**Operation of**
**Flaming Gorge Dam**
**Final Environmental**
**Impact Statement**


# Modified Run of the River Modeling Report Technical Appendix

# MODIFIED RUN OF THE RIVER MODELING REPORT TECHNICAL APPENDIX

*Page No.*

# Modified Run of the River Modeling Report Technical Appendix

R. Clayton and A. Gilmore
July 17, 2002


## INTRODUCTION

At the request of the National Park Service, a "Run of River" approach for operating Flaming Gorge Dam was modeled by the hydrologic modeling team to see if this type of approach could achieve the *2000 Flow and Temperature Recommendations for Endangered Fishes in the Green River Downstream of Flaming Gorge Dam* (2000 Flow and Temperature Recommendations). The Action and No Action Alternatives of the Flaming Gorge Environmental Impact Statement (Flaming Gorge EIS) are the only two alternatives that have been fully modeled. This study was done to potentially create a third alternative for the Flaming Gorge EIS.

A "Run of River" operational approach provides a more natural hydrograph to river reaches downstream of a reservoir because releases from the reservoir are patterned to mimic the reservoir inflow pattern. The "Run of River" approach modeled for this study followed a simple rule where the daily release volume was set equal to a percentage of the previous day's unregulated inflow volume. There were two main goals this study attempted to achieve. The first goal was to determine what percentage of the previous day's unregulated inflow volume to release so that the flow objectives of the 2000 Flow and Temperature Recommendations would be achieved. This percentage had to meet these flow objectives while also minimizing impacts to other resources associated with the Flaming Gorge facility. The second goal was to compare and quantify the hydrologic effects of this operational approach to the approaches used for the Action and No Action Alternatives.

## MODEL METHODOLOGY

The basic methodology of the “Run of River” approach used for this study was to release a percentage of the previous day’s unregulated inflow during the period from March through July. During other months of the year, the “Run of River” approach determined releases in the same way that the Action Alternative determined releases.

Unregulated inflow is a measure of what volume of water would have flowed into the reservoir over a period of time assuming no upstream regulation occurred. In the case of Flaming Gorge Reservoir, the unregulated inflow is the actual inflow, over a period of time, adjusted for any change in storage or evaporation in Fontenelle Reservoir located upstream from Flaming Gorge Reservoir.

The main difference between the “Run of River” approach and the approach taken by the Action Alternative was the method by which releases from Flaming Gorge Dam were determined during the March through July period. The Action Alternative divided this period into a transitional operations period (March and April) and a spring period (May, June, and July). During the transitional period, the Action Alternative operated Flaming Gorge Dam to achieve a drawdown target by a deadline date of May 1st each year. During this period, a minimum release rate of 800 cubic feet per second (cfs) and a powerplant capacity release rate of 4,600 cfs were the only limits placed upon releases. During the spring period, the Action Alternative classified the anticipated spring hydrology into one of five classifications (dry to wet). From this classification the Action Alternative developed a spring release pattern that would most likely meet the flow objectives defined for that particular classification. It was assumed that future flows of the Yampa River could be predicted within a reasonable degree of accuracy.

The “Run of River” approach, on the other hand, was more indirect in terms of how it attempted to achieve the flow objectives of the 2000 Flow and Temperature Recommendations. Under the “Run of River” approach during the period from March through July, each day Flaming Gorge releases were controlled so that a percentage of the unregulated inflow for the previous day was released. During this period, the “Run of River” approach did not make any direct attempt to achieve the flow objectives of the 2000 Flow and Temperature Recommendation. It was assumed that by releasing a particular percentage of the unregulated inflow, that these flow objectives could be achieved coincidentally. Preliminary analysis of the historic inflows into Flaming Gorge indicated that releasing 87 percent (%) of the unregulated inflow would most likely provide enough storage during the spring to achieve the base flow targets. This percentage was applied to the rule that governed releases under the “Run of River” approach during the period from March through July.

The 2000 Flow and Temperature Recommendations call for riverflows during the base flow period (August through February) that are higher than flows that would have occurred naturally. To achieve these flows, water is released from storage during the base flow period. This draws the water surface elevation of Flaming Gorge down during the base flow period. The challenge of this “Run of River” approach was to find a percentage of the spring unregulated inflow that would provide enough storage to achieve the flow objectives during the base flow period while also setting releases high enough during the spring to achieve the flow objectives for the spring. This proved to be very challenging and was not fully accomplished in this study.

# MODEL RESULTS

Table 1 shows the results of how the "Run of River" approach compared to the Action and No Action Alternatives for the spring flow and duration objectives described in the 2000 Flow and Temperature Recommendations. For many of the spring flow objectives, the "Run of River" approach achieved or exceeded the recommended flows and durations for the recommended frequencies. But for flow objectives with extended durations, the "Run of River" approach did not successfully achieve these flow and duration combinations as frequently as recommended. For example, one flow objective of the 2000 Flow and Temperature Recommendations calls for flows in Reach 2 to meet or exceed 18,600 cfs for at least 2 weeks in 40% of all years. The "Run of River" approach, with a release percentage of 87%, accomplished these flows only about 21% of the time. Even when the release percentage was increased to 100%, which would cause the reservoir to store no water during the spring, this flow objective was achieved only 30% of the time. This was a strong indication that the "Run of River" approach implemented for this study could not achieve the 2000 Flow and Temperature Recommendations without having significant impacts on other resources associated with Flaming Gorge. Without achieving all of the flow objectives of the 2000 Flow and Temperature Recommendations, the "Run of River" approach could not meet the purpose and need for the Flaming Gorge EIS and thus was not considered as a viable alternative. Despite these findings, a study of the hydrologic impacts of this "Run of River" approach was done and the results of which are presented in the remainder of this report.

**Table 1.—Spring Flow Objectives of the 2000 Flow and Temperature Recommendations with Model Results**

| Spring Peak Flow Recommendations | Reach | Target % | Action Ruleset | No Action Ruleset | Run of the River Action Ruleset |
|---|---|---|---|---|---|
| Peak >= 26,400 cfs For at least 1 day | 2 | 10% | 11.3% | 7.1% | 13.8% |
| Peak >= 22,700 cfs For at least 2 weeks. | 2 | 10% | 10.7% | 4.6% | 6.2% |
| Peak >= 18,600 cfs For at least 4 weeks. | 2 | 10% | 11.1% | 6.0% | 7.9% |
| Peak >= 20,300 cfs For at least 1 day. | 2 | 30% | 46.3% | 42.3% | 47.2% |
| Peak >= 18,600 cfs For at least 2 weeks. | 2 | 40% | 41.1% | 15.6% | 21.5% |
| Peak >= 18,600 cfs for at least 1 day. | 2 | 50% | 60.3% | 59.1% | 58.5% |
| Peak >= 8,300 cfs for at least 1 day. | 2 | 100% | 100% | 98.5% | 96.9% |
| Peak >= 8,300 cfs for at least 1 week. | 2 | 90% | 96.8% | 96.9% | 89.2% |
| Peak >= 8,300 cfs for at least 2 days except in extreme dry years. | 2 | 98% | 99.6% | 98.4% | 96.9% |

## RESERVOIR WET AND DRY CYCLE RESULTS

To capture the uncertainty of future hydrologic events, 65 sets of historic inflows for the years 1921 through 1985 were routed through the Flaming Gorge model. Each set was systematically varied from the others to provide a range of reasonable inflow patterns that could potentially happen in the future. Because the inflow sets were constructed from historic hydrology over the period from 1921 though 1985, the extreme wet and dry cycles that occurred in these inflow sets were assumed to be the most reasonable extreme events that could likely occur in the future. An example of how the "Run of River" approach, and the Action and No Action Alternatives, operated Flaming Gorge Dam differently under the most extreme wet and dry events that occurred in the model results are shown in figures 1 through 4. Figures 1 and 2 show a comparison of how the three rulesets operated Flaming Gorge Dam through the most extreme 3-year dry cycle. These historic years are 1939, 1940, and 1941. Figure 1 shows what happened to the reservoir elevation while figure 2 shows the release patterns generated by the three rulesets. For consistency of comparison, the initial elevations were all normalized to the actual water surface elevation that occurred on January 2002. Figures 3 and 4 show a comparison of how the rulesets operated Flaming Gorge Dam through the most extreme 3-year wet cycle. These historic years are 1982, 1983, and 1984. Figure 3 tracks the reservoir elevation for each ruleset through this cycle, while figure 4 shows the release patterns generated by the three rulesets.

## RESERVOIR WATER SURFACE ELEVATION PERCENTILE RESULTS

For each of the 65 sets of inflows that were routed through the model, a potential reservoir elevation was calculated for each month. The potential reservoir elevations for each month were ranked from lowest to highest. Figures 5, 6, and 7 show the reservoir elevations for various probabilities of exceedance. Figure 5, for example, shows the reservoir elevations that the model predicted would have a 10-percent chance of being exceeded over the next 10 years with Flaming Gorge operated under the three rulesets. Figure 6 shows reservoir elevations that would have a 50-percent chance of being exceeded, and figure 7 shows reservoir elevations that would have a 90-percent chance of being exceeded. It is important to note that figures 5, 6 and 7 do not represent the reservoir elevations for any single set of inflows but are rather a composite of all of the results from all 65 sets of inflows that were routed through the model.

Typically, Flaming Gorge Reservoir reaches the lowest elevation of the year in late winter. This is because the reservoir is intentionally drawn down to an water surface elevation that provides enough storage space to safely route the anticipated snowmelt runoff during the spring. For this reason, the distribution of February reservoir elevations is shown in figure 8. Figure 8 shows that reservoir elevations for February, under the "Run of River" approach, are the lowest of the three rulesets studied. Similar results are shown in figure 9, which shows the distributions of June reservoir elevations. At the end of June, the reservoir elevation of is typically nearing the highest level of the year. These figures characterize the general trend of how each of the operational regimes will likely affect the reservoir elevation at the high and low points of the year.

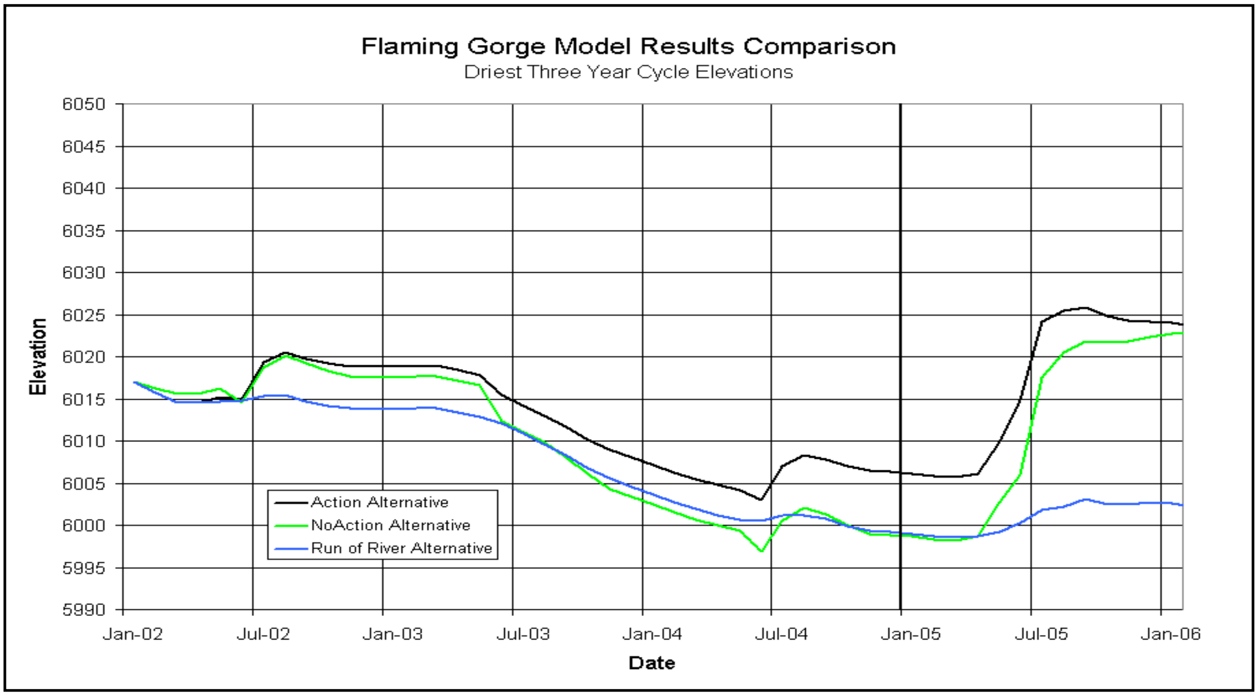


***Figure 1.—Reservoir Elevations Under the Most Extreme 3-Year Dry Cycle.***

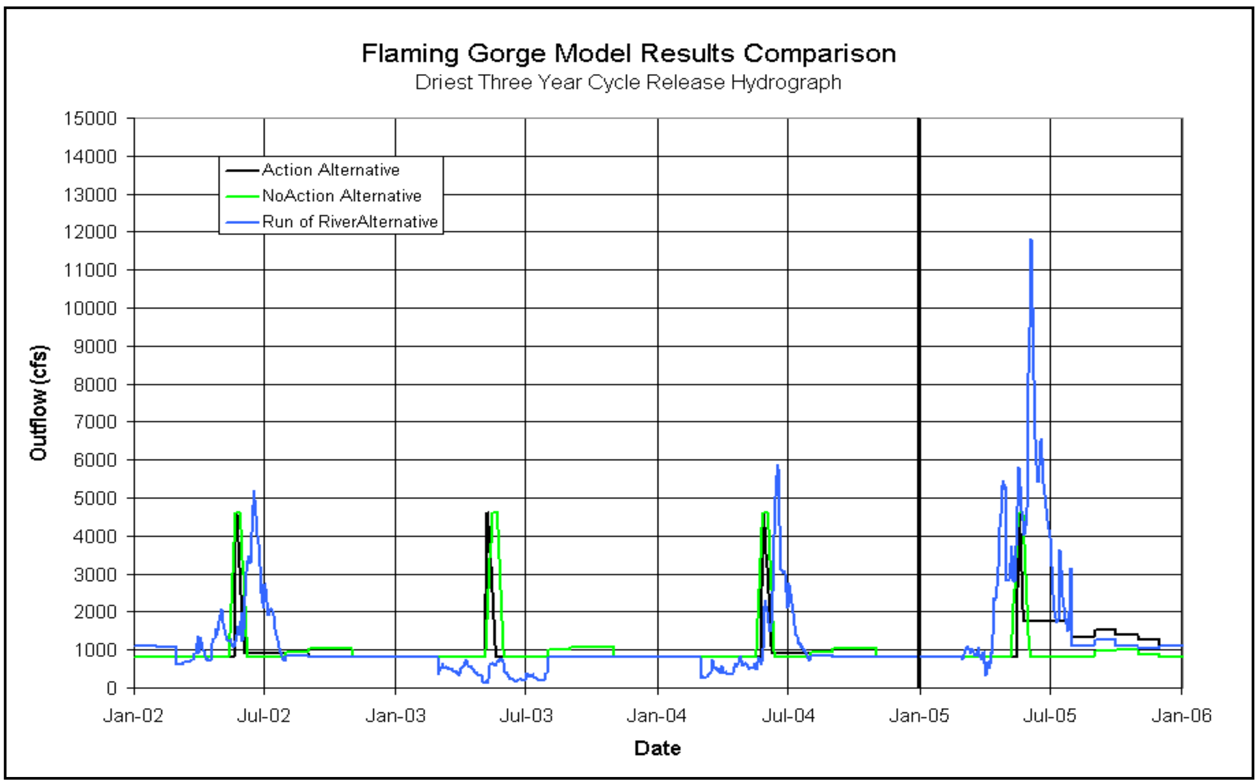


***Figure 2.—Reservoir Releases Under the Most Extreme 3-Year Dry Cycle.***

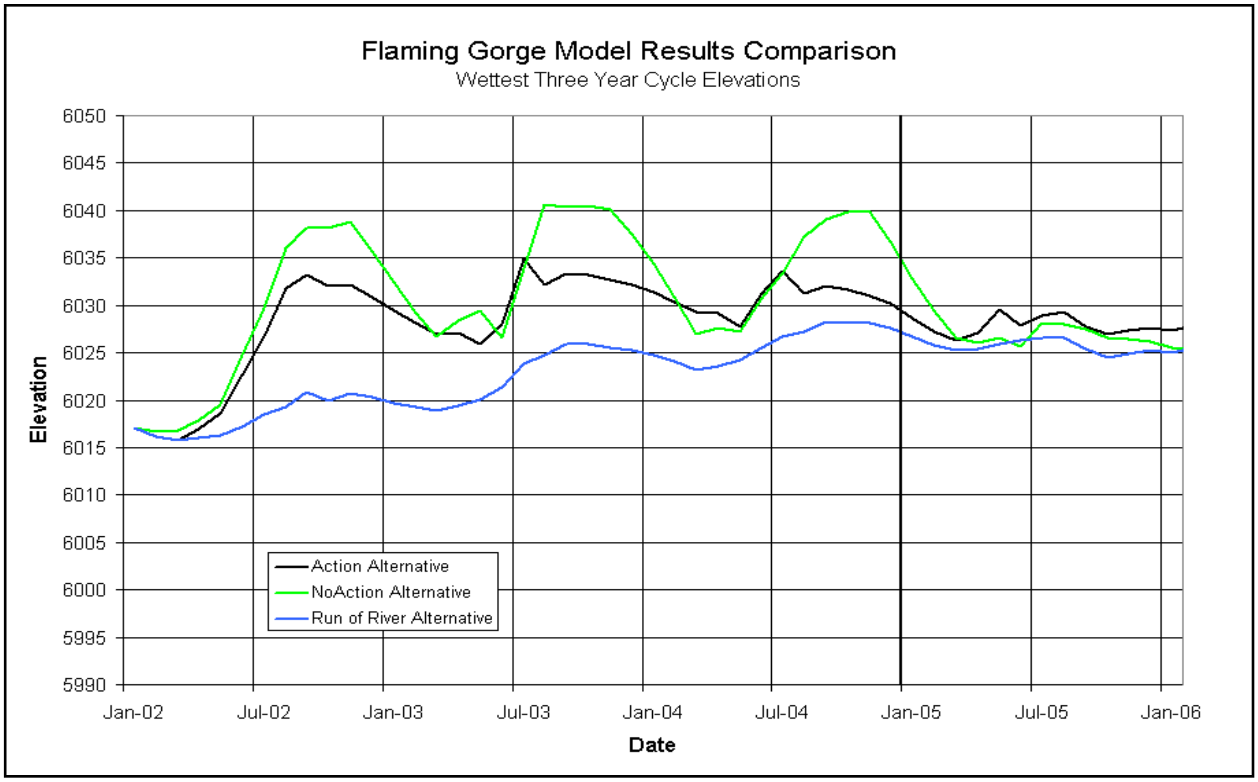


***Figure 3.—Reservoir Elevations Under the Most Extreme 3-Year Wet Cycle.***

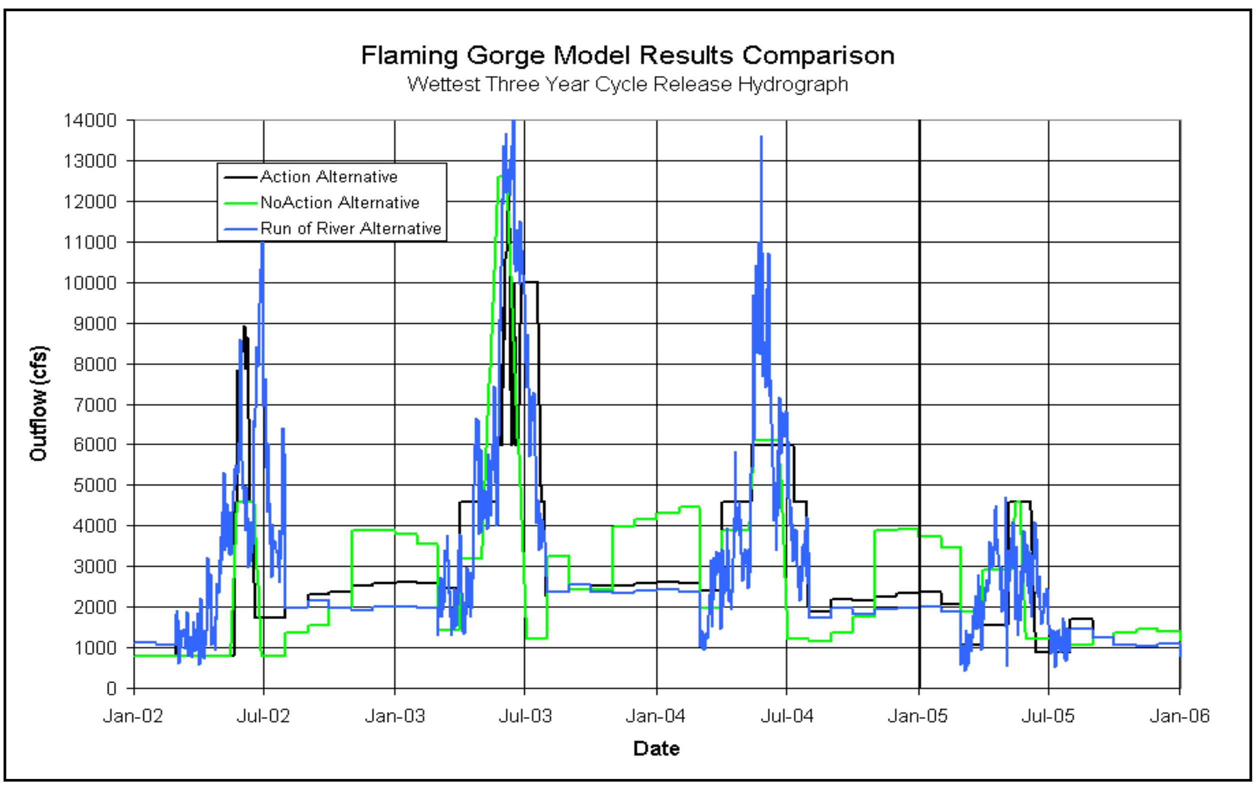


***Figure 4.—Reservoir Releases Under the Most Extreme 3-Year Wet Cycle.***

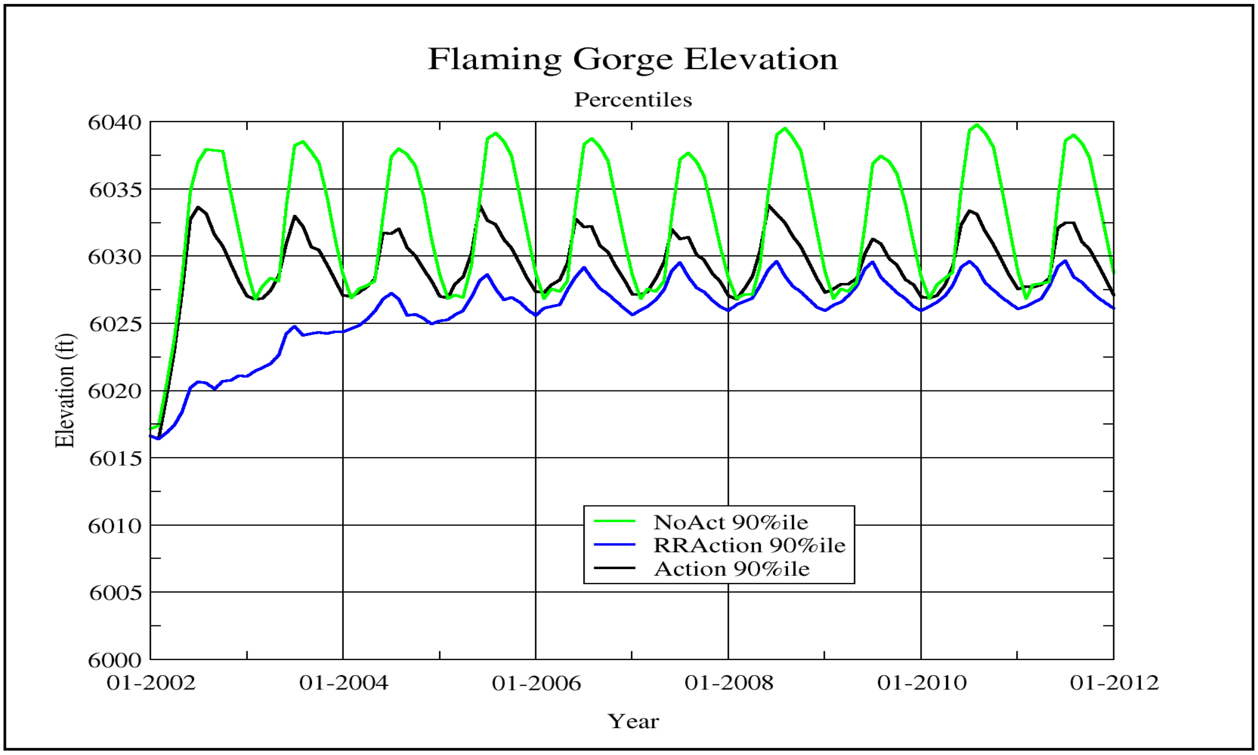


***Figure 5.—10% Exceedance Reservoir Elevations From January 2002 to December 2012.***

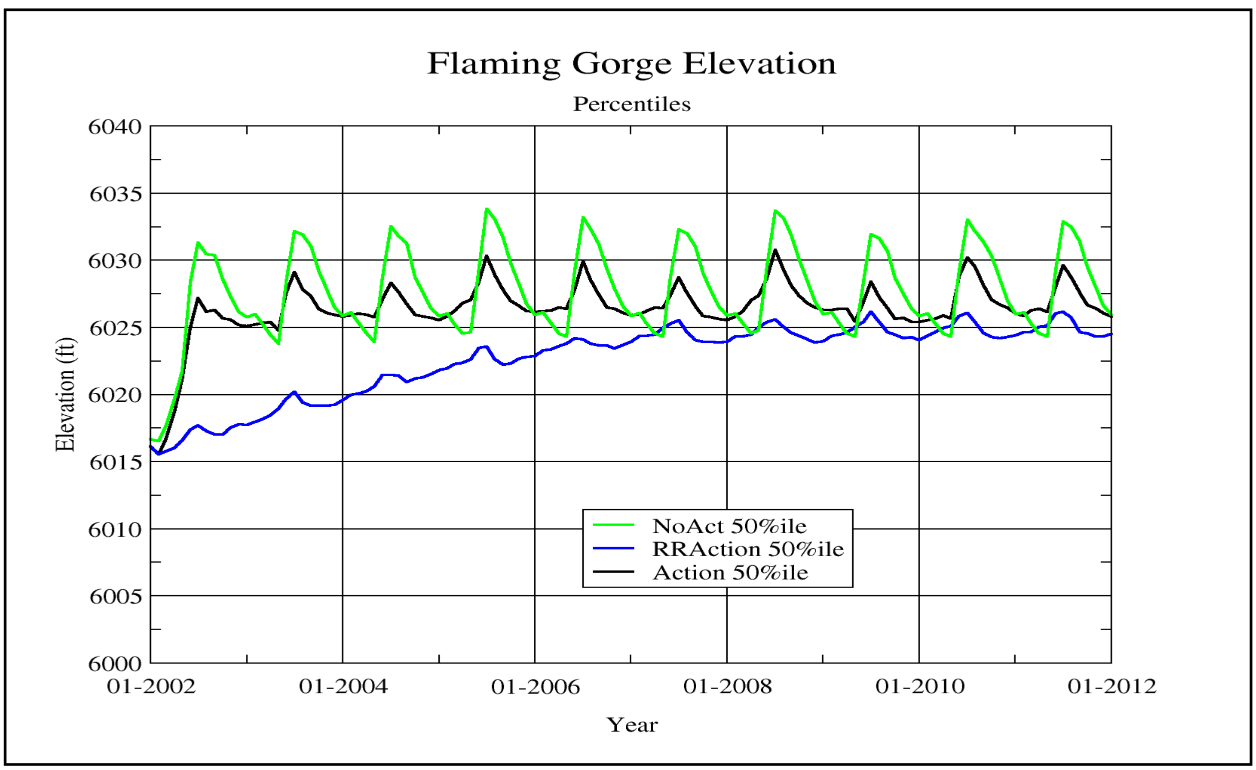


***Figure 6.—50% Exceedance Reservoir Elevations From January 2002 to December 2012.***

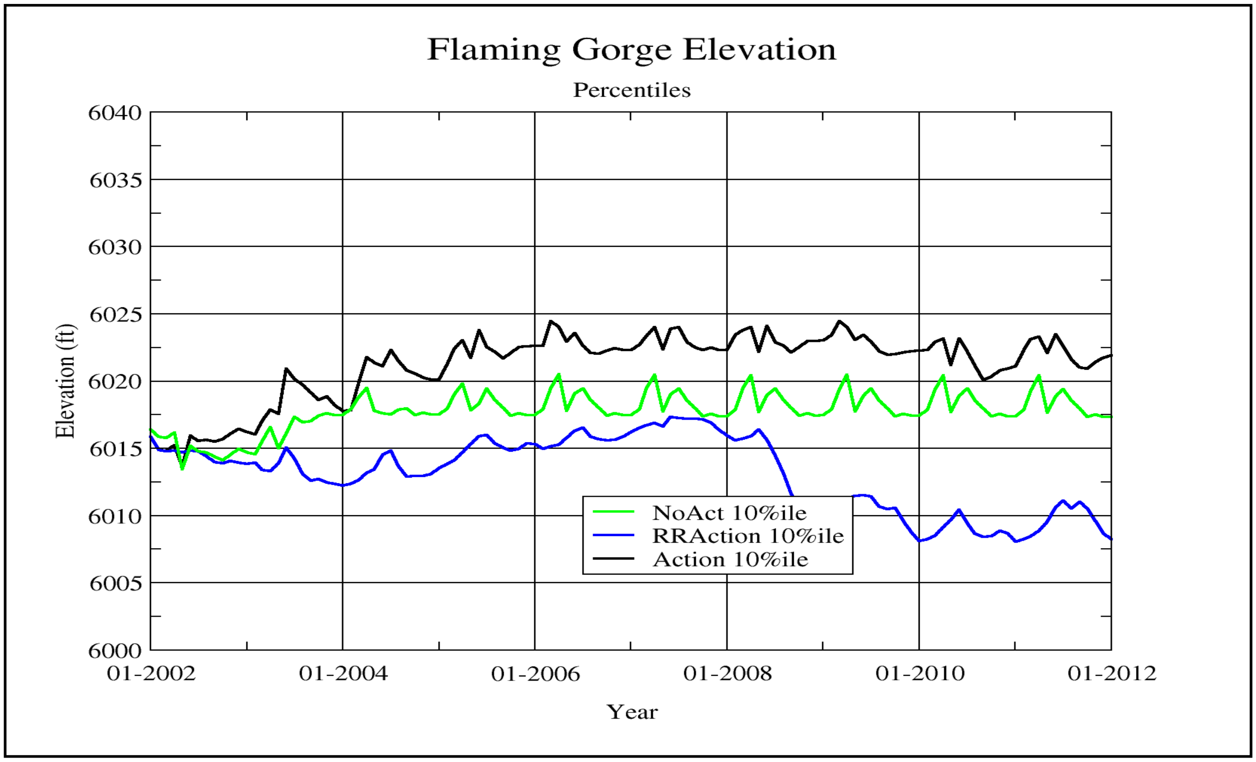


***Figure 7.—90% Exceedance Reservoir Elevations From January 2002 to December 2012.***

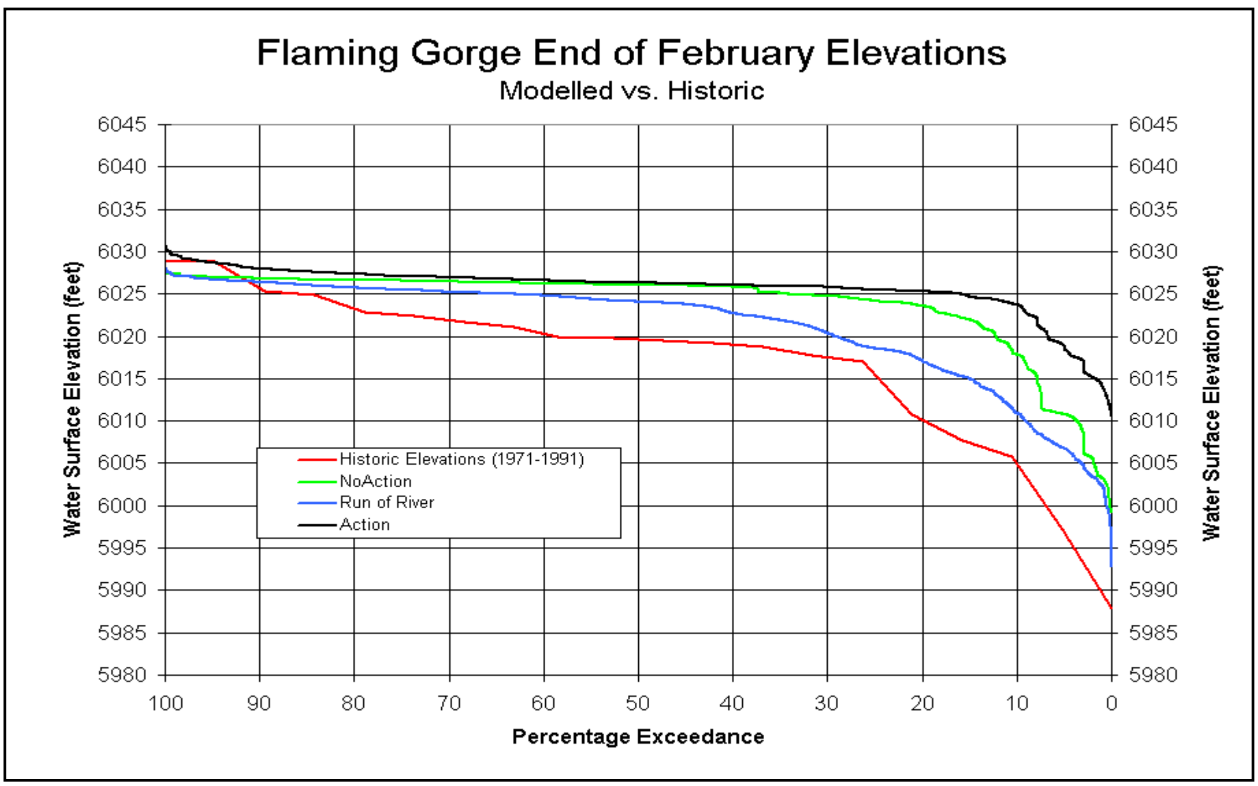


***Figure 8.—February Reservoir Elevation Distribution Plot.***

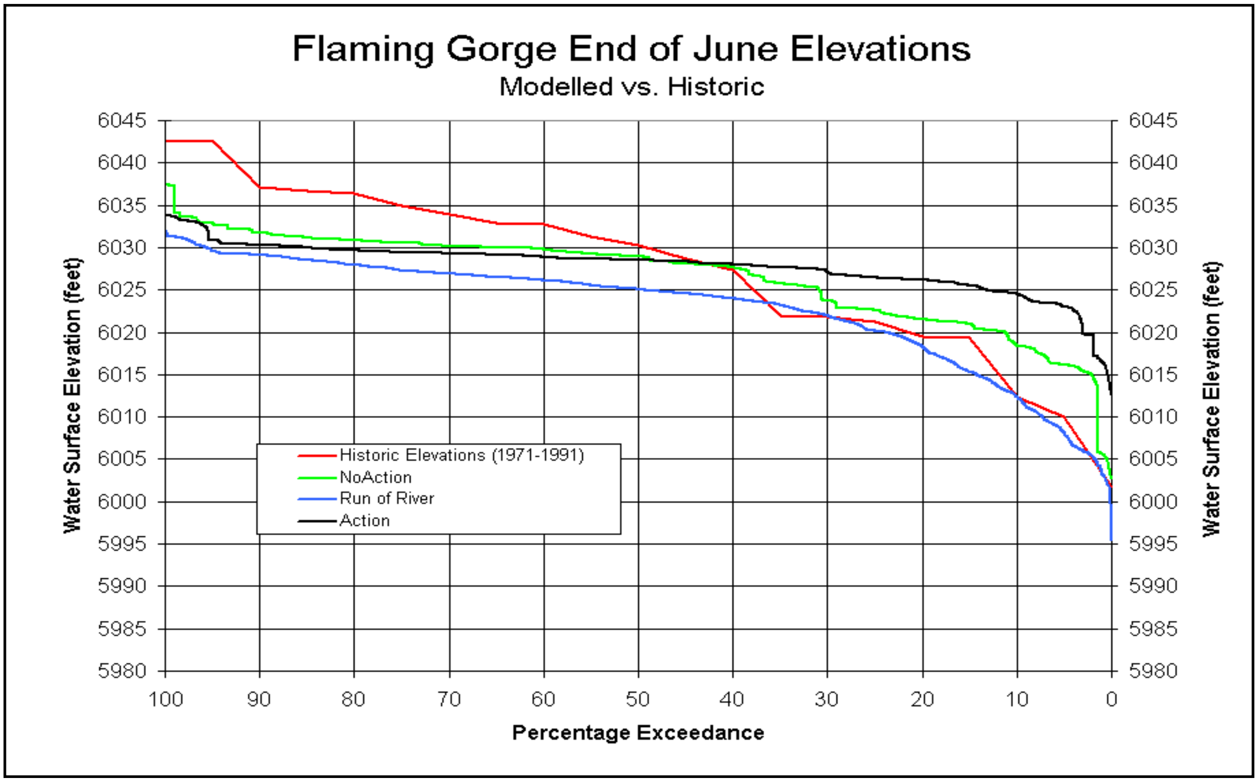


***Figure 9.—June Reservoir Elevation Distribution Plot.***

## REACH 1 SPRING PEAK FLOW RESULTS

The Flaming Gorge model does not account for side inflows that occur along Reach 1 of the Green River. Historically, the volumes of flow contributed by tributaries to the Green River in Reach 1 have been relatively insignificant except during large thunderstorm events. Reach 1 flows that appear in this report are actually the average daily releases made from Flaming Gorge Dam. Figure 10 shows the distribution of peak flows that occurred in the model results having durations of one day for the Action, No Action and "Run of River" approach. Originally, it was assumed that the peak flows would be limited to the months of May, June and July. For the "Run of River" approach, however, it was possible for peak flows to occur in the months of March and April. For this report, however, the peak flows were only analyzed for the May through July period. This is because the flow objectives of the 2000 Flow and Temperature Recommendations during the spring were expected to occur during May-July timeframe and not for the months of March and April. Figures 11 and 12 show the distributions of flows in Reach 1 having durations of two and four weeks respectively. These durations were chosen because the 2000 Flow and Temperature Recommendations specified them as minimum durations for target flows in Reach 2.

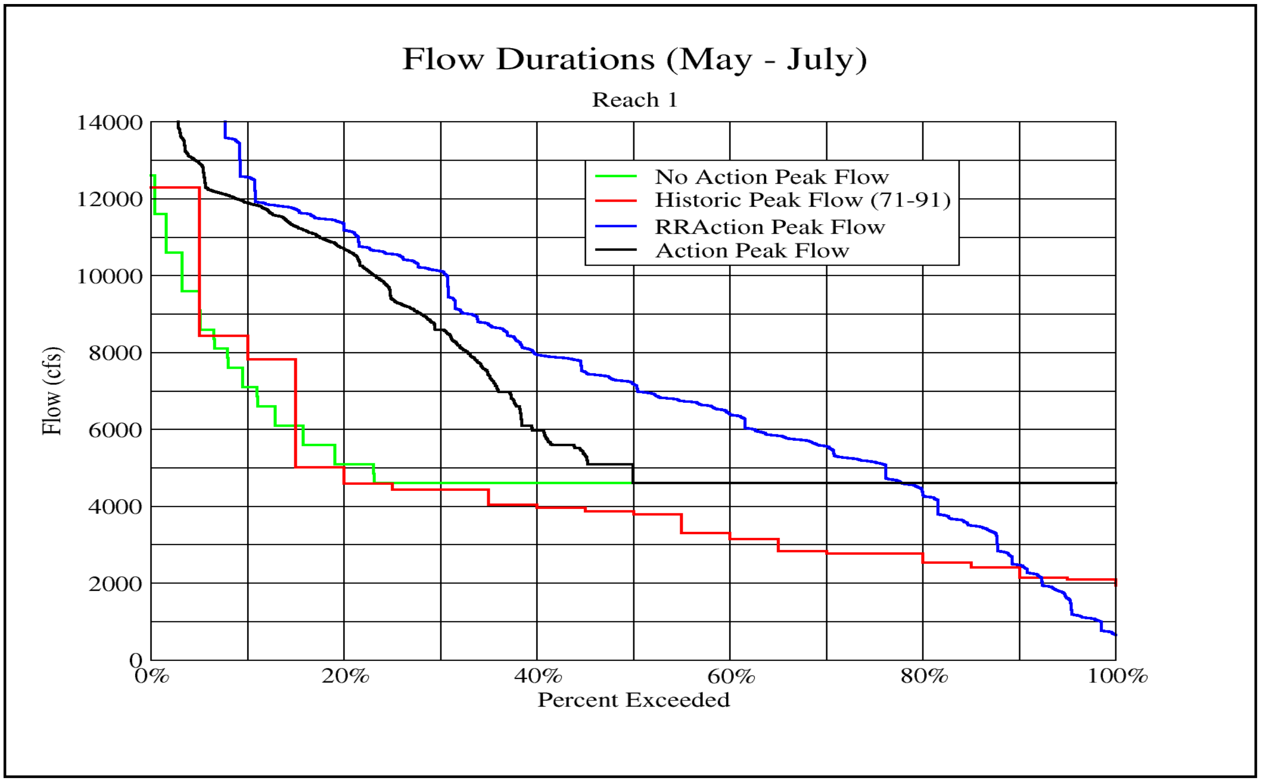


***Figure 10.—Distributions of Peak (1-Day Duration) Releases During May-June.***

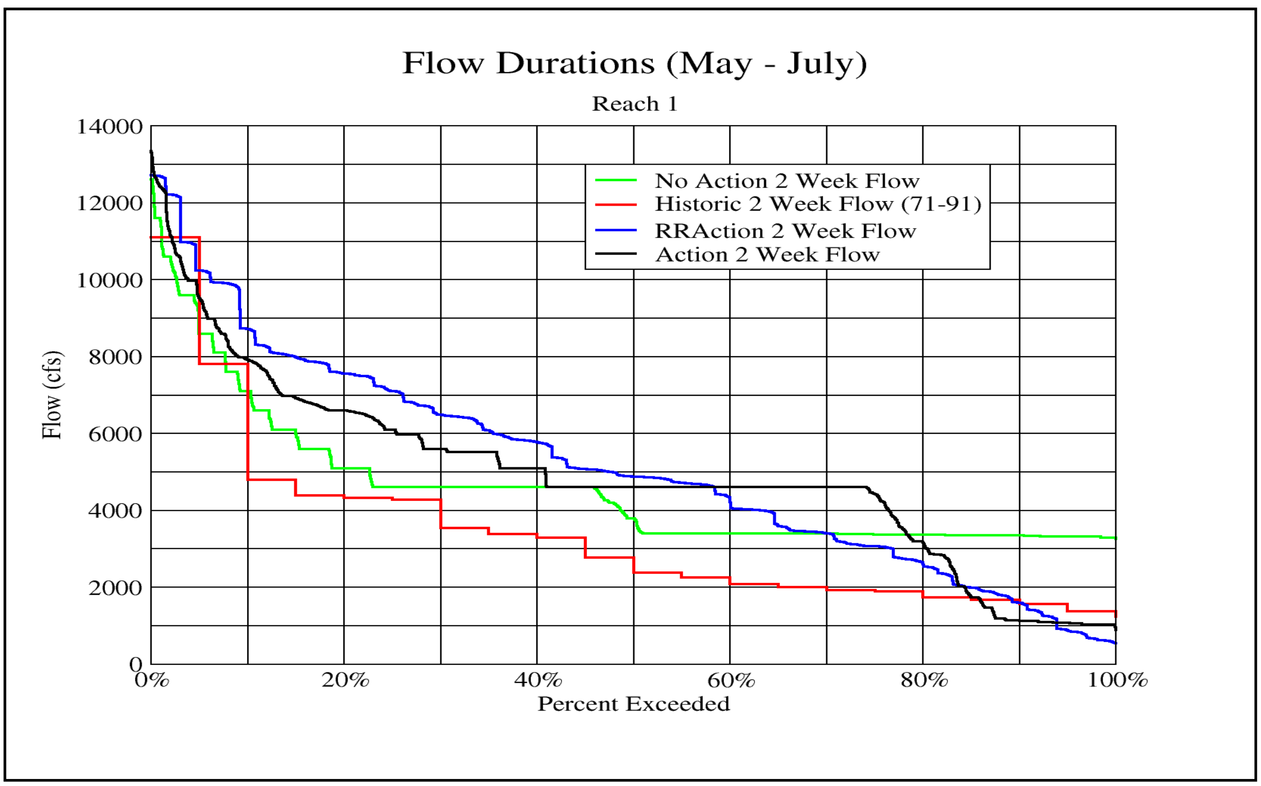


***Figure 11.—Distribution of Peak (2-Week Duration) Releases.***

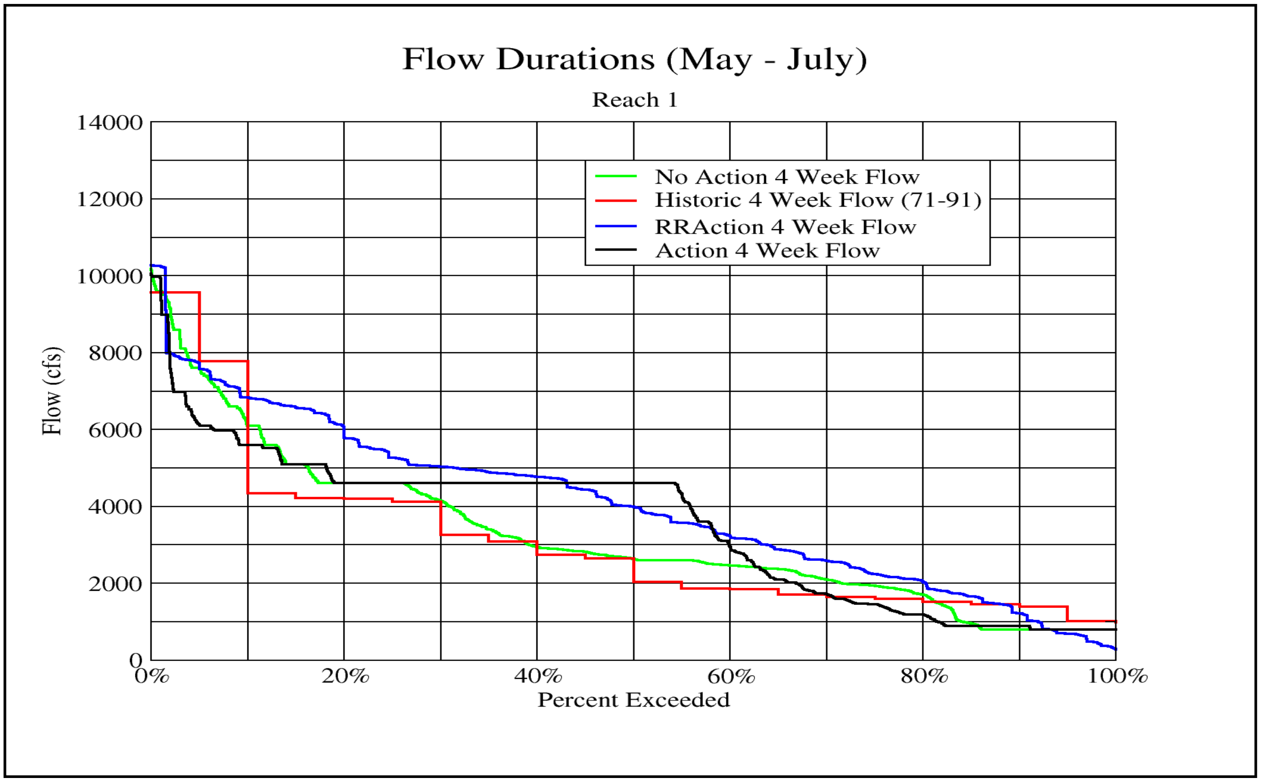


***Figure 12.—Distribution of Peak (4-Week Duration) Releases.***

## FLAMING GORGE ANNUAL BYPASS RELEASE RESULTS

Releases made through the bypass tubes or the spillway that might otherwise have been made through the powerplant have a direct impact on power produced at Flaming Gorge Dam. As a rough method of comparing the Action and No Action Alternatives to the "Run of River" approach in terms of impact to power production, the distributions of annual bypass volumes are shown in figure 13. The figure shows that bypasses occurred most often for the "Run of River" approach and that bypass volumes of the same frequency of occurrence were higher for the "Run of River" approach than for the other two alternatives.

## REACH 1 AUGUST THROUGH FEBRUARY BASE FLOW RELEASE RESULTS

The 2000 Flow and Temperature Recommendations call for specific ranges of base flow levels depending on the hydrologic classification that was determined at the end of the spring period. Under the Action Alternative, and "Run of River" approach, the total spring volume of unregulated inflow measured on August 1st of each year set the hydrologic classification, which in turn, set the target range of flows to be established for the base flow period. A target range of flows was specified for both Reaches 1 and 2. Depending on the reservoir elevation, the model

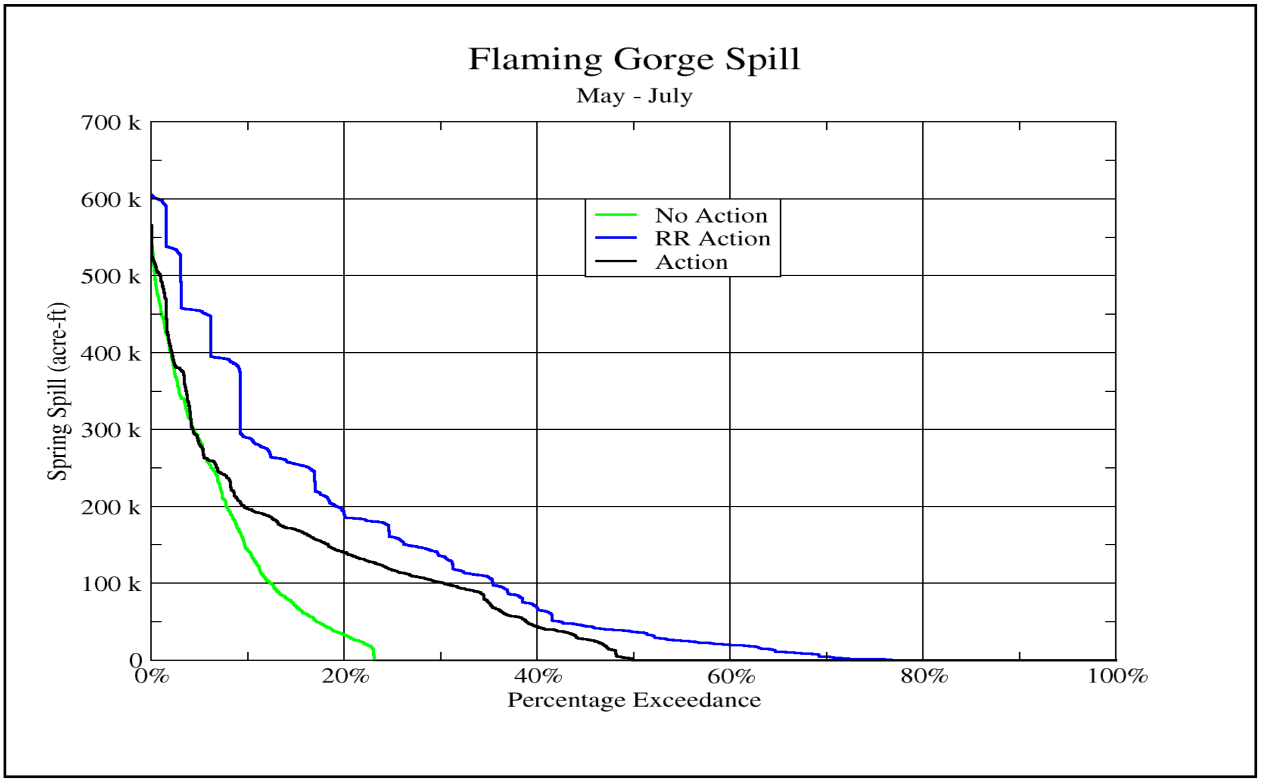


***Figure 13.—Annual Bypass Volume Distributions.***

determined what release rate would achieve the base flow objectives while also achieving a drawdown target by the end of February. When the reservoir elevation was below the normal operational elevation, the release rate was set to a lower level within the specified range. When the reservoir elevation was above the normal operational elevation, the release rate was set to a higher level within the specified range. In all cases, except when safety of the dam was in question, releases were controlled so that the flow objectives in Reach 2 were always achieved for the hydrologic classification, even when the drawdown target for the end of February could not be achieved. Figure 14 shows that the "Run of River" approach consistently selected base flow levels that were lower than the Action and No Action Alternatives. The most likely reason for this was because the reservoir elevations under the "Run of River" approach were often lower than the corresponding elevations under the Action and No Action Alternatives. To give some perspective to the model results shown in figure 14, the distribution of historic inflows and historic unregulated inflows are also shown in the figure. Unregulated inflows are corrected for river regulation at Fontenelle Reservoir and give a better idea of what inflows would be like without upstream reservoir regulation.

## REACH 2 SPRING PEAK FLOW RESULTS

Figures 15, 16, and 17 show the relationships between the peak flows that occurred each spring in Reach 2. Although, the "Run of River" approach did not achieve all of the flow objectives of the 2000 Flow and Temperature Recommendations, the distribution of peak flows generated by the "Run of River" approach, compared to those for the Action and No Action Alternatives, was very similar in Reach 2.

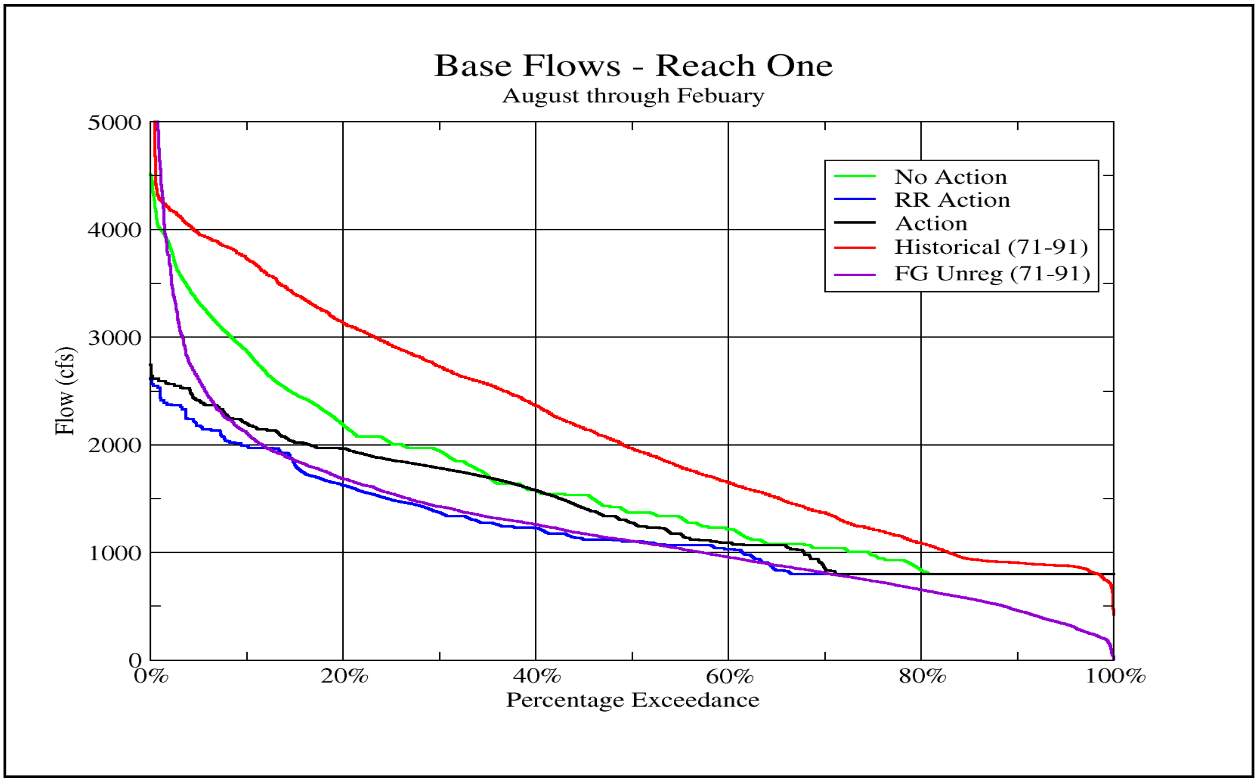


***Figure 14.—Exceedance Percentage Flows for Reach 1 Flows During Base Flow Period.***

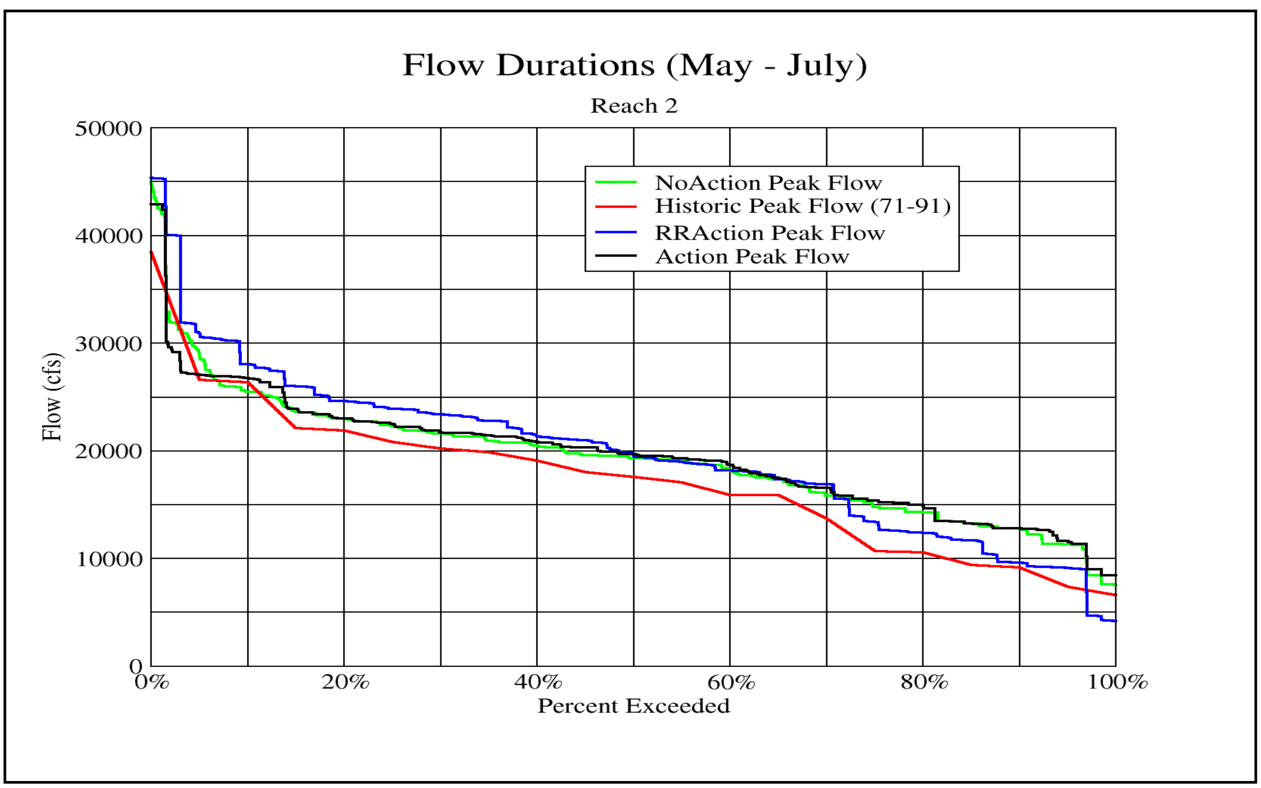


***Figure 15.—Distribution of Peak Flows (1-Day Duration) in Reach 2.***

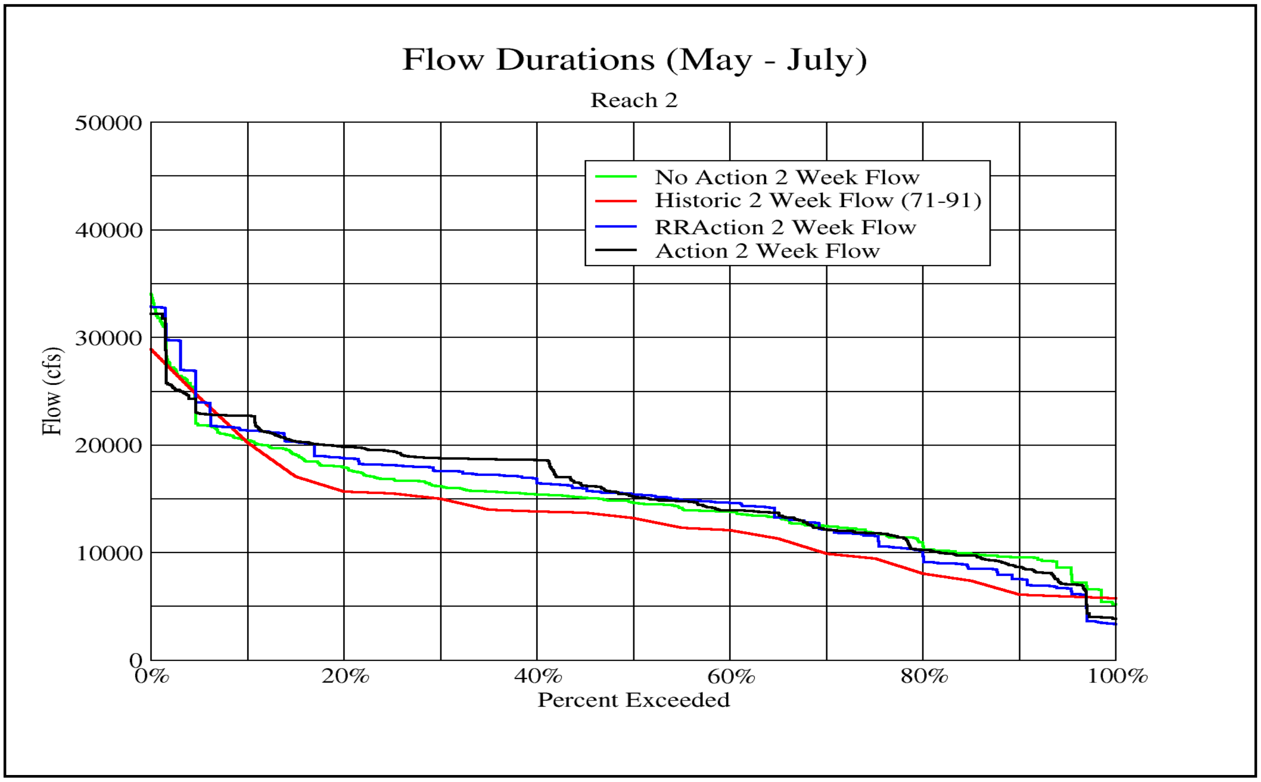


*Figure 16.—Distribution of Peak Flows (2-Week Durations) in Reach 2.*

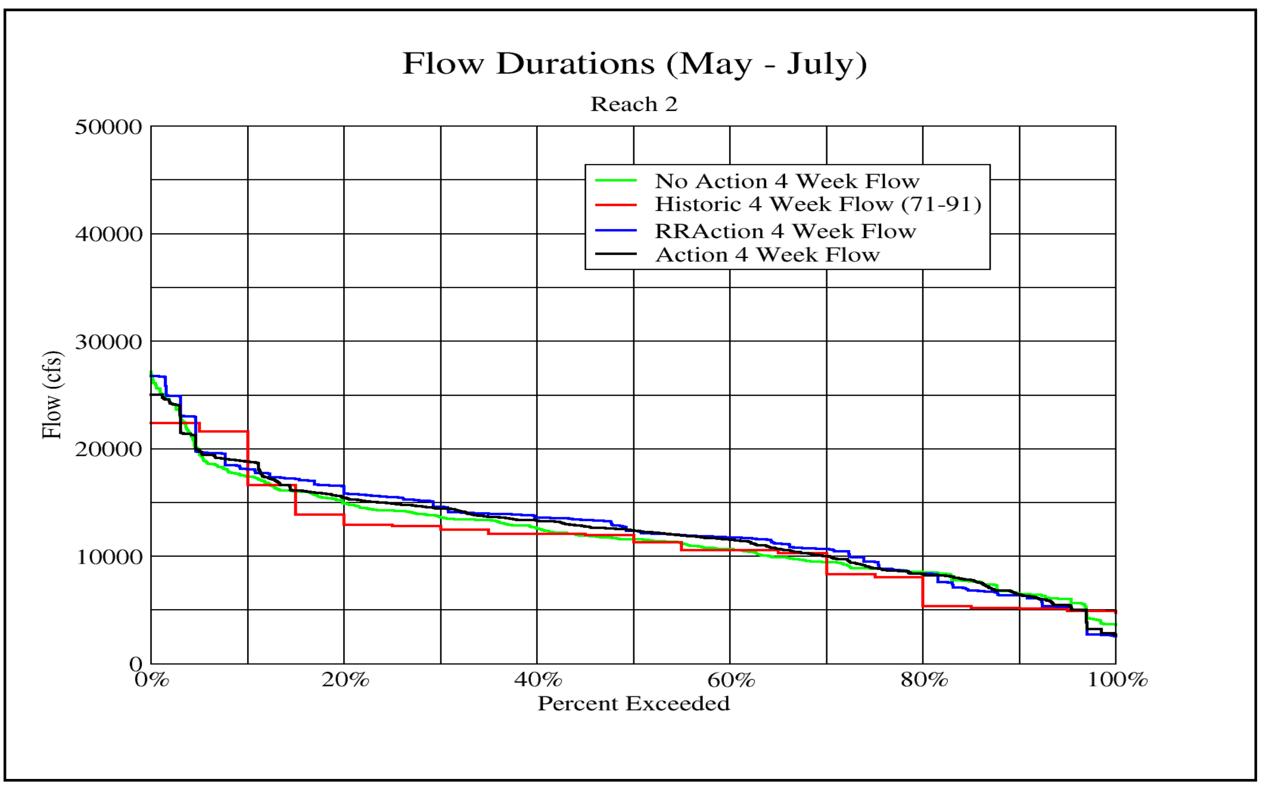


*Figure 17.—Distribution of Peak Flows (4-Week Durations) in Reach 2.*

## REACH 2 BASE FLOW RELEASE RESULTS

Figure 18 shows the distribution of base flows that occurred in Reach 2. Base flow levels were noticeably lower under the "Run of River" approach. As with Reach 1, the difference between the base flow levels for the Action Alternative and the "Run of River" approach can largely be attributed to the difference between the reservoir elevations generated under the respective rulesets. Typically, the "Run of River" ruleset operated Flaming Gorge Dam such that the reservoir elevations were often lower than when the dam was operated under the Action and No Action Alternatives.

## SUMMARY

Preliminary analysis of the historic inflows into Flaming Gorge did show that it might be possible to operate Flaming Gorge under a modified "Run of River" approach to achieve the flow objectives of the 2000 Flow and Temperature Recommendations during the spring. However, this analysis did not account for the current levels of consumptive water use that is occurring along the Green River above Flaming Gorge or the fact that this rate of consumptive use is expected to increase in the future. The Flaming Gorge model, on the other hand, does account for current and increasing consumptive use in the future. Currently, about 450,000 acre-feet of Green River water is consumed above Flaming Gorge Reservoir each year. This is about 25% of the mean annual natural inflow into Flaming Gorge Reservoir. More importantly, diversions for

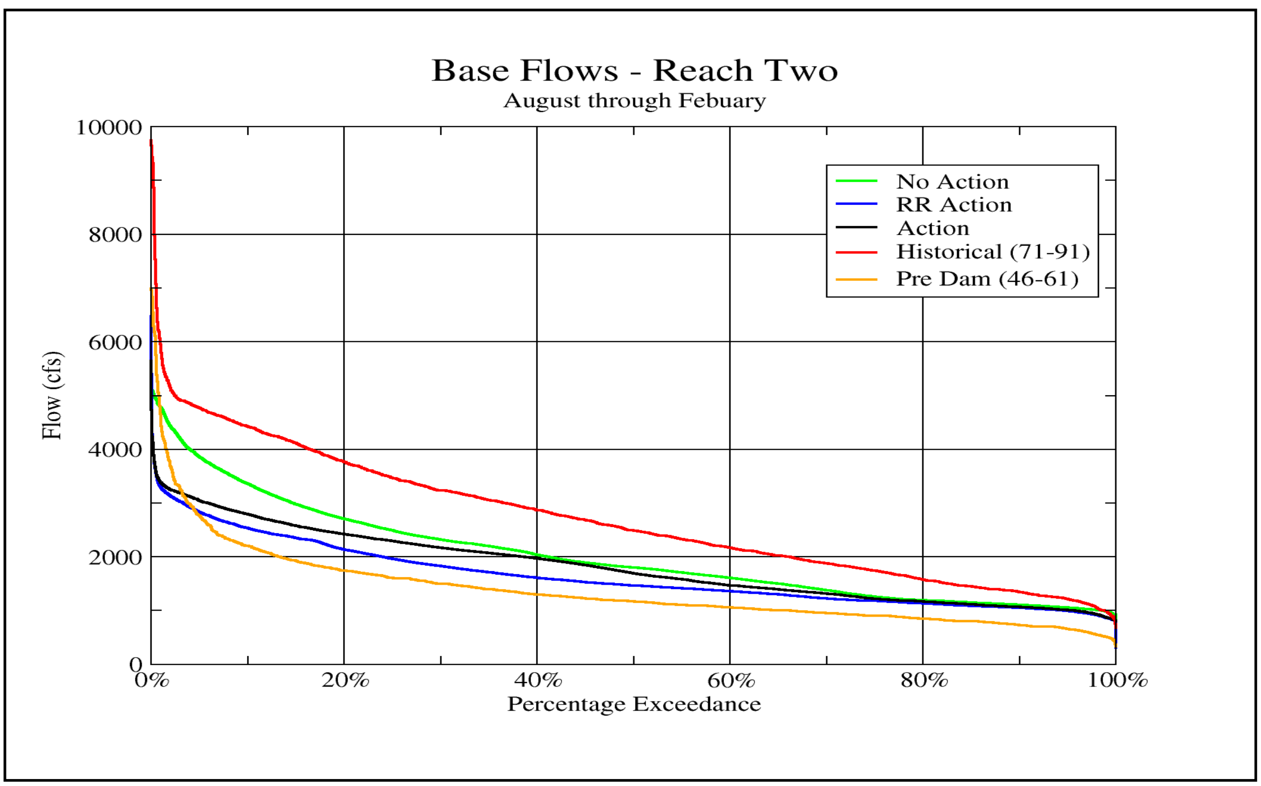


***Figure 18.—Exceedance Percentage Flows for Reach 2 Flows During Base Flow Period.***

irrigation occur most heavily during the months of May through August. These diversions decrease the unregulated inflow into Flaming Gorge Reservoir during the spring, which in turn, causes the modified "Run of River" methodology to release less water. Water use on the Green River has, and will continue to have, a significant impact on the inflows to Flaming Gorge Reservoir and consequently the impact this increasing use of water will impact the ability of any modified "Run of River" approach to achieving the 2000 Flow and Temperature Recommendations.

While constructing the ruleset for the Action Alternative, it was learned that some of the flow objectives in the 2000 Flow and Temperature Recommendations were more difficult to achieve than others. For example, there are two objectives that call for flows in Reach 2 to be at least 18,600 cfs for a minimum of 2 weeks in at least 40% of all years in one objective, and 18,600 cfs for a minimum of 4 weeks in at least 10% of all years in the other objective. These objectives proved to be the most difficult targets to achieve. To meet this challenge, it was necessary for operational decisions under the Action Alternative to have some input from conditions on the Yampa River. The Action Alternative ruleset assumes that it will be possible to accurately estimate the future flows on the Yampa River given current river flow, snow, temperature, and forecasted temperature conditions in the Yampa River Basin. This assumption allows the Action Alternative ruleset to set releases for the current day such that Reach 2 flows will meet or exceed a target flow objective on the following day within a small degree of error.

Operating Flaming Gorge under the modified "Run of River" methodology, however, does not require information about the Yampa River. Instead, this method relies only on the previous day's unregulated inflow into Flaming Gorge Reservoir for determining what releases are to be made during the current day. As a result, releases from Flaming Gorge, under the modified "Run of River" methodology, were not controlled such that timing with the Yampa Peak was optimal. For this reason, releases under the modified "Run of River" methodology did not achieve all of the flow objectives of the 2000 Flow and Temperature Recommendations even when the volume of water released from Flaming Gorge Dam were typically greater than that released under the Action Alternative. This proved to be the major drawback of the modified "Run of River" methodology because while release volumes during the spring were much higher than those for the Action Alternative, the spring flow objectives of the 2000 Flow and Temperature Recommendations were not fully achieved. Even when the ruleset was adjusted to release 100% of the unregulated inflow, these duration objectives were still not fully achieved. Based on these findings, the modified "Run of River" Alternative proved not to be a viable alternative that could be included for analysis in the Flaming Gorge Environmental Impact Statement.

## DOCUMENTATION OF HOW DAILY INFLOWS WERE CREATED FOR THE MODIFIED RUN OF THE RIVER ALTERNATIVE

The available data for development of the Flaming Gorge daily inflows consisted of the following.

1. Flaming Gorge inflows calculated from releases from Flaming Gorge, delta storage and estimated evaporation.
   Period: October 1, 1962 to December 31, 1985

2. Green River flows measured at the Greendale gauge.
   Period: October 1, 1950 to September 30, 1962
3. Green River flows measured at the Lynnwood gauge.
   Period: October 1, 1928 to September 30, 1950
4. Green River flows measured at the Green River, Utah, gauge less Yampa River flows measured as the sum of the Little Snake River flows measured at the Lily gauge and Yampa River flows measured at the Maybell gauge lagged by 2 days. The adjusted Green River flows were then shifted 2 days to account for travel time between Greendale and Green River, Utah.
   Period: January 1, 1921 to September 30, 1928.

This dataset is then corrected so that the daily volumes summed to each month match the monthly volume of inflow calculated by the Flaming Gorge monthly model, which accounts for current and increasing future depletions above Flaming Gorge. This correction is done during the model run by multiplying the daily input flow by the ratio of the modeled monthly inflow volume over the sum of the daily input volumes for the given month. This correction adjusts the daily flows that the monthly volumes will match those used in the Flaming Gorge monthly model.