5.2 MAINSTEM RESERVOIR SYSTEM HYDROLOGY

This section of Chapter 5 will focus on the hydrologic variation that would result from the operation of the Mainstem Reservoir System under the CWCP and the alternatives submitted for Corps consideration. Total storage, individual lake elevations, and river flows in all of the reaches will vary among the alternatives because they feature a variety of drought conservation and service flows.

5.2.1 Mainstem Reservoir System Storage and Lake Elevations

In the hydrologic modeling process, lake levels and total system storage stand out as two hydrologic features that those whose livelihoods and responsibilities are associated with one or more of the mainstem lakes are most interested in.

Table 5.2-1 displays the minimum system storage levels and minimum lake levels for the upper three lakes for the CWCP and the alternatives. Minimum levels are presented for each of the three major droughts experienced during the 100-year period of record as well as for the period of actual historic operation from 1967 to 1997. The system storage represents the minimum daily total of the combined contents of the six mainstem lakes during each drought period: the 1930 to 1941 drought, the 1954 to 1961 drought, and the 1987 to 1993 drought. Minimum daily lake levels for the upper three lakes (Fort Peck Lake, Lake Sakakawea, and Lake Oahe) during each drought period are also presented. Minimum lake elevations for the other three mainstem lakes (Lake Sharpe, Lake Francis Case, and Lewis and Clark Lake) are not provided. These lakes are much smaller than the upper three, representing only 12 percent of the total storage, and therefore, their operation and lake levels do not vary significantly with the different alternatives.

Table 5.2-1. Minimum system storage (MAF) and lake levels for the upper three lakes (feet).

	System Storage		Fort Peck Lake		Lake Sakakawea		Lake Oahe	
Alternative	**Date**	**Level**	**Date**	**Level**	**Date**	**Level**	**Date**	**Level**
1930-1942 Drought								
CWCP	Sep-41	18.7	Jun-41	2157	Feb-37	1773	May-41	1537
MLDDA	Feb-38	20.1	Feb-38	2162	Mar-38	1775	Feb-38	1540
MRBA	Feb-40	27.2	Mar-40	2181	Mar-40	1793	Feb-40	1559
ARNRC	Feb-35	30.6	Mar-35	2190	Mar-35	1800	Feb-35	1566
MODC	Feb-41	29.0	Mar-41	2182	Jan-41	1795	Jul-39	1563
BIOP	Feb-41	25.8	Mar-40	2178	Mar-40	1790	Feb-40	1557
FWS30	Mar-35	27.3	Mar-37	2181	Mar-35	1793	Mar-35	1560
1954-1962 Drought								
CWCP	Dec-61	40.1	Mar-62	2206	Feb-62	1813	Aug-61	1586
MLDDA	Dec-61	39.8	Mar-62	2206	Feb-62	1812	Aug-61	1586
MRBA	Dec-61	42.1	Mar-62	2209	Feb-62	1817	Aug-55	1586
ARNRC	Dec-61	46.3	Jan-62	2207	May-57	1824	Sep-55	1591
MODC	Dec-61	43.4	Mar-62	2211	Feb-62	1818	Oct-55	1578
BIOP	Dec-61	44.6	Aug-61	2212	Mar-62	1821	Aug-58	1589
FWS30	Dec-61	44.4	Aug-61	2212	Mar-62	1820	Aug-55	1588
1987-1993 Drought								
CWCP	Jan-93	40.2	Apr-91	2206	Mar-93	1813	Aug-90	1585
MLDDA	Jan-93	39.1	Mar-93	2204	Mar-93	1812	Aug-90	1583
MRBA	Jan-93	42.7	Mar-93	2209	Feb-91	1818	Aug-90	1586
ARNRC	Jan-91	45.5	Feb-93	2200	Mar-91	1822	Dec-91	1595
MODC	Jan-93	43.2	Mar-93	2210	Feb-91	1818	Aug-90	1587
BIOP	Jan-93	43.3	Mar-93	2206	Mar-93	1819	Aug-92	1590
FWS30	Jan-93	43.1	Mar-93	2206	Mar-93	1818	Aug-92	1589
Historic Minimums								
1967-1997	Jan-91	40.8	Apr-91	2209	May-91	1815	Nov-89	1581

For all alternatives except the Missouri Levee and Drainage District Association (MLDDA) alternative, minimum storage levels modeled during the three droughts are higher than those modeled under the CWCP. Indeed, one of the primary objectives of the MRBA, ARNRC, BIOP, and FWS30 alternatives was to limit drawdown in the upper three lakes during times of drought.

The MRBA alternative resulted in a minimum storage of 27.2 MAF during the 1930 to 1941 drought. The basic objectives of this alternative were to limit the minimum storage in the 1987 to 1993 drought to about 43 MAF and to limit the minimum storage to about 28 MAF in the 1930 to 1941 drought. The primary way the MRBA alternative achieves this higher storage is through reduced service to navigation (typically a 7.1-month season and 3-kcfs reduction in navigation flow support during drought years). The MODC, BIOP, and FWS30 alternatives were based on the same minimum storage objectives as the MRBA alternative. The MODC alternative is very similar to the MRBA alternative except that it has a flat Gavins Point release until mid-September. As a result, the MODC alternative has slightly higher minimum storage levels than the MRBA alternative. The MRBA alternative was also used as the basis for the two alternatives proposed by the U.S. Fish and Wildlife Service (USFWS). Both the BIOP and FWS30 alternatives added a spring rise at Fort Peck Dam and a spring rise and low summer flows from Gavins Point Dam to the MRBA alternative. Thus, minimum system storage levels are well above those specified in the CWCP and relatively close to the MRBA alternative.

The ARNRC alternative went even further than the MRBA-based alternatives in limiting the amount of drawdown during drought periods. The objective of the ARNRC alternative was to limit drawdown to 44 MAF during droughts such as the 1954 to 1961 drought and the 1987 to 1993 drought. In more severe droughts, such as the 1930 to 1941 drought, system storage was targeted at 31 MAF.

In contrast, the MLDDA alternative was very similar to the CWCP except that it increased the amount of storage available for flood control by lowering the base of the annual flood control zone by 2 MAF. Thus, the resulting minimum system storages were very near those modeled using the CWCP. During the 1930 to 1941 drought, the MLDDA alternative resulted in slightly higher minimum system storage due to the fact that navigation was suspended 3 years using the MLDDA criteria rather than just 1 year with the CWCP criteria. During the other two drought periods, the system storage was slightly below that modeled for the CWCP less water was available in the carryover and multiple use zone and because of the adjusted base of the annual flood control and multiple use zone.

Comparing the alternatives submitted for consideration to the actual historic operation during the period of record, which only includes the 1987 to 1993 drought, we see that all of the alternatives except MLDDA would have resulted in a higher minimum system storage than actually occurred during the latest drought. The MLDDA alternative would have resulted in a system storage that was 1.7 MAF lower than the actual historic operation.

Variations in the lake elevations of the upper three lakes are similar to the total system storage because the storage in the three lakes makes up the bulk of the system storage. There are minor variations due to the unique operating objectives of the individual lakes, such as unbalancing and the Fort Peck spring rise that can affect the timing and distribution of storage in the system. In general, the MRBA alternative and the alternatives that used the MRBA alternative as a base, namely the MODC, BIOP, and FWS30 alternatives, result in higher lake levels than the CWCP. This, of course, is due to the fact that these alternatives were designed to provide a higher minimum storage level (27.2 MAF) than the CWCP (18.7 MAF). The ARNRC alternative generally provides the highest minimum lake levels for Lake Sakakawea and Lake Oahe. This is because of the higher drought conservation measures. At Fort Peck Lake, the ARNRC alternative provides the highest minimum pool during the 1930 to 1941 drought, but provides lower lake levels compared to other alternatives during the 1954 to 1961 and 1987 to 1993 droughts. The MLDDA alternative results in the same or slightly lower lake elevations during the 1954 to 1961 and 1987 to 1993 droughts, and slightly higher levels during the 1930 to 1941 drought for the same reasons given earlier in the discussion about system storage.

In summary, all of the alternatives except the MLDDA result in generally higher minimum system storage and lake levels during the three drought periods. The differences between the alternatives based on the MRBA alternative (MRBA, MODC, BIOP, and FWS30) are generally small, averaging 1 to 3 feet. The ARNRC alternative provides the highest minimum system storage and lake levels, while the MLDDA generally provides the lowest.

5.2.2 Fort Peck Release

A spring rise out of Fort Peck for the benefit of native fish species was included in several of the alternatives submitted to the Corps for consideration. In particular, the ARNRC, FWS30, BIOP, and MODC alternatives were modeled with a spring rise from Fort Peck during the May/June timeframe. The modeling results for the various alternatives are presented on Figures 5.2-1 through 5.2-3 as a derivative of a flow duration-type analysis. The figures presented indicate the percent of years that a given discharge, either 18 or 23 kcfs, is equaled or is exceeded for various durations during the months of May and June. Increased releases of 23 kcfs for 3 weeks from Fort Peck Dam in the mid-May through June timeframe approximately every third year were recommended as a starting point in the USFWS BiOp. Although the USFWS goal was to release 23 kcfs for 3 weeks, some benefit is derived even if the goal is not fully met; therefore, a release of 18 kcfs was also included in the analysis of model results.

For example, Figure 5.2-1 indicates that for a 10-day period during the months of May and June under the CWCP, a release of 18 kcfs can be expected to be equaled or exceeded in about 10 percent of the years, and a release of 23 kcfs can be expected to be equaled or exceeded on average in about 7 percent of the years. Likewise, under the ARNRC alternative for a 10-day duration, Fort Peck's release should equal or exceed 18 kcfs about 23 percent of the years and 23 kcfs about 20 percent of the years.

In Figure 5.2-1, the CWCP is compared to the MLDDA and ARNRC alternatives. Neither the CWCP nor the MLDDA have a Fort Peck spring rise, so the contrast between them and the ARNRC alternative is quite obvious. Figure 5.2-2 compares the MRBA alternative to the two alternatives provided by the USFWS. The MRBA alternative does not include the Fort Peck spring rise, but it does provide more opportunities for higher releases than the CWCP due in part to the unbalancing feature of the MRBA alternative. The two USFWS alternatives include a spring rise but, as Figure 5.2-2 indicates, the BIOP provides a better chance for a 2-week spring rise than the FWS30 alternative. Furthermore, both USFWS alternatives are more effective at providing a spring rise than the ARNRC alternative. The MODC alternative, shown in Figure 5.2-3, actually outperforms all other alternatives in providing an effective spring rise out of Fort Peck with 25 percent of the years having 2 weeks of releases above 18 kcfs.

5.2.3 Lake Sakakawea Elevations

The State of North Dakota has indicated that it has water quality concerns at Lake Sakakawea when the pool is drawn down below elevation 1825 feet. To facilitate the water quality analysis for Lake Sakakawea, Figures 5.2-4 through 5.2-6 were developed to compare the number of days that Lake Sakakawea was below 1,825 feet elevation during the three historic drought periods in the Missouri River basin under the various operating scenarios.

For background purposes, the carryover-multiple use zone under the current operating criteria (CWCP) extends from 1,775 feet to 1,837.5 elevation feet. The actual historic minimum pool level at lake Sakakawea during the 1987 to 1993 drought was 1,815.0 feet.

As simulated using the Daily Routing Model (DRM), Lake Sakakawea was drawn down below 1,825 feet elevation for a period of many years under all of the operating alternatives during the 1930 to 1941 drought. As shown in Figure 5.2-4, Lake Sakakawea was drawn down the longest under the CWCP, nearly 12 consecutive years. The MLDDA alternative was only slightly better, recovering from the drought just a little quicker. All of the alternatives that impose a higher minimum system storage result in fewer days spent below 1,825 feet elevation, although the difference is not as pronounced during the 1930 to 1941 drought as it is in the less severe droughts. During the 1930 to 1941 drought, Lake Sakakawea first fell below elevation 1,825 feet during 1931 under all of the alternatives. Under the alternatives with higher minimum storage requirements the pool spent at least part of the year above 1,825 feet elevation until 1934. Figure 5.2-4 demonstrates that the pool was refilled quicker under the alternatives with higher minimum pools. The least time the pool spent below 1,825 feet elevation was with the ARNRC alternative.

Figures 5.2-5, representing the 1954 to 1961 drought, and 5.2-6, representing the 1987 to 1993 drought, show considerable difference between the various alternatives. During both droughts, the MLDDA, with its 2 MAF reduction in carryover-multiple use storage, results in the most number of days spent below 1,825 feet elevation. The CWCP is only slightly better. The MRBA alternative, and the other three plans that use the MRBA alternative as a base condition, namely the MODC, BIOP, and FWS30, all show a significant improvement over the CWCP due to the higher minimum storage goals. The ARNRC alternative, with its even higher minimum pool levels, performs the best in this aspect, virtually eliminating the time spent below 1,825 feet elevation in the 1954 to 1961 drought and greatly reducing the duration in the 1987 to 1993 drought.

5.2.4 Bismarck Flow Duration

A flow duration-type analysis was done using the DRM results at Bismarck. In the analysis, the number of days during the April to June timeframe when flows at Bismarck exceed 55 kcfs was totaled for each year in the 100-year period of record and a duration-type analysis was performed. Flood damages in the Bismarck area begin when the flows exceed the 55- to 60-kcfs range. Figures 5.2-7 through 5.2-9 compare the results of the analysis for the CWCP and the alternatives submitted to the Corps for consideration.

In Figure 5.2-7, comparing the CWCP with the MLDDA and ARNRC alternatives, the affect of the Gavins Point Dam spring rise in the ARNRC alternative can be noted. In order to support a spring rise from Gavins Point Dam, higher releases need to be passed down through the system. The result is a slight increase in the number of days that flows at Bismarck exceed 55 kcfs during the April through June period. The CWCP and MLDDA alternatives are very similar because neither has a spring rise from Gavins Point Dam.

Figure 5.2-8 compares the MRBA alternative with the two alternatives provided by the USFWS (BIOP and FWS30). The BIOP and FWS30 alternatives, both of which contain a Gavins Point Dam spring rise, result in a slight increase in the frequency of flows exceeding 55 kcfs at Bismarck.

Figure 5.2-9 compares the MRBA and MODC alternatives to the CWCP. Very little difference is noted except for the most rare events, less than 5 percent of the years. The MRBA and MODC alternatives result in a slight increase in the number of days Bismarck is above 55 kcfs due to the movement of water between the lakes for the Fort Peck Dam spring rise and unbalancing storage in the upper three lakes.

5.2.5 Gavins Point Dam Release

The alternatives presented for the Corps' consideration contain widely varying Gavins Point Dam releases depending on time of year, navigation support level, whether or not the spring rise and low summer flows are part of the plan, as well as other factors. In order to allow the differences between the alternatives to be displayed and understood, release duration plots were developed for each month, January through December, using average monthly Gavins Point Dam releases for the period of record for the CWCP and the alternatives. The results are 12 monthly figures each displaying seven duration curves, one for each alternative.

Under any given operating alternative, Gavins Point Dam releases vary widely throughout the year; therefore, it is beneficial to examine the model results on a month-by-month basis. Figures 5.2-10 through 5.2-21 allow a month-by-month comparison of the alternatives. The discussion here, however, is limited to pointing out the major differences among the plans. Many of the alternatives presented require the shifting of water from one season to another. For example, a spring rise followed by low summer flows may require higher flows in the fall months in order to evacuate storage accumulated in the flood control pools of the upper three lakes. The navigation season also ends later for these alternatives.

The spring rise is the primary reason for differences between the alternatives. Between January and March, Figures 5.2-10 through 5.2-12, the duration curves for the various alternatives are, for the most part, quite similar in the range and frequency of Gavins Point Dam release.

Figure 5.2-13 shows a significant dichotomy in the duration curves in April. Alternatives with a spring rise and low summer flows are sometimes forced to release extra water during April in wet years due to the release restrictions imposed later in the summer. As a result, the ARNRC, BIOP, and FWS30 alternatives indicate much higher releases than the CWCP and the other three alternatives, namely the MLDDA, MRBA, and MODC alternatives.

This trend continues into May due to the spring rise, as shown in Figure 5.2-14, with the FWS30 resulting in the highest releases, followed closely by the ARNRC and BIOP alternatives. The remaining four alternatives without a spring rise result in much lower releases. Releases in June, as shown on Figure 5.2-15, appear to show little difference between the spring rise and the non-spring rise alternatives. The difference between the alternatives is masked by the use of average monthly flows. The spring rise alternatives had higher Gavins Point Dam releases from May 15 to June 15 followed by lower releases during the latter half of June, causing the average monthly flows for

June to average near the non-spring rise alternatives. If the first and second halves of June were analyzed separately, the first half would show results similar to May and the second half would be similar to July.

In July and August, releases modeled with the two USFWS alternatives (BIOP and FWS30) and the ARNRC alternative are dramatically affected by the low summer flow criteria and the duration curves for these alternatives drop well below the CWCP and other non-spring rise alternatives as seen in Figures 5.2-16 and 5.2-17.

After the low summer flows in the ARNRC, BIOP, and FWS30 alternatives, Gavins Point Dam releases are increased in order to evacuate the remaining excess water in the system storage between September and November, Figures 5.2-18 through 5.2-20. Once again the release duration curves for these alternatives are significantly higher than the other alternatives. The November release duration curve also indicates the shortened navigation season required in 30 to 35 percent of the years under the MRBA and MODC alternatives.

December's duration curves for the CWCP and the other alternatives, Figure 5.2-21, are once again quite similar, although there is some variation in the Gavins Point Dam release at end of the navigation season. The minimum winter release, 12 kcfs, is consistent across the range of alternatives.

5.2.6 Nebraska City Flow Duration

Along the Lower River below the Mainstem Reservoir System, the magnitude, timing, and duration of high flows may affect landowners through direct flooding, high ground water, and/or interior drainage flooding. Because the duration of high flows is a significant factor, the modeling results for the various alternatives are presented on Figures 5.2-22 through 5.2-24 as a derivative of a flow duration-type analysis. In the analysis, the number of days during the April to July time frame when flows at Nebraska City exceed 55 kcfs was totaled for each year in the 100-year period of record and a duration-type analysis was performed. Landowners in the Nebraska City area begin to experience interior drainage problems when flows n the Missouri River approach 55 kcfs. The differences among the alternatives follow a similar pattern because the flows at Nebraska City are highly influenced by the Gavins Point Dam releases.

Figure 5.2-22 shows while the MLDDA alternative is nearly identical to the CWCP, the ARNRC alternative would result in more days with flows above the 55-kcfs level during the period of April through July due to the spring rise. Likewise, Figure 5.2-23 shows as the magnitude of the spring rise increases, as one would expect, the frequency and duration of flows above 55 kcfs at Nebraska City also increase. The BIOP alternative results in greater flows than the MRBA alternative, which does not include a spring rise, and the FWS30 alternative, which has a higher spring rise than the BIOP alternative, results in even more days spent above 55 kcfs.

Figure 5.2-24 shows that there is relatively little difference between the CWCP and the MRBA or MODC alternatives because neither of these two alternatives includes a spring rise.

5.2.7 Boonville Flow Duration

A similar analysis was performed for flows at Boonville, Missouri. Figures 5.2-25 through 5.2-27 show a duration-type analysis of the number of days during the May through June time frame that the flows at the Boonville gage exceed 90 kcfs. Long duration, high flows on this part of the Lower River can restrict releases from tributary lakes. Releases from the Kansas River tributaries begin to be restricted when flows at Waverly, Missouri are greater than 90 kcfs. Waverly is not a control point in the DRM; however, Boonville is the next downstream control point.

For the May through June period, Figure 5.2-25 shows essentially no difference between the CWCP and the MLDDA alternative in the number of days with flow above 90 kcfs at Boonville. The ARNRC alternative, with its spring rise, results in generally 5 to 10 more days with flows above 90 kcfs during the May to June time frame than the CWCP or MLDDA alternative.

The MRBA, BIOP, and FWS30 alternatives are compared in Figure 5.2-26. The MRBA alternative, with no spring rise out of Gavins Point Dam, results in the fewest days with flows above 90 kcfs at Boonville. The BIOP alternative, with its 17.5-kcfs spring rise, and the FWS30 alternative, with its 30-kcfs spring rise, result in an increasingly higher number of days with flow above 90 kcfs.

The MRBA and MODC alternatives are compared to the CWCP in Figure 5.2-27. Neither of these alternatives involve a spring rise from Gavins Point Dam. There is very little difference in the likelihood of high flows at Boonville.

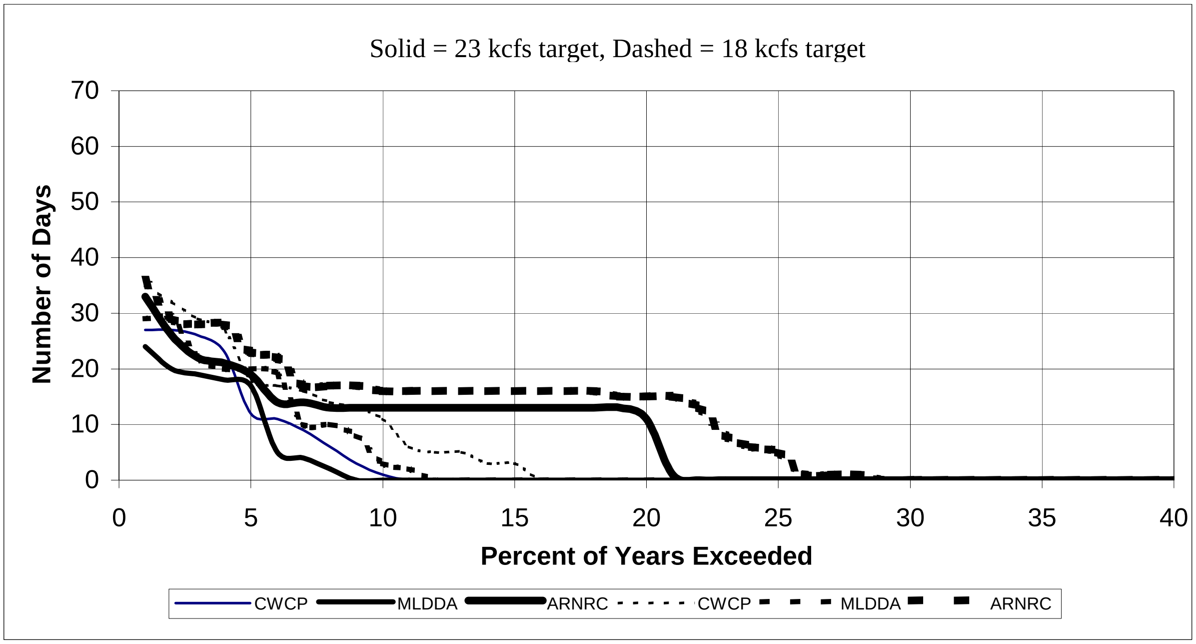

Figure 5.2-1. Number of days in May/June that Fort Peck releases exceed target for CWCP, MLDDA, and ARNRC alternatives.

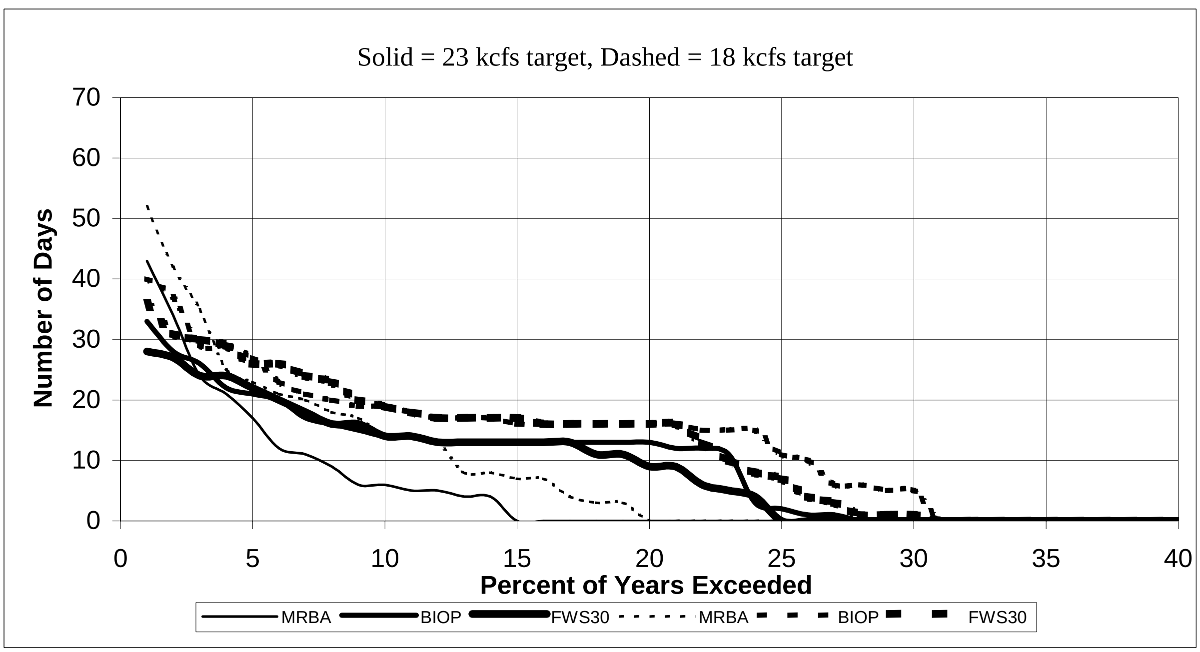

Figure 5.2-2. Number of days in May/June that Fort Peck releases exceed target for MRBA, BIOP, and FWS30 alternatives.

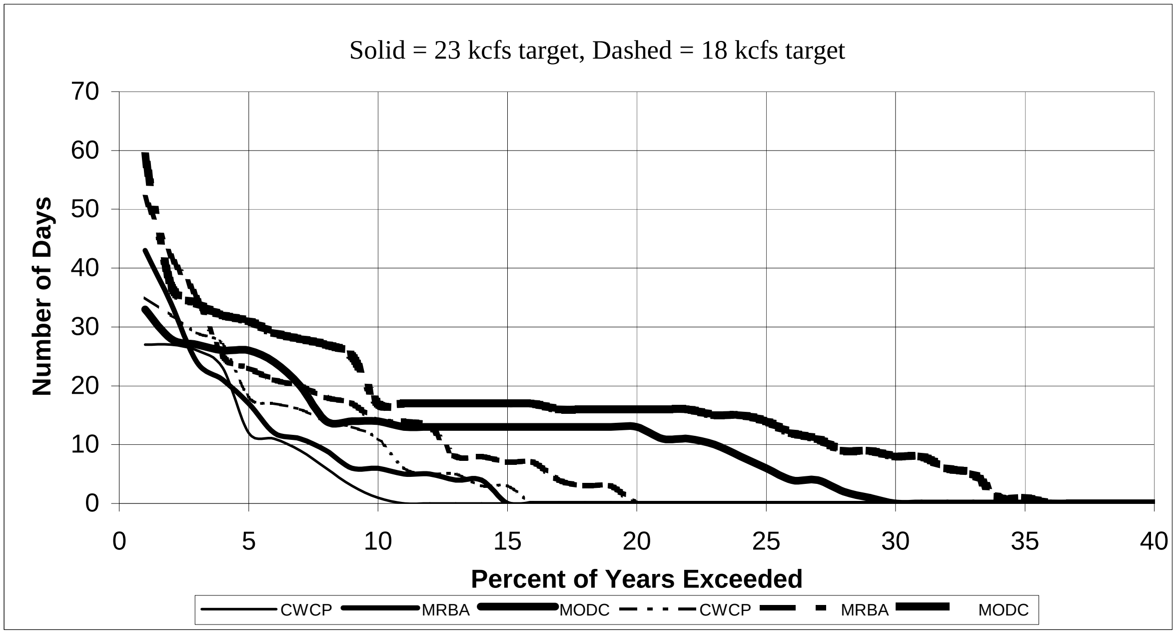

Figure 5.2-3. Number of days in May/June that Fort Peck releases exceed target for CWCP, MRBA, and MODC alternatives.

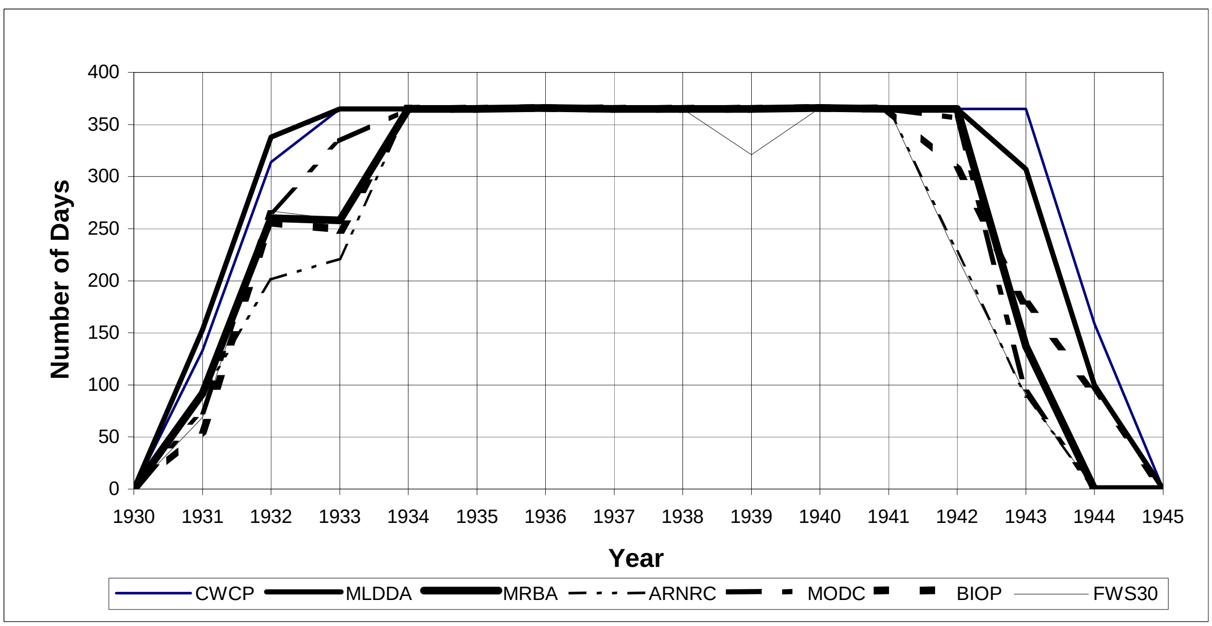

Figure 5.2-4. Lake Sakakawea number of days per year below elevation 1,825 feet, 1930 to 1941 drought.

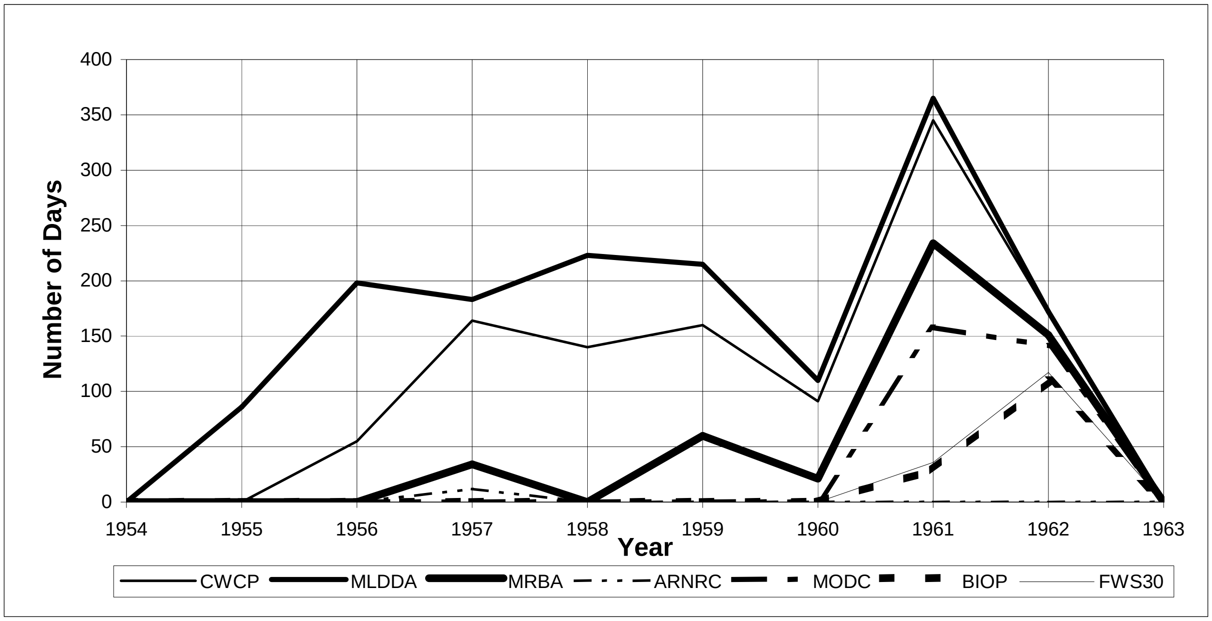

Figure 5.2-5. Lake Sakakawea number of days per year below elevation 1,825 feet, 1954 to 1961 drought.

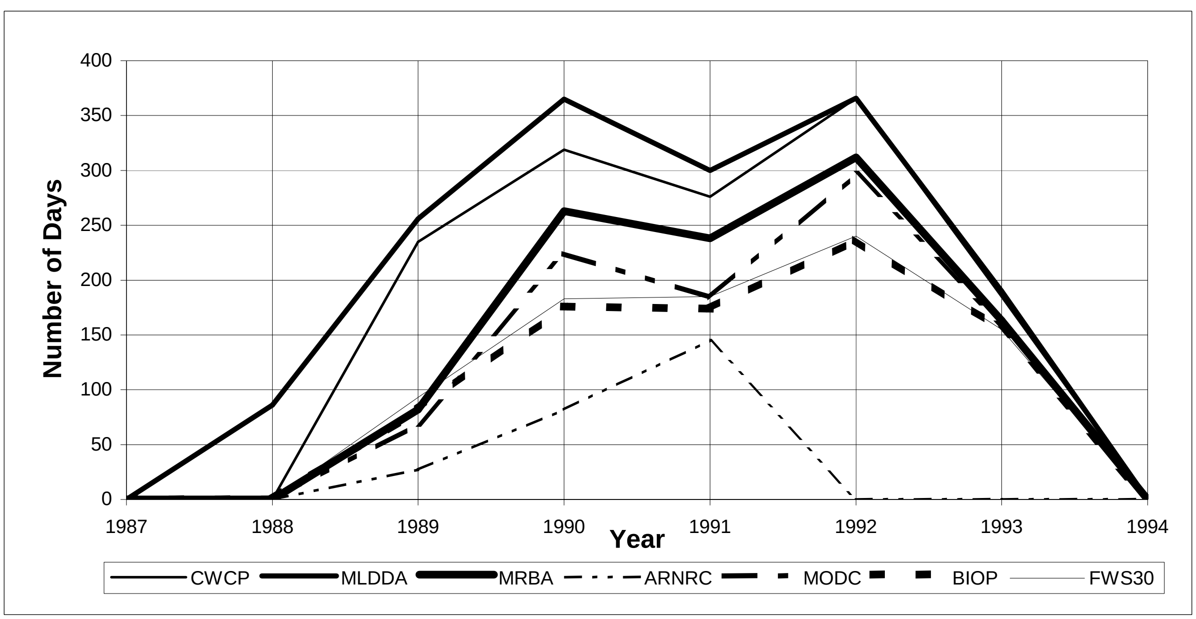

Figure 5.2-6. Lake Sakakawea, number of days per year below elevation 1,825 feet, 1987 to 1993 drought.

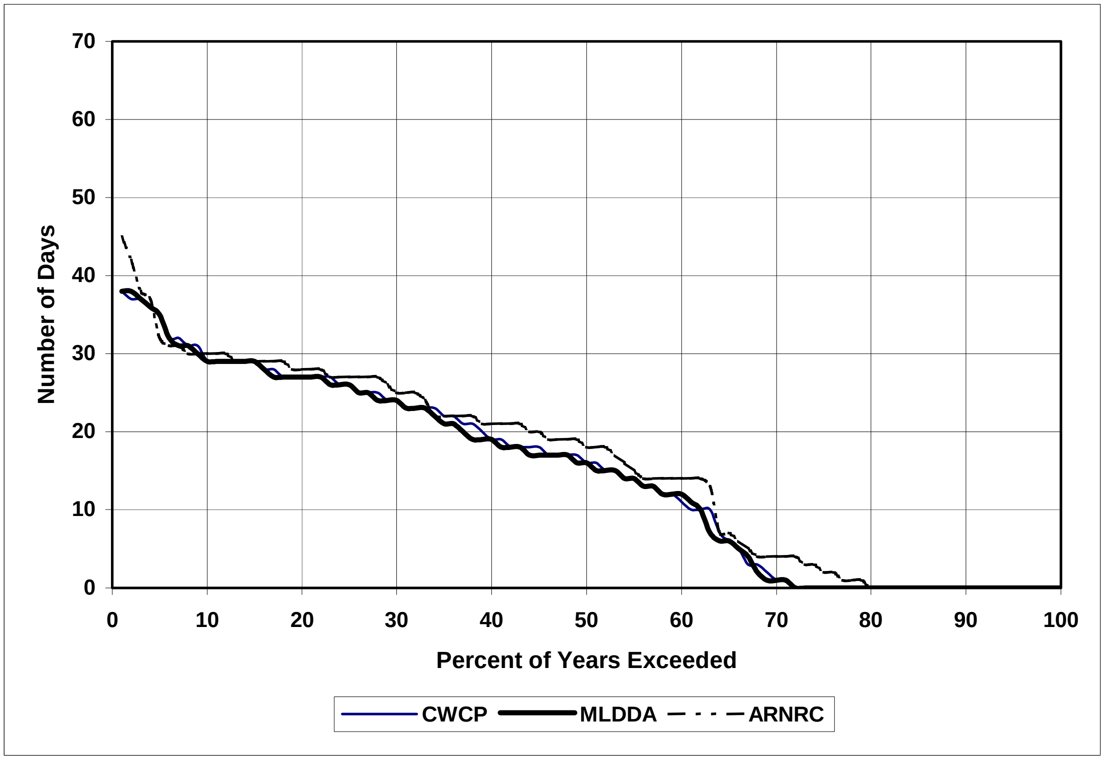

Figure 5.2-7. Missouri River at Bismarck, number of days flows exceed 55 kcfs, April through June for CWCP, MLDDA, and ARNRC alternatives.

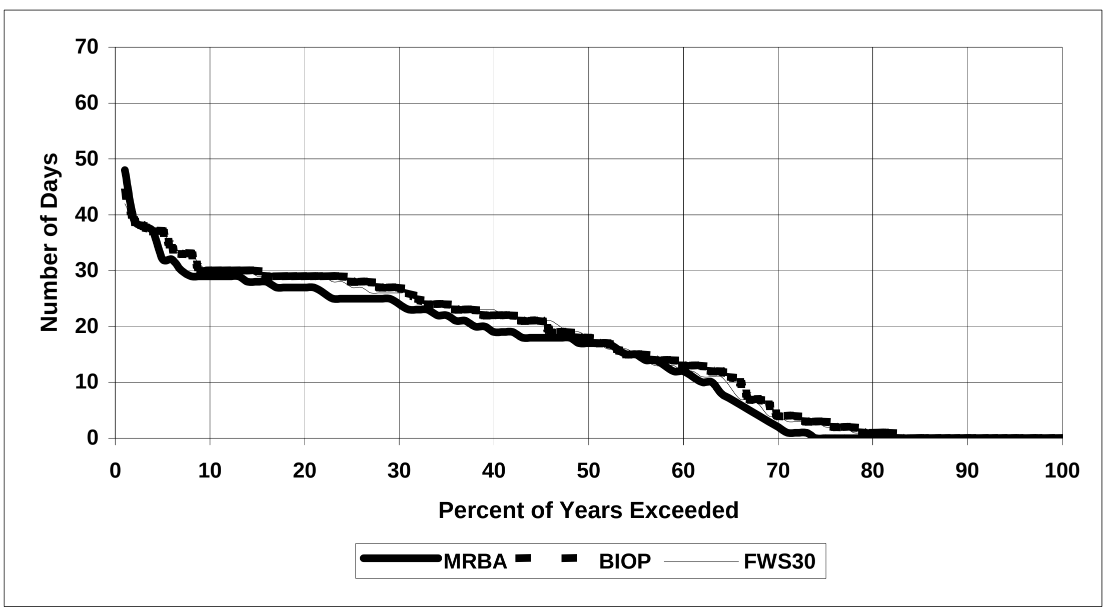

Figure 5.2-8. Missouri River at Bismarck, number of days flows exceed 55 kcfs, April through June for MRBA, BIOP, and FWS30.

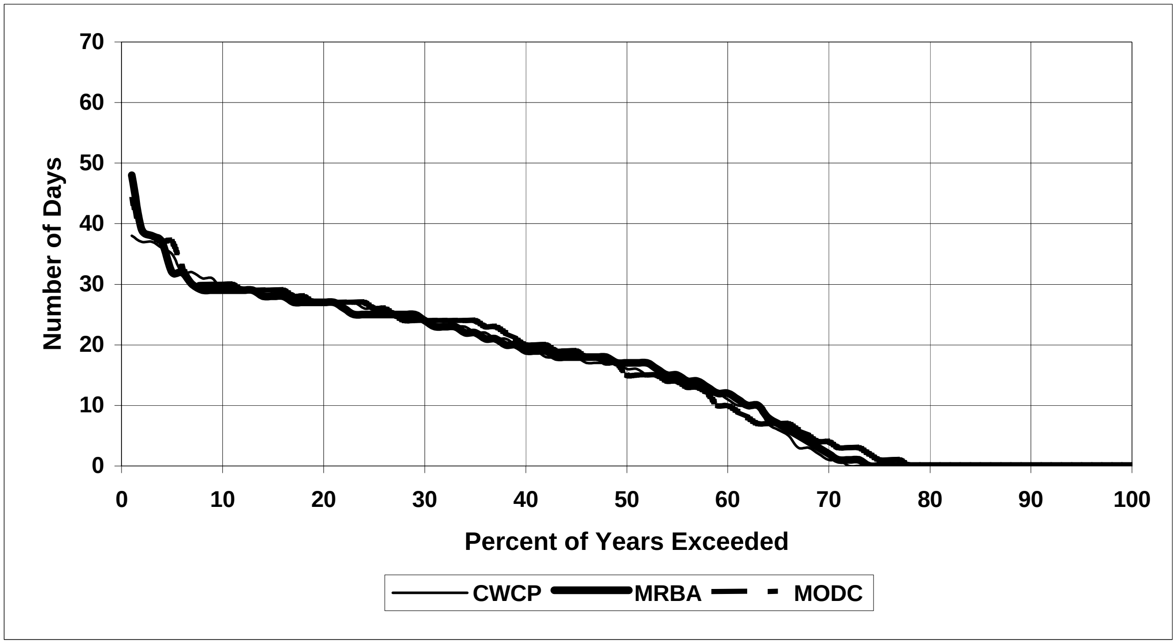

Figure 5.2-9. Missouri River at Bismarck, number of days flows exceed 55 kcfs, April through June for CWCP, MRBA, and MODC alternatives.

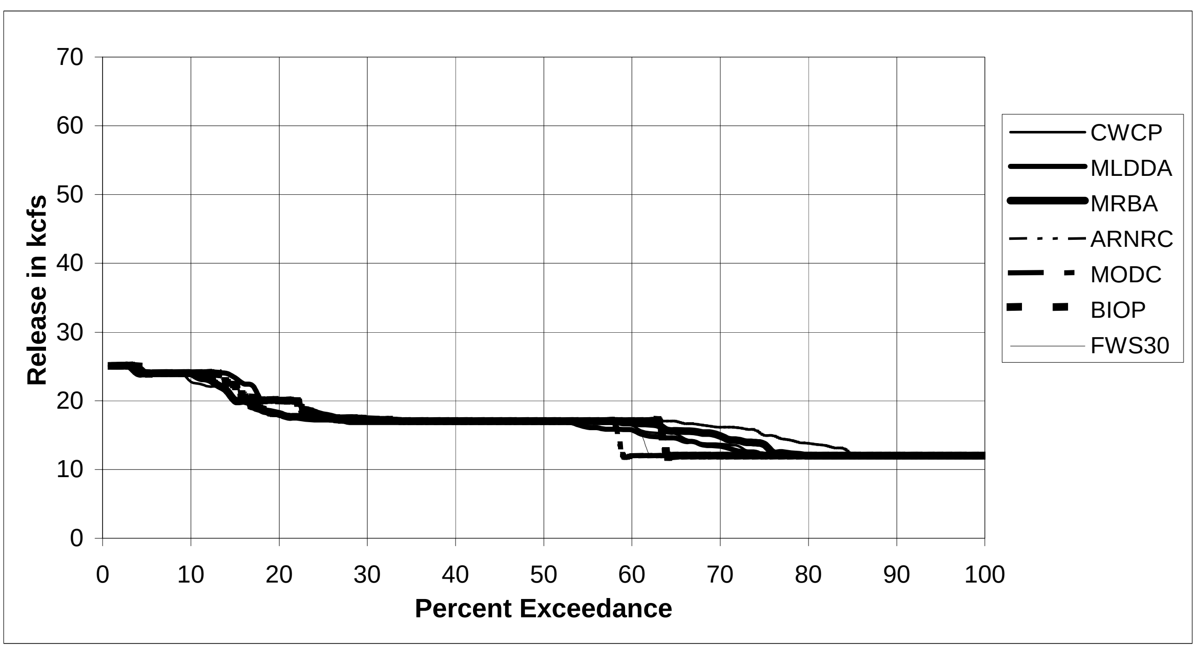

Figure 5.2-10. Gavins Point release duration, January.

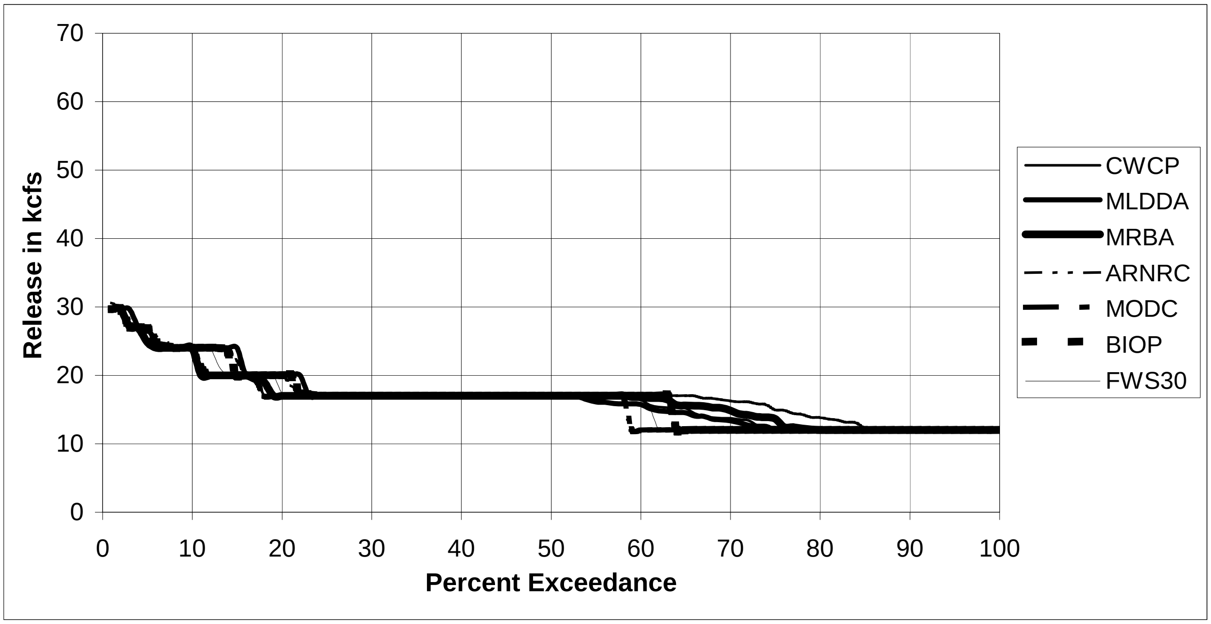

Figure 5.2-11. Gavins Point Dam release duration, February.

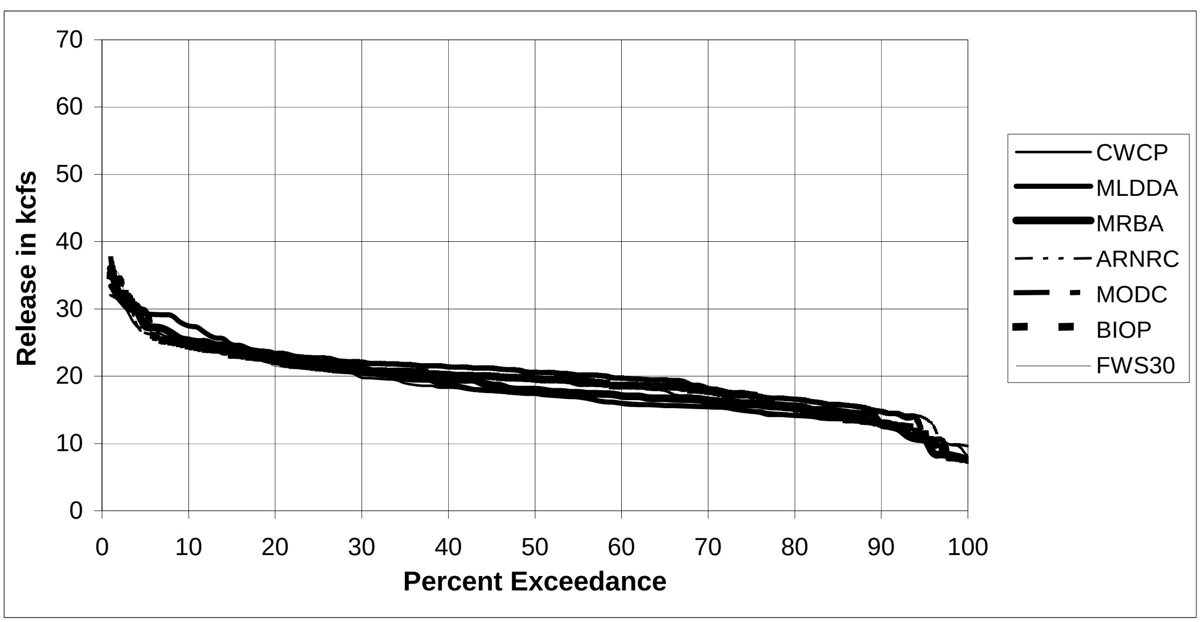

Figure 5.2-12. Gavins Point Dam release duration, March.

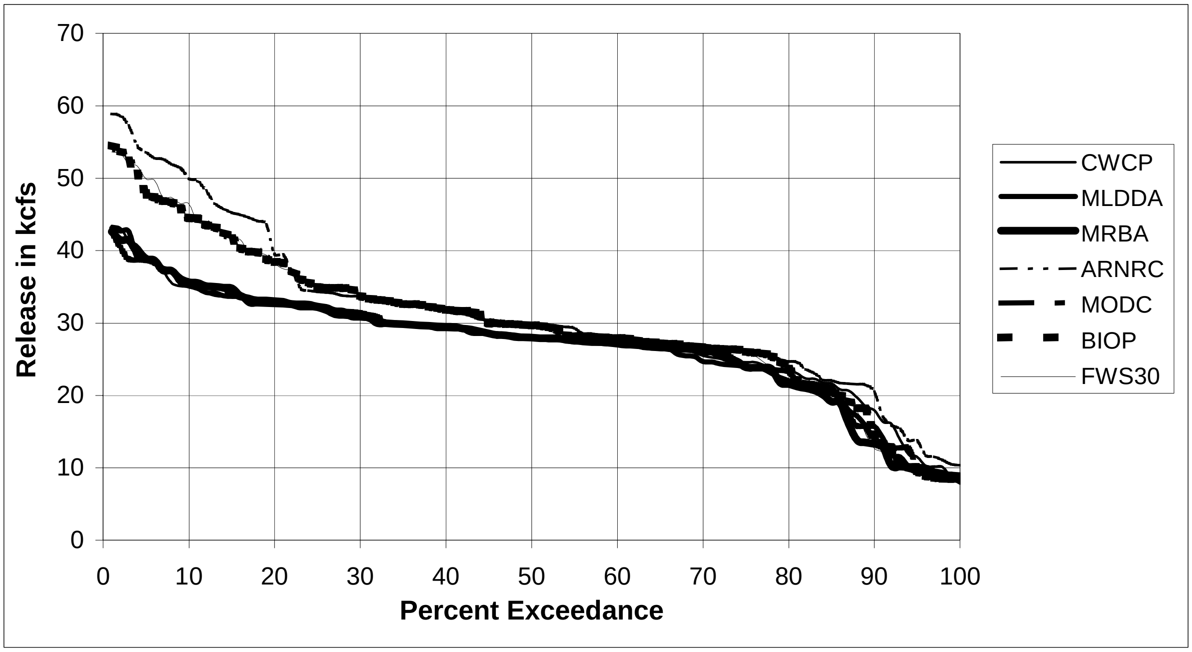

Figure 5.2-13. Gavins Point Dam release duration, April.

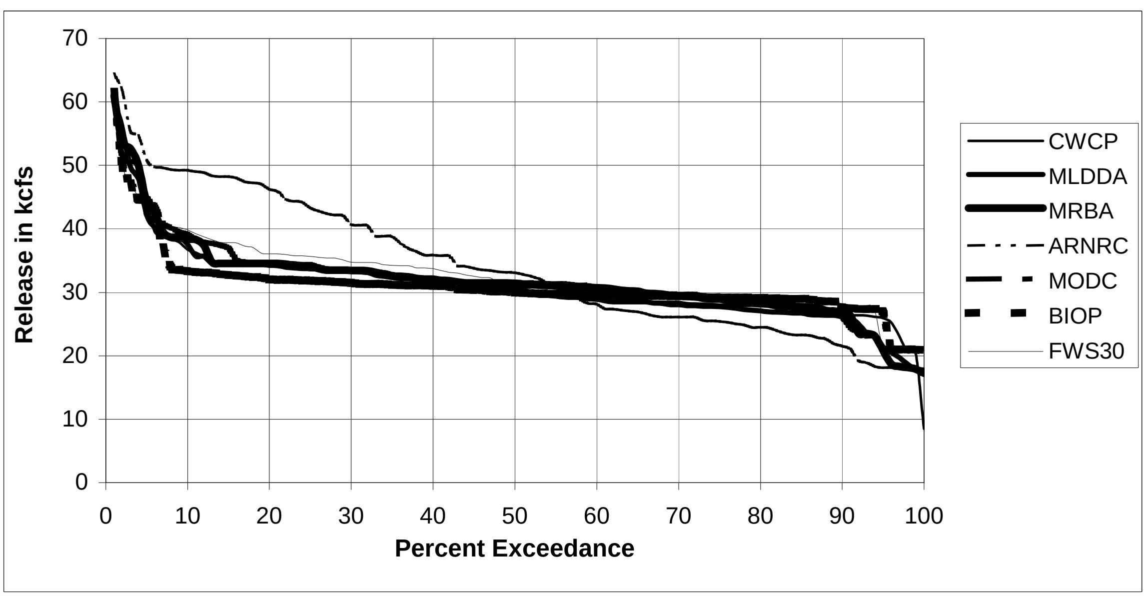

Figure 5.2-14. Gavins Point Dam release duration, May.

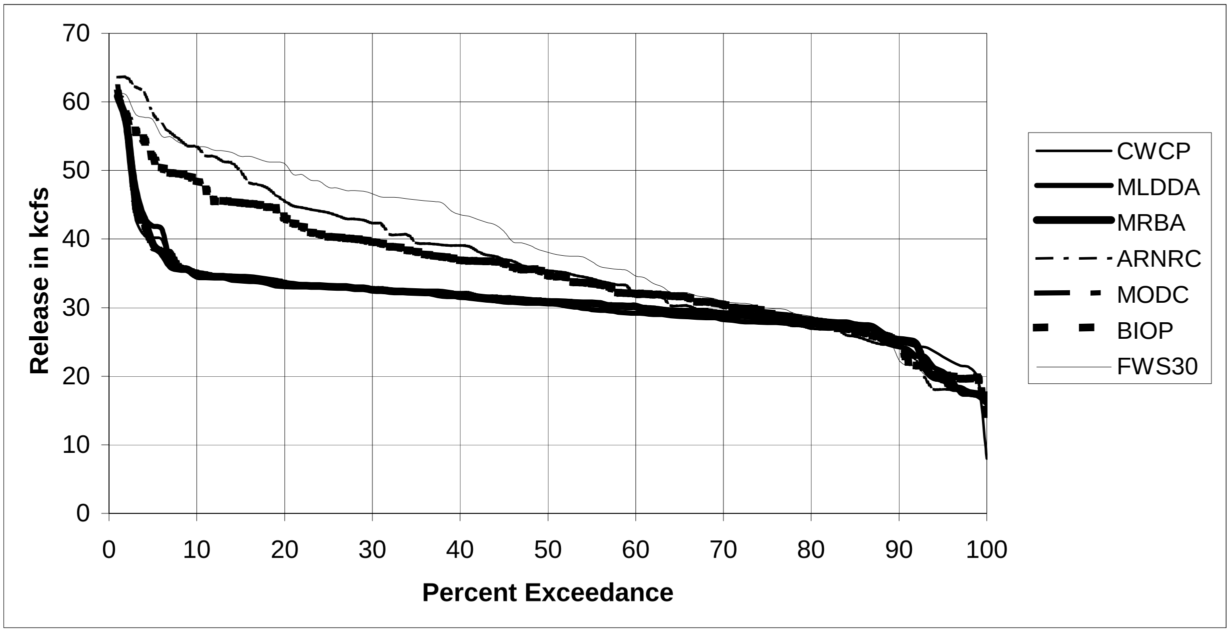

Figure 5.2-15. Gavins Point Dam release duration, June.

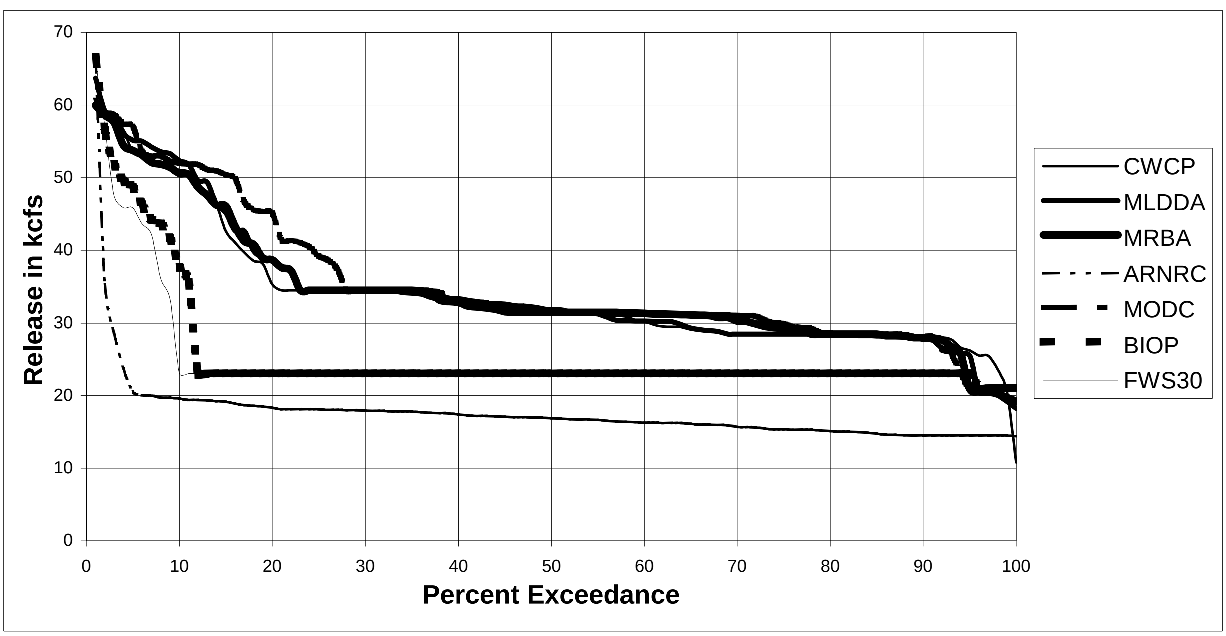

Figure 5.2-16. Gavins Point Dam release duration, July.

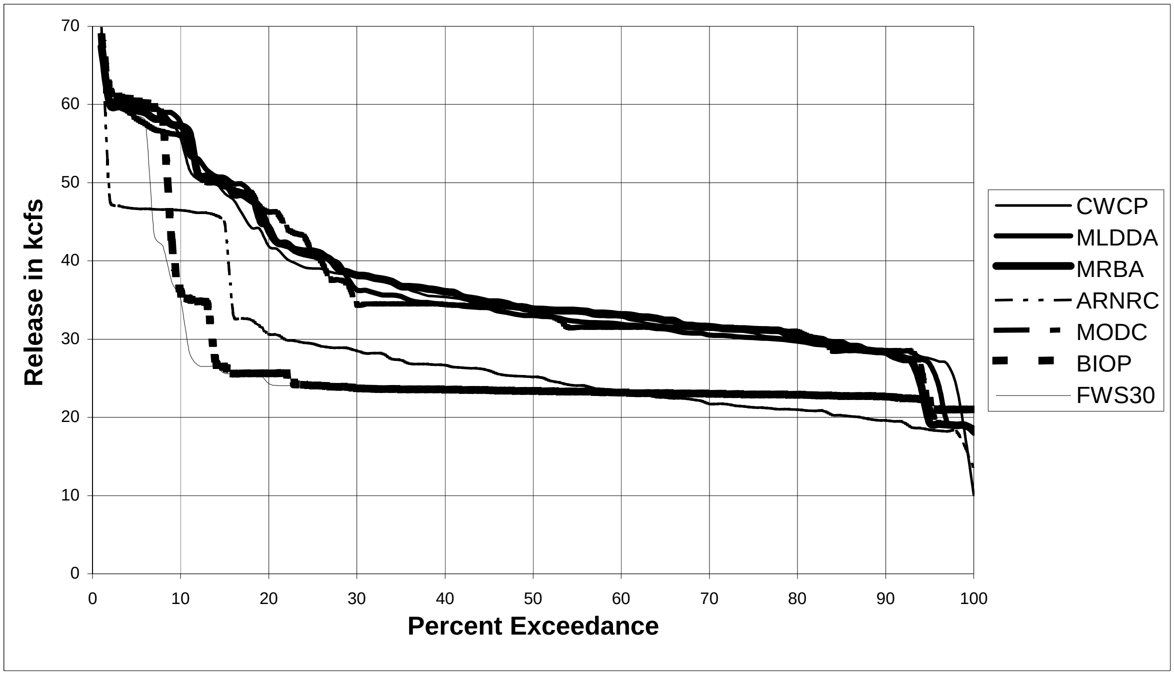

Figure 5.2-17. Gavins Point Dam release duration, August.

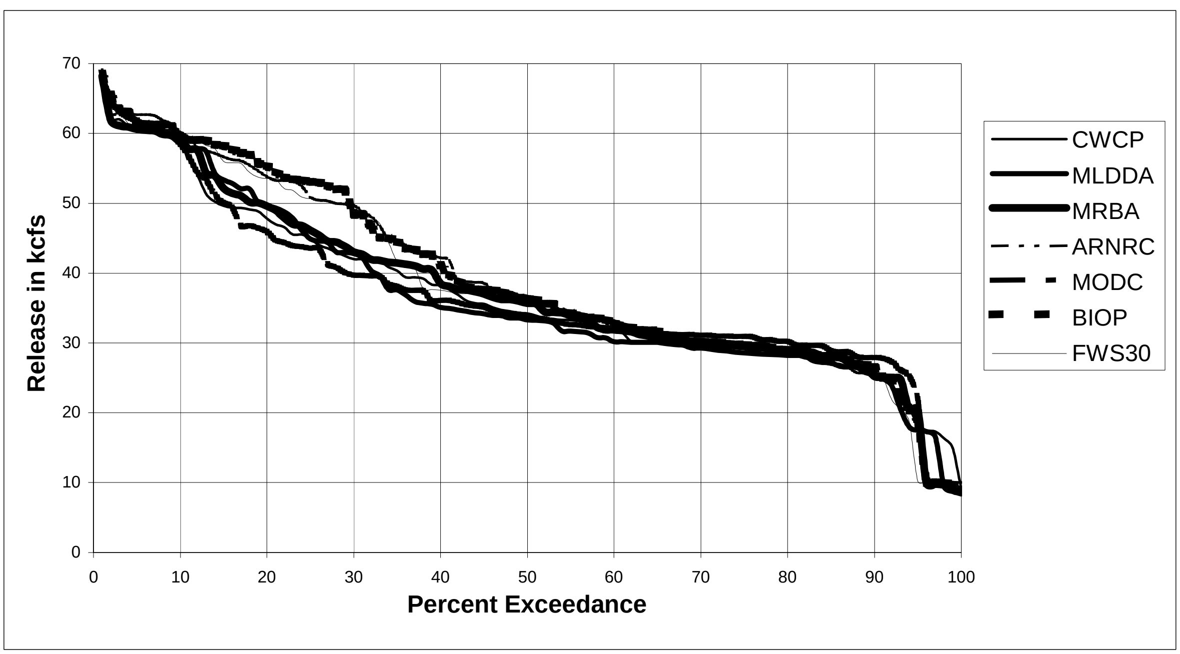

Figure 5.2-18. Gavins Point Dam release duration, September.

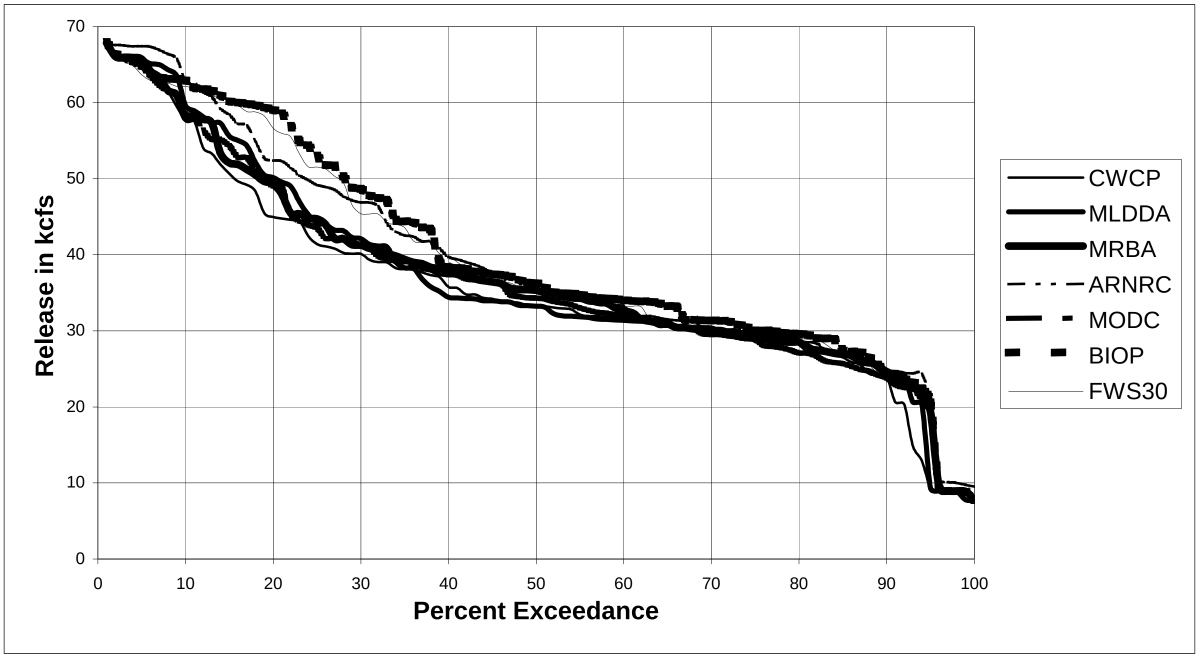

Figure 5.2-19. Gavins Point Dam release duration, October.

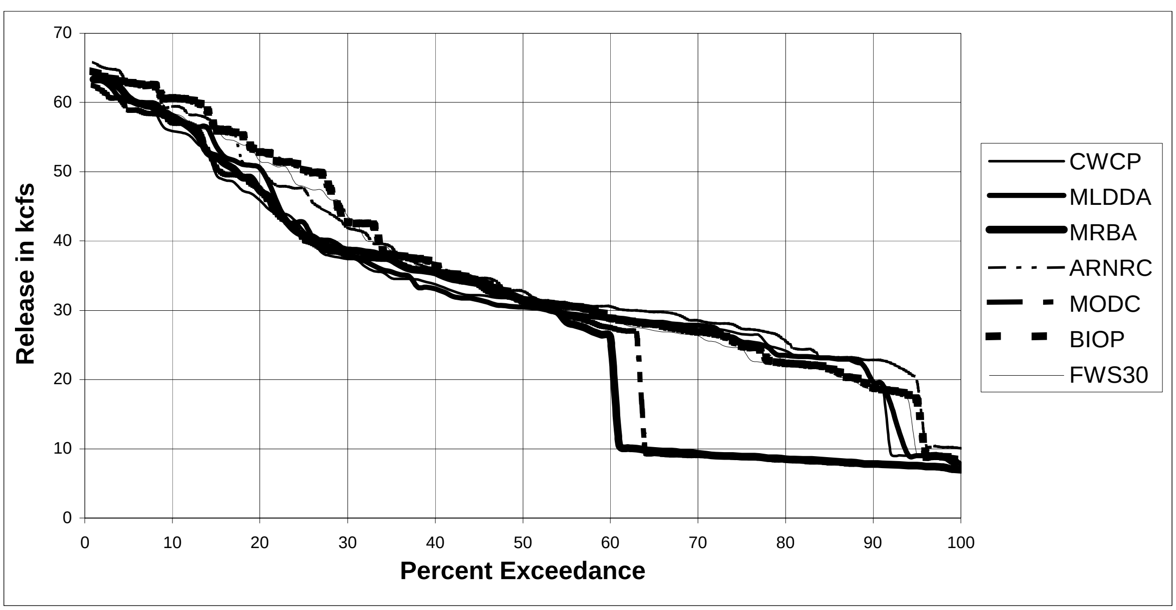

Figure 5.2-20. Gavins Point Dam release duration, November.

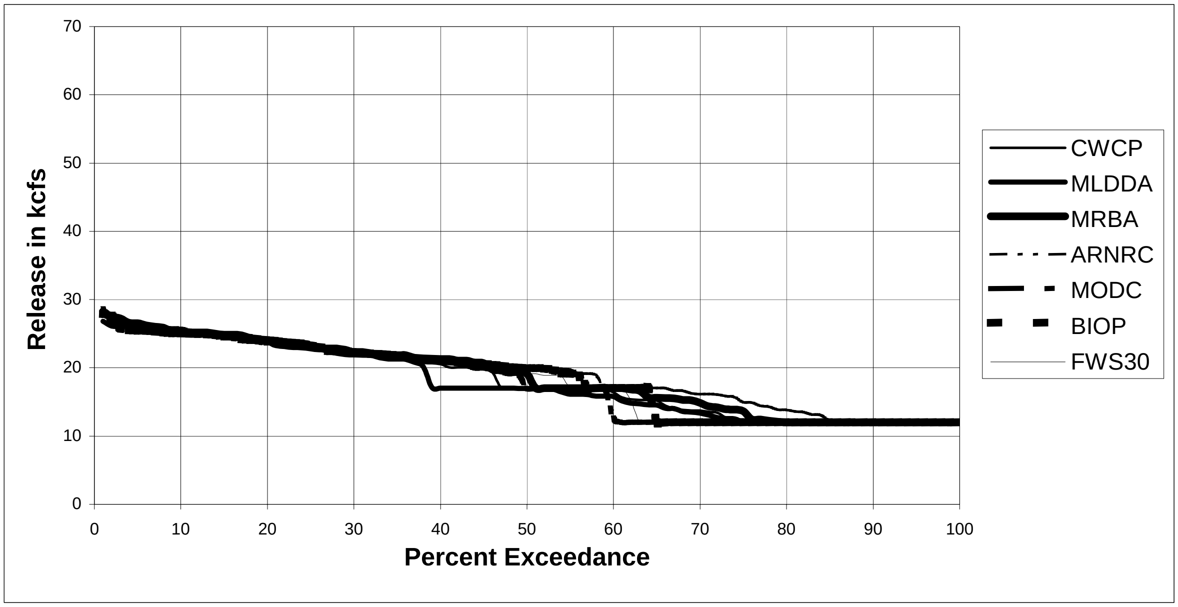

Figure 5.2-21. Gavins Point Dam release duration, December.

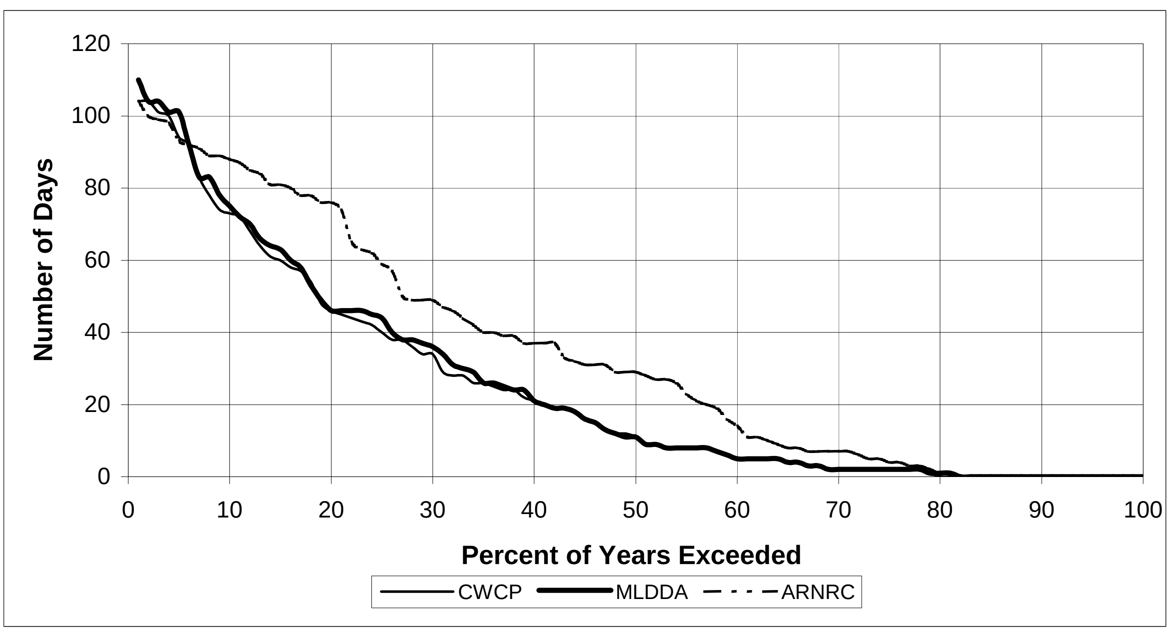

Figure 5.2-22. Missouri River at Nebraska City: Number of days flows exceed 55 kcfs, April through July for CWCP, MLDDA, and ARNRC alternatives.

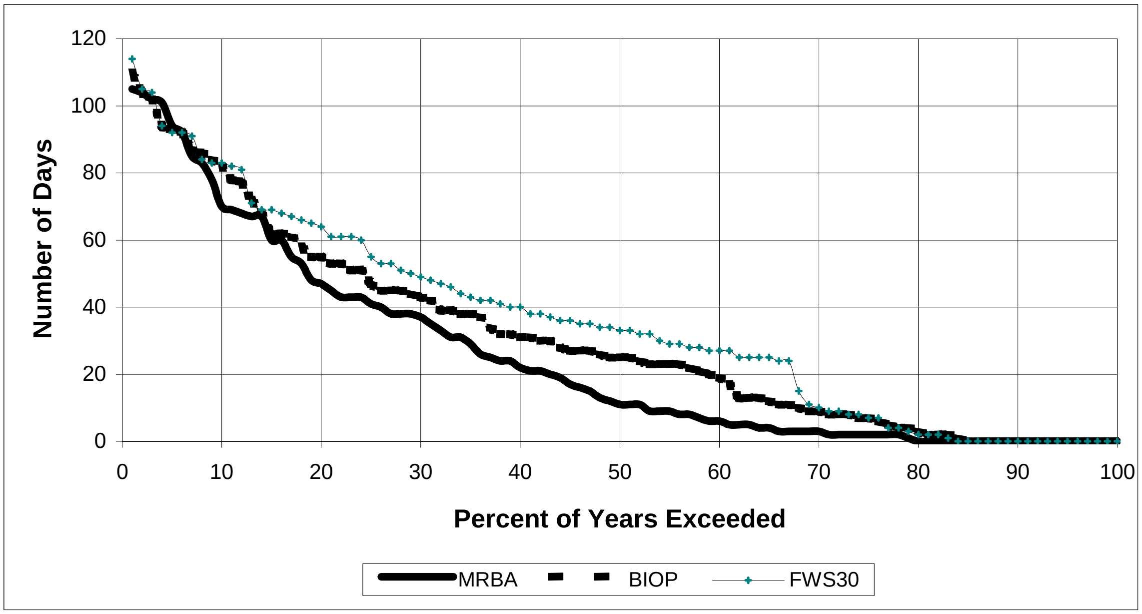

Figure 5.2-23. Missouri River at Nebraska City: Number of days flows exceed 55 kcfs, April through July for MRBA, BIOP, and FWS30 alternatives.

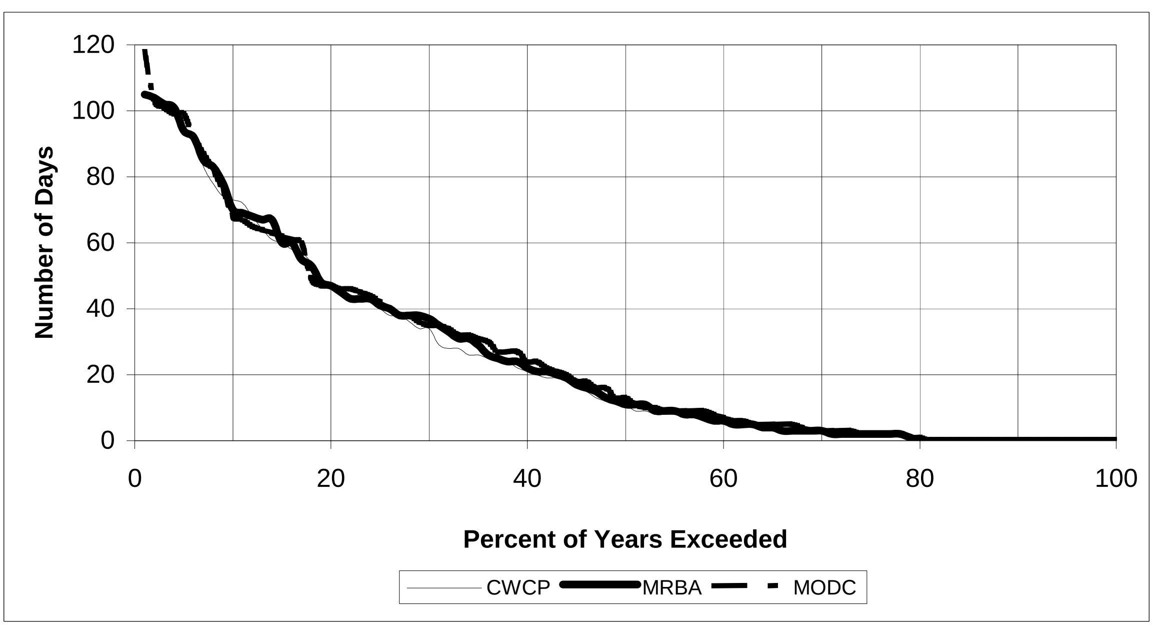

Figure 5.2-24. Missouri River at Nebraska City: Number of days flows exceed 55 kcfs, April through July for CWCP, MRBA, and MODC alternatives.

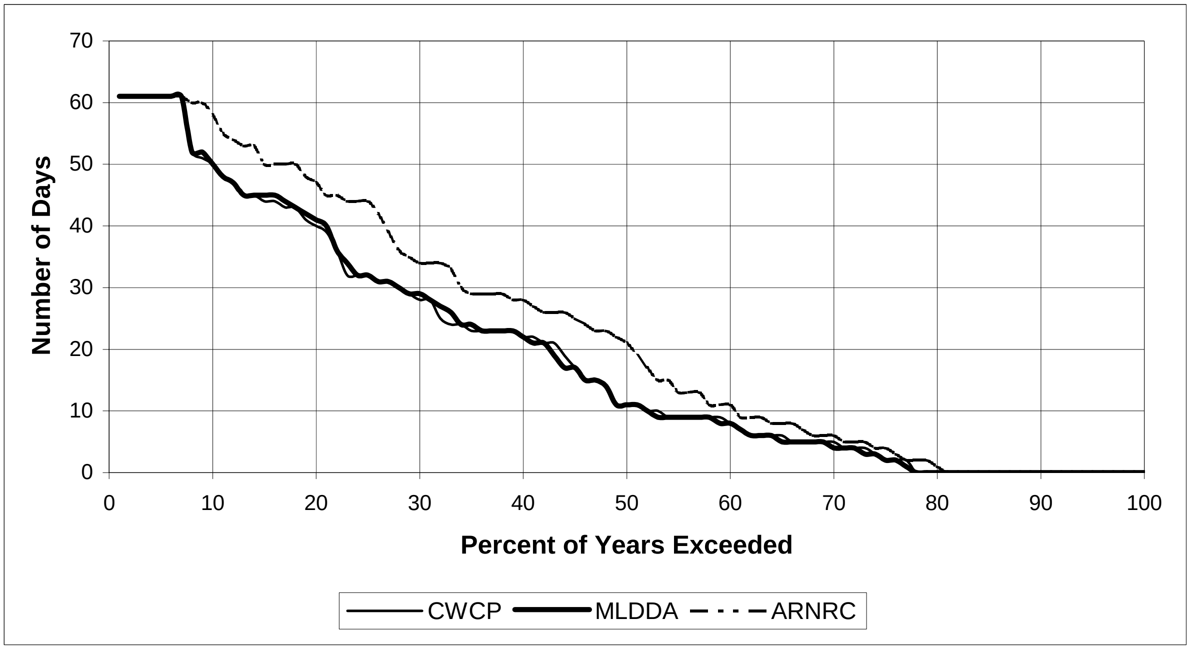

Figure 5.2-25. Missouri River at Boonville: Number of days flows exceed 90 kcfs, May through June for CWCP, MLDDA, and ARNRC alternatives.

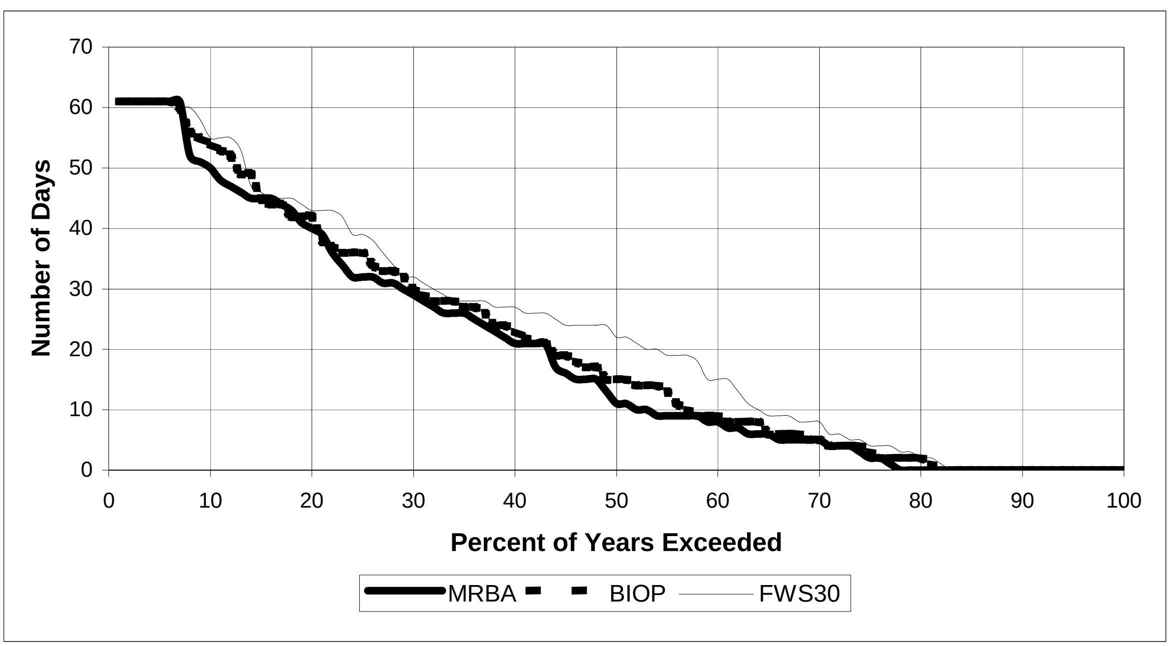

Figure 5.2-26. Missouri River at Boonville: Number of days flows exceed 90 kcfs, May through June for MRBA, BIOP, and FWS30 alternatives.

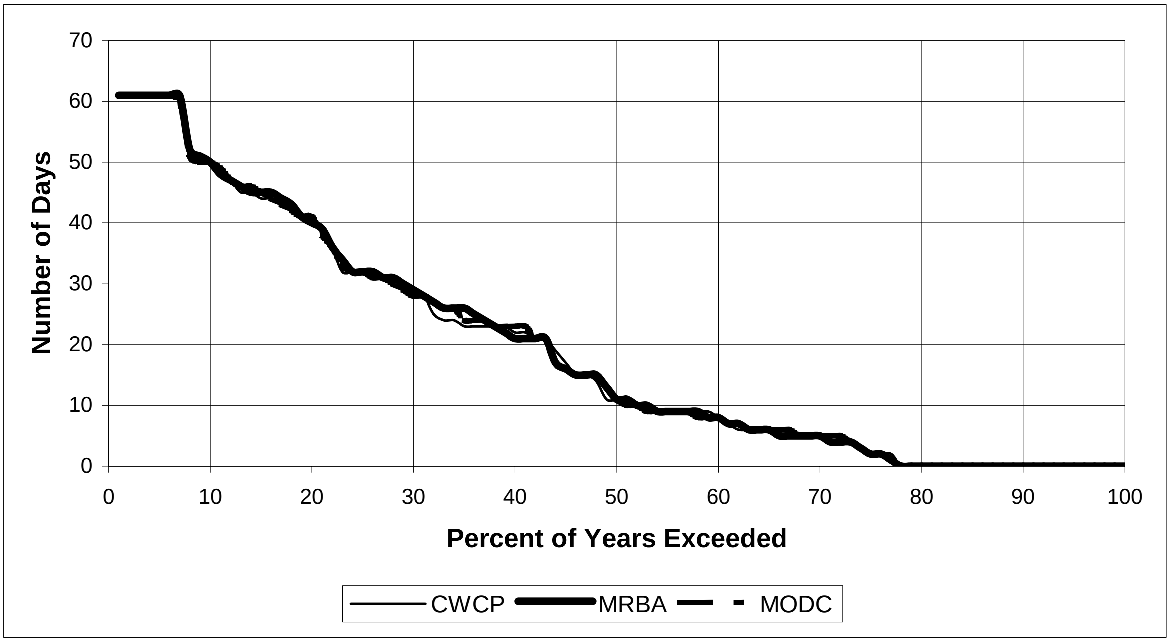

Figure 5.2-27. Missouri River at Boonville: Number of days flows exceed 90 kcfs, May through June for CWCP, MRBA, and MODC alternatives.

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