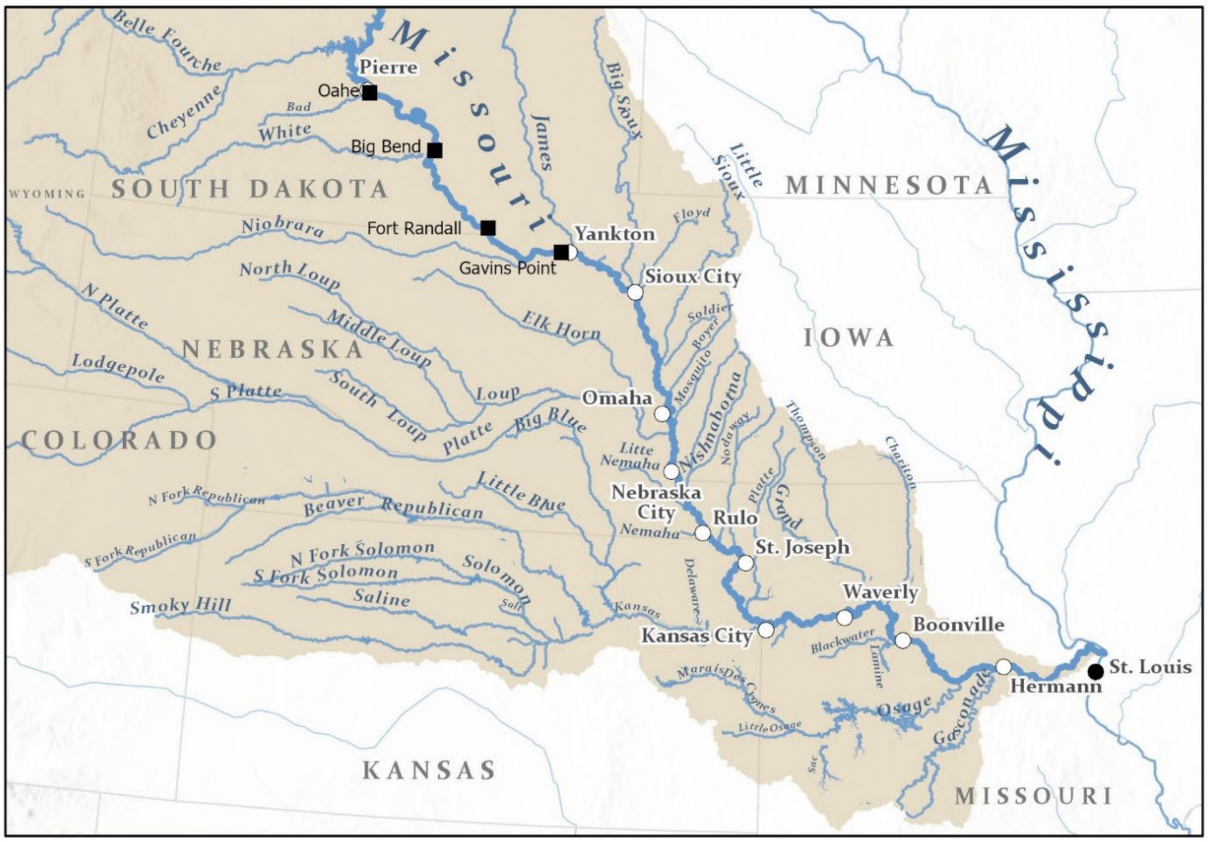
US Army Corps of Engineers ®

Missouri River
Flow Frequency Study

Yankton, South Dakota to Hermann, Missouri

Appendix E: Scaled Floods



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

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Introduction

Scaled Floods

Extrapolation of an unregulated-to-regulated flow transform requires the routing of scaled floods to help define how flows larger than what has historically been observed might be regulated. Scaled floods were modeled using HEC-ResSim. This appendix documents the development of scaled floods across the Missouri River basin.

Scaled flood events were modeled using a combined HEC-ResSim model that included the six mainstem Missouri River reservoirs, the lower seven Kansas River Basin reservoirs (Waconda, Wilson, Kanopolis, Milford, Tuttle Creek, Perry, and Clinton), and the six Osage River Basin reservoirs. The mainstem reservoir modeling was taken from the Mainstem Missouri River HEC-ResSim model summarized in Section 3.2. HEC-ResSim modeling for the Kansas River Basin was taken from the Kansas River Watershed Study summarized in Section 3.2 and Appendix I. For the Osage River watershed, HEC-ResSim modeling developed for the Missouri River Management Plan (ManPlan) and updated for the Stockton Dam reallocation study was used as summarized in Section 3.2 and Appendix I. Figure E-1 depicts the HEC-ResSim model set up used to compute the scaled floods.

Several edits to the HEC-ResSim models were required to adequately represent reservoir operations for the scaled floods. Oftentimes, reservoir operations for the scaled floods put the reservoirs into surcharge operations. Most of the edits to model rules pertained to the surcharge operations.

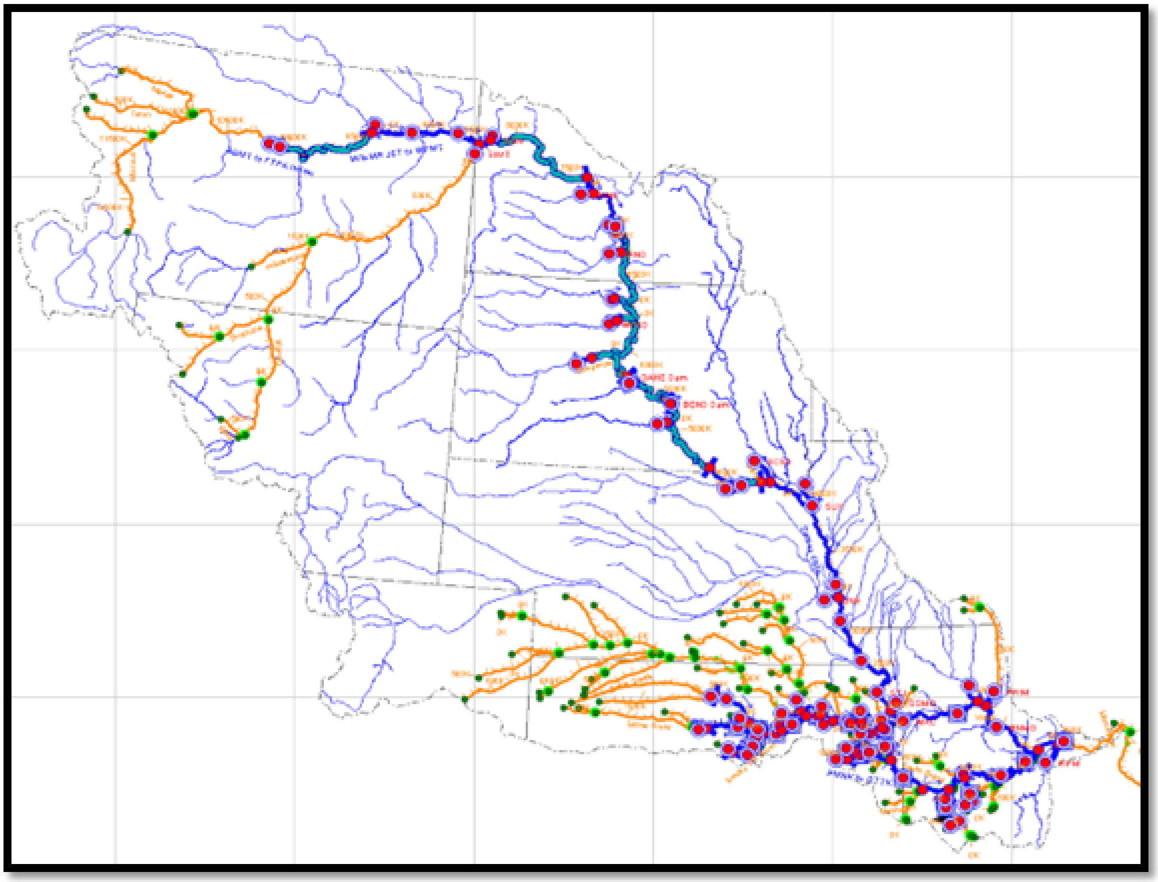
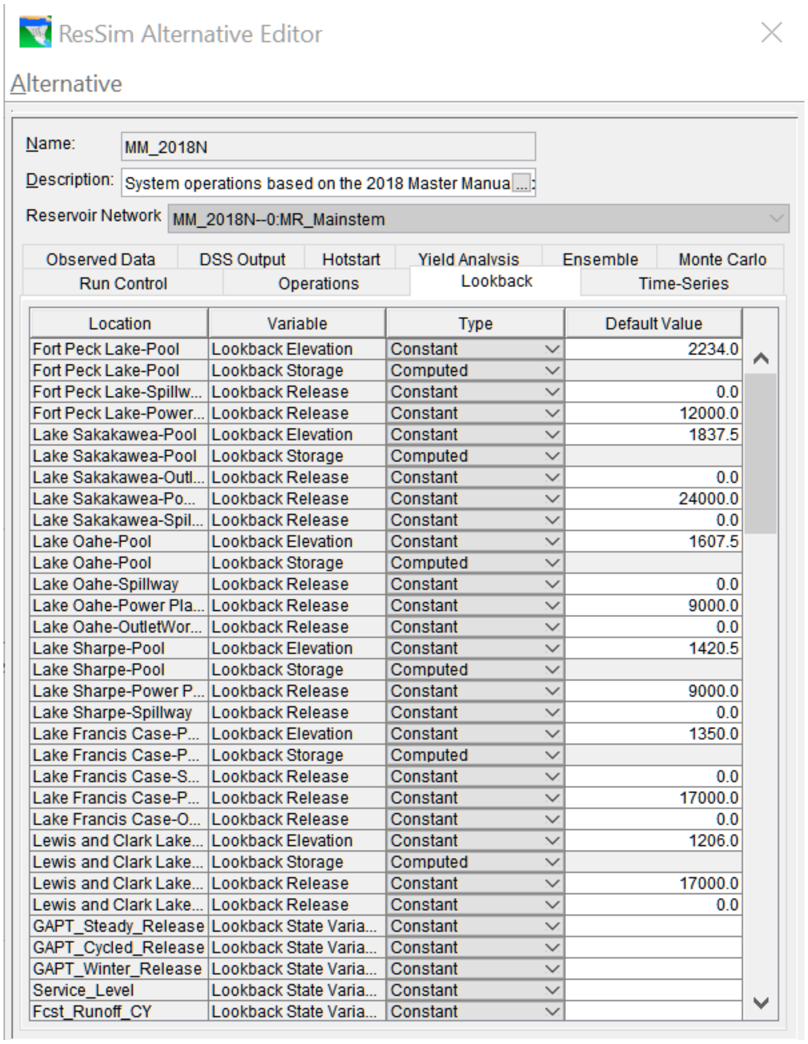


Figure E-1. Combined Missouri River Basin HEC-ResSim Model Schematic

Scaled Flood Methodology

Scaled floods were developed and modeled with the Missouri River Mainstem HEC-ResSim model by factoring up local inflows and inflow forecasts of historical flood years. Each flood year was modeled as a standalone simulation from March 1st of the flood year to March 1st of the following year, with a two-month lookback period. Initial conditions for the simulations were all set to March 1st regulation targets.



Location	Variable	Type	Default Value
Fort Peck Lake-Pool	Lookback Elevation	Constant	2234.0
Fort Peck Lake-Pool	Lookback Storage	Computed	
Fort Peck Lake-Spillw...	Lookback Release	Constant	0.0
Fort Peck Lake-Power...	Lookback Release	Constant	12000.0
Lake Sakakawea-Pool	Lookback Elevation	Constant	1837.5
Lake Sakakawea-Pool	Lookback Storage	Computed	
Lake Sakakawea-Outl...	Lookback Release	Constant	0.0
Lake Sakakawea-Po...	Lookback Release	Constant	24000.0
Lake Sakakawea-Spil...	Lookback Release	Constant	0.0
Lake Oahe-Pool	Lookback Elevation	Constant	1607.5
Lake Oahe-Pool	Lookback Storage	Computed	
Lake Oahe-Spillway	Lookback Release	Constant	0.0
Lake Oahe-Power Pla...	Lookback Release	Constant	9000.0
Lake Oahe-OutletWor...	Lookback Release	Constant	0.0
Lake Sharpe-Pool	Lookback Elevation	Constant	1420.5
Lake Sharpe-Pool	Lookback Storage	Computed	
Lake Sharpe-Power P...	Lookback Release	Constant	9000.0
Lake Sharpe-Spillway	Lookback Release	Constant	0.0
Lake Francis Case-P...	Lookback Elevation	Constant	1350.0
Lake Francis Case-P...	Lookback Storage	Computed	
Lake Francis Case-S...	Lookback Release	Constant	0.0
Lake Francis Case-P...	Lookback Release	Constant	17000.0
Lake Francis Case-O...	Lookback Release	Constant	0.0
Lewis and Clark Lake...	Lookback Elevation	Constant	1206.0
Lewis and Clark Lake...	Lookback Storage	Computed	
Lewis and Clark Lake...	Lookback Release	Constant	17000.0
Lewis and Clark Lake...	Lookback Release	Constant	0.0
GAPT_Steady_Release	Lookback State Varia...	Constant	
GAPT_Cycled_Release	Lookback State Varia...	Constant	
GAPT_Winter_Release	Lookback State Varia...	Constant	
Service_Level	Lookback State Varia...	Constant	
Fcst_Runoff_CY	Lookback State Varia...	Constant	

Figure E-2. Initial Conditions for HEC-ResSim Scaled Flood Simulations

Scaling factors were computed based on the standard deviations of annual incremental flow volumes of four regions of the Missouri River basin, defined as the Mountain Region, the Northern Plains Region, the Southern Plains Region, and the Missouri Hills Region. Figure E-3 depicts the regions used for scaling inflows.

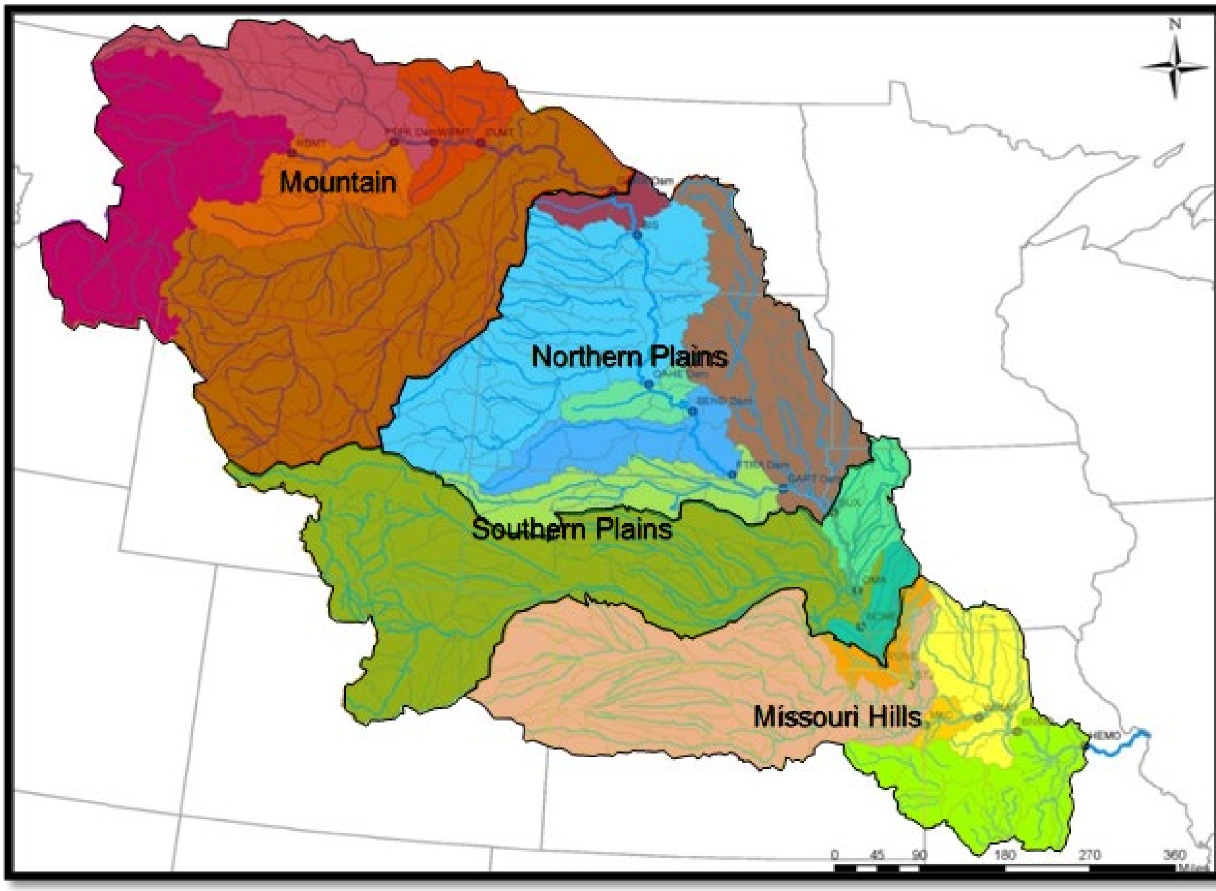


Figure E-3. Regions for Scaling Inflows for Missouri River HEC-ResSim Model

Scaling by Standard Deviation

When scaling a flood across an entire basin, it is possible to end up with very unreasonable flows. For example, if all the local inflows are scaled by a factor of 2.0, some locations may have a 1 in 1,000,000 annual exceedance probability flood (1,000,000 year flood) while others have a 1 in 10 annual chance exceedance flood (10-year flood). Unreasonable distribution of peak and duration maximum flows due to flood scaling was a problem encountered in the Upper Mississippi River System Flow Frequency Study, leading to the exclusion of several scaled floods from the final unregulated-to-regulated flow transform.

In order to preserve a more reasonable distribution of runoff, the technical review group suggested scaling local inflows by standard deviation (TRG, August 2020). A scheme was devised to compute annual incremental volumes for the mountain, northern plains, southern plains, and Missouri hills regions. These annual incremental volumes were expressed as flow averaged over the regulation year, (from March of the current year through February of the following year). Log Pearson III flow frequency curves were computed with these average annual flows for each region.

Initially, the scaling by standard deviation scheme devised utilized the following procedure for computing the local flow scaling factors to apply to an historic flood:

1. Find the annual average flow of the historical year being scaled on the respective flow frequency curve
2. Move the desired number of standard deviations less frequent and look up the flow of that AEP on the flow frequency curve
3. Compute the ratio of the two above flows to get the scaling factor
4. Apply the above scaling factor to all local flows within that region, including inflow forecasts

The advantage of this method would be that it factors in both the standard deviation and skew of the flow data. Figure E-4 illustrates this computation using the annual average flow frequency curve for the mountain region. The annual average flow in the year 2019 was 41,506 cfs, between a 1 in 10 and 1 in 20 annual chance exceedance flow, at z-variate -1.44. The corresponding flow at z-variate -2.44, up one standard deviation, is 53,168. The ratio of the two flows is 53,168 ÷ 41,506 = 1.28, or 28%.

The disadvantage of this method is that each scaled flood requires its own unique set of scaling factors, and therefore each flood would require its own copy of the HEC-ResSim model. The proposed scaled flood years were 1943, 1944, 1947, 1951, 1952, 1960, 1967, 1973, 1978, 1984, 1986, 1987, 1993, 1995, 1997, 2007, 2008, 2010, 2011, 2013, 2015, 2017 and 2019. It was proposed to increase flows by 0.5, 1.0, 1.5, and 2.0 standard deviations. If each flood at each level of increase requires its own copy of the HEC-ResSim model, 7 x 4 = 28 copies of the model would be necessary. This method is also more computationally complex, and therefore more prone to user input error.

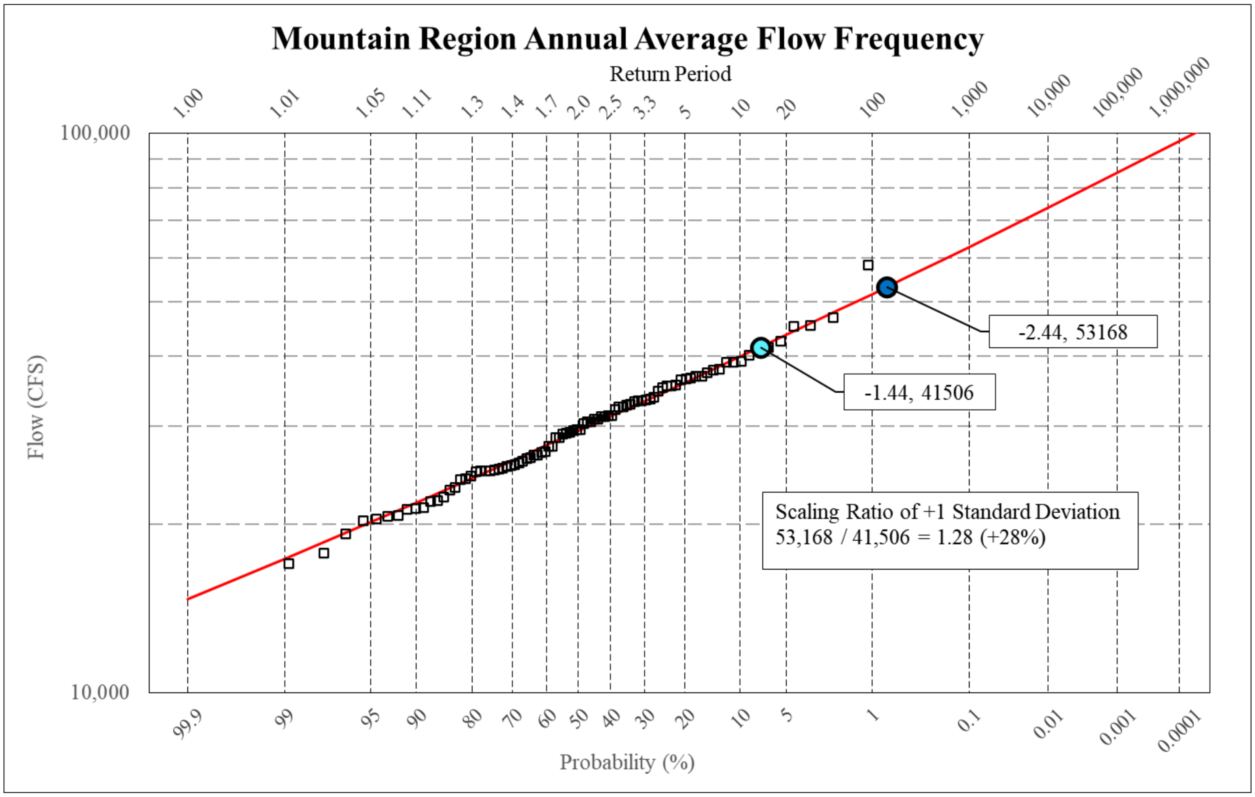


Figure E-4. Example of Computation of Local Flow Scaling Factor by Standard Deviation Along Flow Frequency Curve

Fortunately, the variation in scaling factors across historical events due to differences in skew computed by the aforementioned method is relatively small. Therefore, a simpler method was used, in which the same set of scaling factors for all scaled floods can be computed directly based on only the standard deviation of logs.

The scaling ratio can be computed directly from log of flow and standard deviation of log of flow based on Equation E1.

$$R = \frac{10^{(q+n\sigma)}}{10^{q}} = 10^{n\sigma} \qquad \text{E1}$$

Where *R* is the scaling ratio, *q* is the log of any flow, *n* is the desired number of standard deviations, and σ is the standard deviation of logs of flow. Because the log-normal distribution is “linear” in log space, this equation elegantly simplifies to $10^{n\sigma}$. All that is needed is the standard deviation of logs of flow of the annual maximum series. This does have the disadvantage that if skews are extreme enough, the resultant scaled floods may become unreasonable when checked against the flow frequency curve.

Table E-1 shows the statistics of logs for the regional annual averaged flows. Table E-2 shows the comparison between computing scaling factors for each year based on the flow frequency curve versus computing scaling factors directly based on standard deviation (same set of scaling factors for all events). Based on the results shown in Table E-1 and Table E-2 it was judged that the simplified method based on Equation 01 was sufficient to estimate scaling factors for all scaled floods. This means that if four scales of standard deviation are used, 0.5, 1.0, 1.5, and 2.0, then only four copies of the HEC-ResSim model need to be created, and each one could contain all of the scaled flood years.

Table E-1. Statistics (of Logs) for Regional Annual Averaged Flows

Statistics for Regional Annual Averaged Flows

Statistics	Mean	St. Dev	Skew
Mountain	4.470	0.102	0.087
N. Plains	3.996	0.232	0.228
S. Plains	4.216	0.163	0.436
Mo Hills	4.565	0.237	-0.260

Table E-2. Comparison of Scaling Factors Computed by Multiple Methods

Scaling Factors for Year 1960 by Frequency Curve

1960	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.12	1.26	1.42	1.60
N. Plains	1.32	1.76	2.37	3.23
S. Plains	1.23	1.53	1.93	2.48
Mo Hills	1.31	1.69	2.17	2.74

Scaling Factors for Year 1993 by Frequency Curve

1993	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.13	1.27	1.44	1.63
N. Plains	1.35	1.86	2.57	3.60
S. Plains	1.29	1.70	2.27	3.07
Mo Hills	1.24	1.51	1.83	2.20

Scaling Factors for Year 2019 by Frequency Curve

2019	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.13	1.28	1.45	1.65
N. Plains	1.39	1.95	2.78	3.99
S. Plains	1.29	1.68	2.24	3.02
Mo Hills	1.25	1.55	1.89	2.29

Scaling Factors for Year 1978 by Frequency Curve

1978	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.13	1.28	1.46	1.66
N. Plains	1.34	1.82	2.49	3.46
S. Plains	1.22	1.52	1.92	2.45
Mo Hills	1.30	1.66	2.10	2.63

Scaling Factors for Year 1997 by Frequency Curve

1997	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.13	1.28	1.46	1.66
N. Plains	1.36	1.88	2.62	3.68
S. Plains	1.24	1.55	1.98	2.56
Mo Hills	1.29	1.66	2.09	2.62

Scaling Factors for Year 1984 by Frequency Curve

1984	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.13	1.27	1.44	1.62
N. Plains	1.34	1.83	2.51	3.49
S. Plains	1.28	1.66	2.19	2.93
Mo Hills	1.27	1.59	1.98	2.43

Scaling Factors for Year 2011 by Frequency Curve

2011	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.14	1.29	1.47	1.68
N. Plains	1.37	1.89	2.64	3.72
S. Plains	1.25	1.60	2.07	2.71
Mo Hills	1.30	1.67	2.13	2.68

Minimum Scaling Factors of Selected Scaled Flood Years

MIN	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.12	1.26	1.42	1.60
N. Plains	1.32	1.76	2.37	3.23
S. Plains	1.22	1.52	1.92	2.45
Mo Hills	1.24	1.51	1.83	2.20

Maximum Scaling Factors of Selected Scaled Flood Years

MAX	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	1.14	1.29	1.47	1.68
N. Plains	1.39	1.95	2.78	3.99
S. Plains	1.29	1.70	2.27	3.07
Mo Hills	1.31	1.69	2.17	2.74

Difference in Min and Max Between Select Years

RANGE	0.5 σ	1.0 σ	1.5 σ	2.0 σ
Mountain	0.01	0.03	0.05	0.08
N. Plains	0.07	0.19	0.40	0.76
S. Plains	0.07	0.18	0.35	0.62
Mo Hills	0.07	0.18	0.33	0.54

Mean Scaling Factors of Selected Scaled Flood Years

MEAN	~0.5 σ	~1.0 σ	~1.5 σ	~2.0 σ
Mountain	1.13	1.28	1.45	1.65
N. Plains	1.35	1.85	2.57	3.60
S. Plains	1.26	1.61	2.08	2.75
Mo Hills	1.28	1.62	2.03	2.51

Mean Scaling Factors of All Systematic Events

MEAN	~0.5 σ	~1.0 σ	~1.5 σ	~2.0 σ
Mountain	1.13	1.27	1.43	1.62
N. Plains	1.31	1.74	2.34	3.17
S. Plains	1.21	1.50	1.87	2.38
Mo Hills	1.31	1.69	2.16	2.73

Scaling Factors Directly By Standard Deviation

DIRECT	~0.5 σ	~1.0 σ	~1.5 σ	~2.0 σ
Mountain	1.12	1.26	1.42	1.60
N. Plains	1.31	1.71	2.23	2.91
S. Plains	1.21	1.46	1.76	2.12
Mo Hills	1.31	1.73	2.27	2.98

Scaled Flood Procedures

This section describes the procedures for the computation of scaled floods. HEC-ResSim version 3.5 was used.

1. A backup copy of the Missouri River Mainstem HEC-ResSim model was created
2. A "base" copy of the Missouri River Mainstem HEC-ResSim (base model) was created, and all unnecessary simulations were deleted
3. The base model's InputData.dss file was edited by running the HEC-DSS math function "Screen using Minimum and Maximum" to edit all local inflow locations including RBMT such that all negative flow values were replaced with a value of 1 cfs. During scaling, the intent is to increase the flow. This step was to ensure that during scaling flows would be increased, rather than having negative flows become more negative.
4. The base model's InputData.dss file was then copied out to serve as a base for screening local inflows and scaling inflow forecasts
5. Two alternatives were created in the base model to accommodate standard deviation-scaled local inflows, one for the present condition regulated condition, and the other for the unregulated condition. However, they were left with original inflow scaling factors in the base model.
6. Placeholder simulations were created in the base model for the years 1943, 1944, 1947, 1951, 1952, 1960, 1967, 1973, 1978, 1984, 1986, 1987, 1993, 1995, 1997, 2007, 2008, 2010, 2011, 2013, 2015, 2017 and 2019 with the new alternatives.
7. A +0.5σ copy of the base model was created, and the base model's InputData.dss file was inserted into its shared data folder.
8. The Monthly Runoff Forecasts were adjusted using the mountain region's scaling factors for Fort Peck and Garrison, and the northern plains region's scaling factors for Oahe, Big Bend, Fort Randall, Gavin's Point, and Sioux City. The forecast data in the model was adjusted by the difference in monthly flow from the base model to the scaled inflows for each mainstem reservoir.
9. The inflow multipliers within the new alternatives were edited to reflect the scaling factors in Table E-3.
10. All simulations were computed ("replace from base" command was used to apply the scaling factors in the new alternative).
11. Steps 7 through 11 were repeated for each standard deviation scaling, 1, 1.5, and 2 standard deviations.

Table E-3. Regional Scaling Factors Computed by Standard Deviation

Scaling Factors Directly By Standard Deviation				
DIRECT	~ 0.5 σ	~ 1.0 σ	~ 1.5 σ	~ 2.0 σ
Mountain	1.12	1.26	1.42	1.60
N. Plains	1.31	1.71	2.23	2.91
S. Plains	1.21	1.46	1.76	2.12
Mo Hills	1.31	1.73	2.27	2.98

Inflow Multipliers

The inflow multipliers feature was used in HEC-ResSim in order to scale inflows.

Scaled Flood Selection

Flood years to be scaled were selected from the union of the top ten years by peak and the top ten years by volume at stations throughout the Missouri River basin. The stations included the mainstem dams with the exception of Big Bend, and the 10 study stations which are Gavins Point, Sioux City, Omaha, Nebraska City, Rulo, St. Joseph, Kansas City, Waverly, Boonville, and Hermann. Years which appeared in the top ten lists at enough stations in either the top ten years by volume or top ten years by peak were selected for scaling.

Table E-5 shows the top floods by peak and Table E-6 shows the top floods by volume, as well as which were selected for scaling. The distribution of years also shows how the flood was distributed throughout the basin.

It is worth noting that high volume floods are more frequently found in the more recent part of the period of record, while large floods by peak are distributed more evenly throughout the basin and slightly skewed towards the upper basin. This is evidence that annual flow volumes have been increasing over the previous 90 years since the 1930s drought.

Table E-4 shows the final floods selected for scaling.

Table E-4. Selected Floods to Scale and by Which Criteria

Year	Criteria	
1943	Peak	
1947	Peak	
1952	Peak	
1960	Peak	
1967	Peak	
1972	Peak	
1975		Volume
1978	Peak	Volume
1984		Volume
1986		Volume
1993	Peak	Volume
1995		Volume
1997	Peak	Volume
2008	Peak	
2010		Volume
2011	Peak	Volume
2018		Volume
2019	Peak	Volume

Table E-5. Top 10 Floods by Annual Peak Flow Basin-Wide

Model Node	Year											
FTPK DAM		1943	1944	1947				1953		1964		
GARR DAM	1939	1943		1947			1952	1953				
OAHE DAM		1943		1947	1950		1952	1953				
FTRA DAM		1943		1947	1950		1952	1953				
GAPT DAM		1943		1947	1950		1952		1960			
SUX		1943		1947			1952		1960			1967
OMA		1943		1947			1952		1960			
NCNE							1952		1960			1967
RUNE							1952		1960			1967
STJ							1952		1960			1967
MKC		1943		1947		1951	1952		1960			1967
WVMO		1943				1951	1952		1960		1965	1967
BNMO			1944	1947		1951	1952		1960			1967
HEMO		1943	1944	1947		1951	1952		1960			1967
Model Node	**Year**											
FTPK DAM		1975	1978	1986						2011	2014	
GARR DAM	1972		1978				1997			2011		2019
OAHE DAM	1972		1978				1997			2011		2019
FTRA DAM	1972		1978				1997			2011		2019
GAPT DAM	1972		1978				1997			2011		2019
SUX	1972		1978				1997			2011		2019
OMA	1972		1978				1997	2008		2011		2019
NCNE			1978		1993			2008	2010	2011		2019
RUNE			1978		1993			2008	2010	2011		2019
STJ			1978		1993			2008	2010	2011		2019
MKC					1993			2008		2011		2019
WVMO					1993			2008		2011		2019
BNMO					1993	1995				2011		2019
HEMO				1986	1993	1995						

Selected Flood Excluded Flood

Table E-6. Top 10 Floods by Annual Volume Basin-Wide

Model Node	Year											
FTPK DAM			1965	1967	1970			1975	1976	1978	1982	
GARR DAM	1943		1965	1967		1971		1975		1978		
OAHE DAM	1943					1971		1975		1978	1982	
FTRA DAM	1943					1971		1975		1978	1982	
GAPT DAM						1971		1975		1978	1982	
SUX										1978		
OMA										1978		
NCNE										1978		1984
RUNE										1978		1984
STJ										1978		1984
MKC		1951					1973					1984
WVMO		1951					1973					1984
BNMO		1951					1973				1982	1984
HEMO		1951					1973					
Model Node	**Year**											
FTPK DAM						1997			2011	2018		
GARR DAM						1997			2011	2018	2019	
OAHE DAM				1996		1997			2011	2018	2019	
FTRA DAM				1996		1997			2011	2018	2019	
GAPT DAM	1986			1996		1997			2011	2018	2019	
SUX	1986	1993	1995	1996		1997		2010	2011	2018	2019	
OMA	1986	1993	1995	1996		1997		2010	2011	2018	2019	
NCNE	1986	1993	1995			1997		2010	2011	2018	2019	
RUNE	1986	1993	1995			1997		2010	2011	2018	2019	
STJ	1986	1993	1995			1997		2010	2011	2018	2019	
MKC	1986	1993				1997		2010	2011	2018	2019	
WVMO	1986	1993	1995			1997		2010	2011		2019	
BNMO	1986	1993				1997		2010	2011		2019	
HEMO	1986	1993	1995		1998		2008	2010	2011		2019	

Selected Flood   Excluded Flood

Table E-7. Unregulated Scaled Flood Peaks, Gavins to Rulo

Year	Factor	Gavins Point	Sioux City	Omaha	Nebraska City	Rulo
1943	0.5	317,451	314,082	310,782	308,390	305,120
	1	387,091	398,663	385,331	381,994	383,068
	1.5	474,652	513,209	495,702	489,292	487,718
	2	593,498	661,883	638,934	628,307	622,884
1944	0.5					278,552
	1					335,665
	1.5					406,621
	2					495,045
1947	0.5	325,184	346,499	328,725	334,277	329,751
	1	392,655	421,988	399,041	407,175	400,896
	1.5	476,772	516,763	487,115	499,148	490,454
	2	582,133	636,256	597,917	615,548	603,540

Year	Factor	Gavins Point	Sioux City	Omaha	Nebraska City	Rulo
1951	0.5					264,650
	1					311,905
	1.5					385,245
	2					485,246
1952	0.5	616,441	636,638	622,699	610,882	605,768
	1	770,311	797,427	778,442	757,814	753,123
	1.5	967,141	1,003,384	977,731	954,742	941,245
	2	1,219,566	1,267,833	1,233,390	1,207,975	1,182,089
1960	0.5	292,307	346,425	395,845	452,939	465,727
	1	352,579	422,873	482,051	550,108	565,345
	1.5	427,788	519,166	589,872	671,163	689,278
	2	522,069	641,587	725,215	822,979	843,985
1967	0.5	289,596	293,571	307,399	389,766	397,178
	1	348,515	353,819	370,034	463,818	475,313
	1.5	423,070	430,118	449,070	559,376	572,835
	2	517,750	527,084	549,155	679,212	694,941
1972	0.5	300,409	304,852	305,472	312,596	
	1	352,308	359,093	359,894	369,841	
	1.5	415,238	425,208	426,219	439,863	
	2	491,973	507,976	509,820	525,960	
1973	0.5					194,217
	1					222,514
	1.5					256,871
	2					298,722
1975	0.5	195,235	196,491	200,589	221,719	
	1	216,691	218,172	222,981	244,916	
	1.5	241,652	243,245	251,633	271,828	
	2	292,604	288,214	304,372	323,187	
1978	0.5	355,156	367,844	369,032	381,692	
	1	422,669	439,512	440,867	456,525	
	1.5	505,842	529,700	531,206	549,128	
	2	608,846	642,939	644,821	664,277	
1984	0.5	154,153	258,739	275,168	351,214	
	1	179,883	316,210	335,351	415,804	
	1.5	212,158	389,926	412,134	495,084	
	2	252,816	484,694	510,332	592,617	
1986	0.5	223,798	226,094	229,933	241,488	238,733
	1	269,053	271,520	276,803	290,357	284,136
	1.5	325,302	329,701	336,055	351,037	344,337

Year	Factor	Gavins Point	Sioux City	Omaha	Nebraska City	Rulo
	2	395,556	402,652	410,247	426,726	419,600
1987	0.5					369,023
	1					465,272
	1.5					588,364
	2					746,036
1993	0.5	148,501	212,291	245,929	354,560	471,443
	1	175,222	258,157	298,260	425,138	566,599
	1.5	208,264	316,178	363,862	512,052	683,263
	2	249,329	389,841	446,380	619,343	826,571
1995	0.5	184,590	210,128	224,386	259,153	283,169
	1	225,557	265,580	282,561	313,073	352,419
	1.5	287,192	337,419	357,618	384,844	440,781
	2	367,212	430,586	454,582	485,841	553,713
1997	0.5	321,459	348,300	353,728	360,549	
	1	402,954	437,994	444,372	452,353	
	1.5	507,195	552,966	560,433	569,815	
	2	640,871	700,686	709,391	720,462	
2007	0.5					273,443
	1					325,916
	1.5					389,509
	2					466,637
2008	0.5	265,242	293,495	322,562	404,227	436,198
	1	321,542	358,510	392,450	487,431	526,086
	1.5	393,246	441,616	481,159	592,290	639,006
	2	484,838	548,127	594,068	724,791	781,228
2010	0.5	177,893	224,187	230,168	353,488	399,815
	1	208,450	269,209	292,143	421,684	471,821
	1.5	246,676	326,363	371,800	506,631	560,062
	2	298,002	415,017	474,331	612,723	668,464
2011	0.5	394,104	398,309	409,662	447,048	519,482
	1	465,772	471,051	484,113	523,914	608,601
	1.5	554,856	561,502	576,450	619,702	717,505
	2	666,127	674,515	691,511	738,750	851,077
2013	0.5					221,724
	1					254,041
	1.5					298,713
	2					358,877

Year	Factor	Gavins Point	Sioux City	Omaha	Nebraska City	Rulo
2015	0.5					265,784
	1					307,818
	1.5					358,900
	2					421,174
2017	0.5					209,210
	1					245,047
	1.5					288,580
	2					341,594
2018	0.5	196,365	239,683	277,449	332,032	
	1	220,284	284,363	324,322	386,368	
	1.5	248,330	340,867	382,202	457,418	
	2	281,366	412,584	453,977	546,070	
2019	0.5	371,066	422,195	433,465	485,182	477,937
	1	464,491	531,217	544,285	603,546	597,080
	1.5	584,011	671,111	686,218	752,346	747,522
	2	737,303	851,018	868,417	943,445	937,808

Table E-8. Unregulated Scaled Flood Peaks, St. Joseph to Hermann

Year	Factor	St. Joseph	Kansas City	Waverly	Boonville	Hermann
1943	0.5	302,324	465,399	448,523	507,090	891,172
	1	377,849	579,508	557,932	637,394	1,157,256
	1.5	481,776	725,889	698,228	805,558	1,505,532
	2	616,101	914,132	878,579	1,023,008	Not Used
1944	0.5	272,281	363,403	404,106	614,291	763,986
	1	327,037	464,734	517,503	795,178	992,005
	1.5	394,835	596,019	664,549	1,031,055	1,289,835
	2	479,041	766,350	855,484	1,338,865	1,679,075
1947	0.5	332,996	459,742	460,855	663,989	750,587
	1	404,962	571,370	572,594	839,021	953,036
	1.5	495,540	714,098	715,368	1,064,735	1,214,910
	2	609,893	897,021	898,228	1,356,299	1,554,158
1951	0.5	274,539	764,556	766,632	769,777	978,101
	1	326,689	981,152	983,916	987,981	1,261,681
	1.5	390,791	1,263,940	1,267,665	1,272,965	1,632,535
	2	472,949	1,633,421	1,638,478	1,645,427	2,117,787

Year	Factor	St. Joseph	Kansas City	Waverly	Boonville	Hermann
1952	0.5	597,010	607,811	617,657	632,959	692,767
	1	744,063	754,988	763,495	790,164	867,089
	1.5	932,082	942,806	957,339	991,421	1,090,655
	2	1,173,116	1,183,175	1,208,946	1,249,744	1,378,097
1960	0.5	461,043	581,808	587,529	691,595	729,502
	1	559,509	718,846	734,947	863,749	915,467
	1.5	681,971	896,422	924,931	1,087,387	1,153,388
	2	835,045	1,132,859	1,175,701	1,377,439	1,463,880
1967	0.5	406,538	604,422	580,874	625,524	712,756
	1	488,352	748,551	717,235	775,854	890,579
	1.5	590,767	932,973	891,395	968,378	1,119,264
	2	719,366	1,169,480	1,114,359	1,215,484	1,415,227
1972	0.5					
	1					
	1.5					
	2					
1973	0.5	246,330	547,734	533,662	540,044	660,990
	1	309,714	705,170	687,430	696,495	859,496
	1.5	390,429	909,389	886,968	899,687	1,119,090
	2	493,424	1,174,566	1,146,161	1,163,835	1,458,715
1975	0.5					
	1					
	1.5					
	2					
1978	0.5					
	1					
	1.5					
	2					
1984	0.5					
	1					
	1.5					
	2					
1986	0.5	289,201	401,215	381,890	479,593	1,280,588
	1	355,015	501,918	475,991	617,852	1,669,793
	1.5	438,909	631,675	597,037	797,663	2,179,232
	2	546,085	799,139	753,024	1,031,762	Not Used

Year	Factor	St. Joseph	Kansas City	Waverly	Boonville	Hermann
1987	0.5	394,960	548,986	544,416	556,204	599,140
	1	498,964	701,502	696,115	710,757	767,507
	1.5	632,165	898,537	892,216	910,426	985,400
	2	803,021	1,153,376	1,146,002	1,168,676	1,267,691
1993	0.5	532,743	877,817	987,149	1,127,668	1,188,274
	1	650,218	1,102,977	1,248,124	1,437,091	1,517,135
	1.5	796,886	1,391,262	1,583,785	1,837,339	1,943,026
	2	980,438	1,761,038	2,016,190	2,355,729	2,495,229
1995	0.5	333,787	464,468	482,685	655,174	1,171,973
	1	418,729	591,390	612,417	842,066	1,521,144
	1.5	527,651	756,093	784,163	1,085,574	1,977,809
	2	667,526	970,023	1,007,398	1,403,054	2,575,277
1997	0.5					
	1					
	1.5					
	2					
2007	0.5	268,501	494,985	487,924	597,247	699,705
	1	325,379	621,419	615,391	756,835	891,883
	1.5	396,124	783,156	779,114	962,489	1,140,460
	2	484,294	990,403	989,728	1,227,863	1,462,352
2008	0.5	458,895	532,380	537,399	608,971	741,526
	1	556,349	652,156	658,190	751,890	925,936
	1.5	679,281	804,404	811,695	934,425	1,162,977
	2	834,748	998,368	1,007,220	1,168,040	1,468,419
2010	0.5	394,088	464,237	469,934	542,613	600,620
	1	465,029	556,830	568,222	670,382	746,513
	1.5	552,038	672,347	699,800	834,021	937,848
	2	659,024	831,154	867,635	1,044,034	1,215,669
2011	0.5	499,809	522,298	520,572	562,586	547,677
	1	585,056	629,969	630,026	669,252	658,181
	1.5	689,347	765,004	767,634	802,249	835,911
	2	817,428	935,088	941,358	968,727	1,065,915
2013	0.5	248,329	325,504	381,021	578,546	772,077
	1	299,201	400,393	473,487	733,004	987,873
	1.5	363,132	495,956	592,148	933,133	1,268,664
	2	443,688	618,166	744,709	1,192,756	1,634,349

Year	Factor	St. Joseph	Kansas City	Waverly	Boonville	Hermann
2015	0.5	288,730	428,866	505,741	526,867	916,484
	1	342,579	540,491	641,131	668,584	1,195,829
	1.5	409,649	685,151	817,003	852,757	1,561,262
	2	493,459	872,856	1,045,705	1,092,354	2,039,502
2017	0.5	223,384	308,570	316,091	357,674	878,788
	1	263,823	375,734	386,088	433,470	1,143,549
	1.5	313,419	460,494	474,632	547,271	1,489,891
	2	374,417	567,753	586,938	701,033	1,943,165
2018	0.5					
	1					
	1.5					
	2					
2019	0.5	505,911	634,658	653,987	724,988	857,468
	1	629,911	799,142	824,711	919,829	1,105,502
	1.5	788,606	1,011,165	1,045,041	1,171,967	1,429,310
	2	992,085	1,284,877	1,329,799	1,498,650	1,852,294

Table E-9. Regulated Scaled Flood Peaks, Gavins to Rulo

Year	Factor	Gavins Point	Sioux City	Omaha	Nebraska City	Rulo
1943	0.5	67,500	94,586	151,746	144,974	141,437
	1	76,500	119,182	181,153	173,536	169,269
	1.5	104,500	150,368	242,461	233,825	228,676
	2	205,000	198,901	383,763	377,401	367,134
1944	0.5					168,846
	1					203,786
	1.5					251,721
	2					315,656
1947	0.5	67,500	95,990	91,947	161,718	162,921
	1	72,000	116,985	114,535	192,583	194,108
	1.5	80,000	146,931	137,413	233,283	235,210
	2	133,500	200,484	183,093	286,843	287,271
1951	0.5					208,311
	1					244,932
	1.5					295,483
	2					356,430

Year	Factor	Gavins Point	Sioux City	Omaha	Nebraska City	Rulo
1952	0.5	147,500	159,345	288,276	323,899	361,447
	1	238,000	260,825	417,807	462,643	507,429
	1.5	312,949	353,784	537,949	588,910	638,305
	2	394,737	424,687	642,716	709,053	779,425
1960	0.5	44,500	125,187	153,661	224,266	228,821
	1	65,000	173,780	207,981	293,284	298,138
	1.5	97,500	253,918	292,989	396,651	401,374
	2	109,000	329,633	375,796	501,172	506,169
1967	0.5	63,500	64,342	98,139	222,161	206,489
	1	72,500	74,912	119,420	269,367	250,401
	1.5	95,500	107,339	146,157	327,414	304,430
	2	140,000	153,348	178,853	398,022	369,864
1972	0.5	55,500	73,166	85,455	104,597	
	1	68,100	89,798	103,837	127,762	
	1.5	84,900	110,846	126,719	156,298	
	2	111,500	153,467	155,841	192,066	
1973	0.5					160,274
	1					191,563
	1.5					233,249
	2					286,635
1975	0.5	73,000	76,607	85,954	103,017	
	1	85,000	91,780	102,962	123,808	
	1.5	137,500	139,900	141,851	148,720	
	2	153,000	160,726	164,125	195,599	
1978	0.5	121,000	133,198	140,527	223,768	
	1	123,000	139,378	162,722	276,071	
	1.5	165,500	198,531	203,670	339,675	
	2	315,000	352,992	361,877	401,910	
1984	0.5	51,500	167,362	179,472	246,889	
	1	53,300	203,853	217,428	290,195	
	1.5	65,100	261,432	276,440	351,934	
	2	107,000	377,384	394,281	439,019	
1986	0.5	77,500	86,137	115,167	142,385	176,877
	1	92,500	111,083	143,134	174,480	213,985
	1.5	113,000	162,211	193,126	217,654	259,840
	2	164,000	228,298	265,764	294,768	337,373

Year	Factor	Gavins Point	Sioux City	Omaha	Nebraska City	Rulo
1987	0.5					155,833
	1					210,818
	1.5					256,044
	2					442,784
1993	0.5	86,400	130,487	181,303	264,177	386,124
	1	89,500	153,811	214,084	311,094	458,897
	1.5	106,800	197,956	269,839	382,890	562,082
	2	122,900	255,099	339,409	475,678	688,806
1995	0.5	77,700	97,145	115,291	149,439	167,821
	1	94,700	143,991	164,150	204,213	215,846
	1.5	117,900	198,842	220,158	269,745	284,837
	2	264,000	367,730	390,433	450,943	462,053
1997	0.5	217,000	274,452	283,642	288,288	
	1	157,000	205,955	213,310	220,026	
	1.5	317,000	399,108	414,570	426,178	
	2	315,500	434,263	448,842	462,857	
2007	0.5					243,862
	1					290,153
	1.5					365,991
	2					450,495
2008	0.5	63,500	68,111	83,699	156,461	188,948
	1	75,600	100,671	145,366	237,593	278,837
	1.5	87,100	113,719	168,827	278,411	326,236
	2	102,800	130,734	198,416	329,489	386,130
2010	0.5	69,000	121,703	153,854	215,683	277,928
	1	78,300	156,538	194,931	258,864	334,231
	1.5	96,000	200,931	246,733	330,134	421,013
	2	135,000	249,936	304,519	416,988	527,387
2011	0.5	184,000	212,058	246,389	256,359	328,927
	1	267,000	302,359	313,153	340,427	386,331
	1.5	344,000	385,321	430,238	448,391	517,279
	2	425,828	484,991	494,606	537,175	572,421
2013	0.5					115,808
	1					138,511
	1.5					202,016
	2					249,487

Year	Factor	Gavins Point	Sioux City	Omaha	Nebraska City	Rulo
2015	0.5					142,619
	1					167,853
	1.5					198,893
	2					237,475
2017	0.5					151,329
	1					180,706
	1.5					216,702
	2					260,869
2018	0.5	69,100	129,735	153,322	196,895	
	1	79,500	158,270	185,315	238,083	
	1.5	102,500	199,358	230,143	294,065	
	2	164,000	272,157	307,680	384,350	
2019	0.5	121,700	214,594	277,021	426,682	431,078
	1	154,000	282,392	358,500	527,617	540,068
	1.5	323,000	412,979	429,703	573,837	652,488
	2	383,000	497,581	559,060	779,982	829,670

Table E10. Regulated Scaled Flood Peaks, St. Joseph to Hermann

Year	Factor	St. Joseph	Kansas City	Waverly	Boonville	Hermann
1943	0.5	142,592	232,966	227,562	340,267	451,090
	1	176,727	296,970	292,502	444,590	582,916
	1.5	245,672	405,248	398,031	588,035	804,445
	2	405,123	575,920	600,131	858,493	Not Used
1944	0.5	161,468	268,433	314,221	542,111	547,954
	1	194,086	358,411	417,324	722,942	730,330
	1.5	239,513	461,384	538,620	947,673	1,042,655
	2	302,387	607,454	702,612	1,259,365	1,513,927
1947	0.5	177,300	229,842	244,171	462,168	450,949
	1	216,873	285,237	304,617	587,709	572,655
	1.5	269,804	360,529	384,013	760,133	807,458
	2	334,716	575,045	591,437	1,111,509	1,202,552
1951	0.5	212,458	615,137	659,879	679,978	816,348
	1	285,903	821,732	898,989	948,120	1,132,851
	1.5	356,358	1,084,153	1,188,534	1,249,722	1,513,274
	2	448,713	1,439,097	1,559,166	1,619,489	1,944,806

Year	Factor	St. Joseph	Kansas City	Waverly	Boonville	Hermann
1952	0.5	423,003	428,834	418,909	401,225	396,289
	1	590,606	597,773	585,616	562,332	556,211
	1.5	751,673	759,088	744,191	714,200	706,164
	2	941,227	949,076	942,188	909,301	902,164
1960	0.5	225,404	273,466	269,350	385,648	383,129
	1	293,798	356,282	350,983	503,253	498,652
	1.5	396,000	476,505	471,114	668,519	662,887
	2	499,264	682,347	672,707	925,076	914,368
1967	0.5	208,804	317,045	306,667	341,979	380,655
	1	260,582	402,079	390,619	436,871	483,277
	1.5	325,361	520,323	510,458	559,310	631,398
	2	404,204	681,711	664,668	744,939	968,610
1972	0.5					
	1					
	1.5					
	2					
1973	0.5	259,654	394,246	378,513	397,794	543,952
	1	323,894	527,054	522,854	619,820	804,420
	1.5	409,234	783,011	776,800	868,792	1,053,834
	2	520,413	1,085,064	1,070,832	1,132,802	1,380,617
1975	0.5					
	1					
	1.5					
	2					
1978	0.5					
	1					
	1.5					
	2					
1984	0.5					
	1					
	1.5					
	2					
1986	0.5	203,979	238,182	222,655	407,300	670,901
	1	249,755	311,579	292,450	538,787	1,019,923
	1.5	346,839	437,746	414,866	702,141	1,315,988
	2	461,193	596,422	566,334	1,010,081	Not Used

Year	Factor	St. Joseph	Kansas City	Waverly	Boonville	Hermann
1987	0.5	244,518	278,281	262,975	274,946	284,906
	1	291,466	336,588	316,377	335,846	392,733
	1.5	382,101	456,178	448,059	507,574	568,963
	2	492,288	702,156	722,029	797,990	878,894
1993	0.5	440,262	711,862	820,458	969,751	972,244
	1	533,425	952,591	1,090,012	1,273,212	1,373,644
	1.5	664,108	1,227,944	1,416,013	1,666,016	1,780,574
	2	833,298	1,565,319	1,818,634	2,166,235	2,317,876
1995	0.5	209,341	272,617	329,948	464,746	680,574
	1	262,763	367,141	462,135	605,229	887,751
	1.5	330,626	513,550	634,996	801,733	1,280,543
	2	487,136	754,620	915,419	1,139,240	1,826,524
1997	0.5					
	1					
	1.5					
	2					
2007	0.5	220,618	347,520	362,254	450,207	441,663
	1	264,514	430,967	452,225	569,407	558,490
	1.5	350,934	557,333	586,476	750,651	738,387
	2	428,199	718,764	758,911	986,954	1,014,599
2008	0.5	201,950	237,173	248,331	382,807	467,162
	1	293,290	338,473	353,442	496,685	654,583
	1.5	350,992	416,475	436,126	640,592	819,531
	2	423,934	563,128	585,639	830,197	1,071,725
2010	0.5	270,131	273,715	287,944	366,573	400,673
	1	324,586	346,758	362,317	492,638	539,928
	1.5	409,080	519,410	529,957	641,288	699,827
	2	512,383	653,605	668,800	861,789	956,796
2011	0.5	305,614	301,574	317,915	365,218	354,818
	1	387,425	389,130	419,359	437,285	454,037
	1.5	508,645	517,503	557,069	589,698	612,046
	2	602,707	613,503	650,818	668,947	834,066
2013	0.5	154,858	187,615	247,177	443,657	558,500
	1	189,597	233,221	310,943	569,475	716,017
	1.5	268,748	326,594	427,483	767,788	951,654
	2	337,223	413,825	546,244	993,598	1,255,155

Year	Factor	St. Joseph	Kansas City	Waverly	Boonville	Hermann
2015	0.5	176,978	259,669	325,045	340,686	595,587
	1	213,257	336,377	429,150	453,787	785,359
	1.5	262,256	473,081	589,940	617,972	1,017,328
	2	327,849	630,692	801,472	856,221	1,406,207
2017	0.5	168,022	206,240	213,545	280,526	637,006
	1	202,934	253,649	264,141	358,529	817,011
	1.5	246,266	318,240	331,456	458,790	1,057,069
	2	300,147	412,680	430,196	587,706	1,520,143
2018	0.5					
	1					
	1.5					
	2					
2019	0.5	425,953	440,766	456,802	528,542	615,952
	1	524,494	548,716	573,152	664,355	934,173
	1.5	650,583	722,800	766,234	890,908	1,204,883
	2	828,560	904,613	959,636	1,130,286	1,518,175