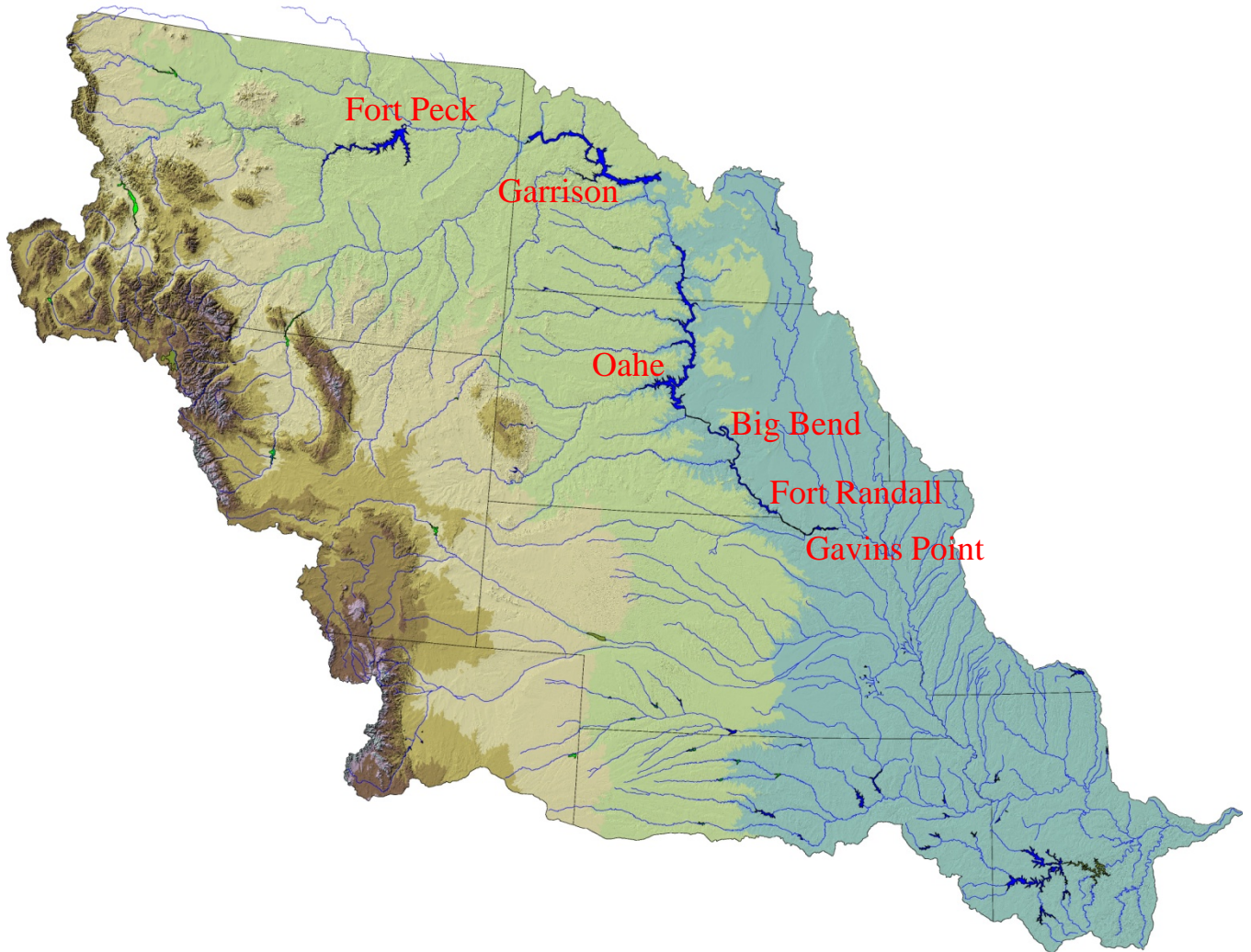




**US Army Corps
of Engineers** ®
Northwestern Division

Runoff Volumes for AOP Studies

Technical Report



Missouri River Basin Water Management Division
Omaha, Nebraska

August 2013

Missouri River Basin Water Management Division

Technical Report – Runoff Volumes for Annual Operating Plan Studies, August 2013

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I. GENERAL

A) Prior Studies

This report is an update to the report titled “*Missouri River Main Stem Reservoirs, Runoff Volumes for Annual Operating Plan Studies, RCC Technical Report Jy-08*”, dated July 2008. The Jy-08 report supersedes several prior published and unpublished reports including:

Addendum to RCC Technical Report O-98, Runoff Volumes for Annual Operation Plan Studies Upper Decile and Upper Quartile Runoff Extensions, October 2004.

MRD Technical Report O-98, Missouri River Main Stem Reservoirs, Runoff Volumes Appropriate for Annual Operating Plan Studies, October 1998.

Two unpublished updates in 1985 and 1993.

MRD Technical Report A-75, Missouri River Main Stem Reservoirs, Runoff Volumes Appropriate for Annual Operating Plan Studies, August 1975.

The A-75 report should be referred to for a history of how the runoff volumes were developed and used for Annual Operating Plan (AOP) studies. The unpublished 1985 study was an update to the 1975 report, although there were several differences in the method of computing runoff volumes. The 1993, 1998, and 2008 studies, along with the current study, were completed following essentially the same methodology used in the 1975 study.

B) Purpose

The AOP studies utilize statistically derived runoff volumes based on the 114-year historical record of runoff above Sioux City, IA during the period 1898 to 2011. The AOP studies are comprised of five runoff levels with statistical significance implied by their titles: upper decile, upper quartile, median, lower quartile and lower decile. All volumes discussed in this report are adjusted to the 1949 level of water resources development in the Missouri River basin. This report contains five additional years of runoff from 2007-2011 since the publication of the Jy-08 report including the record runoff of 61.0 MAF in 2011.

Two additional runoff volume scenarios were developed for this study update. While the upper and lower decile runoff volumes cover 80 percent of the historic runoff record, these two new scenarios, one on either side of the runoff spectrum will encompass 96 percent of the historic runoff records. The 2 percent non-exceedance has a 1 in 50 chance of occurring. While the 98 percent non-exceedance (or conversely, 2 percent exceedance) has a 1 in 50 chance of having equal or greater runoff. These runoff volumes will not become part of the AOP scenarios but could be implemented for any given runoff season should the runoff forecast exceed the upper decile runoff scenario or be less than the lower decile runoff scenario.

The following sections outline the steps used to determine the runoff volumes for AOP studies. In this report the terms "runoff" and "inflow" are used interchangeably.

II. DETERMINATION OF RUNOFF VOLUMES

A) Basin Annual Runoff Volumes

The total annual runoff for the Missouri River basin above Sioux City, IA for each of the seven runoff levels, 98th percentile (U2), upper decile (UD), upper quartile (UQ), median (MED), lower quartile (LQ), lower decile (LD), and 2nd percentile (L2) was determined using the steps outlined below.

The MRBWM in-house computer program "FLOW" was used to rank the Summation of Inflow above Sioux City for the period of record (1898 - 2011).

A volume-duration curve using total annual runoff was developed for the Missouri River above Sioux City as shown on Plate 1. The five additional years included in this update analysis are indicated in red. The annual volume for each of the seven runoff levels was determined based on their statistical representation. For example, the LD is the annual runoff volume corresponding to a 10 percent non-exceedance (or conversely, an exceedance rate of 90 percent). Likewise, the UQ was the annual runoff volume with a non-exceedance rate of 75 percent (or exceedance rate of 25 percent.) Note the selected runoff volumes were not actual historical runoff volumes, but rather were derived from the volume-duration curve for total annual runoff above Sioux City. Table 1 shows the annual runoff volume in million acre-feet (MAF) for the basin above Sioux City for each of the runoff levels for the 114-year period (1898-2011) as well as the Jy-08 (1898-2006) and O-98 (1898-1997) reports which had 109 and 100 years of record, respectively.

The five additional years (2007-2011) used in this study included four out of five years of above normal runoff including the first (2011) and fourth (2010) largest runoff years in the 114 years of record. The five additional years of record resulted in a slight reduction in the lower decile runoff, no change to the lower quartile and a modest increase in the median, upper quartile and upper decile of between 0.2 and 0.3 MAF from the previous report Jy-08 (1898-1997). The runoff during this 5-year period in the upper portion of the basin (above Fort Peck and the Fort Peck to Garrison Reach) is distributed fairly evenly with the exception of the 2011 event which was the largest event in 114 years for both reaches as shown on Plates 2 and 3. The runoff during the 5-year period in the middle portion of the basin in the Garrison to Oahe reach was generally above normal with two of three highest runoff years on record occurring, as shown on Plate 4. The Oahe to Fort Randall reach runoff (shown on Plate 5) was more evenly distributed during this 5-year period with the second and fifth highest runoff years in the 114 years of record. Annual runoff in the Fort Randall to Gavins Point reach for this 5-year period were all located on the upper half of the curve as shown in Plate 6. However, the largest event in the 5-year period was only the 10th highest event in the 114 years of record. The runoff during this 5-year period in the lower portion of the basin (Gavins Point to Sioux City Reach) is well above normal as shown on Plate 7 including the two highest runoff years in 114 years of record.

B) Distribution of Runoff by Reach

Six reaches are defined for use in the AOP studies: (1) the Fort Peck reach is the basin above Fort Peck dam, 57,500 square miles; (2) the Garrison reach includes the basin between Fort Peck and Garrison dams, 123,900 sq. mi.; (3) the Oahe reach includes the basin between Garrison and Oahe dams, 62,090 sq. mi.; (4) the Fort Randall reach includes the basin between Oahe and Fort Randall dams, 19,990 sq. mi.; (5) the Gavins Point reach includes the basin between Fort Randall and Gavins Point dams, 16,000 sq. mi.; and (6) the Sioux City reach includes the basin between Gavins Point dam and Sioux City, Iowa, 39,080 sq. mi.

Table 1
Annual Runoff Volume above Sioux City, IA

Runoff Level	Annual Volume in MAF (1898-2011)	Annual Volume in MAF (1898-2006)	Annual Volume in MAF (1898-1997)
2nd Percentile (L2)	11.4	-----	-----
Lower Decile (LD)	16.1	16.2	15.5
Lower Quartile (LQ)	19.3	19.3	19.5
Median (MED)	24.6	24.4	24.6
Upper Quartile (UQ)	30.6	30.3	30.6
Upper Decile (UD)	34.5	34.3	34.5
98th Percentile (U2)	40.1	-----	-----

The following steps were used to distribute the total annual runoff for the Missouri River basin above Sioux City among the six reaches.

1. The MRBWM in-house computer program "FLOW" was used to rank the annual runoff volume from each of the six reaches for the historic period of record (1898 - 2011).

2. Volume-duration curves for the annual runoff were developed and plotted for each reach using the results of the FLOW program. The five additional years included in this updated analysis are indicated in red. The volume-duration curves are shown on Plates 2 through 7.

3. Due to the vast size of the Missouri River basin above Sioux City and its natural variation in the areal distribution of runoff, the sum of the six incremental reaches annual runoff for a specific non-exceedance level is not necessarily equal to the total annual basin runoff for that same non-exceedance level. In other words, the 10 percent non-exceedance annual runoff volumes for each of the six individual reaches combined is 13.4 MAF which does not equal the 10 percent non-exceedance annual runoff of 16.1 MAF derived for the Missouri River basin above Sioux City. The two runoff values would only be equal if all of the reaches had identical annual rankings. For example, the Fort Randall and Gavins Point reaches had their highest annual runoff in 1997, but it was only the 7th highest runoff year for the Fort Peck reach, 2nd

highest for the Garrison and Oahe reaches, and 6th highest for the Sioux City reach. This compares to the 1997 annual runoff for the Missouri River basin above Sioux City which was the 2nd highest annual runoff on record.

Therefore, the annual runoff for each of the six reaches were ranked from lowest to highest and then combined to create a volume-duration curve. The annual runoff for each of the specific non-exceedance levels for the Missouri River basin above Sioux City were then located on the combined reach volume-duration curve to determine the incremental reach inflows that are equally likely to occur and which, when summed for the six reaches, equal the runoff for the basin as a whole. For example, the 16.1 MAF determined for the lower decile (i.e. 10 percent non-exceedand) runoff for the basin above Sioux City was represented as a 21 percent non-exceedance rate on the duration curve based on the sum of the reach inflows.

4. This procedure was repeated for the remaining runoff levels with the following outcomes: the sum of the 31 percent non-exceedance reach inflows equals the total basin LQ runoff, the sum of the 54 percentile reach inflows equals the total basin MED runoff, the sum of the 74 percentile reach inflows equals the UQ, and the sum of the 83 percentile reach inflows equals the UD. These percentiles were very close to the 1898-2008 study with the LD and LQ dropping just 1 percent while the MED and UQ rose 1 percent. The UD stayed the same. For the two additional runoff scenarios, the sum of the 4 percent non-exceedance reach inflows equals the total basin L2 runoff while the 92 percent non-exceedance reach inflows equals the total basin U2 runoff. The resultant incremental reach runoff volumes in MAF are shown in Table 2 for the various runoff levels. The percent of runoff originating from each reach is shown in Table 3.

Table 2
Annual Incremental Reach Runoff Volumes

Runoff Level	L2	LD	LQ	MED	UQ	UD	U2
Reach Percentile	4	21	31	54	74	83	92
Reach	Annual Volume in MAF						
Fort Peck	3.85	5.30	5.95	7.20	8.65	9.45	10.45
Garrison	5.60	7.40	9.15	10.9	12.75	14.00	15.25
Oahe	0.50	1.15	1.35	2.30	3.20	3.90	4.95
Fort Randall	0.10	0.35	0.45	0.90	1.20	1.50	2.05
Gavins Point	1.10	1.20	1.30	1.50	2.00	2.25	2.75
Sioux City	0.25	0.70	1.10	1.80	2.80	3.40	4.65
Total	11.40	16.10	19.30	24.60	30.60	34.50	40.10

Table 3
Distribution of Runoff by Reach
in Percent of Total Runoff above Sioux City

Runoff Level	L2	LD	LQ	MED	UQ	UD	U2
Reach	Annual Runoff in Percent						
Fort Peck	33.8	32.9	30.8	29.3	28.3	27.4	26.1
Garrison	49.1	46.0	47.4	44.3	41.7	40.6	38.0
Oahe	4.4	7.1	7.0	9.3	10.5	11.3	12.3
Fort Randall	0.9	2.2	2.3	3.7	3.9	4.3	5.1
Gavins Point	9.6	7.5	6.8	6.1	6.5	6.5	6.9
Sioux City	2.2	4.3	5.7	7.3	9.1	9.9	11.6

C) Distribution of Runoff by Month

While the aforementioned procedure results in the areal distribution of runoff, Annual Operating Plan studies require annual runoff to be distributed by month. A monthly distribution was computed for each reach for the seven different runoff scenarios. In order to maintain the character provided by specific years, the following procedure was used to distribute the annual runoff by month.

1. The MRBWMD in-house computer program "FLOW" was used to rank the annual runoff for the period of record for the six reaches.
2. Using the ranked reach inflows, the ten individual years whose annual runoff was closest to the annual runoff for the 2 percentile, lower decile and quartile, median, upper quartile and decile, and 98 percentile conditions were identified for each of the six reaches.
3. Monthly runoff was expressed as a percentage of annual reach runoff for each of the 10 years.
4. By analysis of each 10-year group of years, the month that usually has the maximum runoff was determined. Similar determinations were made of the usual month that the 2nd largest runoff, 3rd largest runoff, etc. occurred.
5. The monthly runoff percentages (as computed in c) were ranked from highest to lowest for each year. Then, for each 10-year group the average of the highest percentage from each year was computed, irrespective of what month in each particular year the maximum runoff occurred. The same process was used to compute the average runoff percentage for the 2nd highest month, 3rd highest month, etc.
6. The distribution of annual runoff was accomplished by placing the average monthly runoff percentage (as determined in 5) in the appropriate month (as determined in 4). For

example, the highest average monthly runoff percentage was assigned to the month that the maximum runoff usually occurs, the second highest percentage to the month that the second highest runoff usually occurs, etc. This process was repeated for each reach/runoff level resulting in a monthly distribution for each of the seven runoff levels (L2, LD, LQ, MED, UQ, UD, and U2) for each of the 6 reaches for a total of 42 unique distributions.

7. The resulting monthly distributions were multiplied by the annual runoff for the particular reach/runoff scenario to determine the monthly runoff and were plotted.

8. Using specific years to distribute the reach inflows can create some inconsistencies. In particular, there are instances when monthly reach runoff representing a lower runoff condition, such as the LD or LQ, are greater than the flows representing a higher runoff condition, such as the UD or UQ. If these inconsistencies were large, then the monthly distribution percentages for one runoff level that better represented the typical runoff pattern for that particular reach was applied to another runoff level to eliminate or reduce the inconsistencies. For the inconsistencies where the monthly distribution patterns were similar for a reach but a particular month for a lower runoff level had a higher monthly runoff than a higher runoff level, then the monthly reach inflows were smoothed by engineering judgment to account for the inconsistencies while keeping the annual reach inflow the same.

For the final monthly runoffs for each reach, the upper decile runoff distribution was used for both the upper decile and upper quartile runoffs. Likewise, the median runoff distribution was used for the median and lower quartile runoffs. The lower decile, 98 percentile, and 2 percentile runoffs used their own calculated distributions. The resultant monthly reach inflow volumes in MAF are shown in Table 4 for the seven runoff levels. After smoothing the runoff volumes, the monthly runoff distributions (in percent of annual reach inflow) were recomputed. Table 5 shows the monthly volumes as percentages of annual reach runoff.

Table 4
Monthly Reach Runoff Volumes
1000 Acre-Feet

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
<u>2 Percentile (L2)</u>													
Fort Peck	220	270	390	385	480	670	320	185	180	290	250	210	3850
Garrison	160	260	760	560	715	1400	500	255	205	375	290	120	5600
Oahe	-30	30	220	125	95	80	10	30	25	-15	10	-80	500
Fort Randall	-30	15	75	45	25	35	15	10	-10	-30	-25	-25	100
Gavins Point	65	90	160	110	120	115	70	55	65	95	90	65	1100
Sioux City	-15	15	100	35	20	45	60	30	0	-5	10	-45	250
Total	370	680	1705	1260	1455	2345	975	565	465	710	625	245	11400
<u>Lower Decile (LD)</u>													
Fort Peck	230	295	400	440	850	1180	595	260	230	310	290	220	5300
Garrison	195	270	790	580	1100	2165	935	325	215	385	300	140	7400
Oahe	-20	40	350	200	110	305	105	40	45	5	15	-45	1150
Fort Randall	-25	35	140	85	50	95	25	15	-5	-25	-20	-20	350
Gavins Point	70	100	165	120	130	135	80	60	75	100	95	70	1200
Sioux City	15	20	180	90	120	65	70	40	30	30	35	5	700
Total	465	760	2025	1515	2360	3945	1810	740	590	805	715	370	16100
<u>Lower Quartile (LQ)</u>													
Fort Peck	240	310	415	460	945	1510	645	290	240	320	335	240	5950
Garrison	210	280	835	640	1150	2600	1700	475	395	395	320	150	9150
Oahe	-15	50	365	285	130	315	110	50	55	15	25	-35	1350
Fort Randall	-20	40	160	80	65	110	35	25	0	-20	-15	-10	450
Gavins Point	75	105	190	125	140	150	85	70	80	105	100	75	1300
Sioux City	20	50	250	145	185	115	100	80	65	35	45	10	1100
Total	510	835	2215	1735	2615	4800	2675	990	835	850	810	430	19300
<u>Median (MED)</u>													
Fort Peck	260	350	470	560	1145	1830	840	365	290	385	410	295	7200
Garrison	255	310	990	780	1300	3120	2100	580	480	445	360	180	10900
Oahe	-10	70	535	405	220	625	170	70	95	45	90	-15	2300
Fort Randall	-10	45	250	160	165	135	70	60	35	0	-10	0	900
Gavins Point	85	120	210	145	165	175	100	90	95	120	115	80	1500
Sioux City	25	75	335	280	345	190	165	130	110	60	60	25	1800
Total	605	970	2790	2330	3340	6075	3445	1295	1105	1055	1025	565	24600
<u>Upper Quartile (UQ)</u>													
Fort Peck	285	385	640	755	1285	2155	1105	405	350	440	525	320	8650
Garrison	295	380	995	1230	1675	3200	2475	760	520	555	430	235	12750
Oahe	0	80	945	430	310	640	250	95	150	120	190	-10	3200
Fort Randall	-5	50	255	350	185	140	75	65	75	10	-5	5	1200
Gavins Point	95	165	220	240	290	210	180	145	115	135	120	85	2000
Sioux City	30	115	340	390	730	435	240	180	135	70	85	50	2800
Total	700	1175	3395	3395	4475	6780	4325	1650	1345	1330	1345	685	30600
<u>Upper Decile (UD)</u>													
Fort Peck	310	420	705	825	1400	2355	1205	440	385	480	575	350	9450
Garrison	315	415	1095	1355	1840	3460	2715	835	570	645	495	260	14000
Oahe	10	90	1175	510	390	710	310	125	185	145	235	15	3900
Fort Randall	0	60	310	440	230	155	80	70	100	40	0	15	1500
Gavins Point	105	190	230	280	330	245	205	165	130	150	130	90	2250
Sioux City	35	140	390	470	890	550	290	225	165	85	100	60	3400
Total	775	1315	3905	3880	5080	7475	4805	1860	1535	1545	1535	790	34500
<u>98 Percentile (U2)</u>													
Fort Peck	340	465	780	915	1550	2600	1330	485	425	530	640	390	10450
Garrison	340	440	1150	1445	2060	3830	2960	900	620	690	530	285	15250
Oahe	20	95	1485	645	490	895	405	155	230	180	310	40	4950
Fort Randall	5	65	570	475	320	205	110	85	140	50	5	20	2050
Gavins Point	125	210	385	305	360	300	260	210	165	190	145	95	2750
Sioux City	115	180	495	795	1095	620	370	305	240	210	155	70	4650
Total	945	1455	4865	4580	5875	8450	5435	2140	1820	1850	1785	900	40100

Table 5
Monthly Distribution of Reach Runoff in Percent of Annual

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
<u>2 Percentile (L2)</u>													
Fort Peck	5.7	7.0	10.1	10.0	12.5	17.4	8.3	4.8	4.7	7.5	6.5	5.5	100.0
Garrison	2.9	4.6	13.6	10.0	12.8	25.0	8.9	4.6	3.7	6.7	5.2	2.1	100.0
Oahe	-6.0	6.0	44.0	25.0	19.0	16.0	2.0	6.0	5.0	-3.0	2.0	-16.0	100.0
Fort Randall	-30.0	15.0	75.0	45.0	25.0	35.0	15.0	10.0	-10.0	-30.0	-25.0	-25.0	100.0
Gavins Point	5.9	8.2	14.5	10.0	10.9	10.5	6.4	5.0	5.9	8.6	8.2	5.9	100.0
Sioux City	-6.0	6.0	40.0	14.0	8.0	18.0	24.0	12.0	0.0	-2.0	4.0	-18.0	100.0
Basin Total	3.2	6.0	15.0	11.1	12.8	20.6	8.6	5.0	4.1	6.2	5.5	2.1	100.0
<u>Lower Decile (LD)</u>													
0.Fort Peck	4.3	5.6	7.5	8.3	16.0	22.3	11.2	4.9	4.3	5.8	5.5	4.2	100.0
Garrison	2.6	3.6	10.7	7.8	14.9	29.3	12.6	4.4	2.9	5.2	4.1	1.9	100.0
Oahe	-1.7	3.5	30.4	17.4	9.6	26.5	9.1	3.5	3.9	0.4	1.3	-3.9	100.0
Fort Randall	-7.1	10.0	40.0	24.3	14.3	27.1	7.1	4.3	-1.4	-7.1	-5.7	-5.7	100.0
Gavins Point	5.8	8.3	13.8	10.0	10.8	11.3	6.7	5.0	6.3	8.3	7.9	5.8	100.0
Sioux City	2.1	2.9	25.7	12.9	17.1	9.3	10.0	5.7	4.3	4.3	5.0	0.7	100.0
Basin Total	2.9	4.7	12.6	9.4	14.7	24.5	11.2	4.6	3.7	5.0	4.4	2.3	100.0
<u>Lower Quartile (LQ)</u>													
Fort Peck	4.0	5.2	7.0	7.7	15.9	25.4	10.8	4.9	4.0	5.4	5.6	4.0	100.0
Garrison	2.3	3.1	9.1	7.0	12.6	28.4	18.6	5.2	4.3	4.3	3.5	1.6	100.0
Oahe	-1.1	3.7	27.0	21.1	9.6	23.3	8.1	3.7	4.1	1.1	1.9	-2.6	100.0
Fort Randall	-4.4	8.9	35.6	17.8	14.4	24.4	7.8	5.6	0.0	-4.4	-3.3	-2.2	100.0
Gavins Point	5.8	8.1	14.6	9.6	10.8	11.5	6.5	5.4	6.2	8.1	7.7	5.8	100.0
Sioux City	1.8	4.5	22.7	13.2	16.8	10.5	9.1	7.3	5.9	3.2	4.1	0.9	100.0
Basin Total	2.6	4.3	11.5	9.0	13.5	24.9	13.9	5.1	4.3	4.4	4.2	2.2	100.0
<u>Median (MED)</u>													
Fort Peck	3.6	4.9	6.5	7.8	15.9	25.4	11.7	5.1	4.0	5.3	5.7	4.1	100.0
Garrison	2.3	2.8	9.1	7.2	11.9	28.6	19.3	5.3	4.4	4.1	3.3	1.7	100.0
Oahe	-0.4	3.0	23.3	17.6	9.6	27.2	7.4	3.0	4.1	2.0	3.9	-0.7	100.0
Fort Randall	-1.1	5.0	27.8	17.8	18.3	15.0	7.8	6.7	3.9	0.0	-1.1	0.0	100.0
Gavins Point	5.7	8.0	14.0	9.7	11.0	11.7	6.7	6.0	6.3	8.0	7.7	5.3	100.0
Sioux City	1.4	4.2	18.6	15.6	19.2	10.6	9.2	7.2	6.1	3.3	3.3	1.4	100.0
Basin Total	2.5	3.9	11.3	9.5	13.6	24.7	14.0	5.3	4.5	4.3	4.2	2.3	100.0
<u>Upper Quartile (UQ)</u>													
Fort Peck	3.3	4.5	7.4	8.7	14.9	24.9	12.8	4.7	4.0	5.1	6.1	3.7	100.0
Garrison	2.3	3.0	7.8	9.6	13.1	25.1	19.4	6.0	4.1	4.4	3.4	1.8	100.0
Oahe	0.0	2.5	29.5	13.4	9.7	20.0	7.8	3.0	4.7	3.8	5.9	-0.3	100.0
Fort Randall	-0.4	4.2	21.3	29.2	15.4	11.7	6.3	5.4	6.3	0.8	-0.4	0.4	100.0
Gavins Point	4.8	8.3	11.0	12.0	14.5	10.5	9.0	7.3	5.8	6.8	6.0	4.3	100.0
Sioux City	1.1	4.1	12.1	13.9	26.1	15.5	8.6	6.4	4.8	2.5	3.0	1.8	100.0
Basin Total	2.3	3.8	11.1	11.1	14.6	22.2	14.1	5.4	4.4	4.3	4.4	2.2	100.0
<u>Upper Decile (UD)</u>													
Fort Peck	3.3	4.4	7.5	8.7	14.8	24.9	12.8	4.7	4.1	5.1	6.1	3.7	100.0
Garrison	2.3	3.0	7.8	9.7	13.1	24.7	19.4	6.0	4.1	4.6	3.5	1.9	100.0
Oahe	0.3	2.3	30.1	13.1	10.0	18.2	7.9	3.2	4.7	3.7	6.0	0.4	100.0
Fort Randall	0.0	4.0	20.7	29.3	15.3	10.3	5.3	4.7	6.7	2.7	0.0	1.0	100.0
Gavins Point	4.7	8.4	10.2	12.4	14.7	10.9	9.1	7.3	5.8	6.7	5.8	4.0	100.0
Sioux City	1.0	4.1	11.5	13.8	26.2	16.2	8.5	6.6	4.9	2.5	2.9	1.8	100.0
Basin Total	2.2	3.8	11.3	11.2	14.7	21.7	13.9	5.4	4.4	4.5	4.4	2.3	100.0
<u>98 Percentile (U2)</u>													
Fort Peck	3.3	4.4	7.5	8.8	14.8	24.9	12.7	4.6	4.1	5.1	6.1	3.7	100.0
Garrison	2.2	2.9	7.5	9.5	13.5	25.1	19.4	5.9	4.1	4.5	3.5	1.9	100.0
Oahe	0.4	1.9	30.0	13.0	9.9	18.1	8.2	3.1	4.6	3.6	6.3	0.8	100.0
Fort Randall	0.2	3.2	27.8	23.2	15.6	10.0	5.4	4.1	6.8	2.4	0.2	1.0	100.0
Gavins Point	4.5	7.6	14.0	11.1	13.1	10.9	9.5	7.6	6.0	6.9	5.3	3.5	100.0
Sioux City	2.5	3.9	10.6	17.1	23.5	13.3	8.0	6.6	5.2	4.5	3.3	1.5	100.0
Basin Total	2.4	3.6	12.1	11.4	14.7	21.1	13.6	5.3	4.5	4.6	4.5	2.2	100.0

I. DETERMINATION OF EXTENSION YEARS' RUNOFF

In addition to an analysis of the effects of various levels of runoff upon system functions during the coming year, the Annual Operating plan presents five-year extensions beyond the coming year to serve long-range planning purposes primarily to hydropower generation. Extensions are included for the upper decile, upper quartile, median, lower quartile and lower decile runoff levels. At this time, it has not been determined that running extensions for the 2 percentile and 98 percentile add significant value to the intended use of these extensions.

A) Distribution of Runoff for Extension Years by Reach

The median extension consists of a succession of five median years. However, if a similar procedure was used for the quartile and decile runoff levels, the probability of such a succession would be considerably more remote than the runoff description indicates. Therefore a procedure was used which accounts for the probability of successive years of low or high runoff. The procedure and resulting runoff volumes for the lower decile, lower quartile, upper quartile, and upper decile extension years are outlined below.

1. Running averages of annual runoff above Sioux City were computed for 2-, 3-, 4-, 5-, and 6-year periods.

2. The running averages were ranked and volume durations were plotted. The resulting durations are shown on Plates 8 through 12.

3. The 2-, 3-, 4-, 5- and 6-year average runoff volumes were determined from the durations for the lower decile (10%), lower quartile (25%), upper quartile (75%) and upper decile (90%) levels.

4. The actual runoff for the 2nd, 3rd, 4th, 5th, and 6th years were determined by working backward from the prior years' runoff. For example, the initial lower decile runoff volume was 16.1 MAF and the 2-year average for the lower decile condition was 16.6 MAF, so the 2nd year of a lower decile runoff period was calculated to be $[(2 * 16.6) - 16.1] = 17.1$ MAF. The running averages were adjusted slightly to avoid having the runoff in the 2nd through 6th years vary greatly and to provide a smooth transition back toward normal runoff levels. The resultant annual runoff volumes for the 5-year extension period for the lower decile and lower quartile runoff levels are shown in Table 6. The resultant annual runoff volumes for the 5-year extension period for the upper quartile and upper decile runoff levels are shown in Table 7.

Table 6
Annual Runoff Volumes for Extension Years, LD and LQ

Lower Decile			
Number of years (n)	n-year Average Flow (MAF)	Year	Runoff (MAF)
1	16.1	Initial	16.1
2	16.6	1st extension	17.1
3	16.9	2nd extension	17.5
4	17.3	3rd extension	18.5
5	17.7	4th extension	19.3
6	18.0	5th extension	19.5
Lower Quartile			
Number of years (n)	n-year Average Flow (MAF)	Year	Runoff (MAF)
1	19.3	Initial	19.3
2	19.6	1st extension	19.9
3	19.8	2nd extension	20.2
4	20.3	3rd extension	21.8
5	20.8	4th extension	22.8
6	21.4	5th extension	24.4

Table 7
Annual Runoff Volumes for Extension Years, UQ and UD

Upper Quartile			
Number of years (n)	n-year Average Flow (MAF)	Year	Runoff (MAF)
1	30.6	Initial	30.6
2	29.3	1st extension	28.0
3	28.8	2nd extension	27.8
4	28.5	3rd extension	27.6
5	28.3	4th extension	27.5
6	28.1	5th extension	27.1
Upper Decile			
Number of years (n)	n-year Average Flow (MAF)	Year	Runoff (MAF)
1	34.5	Initial	34.5
2	32.4	1st extension	30.3
3	31.2	2nd extension	28.8
4	30.5	3rd extension	28.4
5	30.0	4th extension	28.0
6	29.6	5th extension	27.6

B) Distribution of Runoff for Extension Years by Month

As with the initial year's runoff, it was necessary to distribute the extension years' runoff by reach and by month. The areal distribution of runoff for the extension years was based on the areal distribution of the initial year. Since the total basin runoff for the extension years varies widely, for example from 19.3 MAF to 24.4 MAF for the lower quartile runoff condition, it was not appropriate to use the initial year's reach distribution percentages directly. Rather, a straight-line interpolation between the reach runoff percentages used. In the case of the lower quartile example, the straight line interpolation was between the lower quartile and median reach runoff percentages. The reach runoffs (in 1000 acre-feet) are shown in Table 8 for the lower decile and lower quartile runoffs. The reach runoffs (in 1000 acre-feet) are shown in Table 9 for the upper quartile and upper decile runoffs.

Table 8
Annual Incremental Reach Runoff Volumes
for Extension Years, LD and LQ
1000 Acre-Feet

Lower Decile					
Reach	1st Year	2nd Year	3rd Year	4th Year	5th Year
Fort Peck	5517	5601	5800	5950	6000
Garrison	7937	8154	8704	9150	9222
Oahe	1214	1239	1301	1350	1381
Fort Randall	380	393	424	450	465
Gavins Point	1236	1249	1279	1300	1309
Sioux City	816	864	992	1100	1123
Total	17100	17500	18500	19300	19500
Lower Quartile					
Reach	1st Year	2nd Year	3rd Year	4th Year	5th Year
Fort Peck	6100	6174	6560	6794	7156
Garrison	9365	9470	10016	10343	10840
Oahe	1445	1494	1767	1949	2260
Fort Randall	494	516	645	731	880
Gavins Point	1326	1339	1403	1440	1494
Sioux City	1170	1207	1409	1543	1770
Total	19900	20200	21800	22800	24400

Table 9
Annual Incremental Reach Runoff Volumes
for Extension Years, UQ and UD
1000e-Feet

Upper Quartile					
Reach	1st Year	2nd Year	3rd Year	4th Year	5th Year
Fort Peck	8036	7988	7940	7916	7819
Garrison	11987	11926	11865	11834	11709
Oahe	2794	2764	2733	2718	2659
Fort Randall	1066	1056	1046	1041	1021
Gavins Point	1777	1760	1743	1735	1702
Sioux City	2340	2306	2273	2256	2190
Total	28000	27800	27600	27500	27100
Upper Decile					
Reach	1st Year	2nd Year	3rd Year	4th Year	5th Year
Fort Peck	8580	8228	8132	8036	7940
Garrison	12665	12228	12108	11987	11865
Oahe	3152	2916	2855	2794	2733
Fort Randall	1184	1107	1086	1066	1046
Gavins Point	1974	1844	1811	1777	1743
Sioux City	2745	2477	2408	2340	2273
Total	30300	28800	28400	28000	27600

The monthly distributions of runoff developed for the initial year were used to distribute the reach runoff for the extension years. The LD distribution was used for the five lower decile extension years, the LQ distribution was used for the five lower quartile extension years, the UQ distribution was used for the five upper quartile years, and the UD distribution was used for the upper decile years. The resulting monthly flows for each of the lower decile extension years are shown in Table 10. Table 11 shows the monthly flows for the lower quartile extension years. Table 12 shows the monthly flows for the upper quartile extension years and Table 13 shows the monthly flows for the upper decile extension years.

Table 10
Lower Decile
Extension Years
Monthly Reach Runoff Volumes
1000 Acre-Feet

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
<u>1st Extension Year</u>													
Fort Peck	239	307	417	458	885	1228	619	271	240	323	302	229	5518
Garrison	209	290	847	622	1180	2322	1003	349	230	413	322	150	7937
Oahe	-21	42	369	211	116	322	111	42	47	5	16	-47	1213
Fort Randall	-27	38	152	92	54	103	27	16	-5	-27	-21	-22	380
Gavins Point	72	103	170	124	134	139	82	62	77	103	98	72	1236
Sioux City	17	23	210	105	140	76	82	46	35	35	41	6	816
Total	489	803	2165	1612	2509	4190	1924	786	624	852	758	388	17100
<u>2nd Extension Year</u>													
Fort Peck	243	312	423	465	898	1247	629	275	243	328	306	232	5601
Garrison	215	298	871	639	1212	2386	1030	358	236	424	331	154	8154
Oahe	-22	43	377	215	118	329	113	44	49	5	16	-48	1239
Fort Randall	-28	39	157	95	56	107	28	17	-6	-28	-22	-22	393
Gavins Point	73	104	172	125	135	141	83	62	78	104	99	73	1249
Sioux City	19	25	222	111	148	80	86	49	38	37	43	6	864
Total	500	821	2222	1650	2567	4290	1969	805	638	870	773	395	17500
<u>3rd Extension Year</u>													
Fort Peck	252	323	438	482	930	1291	651	285	251	339	317	241	5800
Garrison	229	318	929	682	1294	2546	1100	382	253	453	353	165	8704
Oahe	-23	45	396	226	124	345	119	45	52	6	17	-51	1301
Fort Randall	-30	42	170	103	61	115	30	18	-7	-30	-24	-24	424
Gavins Point	75	107	176	128	139	144	85	64	80	106	100	75	1279
Sioux City	21	28	255	128	170	92	99	57	42	43	50	7	992
Total	524	863	2364	1749	2718	4533	2084	851	671	917	813	413	18500
<u>4th Extension Year</u>													
Fort Peck	258	331	449	494	954	1325	668	292	258	348	326	247	5950
Garrison	241	334	977	717	1360	2677	1156	402	266	476	371	173	9150
Oahe	-23	47	411	235	129	358	123	47	52	6	18	-53	1350
Fort Randall	-32	45	180	109	64	122	32	19	-6	-31	-26	-26	450
Gavins Point	76	108	179	130	141	146	87	65	81	108	103	76	1300
Sioux City	24	31	283	141	189	102	110	63	55	39	55	8	1100
Total	544	896	2479	1826	2837	4730	2176	888	706	946	847	425	19300
<u>5th Extension Year</u>													
Fort Peck	260	334	453	498	962	1336	674	294	260	352	328	249	6000
Garrison	243	336	985	723	1371	2698	1165	405	268	480	374	174	9222
Oahe	-24	48	420	240	132	366	126	48	55	6	18	-54	1381
Fort Randall	-33	46	186	113	66	126	33	20	-6	-32	-27	-27	465
Gavins Point	76	109	180	131	142	147	87	65	82	109	105	76	1309
Sioux City	24	32	289	144	193	104	112	64	49	48	56	8	1123
Total	546	905	2513	1849	2866	4777	2197	896	708	963	854	426	19500

Table 11
Lower Quartile
Extension Years
Monthly Reach Runoff Volumes
1000 Acre-Feet

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
<u>1st Extension Year</u>													
Fort Peck	246	318	425	472	969	1548	661	297	246	329	343	246	6100
Garrison	215	287	855	655	1177	2661	1740	486	403	404	328	154	9365
Oahe	-16	54	391	305	139	337	118	54	58	15	27	-37	1445
Fort Randall	-22	44	176	88	71	121	38	27	0	-22	-16	-11	494
Gavins Point	77	107	194	128	143	153	87	71	81	106	102	77	1326
Sioux City	21	53	266	154	197	122	106	85	70	37	48	11	1170
Total	521	863	2307	1802	2696	4942	2750	1020	858	869	832	440	19900
<u>2nd Extension Year</u>													
Fort Peck	249	322	431	477	981	1567	669	301	249	331	348	249	6174
Garrison	217	290	864	662	1190	2691	1760	492	409	409	331	155	9470
Oahe	-17	55	404	315	144	349	122	55	61	17	28	-39	1494
Fort Randall	-23	46	184	92	75	126	40	29	0	-24	-17	-11	517
Gavins Point	77	108	196	129	144	154	88	72	82	108	103	77	1338
Sioux City	22	55	274	159	203	126	110	88	71	39	49	11	1207
Total	525	876	2353	1834	2737	5013	2789	1037	872	880	842	442	20200
<u>3rd Extension Year</u>													
Fort Peck	265	342	458	507	1042	1665	711	320	264	353	368	265	6560
Garrison	230	307	914	701	1259	2846	1861	520	432	432	350	164	10016
Oahe	-20	65	478	373	170	412	144	65	72	21	33	-46	1767
Fort Randall	-29	57	229	115	93	158	50	36	0	-29	-21	-14	645
Gavins Point	81	113	205	135	151	162	92	76	86	113	108	81	1403
Sioux City	26	64	320	186	237	147	128	102	83	45	58	13	1409
Total	553	948	2604	2017	2952	5390	2986	1119	937	935	896	463	21800
<u>4th Extension Year</u>													
Fort Peck	274	354	474	525	1079	1724	736	331	275	365	383	274	6794
Garrison	237	316	944	723	1300	2939	1922	537	447	446	362	170	10343
Oahe	-22	72	527	412	188	455	159	72	79	22	36	-51	1949
Fort Randall	-33	65	260	130	106	179	57	41	-1	-33	-24	-16	731
Gavins Point	83	116	210	138	155	166	94	78	89	117	111	83	1440
Sioux City	28	70	351	203	260	161	140	112	91	50	63	14	1543
Total	567	993	2766	2131	3088	5624	3108	1171	980	967	931	474	22800
<u>5th Extension Year</u>													
Fort Peck	289	373	499	553	1137	1816	776	349	289	384	402	289	7156
Garrison	249	332	989	758	1362	3080	2014	563	468	468	379	178	10840
Oahe	-25	84	611	477	218	527	184	84	92	25	42	-59	2260
Fort Randall	-39	78	313	157	127	215	68	49	0	-39	-29	-20	880
Gavins Point	86	121	218	144	161	172	98	80	92	121	115	86	1494
Sioux City	32	80	402	233	298	185	161	129	105	57	72	16	1770
Total	592	1068	3032	2322	3303	5995	3301	1254	1046	1016	981	490	24400

Table 12
Upper Quartile
Extension Years
Monthly Reach Runoff Volumes
1000 Acre-Feet

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
<u>1st Extension Year</u>													
Fort Peck	265	358	595	701	1194	2002	1027	376	325	408	488	297	8036
Garrison	277	357	935	1156	1575	3009	2327	715	489	522	404	221	11987
Oahe	0	70	825	375	271	559	218	83	131	105	166	-9	2794
Fort Randall	-4	44	227	311	164	124	67	58	66	9	-4	4	1066
Gavins Point	84	147	195	213	258	187	160	129	102	120	106	76	1777
Sioux City	25	96	284	326	610	363	201	150	113	58	72	42	2340
Total	647	1072	3061	3082	4072	6244	4000	1511	1226	1222	1232	631	28000
<u>2nd Extension Year</u>													
Fort Peck	263	356	591	697	1187	1990	1020	374	323	406	485	296	7988
Garrison	276	355	931	1151	1567	2993	2315	711	486	519	402	220	11926
Oahe	0	69	816	371	268	553	216	82	130	104	164	-9	2764
Fort Randall	-4	44	224	308	163	123	66	57	66	9	-4	4	1056
Gavins Point	84	145	194	211	255	185	158	128	100	119	106	75	1760
Sioux City	25	95	280	321	601	358	198	148	111	58	70	41	2306
Total	644	1064	3036	3059	4041	6202	3973	1500	1216	1215	1223	627	27800
<u>3rd Extension Year</u>													
Fort Peck	262	353	587	693	1180	1978	1014	372	321	404	482	294	7940
Garrison	275	354	926	1145	1559	2978	2303	707	484	515	400	219	11865
Oahe	0	68	807	367	265	547	214	81	128	103	162	-9	2733
Fort Randall	-4	44	222	305	161	122	65	57	65	9	-4	4	1046
Gavins Point	83	144	192	209	253	183	157	126	100	117	105	74	1743
Sioux City	24	93	276	317	592	353	195	146	110	57	69	41	2273
Total	640	1056	3010	3036	4010	6161	3948	1489	1208	1205	1214	623	27600
<u>4th Extension Year</u>													
Fort Peck	261	352	586	691	1176	1972	1011	371	320	403	480	293	7916
Garrison	274	353	923	1142	1555	2970	2297	705	483	515	399	218	11834
Oahe	0	68	803	365	263	544	212	81	127	102	161	-8	2718
Fort Randall	-4	43	221	304	160	121	65	56	66	9	-4	4	1041
Gavins Point	82	143	191	208	252	182	156	126	100	117	104	74	1735
Sioux City	24	93	274	314	588	350	193	145	109	57	69	40	2256
Total	637	1052	2998	3024	3994	6139	3934	1484	1205	1203	1209	621	27500
<u>5th Extension Year</u>													
Fort Peck	258	348	578	682	1162	1948	999	366	316	398	475	289	7819
Garrison	271	349	914	1130	1538	2939	2273	698	477	509	395	216	11709
Oahe	0	66	785	357	258	532	208	79	124	100	158	-8	2659
Fort Randall	-4	43	217	298	157	119	64	54	64	9	-4	4	1021
Gavins Point	81	140	187	204	247	179	153	123	99	115	102	72	1702
Sioux City	23	90	266	305	571	340	188	141	106	55	66	39	2190
Total	629	1036	2947	2976	3933	6057	3885	1461	1186	1186	1192	612	27100

Table 13
Upper Decile
Extension Years
Monthly Reach Runoff
Volumes
1000 Acre-Feet

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
<u>1st Extension Year</u>													
Fort Peck	281	381	640	749	1271	2138	1094	400	350	436	522	318	8580
Garrison	296	360	1150	906	1511	3625	2440	674	558	518	418	209	12665
Oahe	8	73	950	412	315	574	251	101	150	116	190	12	3152
Fort Randall	0	47	245	347	182	122	63	55	79	32	0	12	1184
Gavins Point	92	167	202	246	289	215	180	145	114	131	114	79	1974
Sioux City	28	113	315	379	718	444	234	182	133	70	81	48	2745
Total	705	1141	3502	3039	4286	7118	4262	1557	1384	1303	1325	678	30300
<u>2nd Extension Year</u>													
Fort Peck	270	366	614	718	1219	2050	1049	383	335	418	501	305	8228
Garrison	286	348	1111	875	1458	3500	2356	651	538	499	404	202	12228
Oahe	7	67	879	381	292	531	232	93	138	109	176	11	2916
Fort Randall	0	44	229	325	170	114	59	52	73	30	0	11	1107
Gavins Point	86	156	189	230	271	201	168	135	106	122	106	74	1844
Sioux City	25	102	284	342	648	401	211	164	120	63	73	44	2477
Total	674	1083	3306	2871	4058	6797	4075	1478	1310	1241	1260	647	28800
<u>3rd Extension Year</u>													
Fort Peck	267	361	607	710	1205	2027	1037	379	331	412	495	301	8132
Garrison	283	344	1100	866	1444	3466	2333	644	533	495	400	200	12108
Oahe	7	66	860	373	285	520	227	91	136	107	172	11	2855
Fort Randall	0	43	225	319	167	112	58	51	71	29	0	11	1086
Gavins Point	84	153	185	225	266	197	165	133	105	121	105	72	1811
Sioux City	25	99	255	389	687	297	205	160	117	60	72	42	2408
Total	666	1066	3232	2882	4054	6619	4025	1458	1293	1224	1244	637	28400
<u>4th Extension Year</u>													
Fort Peck	264	357	600	702	1191	2003	1025	374	326	407	489	298	8036
Garrison	280	341	1089	858	1430	3431	2309	638	528	489	396	198	11987
Oahe	7	64	842	365	279	509	222	90	133	104	168	11	2794
Fort Randall	0	43	220	313	163	110	57	50	71	28	0	11	1066
Gavins Point	83	150	182	221	261	193	162	130	103	118	103	71	1777
Sioux City	24	96	268	323	612	378	200	155	115	59	69	41	2340
Total	658	1051	3201	2782	3936	6624	3975	1437	1276	1205	1225	630	28000
<u>5th Extension Year</u>													
Fort Peck	260	353	592	693	1176	1979	1012	371	324	403	483	294	7940
Garrison	278	337	1078	849	1415	3396	2286	631	522	485	392	196	11865
Oahe	7	63	824	357	273	498	217	88	129	101	165	11	2733
Fort Randall	0	42	216	307	160	108	56	49	70	28	0	10	1046
Gavins Point	81	147	178	217	256	190	159	127	101	116	101	70	1743
Sioux City	23	94	261	314	595	368	194	150	110	57	67	40	2273
Total	649	1036	3149	2737	3875	6539	3924	1416	1256	1190	1208	621	27600

Missouri River above Sioux City Annual Runoff, 1898 - 2011

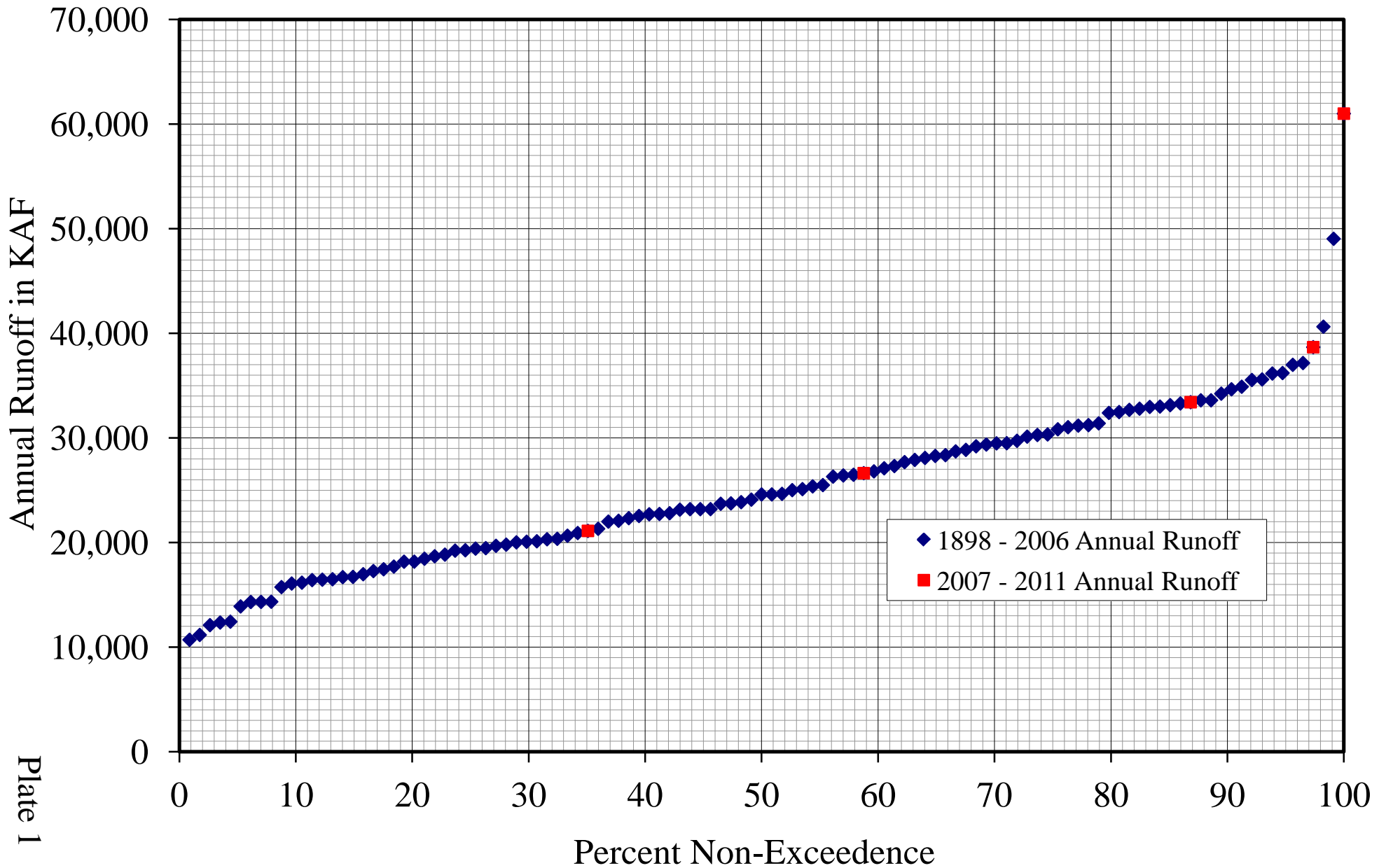
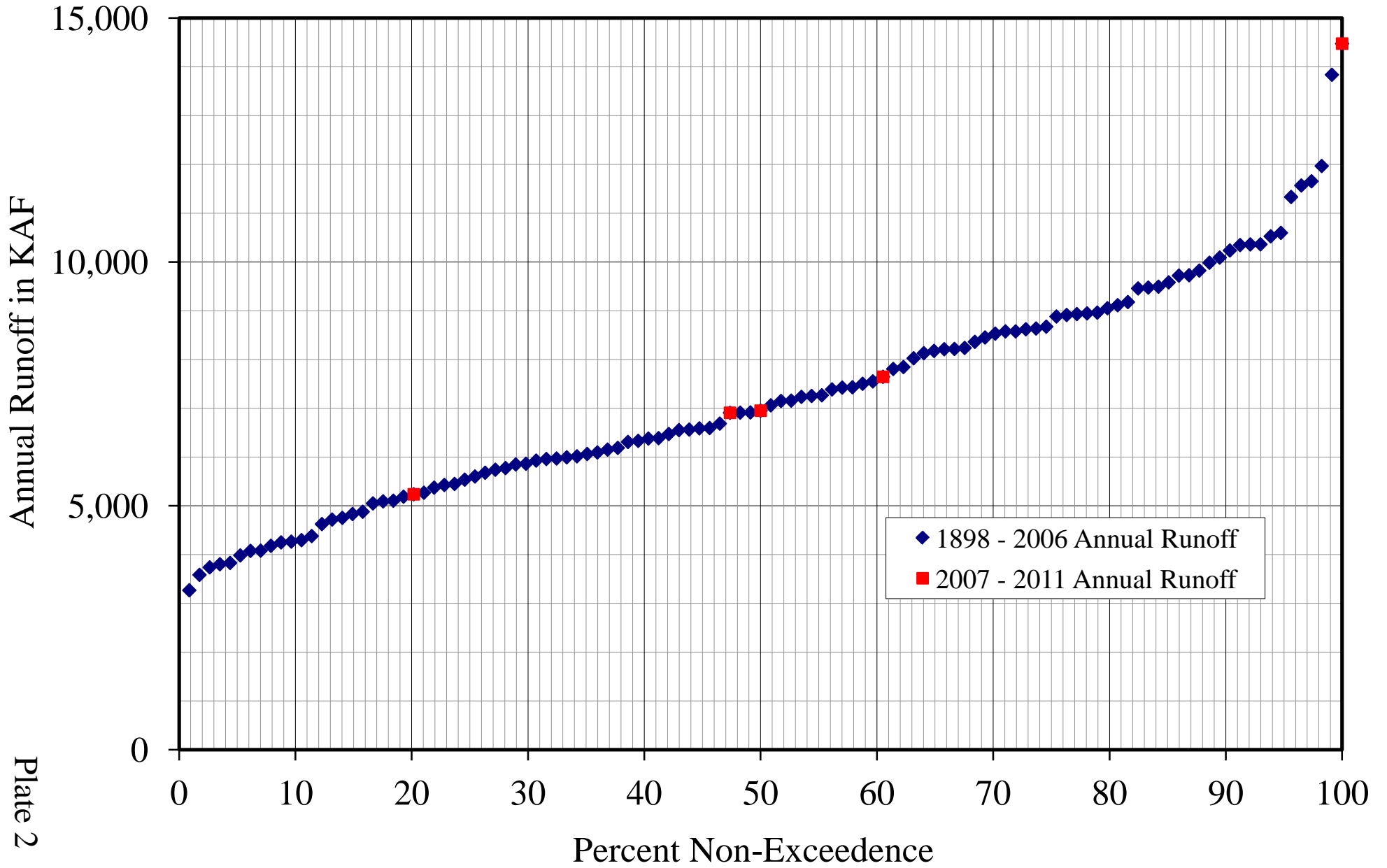
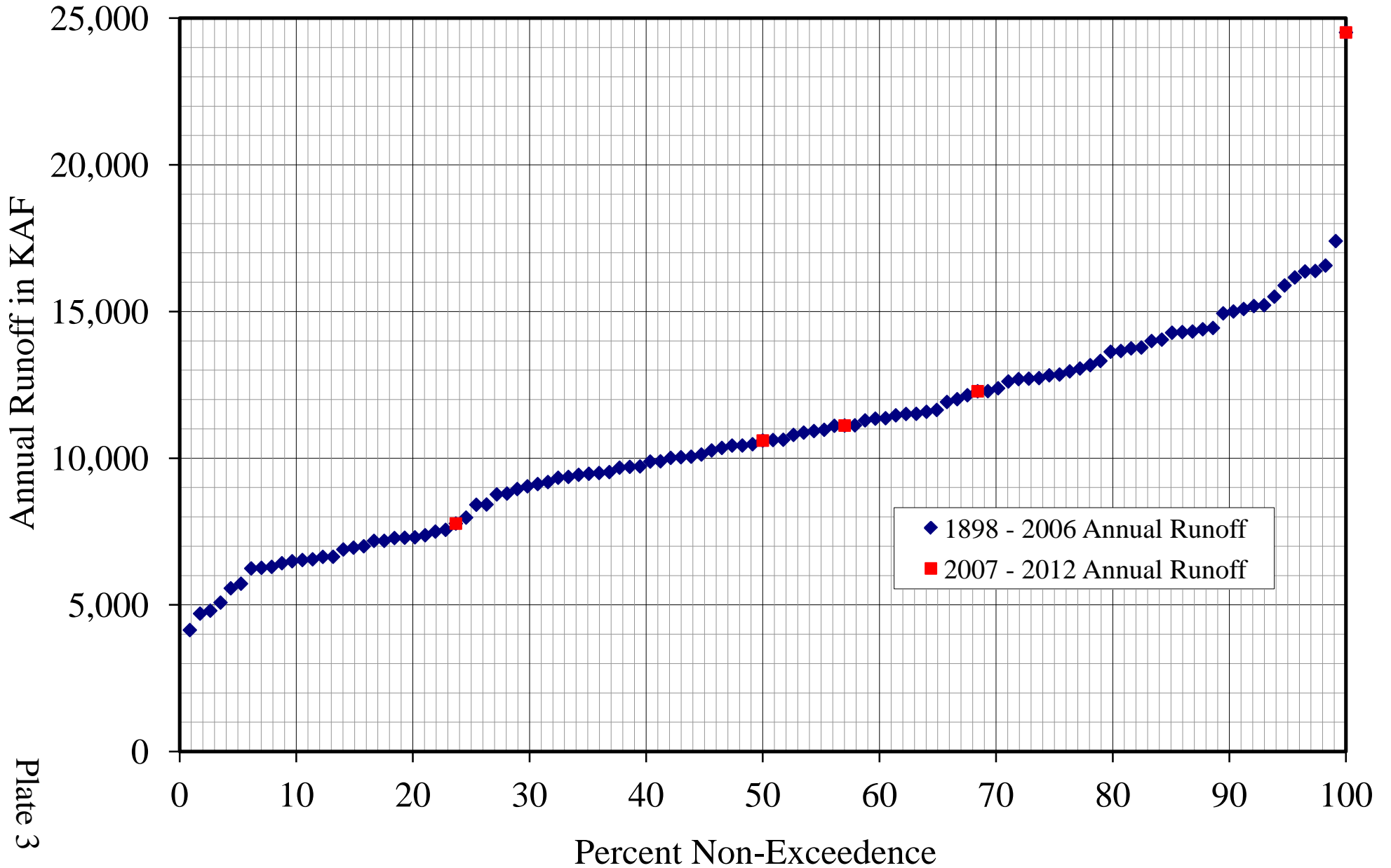


Plate 1

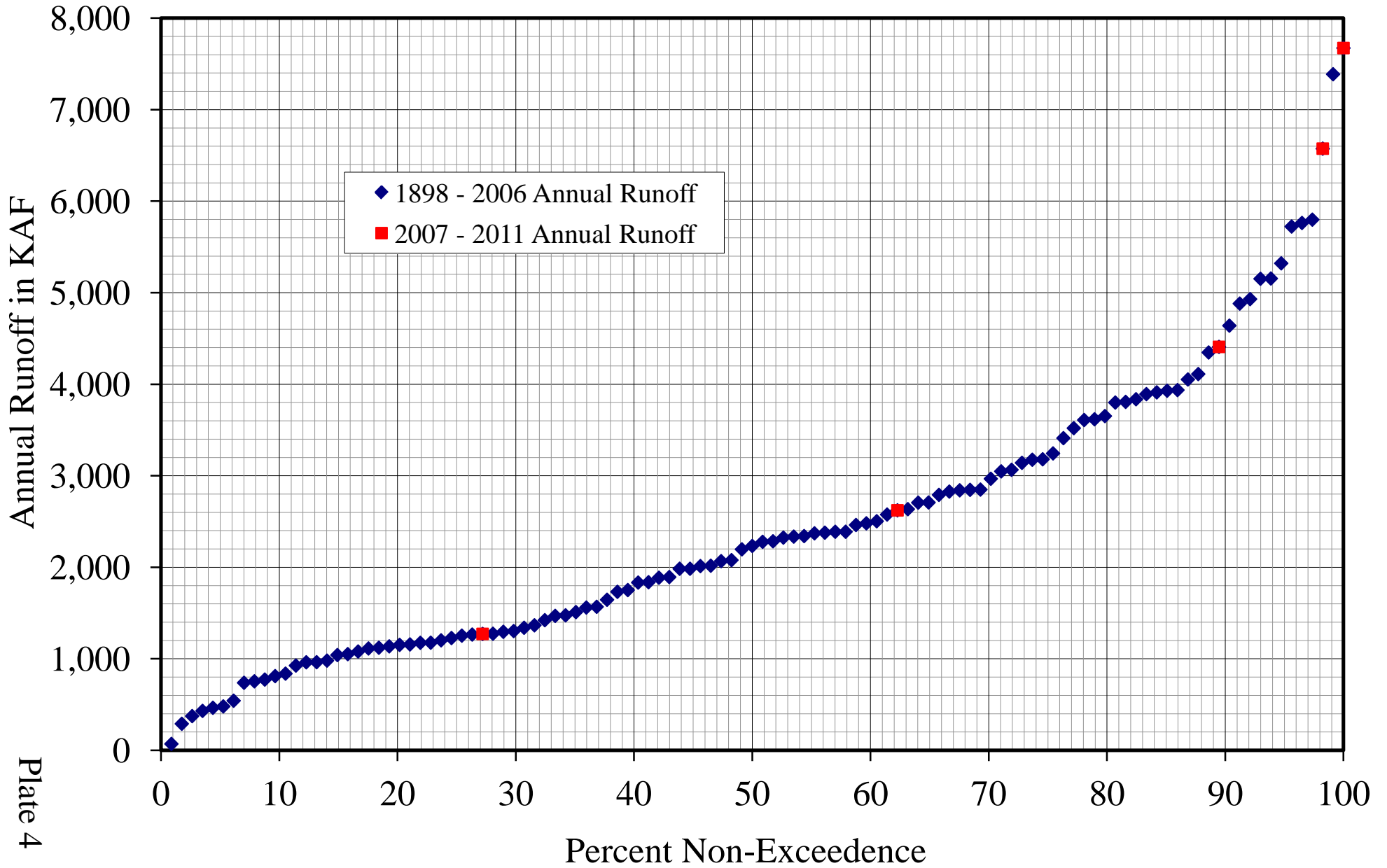
Missouri River above Fort Peck Annual Runoff, 1898 - 2011



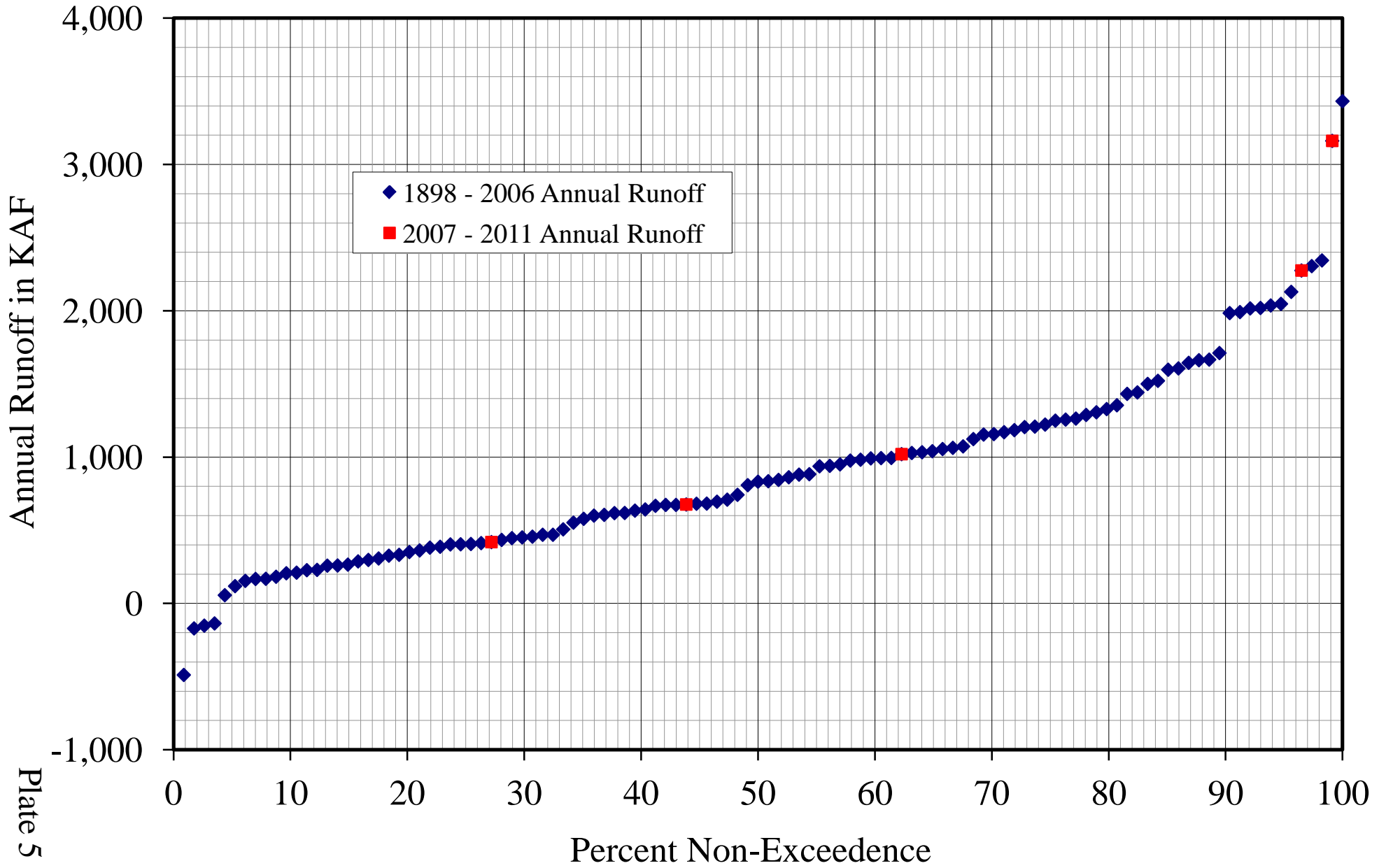
Fort Peck to Garrison Annual Runoff, 1898 - 2011



Garrison to Oahe Annual Runoff, 1898 - 2011



Oahe to Fort Randall Annual Runoff, 1898 - 2011



Fort Randall to Gavins Point Annual Runoff, 1898 - 2011

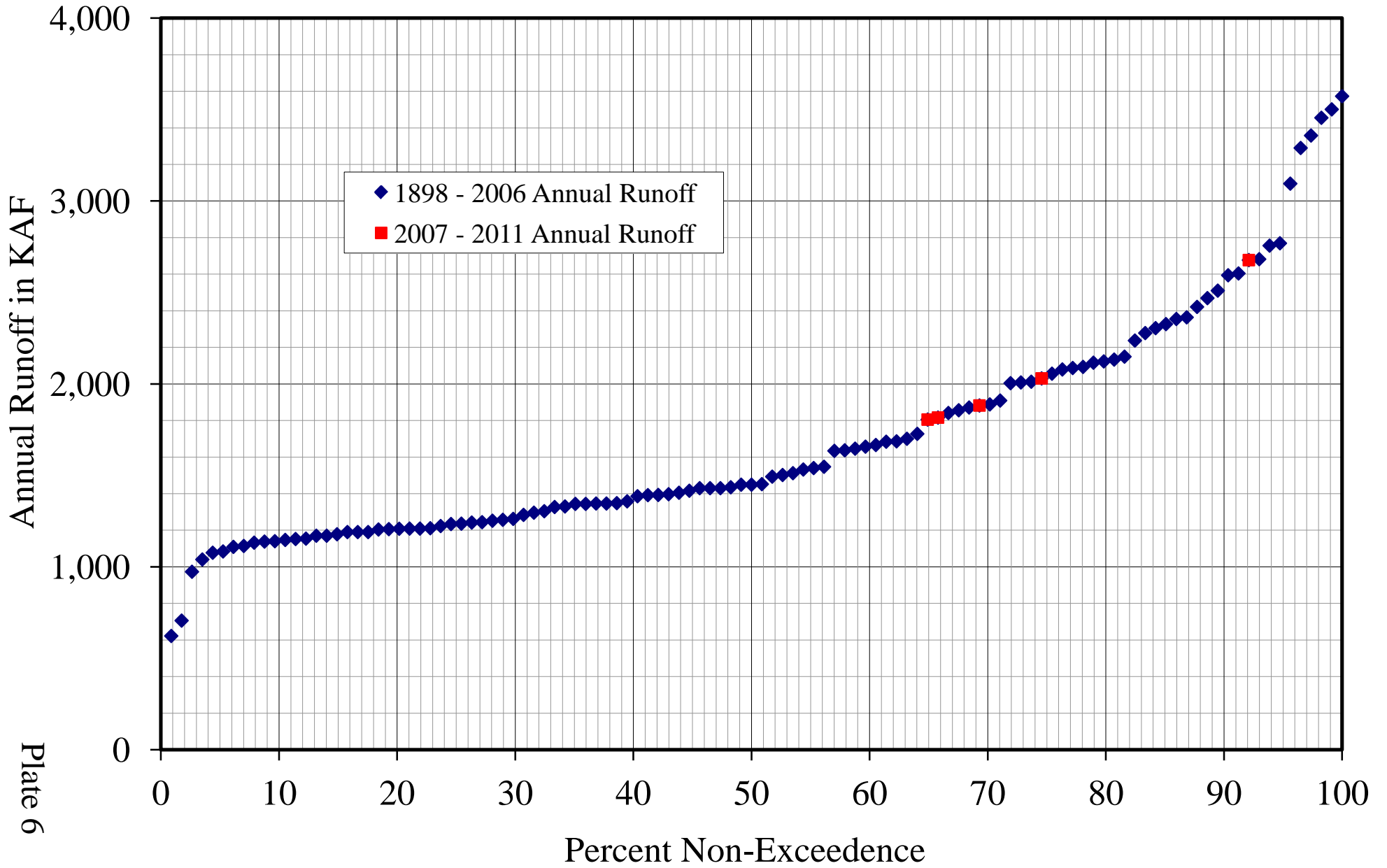


Plate 6

Gavins Point to Sioux City Annual Runoff, 1898 - 2011

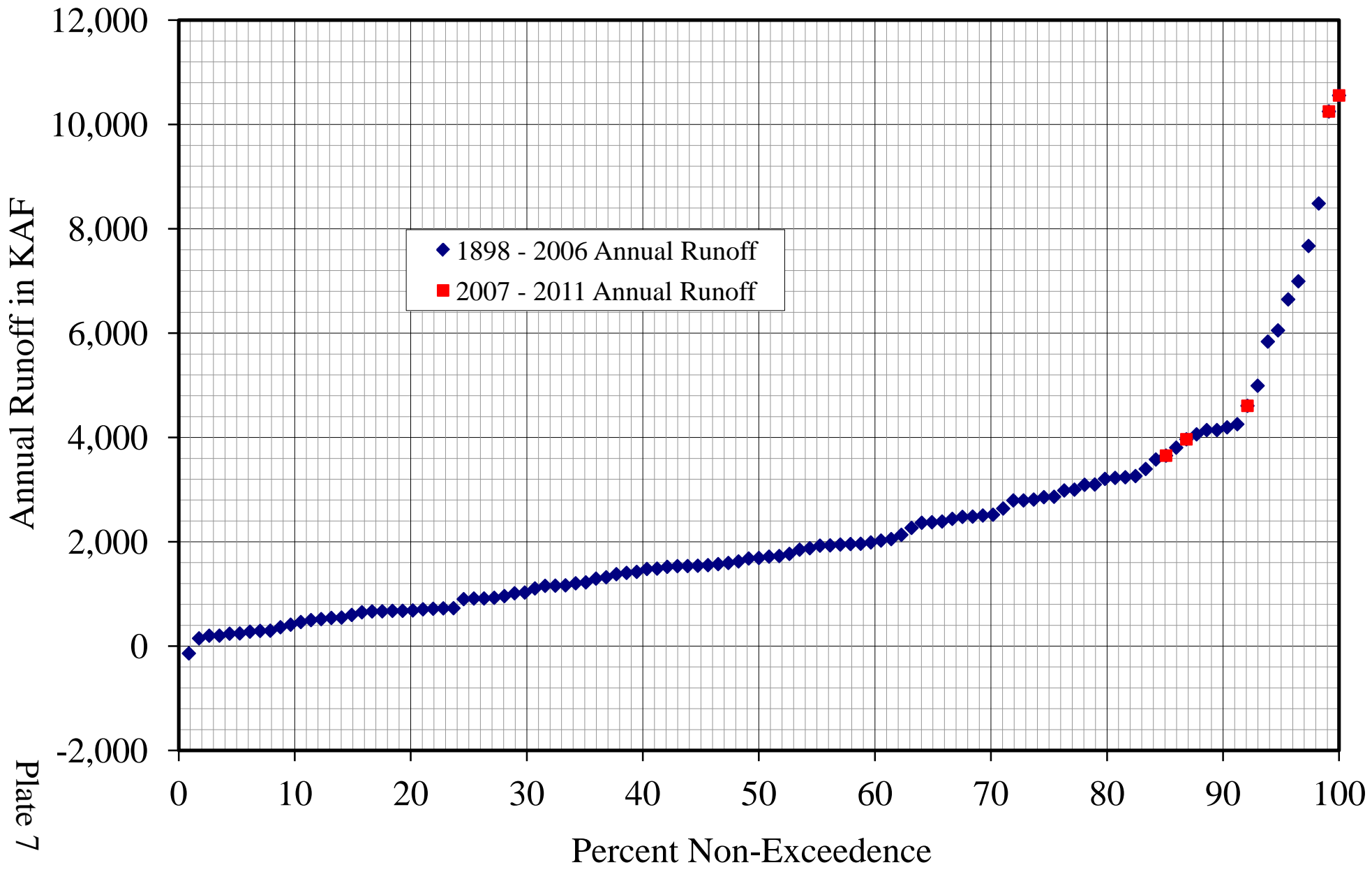
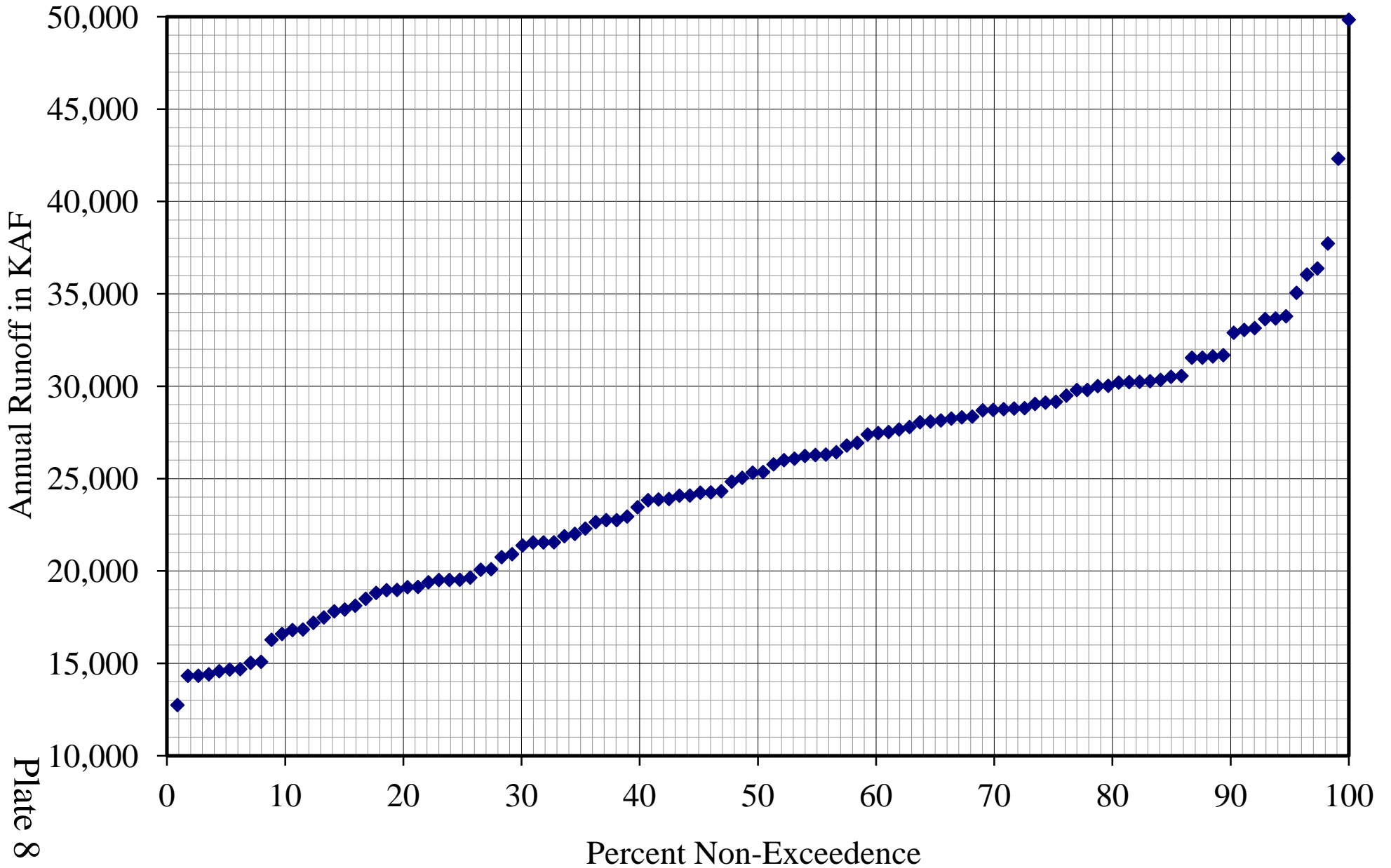


Plate 7

Missouri River above Sioux City

2-Year Average - Annual Runoff, 1898 - 2011



Missouri River above Sioux City

3-Year Average - Annual Runoff, 1898 - 2011

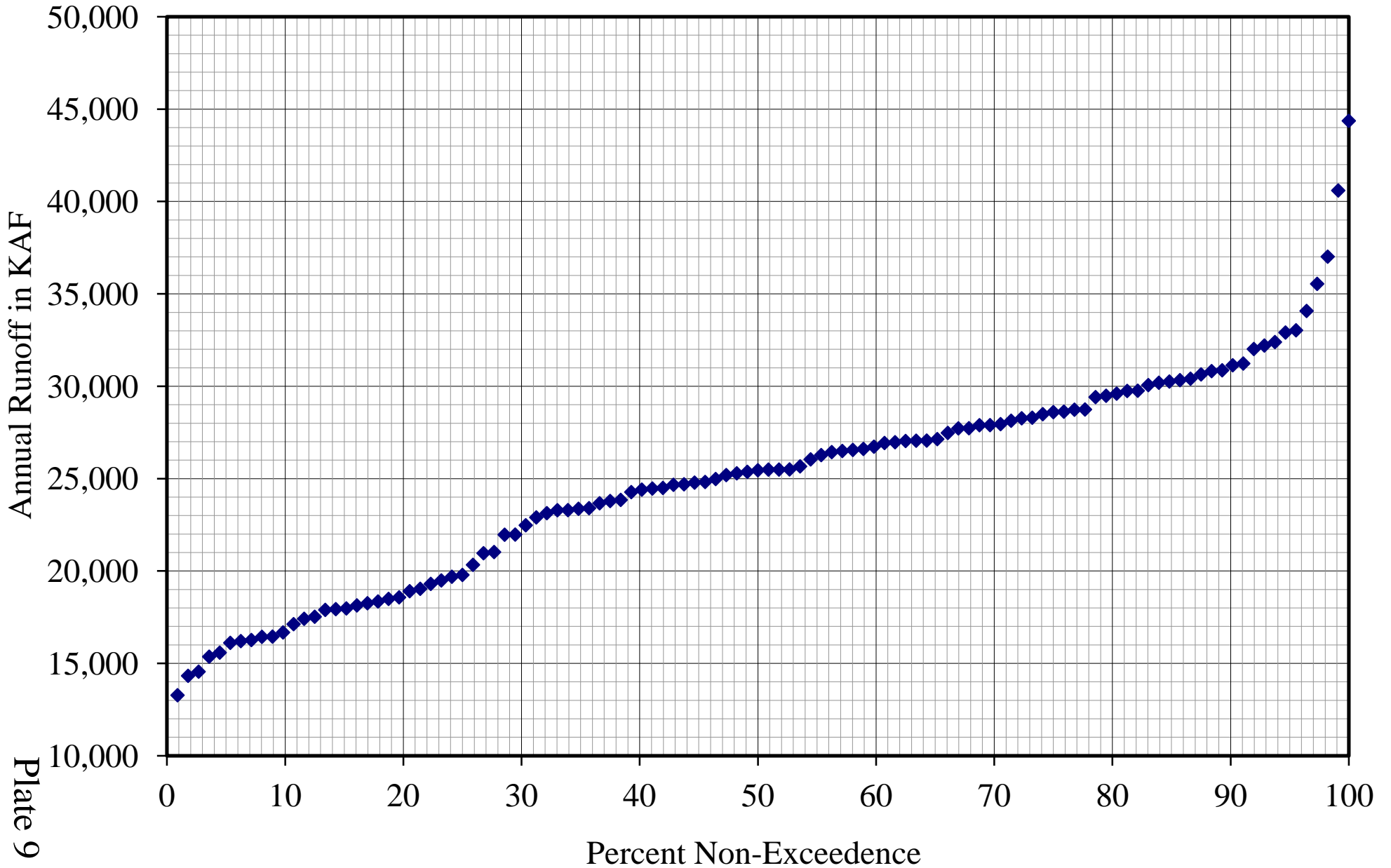
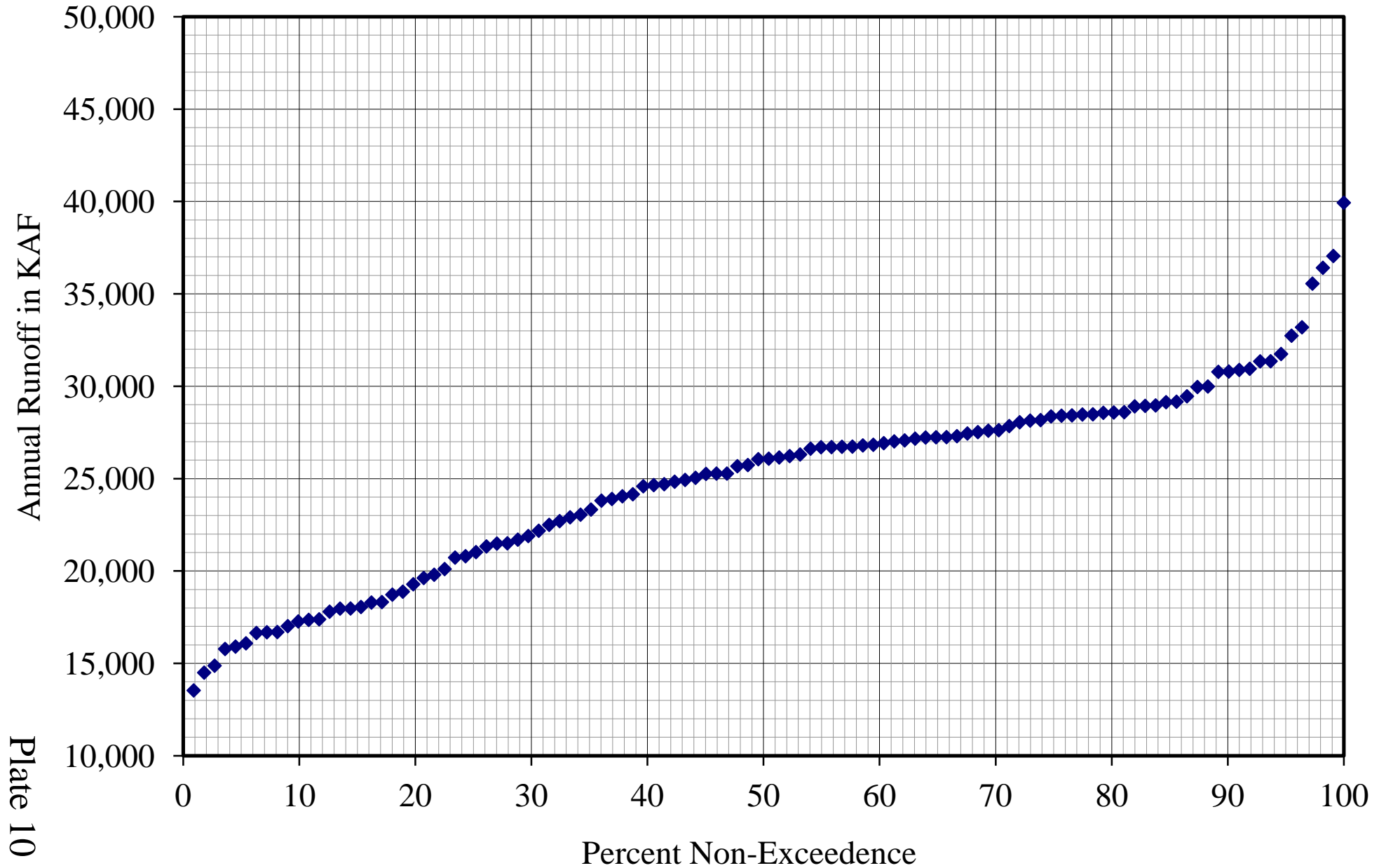


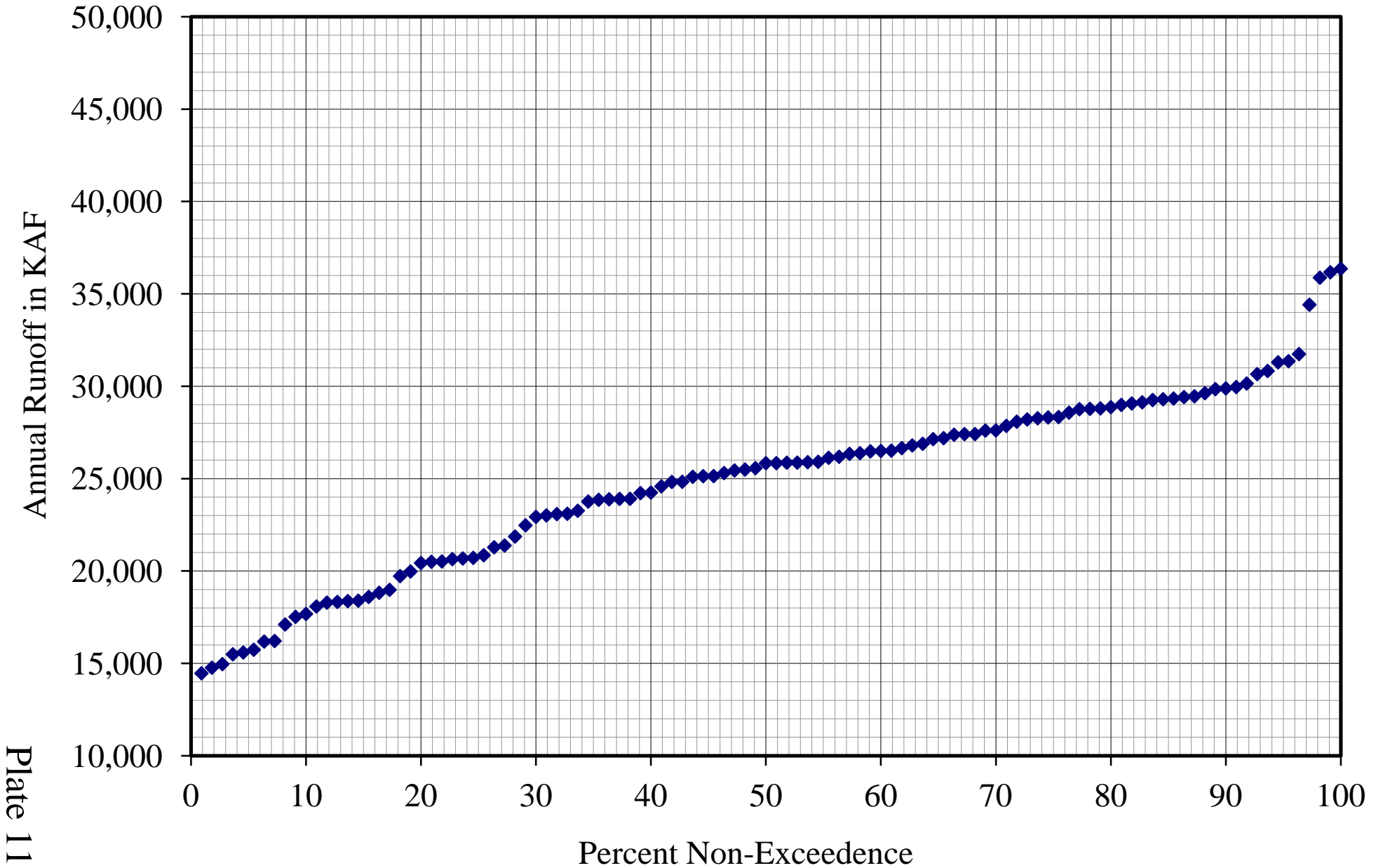
Plate 9

Missouri River above Sioux City 4-Year Average - Annual Runoff, 1898 - 2011



Missouri River above Sioux City

5-Year Average - Annual Runoff, 1898 - 2011



Missouri River above Sioux City 6-Year Average - Annual Runoff, 1898 - 2011

