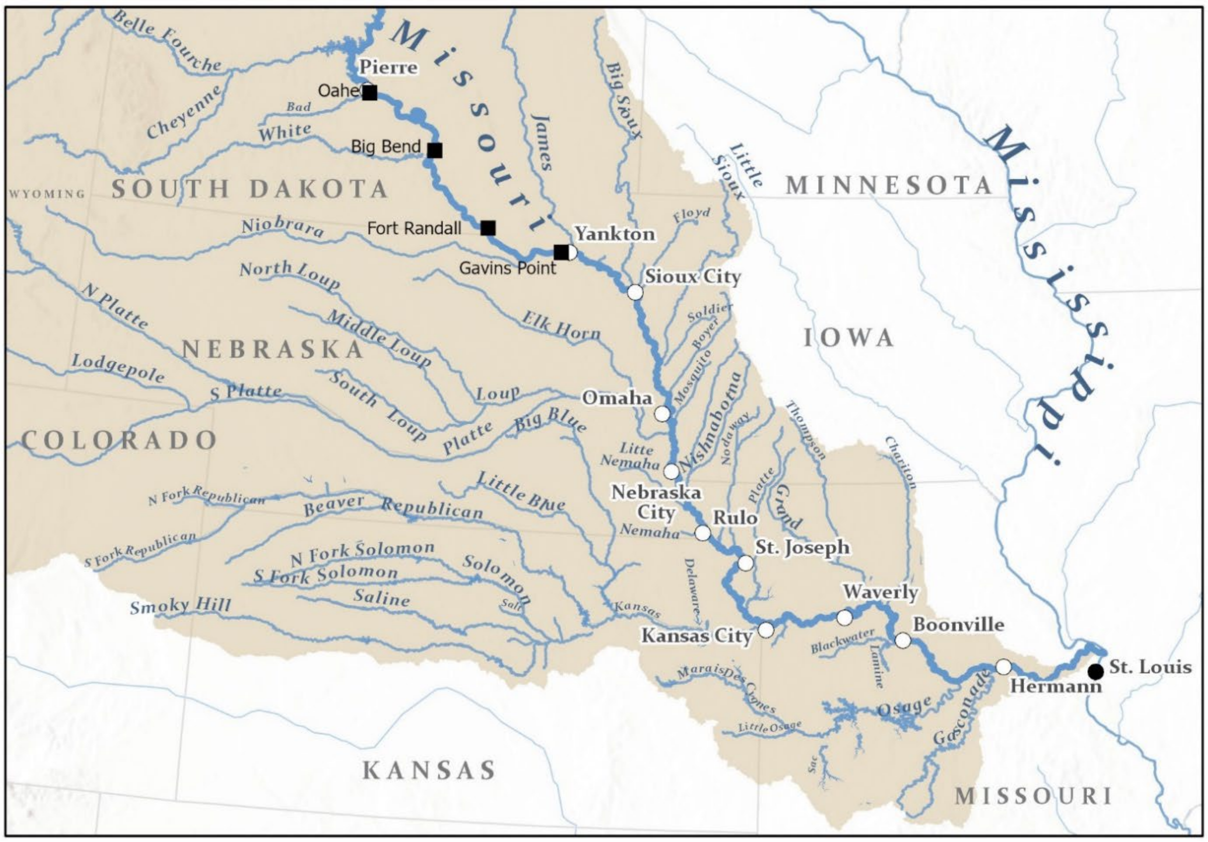
US Army Corps
of Engineers ®

Missouri River
Flow Frequency Study

Yankton, South Dakota to Hermann, Missouri

Appendix D: Differences in Unregulated Flow Frequency from 2003 UMRSFFS



U.S. Army Corps of Engineers
Northwestern Division
Omaha District, Kansas City District, and
Missouri River Basin Water Management

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Introduction

The current Bulletin 17C unregulated flow frequency estimate on the Missouri River differs greatly from the unregulated flow frequency results of the 2003 UMRSFFS. Although the unregulated flow development and statistical analysis methods employed were fundamentally the same, there are four important differences:

1. A new unregulated flow development model
2. Additional period of record since 1998 with two major floods
3. Current Bulletin 17C guidance versus the earlier Bulletin 17B
4. Changing treatment of the pre-1930 period (pre-systematic record)

D1. New Unregulated Flow Development Model

A great difficulty of estimating unregulated (no regulation, no irrigation) flow on the Missouri River is that there are very few measurements of the river's peak flow in the study reach prior to regulation on the mainstem starting in 1930 and continuing to be built out into the 1960s. This lack of observations makes it very difficult to assess whether an unregulated flow development model is accurate because there is little data to compare against. Gaged discharge records begin on most Missouri River stations downstream of Gavins Point dam circa 1930. Stage gaging began in the late 1800s, however, these records cannot reliably be converted to discharge (see also Section 3.5 of the report for how this is done for historic peak floods). Meanwhile, several smaller dams were being built on Missouri River tributaries, and land use and development was changing the basin throughout the 20th century. Most of these smaller tributary projects would likely not have had a major effect on Missouri River peak flows. Fort Peck dam on the Missouri was closed in 1937. This creates about a 7-year window of more-or-less unregulated, although not completely natural recorded flows in the early 1930s. However, the 1930s were characterized by widespread drought, and therefore the peak flow record during this period is not useful for assessing if an unregulated flow estimate is accurate with respect to large floods in that the period is too short, and time period not representative of the hydrologic risk.

The method for computing unregulated flow for the current flow frequency study is fundamentally the same as was done in the 2003 UMRSFFS but using a different computational model. Historical depletions were added back into historical observed flow, which was routed downstream without the reservoirs to create a no regulation and no irrigation daily flow dataset spanning the period of record from 1930 through 2019. The unregulated flow development model (UFDM) was used in the 2003 study. For details about this model, see UMRSFFS (USACE, 2003). The current flow frequency study utilized the Missouri River Mainstem HEC-ResSim model (USACE, 2018), which is used by Water Management (MRBWM) for planning studies, and the latest HEC-ResSIM models for Kansas

City District Tributary Projects. This is the most up-to-date model that USACE has that can compute unregulated flow on the Missouri River.

The two models differ in their routing methods, how the effects of tributary reservoirs were handled, and the Bureau of Reclamation estimated depletions. The UFDM used lag-average routing, while the HEC-ResSim model used coefficient routing. Tributary reservoir effects were accounted for explicitly in the UFDM, but were combined into depletions in the current HEC-ResSim model, except for the Kansas and Osage rivers, which were modeled explicitly. In the 2003 Study, Kansas and Osage Basin Reservoirs were modeled using Microsoft Access and Microsoft Excel tools to route the flows. The Bureau of Reclamation developed depletion estimates for both models, and periodically updates their estimates of historical depletions, so the values used in 2003 differ from the values used in 2021. The HEC-ResSim model uses the most up-to-date estimate of historical depletions from the Bureau of Reclamation. Table-D-1 summarizes the differences between the unregulated flow models.

Table-D-1. Comparison of Unregulated Flow Development Models

Model Component	UFDM 2003	HEC-ResSim 2021
Routing Method	Lag-Average	Coefficient
Tributary Reservoirs	Modeled explicitly	Effects of tributary projects were combined into depletions, except Kansas and Osage Rivers which were modeled explicitly
Depletions	Reclamation circa 2000	Reclamation 2017 Update

The effect of a change in the unregulated flow model on the estimate of unregulated peak flow frequency can be seen by comparing time-series plots and flow frequency computed using output from both models spanning their concurrent period of record from 1930-1997. A time-series plot of annual peaks in the plains snowmelt season from January through April is shown in Figure D-1, and the corresponding flow frequency plot is shown in Figure D-2. A time-series plot of annual peaks in the mountain snowmelt and rain season from May through December is shown in Figure D-3, and the corresponding flow frequency plot is shown in Figure D-4. The timeseries plots show how in the snowmelt season, unregulated peaks computed with the current HEC-ResSim model tend to be the same as the UMRSFFS unregulated peaks on the low flow end, but higher on the high flow end. Meanwhile, in the mountain snowmelt and rain season, unregulated peak flows computed with the current HEC-ResSim model tend to be lower in general. Because the snowmelt season controls the frequency of the most extreme peak flows, and because the variance of the snowmelt season peak flows is greater with higher high flows, flow frequency computed with the current HEC-ResSim unregulated peak flows will tend to produce larger estimates of the 1% and 0.2% AEP floods. A comparison of annual peak flows for all 10 study gages, 1930-1997, is presented in Table D-2.

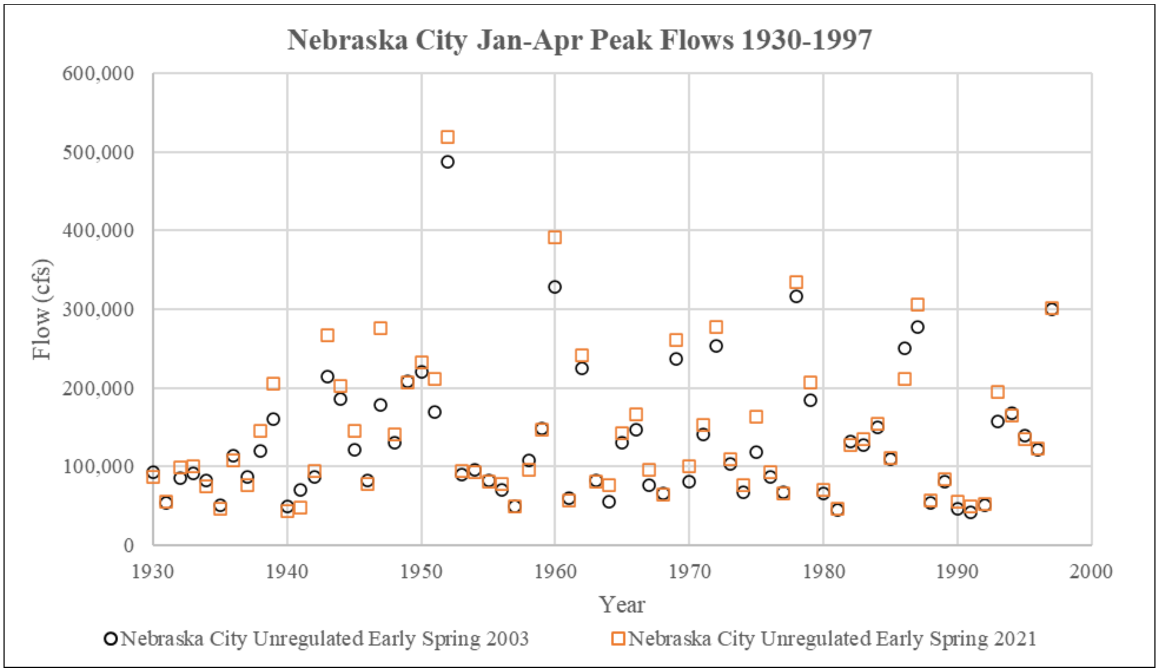

Figure D-1. Timeseries plot of Nebraska City Unregulated Early Spring Peak Flow

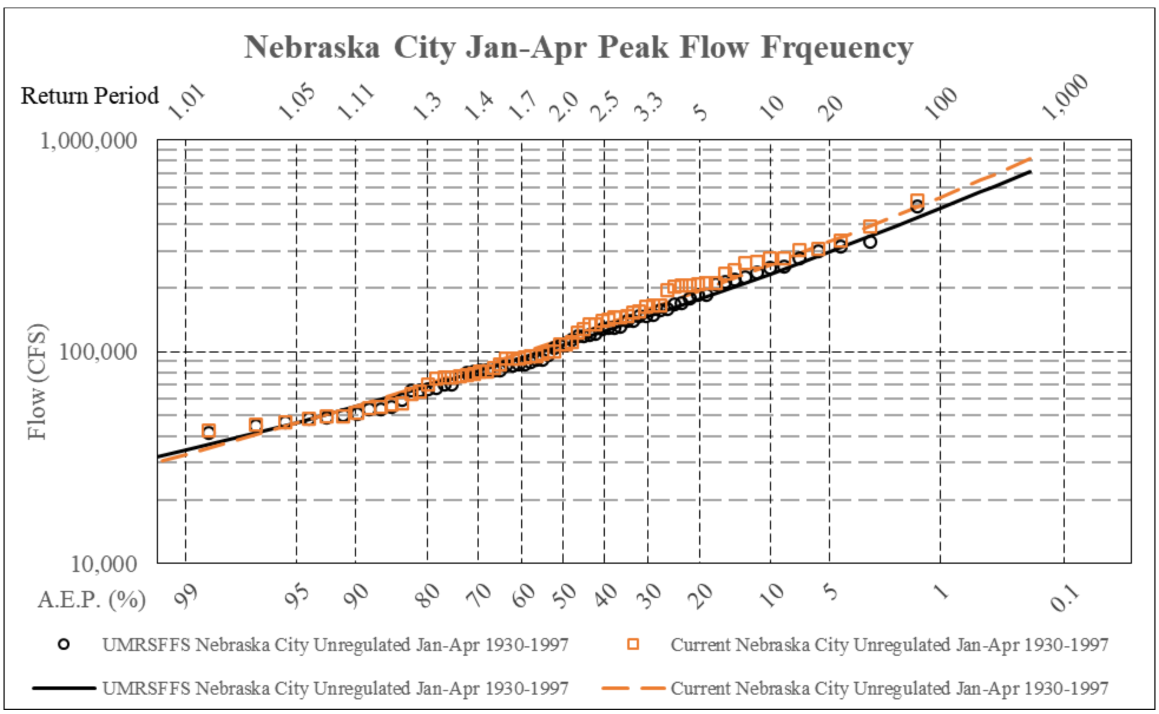

Figure D-2. Nebraska City Early Spring Flow Frequency

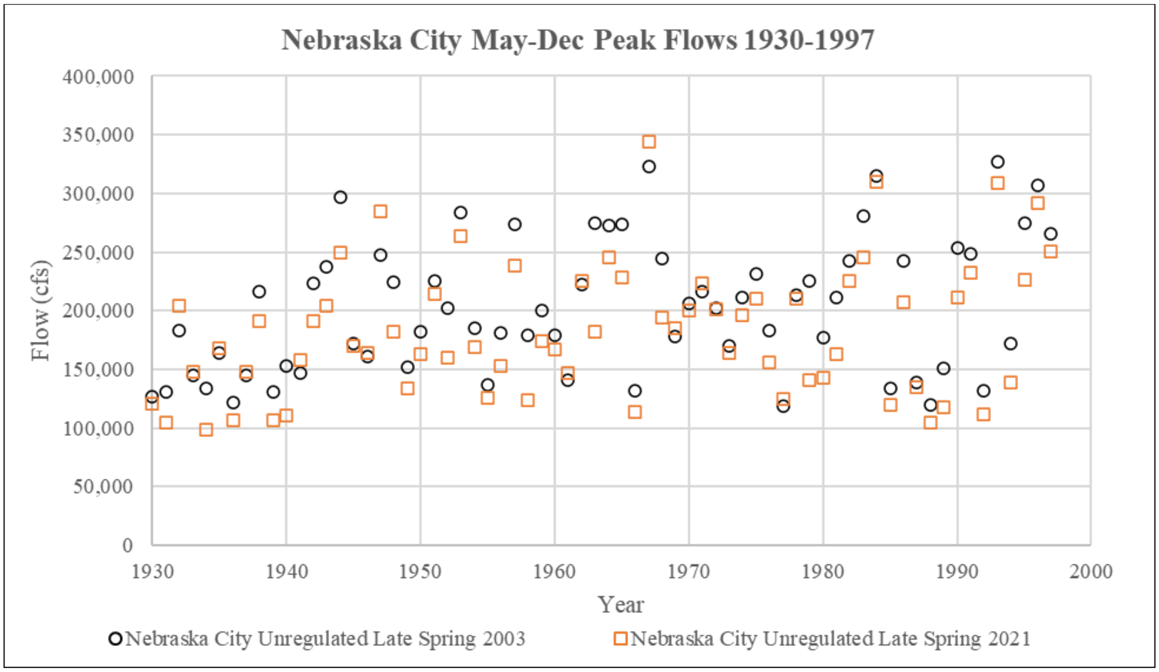

Figure D-3. Timeseries plot of Nebraska City Unregulated Late Spring Peak Flow

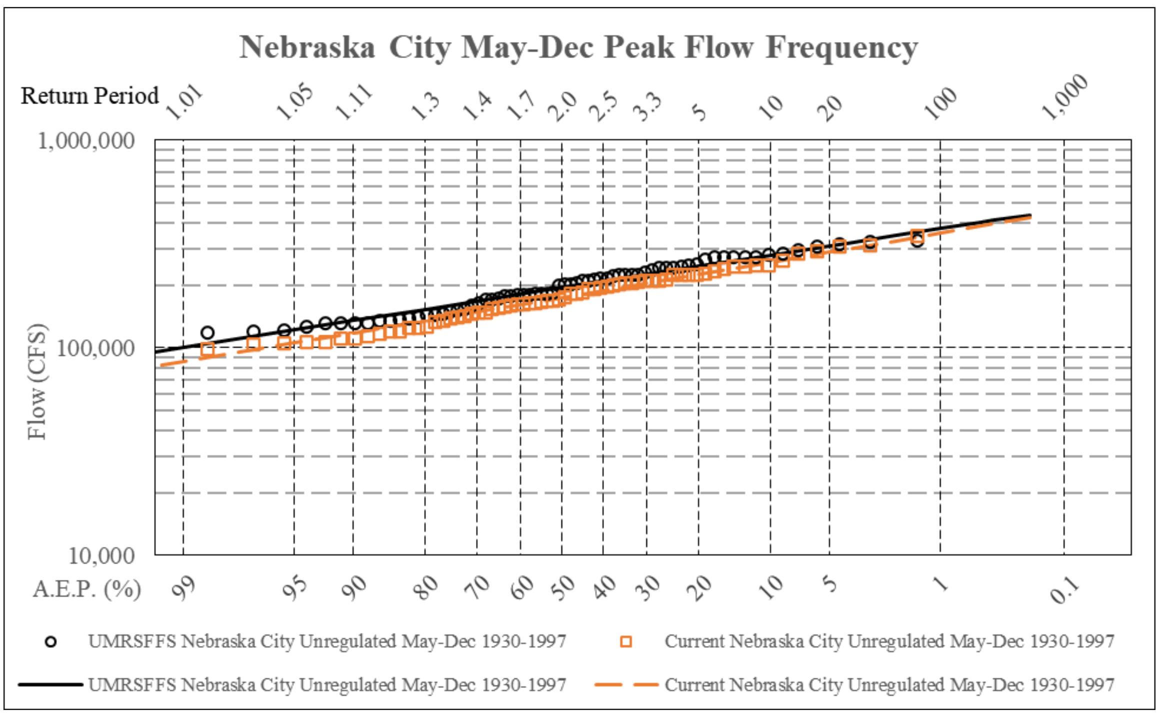

Figure D-4. Nebraska City Late Spring Flow Frequency

Table D-2a. Comparison of 2003 Study to Current, Unregulated Annual Peak Flows in cfs

Year	Yankton			Sioux City			Omaha		
	2003 Study	Current	Current / 2003	2003 Study	Current	Current/ 2003	2003 Study	Current	Current/ 2003
1930	87700	83300	0.95	88800	90600	1.02	87300	88300	1.01
1931	81200	76400	0.94	83000	83200	1.00	85900	82400	0.96
1932	151400	146900	0.97	151400	153500	1.01	157900	162900	1.03
1933	134200	125100	0.93	132700	124600	0.94	129900	121800	0.94
1934	74100	72000	0.97	79200	69200	0.87	91000	75800	0.83
1935	162500	134400	0.83	160800	129700	0.81	133400	126300	0.95
1936	102900	88600	0.86	102100	87100	0.85	101000	95000	0.94
1937	130700	137800	1.05	130000	138200	1.06	133100	136800	1.03
1938	174400	163200	0.94	171900	167500	0.97	164800	169200	1.03
1939	171500	217700	1.27	170000	211400	1.24	146400	207400	1.42
1940	85700	83500	0.97	91100	91600	1.01	93700	87900	0.94
1941	167700	152300	0.91	151400	158400	1.05	138200	154300	1.12
1942	151300	150000	0.99	153200	165100	1.08	154400	172400	1.12
1943	291400	284200	0.98	221600	274400	1.24	218400	268500	1.23
1944	196700	207100	1.05	208100	216000	1.04	188700	202700	1.07
1945	120100	120000	1.00	133200	145500	1.09	128500	140400	1.09
1946	126300	120800	0.96	126700	136100	1.07	122400	130700	1.07
1947	187600	280500	1.50	195000	296300	1.52	186800	278500	1.49
1948	169700	166600	0.98	173400	171600	0.99	173500	171700	0.99
1949	183200	192800	1.05	192000	198900	1.04	201600	195800	0.97
1950	260300	265900	1.02	247700	242500	0.98	226500	232000	1.02
1951	130200	152000	1.17	161000	219800	1.37	163500	205900	1.26
1952	497300	520300	1.05	479400	530800	1.11	469200	521200	1.11
1953	272700	236000	0.87	262500	233800	0.89	271600	238600	0.88
1954	95900	86600	0.90	105100	105400	1.00	138600	134900	0.97
1955	105400	92500	0.88	106900	90100	0.84	115500	97200	0.84
1956	161800	140500	0.87	159700	134900	0.84	161500	135000	0.84
1957	150500	142000	0.94	160800	145400	0.90	169500	156100	0.92
1958	152400	101800	0.67	148800	100800	0.68	153000	105200	0.69
1959	138100	139000	1.01	135900	137500	1.01	140100	138000	0.99
1960	219200	253400	1.16	256300	296100	1.16	273800	340200	1.24
1961	111900	104600	0.93	112000	105900	0.95	114800	116400	1.01
1962	176800	178800	1.01	185400	191600	1.03	188900	197900	1.05
1963	175100	143700	0.82	173900	143500	0.83	176200	146900	0.83
1964	237700	208100	0.88	231900	208500	0.90	234500	210700	0.90
1965	173400	167500	0.97	178600	174100	0.97	181300	174900	0.96
1966	132600	151000	1.14	134600	153800	1.14	135900	153900	1.13
1967	238700	249900	1.05	242300	251200	1.04	255700	266900	1.04
1968	160600	153200	0.95	158100	151900	0.96	161600	159200	0.99

Year	Yankton			Sioux City			Omaha		
	2003 Study	Current	Current / 2003	2003 Study	Current	Current/ 2003	2003 Study	Current	Current/ 2003
1969	157400	162200	1.03	196400	228200	1.16	225700	254100	1.13
1970	169900	173900	1.02	169200	174100	1.03	172300	176600	1.02
1971	166400	163900	0.98	166500	171500	1.03	172200	181400	1.05
1972	245200	267500	1.09	244500	269800	1.10	247300	271300	1.10
1973	115200	132900	1.15	114300	127100	1.11	118200	126800	1.07
1974	190000	176100	0.93	188000	176300	0.94	191400	179700	0.94
1975	216200	182500	0.84	213900	182300	0.85	219500	188400	0.86
1976	144700	135700	0.94	145400	134800	0.93	149200	136800	0.92
1977	91000	96100	1.06	91300	96900	1.06	95100	105400	1.11
1978	271400	312200	1.15	281100	321400	1.14	287400	323700	1.13
1979	179000	185000	1.03	180400	190500	1.06	188000	192700	1.03
1980	114100	111500	0.98	114800	111100	0.97	119000	113600	0.95
1981	170300	142900	0.84	172000	137700	0.80	182800	145600	0.80
1982	175300	154200	0.88	175100	157800	0.90	193000	173100	0.90
1983	125500	115800	0.92	151500	149100	0.98	188200	181900	0.97
1984	130700	137400	1.05	220100	218600	0.99	235300	236100	1.00
1985	92700	79300	0.86	98700	80800	0.82	105400	85100	0.81
1986	169800	194800	1.15	187200	196500	1.05	227000	200500	0.88
1987	207500	230300	1.11	219600	237000	1.08	232300	247300	1.06
1988	89600	80200	0.90	89200	81500	0.91	92600	85000	0.92
1989	104300	94900	0.91	104400	94000	0.90	109600	98100	0.90
1990	101600	99200	0.98	103900	104400	1.00	123300	145000	1.18
1991	164800	169300	1.03	164000	167200	1.02	205800	180500	0.88
1992	89100	80400	0.90	95900	82000	0.86	111700	97100	0.87
1993	117100	130500	1.11	170500	179800	1.05	216000	211400	0.98
1994	144200	136200	0.94	152900	147900	0.97	156800	156400	1.00
1995	193900	168500	0.87	198500	177700	0.90	209700	190600	0.91
1996	177700	197900	1.11	185800	199300	1.07	230900	245600	1.06
1997	245300	267700	1.09	290300	288600	0.99	293800	294500	1.00
Max	497300	520300	1.50	479400	530800	1.52	469200	521200	1.49
Average Ratio			0.99			1.00			1.00
Minimum Ratio			0.67			0.68			0.69
Standard Deviation of Ratio			0.12			0.13			0.14
Ratio of maximum flow			1.05			1.11			1.11
Flow at max ratio			280500			296300			278500
Flow at max / max 2003 flow			56%			62%			59%

Table D-2b. Comparison of 2003 Study to Current, Unregulated Annual Peak Flows in cfs

	Nebraska City			Rulo			St. Joseph		
Year	2003 Study	Current	Current/ 2003	2003 Study	Current	Current/ 2003	2003 Study	Current	Current/ 2003
1930	127000	120300	0.95	128000	120000	0.94	136000	125000	0.92
1931	130800	104800	0.80	132000	108000	0.82	137000	111000	0.81
1932	182800	204600	1.12	183000	198000	1.08	193000	190000	0.98
1933	144900	147500	1.02	146000	150000	1.03	147000	150000	1.02
1934	134100	98800	0.74	139000	96000	0.69	150000	108000	0.72
1935	164300	167700	1.02	159000	168000	1.06	168000	161000	0.96
1936	122200	108000	0.88	113000	106000	0.94	123000	113000	0.92
1937	144900	147700	1.02	141000	146000	1.04	149000	149000	1.00
1938	216600	191000	0.88	211000	192000	0.91	204000	184000	0.90
1939	159800	205100	1.28	149000	206000	1.38	162000	198000	1.22
1940	153100	111100	0.73	152000	112000	0.74	159000	114000	0.72
1941	146500	158300	1.08	141000	160000	1.13	159000	171000	1.08
1942	223500	191200	0.86	224000	194000	0.87	234000	204000	0.87
1943	237200	266500	1.12	236000	267000	1.13	237000	257000	1.08
1944	296400	249600	0.84	276000	246000	0.89	237000	235000	0.99
1945	172100	169800	0.99	189000	183000	0.97	195000	192000	0.98
1946	160600	164200	1.02	163000	170000	1.04	165000	185000	1.12
1947	247700	284700	1.15	246000	287000	1.17	244000	284000	1.16
1948	224700	182000	0.81	220000	184000	0.84	223000	186000	0.83
1949	207600	207200	1.00	199000	206000	1.04	209000	199000	0.95
1950	220600	232600	1.05	223000	229000	1.03	210000	221000	1.05
1951	225200	214300	0.95	250000	241000	0.96	254000	243000	0.96
1952	487800	518600	1.06	447000	519000	1.16	467000	499000	1.07
1953	283800	263600	0.93	285000	260000	0.91	278000	255000	0.92
1954	185300	169100	0.91	199000	186000	0.93	176000	173000	0.98
1955	137100	125900	0.92	134000	128000	0.96	146000	150000	1.03
1956	180700	153300	0.85	180000	155000	0.86	178000	151000	0.85
1957	273900	238400	0.87	274000	247000	0.90	286000	250000	0.87
1958	179000	124000	0.69	183000	156000	0.85	204000	185000	0.91
1959	200300	174400	0.87	210000	200000	0.95	210000	205000	0.98
1960	328900	390900	1.19	360000	409000	1.14	353000	396000	1.12
1961	140500	146600	1.04	148000	151000	1.02	146000	152000	1.04
1962	224100	241700	1.08	231000	238000	1.03	229000	237000	1.03
1963	274300	182400	0.66	283000	197000	0.70	271000	190000	0.70
1964	272300	245600	0.90	270000	265000	0.98	272000	273000	1.00
1965	273400	227900	0.83	294000	261000	0.89	317000	311000	0.98
1966	147200	166400	1.13	146000	170000	1.16	147000	167000	1.14

	Nebraska City			Rulo			St. Joseph		
Year	2003 Study	Current	Current/ 2003	2003 Study	Current	Current/ 2003	2003 Study	Current	Current/ 2003
1967	323000	344100	1.07	329000	354000	1.08	323000	353000	1.09
1968	244500	194600	0.80	242000	202000	0.83	238000	198000	0.83
1969	236500	261100	1.10	240000	263000	1.10	239000	267000	1.12
1970	205900	200500	0.97	207000	203000	0.98	204000	203000	1.00
1971	216800	223700	1.03	217000	229000	1.06	216000	231000	1.07
1972	253700	276900	1.09	252000	282000	1.12	249000	276000	1.11
1973	169800	163600	0.96	185000	181000	0.98	203000	179000	0.88
1974	211600	196600	0.93	213000	202000	0.95	212000	204000	0.96
1975	231600	210400	0.91	232000	217000	0.94	233000	216000	0.93
1976	183400	155500	0.85	185000	171000	0.92	187000	180000	0.96
1977	118200	124800	1.06	119000	128000	1.08	128000	126000	0.98
1978	316100	335100	1.06	330000	340000	1.03	335000	334000	1.00
1979	225200	207100	0.92	228000	242000	1.06	237000	260000	1.10
1980	177100	142900	0.81	177000	155000	0.88	175000	171000	0.98
1981	210800	162900	0.77	210000	168000	0.80	208000	163000	0.78
1982	242000	225800	0.93	244000	257000	1.05	253000	289000	1.14
1983	280500	245900	0.88	292000	251000	0.86	293000	253000	0.86
1984	315400	310400	0.98	359000	352000	0.98	328000	331000	1.01
1985	134200	119800	0.89	136000	126000	0.93	137000	129000	0.94
1986	250100	210800	0.84	252000	223000	0.88	268000	246000	0.92
1987	276800	305300	1.10	275000	311000	1.13	268000	325000	1.21
1988	119700	104500	0.87	123000	108000	0.88	124000	108000	0.87
1989	150600	117400	0.78	155000	131000	0.85	188000	173000	0.92
1990	253600	211700	0.83	261000	218000	0.84	270000	230000	0.85
1991	248700	232700	0.94	251000	241000	0.96	265000	245000	0.92
1992	132100	111500	0.84	151000	139000	0.92	183000	165000	0.90
1993	327000	309000	0.94	411000	417000	1.01	464000	454000	0.98
1994	171800	165200	0.96	183000	171000	0.93	192000	173000	0.90
1995	274600	225900	0.82	284000	243000	0.86	312000	277000	0.89
1996	307000	291500	0.95	323000	310000	0.96	323000	313000	0.97
1997	299600	301200	1.01	309000	309000	1.00	301000	301000	1.00
Max	487800	518600	1.28	447000	519000	1.38	467000	499000	1.22
Average Ratio			0.94			0.97			0.97
Minimum Ratio			0.66			0.69			0.70
Standard Deviation of Ratio			0.12			0.12			0.11
Ratio of maximum flow			1.06			1.16			1.07
Flow at max ratio			205100			206000			198000
Flow at max / max 2003 flow			42%			46%			42%

Table D-2c. Comparison of 2003 Study to Current, Unregulated Annual Peak Flows in cfs

	Kansas City			Waverly		
Year	**2003 Study**	**Current**	**Current / 2003**	**2003 Study**	**Current**	**Current / 2003**
1930	172000	170000	0.99	154000	172000	1.12
1931	138000	135000	0.98	149000	142000	0.95
1932	219000	207000	0.95	176000	203000	1.15
1933	149000	150000	1.01	115000	157000	1.37
1934	146000	102000	0.70	81000	101000	1.25
1935	262000	277000	1.06	225000	274000	1.22
1936	130000	116000	0.89	126000	121000	0.96
1937	157000	155000	0.99	114000	157000	1.38
1938	202000	185000	0.92	161000	182000	1.13
1939	158000	197000	1.25	151000	190000	1.26
1940	160000	118000	0.74	83000	118000	1.42
1941	254000	286000	1.13	196000	278000	1.42
1942	294000	272000	0.93	263000	265000	1.01
1943	420000	397000	0.95	342000	381000	1.11
1944	325000	292000	0.90	355000	327000	0.92
1945	285000	275000	0.96	254000	271000	1.07
1946	170000	203000	1.19	130000	194000	1.49
1947	322000	374000	1.16	301000	377000	1.25
1948	264000	234000	0.89	229000	241000	1.05
1949	260000	237000	0.91	210000	228000	1.09
1950	282000	253000	0.90	231000	249000	1.08
1951	621000	623000	1.00	568000	599000	1.05
1952	477000	505000	1.06	429000	515000	1.20
1953	279000	250000	0.90	236000	256000	1.08
1954	202000	198000	0.98	144000	190000	1.32
1955	165000	171000	1.04	127000	175000	1.38
1956	179000	155000	0.87	122000	152000	1.25
1957	302000	271000	0.90	244000	269000	1.10
1958	271000	248000	0.92	226000	234000	1.04
1959	246000	212000	0.86	168000	210000	1.25
1960	416000	502000	1.21	389000	502000	1.29
1961	169000	189000	1.12	184000	204000	1.11
1962	282000	289000	1.02	281000	308000	1.10
1963	279000	204000	0.73	219000	208000	0.95
1964	297000	362000	1.22	259000	364000	1.41
1965	387000	374000	0.97	348000	383000	1.10
1966	170000	167000	0.98	147000	187000	1.27
1967	450000	505000	1.12	420000	491000	1.17
1968	236000	202000	0.86	163000	197000	1.21

	Kansas City			Waverly		
Year	2003 Study	Current	Current / 2003	2003 Study	Current	Current / 2003
1969	266000	270000	1.02	265000	269000	1.02
1970	223000	248000	1.11	197000	253000	1.28
1971	236000	250000	1.06	171000	249000	1.46
1972	248000	273000	1.10	245000	269000	1.10
1973	405000	430000	1.06	377000	422000	1.12
1974	225000	241000	1.07	252000	281000	1.12
1975	277000	265000	0.96	208000	260000	1.25
1976	196000	183000	0.93	140000	180000	1.29
1977	244000	238000	0.98	249000	280000	1.12
1978	362000	343000	0.95	353000	350000	0.99
1979	282000	341000	1.21	266000	335000	1.26
1980	215000	209000	0.97	220000	222000	1.01
1981	224000	213000	0.95	174000	213000	1.22
1982	327000	328000	1.00	311000	335000	1.08
1983	322000	302000	0.94	271000	295000	1.09
1984	418000	404000	0.97	367000	416000	1.13
1985	254000	243000	0.96	251000	241000	0.96
1986	327000	326000	1.00	272000	316000	1.16
1987	312000	442000	1.42	312000	441000	1.41
1988	127000	110000	0.87	71000	111000	1.56
1989	258000	242000	0.94	214000	237000	1.11
1990	290000	270000	0.93	222000	278000	1.25
1991	266000	253000	0.95	237000	256000	1.08
1992	264000	251000	0.95	220000	255000	1.16
1993	705000	722000	1.02	715000	802000	1.12
1994	196000	174000	0.89	171000	177000	1.04
1995	357000	381000	1.07	362000	407000	1.12
1996	322000	336000	1.04	260000	359000	1.38
1997	360000	300000	0.83	370000	307000	0.83
Max	705000	722000	1.42	715000	802000	1.56
Average Ratio			1.00			1.17
Minimum Ratio			0.70			0.83
Standard Deviation of Ratio			0.13			0.15
Ratio of maximum flow			1.02			1.12
Flow at max ratio			442000			111000
Flow at max / max 2003 flow			63%			16%

Table D-2d. Comparison of 2003 Study to Current, Unregulated Annual Peak Flows in cfs

	Boonville			Hermann		
Year	2003 Study	Current	Current / 2003	2003 Study	Current	Current / 2003
1930	180000	176000	0.98	216000	203000	0.94
1931	223000	219000	0.98	272000	267000	0.98
1932	217000	202000	0.93	228000	216000	0.95
1933	162000	161000	0.99	224000	200000	0.89
1934	145000	99000	0.68	146000	103000	0.71
1935	337000	341000	1.01	495000	503000	1.02
1936	138000	133000	0.96	145000	142000	0.98
1937	177000	173000	0.98	234000	228000	0.97
1938	202000	181000	0.90	254000	254000	1.00
1939	187000	196000	1.05	276000	237000	0.86
1940	166000	124000	0.75	196000	157000	0.80
1941	246000	279000	1.13	285000	289000	1.01
1942	411000	376000	0.91	530000	494000	0.93
1943	442000	419000	0.95	558000	579000	1.04
1944	522000	486000	0.93	596000	564000	0.95
1945	317000	298000	0.94	406000	404000	1.00
1946	186000	211000	1.13	231000	223000	0.97
1947	504000	538000	1.07	550000	588000	1.07
1948	284000	291000	1.02	400000	417000	1.04
1949	260000	239000	0.92	308000	291000	0.94
1950	289000	262000	0.91	339000	304000	0.90
1951	600000	585000	0.98	677000	673000	0.99
1952	435000	520000	1.20	444000	552000	1.24
1953	281000	255000	0.91	282000	256000	0.91
1954	195000	187000	0.96	203000	199000	0.98
1955	196000	199000	1.02	195000	198000	1.02
1956	190000	158000	0.83	203000	164000	0.81
1957	310000	269000	0.87	327000	308000	0.94
1958	314000	290000	0.92	401000	382000	0.95
1959	245000	226000	0.92	245000	243000	0.99
1960	495000	580000	1.17	502000	578000	1.15
1961	278000	265000	0.95	409000	421000	1.03
1962	315000	316000	1.00	311000	321000	1.03
1963	280000	201000	0.72	282000	204000	0.72
1964	320000	386000	1.21	341000	401000	1.18
1965	424000	397000	0.94	442000	428000	0.97
1966	253000	244000	0.96	263000	248000	0.94

	Boonville			Hermann		
Year	**2003 Study**	**Current**	**Current / 2003**	**2003 Study**	**Current**	**Current / 2003**
1967	500000	523000	1.05	595000	574000	0.96
1968	235000	198000	0.84	246000	208000	0.85
1969	333000	353000	1.06	403000	404000	1.00
1970	258000	279000	1.08	332000	350000	1.05
1971	241000	249000	1.03	245000	273000	1.11
1972	250000	268000	1.07	253000	273000	1.08
1973	417000	433000	1.04	505000	510000	1.01
1974	327000	319000	0.98	334000	349000	1.04
1975	294000	278000	0.95	312000	326000	1.04
1976	198000	194000	0.98	225000	235000	1.04
1977	291000	286000	0.98	294000	293000	1.00
1978	419000	394000	0.94	461000	506000	1.10
1979	325000	392000	1.21	377000	417000	1.11
1980	224000	222000	0.99	263000	272000	1.03
1981	324000	314000	0.97	453000	451000	1.00
1982	413000	398000	0.96	466000	460000	0.99
1983	375000	359000	0.96	532000	521000	0.98
1984	444000	431000	0.97	459000	467000	1.02
1985	338000	322000	0.95	542000	648000	1.20
1986	384000	405000	1.05	876000	1051000	1.20
1987	315000	444000	1.41	364000	480000	1.32
1988	125000	112000	0.90	210000	271000	1.29
1989	276000	259000	0.94	262000	253000	0.97
1990	345000	349000	1.01	460000	543000	1.18
1991	277000	254000	0.92	281000	259000	0.92
1992	306000	278000	0.91	370000	433000	1.17
1993	883000	902000	1.02	931000	955000	1.03
1994	229000	231000	1.01	566000	738000	1.30
1995	485000	535000	1.10	694000	869000	1.25
1996	399000	425000	1.07	410000	450000	1.10
1997	449000	376000	0.84	473000	424000	0.90
Max	883000	902000	1.41	931000	1051000	1.32
Average Ratio			0.98			1.02
Minimum Ratio			0.68			0.71
Standard Deviation of Ratio			0.11			0.12
Ratio of maximum flow			1.02			1.20
Flow at max ratio			444000			480000
Flow at max / max 2003 flow			50%			52%

D.2 Difference between Bulletin 17B and Bulletin 17C

Bulletin 17 is the flood flow frequency guidance in use by the U.S. Army Corps of Engineers. Bulletin 17B was published in 1982, and Bulletin 17C is the latest update published in 2018 (England, et al., 2018). The methods and guidance advanced in Bulletin 17B and Bulletin 17C are fundamentally the same. Both recommend a frequentist approach to estimating flow frequency, where statistics are computed for an historical record of peak flows (a sample), and which are used to estimate the statistics of the population of peak flows at a location on a river using a log Pearson III distribution. The statistics of this distribution are the mean (average of log base 10 of flow), standard deviation (how different are the observations from the mean), and skew (what proportion of observations fall below or above the mean). The statistics computed about a sample are identical between the Bulletin 17B and Bulletin 17C methods when the sample comprises the same record of peak flow information without gaps. The only differences would be in the confidence limits and plotting positions computed by the two methods. Bulletin 17B recommends the method of moments to estimate the sample statistics, while Bulletin 17C recommends the Expected Moments Algorithm (EMA) to estimate the statistics. Figure D-5 shows flow frequency plot using both Bulletin 17B and 17C methods on the same gage for the same period of record. Note that while the computed flow frequency curves are identical, the plotting positions and confidence intervals vary. Bulletin 17C methods utilize the Hirsch-Stedinger plotting positions and the confidence intervals are wider. Bulletin 17B uses a simple equation for confidence intervals assuming the variance at a quantile is normally distributed, whereas Bulletin 17C uses a more complex approach based on a Student T distribution and a function of sample size and censoring threshold. Confidence intervals computed with Bulletin 17C methods are more accurate and wider than in Bulletin 17B.

The results of Bulletin 17C and Bulletin 17B methods begin to differ substantially when historical data and perception thresholds are introduced. While there is a way to incorporate historical events in a Bulletin 17B analysis, there is no way to represent the periods between large flood observations in a flood record with perception thresholds. The ability to represent periods of time with perception thresholds is what sets the new Bulletin 17C method apart from 17B, and where the most consequential differences between the two methods are introduced. When flow frequency is computed with Bulletin 17B and Bulletin 17C methods on the same peak flow dataset with systematic and historical data, the results will be different. Figure D-6 shows the flow frequency plot of the Omaha gage with Bulletin 17B and Bulletin 17C methods with historical flood information. The same systematic and historical data were entered. There are two historical floods, the flood of 1875 at 233,000 cfs, and the flood of 1881 at 370,000 cfs. The difference between the two methods is that Bulletin 17C uses perception thresholds to represent the upper limit to observations that would have been recorded had they occurred based on the smallest floods that were recorded during this period as detailed in Bulletin 17C (England, et al., 2018).

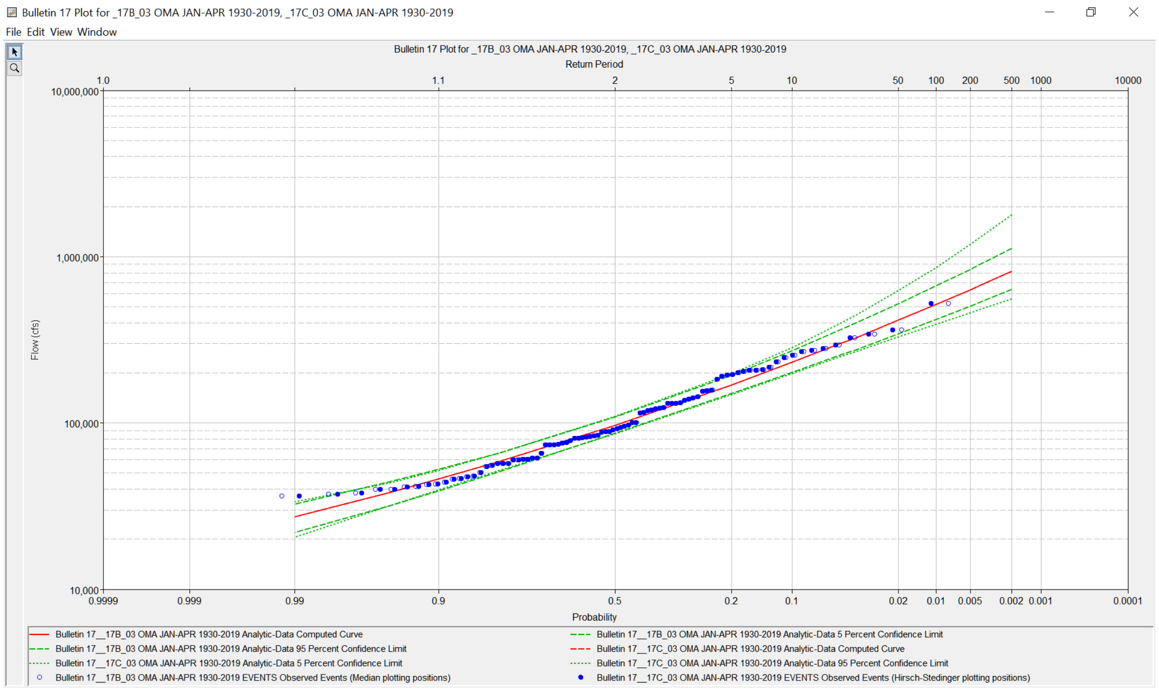

Figure D-5. Bulletin 17C and 17B Flow Frequency Plot of the Omaha Gage Systematic Period of Record Only from 1930-2019.

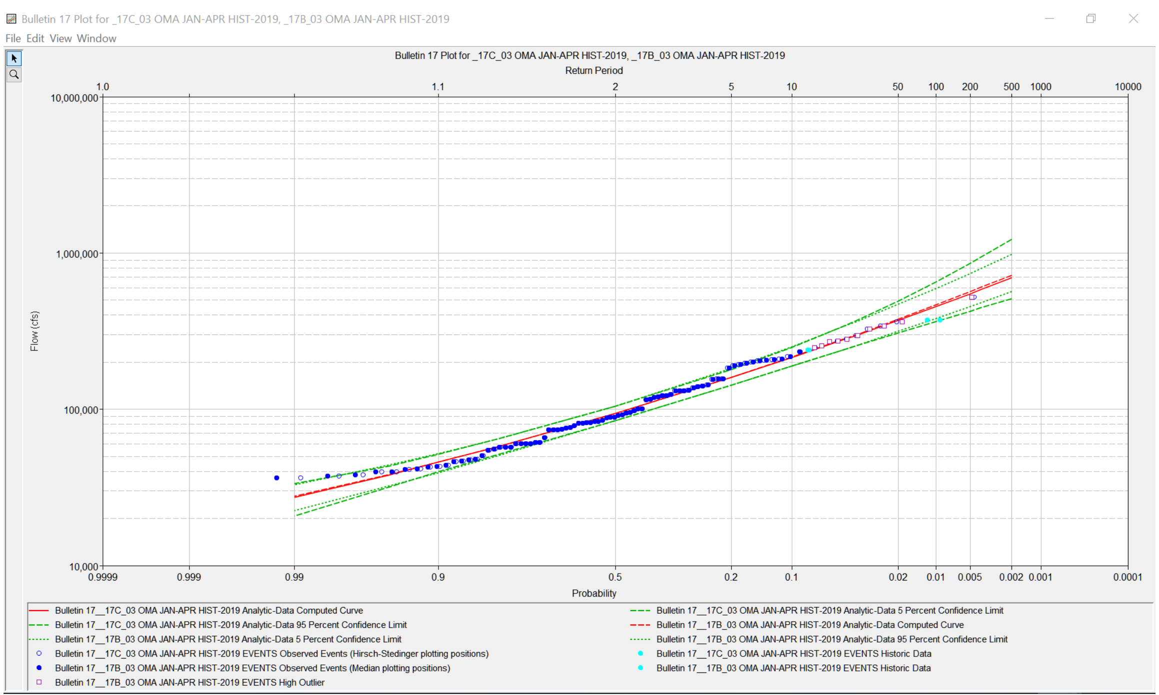

Figure D-6. Bulletin 17C and 17B Flow Frequency Plot of the Omaha Gage Systematic and Historical Gage Record

D.3 Changes due to Changing Treatment of the Pre-1930 Period

The period of record prior to 1930, prior to the start of continuous discharge measurements at most Missouri River stations, presents many difficulties for streamflow estimation. If able to account for datum changes as gages were improved or relocated over time, there are high quality stage measurements prior to 1930. However, due to both natural and human caused changes in basin land use, sediment yield, hydrologic regime, and channel form, it is difficult to accurately convert these stage measurements into discharges. A period of record spanning from 1898-1997 was developed for the Missouri River as part of the Upper Mississippi River System Flow Frequency Study (UMRSFFS) (USACE, 2003). Stage records prior to USGS gaging were converted to discharge by analyzing historical rating curves, old streamflow measurements, and datums, estimating historical depletions, and attempting to match estimated monthly runoff volumes. The peak discharges estimated from 1898 to 1929 by these methods appear to overestimate the lower range of annual peak discharges, which causes a non-stationarity in the dataset, and may artificially reduce the estimated variance and skew of the data, leading to an underestimate of flood frequency. At the time of the 2003 study, it was important to the participating agencies to develop a consistent period of record dataset, and the Bulletin 17C methods available today to analyze historical flows and gaps in streamflow measurements had not yet been developed. With current methods, it is possible to set perception thresholds for periods of time in between large floods for which peak discharge estimates exist, such as prior to 1930.

Figure D-7 through D-14 show the 1898-1997 UMRSFFS peak flow datasets for Gavins Point/Yankton, Sioux City, Omaha, and Nebraska City with a dotted red line showing the break point between 1929 and 1930. Visually the 1898 to 1929 dataset does not look homogenous with the 1930 to 2019 data, which is more pronounced for gages upstream of Kansas City. Effort was made in UMRSFFS 2003 to generate reasonable flows for the 1898 to 1928 period. Ultimately, single rating curves based on summer months with very limited flow measurements specific to the period were used to estimate flows, then validated with analyses using available climate data back to 1895. These analyses compared annual volumes of the 1898 to 1928 period with other periods with the Palmer Drought Severity Index and compared published USGS monthly flows at Sioux City based on recorded discharge at Williston, ND, and weather records. Conclusions of the analysis were that the period may have been wetter than normal, similar to 1993 to 1997, that overall volume may be over-estimated by an equivalent average of 1,400 to 2,800 cfs, assumed to impact mostly the non-summer months, yielding reasonable annual peak estimates. Table D-3 compares the statistics computed when comparing the 1898-1997 period of record and 1930-1997 period of record from the UMRSFFS. The early spring flow frequency curves control the annual peak flow frequency due to their high standard deviation and skew. Note that when excluding the 1898-1929 period, both standard deviation and skew are increased.

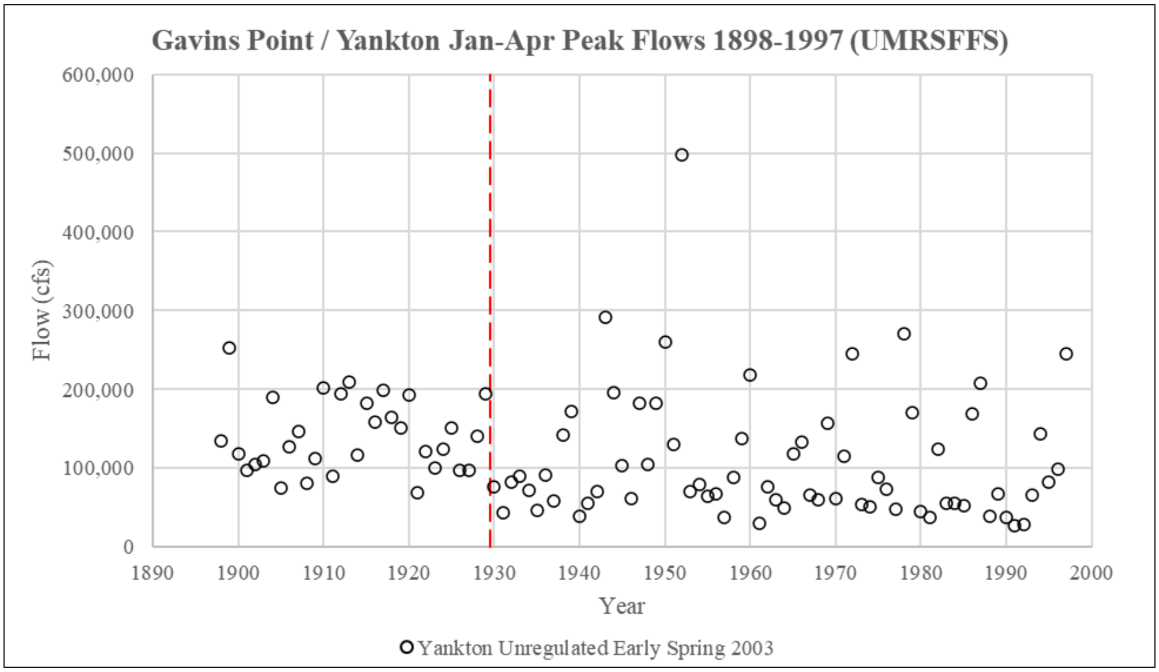

Figure D-7. UMRSFFS Early Spring Unregulated Peak Flow Chronology Plot for the Gavins Point / Yankton Location

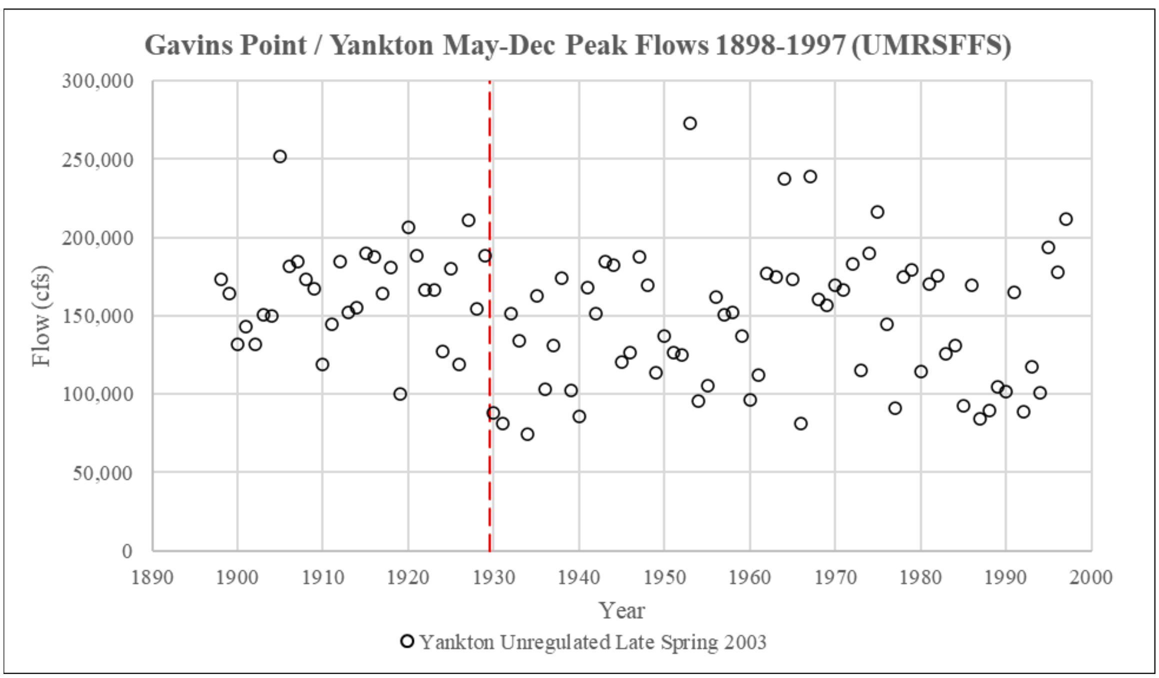

Figure D-8. UMRSFFS Late Spring Unregulated Peak Flow Chronology Plot for the Gavins Point / Yankton Location

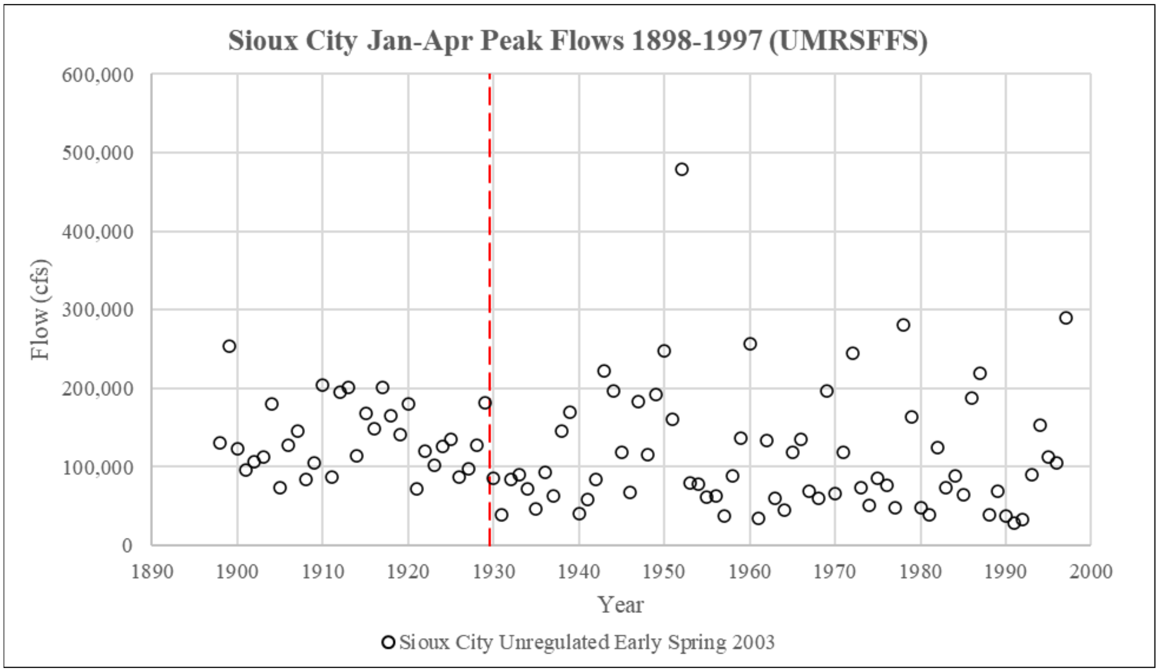

Figure D-9. UMRSFFS Early Spring Unregulated Peak Flow Chronology Plot for the Sioux City Gage

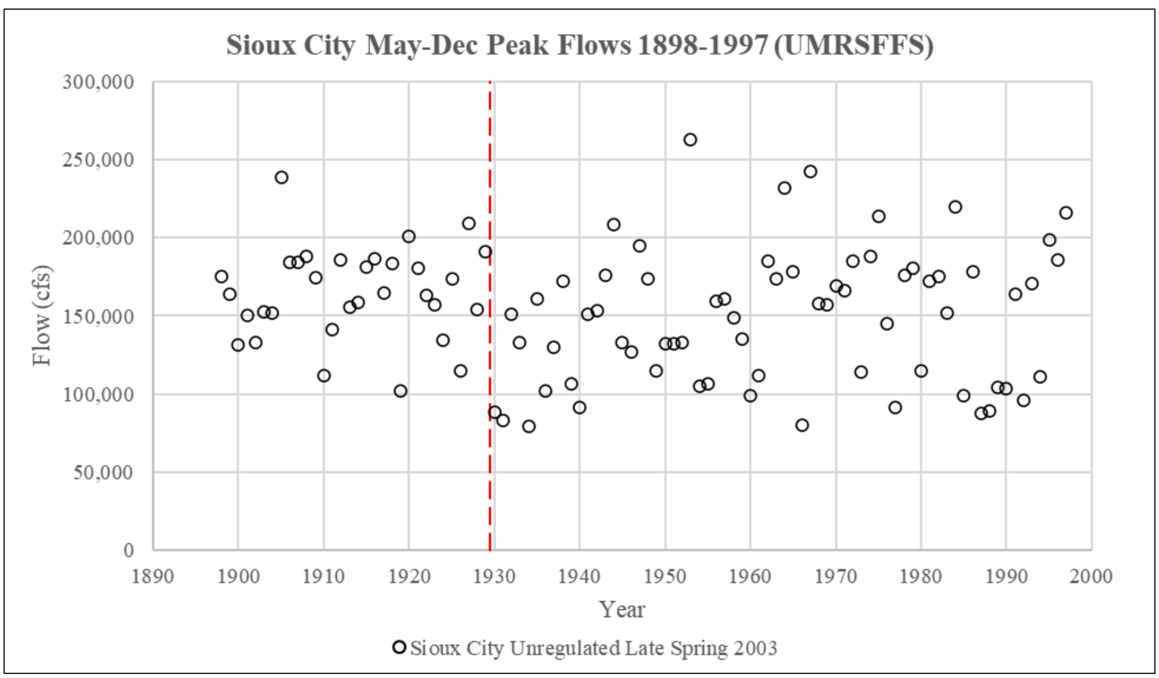

Figure D-10. UMRSFFS Late Spring Unregulated Peak Flow Chronology Plot for the Sioux City Gage

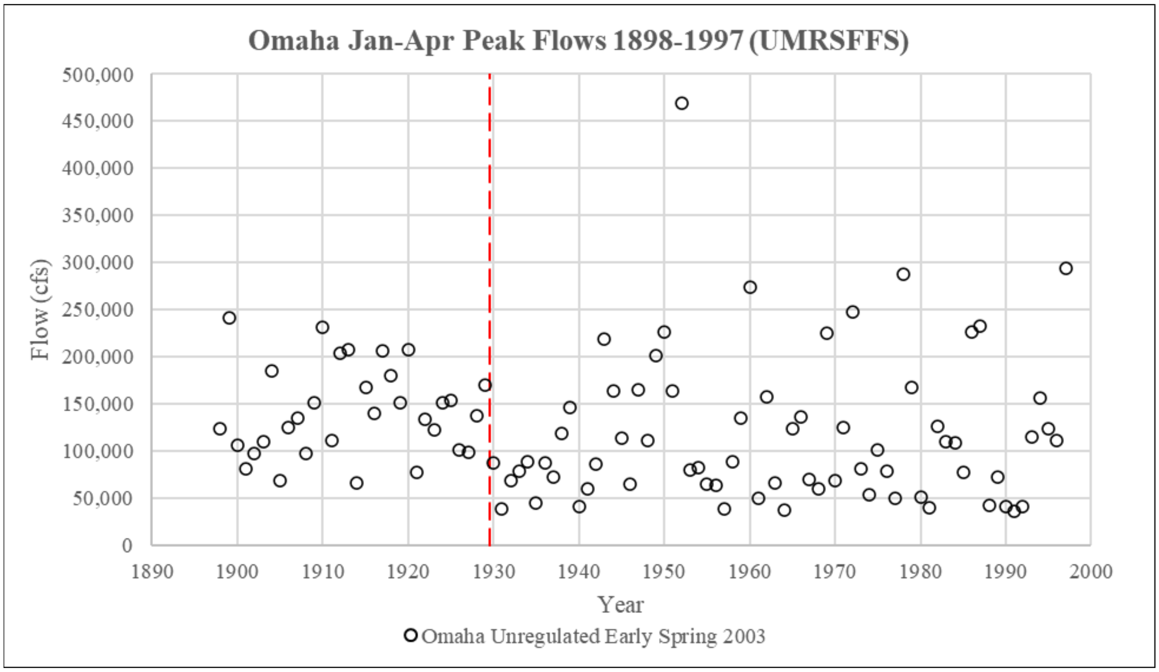

Figure D-11. UMRSFFS Early Spring Unregulated Peak Flow Chronology Plot for the Omaha Gage

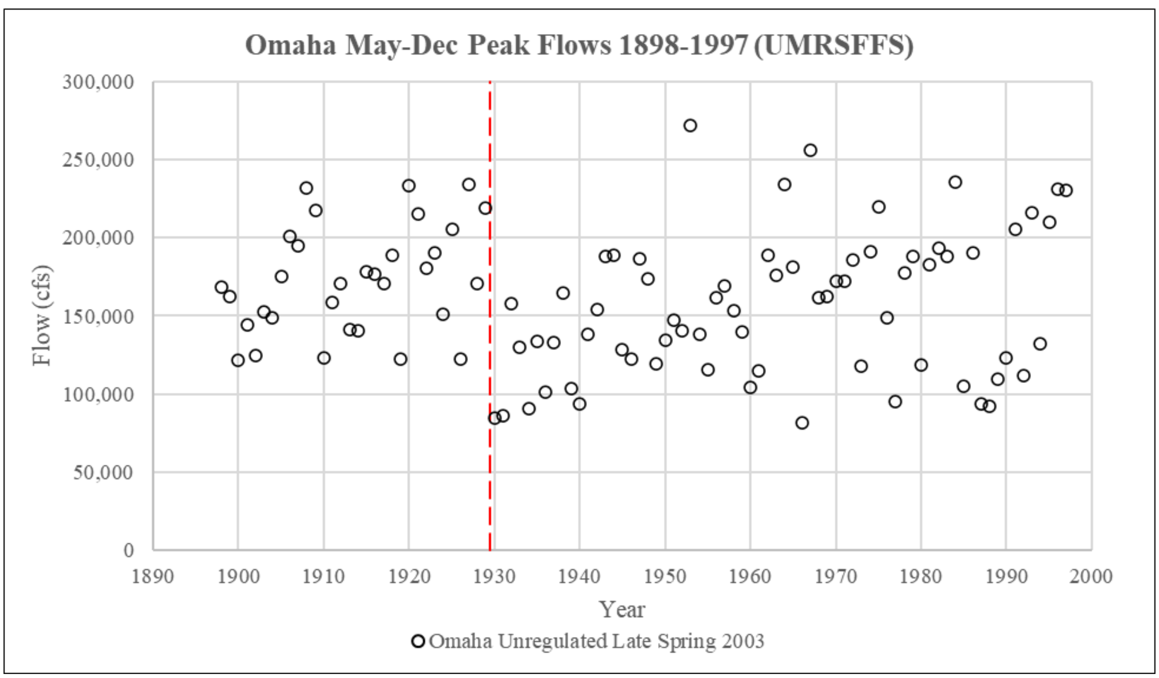

Figure D-12. UMRSFFS Late Spring Unregulated Peak Flow Chronology Plot for the Omaha Gage

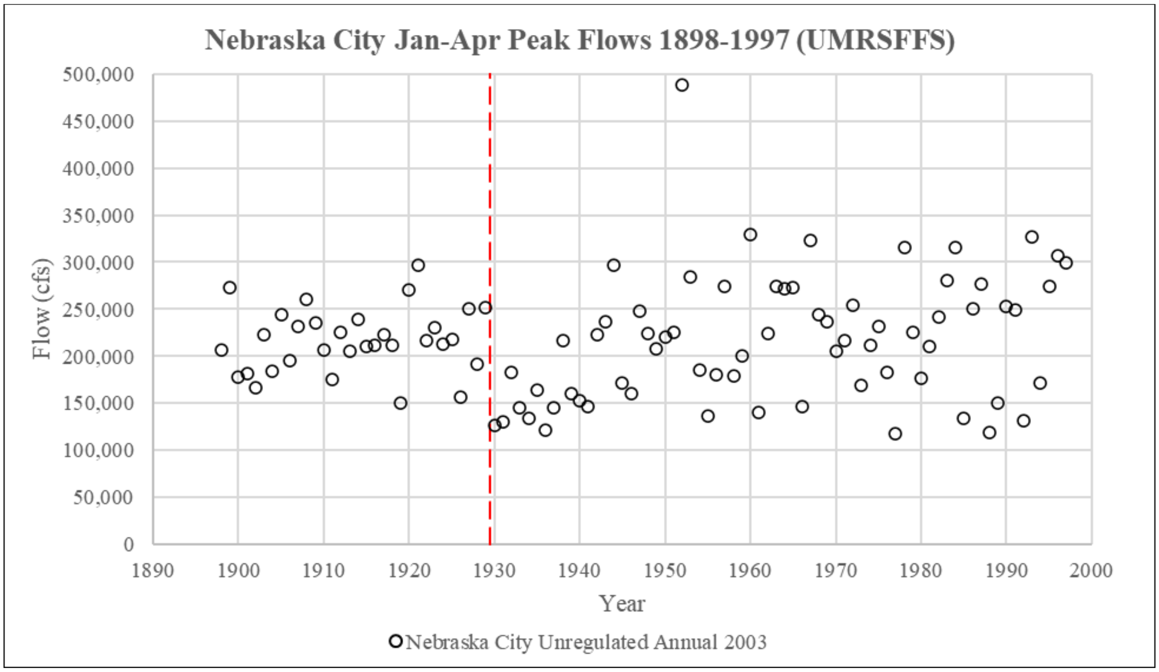

Figure D-13. UMRSFFS Early Spring Unregulated Peak Flow Chronology Plot for the Nebraska City Gage

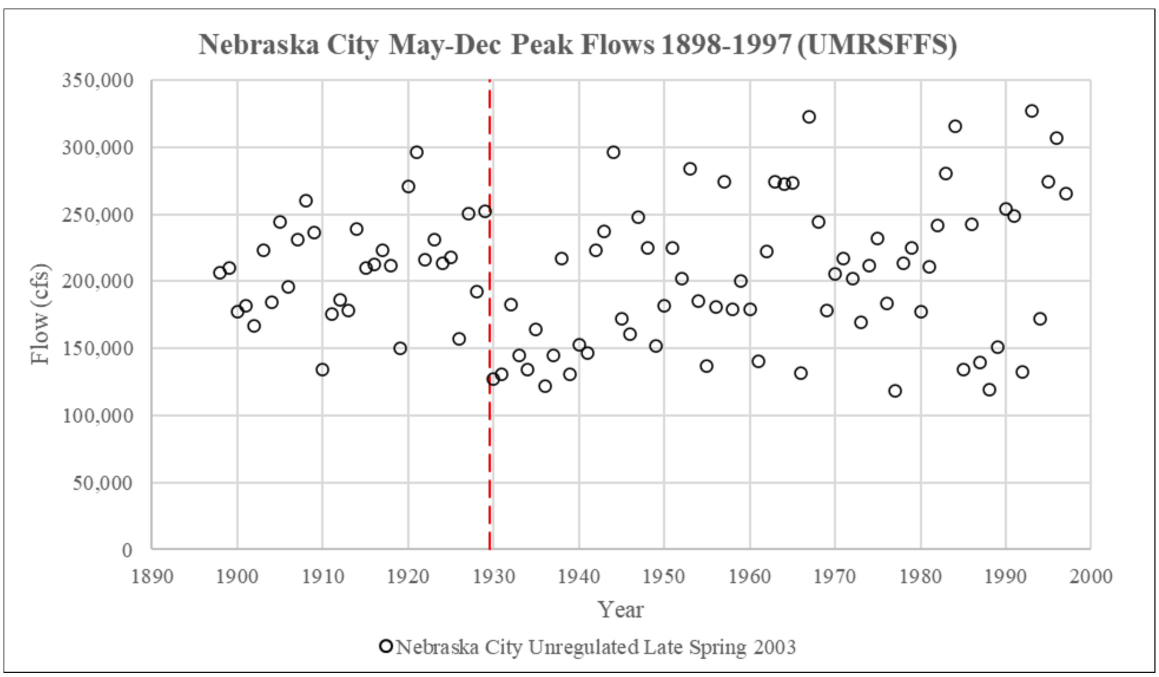

Figure D-14. UMRSFFS Latey Spring Unregulated Peak Flow Chronology Plot for the Nebraska City Gage

Table D-3. Comparison of Bulletin 17C Statistics of Unregulated Peak Flows from the UFDM Models for the 1898-1997 and 1930-1997 Periods, and final current study early spring period

Gavin's Point / Yankton, SD					
	Jan-Apr (Snowmelt Season)			**May-Dec (Rainfall Season)**	
	1898-1997	**1930-1997**	**1844-2019**	**1898-1997**	**1930-1997**
Mean	5.000	4.941	4.948	5.162	5.140
St. Dev	0.256	0.276	0.270	0.123	0.132
Skew	-0.003	0.451	0.229	-0.416	-0.142
Sioux City, IA					
	Jan-Apr (Snowmelt Season)			**May-Dec (Rainfall Season)**	
	1898-1997	**1930-1997**	**1844-2019**	**1898-1997**	**1930-1997**
Mean	5.012	4.968	4.964	5.173	5.155
St. Dev	0.246	0.272	0.271	0.119	0.130
Skew	-0.066	0.268	0.215	-0.472	-0.207
Omaha, NE					
	Jan-Apr (Snowmelt Season)			**May-Dec (Rainfall Season)**	
	1898-1997	**1930-1997**	**1843-2019**	**1898-1997**	**1930-1997**
Mean	5.031	4.985	4.996	5.190	5.172
St. Dev	0.243	0.264	0.266	0.121	0.130
Skew	-0.045	0.310	0.205	-0.344	-0.161
Nebraska City, NE					
	Jan-Apr (Snowmelt Season)			**May-Dec (Rainfall Season)**	
	1898-1997	**1930-1997**	**1843-2019**	**1898-1997**	**1930-1997**
Mean	5.083	5.046	5.057	5.298	5.289
St. Dev	0.221	0.246	0.244	0.111	0.123
Skew	0.009	0.330	0.181	-0.183	-0.024
Rulo, NE					
	Jan-Apr (Snowmelt Season)			**May-Dec (Rainfall Season)**	
	1898-1997	**1930-1997**	**1843-2019**	**1898-1997**	**1930-1997**
Mean	5.084	5.058	5.064	5.306	5.300
St. Dev	0.218	0.240	0.235	0.116	0.128
Skew	0.120	0.323	0.222	-0.092	0.057

			St. Joseph, MO		
	Jan-Apr (Snowmelt Season)			**May-Dec (Rainfall Season)**	
	1898-1997	**1930-1997**	**1843-2019**	**1898-1997**	**1930-1997**
Mean	5.101	5.085	5.079	5.320	5.315
St. Dev	0.214	0.227	0.231	0.118	0.122
Skew	0.172	0.338	0.141	0.036	0.130
			Kansas City, MO		
	1898-1997	**1930-1997**	**1844-2019**	**1819-2019**	
Mean	5.414	5.412	5.370	5.378	
St. Dev	0.143	0.155	0.166	0.158	
Skew	0.287	0.225	0.244	0.231	
			Waverly, MO		
	1898-1997	**1930-1997**	**1844-2019**		
Mean	5.414	5.413	5.384		
St. Dev	0.143	0.154	0.167		
Skew	0.347	0.295	0.181		
			Boonville, MO		
	1898-1997	**1930-1997**	**1844-2019**	**1816-2019**	
Mean	5.458	5.467	5.431	5.432	
St. Dev	0.155	0.164	0.175	0.166	
Skew	0.165	0.114	-0.016	0.034	
			Hermann, MO		
	1898-1997	**1930-1997**	**1844-2019**	**1816-2019**	
Mean	5.534	5.540	5.515	5.520	
St. Dev	0.166	0.176	0.189	0.180	
Skew	0.051	0.160	0.014	-0.026	

* Statistics are based on log base 10 of flow; see the main report and the following section for additional sensitivity analysis. The final full historic period of 1843/1844 to 2019 used is shown here for the early spring period of the six upstream mixed population gages and for the four downstream single season gages for comparison to UMRSFFS data of different time periods. In the final analysis using a historic period of 1843/1844 to 2019, the 1898 to 1929 data was treated as historic peaks of the largest events and using those to set perception thresholds instead of systematic data. In contrast, for the full historic period analysis back to 1819 or 1816 at Kansas City, Boonville, and Hermann, the 1898 to 1929 data was entered as annual peaks for that sensitivity analysis.

Specific to the 1898-1929 Jan-Apr period at Omaha, the mean was 5.127, slightly higher than other periods, standard deviation was 0.152, much lower than other periods, and skew -0.251, also much lower than any other period. Due to concerns of overestimating low flows and how much the 1898-1929 data lowers the standard deviation and skew, the 1898-1929 UMRSFSS data was used to inform perception thresholds and historic peaks of the larger events and was not entered as systematic annual peak data. The main report includes sensitivity analysis of this period at several representative gages. Starting at St. Joseph and working downstream, use of the 1898 to 1929 flows have much less impact on the computed flow frequencies compared to the final analysis, but does lower skew and standard deviation below the Kansas River. Ultimately, a balance was taken to generate perception thresholds for this period and earlier using the largest peaks of the period. As in Table D-3, the full period produces a skew between the 1898 to 1997 and 1930 to 1997 periods, and slightly reduces standard deviation from 1930 to 1997 for the mixed population gages upstream of St. Joseph. For longer historic periods considered at Kansas City, Boonville, and Herman back to 1816 or 1819 depending on the gage, the 1898 to 1929 data was used as systematic peaks, whereas for Omaha and St. Joseph, the 1898 to 1929 data only informed historic peaks. Sensitivity analysis to these different periods and data sources on flows is also included in the main report for representative gages.

D.4 Additional Years of Record from 1998-2019

Since 1997, two historic floods occurred in the Missouri River basin: the flood of 2011, and the flood of 2019. Paradoxically, however, the presence of these floods in the unregulated period of record dataset does little to change the estimate of unregulated peak flow frequency. They do, however, have a significant impact on unregulated volume frequency, and on regulated peak flow frequency. The flood of 2019 occurred in the early spring, driven by extremely rapid melting of a well-developed plains snowpack throughout Nebraska, Iowa, and South Dakota. Little could be done to regulate the observed peak of this flood in March because most of the runoff was located downstream of Gavins Point Dam and Fort Randall Dam was set to zero cfs during the worst of the flooding. Nevertheless, the flood of 2019 is still eclipsed by the flood of 1952 in terms of peak flow, which remains the peak flow of record. Therefore, the 2019 flood does not greatly affect the unregulated snowmelt season peak flow frequency curve. In contrast to the 2019 flood, much of the plains snowmelt runoff in the 1952 event occurred in the upper Missouri River basin and the reservoirs would have been much more effective at reducing the peak of that event.

The flood of 2011 is the flood of record in terms of peak flow and volume of the mountain snowmelt and rainfall season, however, even this flood is still eclipsed by the flood of 1952 in terms of peak flow. The consequence of this fact is that the 2011 flood, while being of epic proportions, does little to change the unregulated peak flow frequency curve. It should be stressed however, that due to the large volume of runoff in this flood, it would have had a significant effect on a long duration volume frequency curve. It should also be stressed that due to the strain that the 2011 volume of runoff had on the Missouri River system, it produced the regulated peak flow of record at many locations. Therefore, while the 2011 and 2019 floods have little effect on unregulated flow frequency, they do cause a significant increase in the estimate of regulated flow frequency.

Figure D-15 and Figure D-16 show the unregulated peak flows of the current study 1930-2019 period of record at Gavins Point. Note that the peak flows appear to be homogenous across the 1997 breakpoint. Also note that the 1952 early spring flood is still the flood of record. This is the case at all the gages upstream of the Kansas River and can be seen in the data tables in Appendix A. Figure D-17 and Figure D-18 show the unregulated peak flow frequency curves comparing the 1930-1997 and 1930-2019 periods at Gavins Point. The early spring season controls, and in fact slightly brings down the 0.2% ACE peak flow. Figure D-19 shows the difference in the regulated peak flow plotting positions at Gavins point between the 1930-1997 and 1930-2019 periods of record. The floods of 1952, 1997, 2011, and 2019 are called out as the largest floods. Note that the regulated 1952 peak is much smaller than the unregulated peak. Because the 2011 flood necessitated a 164,000 cfs release from Gavins Point, it has a significant effect on regulated peak flow frequency, despite having little effect on the unregulated peak flow frequency.

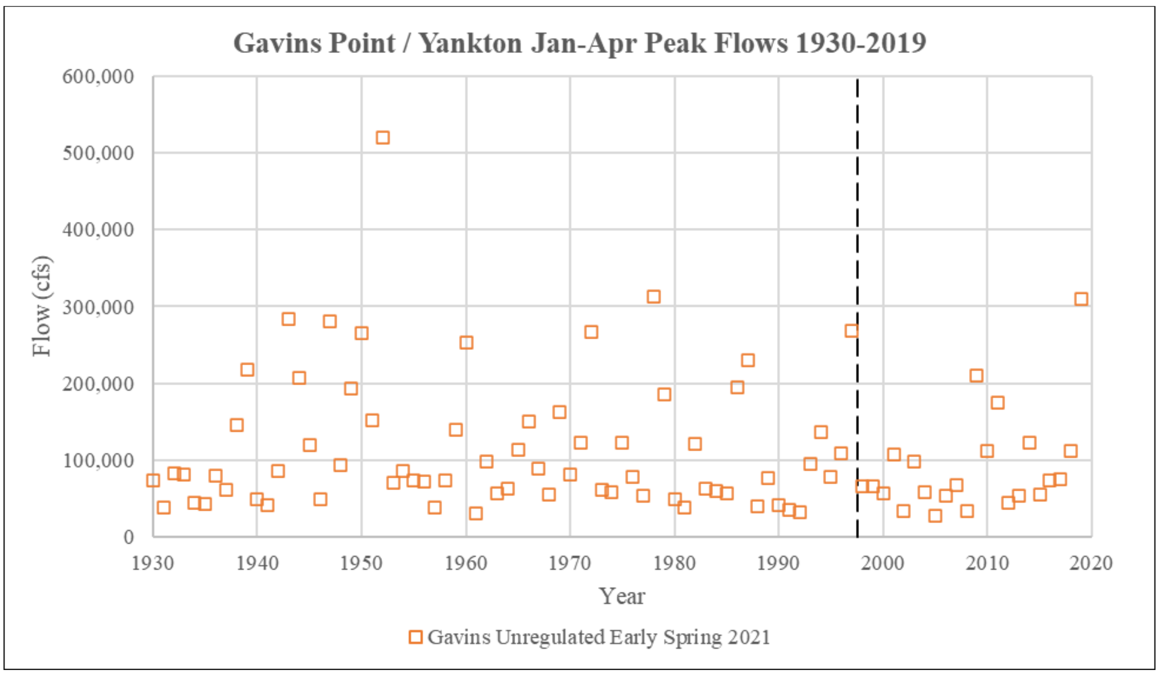

Figure D-15. Unregulated Early Spring Peak Flow Chronology Plot for Gavins Point using the Current Study Dataset 1930-2019

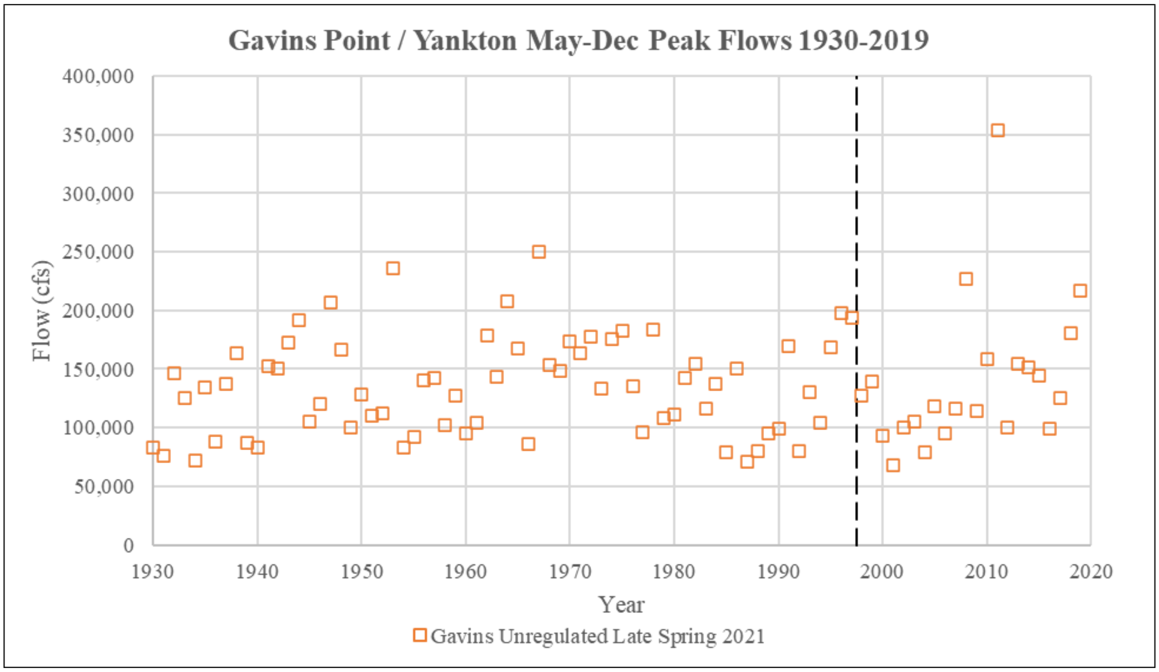

Figure D-16. Unregulated Late Spring Peak Flow Chronology Plot for Gavins Point using the Current Study Dataset 1930-2019

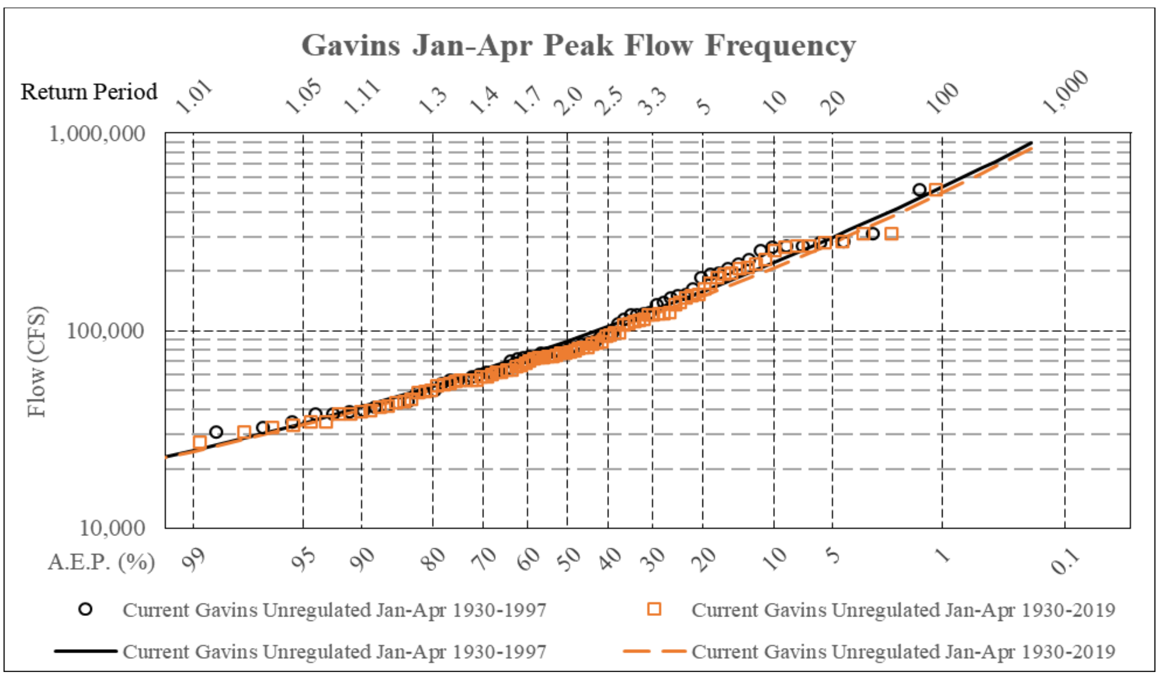

Figure D-17. Unregulated Early Spring Peak Flow Frequency at Gavins Point Comparing the 1930-1997 and 1930-2019 Systematic Periods of Record wth the Current Study Dataset

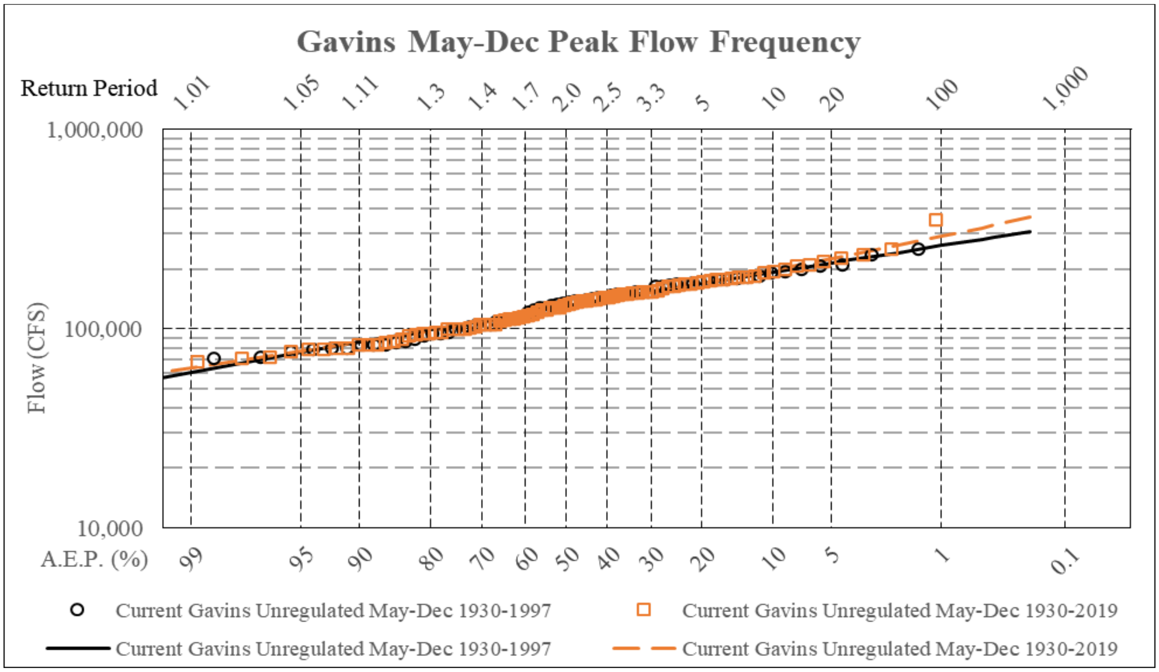

Figure D-18. Unregulated Late Spring Peak Flow Frequency at Gavins Point Comparing the 1930-1997 and 1930-2019 Systematic Periods of Record wth the Current Study Dataset

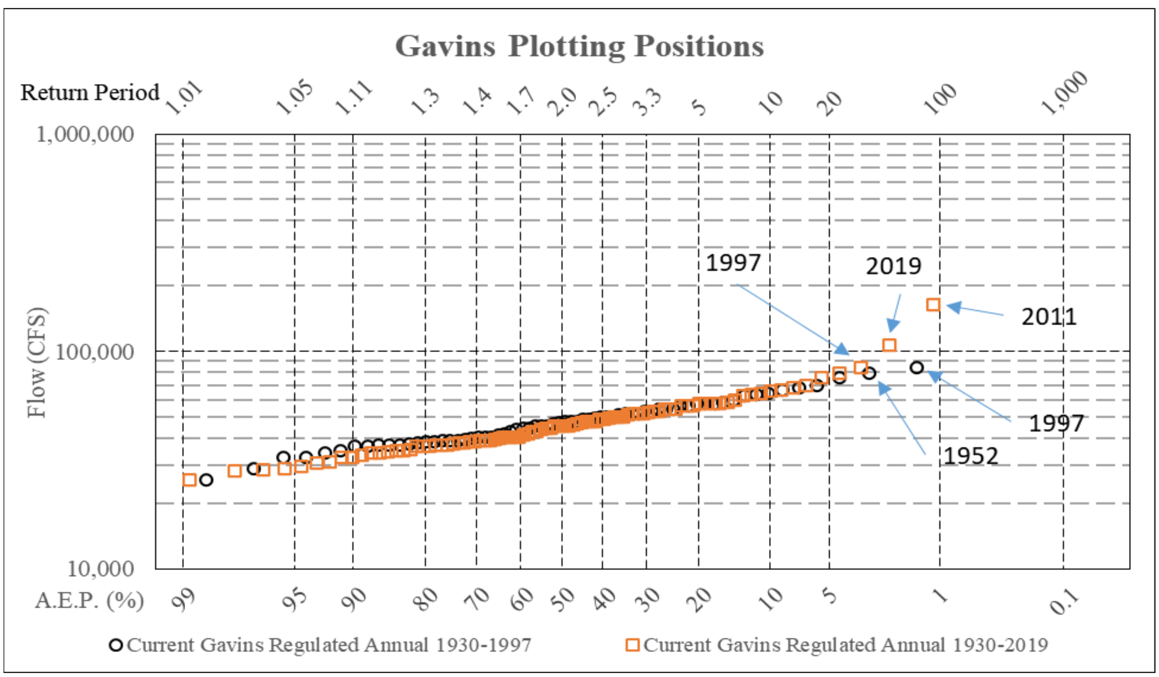

Figure D-19. Annual Regulated Peak Flow Plotting Positions at Gavins Point Dam Comparing the the 1930-1997 and 1930-2019 Systematic Periods of Record wth the Current Study Dataset