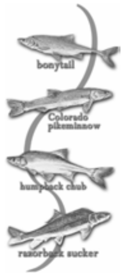
Operation of Flaming Gorge Dam Final Environmental Impact Statement

Hydrologic Modeling Technical Appendix



HYDROLOGIC MODELING TECHNICAL APPENDIX

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Hydrologic Modeling Technical Appendix

RESULTS OF ACTION AND NO ACTION ALTERNATIVE ANALYSIS

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INTRODUCTION

A model of the Green River Basin has been developed to simulate the operations of Flaming Gorge Dam under varying hydrologic conditions. The Green River model was developed for the purpose of characterizing the hydrologic effects to Flaming Gorge Reservoir and the Green River below Flaming Gorge Dam caused by the implementation of the proposed alternatives for the Flaming Gorge Dam Environmental Impact Statement (Flaming Gorge EIS).

Two alternatives have been proposed for the Flaming Gorge EIS. The Action Alternative requires Flaming Gorge Dam to be operated to achieve the flow recommendations described in the *Flow and Temperature Recommendations for Endangered Fishes in the Green River Downstream of Flaming Gorge Dam* (2000 Flow and Temperature Recommendations). The No Action Alternative requires Flaming Gorge Dam to be operated to achieve the recommended flows described in the 1992 Biological Opinion on the Operation of Flaming Gorge Dam (1992 Biological Opinion). At the present time and since 1992, Flaming Gorge Dam has been operated to achieve the flow objectives of the 1992 Biological Opinion.

For each of these alternatives, the authorizing purposes of Flaming Gorge Reservoir are to be "maintained" in such a way that impacts to these resources are minimized. In the Green River model, rules to operate Flaming Gorge Dam to achieve the flow objectives described in the 2000 Flow and Temperature Recommendations and the 1992 Biological Opinion were developed. These rules were then modified to reduce the occurrences and magnitudes of bypass releases while still achieving the flow objectives of the alternative. Reducing the occurrences and frequencies of bypasses was the method used to "maintain" the purposes for which Flaming Gorge Dam was authorized.

The purpose of this report is to summarize the hydrologic effects observed in the model output as a result of achieving the flow objectives of each proposed alternative. The results in this report focus on the model output from Flaming Gorge Reservoir and the Green River below Flaming Gorge Dam.

MODELING SCOPE

The Green River model was created from an existing model called the Colorado River Simulation System (CRSS). The CRSS has been used for several years to identify impacts to reservoirs in the Colorado River Basin under different hydrologic scenarios. Most recently, CRSS was used to quantify the impacts of the proposed alternatives for the Colorado River Interim Surplus Criteria Environmental Impact Study (2000).

All major elements of the Green River System are represented in the Green River model, and some elements are more accurately represented than others. The Green River below Flaming Gorge Dam is divided into three sections, known as reaches, in the 2000 Flow and Temperature Recommendations. All three of these reaches are represented in the Green River model. Reach 1 extends from the tailrace of Flaming Gorge Dam to the confluence with the Yampa River. Reach 2 extends from the confluence of the Green River with the Yampa River to the confluence of the Green River with the White River. Reach 3 extends from the confluence of the Green River with the White River to where the Green River meets the Colorado River. The flows for Reaches 1 and 2 are more accurate in the model than those for Reach 3. This is because the effects of the White and Duchesne Rivers on the flows in the Green River are not fully understood. At this point, these river systems have not been adequately modeled to determine how they will be regulated and developed in the future. For this reason, results for Reach 3 have not been included in this report.

The Green River model routes natural flows (river flows that do not include human interferences such as depletion and regulation), referred to as input hydrology, through the reservoir system on the Green River (Fontenelle and Flaming Gorge Reservoirs). A monthly natural flow database was developed for the Upper Colorado River Basin for use as input hydrology for CRSS. The input hydrology for the Green River model was selected from this database. A period of record was selected that had the most complete natural flow dataset available for the upper Green River Basin. This period begins in January 1921 and ends in December 1985 (65 calendar years). The natural flow data is being extended to 1995; however, this work has not yet been completed. The Green River model will be re-evaluated with this additional data for the Final Flaming Gorge EIS.

The initial conditions of the Green River model were selected to be the state of the Green River system in January of 2002 as described in the 2000 Annual Operating Plan (AOP) for Colorado River System Reservoirs. The 2000 AOP was based on the August 2000 run of the 24-Month Study Operational Model of the Colorado River. The Green River model runs for 39 years to December 2040.

Beyond 2040, estimated depletion schedules for water users represented in the model were considered too speculative to be useful. Depletion schedules were updated to reflect water development forecasts produced by the Upper Colorado River Commission (1999). Given the uncertain nature of water development schedules far into the future and the fact that the model predicted reservoir elevations that appeared stabile in the distant future, ending the model run in 2040 was reasonable.

Different hydrologic scenarios, referred to as input traces, are routed through the Green River model. Each trace is one set of 39 years of natural flows. Because the input hydrology for the model is based on historic hydrology, all the input traces have a high probability of occurring in the future. No single input trace, or set of input traces, has a higher probability of occurring then any of the other input traces. The Index Sequential Method (ISM) was used to construct 65 input traces for the Green River model from the natural flow dataset selected. The ISM involves incrementing the beginning and ending years of the natural flows for the following input trace by 1 year. For example, the first trace of the model began with the natural flows for January 1921, and ended 39 years later with the natural flows for December 1959. The second trace began with natural flows for January 1922 and ended in December 1960. Subsequent traces were developed in this manner until the end of the period of record was reached (December 1985). Once the end of the period of record was reached, additional traces were created by incrementally appending the initial natural flows from the period of record to the end of the trace so that the length of the trace was 39 years long. For example, the 28th trace contained the natural flows for January 1948 through December 1985, but this only equaled 38 years. To extend this trace to a length of 39 years, the natural flows for January 1921 through December 1921 were added to the end of the 28th trace. The 29th trace required that 2 years of natural flows (January 1921 through December 1922) be appended to the end of the trace to achieve a length of 39 years. This process was continued until all 65 traces were constructed. When the Green River model is run, the model run is complete when all 65 input traces have been successfully routed through the Green River system.

To evaluate how well each run of the model achieved the flow objectives of the proposed alternatives, it was necessary to generate output at a daily timestep for river flows in Reaches 1 and 2. A daily post processor model was constructed for this purpose. The daily post processor model generated the spring release hydrograph from the monthly model results and processed it into daily results. The daily release hydrograph was then routed through Reaches 1 and 2 of the Green River. The historic daily flows of the Yampa River for the period from January 1, 1921, to December 31, 1985, were taken from United States Geological Survey stream flow records and were used as the input hydrology by the daily post processor. There are no rules in the daily post processor that operate Flaming Gorge Dam that are unique to the daily postprocessor model. All of the rules necessary to operate Flaming Gorge Dam to achieve the proposed alternatives are present in the monthly model and the daily post processor model.

RULESET DEVELOPMENT

The rules that operate Flaming Gorge Dam to achieve the objectives of the proposed alternatives are referred to as rulesets. For each of the proposed alternatives, one ruleset has been developed. The paragraphs below describe the specific objectives that each ruleset was designed to achieve.

During the spring (April through July), the objectives of the Action Alternative require a peak release magnitude of sufficient duration to achieve flow targets in Reaches 1 and 2. These objectives change depending on the hydrologic condition of the upper Green River Basin. Except for cases when the minimum release rate of 800 cubic feet per second (cfs) is prescribed, the objectives for Reach 2 appear to achieve the objectives for Reach 1 as well. The spring objectives of the Action Alternative for Reach 2 that are achieved by the Action ruleset are described below.

1. Achieve peak of 26,400 cfs for at least 1 day in 10 percent (%) of all years
2. Sustain peak of 22,700 cfs for at least 2 weeks in 10% of all years
3. Sustain peak of 18,600 cfs for at least 4 weeks in 10% of all years
4. Achieve peak of 20,300 cfs for at least 1 day in 30% of all years
5. Sustain peak of 18,600 cfs for at least 2 weeks in 40% of all years
6. Achieve peak of 18,600 cfs for at least 1 day in 50% of all years
7. Sustain peak of 8,300 cfs for at least 1 week in 90% of all years
8. Sustain peak of 8,300 cfs for at least 2 days in 98% of all years
9. Achieve peak of 8,300 cfs for at least 1 day in 100% of all years

These requirements were derived from table 5.5 in the 2000 Flow and Temperature Recommendations. The 2000 Flow and Temperature Recommendations are divided into five separate categories depending on the type of hydrologic conditions experienced in the upper Green River Basin. The objectives described above aggregate all of the flow objectives in the separate categories of the 2000 Flow and Temperature Recommendations into one group.

The Action Alternative also has flow objectives for the summer, autumn and winter. During this period (August through February), the Action ruleset controls the releases from Flaming Gorge Dam to achieve flow objectives for Reach 1 and 2 while attempting to lower the reservoir water surface elevation to a target of 6027 feet above sea level by the beginning of March. The Action ruleset maintains releases to achieve the flow objectives during the base flow period unless the reservoir elevation rises to 6040 feet above sea level or greater. When this occurs, releases are controlled by a maximum storage rule that prevents uncontrolled spills. When the inflow into Flaming Gorge during the base flow period is greater than anticipated and the elevation is below 6040, the flow objectives are maintained; and the target elevation will not be achieved. Releases during March and April attempt to reset the elevation of the reservoir to 6027 feet above sea level by the beginning of May by making releases in the range from 800 to 4,600 cfs.

The No Action Alternative has spring flow objectives that are less specific than the Action Alternative. Instead, the flow objectives of the No Action Alternative focus more on flows during the summer and autumn period. The flow objectives of the No Action Alternative during the spring require a peak release with a magnitude of at least 4,600 cfs (powerplant capacity) and a duration from 1 to 6 weeks in all years. In wet years, the No Action ruleset makes the duration of the peak release approach 6 weeks in length. In dry years, the duration is set to at least 1 week in length. The No Action ruleset determines a spring release volume by attempting to control the reservoir elevation to achieve a fill target for the end of July. This volume is then shaped into a spring peak hydrograph that achieves the spring objectives described above.

During the summer and autumn (before October), releases from Flaming Gorge Dam are managed by the No Action ruleset so that flows in Reach 2 are between 1,100 and 1,800 cfs. In October, releases are managed so that flows in Reach 2 are between 1,100 and 2,400 cfs. From November through February, there are no restrictions placed on flows during the base flow period. The model restricts these flows to the range from 800 to 4,600 cfs to lower the reservoir elevation to a target of 2027 feet above sea level by the beginning of March. These constraints are violated only when the reservoir elevation gets too high for safe operation of , Flaming Gorge Dam (6040 feet above sea level). In March and April, releases are controlled between 800 and 4,600 cfs to achieve a reservoir elevation target of 6027 feet above sea level by May. The rule, which operates Flaming Gorge Dam during March and April, is identical in both the Action and No Action rulesets.

MODELING ASSUMPTIONS

Because of the limitations of the modeling environment, many assumptions were made in the development of the Green River model and the Action and No Action rulesets. The assumptions that are specific to this model are described below:

1. Actual historic forecasting of the spring (April through July) unregulated inflow volume for Flaming Gorge is assumed to represent the current and future level of forecast accuracy. Forecasted spring unregulated inflow volumes into Flaming Gorge have been issued by the National Weather Service since 1963. The Green River model generates spring unregulated inflow forecasts with an error distribution that is similar to the historical error distribution.

2. It is assumed that the timing and magnitude of the peak flow of the Yampa River can be predicted accurately at least 10 days prior to its occurrence. To achieve the spring flow objectives of the Action Alternative, while efficiently managing the resources of Flaming Gorge, the peak release from Flaming Gorge Dam must be optimally timed with the peak flows of the Yampa River. The magnitude of the peak release from Flaming Gorge Dam must also be optimally chosen to efficiently supplement flows on the Yampa River.

3. It is assumed that decisions regarding the operation of Flaming Gorge will be made at the beginning of each month. Even when conditions change mid-month, decisions to react to the changing conditions must wait until the beginning of the following month. In reality, operational decisions at Flaming Gorge Dam are made on a daily basis, but the Green River model is limited by the monthly timestep process.

4. It is assumed that the natural hydrology of the Green River Basin (from 2002 to 2040) will be similar in the future to the natural hydrology that occurred during the period from 1921 to 1985.

5. Whenever flow objectives for Reach 2 are achieved, it is assumed that the flow objectives for Reach 3 are also achieved.

6. River flows in Reach 1 and Reach 2 are assumed to have the same magnitude at all points along the reach. Gains and losses as a result of infiltration, precipitation, or evaporation along the reach are not accounted for in the model.

7. All hourly flow objectives for each of the proposed alternatives are assumed to be achieved and are not directly considered within the Green River model.

8. Flaming Gorge Powerplant is assumed to have a capacity of 4,600 cfs. The bypass tubes are assumed to have a total capacity of 4,000 cfs. The spillway is assumed to have a capacity of approximately 28,000 cfs.

MODEL RESULTS

Analysis of the output for the Action Alternative model run indicated that the magnitude and duration of the peak releases increased significantly as a result of achieving all of the flow objectives of the Action Alternative. Magnitudes and durations of the peak releases in the No Action results were noticeably smaller and shorter. An investigation of the individual flow objectives for the Action Alternative discovered that one flow objective was responsible for most of these increases. The Reach 2 objective requiring a sustained flow on the Green River of 18,600 cfs for at least 2 weeks in 40% of all years required peak releases of at least 8,600 cfs in 40% of all years and at least 10,600 cfs in 20% of all years to achieve this objective.

To help understand the impacts associated with achieving this one objective, two versions of the Action ruleset were constructed. The first version, which is described as the Action (ALL) model run, achieved all flow objectives for the Action Alternative including the 18,600-cfs objective. The second version of the Action ruleset, described as the Action (ALL-1) model run, did not focus on achieving the 18,600-cfs objective. Instead this ruleset focused on achieving all other flow objectives of the Action Alternative and ignored the 18,600-cfs objective. Table 1 summarizes the Action (ALL), Action (ALL-1) and No Action model results in terms of how well the spring flow objectives of the Action Alternative were achieved under each ruleset. It is important to note that even when this objective was ignored by the Action (ALL-1) ruleset, it was still achieved 18.2% of the time as a result of achieving the other flow objectives. Analysis of the Action (ALL-1) results show that 18,600 cfs was achieved 40% of the time in Reach 2 for a duration of 6 days.

Table 1—Controlling Criteria Analysis of Action and No Action Model Results

Spring Peak Flow Recommendations for Reach 2	Target %	Model Results (%)		
		Action (ALL-1)	Action (ALL)	No Action
Achieve Peak at Jensen >= 26,400 cfs	10	11.4	16.4	5.0
Sustained Peak at Jensen >= 22,700 cfs for at least 2 weeks	10	10.8	12.3	4.1
Sustained Peak at Jensen >=18,600 cfs for at least 4 weeks	10	9.5	18.1	5.0
Achieve Peak at Jensen >= 20,300 cfs	30	44.7	57.7	40.4
Sustain Peak at Jensen >= 18,600 cfs for at least 2 weeks	**40**	**18.2**	**43.1**	**14.0**
Achieve Peak at Jensen >= 18,600 cfs	50	60.2	66.0	58.9
Achieve Peak at Jensen >= 8,300 cfs	100	99.7	99.7	98.5
Sustain Peak at Jensen >= 8,300 cfs at least 1 week	90	96.9	96.9	96.9
Sustain Peak at Jensen >= 8,300 cfs at least 2 days except in extreme dry years	98	97.3	97.3	97.3

RESERVOIR WATER SURFACE ELEVATION RESULTS

For each month of the model run, from January 2002 to December 2040, there are 65 elevations that could potentially occur in any given month (one elevation for each trace). These monthly data sets have been sorted from lowest to highest. The 10th, 50th, and 90th percentile values have been selected from each set. Figure 1 shows the 90th percentile elevations that occurred for all three runs of the model for the first 10 years of the model run. The results in figure 1 do not represent any one particular elevation trace. Rather, these curves can best be thought of as a boundary elevation that will be exceeded 10% of the time. To illustrate how individual traces fluctuate through time, trace 54, which achieved the 90% boundary elevation in July, 10 years into the model run, is included in the figure. The amplitude of the curves from year to year indicated how much water was being stored during the spring for release later in the year. The smaller the amplitude, the less storage that took place throughout the year and the less change in elevation that occurred from year to year. Both the Action (ALL) and the Action (ALL-1) model runs have smaller amplitudes than the No Action Alternative, indicating less active storage and less elevation change during the year.

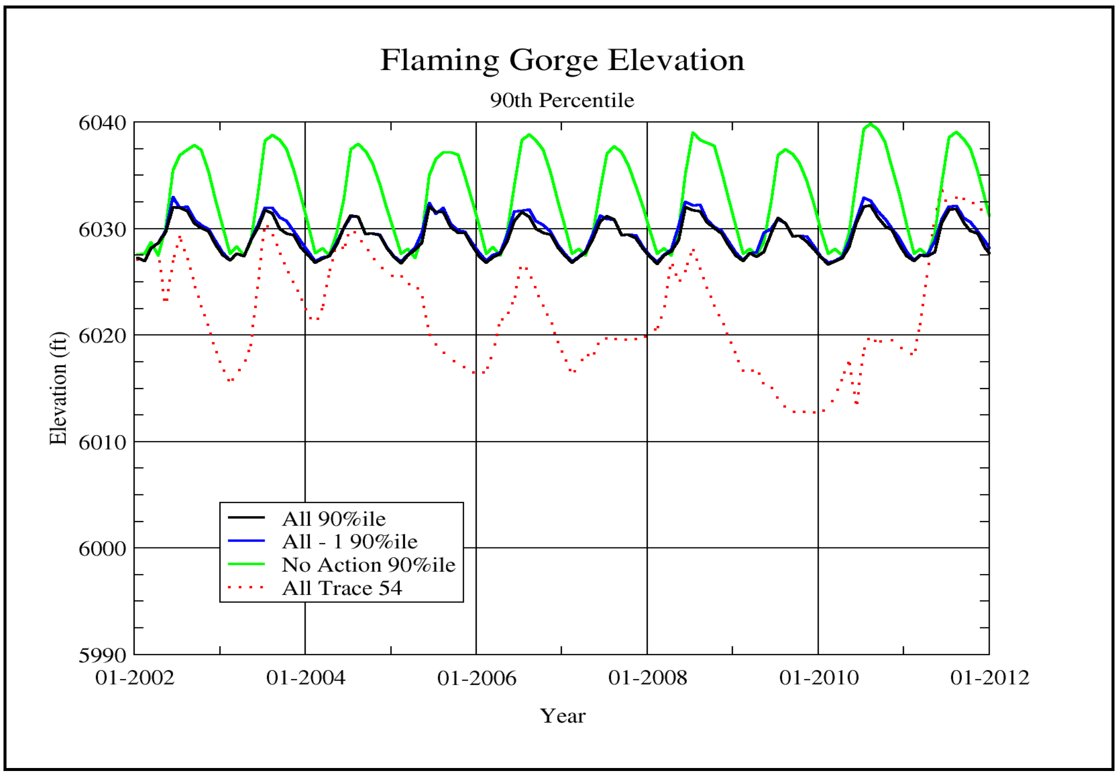


Figure 1.—90th Percentile Elevations from January 2002 to December 2011.

To illustrate an example of the impacts that achieving the 18,600-cfs objective had on the reservoir elevation, figure 2 shows trace 54 results for all three model runs during the first 10 years. Five of the ten years shown in the figure triggered the Action (ALL) ruleset to achieve 18,600-cfs objective because of high flows experienced on the Yampa River. The years when Action (ALL) ruleset was triggered were 2002, 2006, 2008, 2010, and 2011. In these years, the

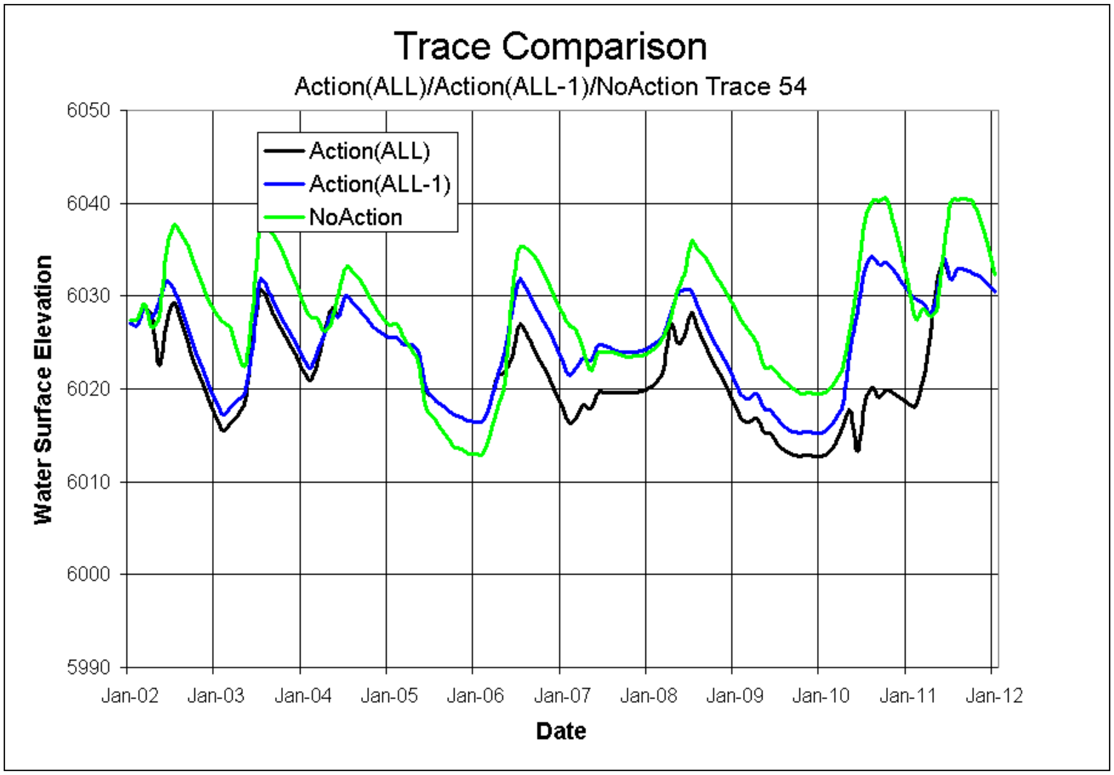


Figure 2.—Trace 54 Elevation Comparison.

peak release from Flaming Gorge Dam was increased (if necessary) to the threshold level necessary to achieve 18,600 cfs in similar years (in some years, this meant increasing to 8,600 cfs and other years to 10,600 cfs). In all years except 2011, the peak release was increased by the Action (ALL) ruleset above the peak release that was calculated for the Action (ALL-1) ruleset. In 2011, the release rate estimated in both the Action (ALL) and the Action (ALL-1) rulesets was high enough to achieve the 18,600-cfs objective. The hydrology for the upper Green River Basin during the spring of 2011 was very wet, and releases during that year were hydrologically driven to control the reservoir elevation and not by the flow objectives of the proposed alternative. The increased releases are evident by the sharp drops in elevation that occurred in the spring of each of the years mentioned above.

The 50th percentile ("most probable") elevations over the first 10 years of the model runs are shown in figure 3. As compared to the two Action Alternatives, the No Action Alternative provided significantly higher reservoir elevations in the summer months. The Action (ALL) results indicated lower elevations than the Action (ALL-1) results. During the winter, elevations were very similar for all three model runs since the draw down target is the same in all three rulesets. As in figure 1, a single trace has been included in figure 3. This trace (trace 16) achieved the 50% exceedance level for the Action (ALL) results in July, 10 years into the trace.

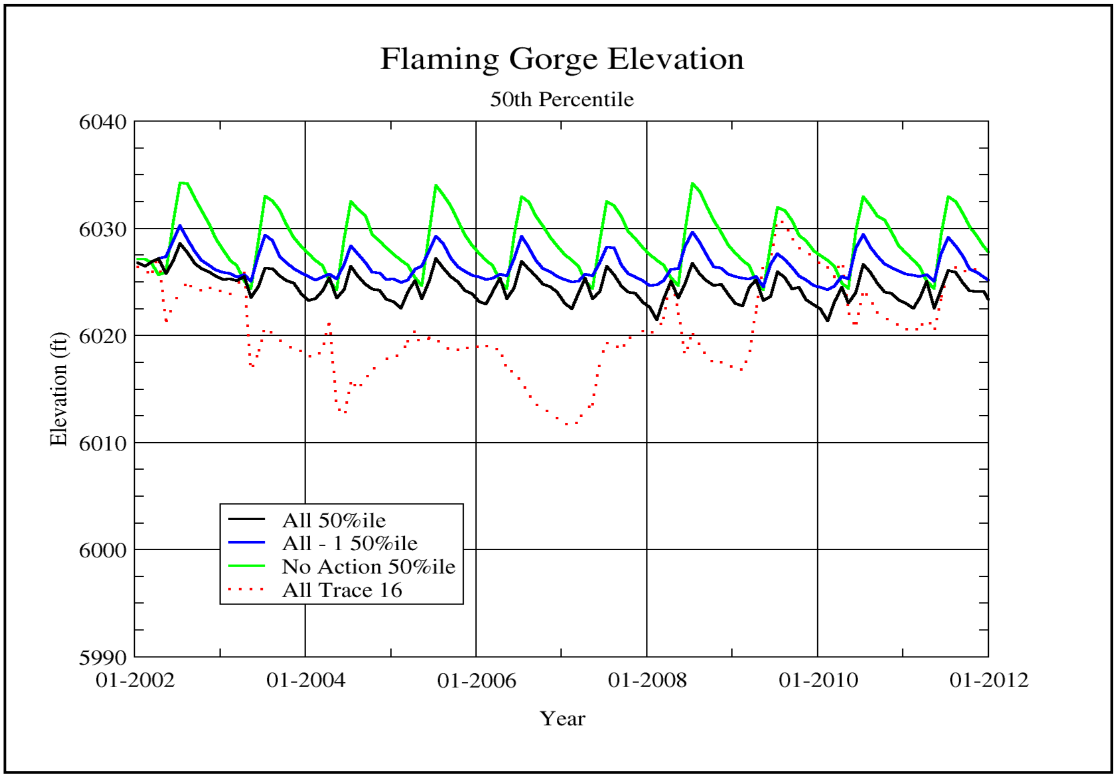


Figure 3.—50th Percentile Elevations from January 2002 to December 2011.

Figure 4 shows another example of how achieving the 18,600-cfs objective had a significant impact to the reservoir elevation of the Action (ALL) results. In this trace (trace 16), there are 5 years where the Yampa River flows during the spring were high and triggered the Action (ALL) ruleset to attempt to achieve the 18,600-cfs objective. These years were 2002, 2003, 2004, 2008, and 2010. Because of the increased peak releases that occurred in these years for the Action (ALL) model run, the reservoir elevation remained substantially lower than the Action (ALL-1) model run for most of the 10-year period shown in the figure. The elevation, fully recovered in 2009, was then depressed in 2010 when the Action (ALL) ruleset was again triggered to achieve the 18,600-cfs objective.

Figure 5 shows the 10th percentile reservoir elevations for the first 10 years of each model run. These elevations were exceeded 90% of the time but were equal or lower than these levels 10% of the time. The Action (ALL) results show a significant impact to the reservoir elevation as a result of the 18,600-cfs objective. Reservoir elevations for the Action (ALL) results decreased substantially over the first 10 years, then stabilized below 6000 feet above sea level for the remainder of the model run. The results for the Action (ALL-1) model run indicated that meeting all flow objectives except for the 18,600-cfs objective did not significantly impact the reservoir elevation through time. An example trace (trace 5) has been included in figure 5 which shows how the reservoir elevation tracked for the Action (ALL) model run. The elevation for this trace of the Action(ALL) model run achieved the 10th percentile value in July, 10 years into the trace.

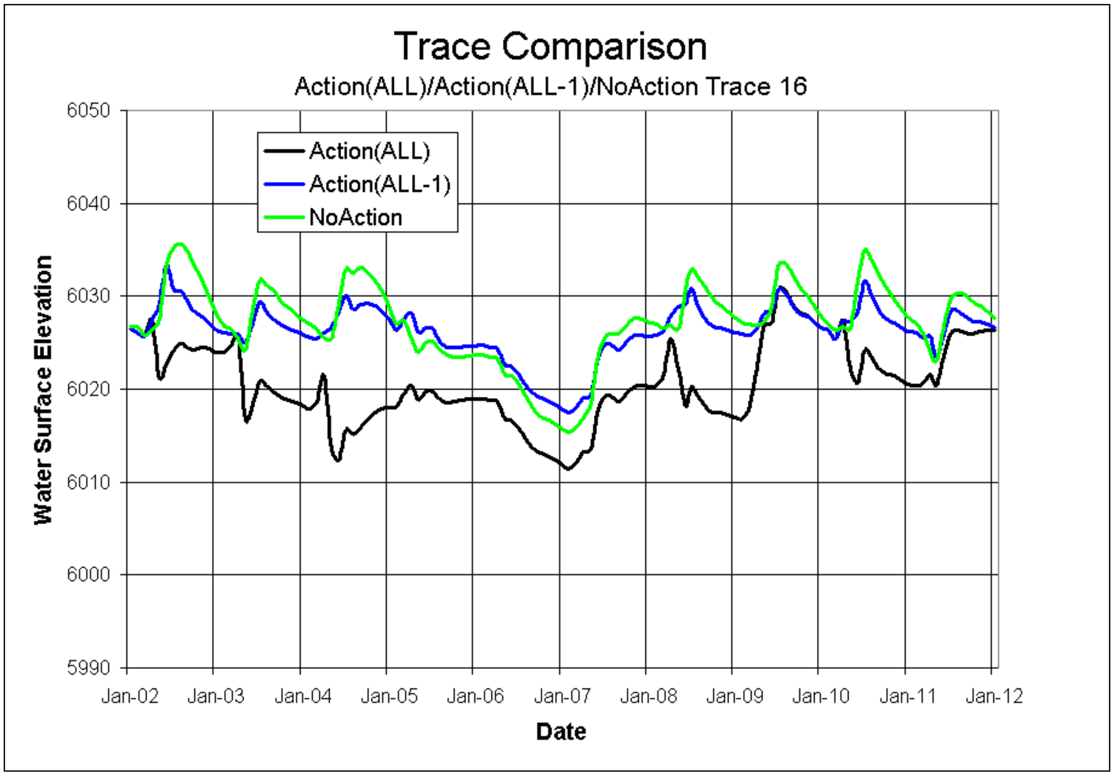


Figure 4.—Trace 16 Elevation Comparison.

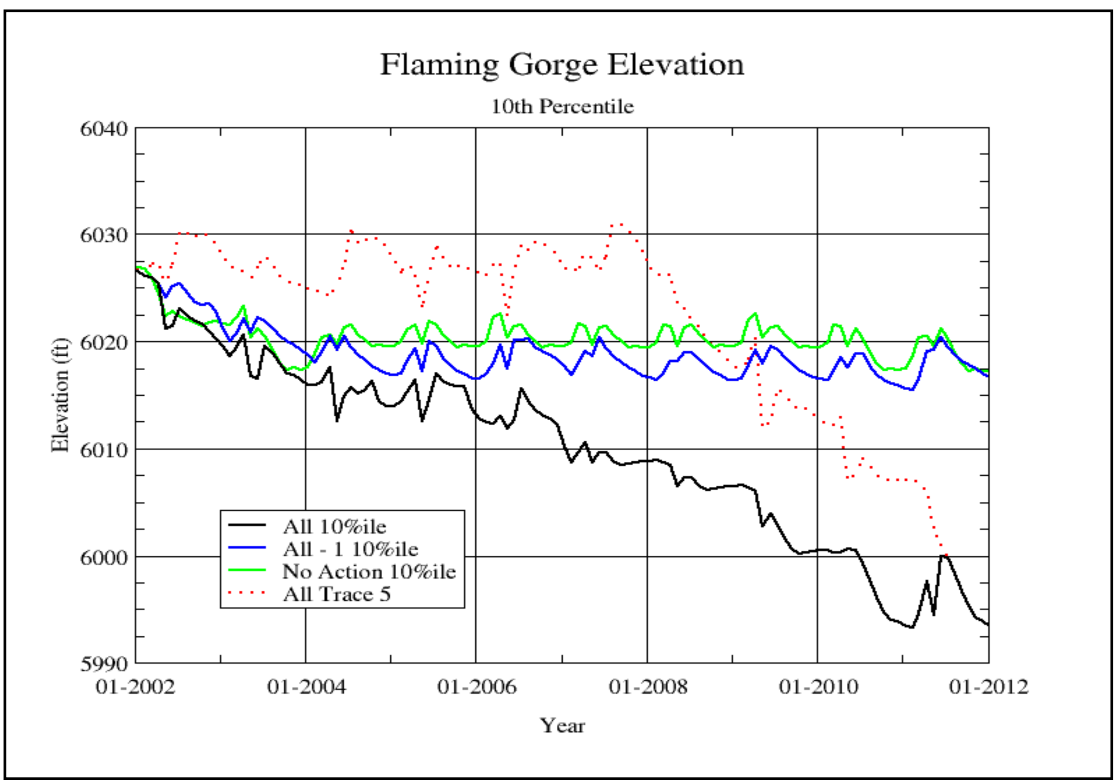


Figure 5.—10th Percentile Elevations from January 2002 to December 2001.

Figure 6 shows another example of how the Action (ALL) and Action (ALL-1) rulesets behave under identical hydrologic conditions. In the first 8 years of trace 5, the Action (ALL) reservoir elevations were the same as the Action (ALL-1) reservoir elevations. This indicated that the releases made by the two rulesets were identical for the first 8 years. However, conditions on the Yampa River in 2005, 2006, and 2007 triggered the Action (ALL) ruleset to attempt to achieve the 18,600-cfs objective. Because conditions were very wet in the upper Green River Basin in those years, the peak release established by the Action (ALL-1) ruleset was equal to or greater than the threshold peak release that the Action (ALL) ruleset would have reset the peak release to. For this reason, the Action (ALL) reservoir elevations did not deviate from the Action (ALL-1) reservoir elevations during the first 8 years of the trace. In 2010, this was not the case. The Action (ALL) ruleset reset the peak release to achieve the 18,600-cfs objective, resulting in the reservoir elevation dropping about 8 feet below the Action (ALL-1) elevation.

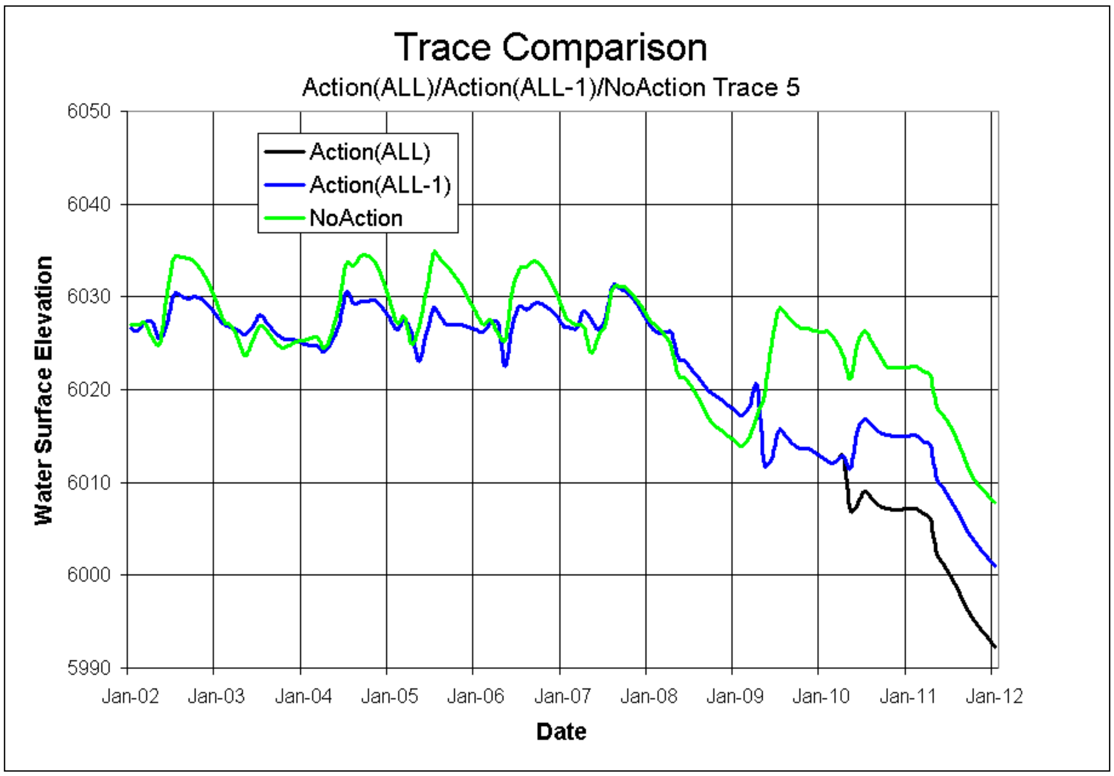


Figure 6.—Trace 5 Elevation Comparison.

During the early spring, the elevation of Flaming Gorge Reservoir is normally at its lowest level of the year. Figures 7 and 8 show the number of occurrences when the elevations at the end of April are within particular ranges. Figure 7 shows a comparison between the Action (ALL-1) and the No Action model output. Figure 8 shows a comparison between the Action (ALL) and the No Action model output. Comparison between figure 7 and figure 8 shows that achieving the 18,600-cfs objective had the effect of increasing the occurrences of lower elevations in the spring. The number of occurrences when elevations at the end of April were below 6000 feet above sea level increased from less than 50 (2% of the time) in the Action (ALL-1) model run to nearly 300 (12% of the time) in the Action (ALL) model run. There were no occurrences in the No Action results where the elevations at the end of April fell below 6000 feet.

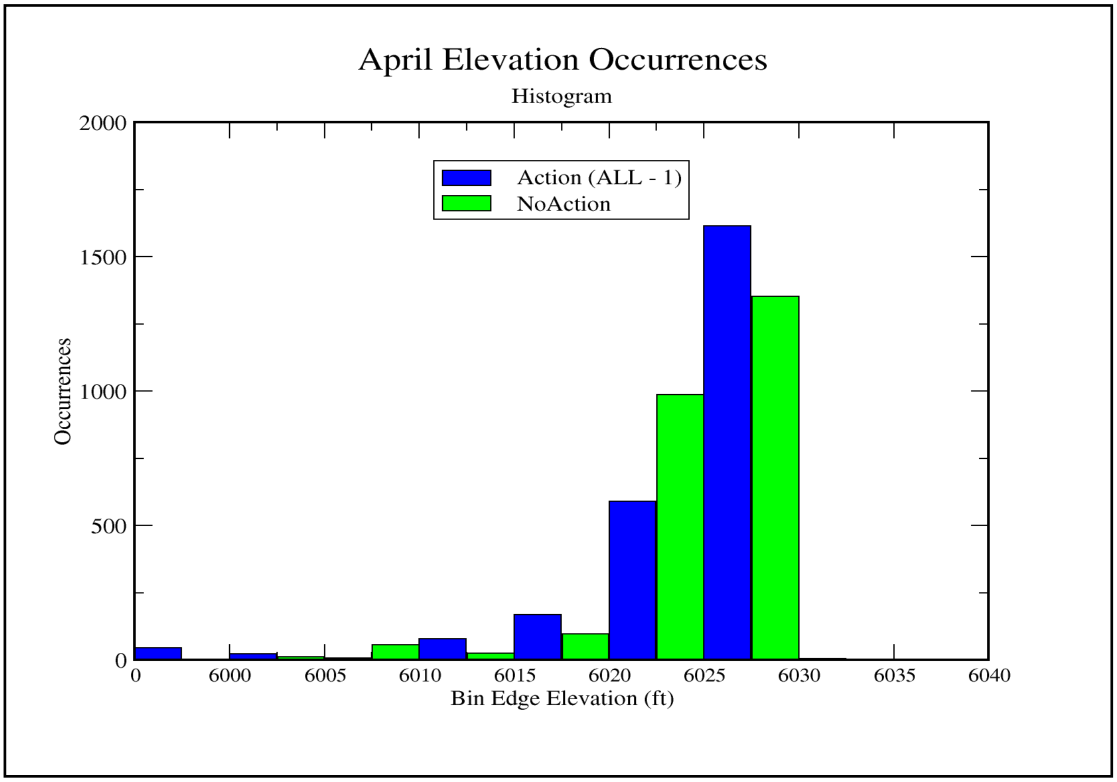


Figure 7.—Histogram of Action (ALL-1) and No Action April Elevations.

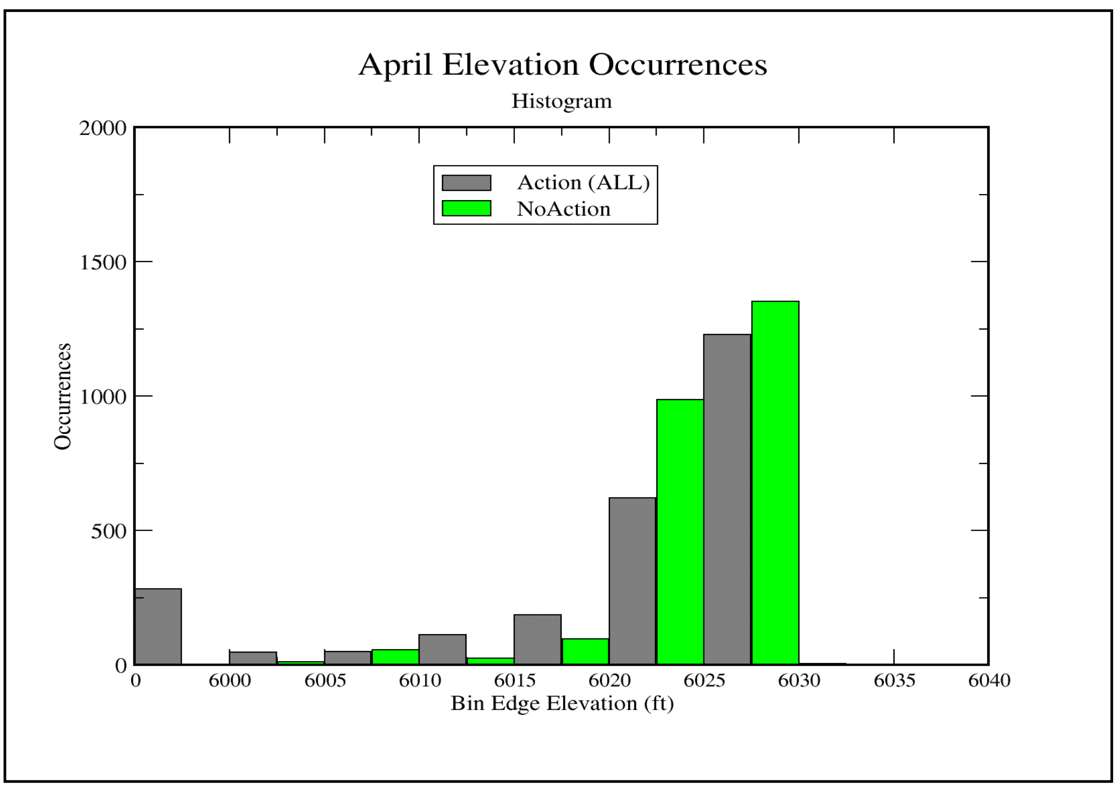


Figure 8.—Histogram of Action (ALL) and No Action April Elevations.

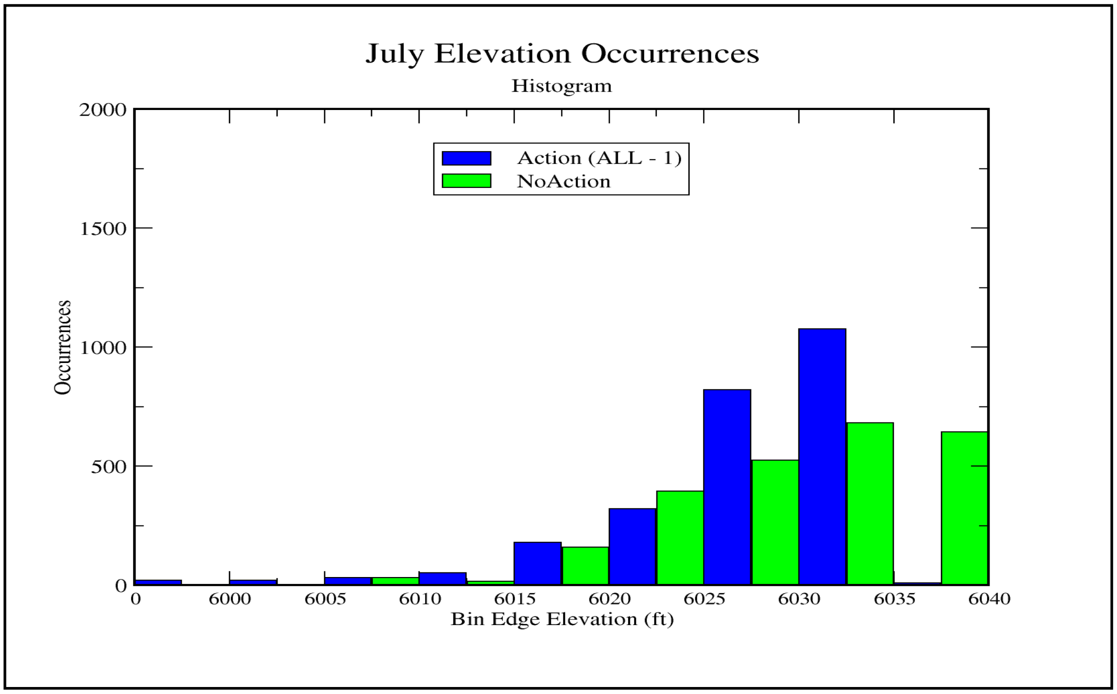


Figure 9.—Histogram of Action (ALL-1) and No Action July Elevations.

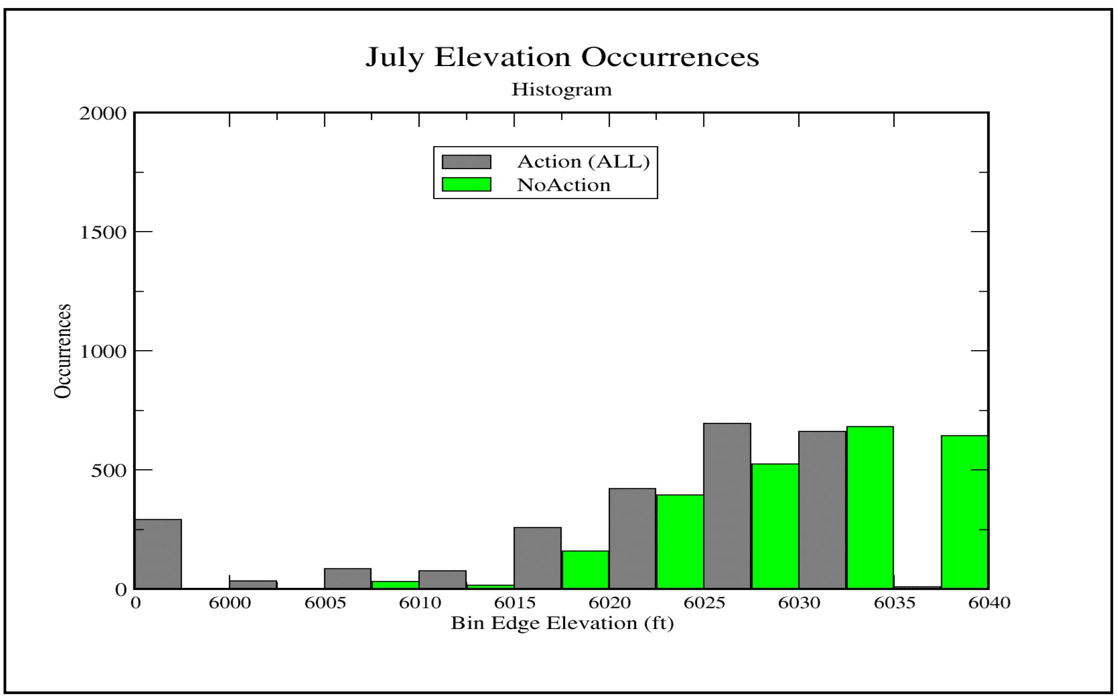


Figure 10.—Histogram of Action (ALL) and No Action July Elevations.

Typically, by the end of July, the reservoir is approaching its highest level of the year. Figures 9 and 10 show the same relationships as figures 7 and 8, only for reservoir elevations at the end of July. Inspection of these figures shows again that the occurrences of elevations at the end of July that were below 6000 feet above sea level increased significantly when the model achieved the 18,600-cfs objective. The Action(ALL-1) occurrences when elevations at the end of July were below 6000 were about 20 (>1% of the time). The Action(ALL) occurrences for this same classification were nearly 300 (12% of the time). The No Action model run had no occurrences where elevations at the end of July were below 6000.

Table 2 shows the exceedance percentage values for all February and July elevations for the Action (ALL and ALL-1) and No Action results. The results in table 2 indicate that the "most likely" (50% exceedance) reservoir elevations at the end of February for the Action (ALL-1) model run were about 2 feet lower than the No Action model run. The "most likely" end-of-July elevations had a difference of nearly 4 feet for the Action (ALL-1) and No Action rulesets. Similar comparison between the Action (ALL) ruleset and the No Action rulesets shows that the "most likely" end-of-February elevations were about 5 feet lower for the Action (ALL) then the No Action ruleset. The July elevation difference was about 7 feet.

Table 2.—Percentage Exceedance February/July Elevations

Percentage Exceedance	Action (ALL-1) (Feet above Sea Level)	Action (ALL) (Feet above Sea Level)	No Action (Feet above Sea Level)
90%	6016.4/6019.2	5992.9/5997.2	6020.1/6021.4
80%	6020.1/6023.6	6013.7/6015.7	6024.7/6024.1
70%	6022.5/6026.4	6017.7/6020.3	6026.3/6026.7
60%	6024.0/6028.0	6020.0/6023.5	6026.9/6028.7
50%	6025.1/6029.1	6022.0/6026.0	6027.0/6032.8
40%	6025.9/6030.3	6024.2/6027.9	6027.2/6033.9
30%	6026.3/6030.7	6025.5/6029.3	6027.3/6034.9
20%	6026.6/6031.2	6026.2/6030.8	6027.5/6036.1
10%	6027.0/6032.1	6026.8/6031.8	6027.7/6038.0

Figures 11 and 12 show the complete distribution of the February and July elevations that were predicted for the three model runs. For reference, historic elevations for the period from 1971 through 1991 have been included on the figures.

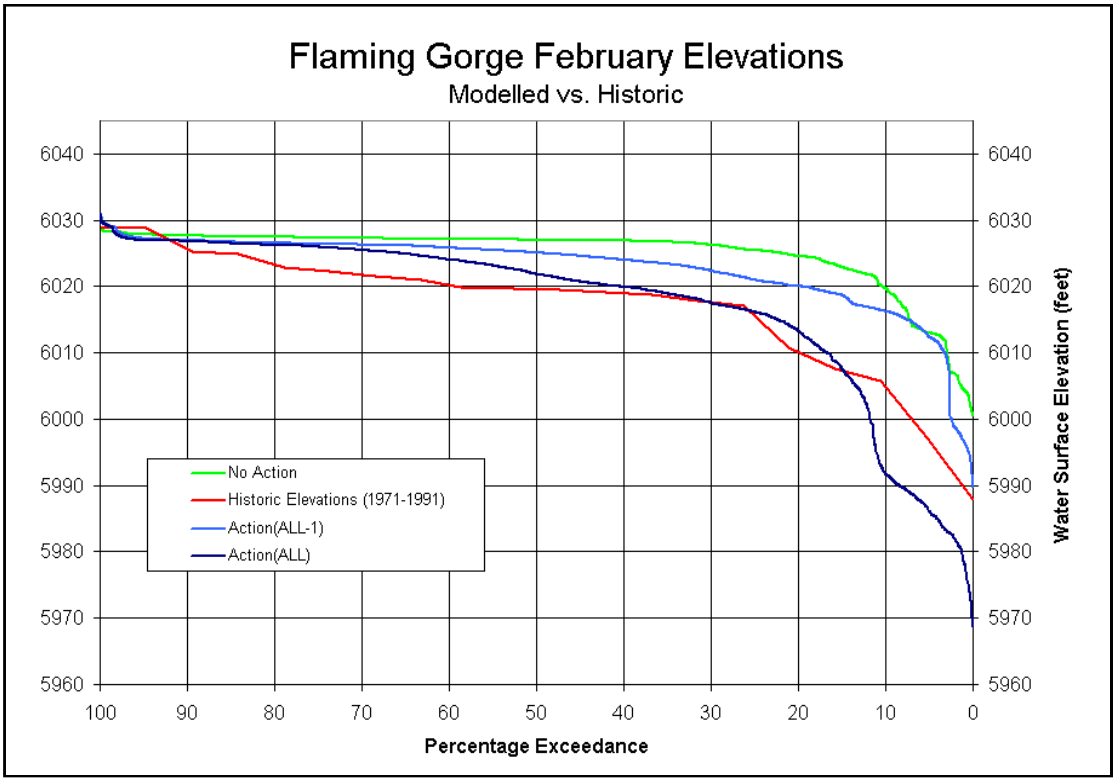


Figure 11.—Distribution of February Water Surface Elevations.

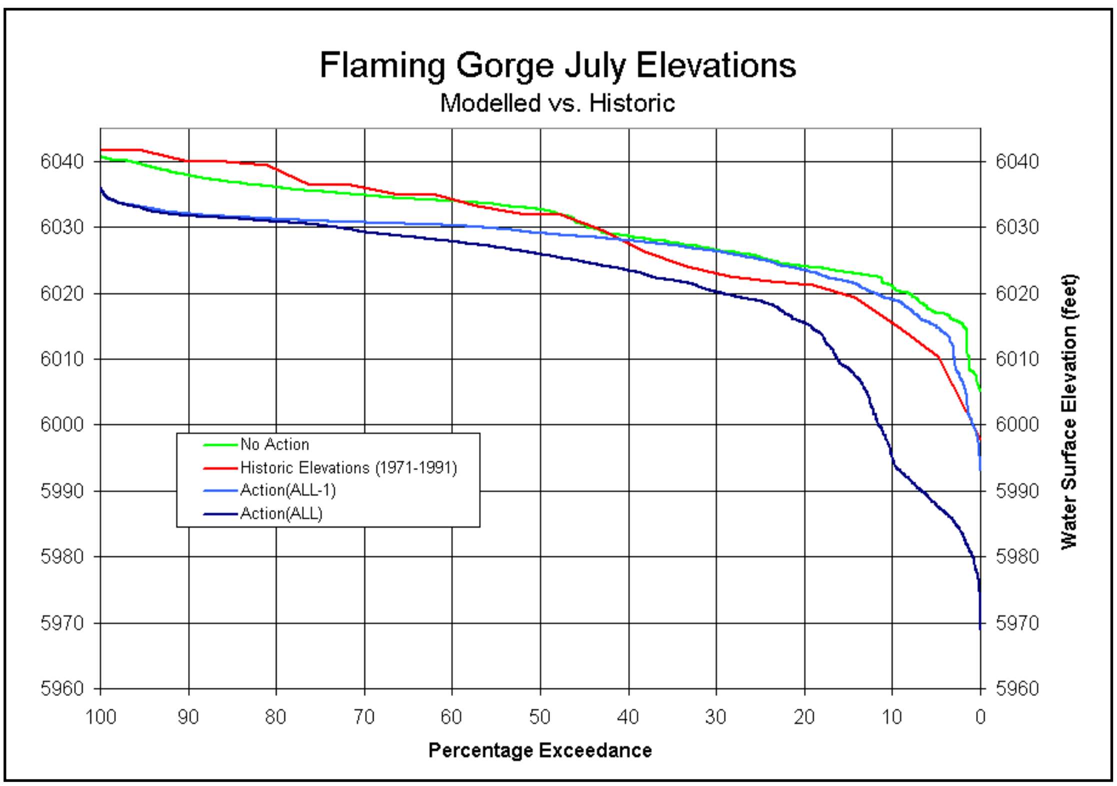


Figure 12.—Distribution of July Water Surface Elevations.

REACH 1 SPRING PEAK RELEASE RESULTS

The estimated flows at all points along Reach 1 were assumed in the model results to be the same as the release rate from Flaming Gorge Dam. During the spring, the model released the volume of water necessary to safely operate the reservoir while also achieving the objectives of the Action (ALL and ALL-1) and No Action Alternatives. Figure 13 shows the distribution of the peak flows (greatest magnitude single day average flow) that occurred in Reach 1 for all three model runs. The capacity of the powerplant at Flaming Gorge is assumed to be 4,600 cfs. Releases greater than 4,600 cfs are considered bypass releases. Figure 13 shows that water was bypassed by the No Action model run in about 18% of all years. The Action (ALL-1) model run bypassed water in about 37% of all years while the Action (ALL) model run bypassed water in about 53% of all years. It is also noted that bypasses from the Action (ALL and ALL-1) model runs had significantly higher magnitudes than those for the No Action model run. For reference, historic peak flows for the period from 1971 to 1991 are included in figure 13. This historic data includes years 1983, 1984, and 1986, which were abnormally wet years in the upper Green River Basin. Statistically, it is very unlikely that 3 years of such high magnitude would occur within 20 years of record. The historic record presented in figure 13 is, therefore, statistically skewed toward wet conditions. Figure 13 also shows that the differences in peak releases between the Action (ALL) and the Action (ALL-1) model runs were significantly larger than the differences between the Action (ALL-1) and No Action model runs.

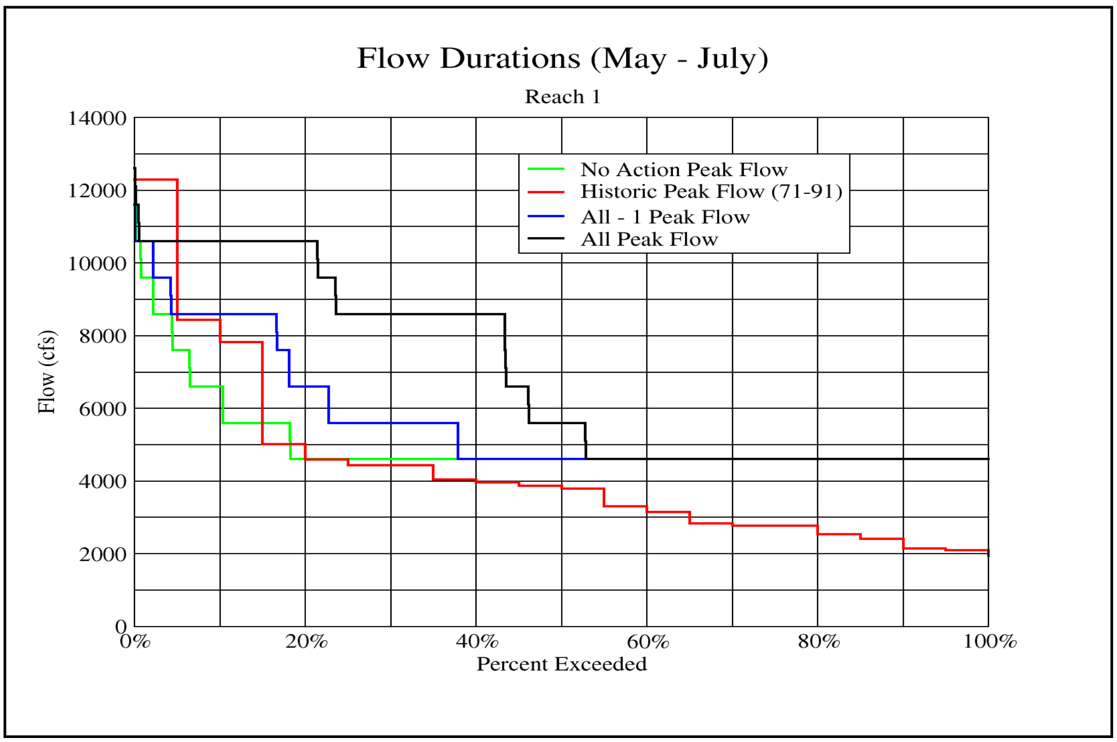


Figure 13.—Distribution of Peak Flows in Reach 1.

To illustrate the impacts to Reach 1 when the Action (ALL) ruleset was triggered to achieve the 18,600-cfs objective, figure 14 shows a sample spring hydrograph in Reach 1 for all three model runs. The data in this figure is from trace 37 in year 2015 from May through July. The peak release that achieved all flow objectives except the 18,600-cfs objective had a magnitude of 4,600 cfs and a duration of about 16 days. Because the Yampa River triggered the Action (ALL) ruleset to attempt to achieve the 18,600-cfs objective, the peak release magnitude was reset by the Action (ALL) ruleset from 4,600 cfs to 8,600 cfs; and the duration was decreased to 14 days. This caused a significant bypass to occur in a year when achieving all other flow objectives would not have required a bypass release. The historic year of this hydrology was 1970. For reference, the No Action model results and the historic spring releases that actually occurred at Flaming Gorge Dam in 1970 are included on the figure.

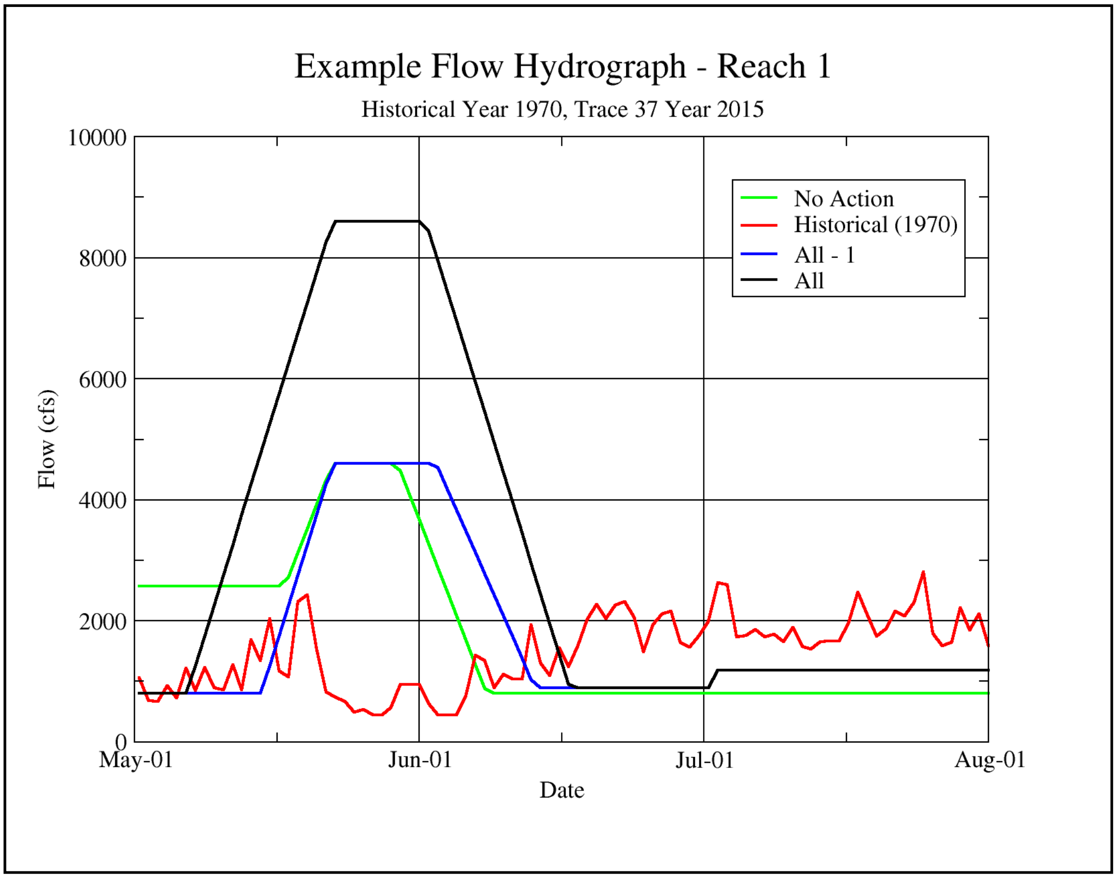


Figure 14.—Sample Hydrograph Comparison of Action (ALL and ALL-1) Reach 1.

Figure 15 shows the corresponding flows that occurred in Reach 2 as a result of the release hydrographs illustrated in figure 14. Figure 15 shows that although the Action(ALL-1) model run did not achieve the 18,600-cfs objective, that 18,600 cfs was sustained for 11 days in Reach 2 during this year. The Yampa River flows decrease very rapidly from the peak. Extending the duration of the 4,600-cfs peak release would not have sustained flows in Reach 2 above 18,600 cfs for 3 additional days.

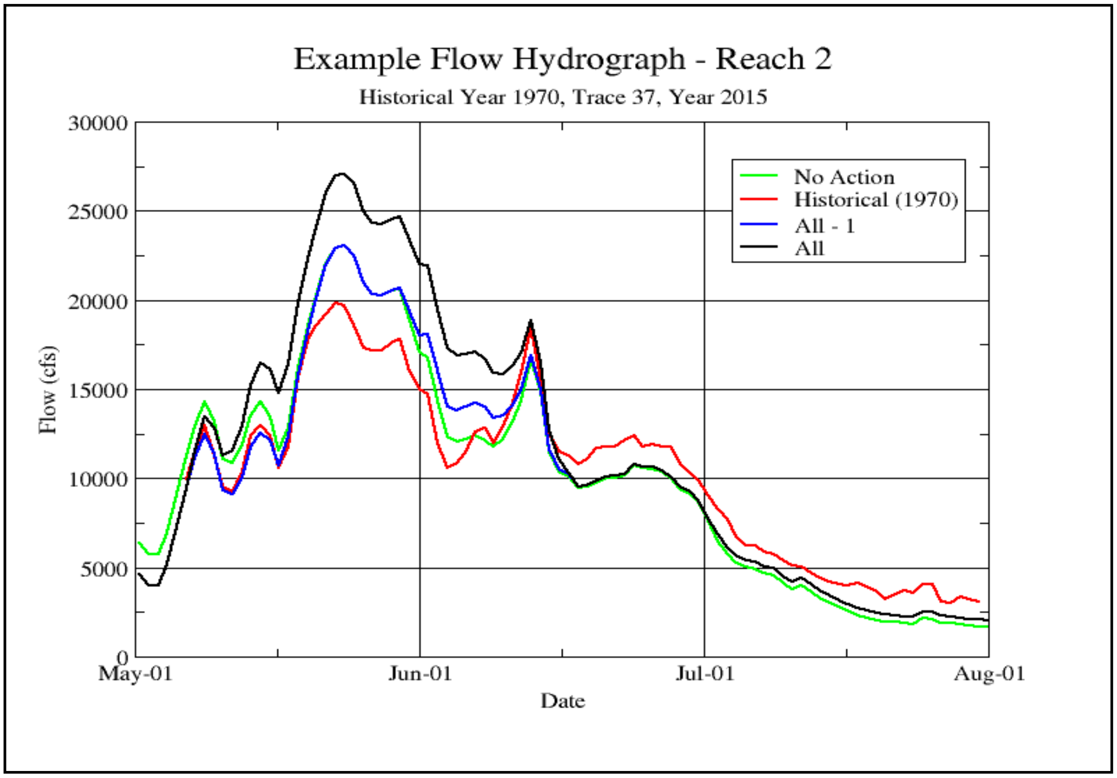


Figure 15.—Sample Hydrograph Comparison of Action (ALL and ALL-1) Reach 2.

Figures 16 and 17 show how the duration of the release peak was affected by the Action (ALL and ALL-1) and No Action rulesets. The distribution of Reach 1 flows that were exceeded for a duration of 2 weeks is presented in figure 16, while figure 17 shows the distribution of Reach 1 flows that were exceeded for 4 weeks. Distributions for all three model runs are presented, while the historic values that occurred during the period from 1971 to 1991 are also presented in these figures.

FLAMING GORGE SPRING BYPASS RESULTS

Figure 18, like figure 13, shows the frequency of bypass releases that occurred during the spring for all three model runs. Figure 18 shows this information in terms of the annual volume of water that was bypassed under the control of the three rulesets. The difference between each of these curves can be related to the power generation that was lost as a result of achieving the objectives of each of the proposed alternatives.

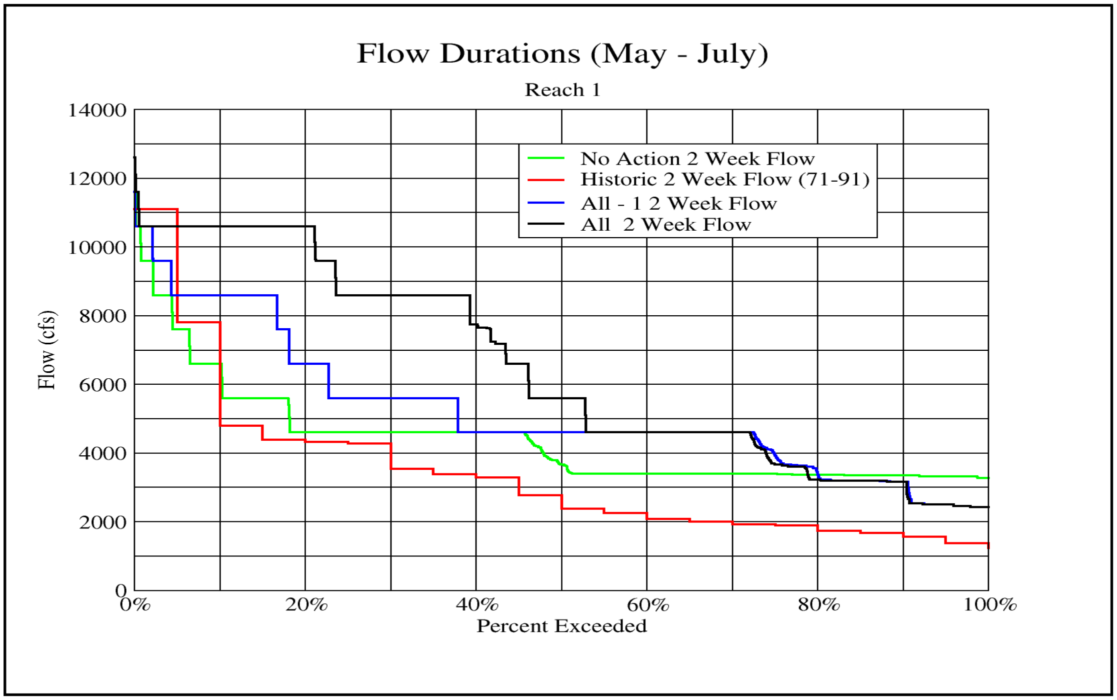


***Figure 16.—Distribution of 2-Week Duration Flows in Reach 1*.**

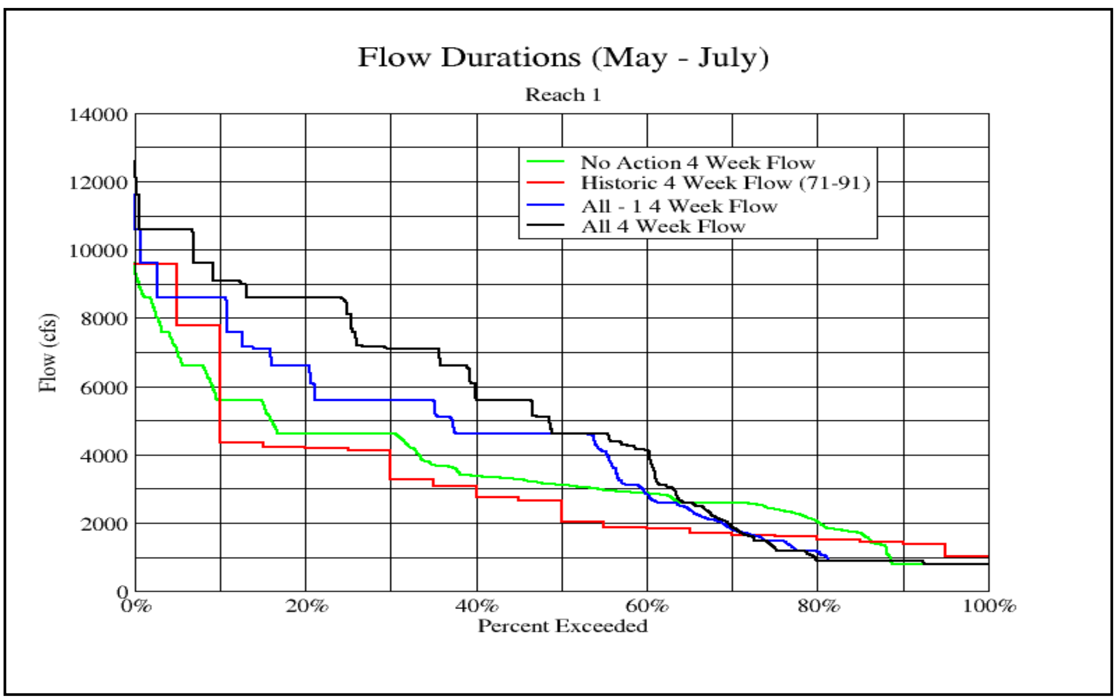


Figure 17.—Distribution of 4-Week Duration Flows in Reach 1.

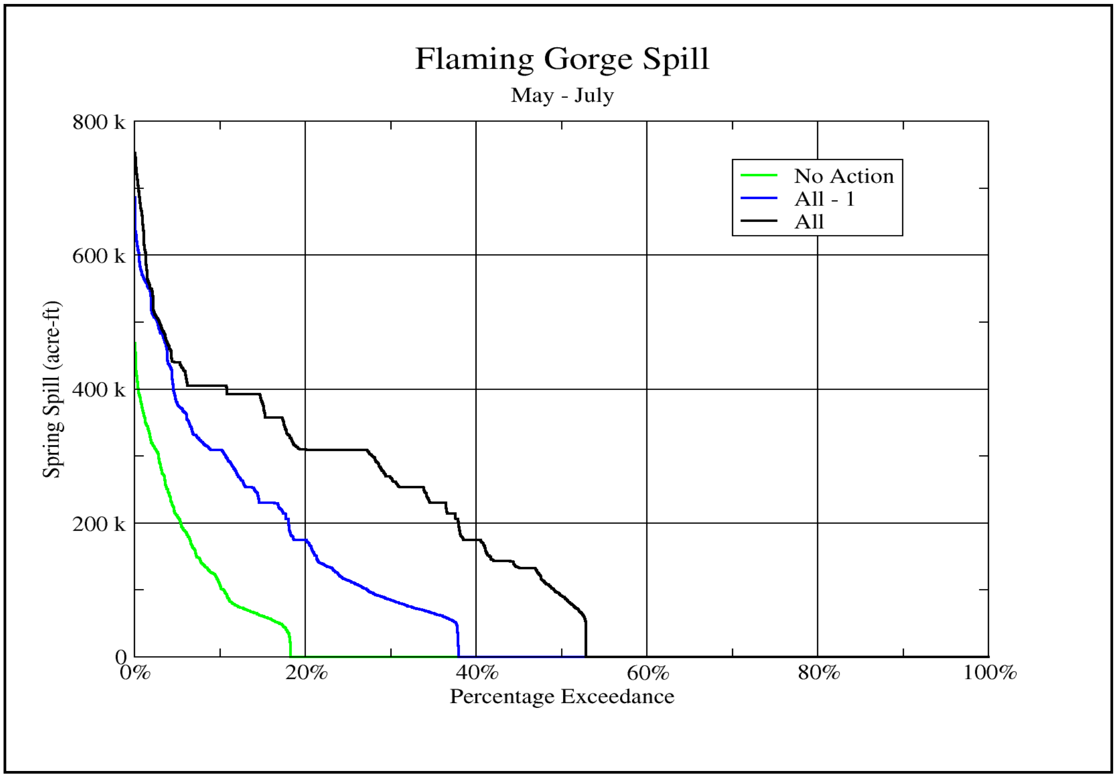


Figure 18.—Exceedance Percentage Bypasses During April Through July.

REACH 1 AUGUST THROUGH FEBRUARY BASE FLOW RELEASE RESULTS

Figure 19 shows the distributions of Reach 1 flows that occurred during the base flow period (August though February), when Reach 1 flows are typically at their lowest. This analysis shows the frequency and magnitude of the Reach 1 flows that occurred during the base flow period under the Action (ALL and ALL-1) and No Action model runs. The most notable difference between the Action and No Action flows during the base flow period was for the 0-20% exceedance flow. The No Action ruleset was more flexible during the base flow period and allowed releases to increase when conditions became wetter in the upper Green River Basin. To give some perspective to the results of the three model runs, historic Reach 1 base flows from 1971 to 1991 and historic Reach 1 unregulated base flows from 1971 to 1991 are included in the figure. The historic flows show how Flaming Gorge Dam operations, prior to the 1992 Biological Opinion, effected the distribution of flows in Reach 1 during the base flow period. Releases prior to 1992 were elevated above natural levels to produce power. The historic unregulated flows for the same period indicate how the distribution of flows in Reach 1 might have been if Flaming Gorge Dam did not regulate the flow of the river.

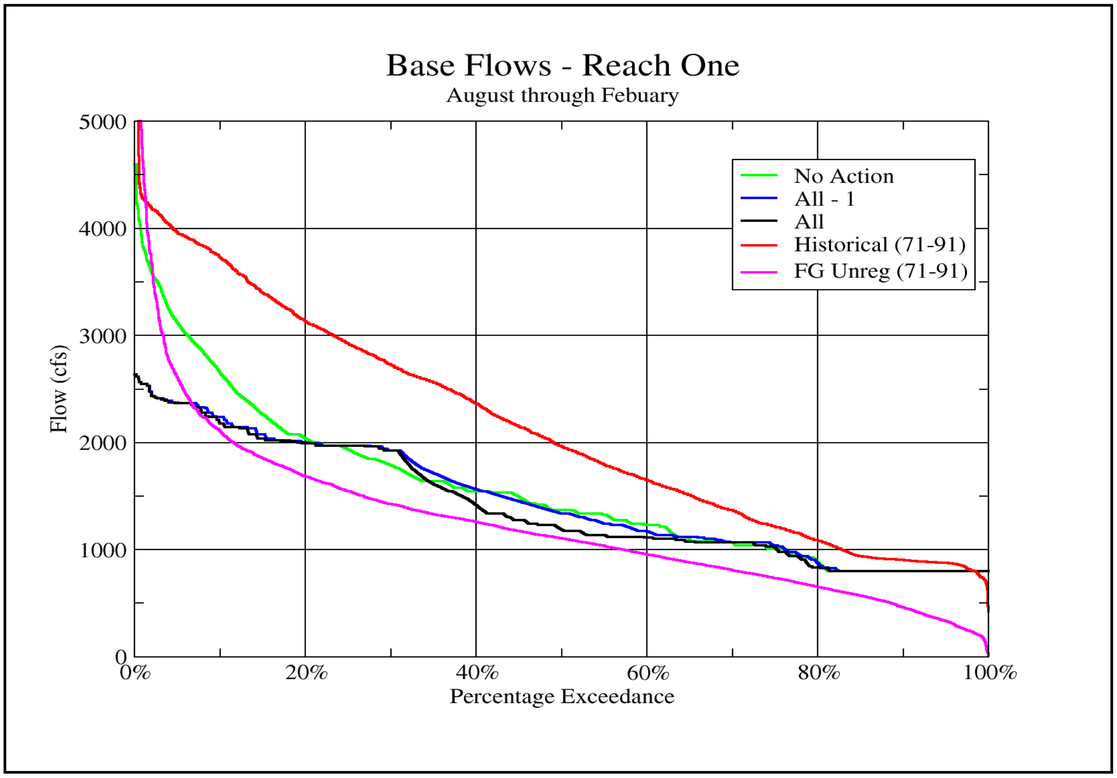


Figure 19.—Exceedance Percentage Flows for Reach 1 Flows During Base Flow Period.

REACH 2 SPRING PEAK RELEASE RESULTS

The model accounts for flows in Reach 2 by adding the flows from the Yampa River to the flows from Reach 1. The estimated flows at all points along Reach 2 were assumed to be equal to the release rate from Flaming Gorge Dam plus the flows on the Yampa River. The Green River model lagged Flaming Gorge Dam releases by 1 day to account for travel time through Reach 1.

Figure 20 shows the distributions of peak flows that occurred in Reach 2 during the spring. Figures 21 and 22 show distributions for flows in Reach 2 that had a duration of 2 and 4 weeks, respectively. Figure 21 shows a noticeable increase in the Action (ALL) results at about 40% exceedance. This was a result of the Action(ALL) ruleset attempting to achieve the 18,600-cfs objective.

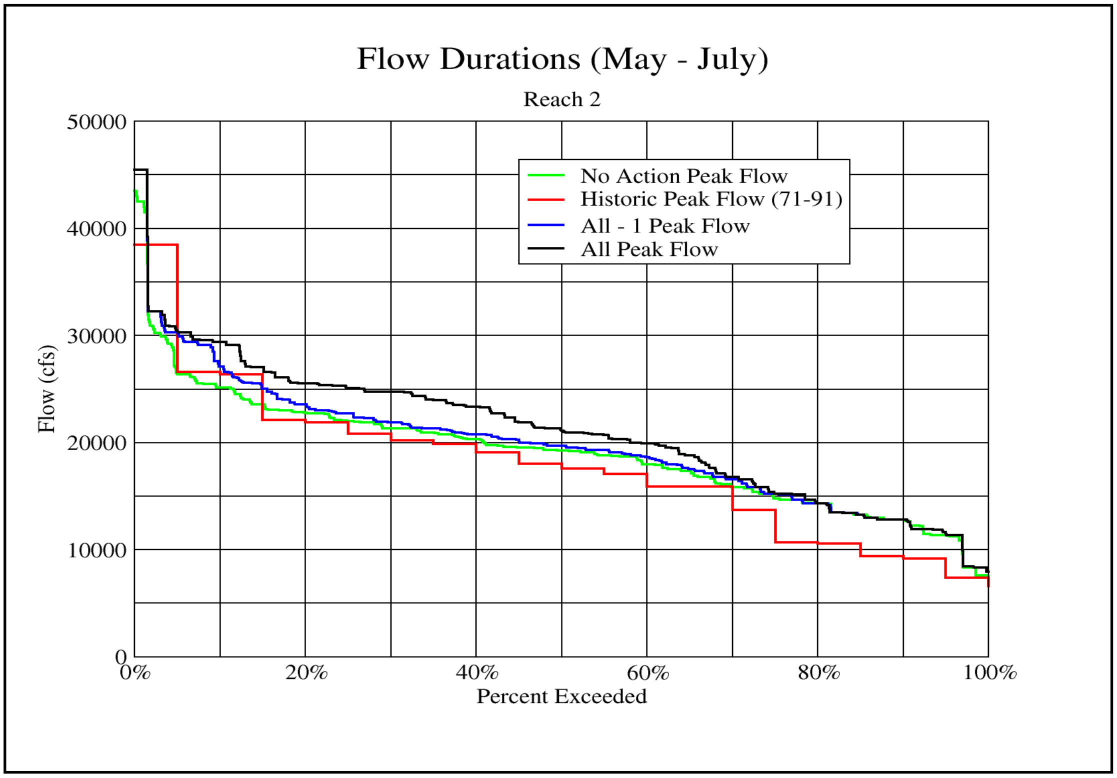


Figure 20.— Distribution of Peak Flows in Reach 2.

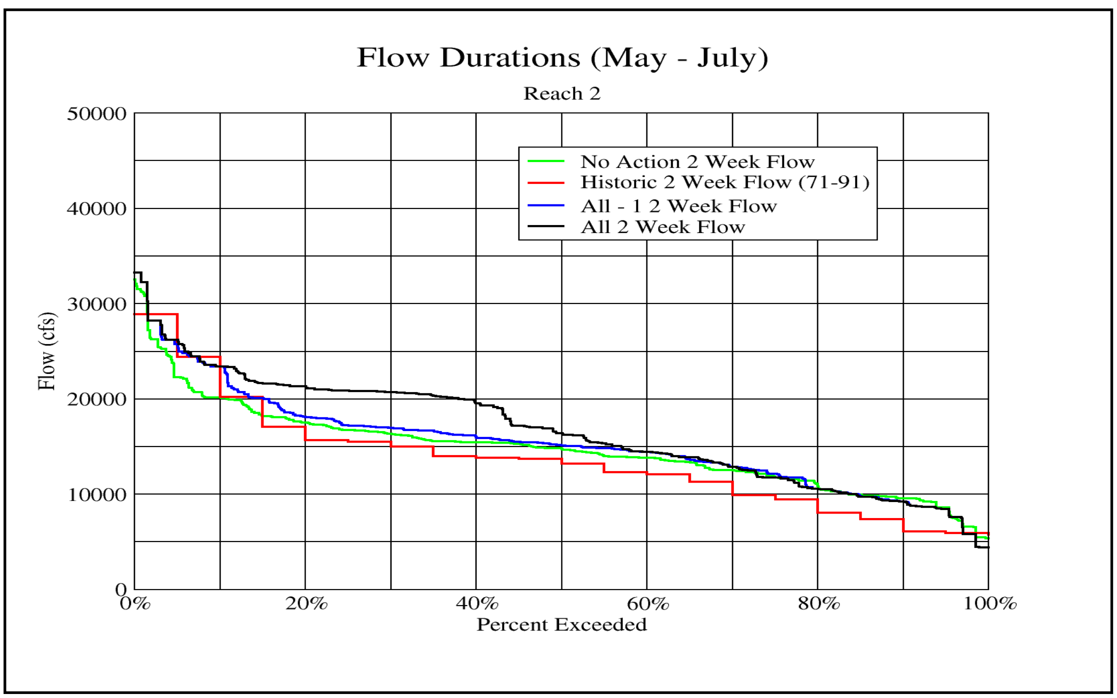


Figure 21.—Distribution of 2-Week Duration Flows in Reach 2.

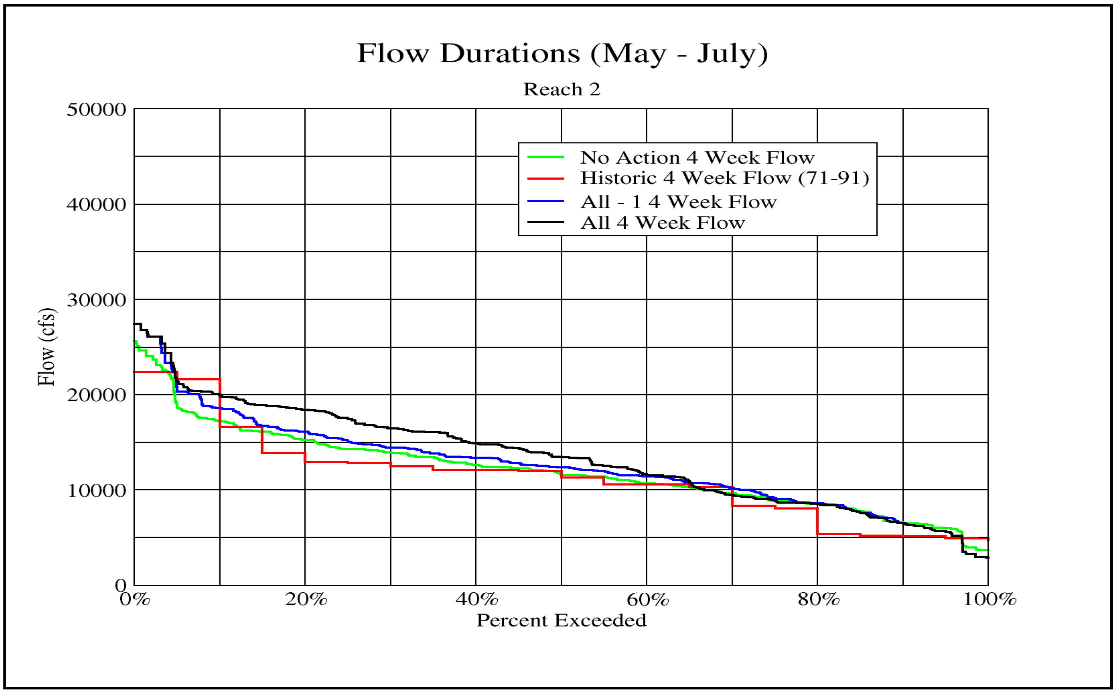


Figure 22.—Distribution of 4-Week Duration Flows in Reach 2.

REACH 2 BASE FLOW RELEASE RESULTS

Figure 23 shows the distribution of Reach 2 flows during the base flow period that occurred in the three model runs. Jensen gauge predam historic flows (1950-1961) during the base flow period and Jensen gauge post-dam historic flows (1971-1991) are also shown in the figure. The historic flows prior to 1961 show the distribution of flows in Reach 2 during the base flow period prior to the construction of Flaming Gorge Dam. Historic flows during the period from 1971 through 1991 show the distribution of Reach 2 flows after the construction of Flaming Gorge Dam but prior to the 1992 Biological Opinion. The most significant change that has occurred in Reach 2 in terms of river regulation occurred during the period from the end of the construction of Flaming Gorge Dam to 1991. Reach 2 flows during the base flow period were elevated substantially as a result of power production at Flaming Gorge Dam. The No Action curve shows the distribution of Reach 2 flows during the base flow period that as a result of operating Flaming Gorge Dam to achieve the flow objectives of the 1992 Biological Opinion. The Action (ALL and ALL-1) curves show how the Action Alternative would adjust the current distribution. Most notably, the Action Alternative operational regime depressed the flows during the base flow period in Reach 2 when conditions are wetter than average in the upper Green River Basin.

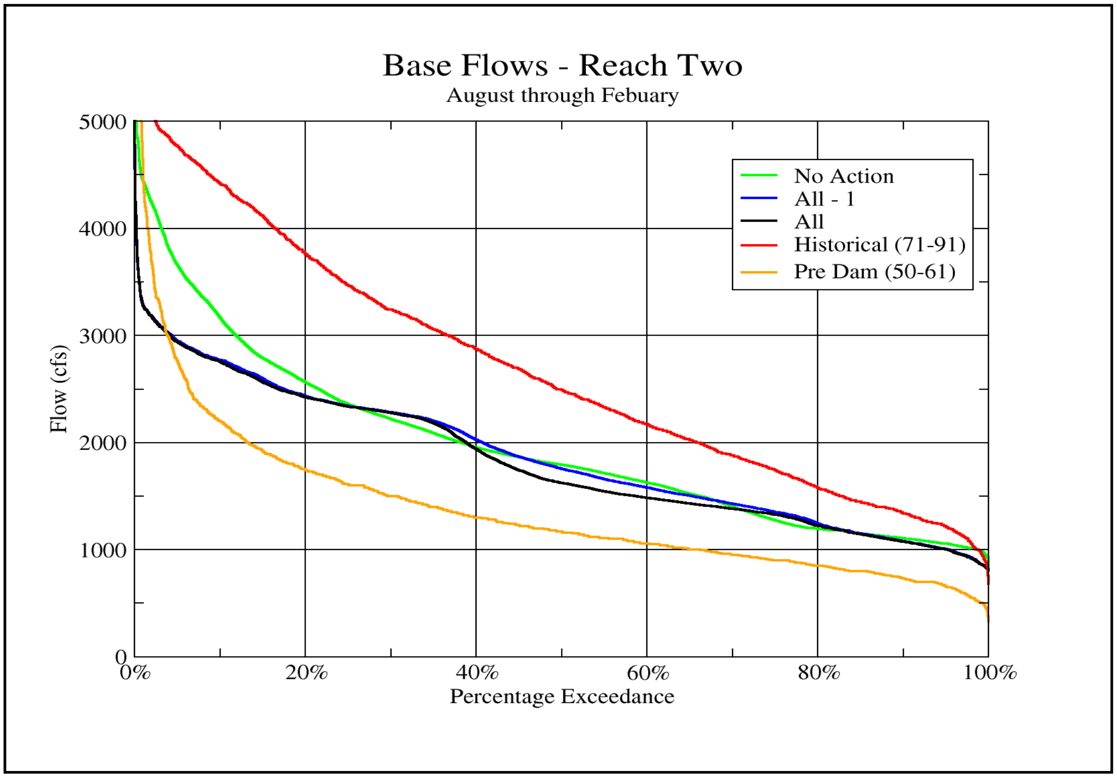


Figure 23.—Exceedance Percentage Flows for Reach 2 Flows During Base Flow Period.

SUMMARY

The results presented in this report describe three separate runs of the Green River model. Two of these runs were controlled by rulesets that achieved the objectives of the Action Alternative while the other run was controlled by a ruleset that achieved the objectives of the No Action Alternative. The Action Alternative is an operational regime for Flaming Gorge Dam that achieves the flow objectives of the 2000 Flow and Temperature Recommendations while "maintaining" the resources for which Flaming Gorge Dam was authorized. The No Action Alternative is an operational regime that achieves the flow objectives of the 1992 Biological Opinion while also "maintaining" the resources associated with the authorization of Flaming Gorge Dam. The rulesets "maintain" the resources associated with the authorizing purposes of Flaming Gorge Dam by minimizing bypass releases as much as possible while achieving the flow objectives for each of the proposed alternatives.

The difference between the two rulesets of the Action Alternative is the degree to which the flow objectives of the Action Alternative are achieved. The first version, referred to as the Action (ALL) ruleset, achieved all of the flow objectives of the Action Alternative. Results from this model run showed that the frequency and magnitude of bypass releases were much greater than in the No Action model run. Bypasses in the Action (ALL) model run were 53%, while the No Action model run had a bypass frequency of 18%. The frequency and magnitude of the bypasses in the Action (ALL) model run had a dramatic effect on the reservoir elevation when compared to the No Action model results. The occurrences of the reservoir elevations below 6000 feet above sea level were significant for the Action (ALL) model run while there were no occurrences of elevations below 6000 feet in the No Action model run. In general, the reservoir elevations during the summer months, on average, were about 7 feet lower in the Action (ALL) model run than they were in the No Action model run.

It was discovered that one flow objective for the Action Alternative caused most of the increase in the frequency and magnitude of the spring bypass releases. The Action Alternative flow objective that requires flows in Reach 2 in excess of 18,600 cfs for 2 weeks in 40% of all years caused most of the increase in the frequency and magnitude of the bypasses that occurred in the Action(ALL) results. To achieve this objective, 40% of all years were required to have peak releases with magnitudes of 8,600 cfs and durations of at least 2 weeks while 20% of all years were required to have magnitudes of 10,600 cfs and durations of at least 2 weeks. Achieving the other objectives of the Action Alternative did not require peak release magnitudes, durations, and frequencies at these levels.

The second version of the Action Alternative model run, referred to as the Action(ALL-1) model run, achieved all the flow objectives of the Action Alternative but did not specifically make any attempt to achieve the 18,600-cfs objective. While achieving all other flow objectives, the Action (ALL-1) model run was able to achieve 18,600 cfs for 2 weeks or greater in 18.2% of all years. Reach 2 flows did achieve 18,600 cfs in 40% of all years, but the duration was 6 days compared to the flow objective duration of 14 days. The results from the Action(ALL-1) model run showed a significant improvement to the impacts that were observed in the reservoir elevations of the Action (ALL) model run. Reservoir elevations for the Action (ALL-1) model run, on average, were 3 to 4 feet lower than the No Action model run results during the summer month as compared to 7 feet lower for the Action (ALL) results. Bypass releases were significantly reduced from the Action (ALL) model results. The frequency of bypass releases in the Action (ALL-1) model results was 38%; while in the Action (ALL) model results, this frequency was 53%. The Action(ALL-1) model run achieved nearly all of the objectives of the Action Alternative while dramatically reducing the impacts to the resource associated with the authorization Flaming Gorge Reservoir.

The intent of this study has been to evaluate the relative differences between the Action and No Action Alternatives proposed for the Flaming Gorge EIS. The modeling of the Green River system and these alternatives is now at a point where these differences are evident. This report provides hydrologic information for the purpose of determining the impacts to the resources associated with Flaming Gorge Reservoir. If additional information is needed for this purpose, it will be provided as needed.

HYDROLOGIC MODELING

R. Clayton and A. Gilmore
February 26, 2002 (Modified August 15, 2003)

INTRODUCTION

In October of 2001, a report titled "Flaming Gorge Environmental Impact Statement Hydrologic Modeling Study Report" was distributed to all Cooperating Agencies and Interdisciplinary (ID) Teams working on the Flaming Gorge Environmental Impact Statement (EIS). The report described the hydrologic impacts observed in the modeled implementation of the 1992 Biological Opinion (No Action Alternative) and the *Flow and Temperature Recommendations for Endangered Fishes in the Green River Downstream of Flaming Gorge Dam* (2000 Flow and Temperature Recommendations) (Action Alternative) for the period from 2002 through 2040. Based on comments received from the Cooperating Agencies, ID Teams, as well as the authors of the 2000 Flow and Temperature Recommendations, the Flaming Gorge Model has been modified to more accurately reflect the intentions of the 2000 Flow and Temperature Recommendations and the 1992 Biological Opinion. The purpose of this report is to detail these modifications and update the model results so the Cooperating Agencies and ID Teams can conduct their impact analyses.

DESCRIPTION OF MODIFICATIONS

The Flaming Gorge Model was populated with natural inflow data generated from historic riverflow and consumptive use records. For the upper Green River and Yampa River Basins, the only records available for consumptive use were recorded as monthly volumes. For this reason, the natural inflow data used to populate the Flaming Gorge Model, as well as the model itself, were developed at a monthly timestep. The monthly timestep framework of the Flaming Gorge Model limited when operational decisions could be made to the beginning of every month. It became apparent very early in the development of this model that limiting the timing of these operational decisions, which was only an artifact of the model framework, made it more difficult for the model to achieve the target flows and durations specified in the 2000 Flow and Temperature Recommendations than would be the case in reality.

In reality, Flaming Gorge Dam is operated to adjust to changing hydrologic conditions the moment these conditions change. The Flaming Gorge Model, however, must wait until the beginning of each month to make these adjustments. Sometimes, this caused the daily average releases determined by the model under the Action Alternative to be set much higher than necessary to achieve specific targets established for Reach 2. After receiving comments from the authors of the 2000 Flow and Temperature Recommendations regarding the report issued in October, it became clear that this artifact of the model did not satisfactorily reflect the intended implementation of the 2000 Flow and Temperature Recommendations.

To get the model to operate Flaming Gorge Dam more realistically while maintaining the monthly timestep framework, a daily model was developed to take monthly results from the Flaming Gorge Model and operate Flaming Gorge Dam to react to daily hydrologic conditions.

This daily model operated Flaming Gorge Dam during the spring (May, June, and July) to match estimated Yampa River flows to achieve target flows for Reach 2. While this caused the release results of the daily model to differ from the release results of the monthly model, it did provide a more reactive approach for achieving the recommended flow targets. To maintain some integrity between the daily and monthly models, the only restriction placed upon the daily model was to match the total volume released during the spring to the total volume released during the spring by the monthly model. After a targeted duration was achieved, the daily model released the necessary volume for the remainder of the spring to match the monthly model while minimizing additional bypass releases. This enhancement of the Flaming Gorge Model greatly reduced the bypass releases that were reported in the October report.

Base flows, under the Action Alternative, are dependent upon the classification of the hydrologic conditions in the upper Green River Basin. In October (2001), the model based this classification on the volume of unregulated inflow into Flaming Gorge that occurred during the preceding spring. Once this classification was set on August 1, it could not change during the base flow period. The 2000 Flow and Temperature Recommendations, however, stated that this classification was flexible and could change if hydrologic conditions changed during the base flow period. The authors, however, did not describe how this determination was to be made. Comments received from the authors gave guidance for how this determination could be made in the model, and the model has now been modified to adjust the hydrologic classification during the base flow period when conditions warrant a change.

Under the Action and No Action Alternatives, a volume of water to be released during the spring is calculated based on forecasted inflows and reservoir conditions. From this volume of water, a peak release hydrograph is developed to achieve the specific parameters of the operational alternative. In the model presented in the October report, both the Action and No Action Alternatives extended the peak release hydrograph to the end of July, when possible, depending on the calculated volume to be released during the spring. The 1992 Biological Opinion, however, states that base flow levels are to be established by July 20 at the latest. For this reason, the No Action Alternative was modified so that July 20 is now the maximum date that the spring release hydrograph can be extended to. This modification increases the peak magnitude and the potential for bypasses in the No Action Alternative as compared to the No Action results presented in the October report.

In October, the Flaming Gorge Model, for both alternatives, had a static drawdown target established for the end of April. During the base flow and transition periods, releases from Flaming Gorge were determined in an attempt to achieve this drawdown target. For both the Action and No Action Alternatives, the drawdown target was set to 6027 feet above sea level independent of the developing hydrology in the upper Green River Basin. In years where the early indications of the developing hydrology are for wet or dry conditions, this target would, in reality, be reset to a more appropriate level. For example, when the early indications are that the spring is going to be wet, Flaming Gorge will typically be drawn down to a target somewhat lower than 6027 feet above sea level to provide space in the reservoir to absorb the above average inflow. Conversely, in years where the early indications are that the spring is going to be dry, the reservoir is typically drawn down to a target higher than 6027 so the reservoir has a better chance of filling despite the dry conditions. This flexibility has now been incorporated into the Flaming Gorge Model. In anticipated wet years, the drawdown target is now set to 6025 feet above sea level and in anticipated dry years, the drawdown target is set to 6029 feet above sea level.

MODEL RESULTS

Flow Recommendations

Table 1 shows the current state of the Action and No Action Alternatives in terms of how well each alternative achieves the specific recommendations of the 2000 Flow and Temperature Recommendations during the spring in Reaches 1 and 2. While the No Action Alternative does not attempt to meet any of these targets, a comparison between the Action and No Action results does indicate some of the key differences between the operational regimes.

Table 1—2000 Flow and Temperature Recommendations Target Flows, Durations, and Frequencies

Spring Peak Flow Recommendations	Reach	Target %	Action Ruleset	No Action Ruleset
Peak >= 26,400 cfs for at least 1 day	2	10%	11.3%	7.1%
Peak >= 22,700 cfs for at least 2 weeks	2	10%	10.7%	4.6%
Peak >= 18,600 cfs for at least 4 weeks	2	10%	11.1%	6.0%
Peak >= 20,300 cfs for at least 1 day	2	30%	46.3%	42.3%
Peak >= 18,600 cfs for at least 2 weeks	2	40%	41.1%	15.6%
Peak >= 18,600 cfs for at least 1 day	2	50%	60.3%	59.1%
Peak >= 8,300 cfs for at least 1 day	2	100%	100%	98.5%
Peak >= 8,300 cfs for at least 1 week	2	90%	96.8%	96.9%
Peak >= 8,300 cfs for at least 2 days except in extreme dry years	2	98%	99.6%	98.4%
Peak >= 8,600 cfs for at least 1 day	1	10%	30.2%	6.5%
Peak >= 4,600 cfs for at least 1 day	1	100%	100%	100%

RESERVOIR WET AND DRY CYCLE RESULTS

In the 65 traces of inflow hydrology used to populate the model, a variety of wet and dry cycles occurred. These cycles were routed through the Flaming Gorge Model with the reservoir elevation set at various levels to show the full range of potential impacts that could realistically occur. The cycles having the driest and wettest intensities with durations of 2, 3, 5, and 7 years were found in the model results. The traces where these cycles occurred at the beginning of the trace were identified so that the differences between the Action and No Action Alternatives could be directly compared. This is because the water surface elevation of the Action and No Action Alternatives were the same in these traces prior to these cycles routing through Flaming Gorge Reservoir. The difference in reservoir elevation at the end of the cycle then could be attributed solely to the operational regime. The reservoir elevations and release hydrographs generated under the Action and No Action Alternatives were plotted to show the differences between these regimes. Figure 1 shows the reservoir elevations resulting from the most intense 3-year dry cycle found in the input hydrology. The plot extends 1 year beyond the end of the dry cycle to show the rate at which the reservoir was able to recover under the two alternatives.

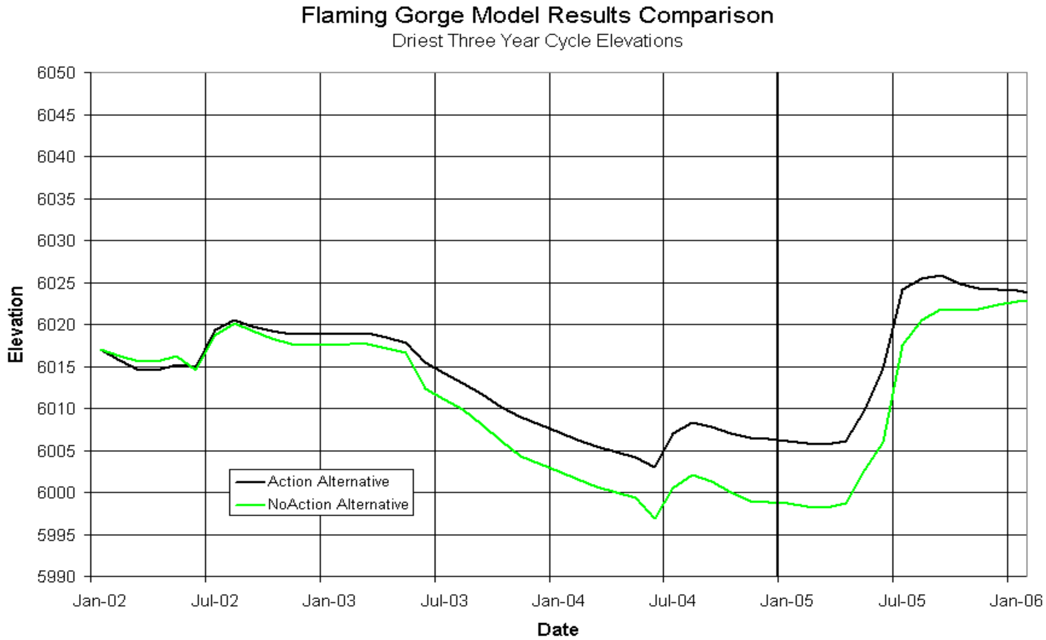


Figure 1.—Reservoir Elevations Under the Most Intense 3-Year Dry Cycle.

By the end of this 3-year cycle, operating under the No Action Alternative caused the reservoir elevation to be about 8 feet lower than operating under the Action Alternative. This can be mostly attributed to the fact that the No Action Alternative requires a spring peak each year with a minimum duration of 7 days while the Action Alternative allows the spring peak with a duration as short as 2 days. The corresponding release hydrographs produced for this 3-year cycle are shown in figure 2. While the peaks, under both alternatives, have a magnitude of 4,600 cfs (powerplant capacity), the No Action Alternative maintains 4,600 cfs for 7 days before declining back to base flow levels where as the Action Alternative peaks for only 2 days. In years classified as dry or moderately dry, the difference between the Action and No Action Alternatives, in terms of minimum duration, can have a significant impact on the reservoir elevation. When dry years occur in series, which is often the case, the year-to-year differences in reservoir elevation caused by the operational regime can compound upon each other as shown in this case.

When conditions are wet, the Action and No Action Alternatives operate Flaming Gorge Dam very differently from when conditions are dry. Spring releases for the Action Alternative in wet years are typically larger than those generated for the No Action Alternative as a result of attempting to achieve specific targets established for Reach 2. This is evident in figure 3, which shows the reservoir elevations that occurred during the most intense 3-year wet cycle found in the inflow hydrology. The higher releases that occur each spring under the Action Alternative cause the reservoir to fill less in the spring as compared to the No Action Alternative. As a result, the releases under the Action Alternative during the base flow period are not as high as those that occur under the No Action Alternative. The No Action Alternative is forced to release greater volumes during the base flow period to achieve the drawdown target established for the following year. This can be seen in figure 4, which shows the daily release hydrographs that occurred during this 3-year wet cycle. In November, the release constraints of the No Action Alternative are relaxed so that releases can increase to powerplant capacity if they are necessary to control the reservoir elevation. Figures showing the reservoir elevations and release hydrographs for 2-, 3-, 5-, and 7-year duration wet and dry cycles are located in the appendix.

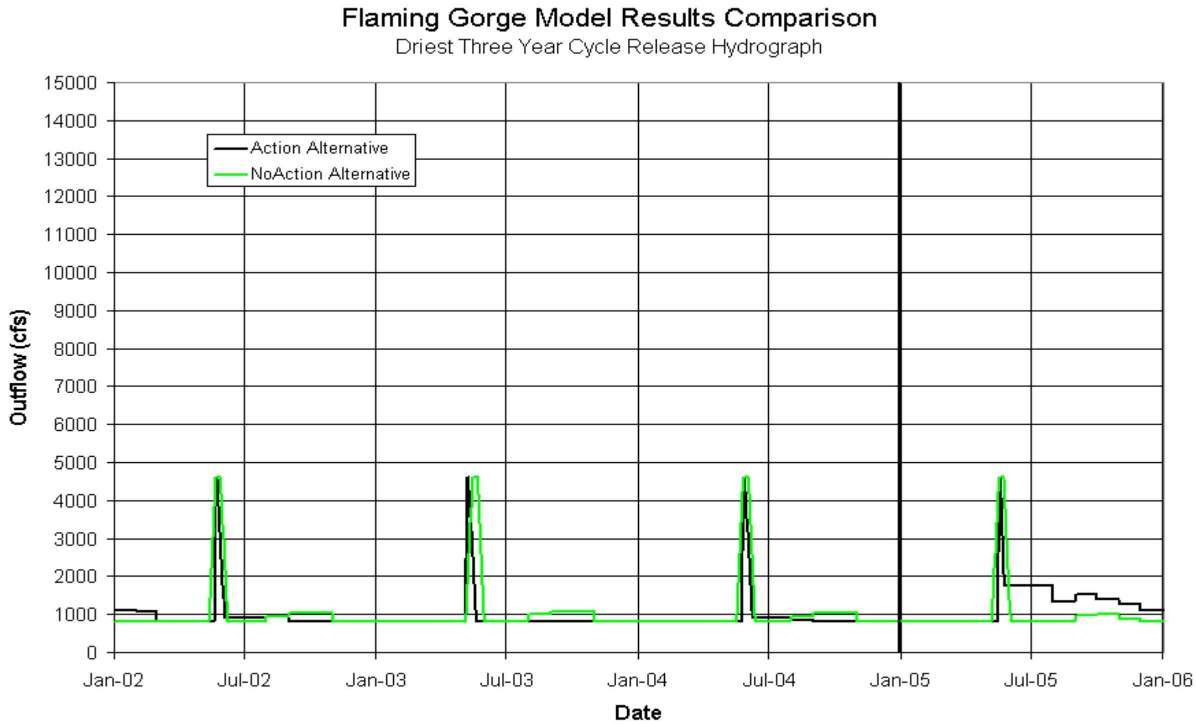


Figure 2.—Reservoir Releases Under the Most Intense 3-Year Dry Cycle.

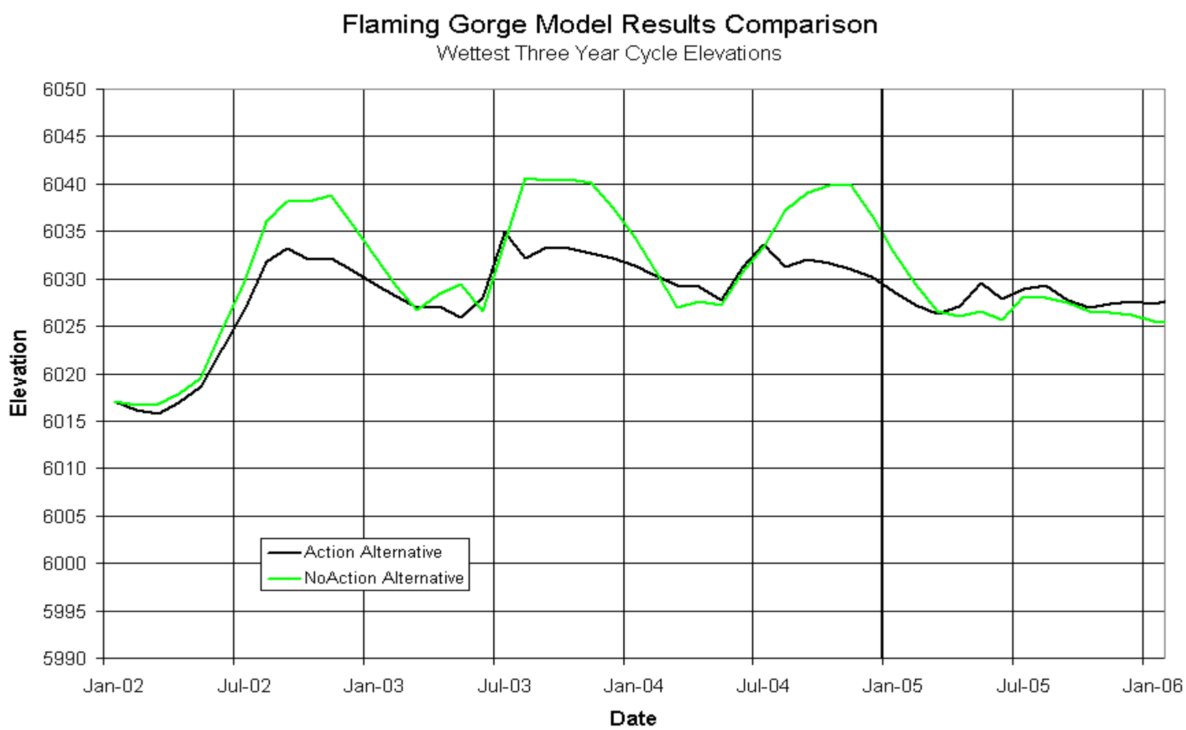


Figure 3.—Reservoir Elevations Under the Most Intense 3-Year Wet Cycle.

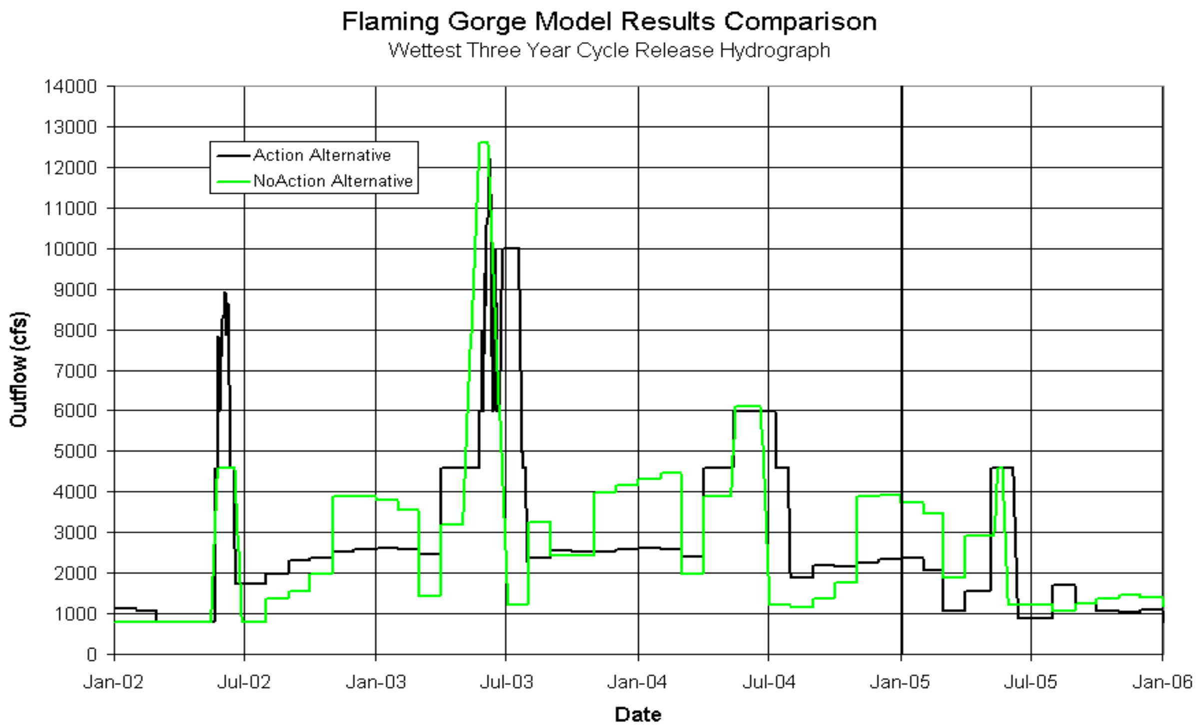


Figure 4.—Reservoir Releases Under the Most Intense 3-Year Wet Cycle.

RESERVOIR WATER SURFACE ELEVATION PERCENTILE RESULTS

For each month of the model run, from January 2002 through December 2040, there are 65 potential reservoir elevations that make up the model results for reservoir elevation for that particular month. Each set of potential elevations was ranked from lowest to highest to determine the probabilities associated with specific reservoir elevations. Figures 5, 6, and 7 show the potential reservoir elevations associated with three levels of probability. Figure 5 shows the 90th percentile reservoir elevations during the first 10 years of the model run. These reservoir elevations were exceeded by only 10% of the 65 potential elevations that occurred in the model results for that month and that year. Reservoir elevations are typically at their lowest level in early spring when the Action and No Action Alternatives attempt to achieve a drawdown target. During the late summer, reservoir elevations are typically at their highest level of the year as a result of storing a portion of the spring runoff. The No Action Alternative typically allows the reservoir elevation to rise significantly higher in the spring than the Action Alternative, as evident in figure 5. Summer reservoir elevations are typically 5 to 7 feet higher for the No Action Alternative than those for the Action Alternative.

Reservoir elevations that occur under more typical (average) hydrologic conditions are shown in figure 6. These reservoir elevations are those that were exceeded by 50% of the 65 potential reservoir elevations that occurred for each month. In the dryer scenarios, reservoir elevations are typically much lower than in the average or wet scenarios. Figure 7 shows reservoir elevations that were exceeded by 90% of the potential reservoir elevations that occurred for each month.

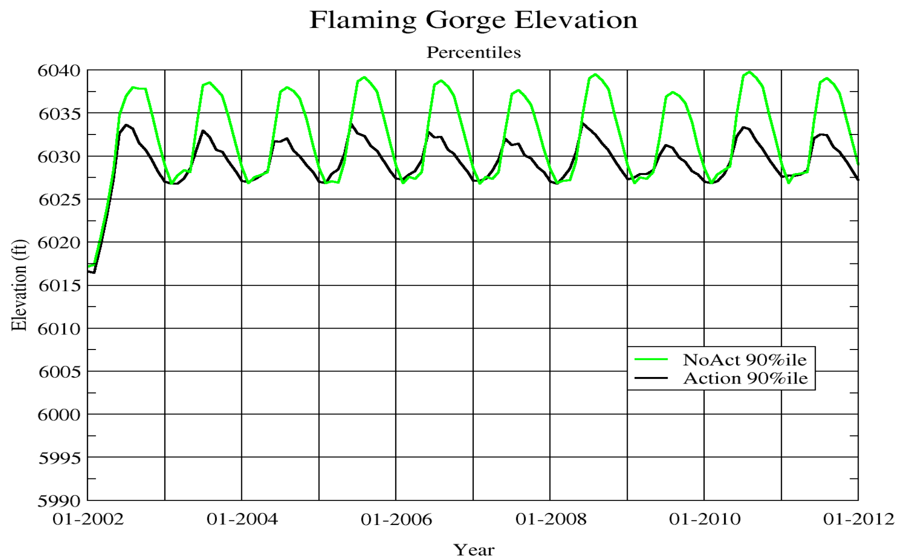


Figure 5.—90th Percentile Reservoir Elevations from January 2002 to December 2012.

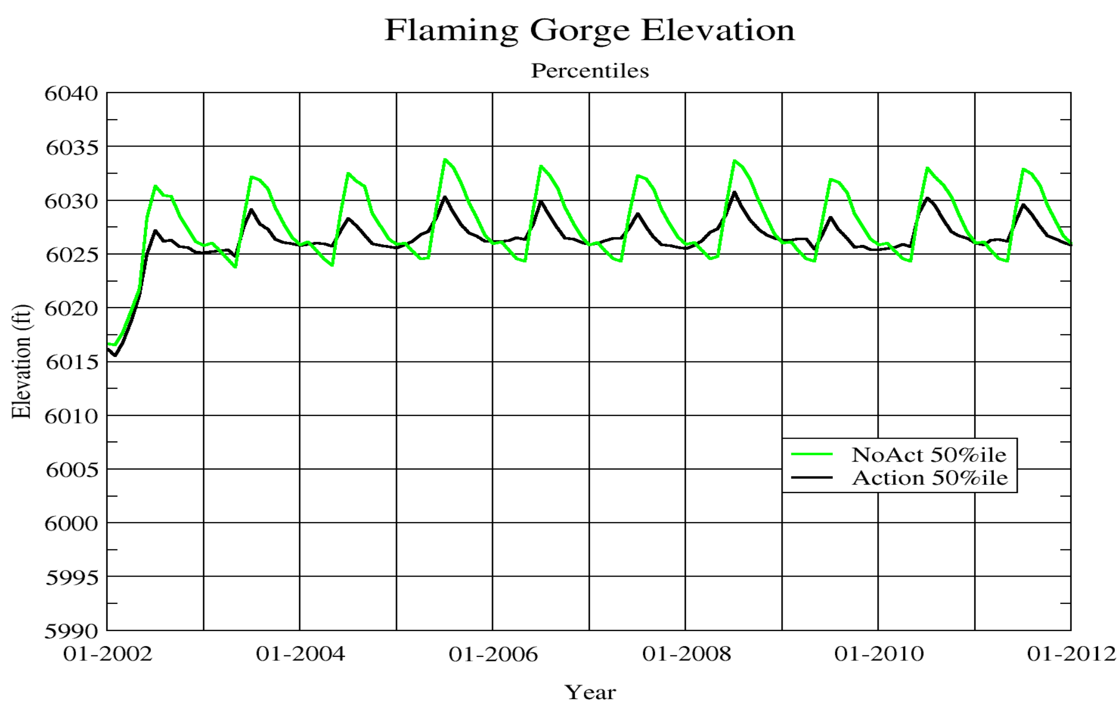


Figure 6.—50th Percentile Reservoir Elevations from January 2002 to December 2012.

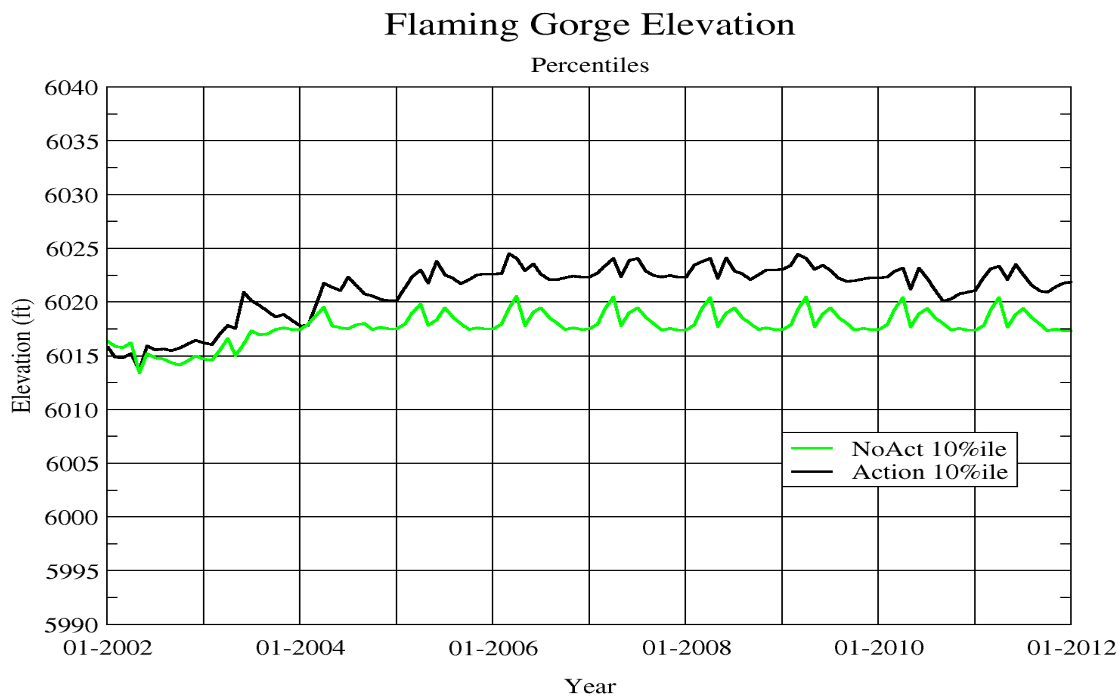


Figure 7.—10th Percentile Reservoir Elevations from January 2002 to December 2012.

Figure 7 is significant because it shows a tremendous improvement for Action Alternative in comparison to what was reported in the October report. Now, the Action Alternative yields reservoir elevations that are even higher than those yielded by the No Action Alternative. The October report showed a large disparity between the Action and No Action Alternatives with the Action Alternative much lower than the No Action Alternative.

The model results indicate that reservoir elevations are basically stable throughout the model run under both alternatives. That is to say the reservoir elevation did not gradually increase or decrease under the Action and No Action Alternatives in the later years of the run. For this reason, it was valid to combine all of the reservoir elevations into a single dataset, grouped by month and then ranked from lowest to highest into monthly distributions. Figures 8 and 9 show these distributions for the months of February and June. These months are shown because reservoir elevations are typically near their lowest level of the year by the end of February and near their highest level by the end of June. Both figures show that the distributions of reservoir elevations for the Action Alternative are now actually higher than the distributions for the No Action Alternative. These results are substantially different from those presented in October and indicate the impact of the modifications made to the model over the past 3 months. Similar plots for all months of the year are located in the appendix.

Figure 10 shows the Action and No Action Alternative reservoir elevations for all months at the 5% probability level grouped by month. The 5% probability level marks the reservoir elevations that were exceeded by 95% of all potential reservoir elevations on average. In other words, for each month of the year there were 5% of all potential reservoir elevations that were below those indicated in the figure. Figure 10 shows that at the 5% probability level, there was a 7- to 8-foot difference between the Action and No Action Alternatives. Similar plots showing the reservoir elevations for the 10%, 25%, 50%, and 75% probability levels are located in the appendix.

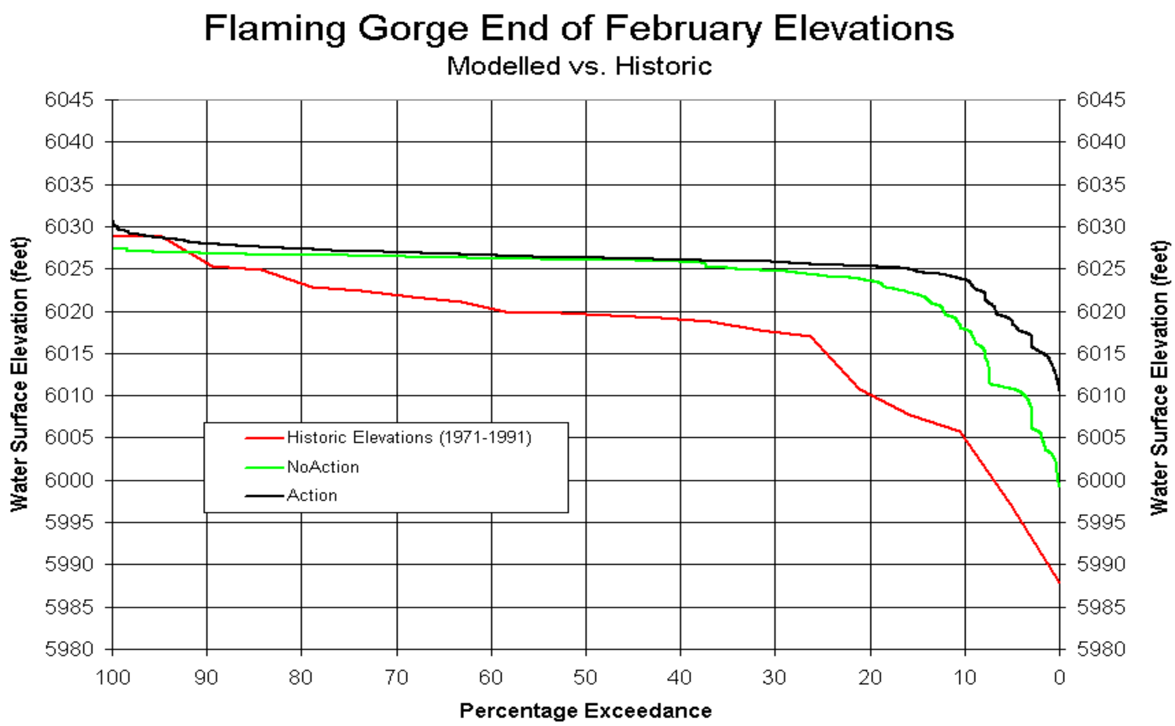


Figure 8.—February Reservoir Elevation Distribution Plot.

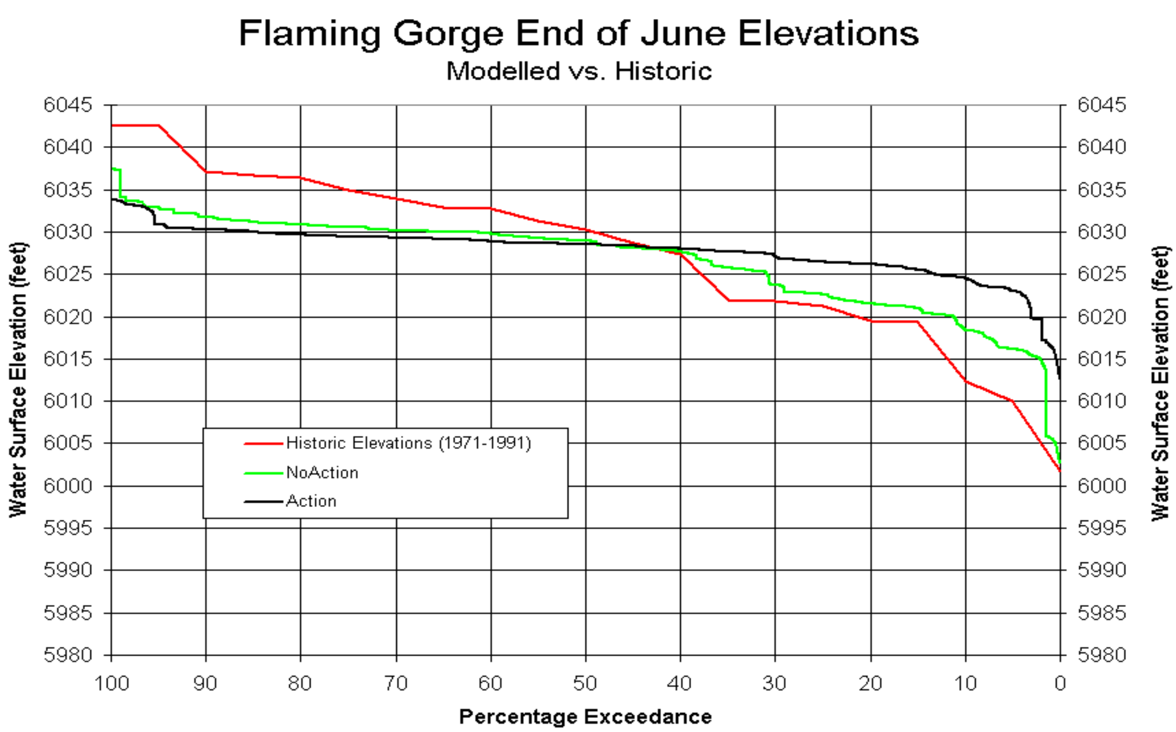


Figure 9.—June Reservoir Elevation Distribution Plot.

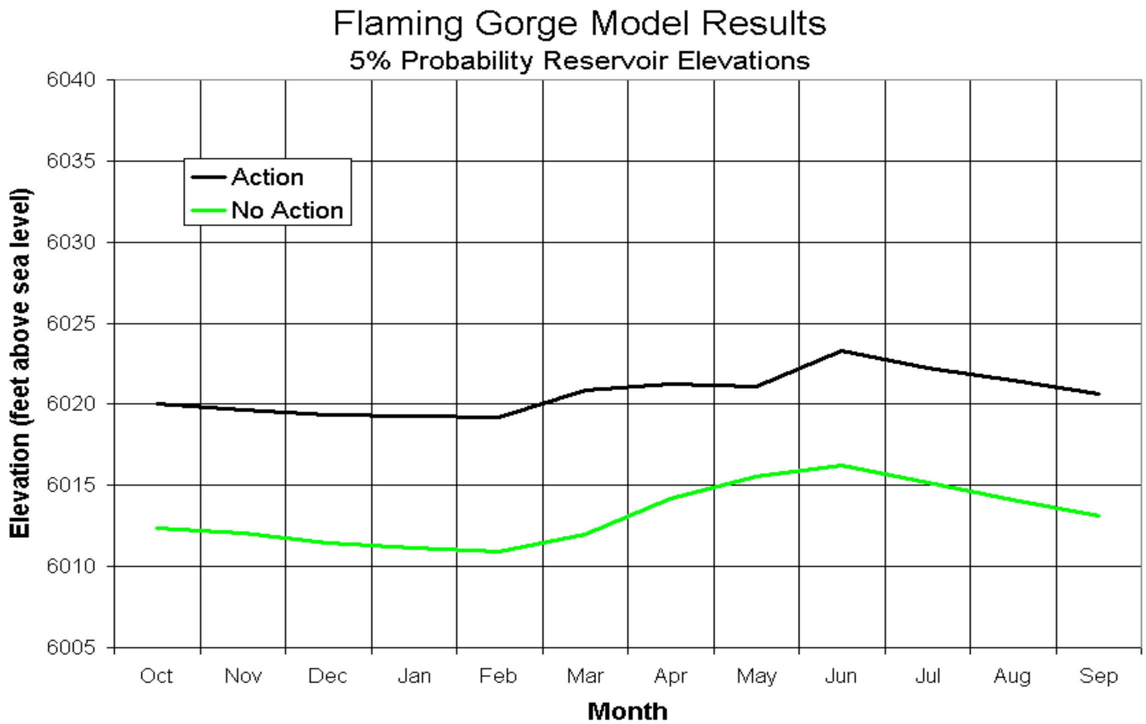


Figure 10.—5% Probability Level Reservoir Elevations (All Months).

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 11 shows the distribution of peak flows having a duration of 1 day that occurred in the model results. It is also assumed that peak flows always occur during the spring period. Thus the distributions that appear in figure 11 can also be used to represent the distribution of annual peaks as well. For reference to how the reservoir was operated prior to the 1992 Biological Opinion, the distribution of historic peak flows in Reach 1 having a duration of 1 day for the period from 1971 to 1991 are included in the figure. Figures 12 and 13 show the distributions of peak flows in Reach 1 having durations of 2 and 4 weeks, respectively.

FLAMING GORGE ANNUAL BYPASS RELEASE RESULTS

Water released through the bypass tubes and the spillway (bypasses) can have a direct impact on the amount of power produced at Flaming Gorge Dam. For the purpose of comparing the Action and No Action Alternatives in terms of impact to power production, the distributions of annual bypass volumes are shown in figure 14. The figure shows the percentage of occurrences associated with the total volume bypassed each year. The model results indicate that the Action

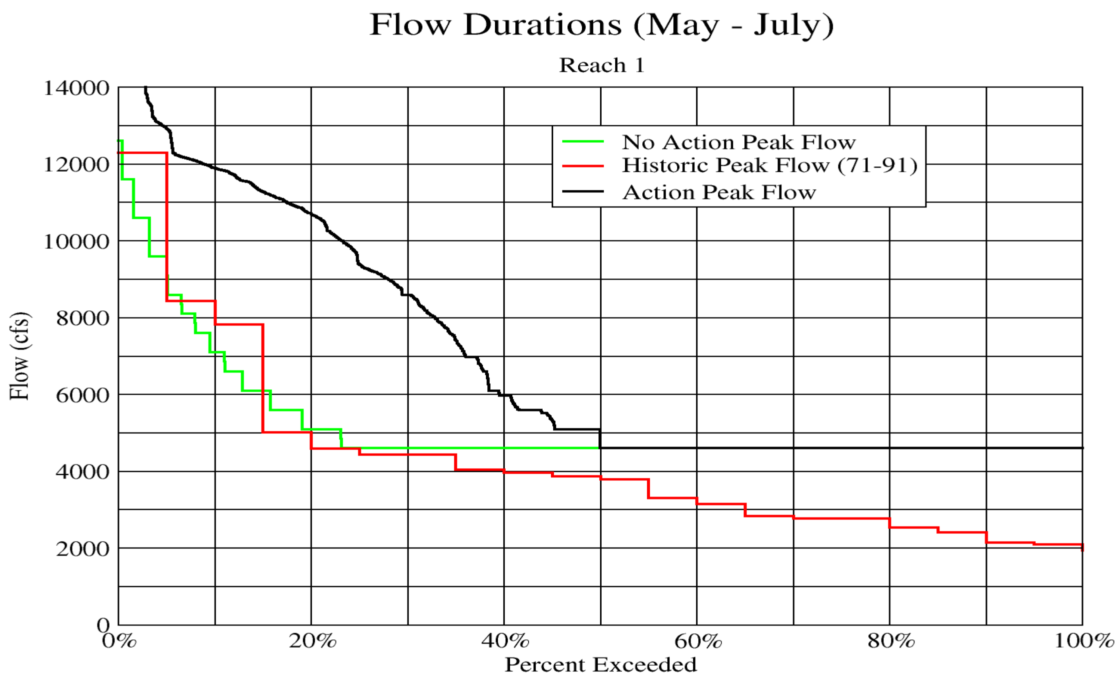


Figure 11.—5% Distribution of Peak (1-Day Duration) Releases.

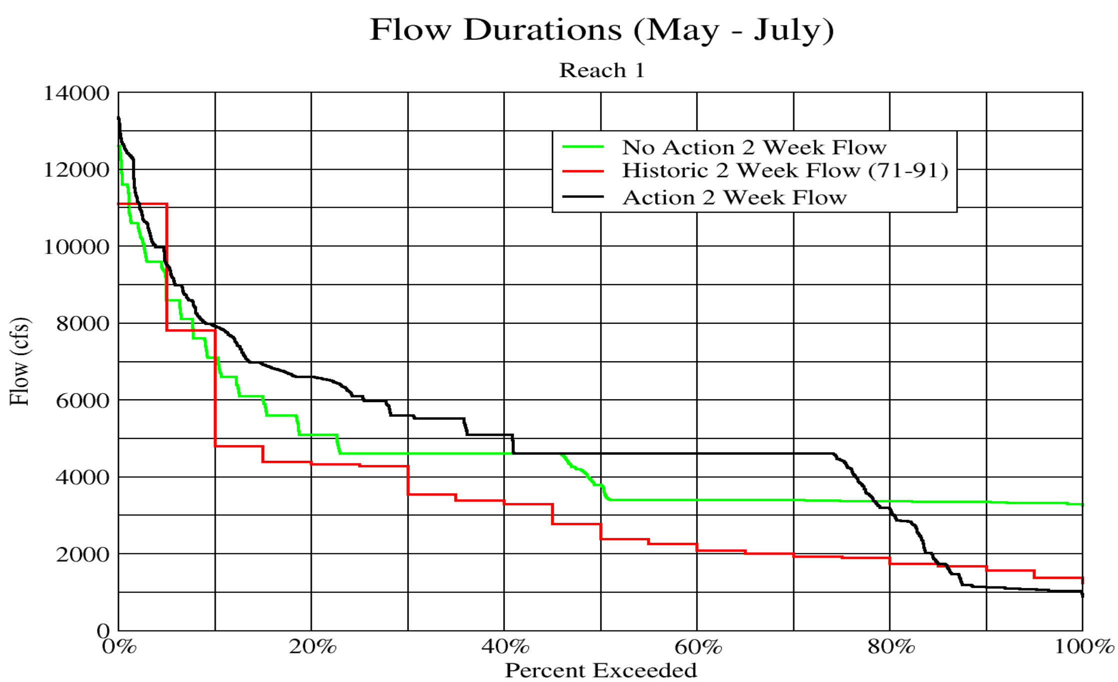


Figure 12.—Distribution of Peak (2-Week Duration) Releases.

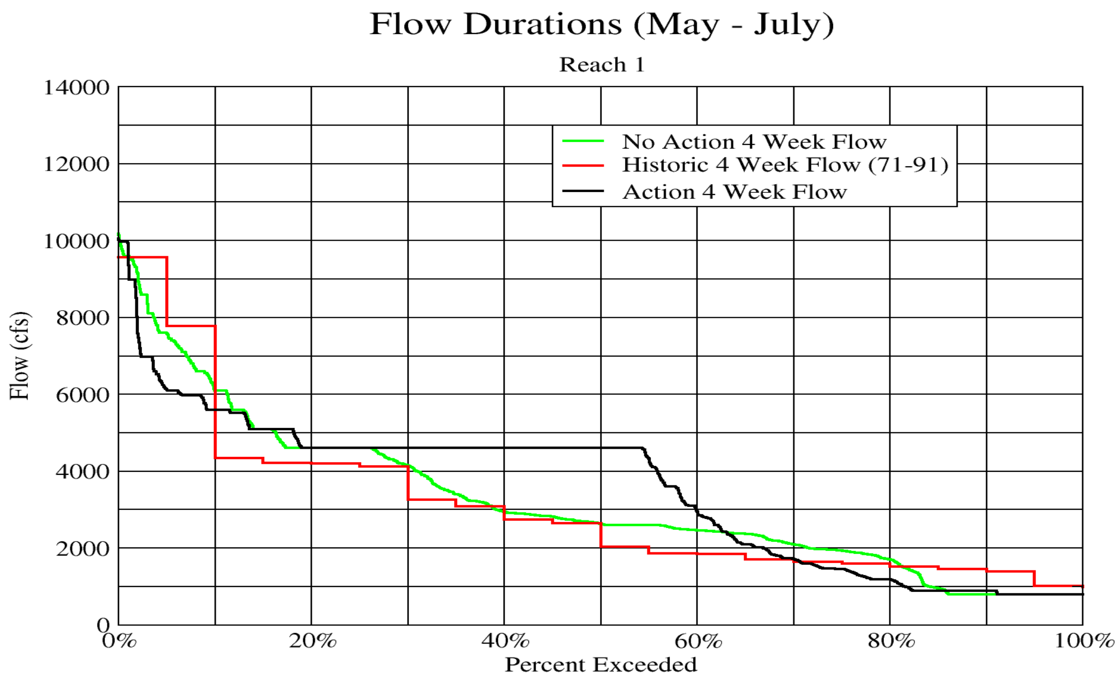


Figure 13.—Distribution of Peak (4-Week Duration) Releases.

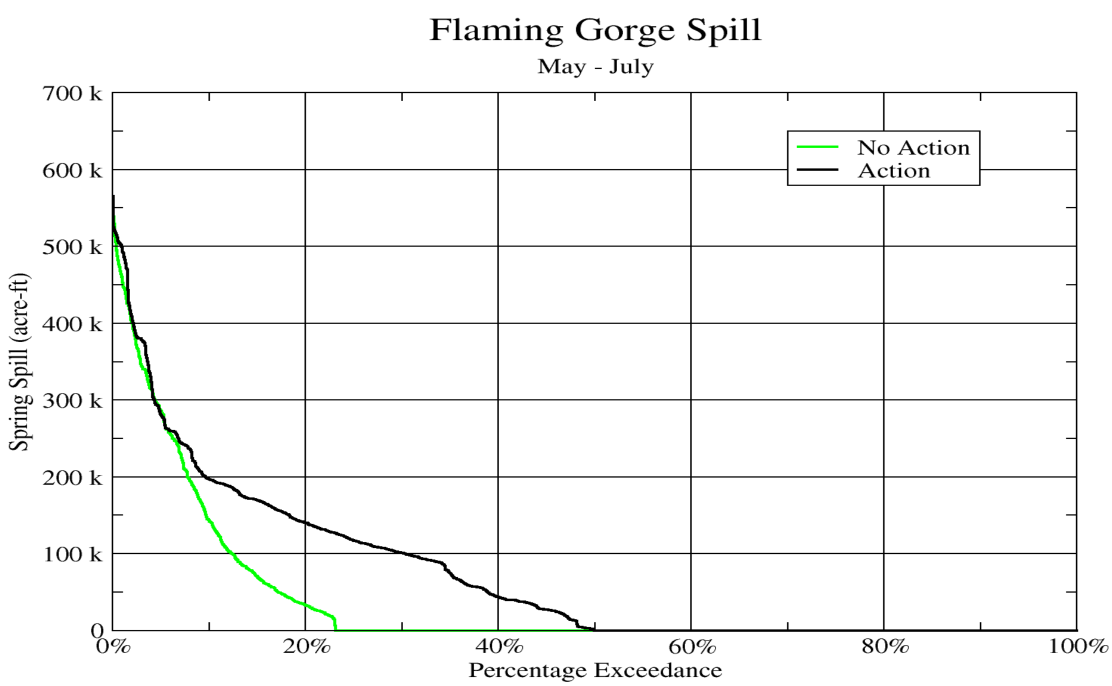


Figure 14.—Annual Bypass Volume Distribution.

Alternative will likely have about a 1 in 2 chance of requiring a bypass (about 50% of the time) in any given year while the No Action Alternative will likely have about a 1 in 5 chance of requiring a bypass (about 22% of the time) in any given year. These frequencies have not changed much from those reported in the October report, however the magnitude (volume) of these bypasses has diminished substantially.

REACH 1 AUGUST THROUGH FEBRUARY BASE FLOW RELEASE RESULTS

Releases made from August 1 through the end of February are referred to as the base flows in Reach 1. Figure 15 shows the distributions of base flows that occurred for Reach 1 in the model as a result of operating under the Action and No Action Alternatives. For reference to how Flaming Gorge Dam was operated prior to 1992, the distribution of actual base flows in Reach 1 that occurred from 1971 though 1991 are included in the figure. The distribution of unregulated inflows to Flaming Gorge Dam during this same period is also included. The unregulated inflows, in comparison to the actual base flows, indicate the effects of reservoir regulation at both Fontenelle Dam and Flaming Gorge Dam on Reach 1 flows during this period. Under the No Action Alternative, releases during the months of November through February are only restricted to be less than powerplant capacity and greater than 800 cfs. The Action Alternative maintains much stricter control of the releases during this period. This difference is evident in figure 15 between 0 and 20% exceedance. In many cases, the No Action Alternative strictly controls releases from August through October only to have releases increase dramatically in November

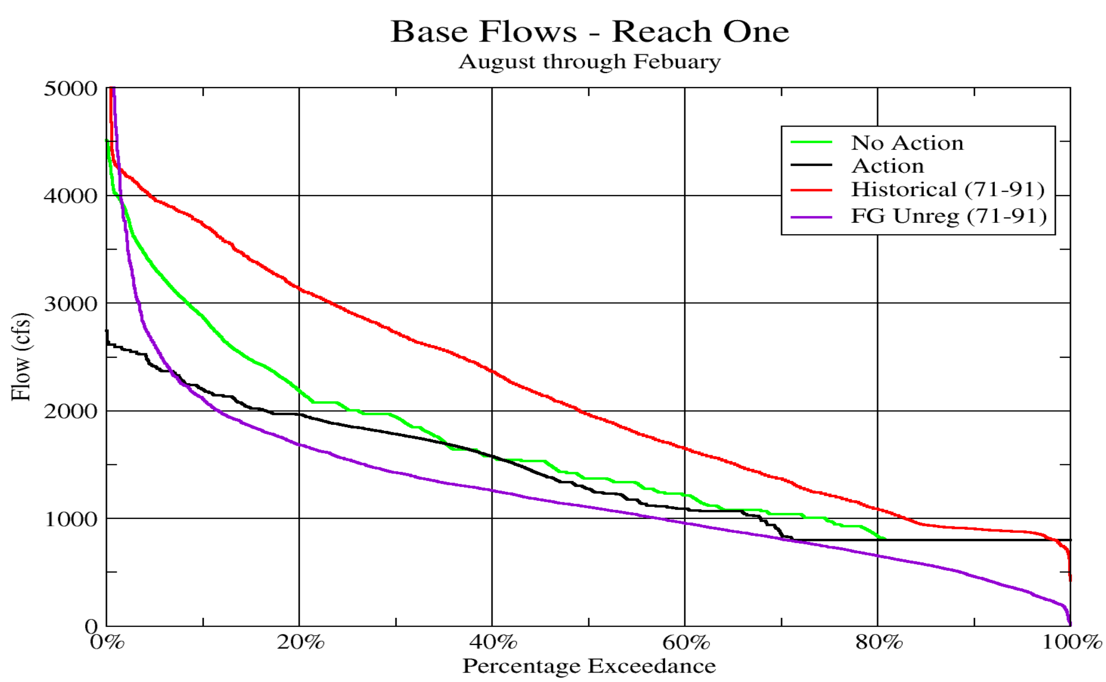


Figure 15.—Exceedance Percentage Flows for Reach 1 Flows During Base Flow Period.

when these controls are no longer valid. A good example of this situation is shown in figure 4. Releases during November for all three of these wet years were nearly double the releases that occurred during the preceding October.

The No Action Alternative restricts flows in Reach 2 from the end of the spring peak until September 15 to the range from 1,100 cfs to 1,800 cfs. In many cases, the Yampa River hydrograph is receding during this period and flows are above base flow levels. In order for the No Action Alternative to meet the base flow recommendation, releases are often times limited to 800 cfs (the minimum objective release). After September 15, the No Action Alternative expands the range of acceptable base flows to 1,100 to 2,400 cfs. In November these restrictions are no longer valid and releases are set within the range from 800 cfs to 4,600 cfs to achieve the drawdown target for the following year. To show the effect of these restrictions, the distribution of flows during the months of September and December were isolated. Graphs showing the distribution of flows for the Action and No Action Alternatives are included in the appendix of this report. There is a significant difference between the two months with respect to the flows generated by the Action and No Action rulesets. In September, flows in Reach 1 are typically less under the No Action Alternative than the flows of the Action Alternative. But in December, this relationship is reversed with flows of the No Action Alternative being much greater than those of the Action Alternative. This relationship translates to the other downstream reaches to a lesser degree. Flow distribution graphs for Reach 2 for the months of September and December are also included in the appendix.

REACH 2 SPRING PEAK FLOW RESULTS

Figures 16, 17, and 18 show the distributions of modeled spring peak flows that occurred in Reach 2. Figure 16 shows the distribution of peak flows having a duration of 1-day while figure 17 and 18 show distributions for peak flows having durations of 2 and 4 weeks, respectively. For perspective, the historic peak flows during the period from 1971 though 1991 are included on each of these figures. While the distributions of the Action and No Action peak flows are similar, there are notable differences at specific percentage exceedances. This is evident in figure 16 where the distribution for the Action Alternative noticeably deviates from the No Action Alternative at about 13% exceedance. Similar deviations occur in the Action Alternative at 10% and 40% exceedance levels for the 2-week duration peak flows. In the 4-week duration peak flows, a deviation in the Action distribution occurs at about 10% exceedance. All of these deviations indicate where peak flows were increased by the Action Alternative in order to achieve the specific targets of the 2000 Flow and Temperature Recommendations.

REACH 2 BASE FLOW RELEASE RESULTS

Figure 19 shows the distribution of base flows that occurred in Reach 2 under the Action and No Action Alternatives. Base flows are noticeably decreased under the Action Alternative especially in wetter years. For reference, the distribution of pre-dam (1946 to 1961) base flows and the distribution of base flows during the period from 1971 through 1991 are included in the figure.

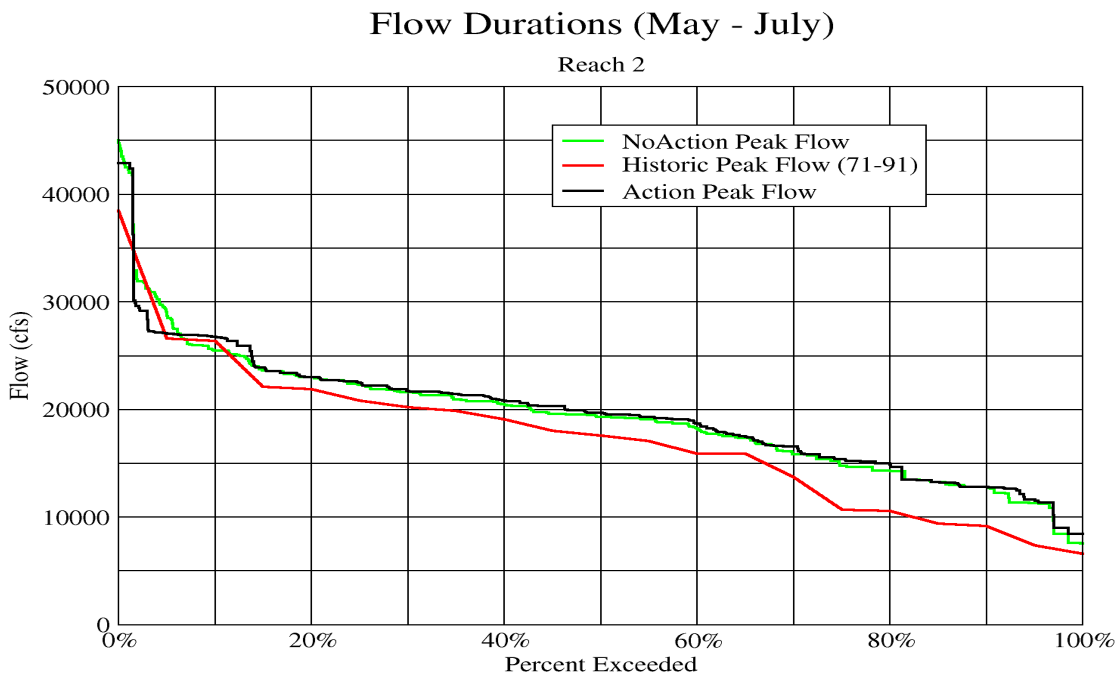


Figure 16.—Distribution of Peak Flows (1-Day Duration) in Reach 2.

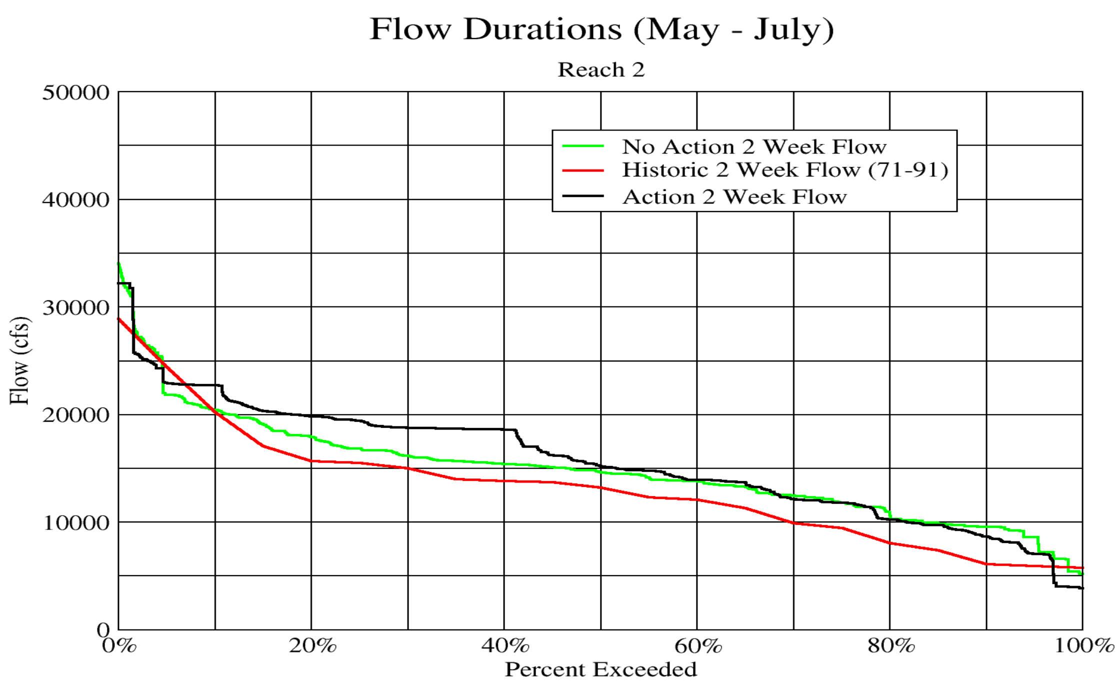


Figure 17.—Distribution of Peak Flows (2-Week Durations) in Reach 2.

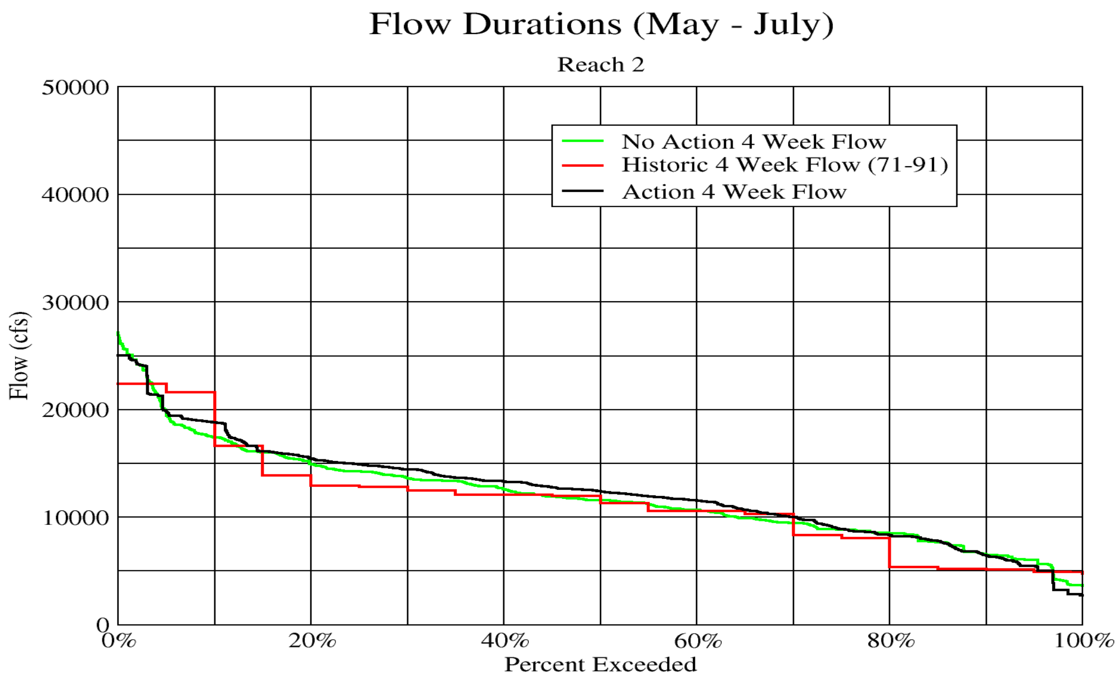


Figure 18.—Distribution of Peak Flows (4-Week Durations) in Reach 2.

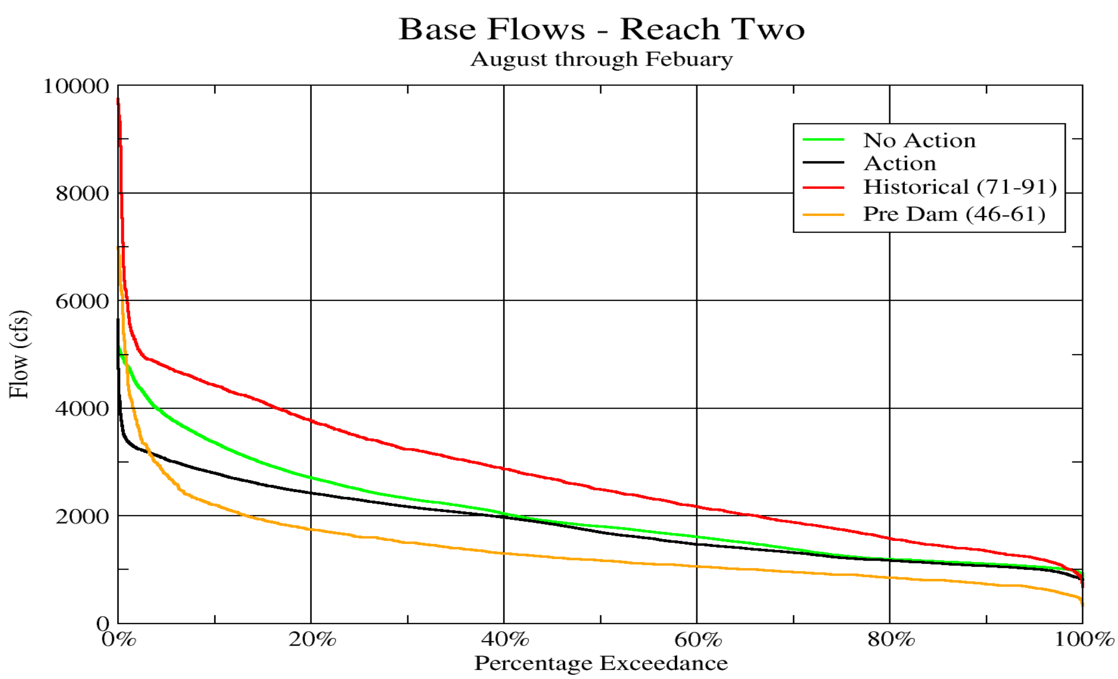


Figure 19.—Exceedance Percentage Flows for Reach 2 Flows During Base Flow Period.

The period from 1946 through 1961 does include a significant dry cycle for the Upper Green River Basin but these two distributions of historic Reach 2 flows give some perspective to the difference between the Action and No Action Alternative base flows.

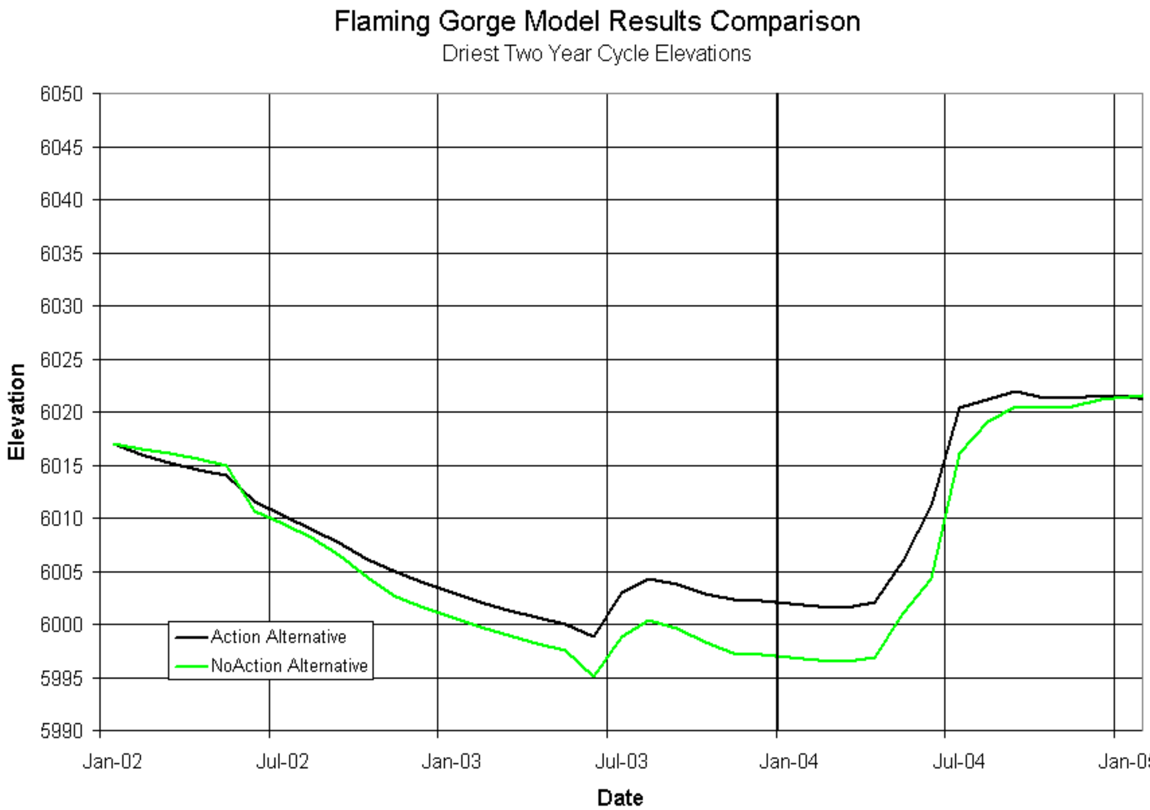
Reach 2 is also impacted by the No Action flow restrictions during the summer months. Flow distribution graphs for the months of September and December characterize how base flows in Reach 2 will transition from low to high during the fall months (October and November). These graphs are located in the appendix of this report.

SUMMARY

The results described in this report show significantly reduced impacts to reservoir related resources. Of all of the modifications made since October, the most significant was the implementation of the daily model to react to estimated Yampa River flows. This modification substantially reduced the volume of the spring releases made by the Action Alternative, which in turn, decreased the drawdown effects associated with the spring release. The Action Alternative now yields reservoir elevations that are significantly higher than those presented in the October report. While the frequency of bypasses in the Action Alternative has not changed very much from those reported in October, the bypass volumes have been significantly reduced. In October, there was about a 20% chance that any given year would have a bypass in excess of 300,000 acre-feet. With the modifications made since October, there is now a 20% chance in any given year of a bypass in excess of 150,000 acre-feet.

This report is not comprehensive in terms of the model results analysis presented. It is an attempt to provide some useful analysis for the purposes of determining other resource impacts. Statistical analysis of data depends largely on the question that must be answered. While the results presented in this report do answer many questions about impacts that may occur as a result of implementing the Action or No Action Alternatives, the results will not answer all questions. If additional analysis is required to answer your particular resource questions, it is suggested that you present your questions to the hydrologic modeling team.

APPENDIX


Flaming Gorge Model Results Comparison
Driest Two Year Cycle Elevations
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Action Alternative
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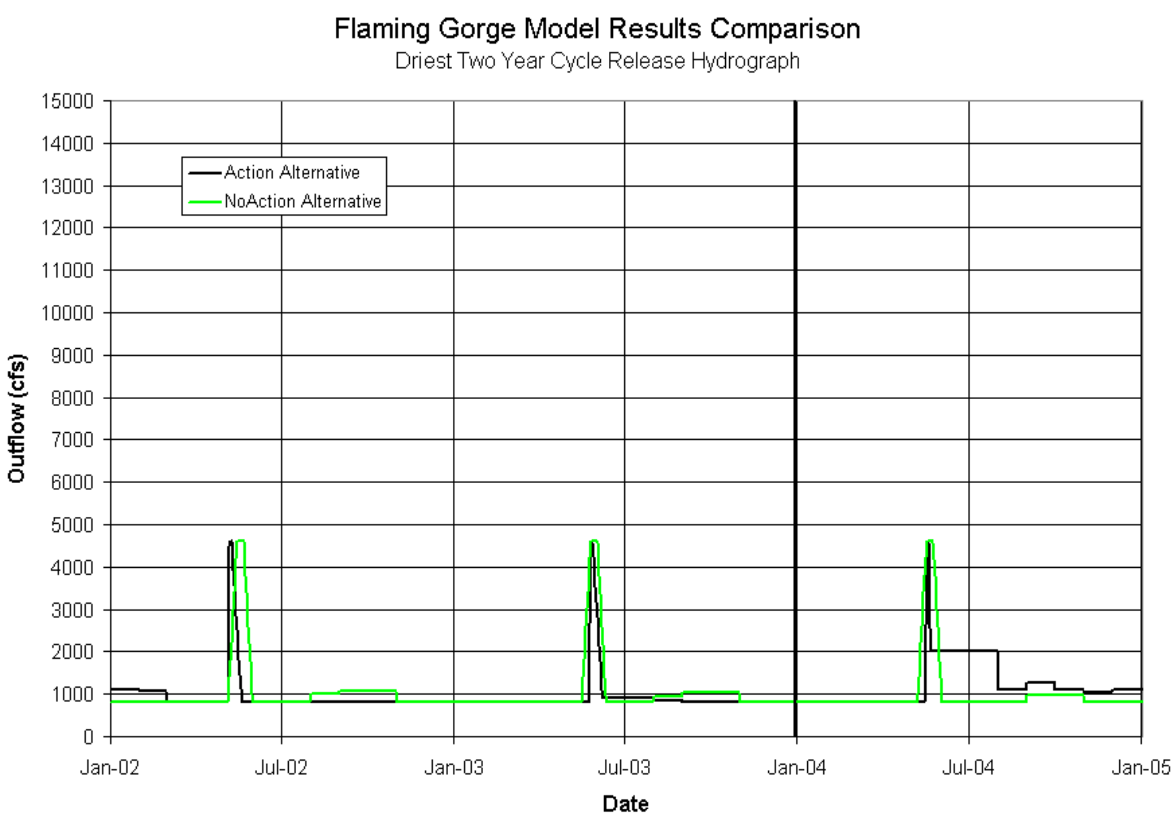
Date


Flaming Gorge Model Results Comparison
Driest Two Year Cycle Release Hydrograph
Outflow (cfs)
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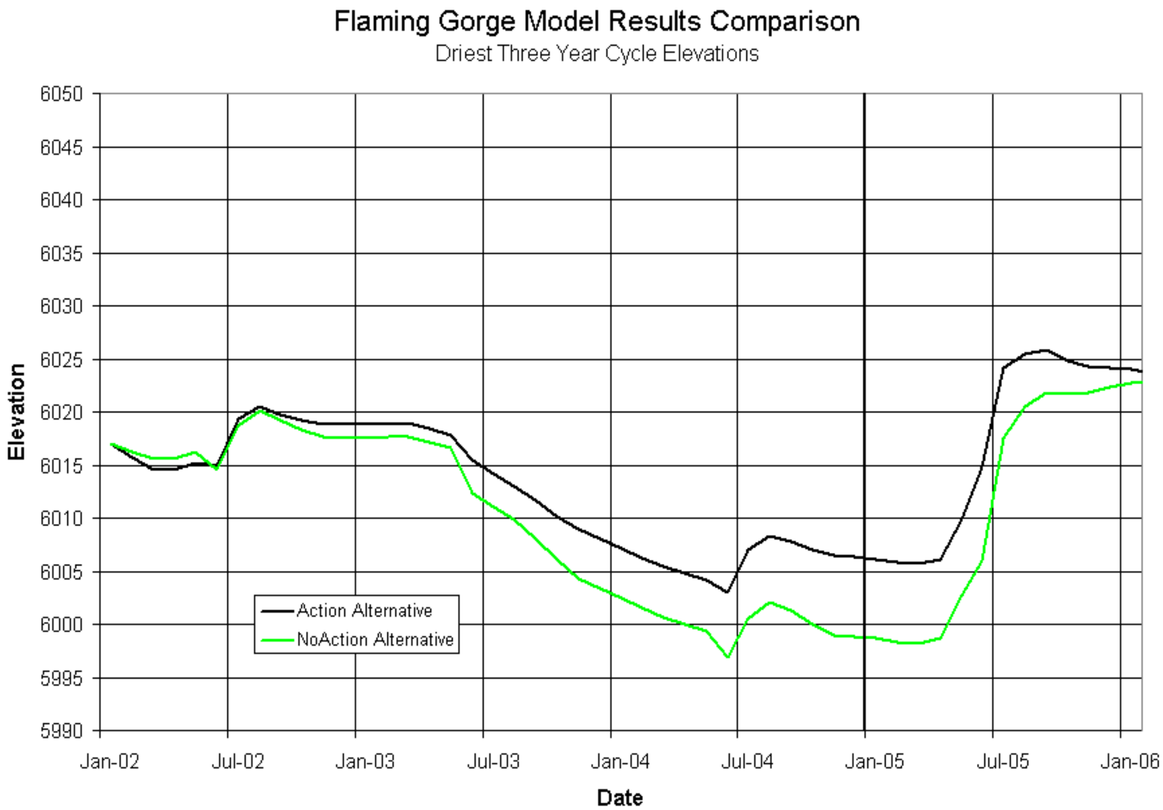

Flaming Gorge Model Results Comparison
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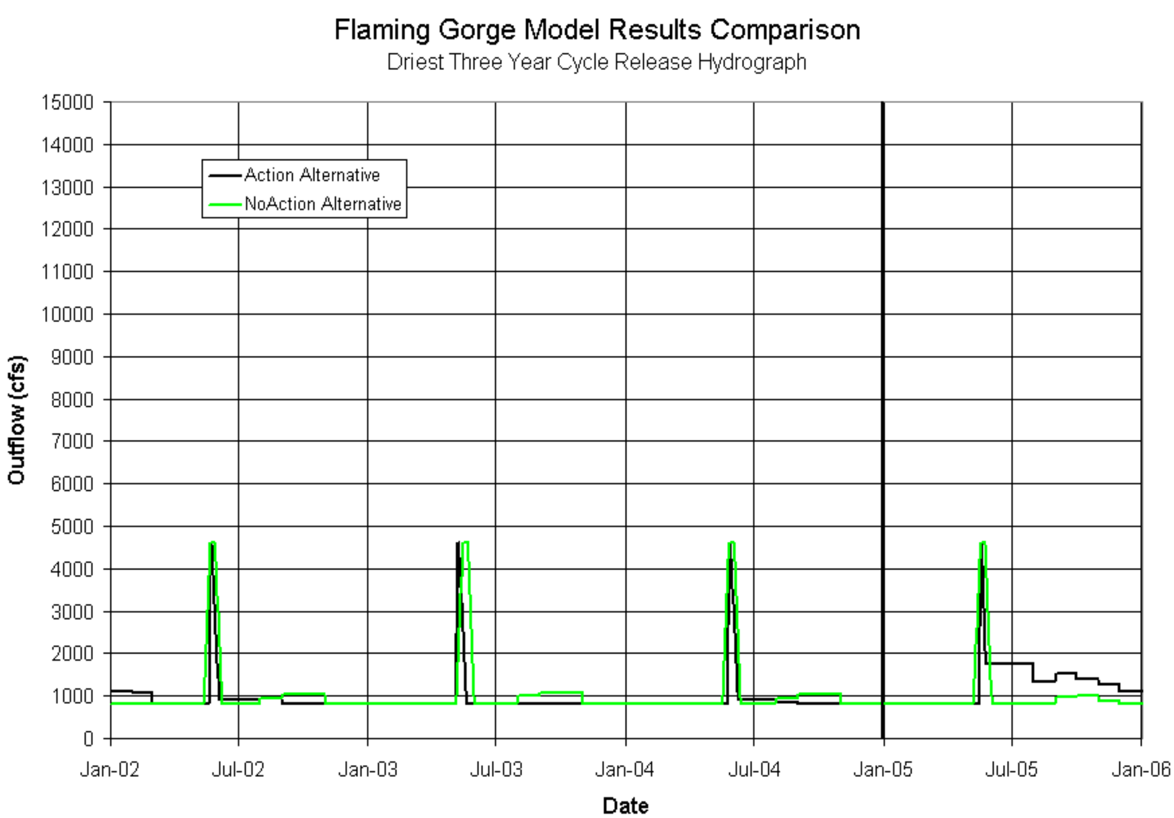

Flaming Gorge Model Results Comparison
Driest Three Year Cycle Release Hydrograph
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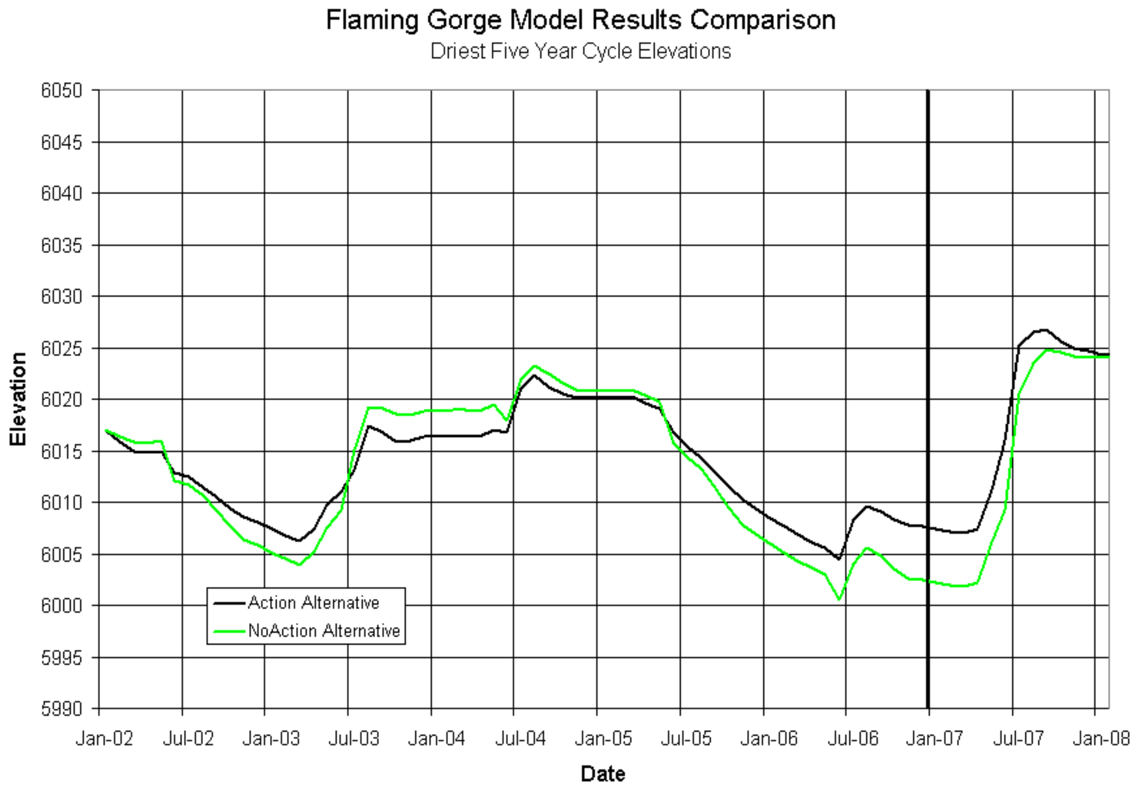
Flaming Gorge Model Results Comparison
Driest Five Year Cycle Elevations
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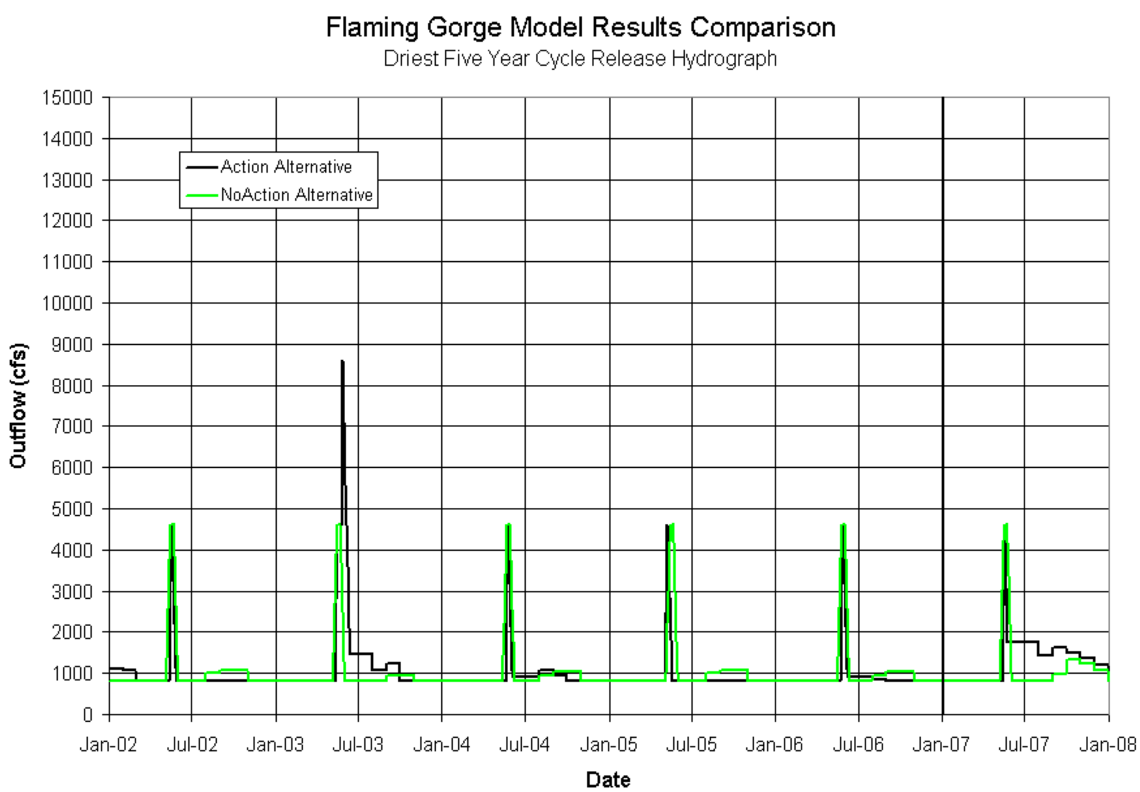
Flaming Gorge Model Results Comparison
Driest Five Year Cycle Release Hydrograph
Outflow (cfs)
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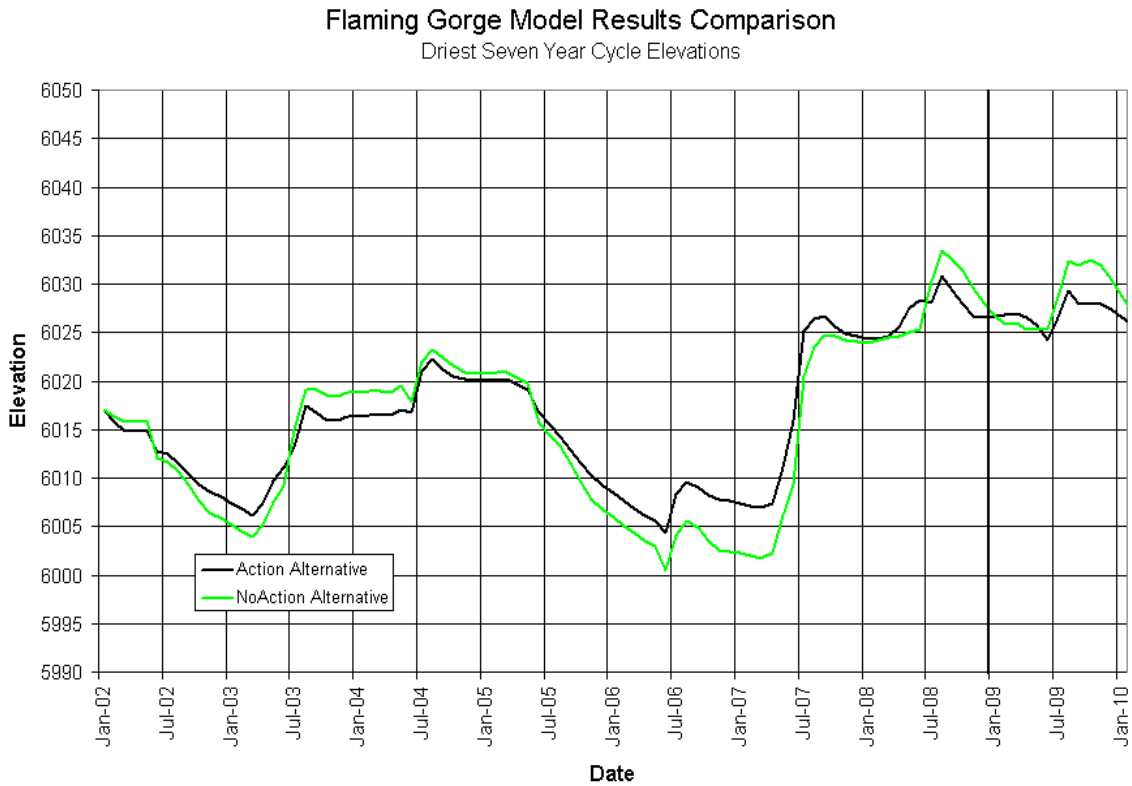
Flaming Gorge Model Results Comparison
Driest Seven Year Cycle Elevations
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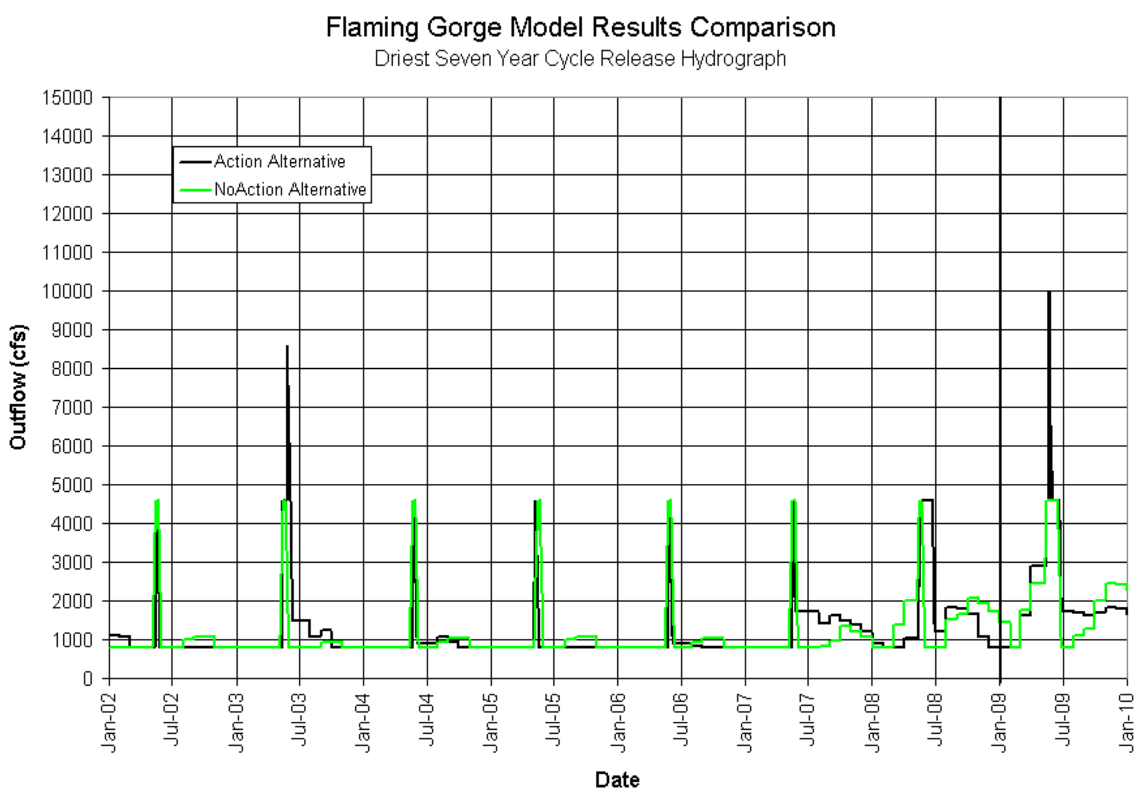
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Driest Seven Year Cycle Release Hydrograph
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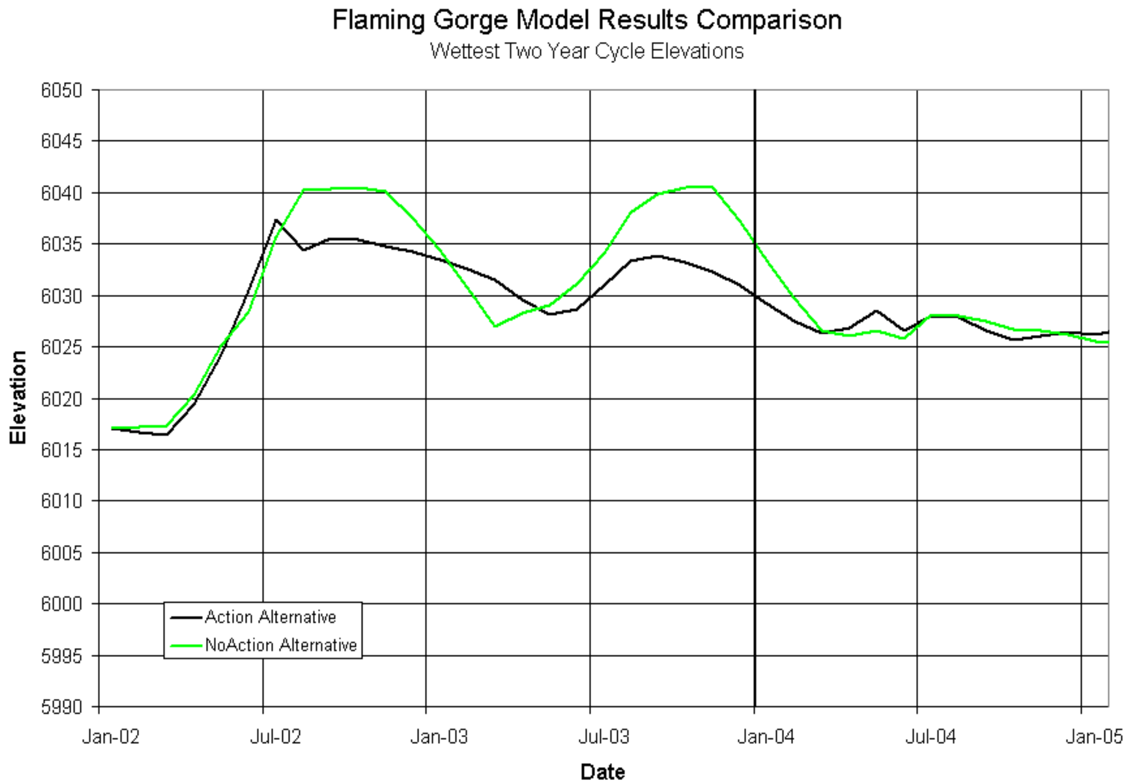

Flaming Gorge Model Results Comparison
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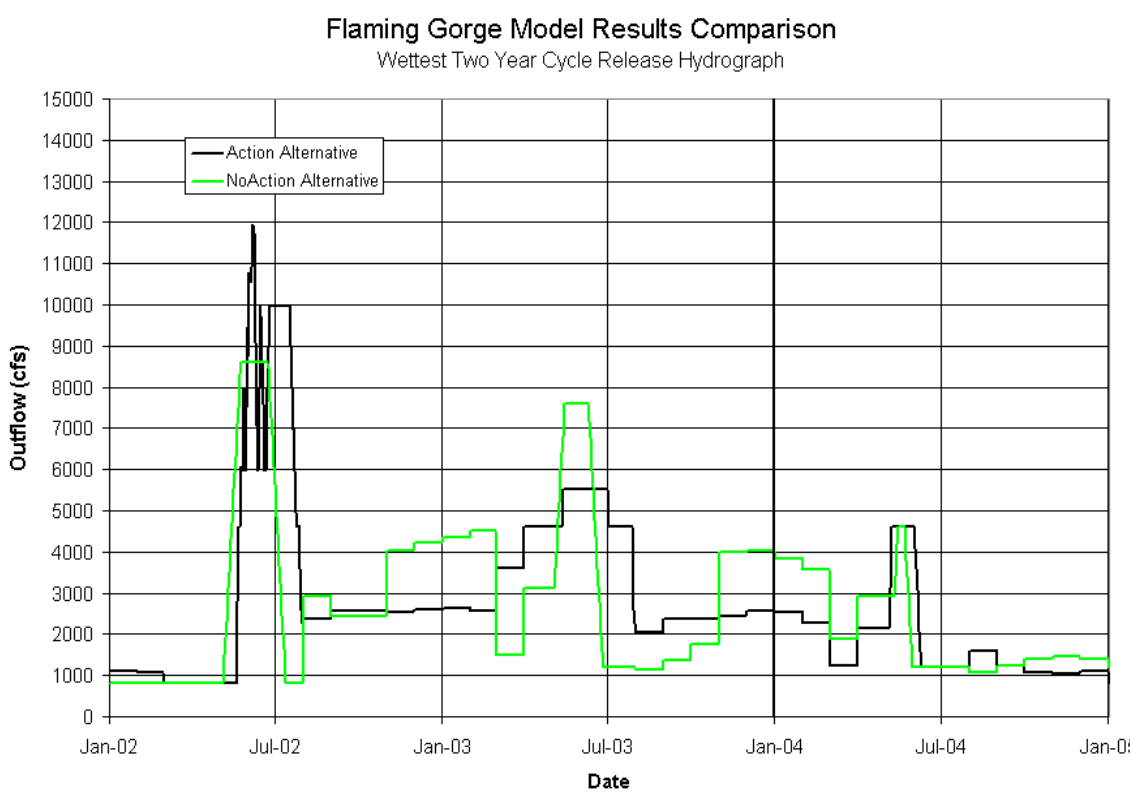

Flaming Gorge Model Results Comparison
Wettest Two Year Cycle Release Hydrograph
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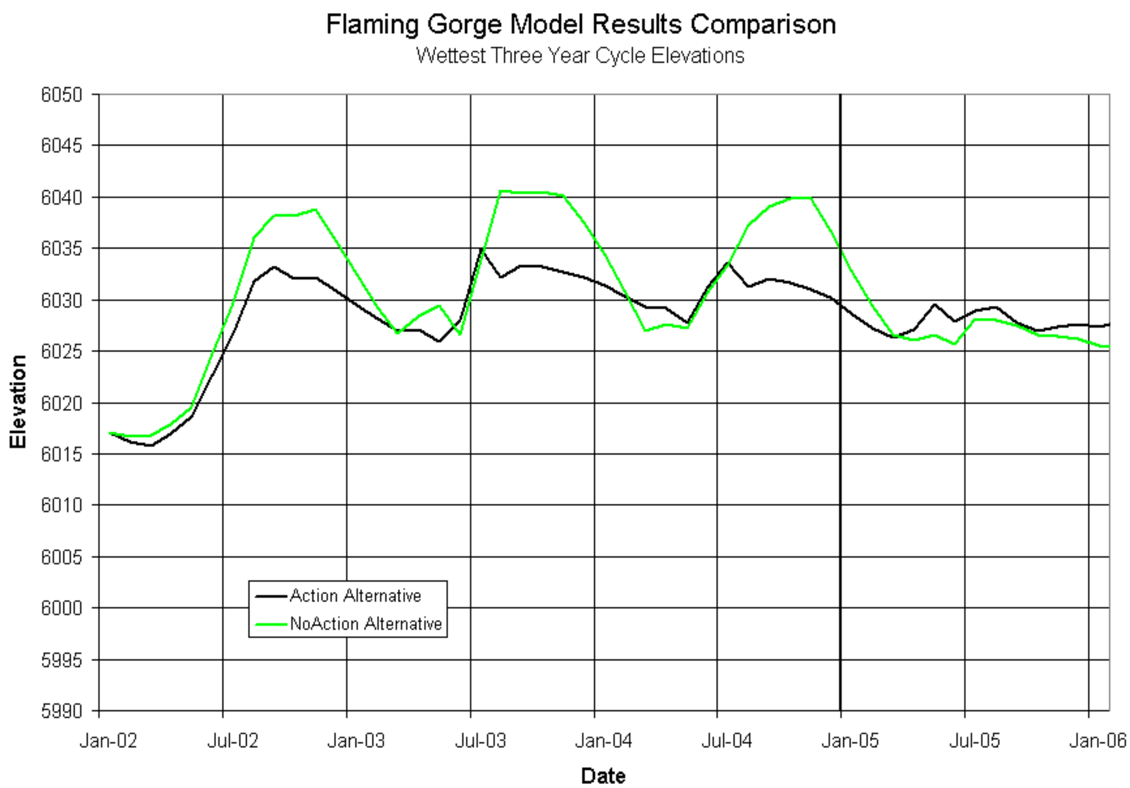

Flaming Gorge Model Results Comparison
Wettest Three Year Cycle Elevations
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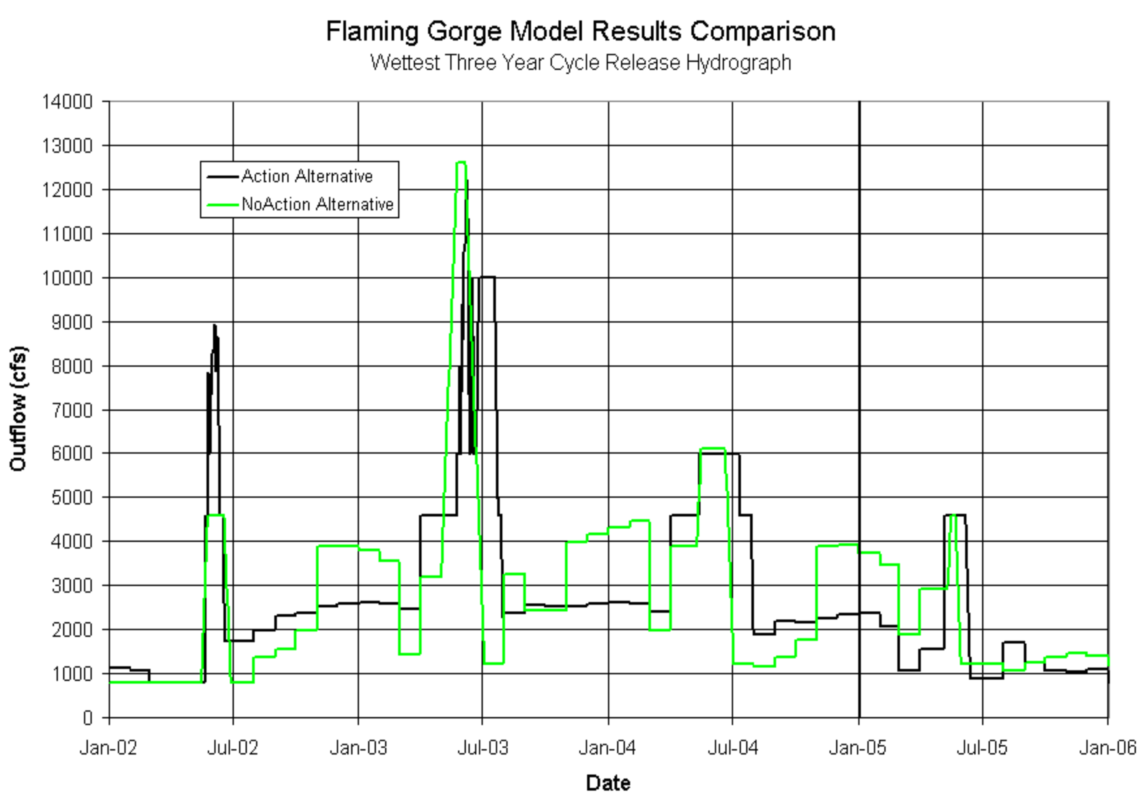

Flaming Gorge Model Results Comparison
Wettest Three Year Cycle Release Hydrograph
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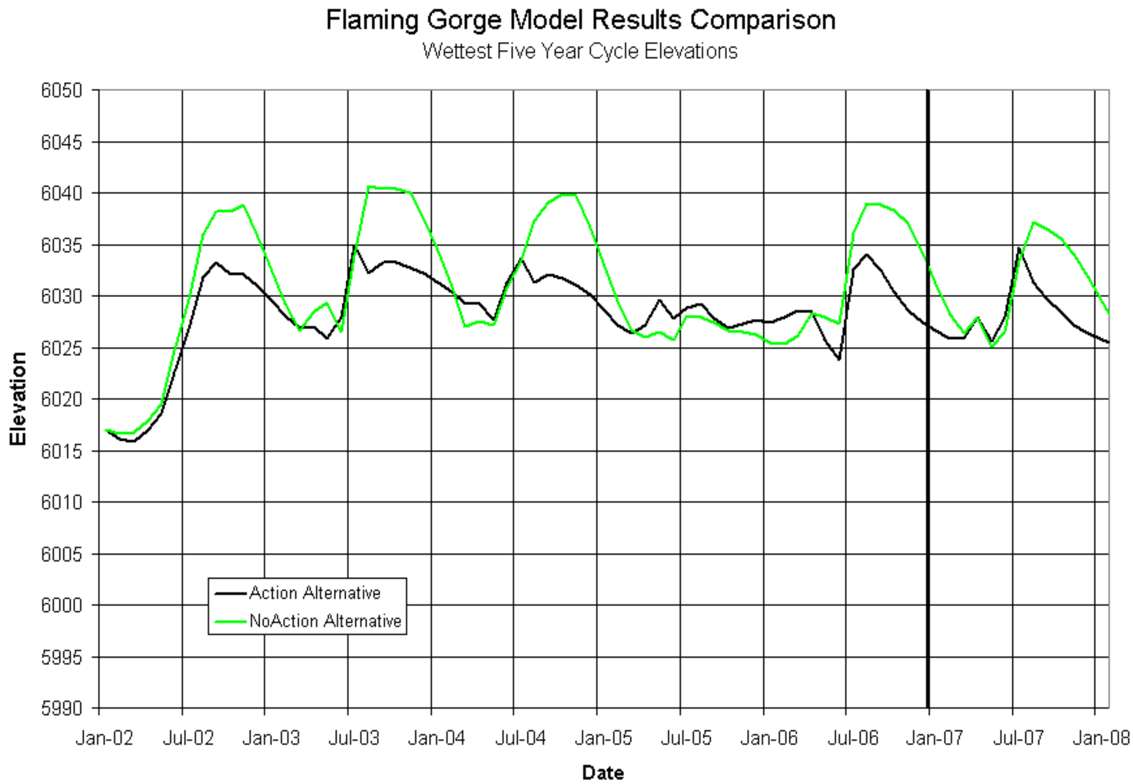
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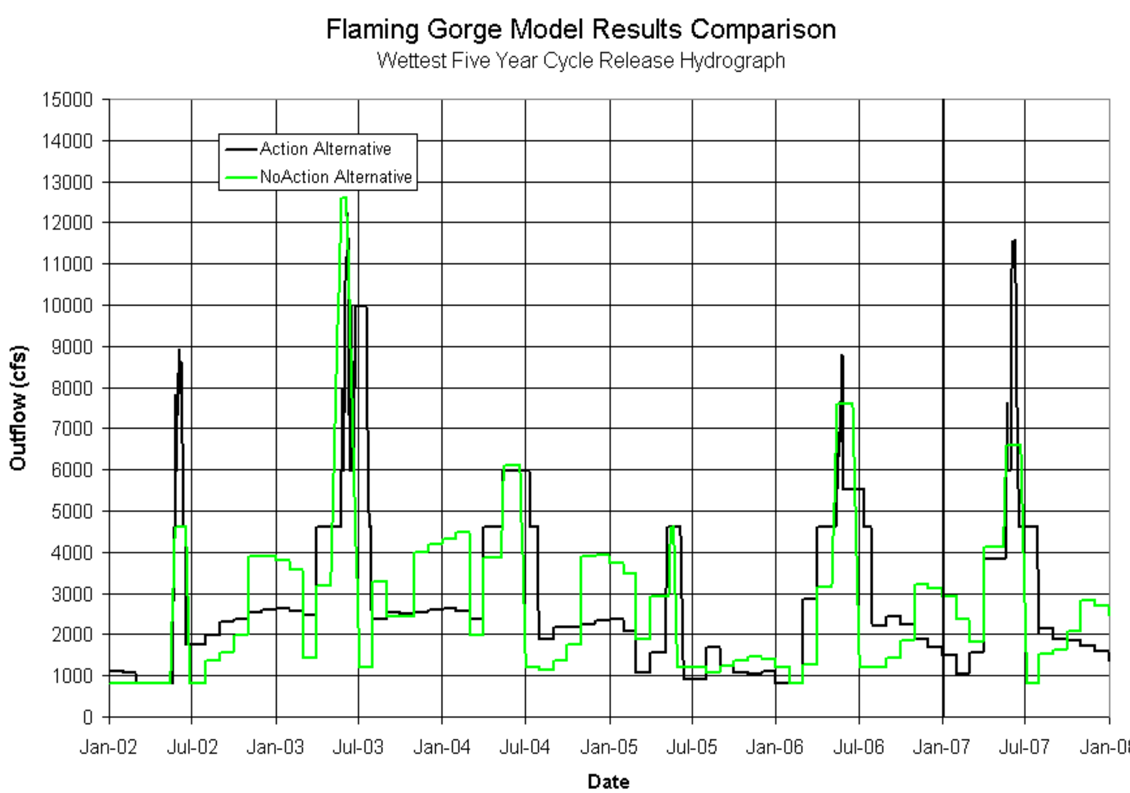
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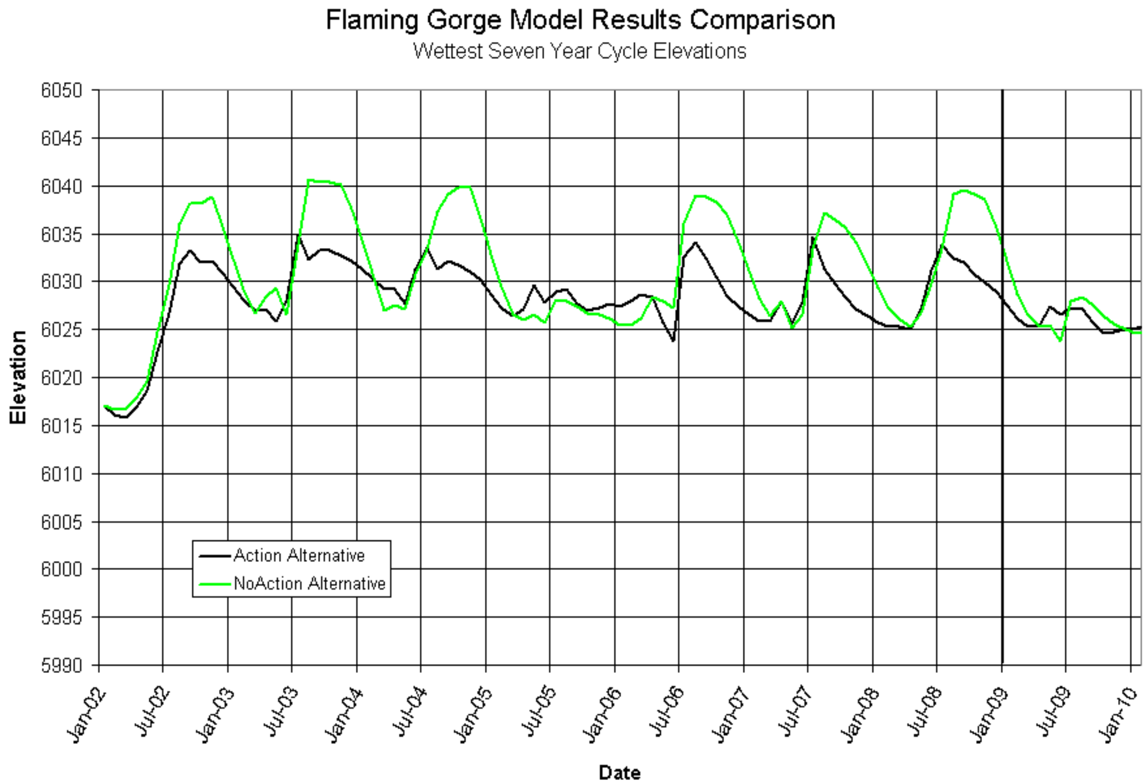
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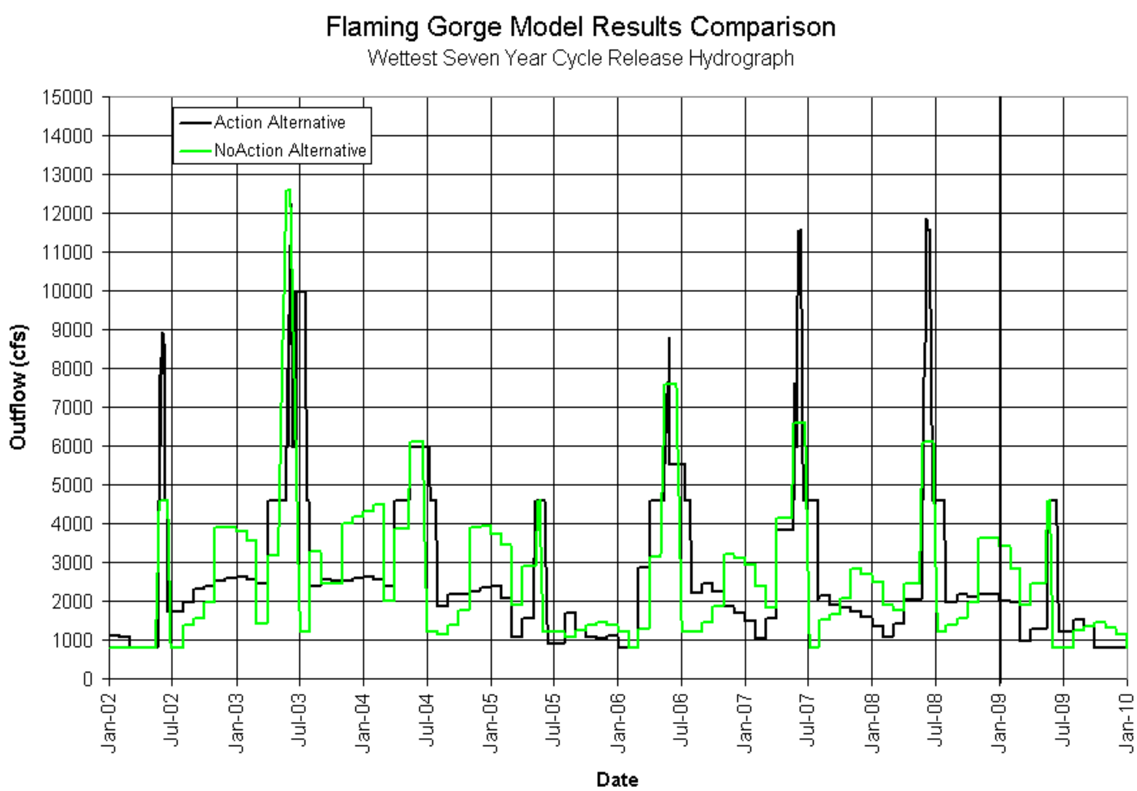
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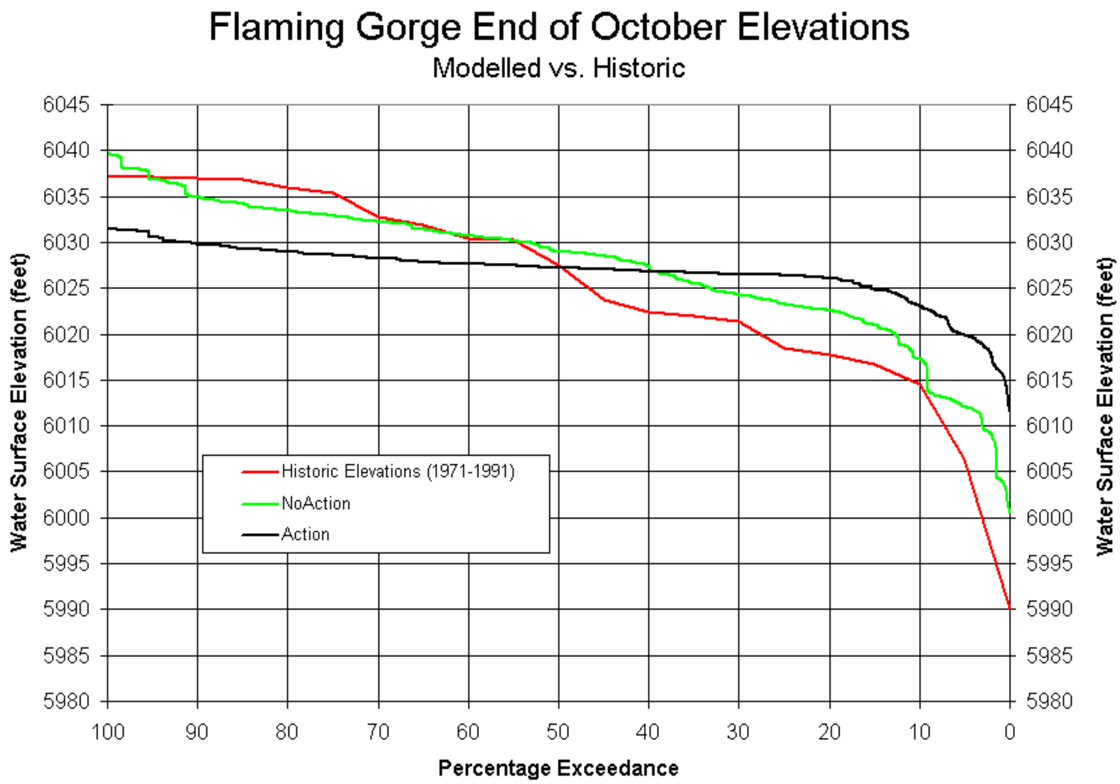
Flaming Gorge End of October Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
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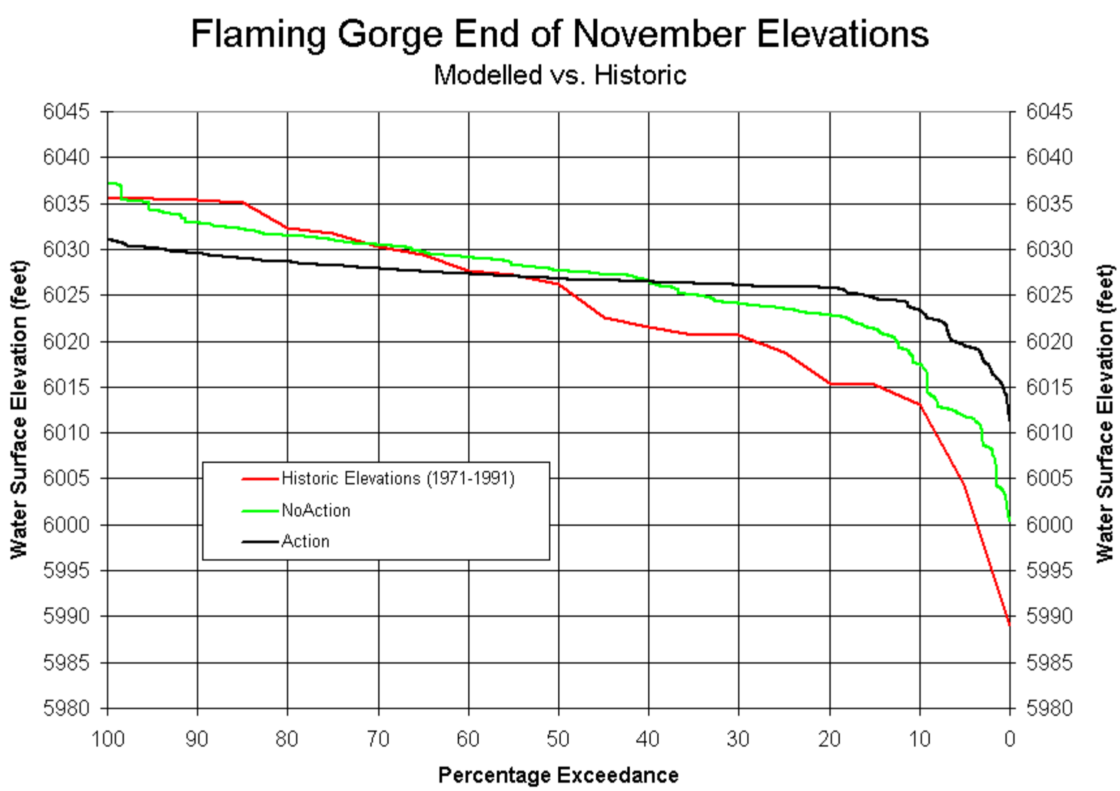
Flaming Gorge End of November Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
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10
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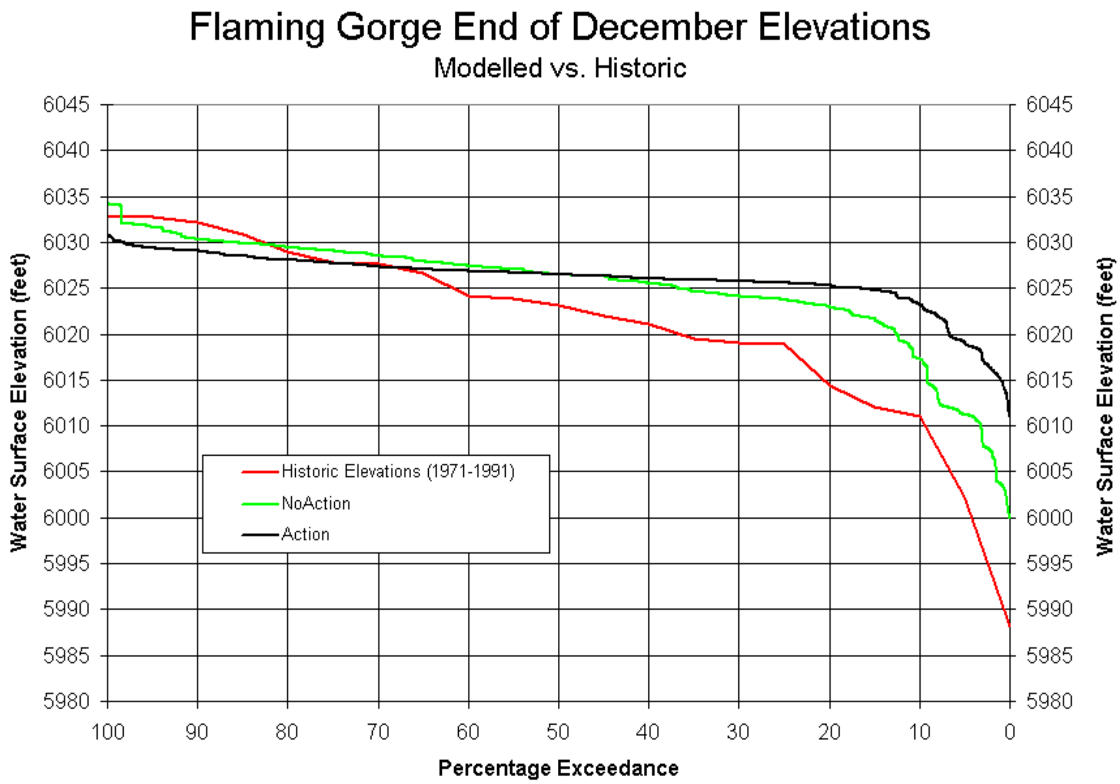
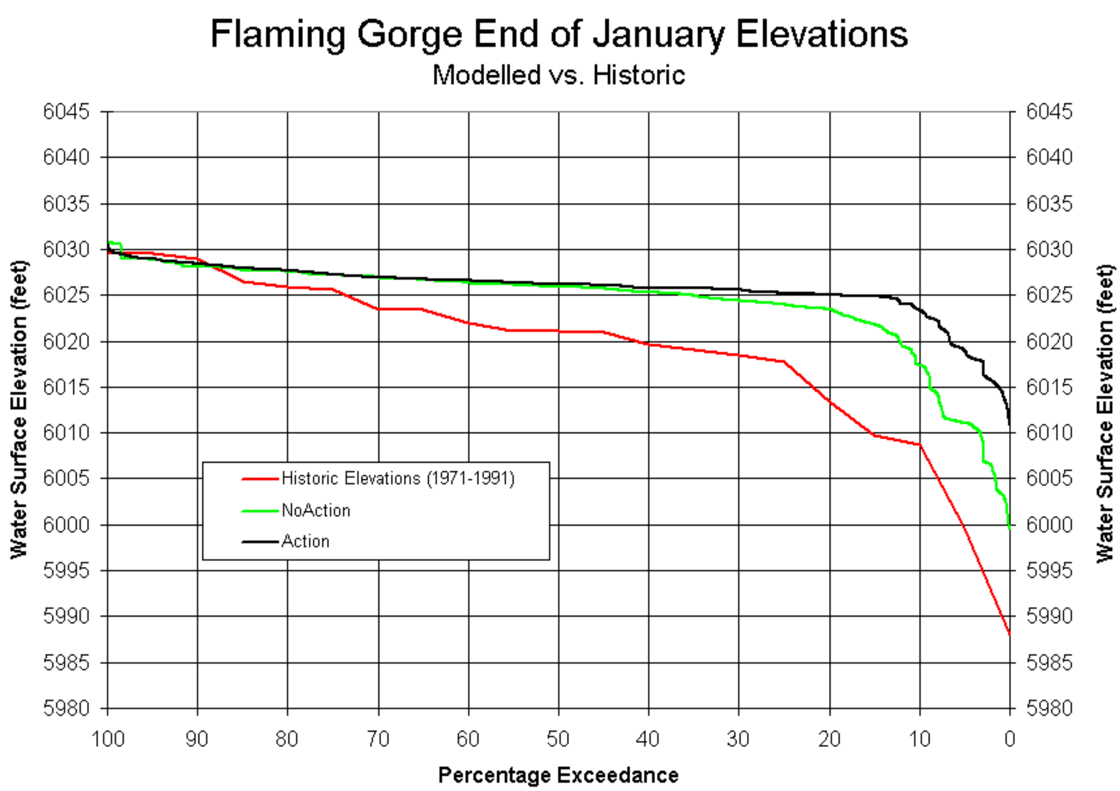

Flaming Gorge End of December Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
5995
5990
5985
5980
100
90
80
70
60
50
40
30
20
10
0


Flaming Gorge End of January Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
5995
5990
5985
5980
100
90
80
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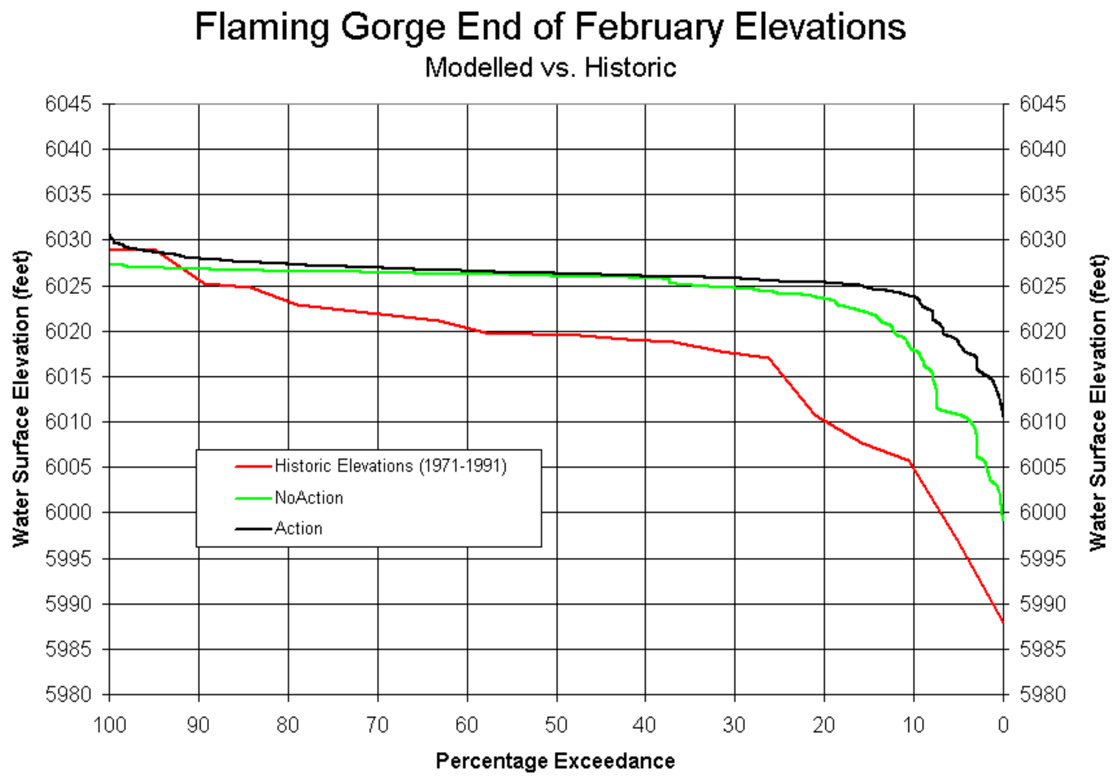
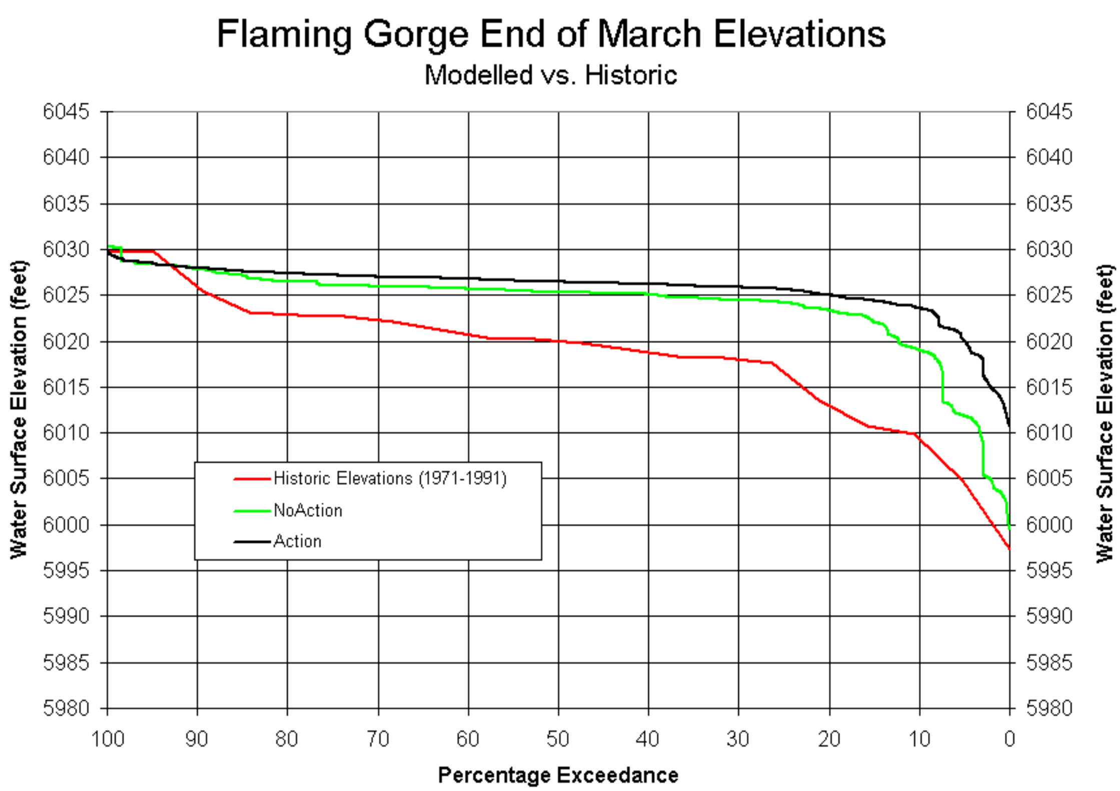
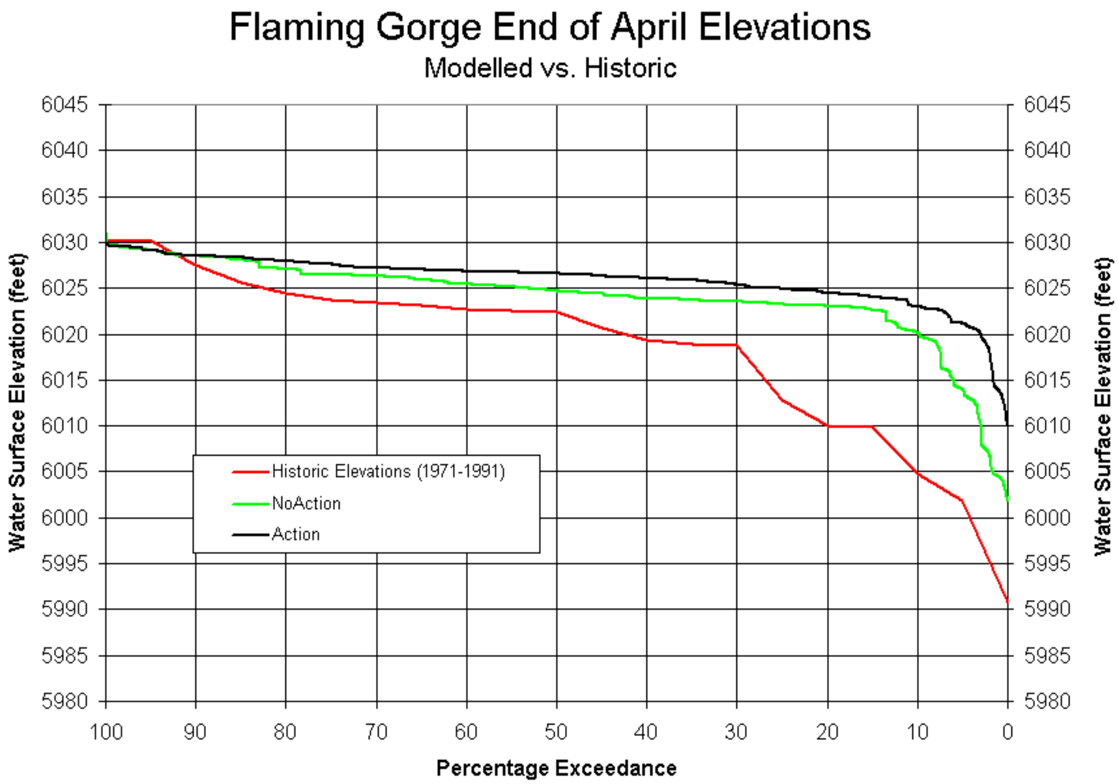
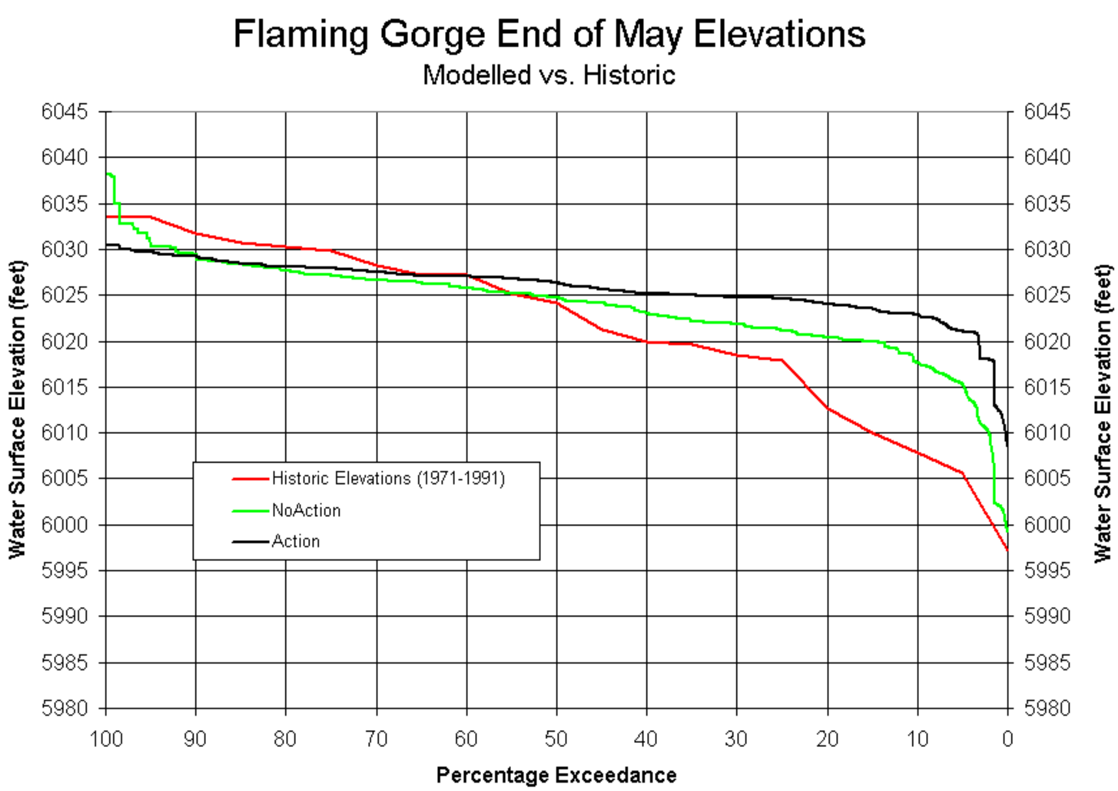
40
30
20
10
0


Flaming Gorge End of February Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action


Flaming Gorge End of March Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action


Flaming Gorge End of April Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
5995
5990
5985
5980
100
90
80
70
60
50
40
30
20
10
0


Flaming Gorge End of May Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
5995
5990
5985
5980
100
90
80
70
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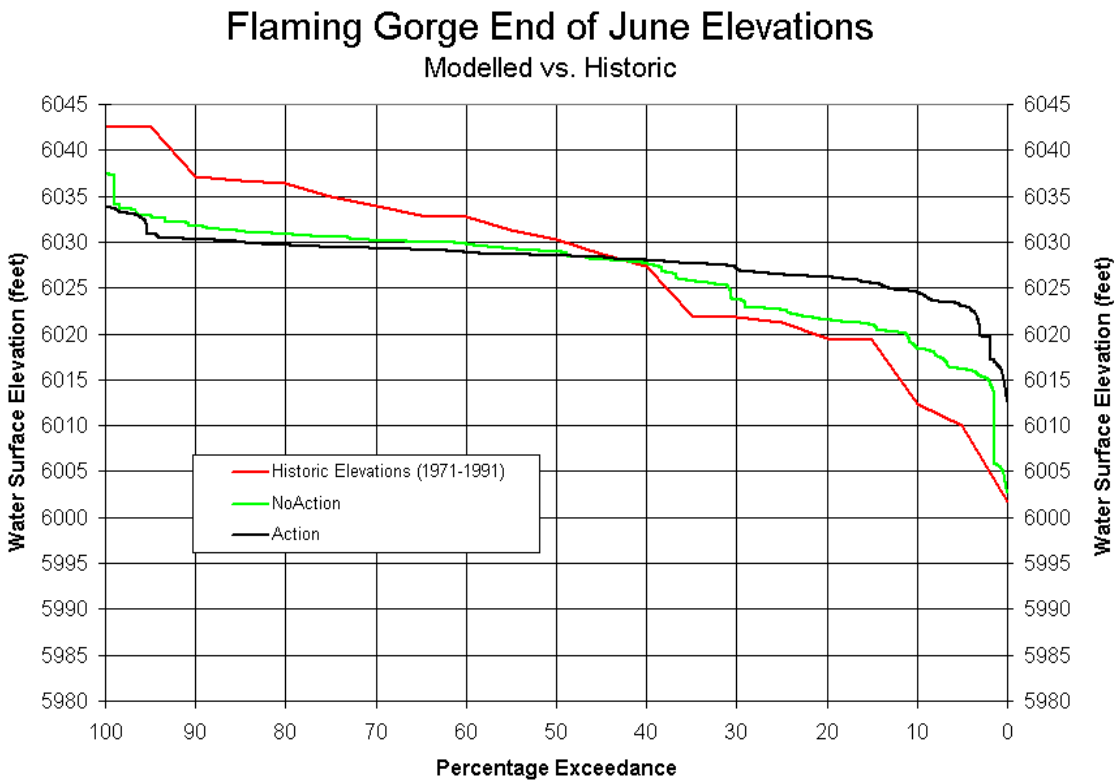
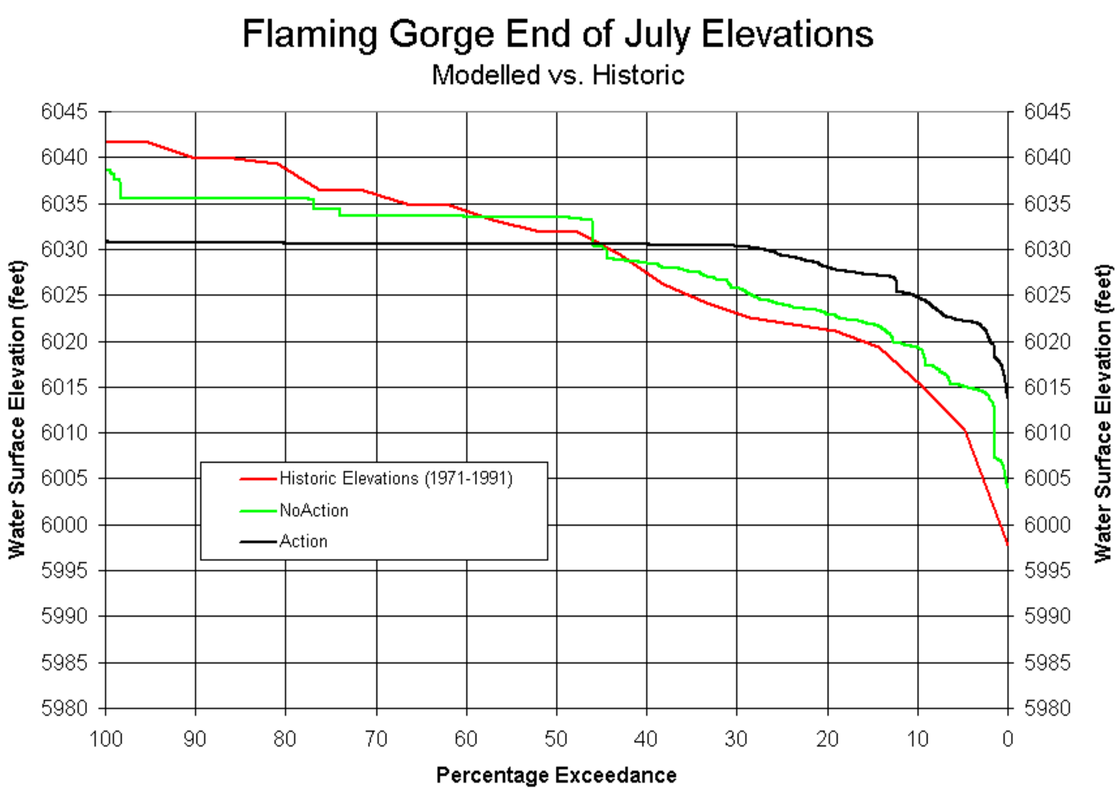
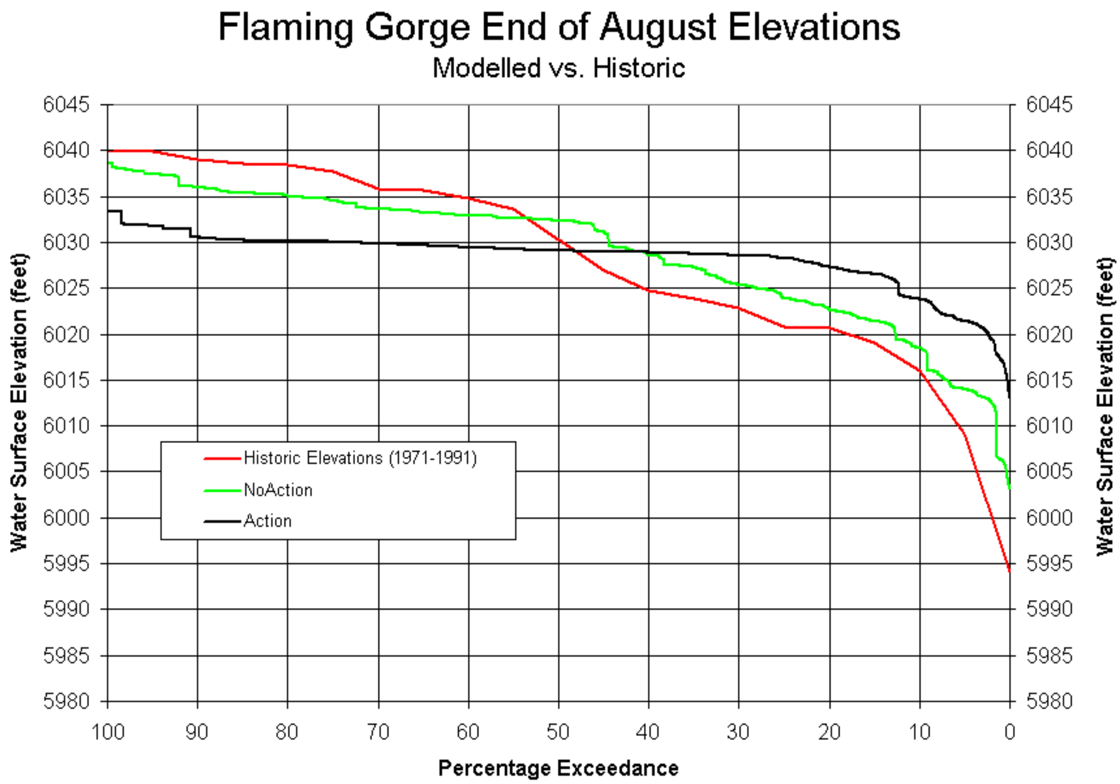
50
40
30
20
10
0

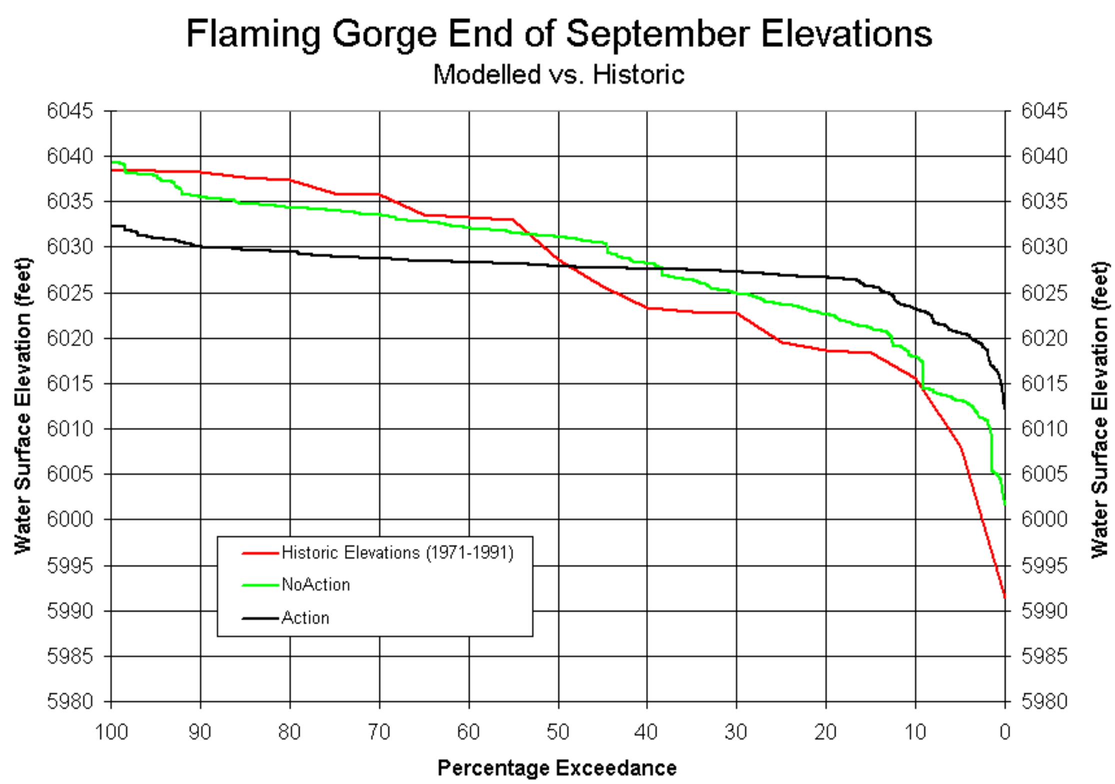


Flaming Gorge End of June Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action

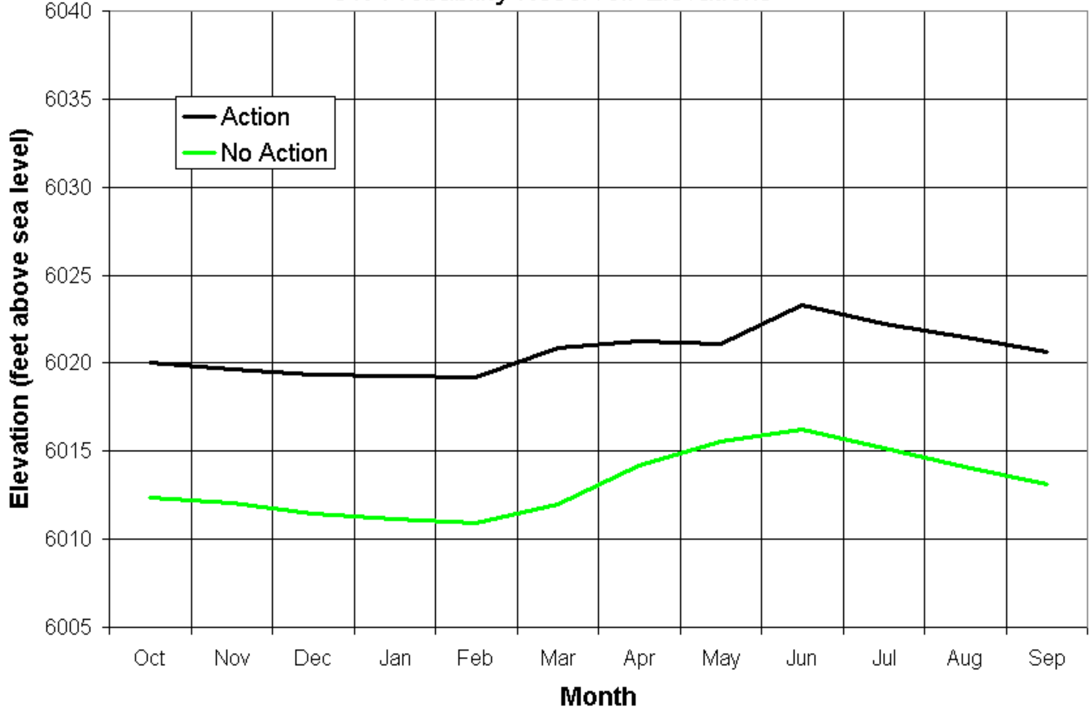


Flaming Gorge End of July Elevations
Modelled vs. Historic
Water Surface Elevation (feet)
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action

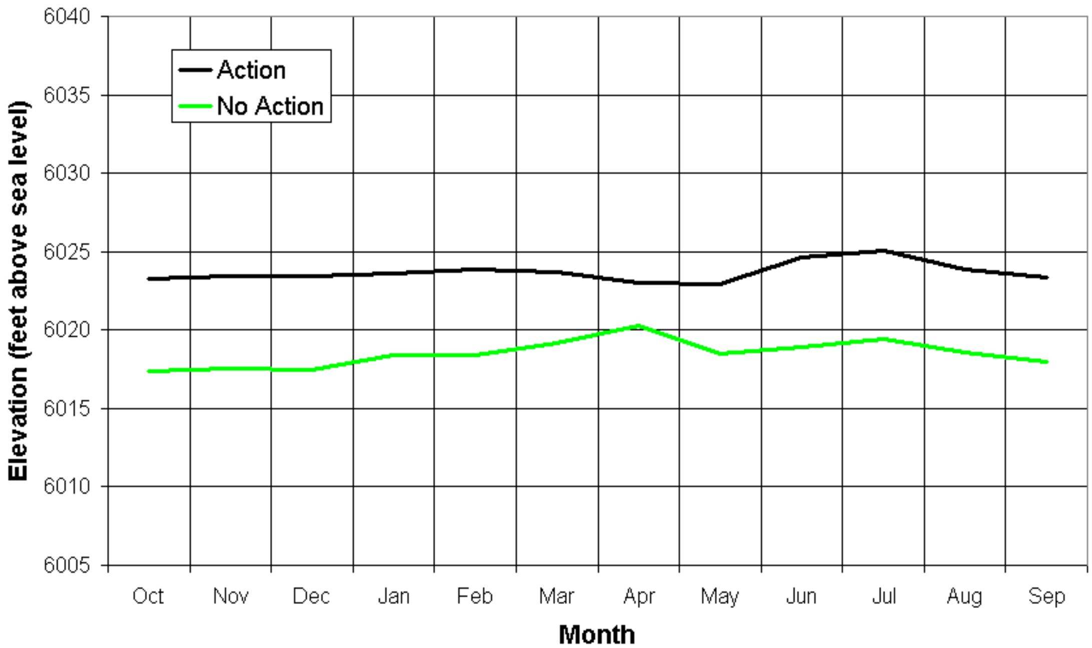

Flaming Gorge End of August Elevations
Modelled vs. Historic
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
5995
5990
5985
5980
Water Surface Elevation (feet)
100
90
80
70
60
50
40
30
20
10
0
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action

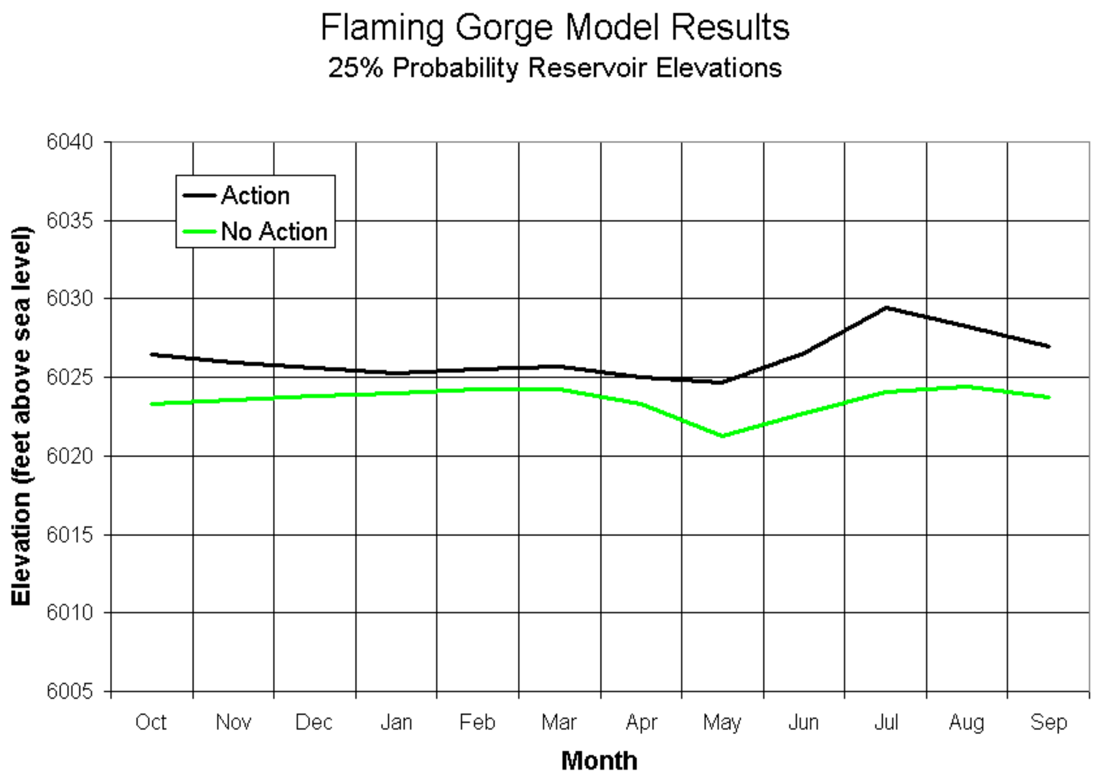

Flaming Gorge End of September Elevations
Modelled vs. Historic
6045
6040
6035
6030
6025
6020
6015
6010
6005
6000
5995
5990
5985
5980
Water Surface Elevation (feet)
100
90
80
70
60
50
40
30
20
10
0
Percentage Exceedance
Historic Elevations (1971-1991)
NoAction
Action

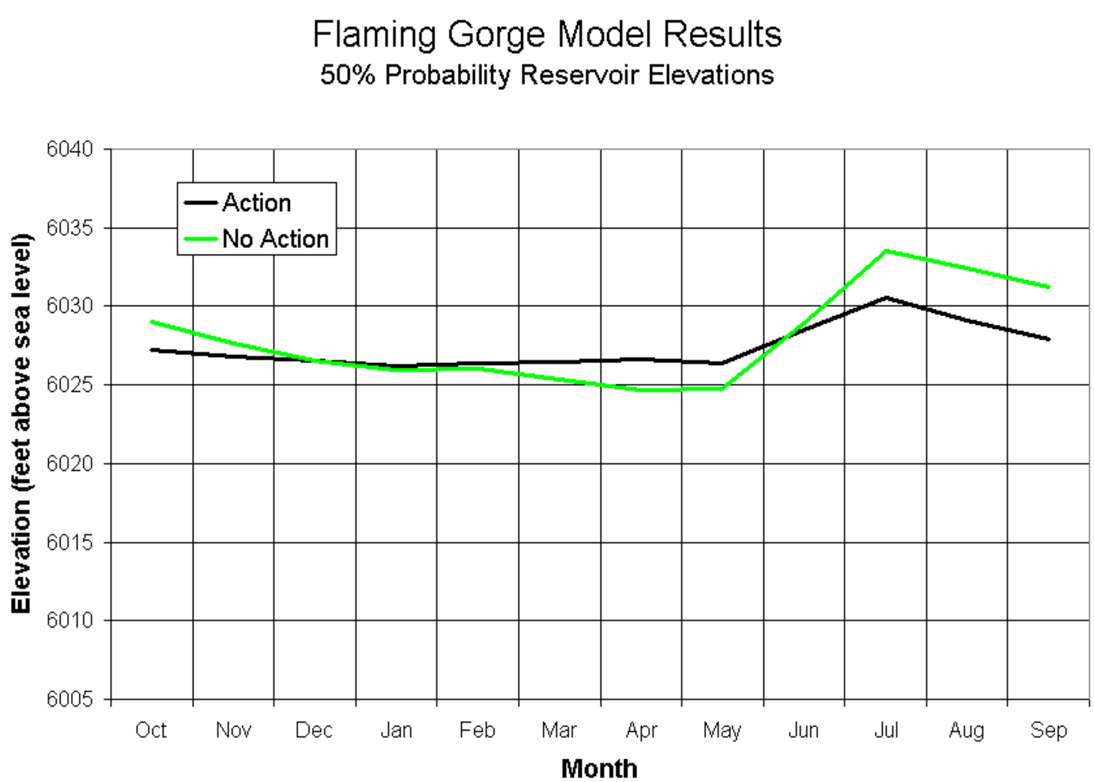
Flaming Gorge Model Results
5% Probability Reservoir Elevations

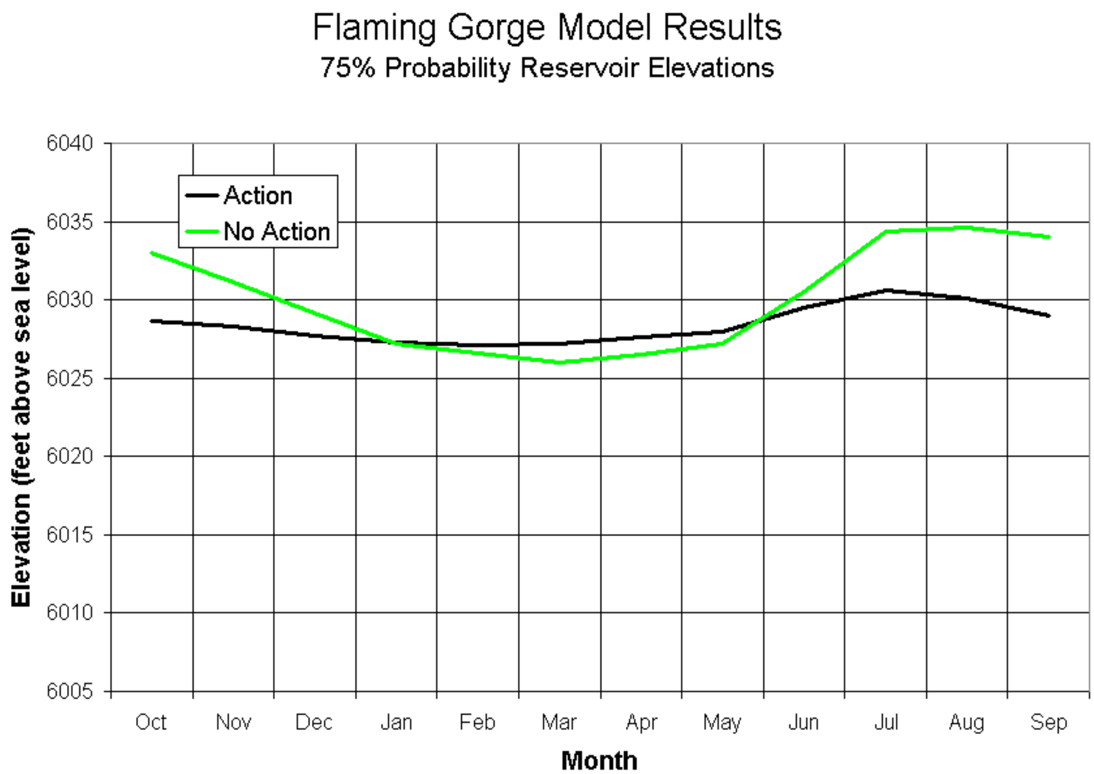


Flaming Gorge Model Results
10% Probability Reservoir Elevations

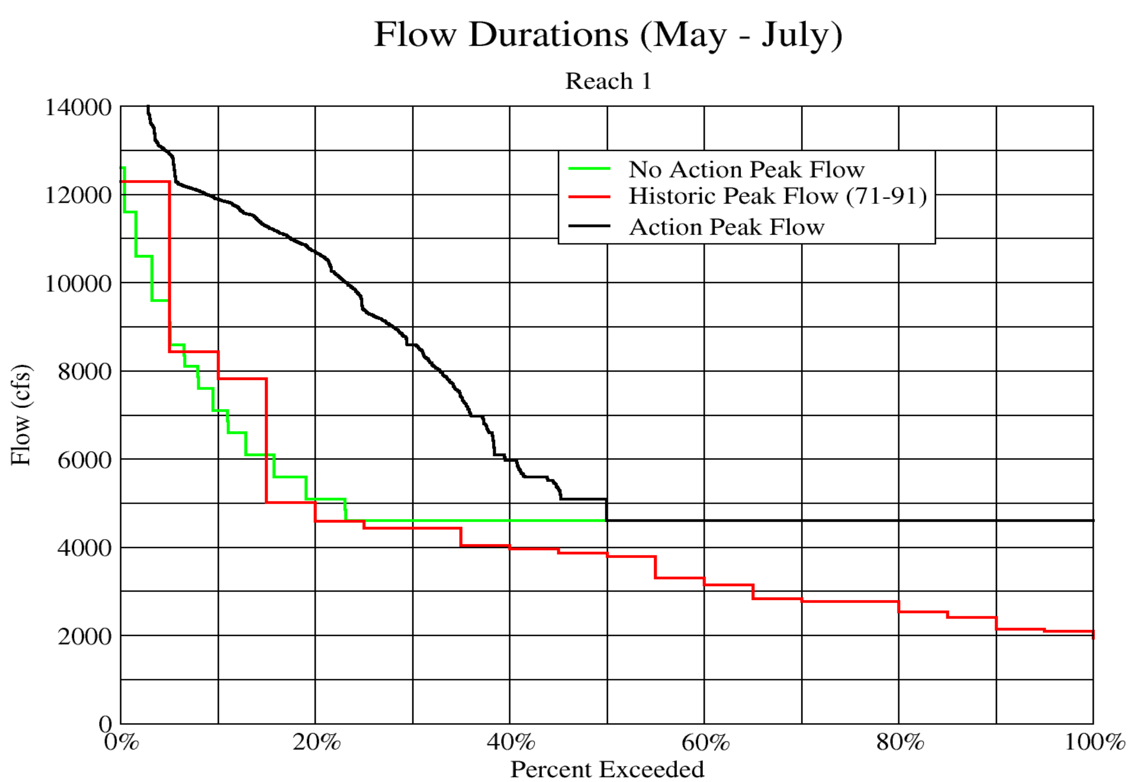



Flaming Gorge Model Results
25% Probability Reservoir Elevations
Elevation (feet above sea level)
6040
6035
6030
6025
6020
6015
6010
6005
Action
No Action
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Month

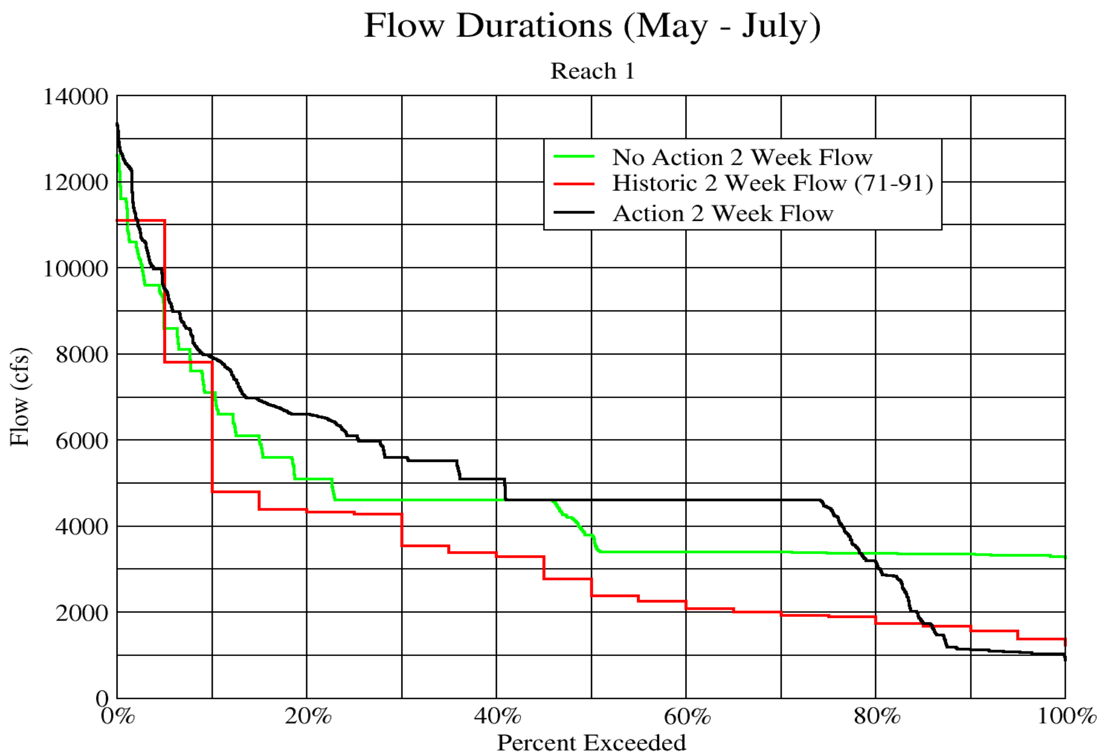

Flaming Gorge Model Results
50% Probability Reservoir Elevations
Elevation (feet above sea level)
6040
6035
6030
6025
6020
6015
6010
6005
Action
No Action
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Month

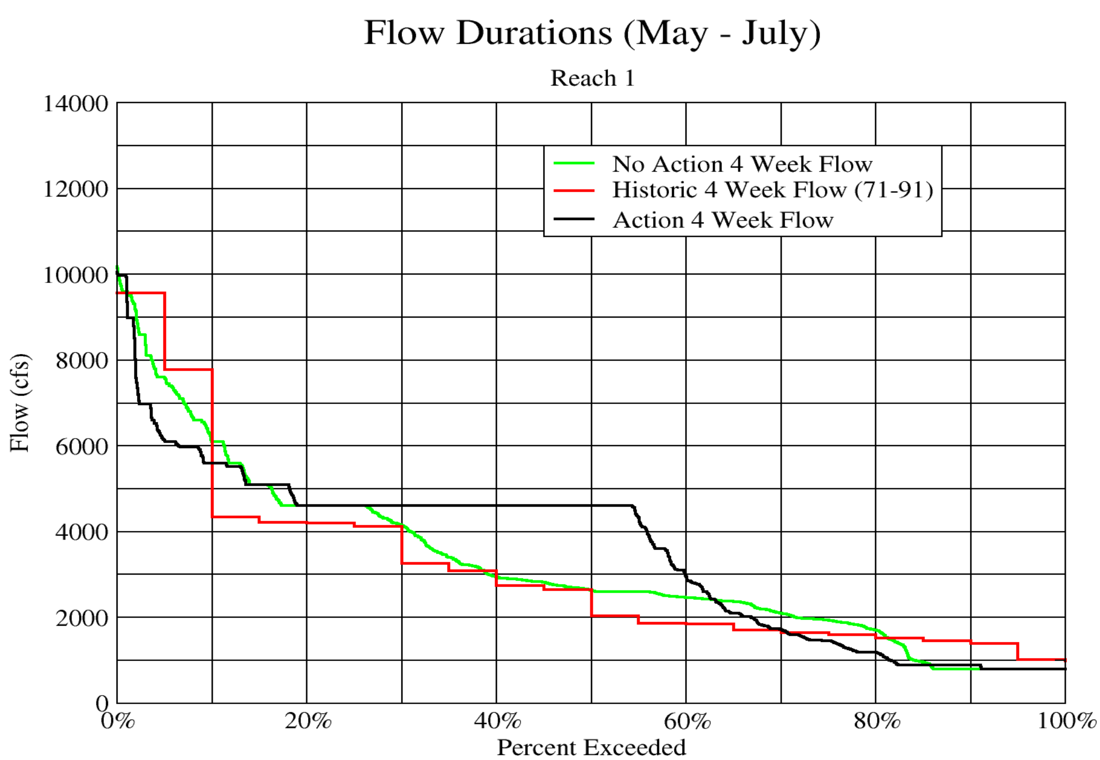


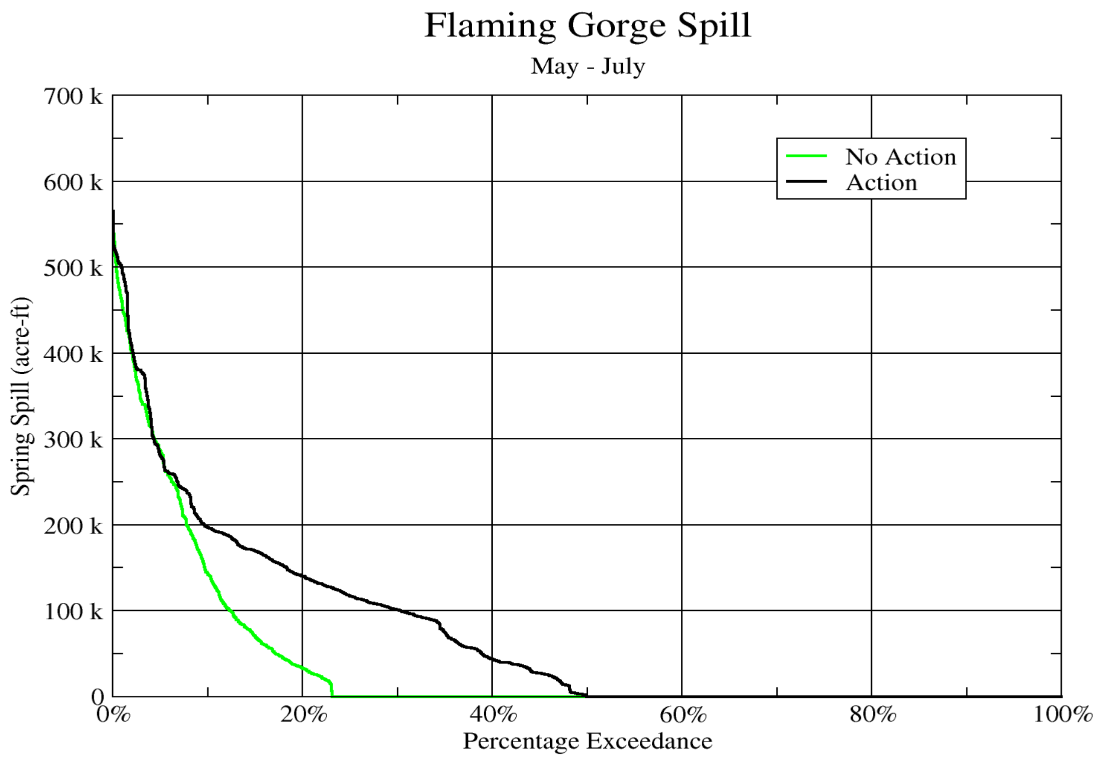
Flaming Gorge Model Results
75% Probability Reservoir Elevations
Action
No Action
Elevation (feet above sea level)
6040
6035
6030
6025
6020
6015
6010
6005
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Month



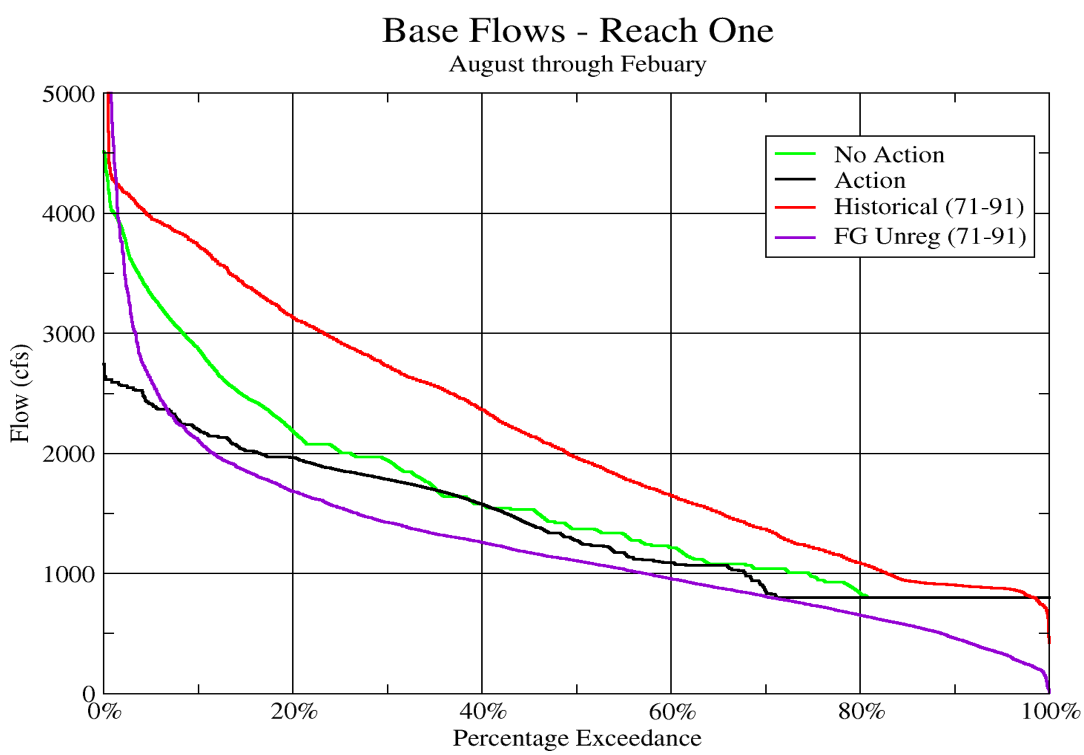
Flow Durations (May - July)
Reach 1
No Action Peak Flow
Historic Peak Flow (71-91)
Action Peak Flow
Flow (cfs)
14000
12000
10000
8000
6000
4000
2000
0
0%
20%
40%
60%
80%
100%
Percent Exceeded


Flow Durations (May - July)
Reach 1
No Action 2 Week Flow
Historic 2 Week Flow (71-91)
Action 2 Week Flow
Flow (cfs)
14000
12000
10000
8000
6000
4000
2000
0
0%
20%
40%
60%
80%
100%
Percent Exceeded

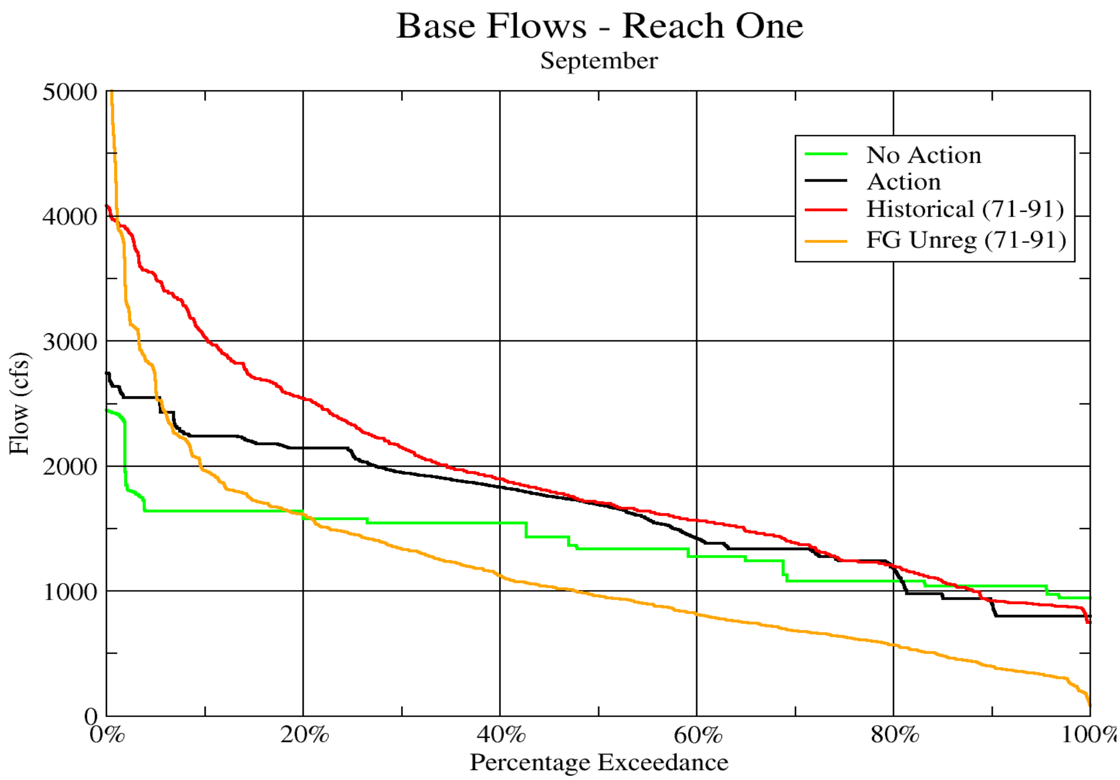

Flow Durations (May - July)
Reach 1
No Action 4 Week Flow
Historic 4 Week Flow (71-91)
Action 4 Week Flow
Flow (cfs)
14000
12000
10000
8000
6000
4000
2000
0
0%
20%
40%
60%
80%
100%
Percent Exceeded



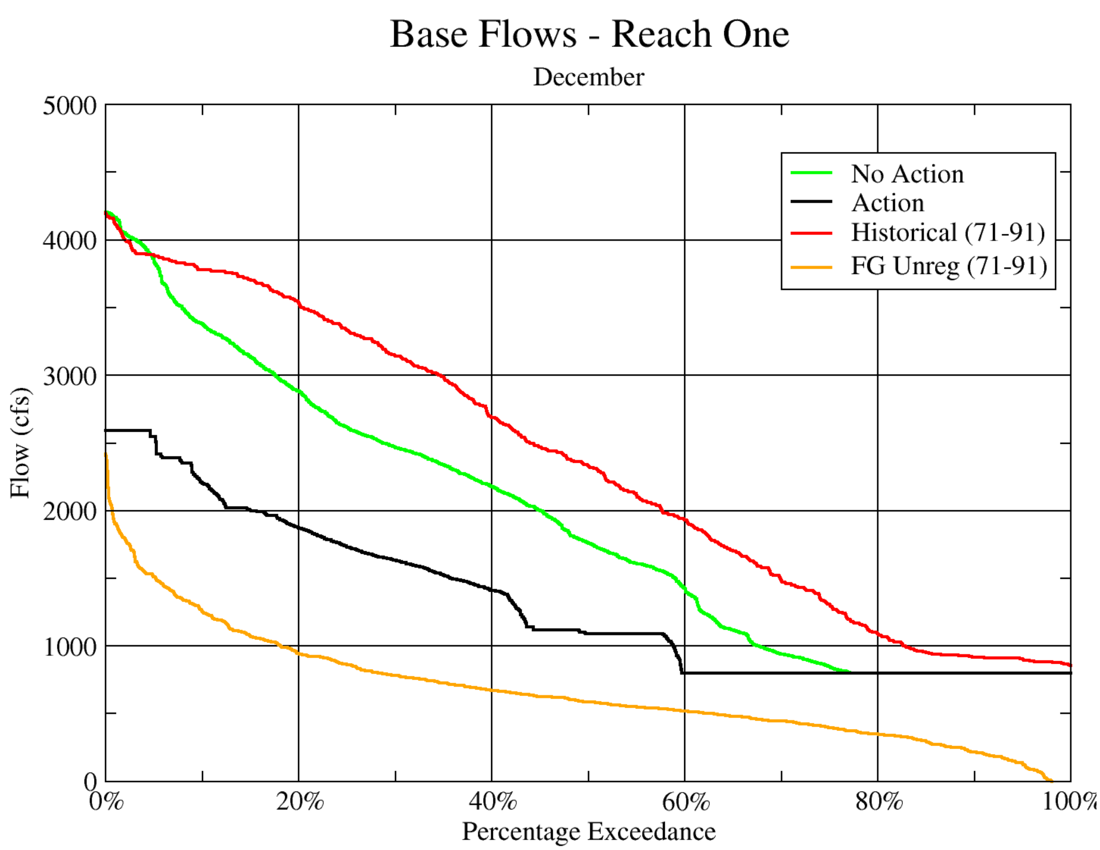
Flaming Gorge Spill
May - July
700 k
600 k
500 k
400 k
300 k
200 k
100 k
0
Spring Spill (acre-ft)
No Action
Action
0%
20%
40%
60%
80%
100%
Percentage Exceedance



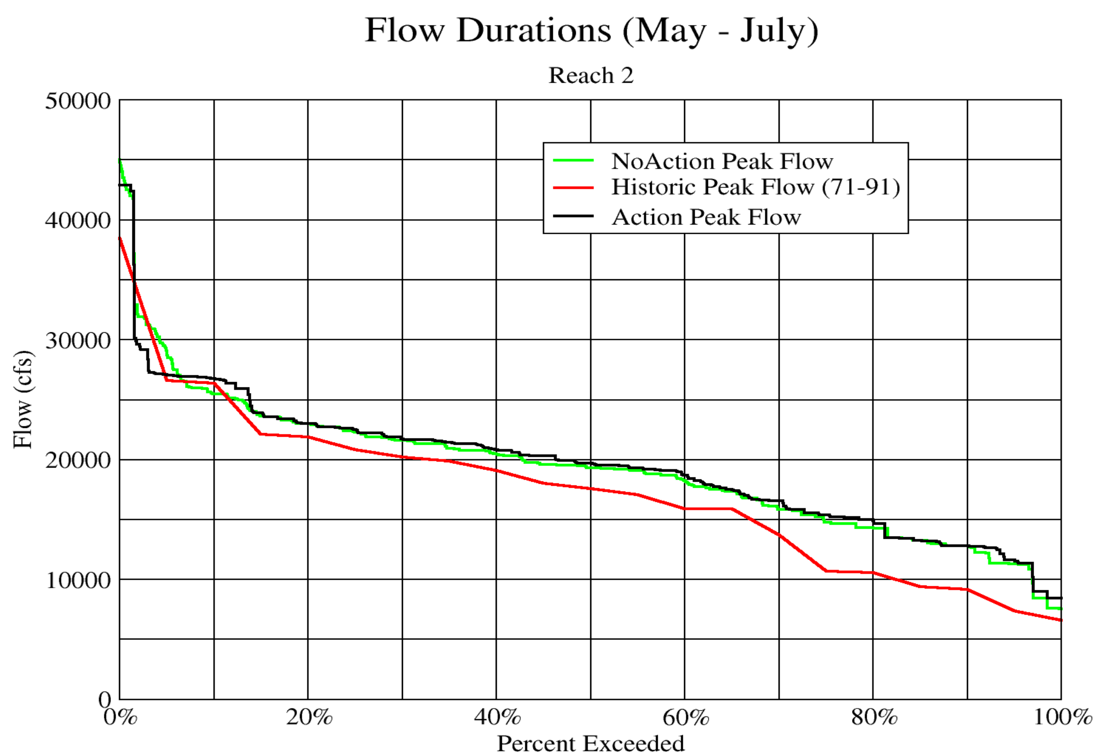
Base Flows - Reach One
August through Febuary
5000
4000
3000
2000
1000
0
Flow (cfs)
No Action
Action
Historical (71-91)
FG Unreg (71-91)
0%
20%
40%
60%
80%
100%
Percentage Exceedance

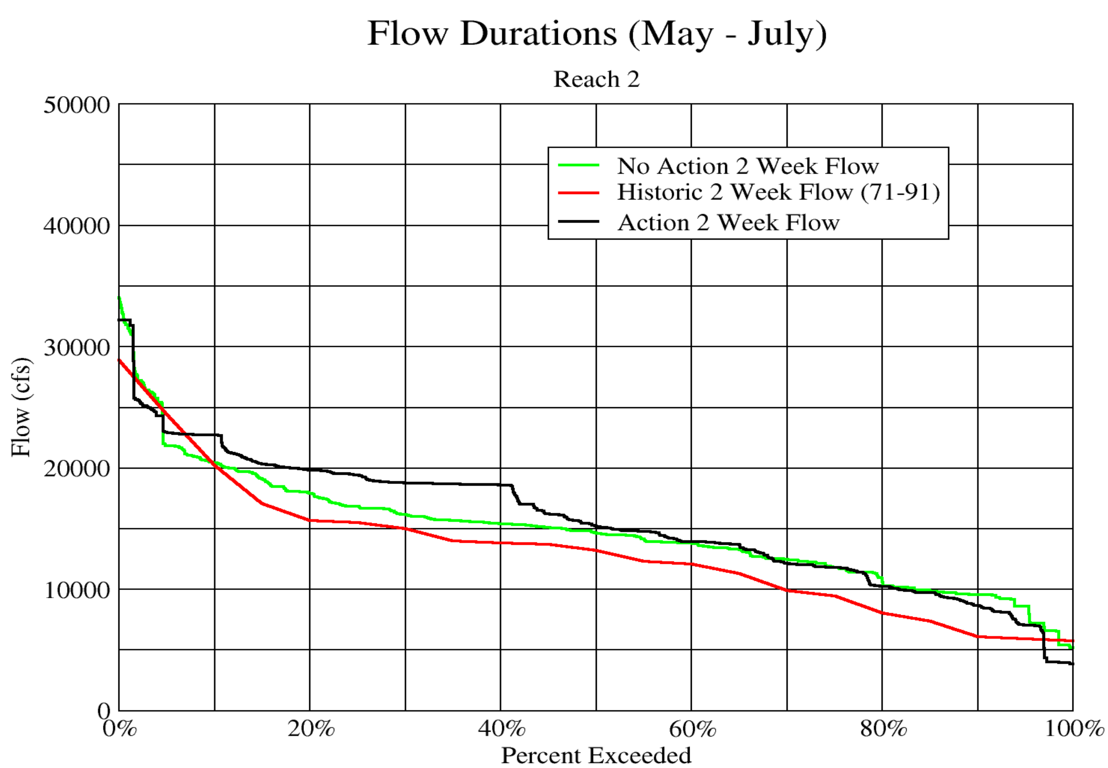


Base Flows - Reach One
September
No Action
Action
Historical (71-91)
FG Unreg (71-91)
Flow (cfs)
Percentage Exceedance
0
1000
2000
3000
4000
5000
0%
20%
40%
60%
80%
100%



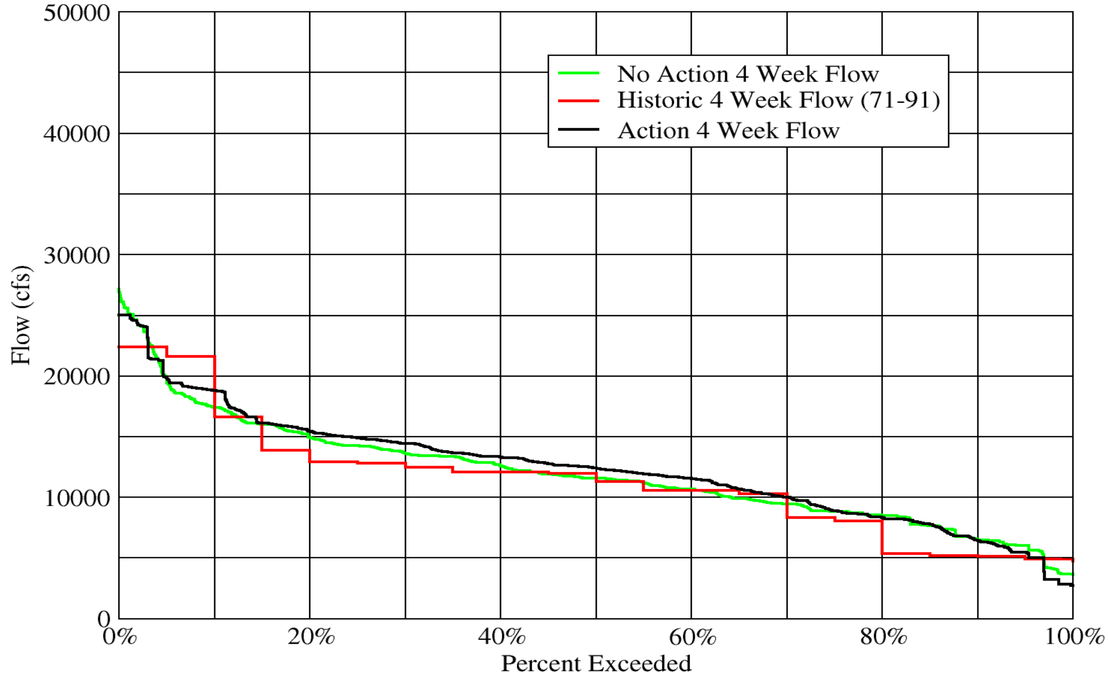
Base Flows - Reach One
December
No Action
Action
Historical (71-91)
FG Unreg (71-91)
Flow (cfs)
Percentage Exceedance
0
1000
2000
3000
4000
5000
0%
20%
40%
60%
80%
100%


Flow Durations (May - July)
Reach 2
NoAction Peak Flow
Historic Peak Flow (71-91)
Action Peak Flow
Flow (cfs)
Percent Exceeded
0
10000
20000
30000
40000
50000
0%
20%
40%
60%
80%
100%


Flow Durations (May - July)
Reach 2
No Action 2 Week Flow
Historic 2 Week Flow (71-91)
Action 2 Week Flow
Flow (cfs)
Percent Exceeded
0
10000
20000
30000
40000
50000
0%
20%
40%
60%
80%
100%

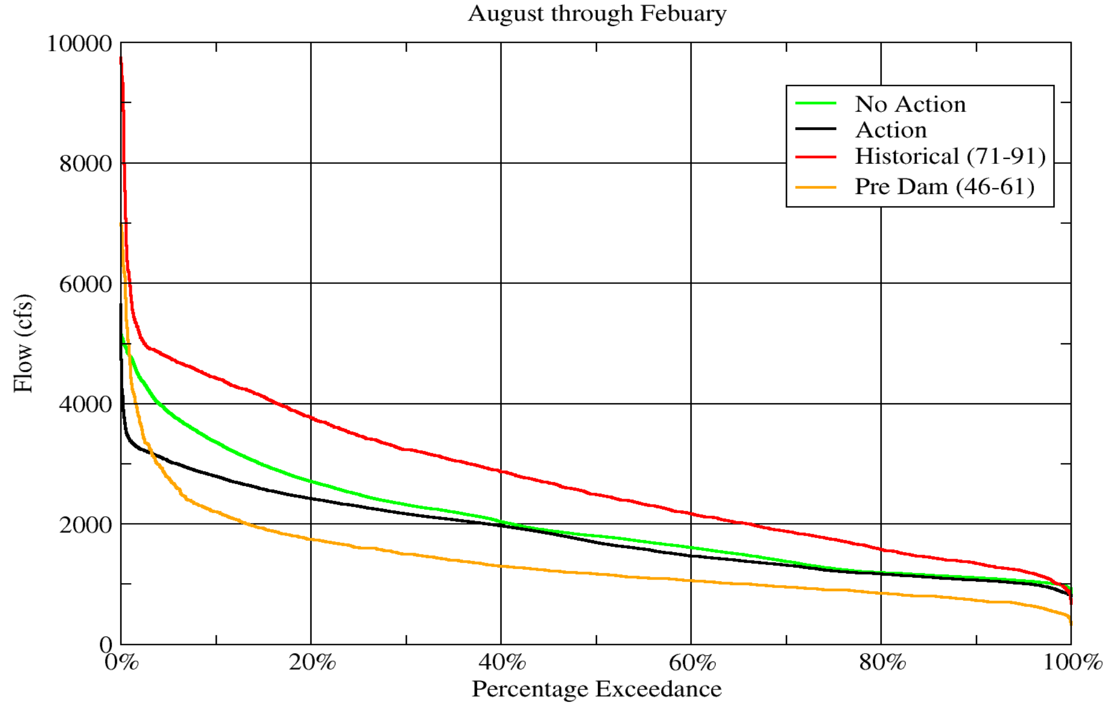
Flow Durations (May - July)

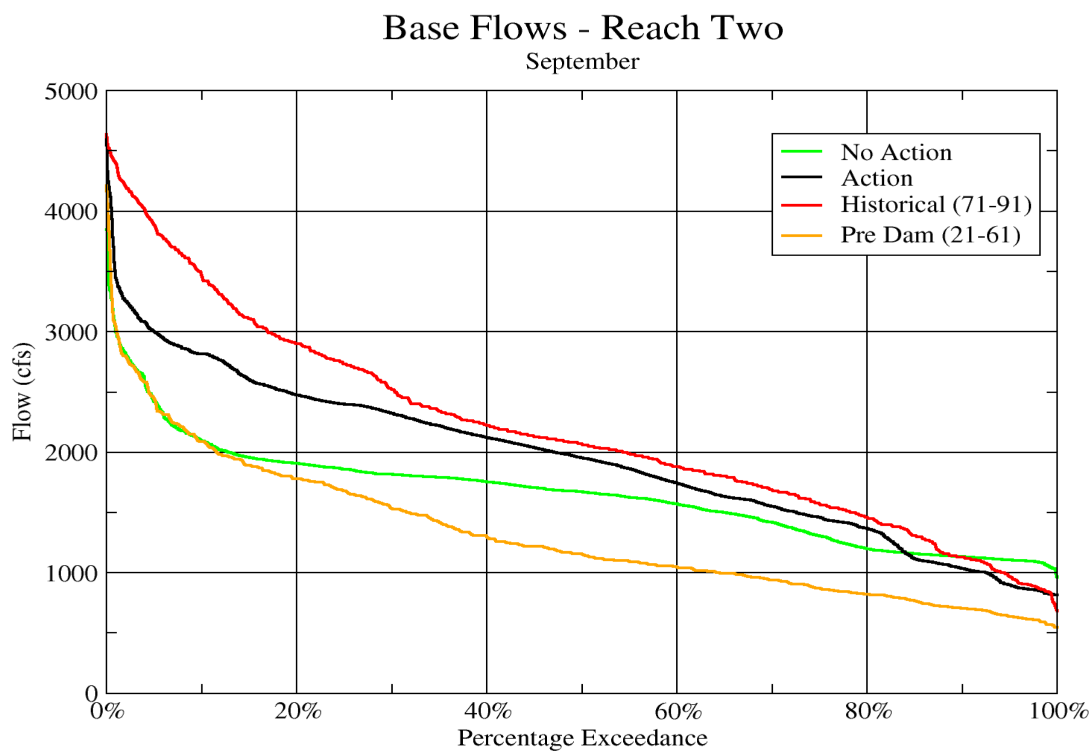
Reach 2

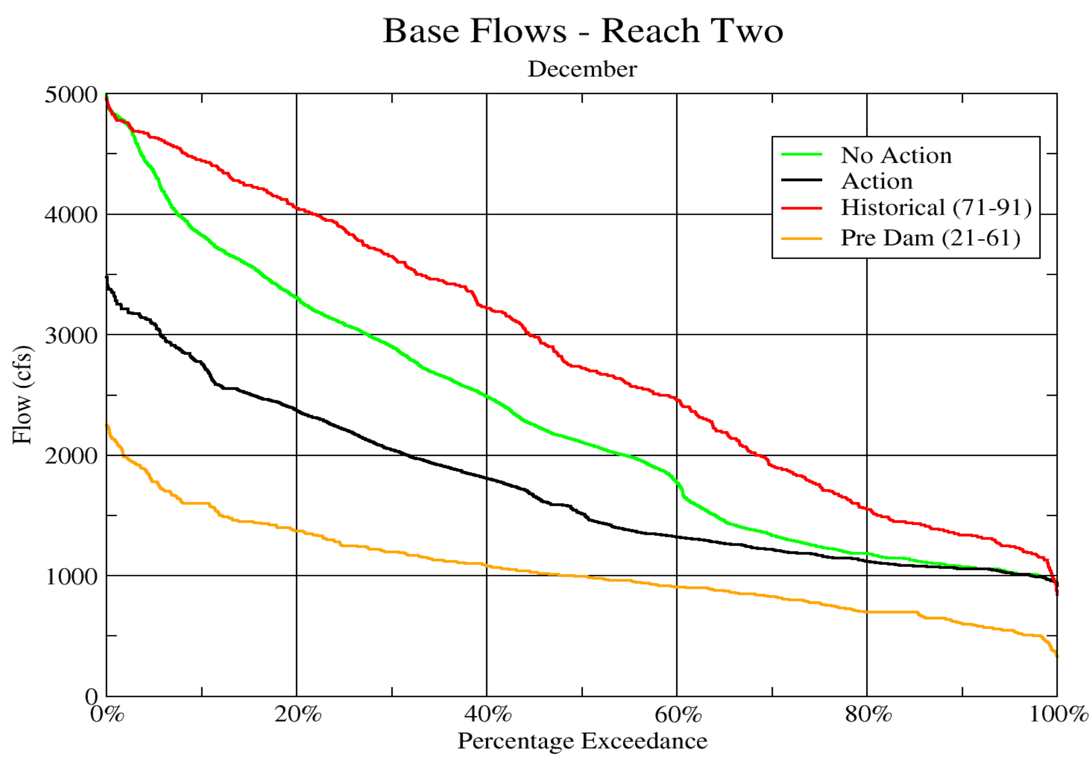


Base Flows - Reach Two

August through Febuary




Base Flows - Reach Two
September
No Action
Action
Historical (71-91)
Pre Dam (21-61)
Flow (cfs)
Percentage Exceedance
0
1000
2000
3000
4000
5000
0%
20%
40%
60%
80%
100%


Base Flows - Reach Two
December
No Action
Action
Historical (71-91)
Pre Dam (21-61)
Flow (cfs)
Percentage Exceedance
0
1000
2000
3000
4000
5000
0%
20%
40%
60%
80%
100%

FLAMING GORGE FINAL ENVIRONMENTAL IMPACT STATEMENT AMENDMENT TO HYDROLOGIC MODELING REPORT

R. Clayton and A. Gilmore
August 5, 2003

INTRODUCTION

During the development of the Flaming Gorge Model, it was decided that the model would be developed to use the longest reasonable historic hydrologic record available. While records for the Green River and Yampa River extended back to 1921, historic records for the tributary rivers in Reach 3 only extended back to the mid 1940's. Because of the uncertainties associated with modeling Reach 3, it was decided that the Flaming Gorge Model would focus on Reaches 1 and 2 using the extended hydrologic record from 1921 to 1985 rather than including details for Reach 3 and having a much shorter hydrologic record.

For these reasons, the Hydrologic Modeling Report issued in February of 2002 did not include analysis of the predicted future flows in Reach 3. Since that time, a concern for the lack of Reach 3 information within the draft EIS has developed, prompting several requests for a hydrologic analysis of the Reach 3 predicted future flows for the Action and No Action alternatives. To help satisfy this request, this report provides hydrologic analysis of the estimated future flows of the Green River in Reach 3.

DATA DESCRIPTION AND ASSUMPTIONS

The Flaming Gorge Model produced the predicted future flows of the Green River in Reach 2 for the period beginning in January 2002 and extending to December of 2040. Sixty-five traces, or sequences of historic flows, were routed through the Flaming Gorge Model to generate 65 potential future operations for this future time period. The historic hydrologic record from January 1921 to December 1985 formed the basis for these inflow traces. For each inflow trace that was routed through the model there is a sequence of historic hydrology that the trace was constructed from.

In order to generate an estimate of the potential future flows in Reach 3 that would result from operating Flaming Gorge Dam under the Action and No Action Alternatives, an estimate of tributary contribution to the flows in Reach 3 is required. Without the historic records of the tributaries extended back to 1921, it was not possible to determine what each individual tributary contributed to the Green River for the historic period that the model was run. However it was possible to estimate the approximate contribution to the Green River of all tributaries located in Reaches 2 and 3 because complete historic records were available for the Green River located near Flaming Gorge Dam and Green River, Utah. The difference between the historic daily average flow for the Greendale and Green River, Utah gauges was used to estimate of historic daily contribution of all tributaries along the Green River including channel losses. This estimate included the historic flow of the Yampa River in addition to all of the other tributaries in Reach 3. The estimated future flow in Reach 3 described in this report was generated by adding the Flaming Gorge release data predicted by the Flaming Gorge Model to the corresponding historic tributary input with an estimated lag period of 5 days.

REACH 3 ANALYSIS

Flow Recommendations

Table 1 shows the Action and No Action alternatives (as modeled) in terms of how well each alternative achieves the specific recommendations of the 2000 Flow and Temperature Recommendations during the spring in Reach 3. While the No Action alternative does not attempt to meet any of these targets, a comparison between the Action and No Action results does indicate some of the key differences between the operational regimes. The Action alternative has been modeled to achieve all of the targeted flows and durations for Reach 2 and it was assumed that if the Reach 2 flow recommendations were achieved that Reach 3 flow recommendations would also be achieved. The results show that, except for the single day peak flow of 39,000 cfs in Reach 3, all other recommended flows, durations and frequencies are achieved by the Action Alternative as currently modeled.

Table 1—Reach 3 Recommendations Targets and Predicted Results

Spring Peak Flow Recommendations	Reach	Target %	Action Ruleset	No Action Ruleset
Peak >= 39,000 cfs for at least 1 day	3	10%	4.6%	5.9%
Peak >= 24,000 cfs for at least 2 weeks	3	10%	22.0%	14.4%
Peak >= 22,000 cfs for at least 4 weeks	3	10%	12.0%	8.4%
Peak >= 24,000 cfs for at least 1 day	3	30%	65.2%	59.4%
Peak >= 22,000 cfs for at least 2 weeks	3	40%	40.2%	33.8%
Peak >= 22,000 cfs for at least 1 day	3	50%	70.3%	69.4%
Peak >= 8,300 cfs for at least 1 day	3	100%	100%	98.5%
Peak >= 8,300 cfs for at least 1 week	3	90%	96.9%	96.9%
Peak >= 8,300 cfs for at least 2 days except in extreme dry years	3	98%	100%	98.5%

Peak Flows in Reach 3

Figures 1, 2, and 3 show the distribution of single day peak, 14-day duration peak, and 28-day duration peak flows that will likely occur if Flaming Gorge Dam is operated under the Action or No Action Alternative during the period from January 2002 to December 2040. Peak flows in Reach 3 are only subtly different under the two alternatives. The most notable difference between the two alternatives is that flow durations under the Action Alternative appear to be longer than those of the No Action Alternative.

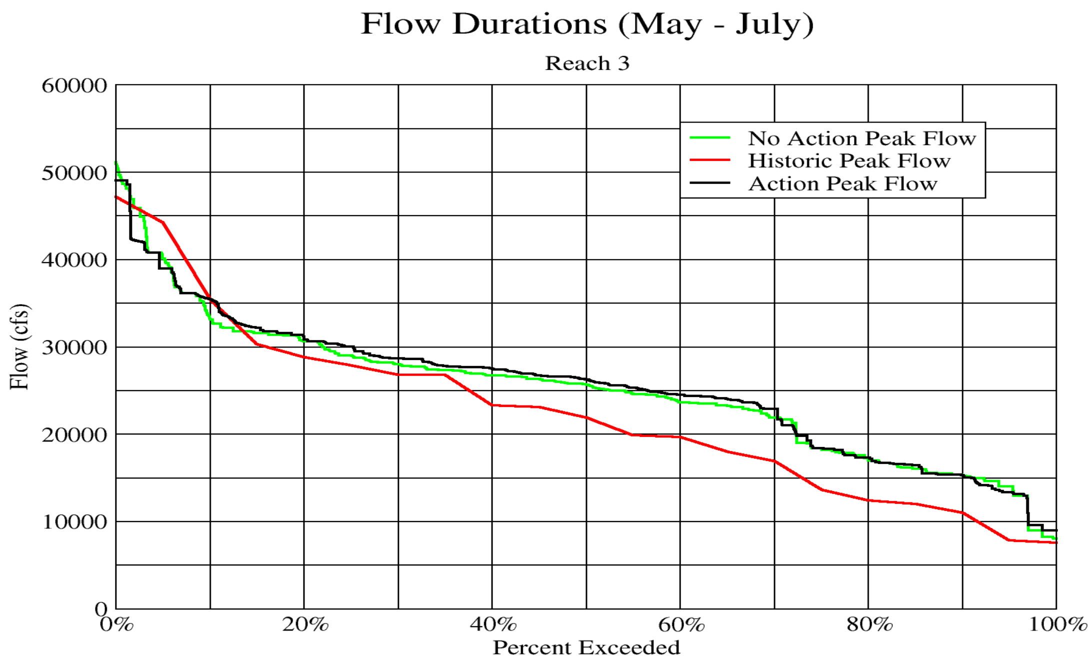


Figure 1.—Reach 3 Distribution of 1-Day Peak Flows.

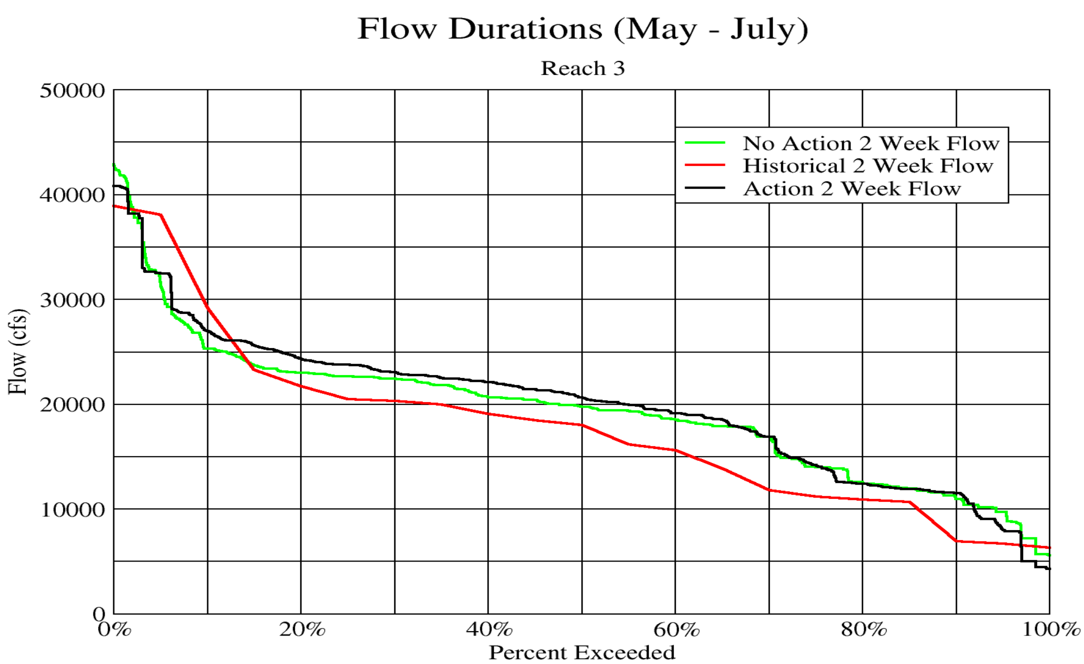


Figure 2.—Reach 3 Distribution of 2-Week Duration Peak Flows.

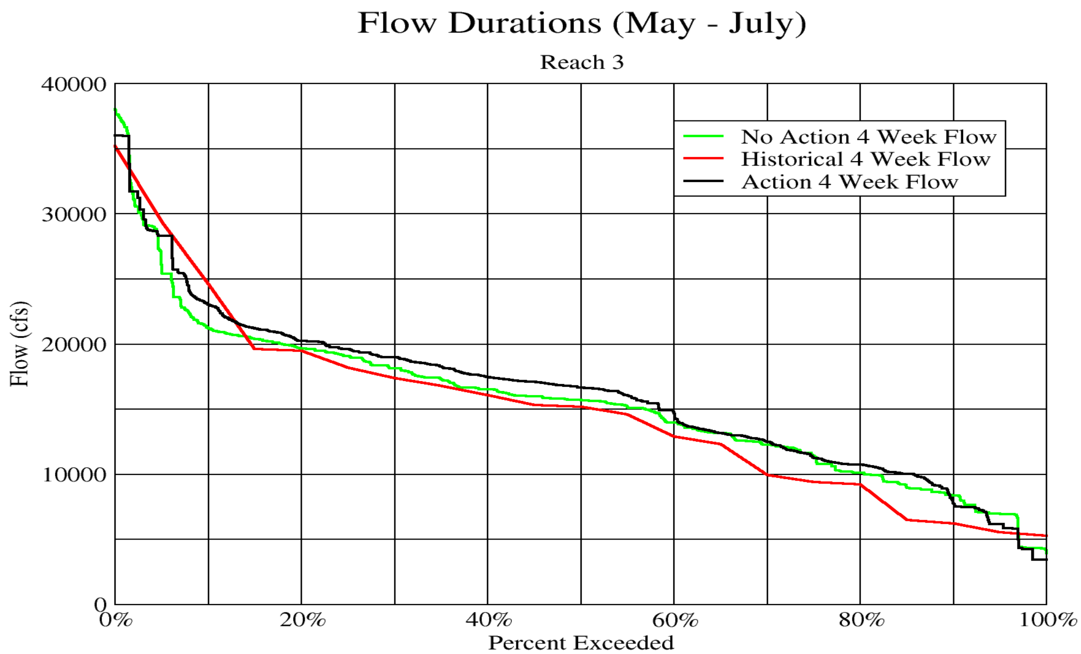


Figure 3.—Reach Distribution of 4-Week Duration Peak Flows.

Base Flows in Reach 3

Overall, the base flows in Reach 3 that will occur if Flaming Gorge Dam is operated under the Action and No Action Alternatives will be similar. In general, the base flows under the Action Alternative will be slightly lower than those of the No Action Alternative as shown in figure 4.

As with Reaches 1 and 2 the relationship between the flows of the Action and No Action Alternatives is dependant on the time of year. During the summer months, when the No Action Alternative restricts the flows in Reach 2, the base flows in Reach 2 will likely be less than those of the Action Alternative. When these restrictions are lifted in November, base flows in Reach 3 under the No Action Alternative will likely be higher than those of the Action Alternative. This can clearly be seen in figures 5 and 6 that show the distribution of flows in Reach 3 that occur under each alternative during the months of September and December. Reach 3 flows during the period from November through February will most likely be 500 to 1000 cfs greater than those of the Action Alternative. This is especially true in wet years. Reach 3 flows during the summer months including late July, August and September will most likely see flows under the No Action Alternative that are lower than those of the Action Alternative by 300 to 700 cfs.

SUMMARY

The data provided in this report has been generated to match the data that was provided for Reaches 1 and 2 in the Hydrologic Modeling Report issued in February of 2002. Although the data for this report was not a product of the model output, as was the data for Reaches 1 and 2,

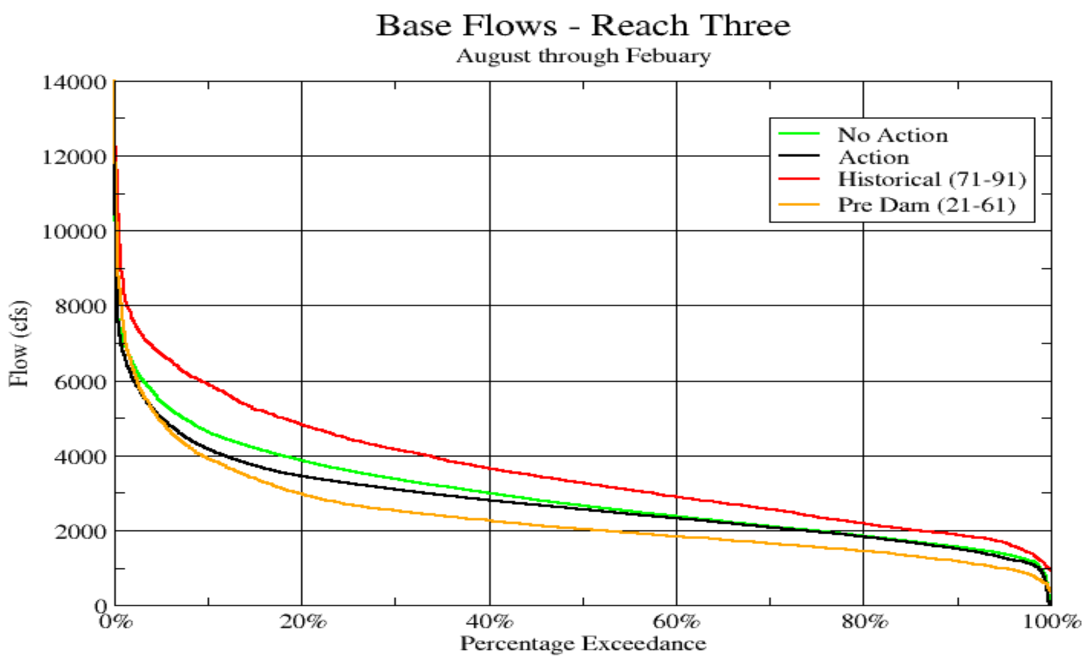


Figure 4—Reach 3 Distribution of Flows (August through February.

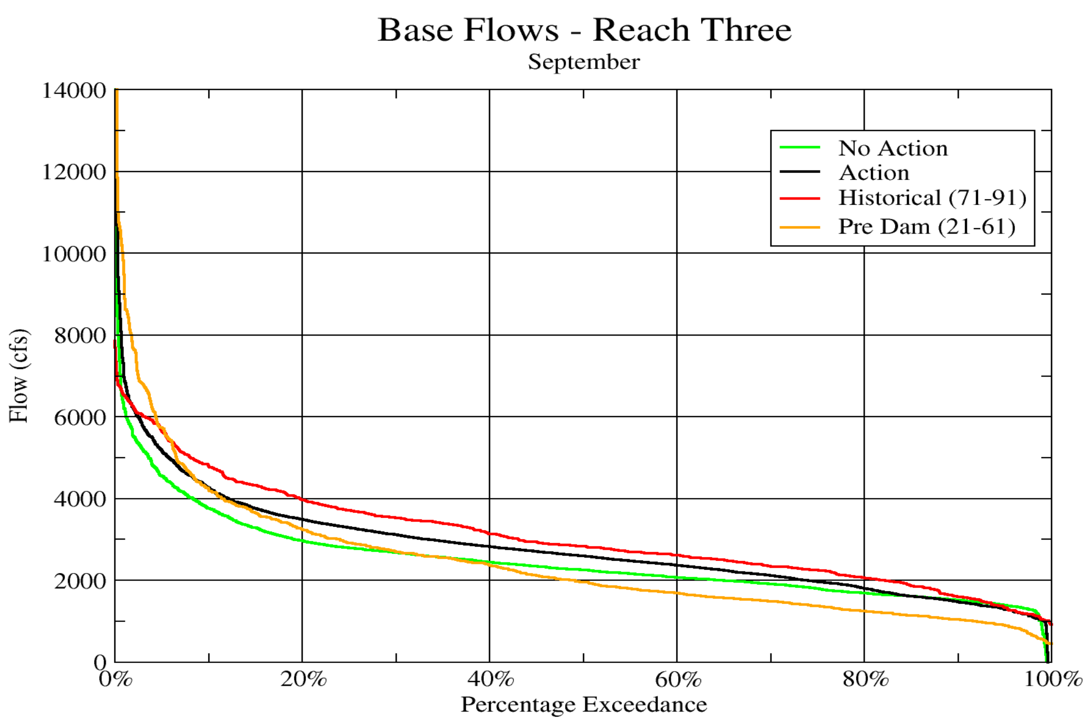


Figure 5.—Reach 3 Distribution of Flows (September).

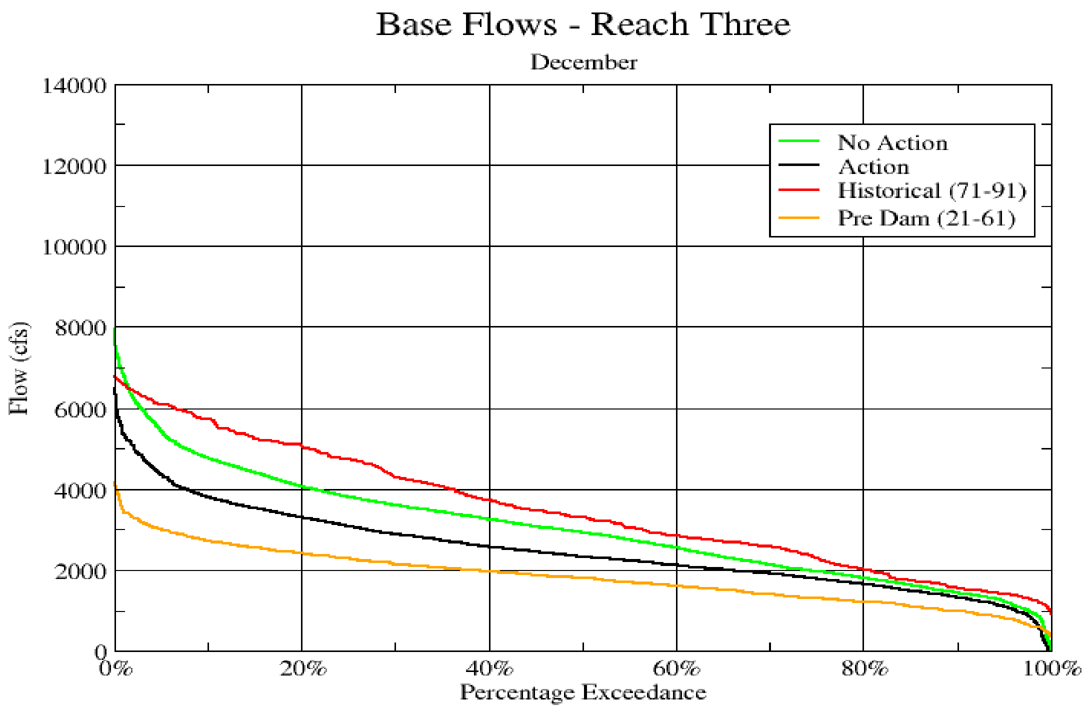


Figure 6.—Reach 3 Distribution of Flows (December).

it does represent the best possible estimate of the predicted future flows in Reach 3 that would result from operating Flaming Gorge Dam under the Action and No Action Alternatives.

It is important to note that the consumptive uses and losses implicitly included in the Reach 3 flows are historical and do not represent consumptive uses and losses that will occur in the future. The trend of water consumption in the Green River Basin is increasing so it would be safe to assume that the Reach 3 flows that would actually occur if Flaming Gorge was operated under the Action and No Action Alternatives would be marginally less than those reported here in. Future consumptive uses and losses are speculative and hard to accurately quantify and therefore no attempt has been made to characterize how these future consumptive uses and losses would affect the flows of Reach 3. However, the incremental differences between the Reach 3 flows under the two alternatives should be relatively accurate.

September 8, 2003

TO: Peter Crookston, Flaming Gorge EIS Manager

FROM: Tom Ryan[1], Kirk LaGory[2], and John Hayse[3]

SUBJECT: Review of the Green River Model Developed for the Flaming Gorge Dam EIS[4]

Background

A river simulation model was developed for the Green River system to assess impacts of Flaming Gorge Dam operations in the Operation of Flaming Gorge Dam Environmental Impact Statement (Flaming Gorge EIS). The model was developed using the RiverWare simulation modeling software package. The Green River Model evaluates two alternative operations: the no-action alternative (operation of Flaming Gorge Dam as prescribed by the 1992 Biological Opinion; FWS 1992) and the action alternative (operation of Flaming Gorge Dam to meet the flow recommendations developed by Muth et al. 2000). Input to the model includes the inflows to Flaming Gorge Reservoir and inflow to the Green River from the Yampa River, and predicts flow at the USGS streamflow gage on the Green River at Jensen, Utah approximately 93 miles downstream from Flaming Gorge Dam.

For the action alternative, the Green River Model predicts significant use of the bypass tubes and spillway at Flaming Gorge Dam when compared to the no-action alternative. Under the action alternative, the Green River Model predicts that the bypass tubes would be used in 49.9% of years and the spillway would be used in 29.4% of years. These relatively high frequencies have caused concern among those involved in the management of Flaming Gorge Dam. Our review of the Green River Model was performed to evaluate whether the degree of bypass and spill predicted by the Green River Model would be necessary to meet the requirements of the flow recommendations. Our review did not include an evaluation of the no-action alternative. While the main focus of our model review was the frequency of bypass and spillway use, we also examined the model's behavior in its entirety, and evaluated how the model simulated the year-round operation of Flaming Gorge Dam to meet the flow recommendations.

Review Approach

The Green River Model uses the indexed sequential method where multi-trace output is created. The model simulates the Green River system including the operation of Fontenelle and Flaming Gorge Dams for the years 2002 through 2040 (39 years). For the EIS, the model was used to simulate these 39 years 65 separate times using hydrology from 1921 through 1985 (rotating among these 65 years to create 65 distinct traces). Thus, the model simulates the operation of the Green River system for 2,535 different years (39 times 65). For our review, a sample of these 2,535 years was taken. The sample size was 65 years, and included one representation from each year of hydrology used in the model. Specifically, we reviewed simulations of Trace 0 from 2002 until 2040 (using the hydrology from 1921 through 1959), and Trace 39 from 2002 until 2025 (using the hydrology from 1960 through 1985). To determine if the sample was a good

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[4] Green River Model is Flaming Gorge Model as referenced throughout the EIS and the hydrology modeling reports.

representation of all years, model statistics for meeting flow recommendations in Reach 2 were compiled for the sample and compared to results for all years. The following table shows this comparison. It can be seen that the difference between the sample (65 years) and all years (2,535) is very small.

Flow Recommendations for Reach 2 and Predicted Occurrence of Target Achievement in All Years of Analysis and in the Sample Review Period Under the Action Alternative

Spring Peak Flow Recommendations	Recommended	Sample Period (Trace 0 and 39)	All Years	Difference
Peak >= 26,400 cfs for at least 1 day	10	12.3	11.3	1.0
Peak >= 22,700 cfs for at least 2 weeks	10	10.7	10.7	0.0
Peak >= 18,600 cfs for at least 4 weeks	10	10.7	11.1	0.4
Peak >= 20,300 cfs for at least 1 day	30	47.7	46.3	1.4
Peak >= 18,600 cfs for at least 2 weeks	40	40.0	41.1	1.1
Peak >= 18,600 cfs for at least 1 day	50	60.0	60.3	0.3
Peak >= 8,300 cfs for at least 1 day	100	100	100	0.0
Peak >= 8,300 cfs for at least 1 week	90	96.9	96.8	0.1
Peak >= 8,300 cfs for at least 2 days except in extreme dry years	98	98.5	99.6	0.9
Frequency of bypass (> 4,600 cfs)	NA	50.7	49.9	0.8
Frequency of spills (>8,600 cfs)	NA	27.7	29.4	1.7

We evaluated performance of the Green River Model in each of the 65 years in the sample (1921 through 1985). We considered the May 1 forecasted inflow and actual inflow to Flaming Gorge Reservoir, reservoir storage and flow regimes on the Yampa River in evaluating how well the Green River Model simulated the operation of Flaming Gorge Dam to meet flow recommendations in Reach 2, and to manage Flaming Gorge Reservoir under existing authorities. We also evaluated how well the model met recommended base-flow targets.

We tried to be conservative in our evaluation. In some years, the Green River Model predicted bypasses or spills, and very precise adjustment of releases could eliminate these above-powerplant-capacity releases. We chose not to include these borderline years among those where spills or bypasses could more clearly be eliminated using realistic operational decisions.

Findings

In most situations, the Green River Model appears to properly simulate the operation of Flaming Gorge Dam to meet flow recommendations in Reach 2, while minimizing the effects on authorized purposes of the dam. Modeling of the action alternative is complicated by the intricacies of the flow recommendations, hydrologic variability and the degree of hydrologic difference between the Green and Yampa Rivers. Within the RiverWare modeling package a complex "rule set" has been developed for the action alternative that controls the behavior of the model and thus the simulated operation of Flaming Gorge Dam. Much of the logic of the rule set is presented in this review.

A few specific issues were identified in our review of the Green River Model in the action alternative. These issues are related to how the model moves water in wetter than average years. We found that, in some years, predicted bypass releases might not be necessary for either hydrologic reasons or to meet downstream targets. Additionally, there are some years where the model predicts spills that produce flows that are greater than recommended Reach 2 targets. The following text discusses these issues as they relate to the predicted frequency of bypasses and spills from Flaming Gorge Dam.

1. Mass balance rules result in higher bypass frequency than is needed to meet recommended flow targets

The Green River Model uses a March 1 drawdown target for the reservoir of 6,027 feet (13 feet from full pool). This drawdown target is a dam safety constraint, where the 13 feet of vacant space assures a safe spring operation even under very wet hydrology. The model balances water to achieve this March 1 drawdown target throughout the year, but it is important to understand how the model performs this balance in the spring period.

In May, the model generates an inflow forecast (which includes a forecast error term), and places the year in one of 7 hydrologic classifications (wet, moderately wet, average wet, average, average dry, moderately dry, or dry). The model determines the Flaming Gorge Dam release that would be needed to meet the base-flow recommendations in Reach 1 for the year's hydrologic classification. The model then performs a mass balance to calculate how much water should be released in the months of May, June, and July, in combination with the August through March base flows, to result in a reservoir elevation of 6,027 feet (or below in drought years) on March 1 of the following year. The model then shapes releases from May through July to meet Reach 2 peak flow and duration targets.

Generally, the Green River Model shapes this May through July release volume appropriately, matching the Yampa River peak flows and meeting recommended Reach 2 targets. However, in 6 of the 65 years evaluated in our review (1943, 1944, 1950, 1951, 1956, and 1967), the model bypassed water to meet the mass balance requirements, but these bypasses did not result in meeting any Reach 2 targets. In these years, the reservoir remained 8 to 11 feet below the full-pool elevation in July, and therefore bypass was not required for safety considerations. All of these years were either classified as moderately wet or average wet. Evaluation of the model determined that these bypasses were not necessary for safe operation of the dam or to meet base flow requirements after the runoff season. Other operating options would be available, but the model does not have the capability to evaluate all these other options, and the multiple combinations in which they might be implemented.

One option available to move additional water during the May through July time period is to extend the peak flow duration. The flow recommendations allow for peak flows to extend to July 15 in average years, August 1 in moderately wet years, and August 15 in wet years. In most of the 6 years discussed above, releases were ramped down to base flows before these specified dates.

Another option is the ability to increase releases from Flaming Gorge Dam in April and May. The Green River Model generally does not increase releases from Flaming Gorge Dam to the maximum powerplant capacity of 4,600 cfs (unless reservoir storage is above a set threshold) until the Yampa River is about to reach its peak (usually in late May). The model delays increasing releases even in wetter than average years. Unless the model is constrained by meeting a drawdown target in the months of April and May (which it generally is not), simulated increases in releases from Flaming Gorge do not generally begin until the middle of May. In wetter than average years, the model frequently misses an opportunity to move water in these months. In the all of the 6 years mentioned above, additional water could be moved in April and May. In wet, moderately wet, and average wet years, it is appropriate to increase releases in this period to release water and avoid a bypass later without compromising the recommended flow targets (releases could be increased to a level intermediate between the base flow and 4,600 cfs or in very wet years, all the way to 4,600 cfs).

In making mass balance adjustments, the Green River Model first assures that the base flow is consistent with the flow recommendations by targeting the mean base flow for the hydrologic category. However, the flow recommendations provide a range for target flows rather than a single flow and also allow for adjustment of flows during the base-flow period. For the period reviewed, there were several years in which Reach 2 peak flow targets could not be reasonably met, and in which more runoff could be put into storage and base flows raised to meet the March 1 drawdown target. Some bypasses predicted by the Green River Model are being driven by the need to meet the base flow targets, even though the flow recommendations allow for a range of base flows.

The option of increasing releases from Flaming Gorge Dam in April or May in wetter years has an additional benefit as well. There are some years (e.g., 1962 and 1974) where the Yampa River has an early 'first' peak in late April or early May that sometimes exceed 14,000 cfs. The model has been developed to match the later more significant peak, but in wetter years additional days at 18,600 cfs (a significant duration target in the flow recommendations) in Reach 2 could be achieved by appropriately increasing releases in April or May in wetter years, and, on occasion, eliminate the need for bypass releases to reach downstream targets.

The year 1962 was also identified as one in which bypass releases would not be required. It is an 'early' runoff year with two large peaks on the Yampa River, one in late-April and one in mid-May. It was a moderately wet year in the upper Green River Basin (upstream of Flaming Gorge Dam) with the need to release a significant amount of water from the reservoir for hydrologic reasons. The modeled operation shows a large bypass and spill (with a peak release of 12,200 cfs) in late May to achieve the 18,600 cfs, 2-week, Reach 2 target. This large release is made as the Yampa River flow declines from its second peak. This same target could be met, and the same volume of water released from the reservoir, by eliminating the bypass and spill entirely, and releasing 4,600 cfs from late April through mid July.

There were 3 years identified as borderline years in terms of the use of the bypass tubes in the Green River Model. These were 1932, 1970, and 1974. In each of these years, bypass releases were used to meet the 18,600-cfs, 2-week, Reach 2 target. In these 3 years, a steady release of 4,600 cfs would achieve the same Reach 2 target without bypass. Because of the difficulty in precisely predicting the behavior of the Yampa River, however, our review concludes that the use of the bypass to meet downstream targets may have been warranted in these years.

2. Spillway releases frequently occur when Reach 2 targets are being exceeded.

In some years, the Green River Model predicts releases from Flaming Gorge Dam that are higher than those needed to achieve recommended Reach 2 peak flow targets. In the rule set for the model, bypass and spill releases are increased by a factor of 1.2 when the mass balance calculation indicates that additional water needs to be bypassed after the Yampa River has finished peaking. The 1.2 rule in the model may be causing releases from Flaming Gorge Dam to exceed 8,600 cfs, the threshold where spillway use is required in wet and moderately wet years.

There are 10 years (1922, 1923, 1927, 1947, 1971, 1973, 1975, 1978, 1980, and 1982) where releases exceed 8,600 cfs, where flows in Reach 2 are greater than target levels. In each of these years, all of the same Reach 2 targets could be met using bypass releases. With the exception of 1973, these years are all moderately wet or wet years. The spillway was not required for dam safety considerations in these years because in each one, there is at least 6 feet of vacant space at the end of the runoff period. Other operating options would be available to meet the downstream targets and evacuate the appropriate amount of water from the reservoir. In most cases the volume released through the spillway could be shifted to an extended use of the bypass tubes to meet the downstream target. In other years, the spill could be eliminated and the additional water evacuated by extending the period of powerplant capacity flows to the end of July (in moderately wet years) or to August 15 (in wet years), by releasing additional water in April or May, or by storing some additional water and making minor adjustments to base flows.

In our review, we classified 2 of these 10 years as borderline years (1927 and 1947). Given the hydrologic uncertainty in these 2 years, and the fact that the Reach 2 targets would just barely be reached without releases greater than 8,600 cfs, our review concludes the use of the spillway in these 2 years to be reasonable.

There are 2 years where the Green River Model predicts releases from Flaming Gorge Dam that are just above 8,600 cfs. This occurs in 1938 when releases of about 9,000 cfs are made for 3 days, and in 1942, when releases for 2 days are about 8,800 cfs. In each of these 2 years, releases could be limited to 8,600 cfs to achieve the same Reach 2 targets. There is no sensitivity to 8,600 cfs as a threshold in the Green River Model. The 2 years mentioned show up as “spill” years in the Flaming Gorge Model, even though the volume released through the spillway is negligible. In actual practice, the spillway would not likely be used for such a small amount of release (200 to 400 cfs).

The following table displays those years in which the Green River Model predicted bypass or spill, but we concluded that such use may not be necessary.

Years In Which Bypass or Spill Was Predicted by the Green River Model, but May Not Be Necessary

Unnecessary Bypass Release Years	Unnecessary Spillway Release Years
1943	1922
1944	1923
1950	1938
1951	1942
1956	1962
1962	1971
1967	1973
	1975
	1978
	1980
	1982

3. Other Findings

There is considerable variability between the hydrology of the Green River and Yampa River basins on a year-to-year basis. There are numerous wetter years in the Yampa River Basin where hydrologic conditions are average in the upper Green River Basin. The reverse is also true. The Green River Model's approach is to capitalize on Yampa River Basin hydrology so to limit the volume of spills and bypasses from Flaming Gorge Dam while achieving the flow recommendations. The model attempts to achieve Reach 2 targets by considering Yampa River Basin hydrology in combinations with hydrologic conditions in upper Green River Basin. There are numerous years where moderately wet or wet Reach 2 targets are met with a limited amount of bypass (with 1929, 1957, 1958, 1970, and 1984 as example years). We believe the approach used in the Green River Model is appropriate, and that if the model were configured to try and 'force' the achievement of the flow recommendations based solely on hydrologic classifications in the upper Green River, that significantly larger volumes of water would have to be bypassed or spilled at Flaming Gorge Dam.

Down-ramp rates when the bypass tubes or the spillway are used in the Green River Model vary. In moderately wet and wet years the down-ramp rate is 1,000 cfs per day. Occasionally the model bypasses some water in average or average wet years to take advantage of opportunities on the Yampa River. In these years, the down ramp rate is only 500 cfs per day. Consideration should perhaps be given to increasing this down ramp to 1,000 cfs per day to reduce the volume of water bypassed.

Conclusions

The Green River Model predicts the use of the bypass or spillway at Flaming Gorge in 33 of 65 years. Our review concludes that in 26 of these 65 years this use is appropriate for hydrologic reasons or to meet targets in Reach 2. In 11 of these 26 years (1921, 1922, 1923, 1927, 1928, 1929, 1947, 1952, 1972, 1978, and 1980), it appears that the volume of bypass produced by the Green River Model was higher than necessary, and could be reduced while still meeting the same objectives in Reach 2. The same strategies discussed previously to reduce bypass and spills are relevant, i.e., extend the duration of the peak flow to August 1 in moderately wet years and August 15 in wet years, increase releases from Flaming Gorge Dam in April or early May in wetter years, and take advantage of flexibility in the base-flow period when needed.

The Green River Model performs well in dry, moderately dry, average dry, and average years. In many of the wetter years the model also performs well (1957 and 1984 are examples of excellent wet year operations). The model appears to bypass or spill more water than may necessary in average wet, moderately wet, and wet years, however. The Green River Model operates Flaming Gorge Dam to assure that frequencies of peak flow targets and duration targets as specified in the flow recommendations are met. The model also meets base flow targets as specified in the flow recommendations.

A key issue with river simulation modeling is lack of flexibility. Rules must be 'hard coded'. While rules allow for decision trees, a model such as the Green River Model will not be able to adjust to all situations and be able to consider the balance of all available operating options. The inability to program extensive flexibility into the model's rules makes precise modeling of the effects of flow recommendations, which are inherently flexible, more difficult.

Three key findings were made in reviewing the model:

- ❖ The model does not take advantage of the ability to move water in April and early May in wetter than average years. By not increasing releases during this period the frequency of spills and bypass releases in the Green River Model is increased, and some opportunities to more easily achieve targets in Reach 2 are missed.
- ❖ Modeled releases frequently exceed 8,600 cfs (requiring spillway use) even when such spillway releases are not needed to meet downstream targets or for hydrologic reasons. The 1.2 rule may be contributing to this phenomenon.
- ❖ The Green River Model mass balance procedure in the spring ‘locks’ in base flows for the following August through February time frame and also locks in the amount of water to be released in the May through July time period. The model is not able to capitalize on the flexibility allowed by the flow recommendations for base flows as it moves through the operation in the May through July time period.

Each of these factors contributes to the Green River Model bypassing and spilling more water than may be necessary. Based on the evaluation of the Green River Model, the frequency of use of the spillway and bypass predicted by the model in the action alternative is probably higher than necessary to achieve the flow recommendations. We found 7 years out of 65 when bypasses occurred, but were not required. We believe that operations at Flaming Gorge Dam could meet the flow recommendations by using the bypass tubes about 40.0% of the time, a reduction of 9.9% from that predicted by the Green River Model. The frequency of spillway use appears to be overstated by the model as well. We found 11 years in which the model predicted spills (releases greater than 8,600 cfs), but those spills did not result in meeting downstream targets nor were they needed for hydrologic reasons. We believe that the use of the spillway may be needed about 10.8% of the time to meet the flow recommendation, a reduction of 18.6% percent from that predicted by the Green River Model. The total volume of water released above powerplant capacity (as bypasses or spills) as predicted by the Green River Model may also be greater than necessary.