Green River Evaluation and Analysis Team Hydrologic Modeling Methodology

December 2018
Heather E. Patno

Overview

Through coordination with the State of Utah Division of Water Resources (State), the Bureau of Reclamation (Reclamation) conducted several hydrologic modeling runs using Reclamation’s long-term planning model, Colorado River Simulation System (CRSS). The results of these model runs are being used to determine potential impacts on the hydrology of the Colorado River System from development of the Green River Block of the Ultimate Phase depletions (GRB). These depletions and diversions were covered in the Operation of Flaming Gorge Dam Final Environmental Impact Statement published in September 2005 (FEIS), and are being analyzed for the purpose of signing Water Exchange Contract No. 17-WC-46-655 for exchange of Green River Block water between the United States of America and the State of Utah.

This report presents the results of two sets of hydrologic modeling runs. The modeling runs present modeling results comparing the GRB depletion against the no action alternative using historic natural flow hydrology.

Two different assumptions regarding reasonably foreseeable depletions are analyzed for each hydrologic run. The no action and GRB scenarios assume that all future Upper Basin depletions except for the GRB are modeled as constant at the 2018 depletion levels for the entire model run (GRB Depletion Scenario). The GRB plus reasonably foreseeable (Full Depletion Scenario) holds all future Upper Basin depletions except for the GRB and other future depletions assumed to the reasonably foreseeable as constant at the 2018 depletions levels, while the GRB and all reasonably foreseeable depletions are held constant at the 2060 levels. In this context, a reasonably foreseeable future depletion is one which has state legislation, or a tribal resolution or federal Indian water settlement, or a federal finding of no significant impact (FONSI) or record of decision (ROD). See the Discussion section of this document for further discussion and for specific CRSS model depletion nodes.

This modeling assumption is different than standard CRSS model runs that are used in a long-term basin-wide planning context (e.g., the 2012 Colorado River Basin Water Supply and Demand Study (Basin Study1)). CRSS runs performed in a basin-wide planning context typically project that future Upper Basin depletions increase throughout the entire model run period. The model runs presented in this report analyze the difference between diverting water out of the Green River directly below Flaming Gorge.

---

Dam (FG) and not diverting the water. In this analysis, the State’s total depletions in the GRB and basecase differ by the volume of water being diverted below Flaming Gorge Dam. This modeling approach isolates the impact of diverting water out of the Green River and the impact of the GRB as compared against reasonably foreseeable depletions.

Three scenarios were compared in this analysis for each set of hydrology: (1) Upper Basin depletions held constant at 2018 (No Action Scenario) and (2) Upper Basin depletions held constant at 2018 levels except GRB (GRB depletion scenario); and (3) Upper Basin depletions held constant at 2018 levels except GRB and reasonably foreseeable depletions (Full Depletion Scenario).

The first section of this report presents an overview of the data. Next, the general methodology and technical assumptions of CRSS are reviewed, followed by the technical assumptions specific to this study and model runs. The modeling results are then presented with an analysis of the differences between the action and no action alternatives. A discussion section concludes the report.

**Data**

The Green River Block total depletion amount is 72,641 acre-feet (af) of the total Ultimate Phase depletion amount of 158,890 af. The State of Utah has perfected water rights in the amount of 13,684 af for private water users along the Green River. These water rights are included in all three scenarios, and the total future depletion for the Green River amounts to 58,957 af of water remaining under the 72,641 af.

In this study, three future depletion scenarios were modeled: (1) basecase with no Green River diversion; (2) basecase with GRB of 58,957 per year; and (3) Green River Block depletions of 58,957 per year with constant 2060 reasonably foreseeable depletions. For all scenarios, it was assumed that Upper Basin depletions without state legislation, or a tribal resolution or federal Indian water settlement, or a federal finding of no significant impact (FONSI) or record of decision (ROD) remained constant at the 2018 depletion levels currently in CRSS. The GRB depletion includes Reaches 1 and 2 of the Green River. The reasonably foreseeable depletions assumed those depletions for the State of Utah on the Green, White and Yampa River tributaries, and included Ute Indian Compact and Upalco. See the discussion section for further details and for specific CRSS model depletion nodes held constant at the 2060 levels. Note that the 2018 depletions levels modeled are based upon the Upper Basin depletion schedules in CRSS and not the observed (or computed) depletions reported in the 2018 Consumptive Uses and Losses report which was not available at the time of this analysis or the writing of this report and will later be prepared by Reclamation.

For each depletion scenario (no action, GRB depletion and full depletion), one future inflow hydrology scenario was modeled. The inflow scenario uses data from the observed streamflow record (1906-2015).

---

Future Depletion Scenarios

1. No Action Scenario
Under the no action scenario, GRB depletions for this scenario were assumed to be zero for the entire model run (2018-2060). Depletion data for all other locations in CRSS were the Upper Colorado River Commission 2007 depletion schedule held steady at 2018 levels.

2. GRB Scenario
Under the GRB scenario, it was assumed that the GRB depletion location would occur directly below Flaming Gorge Dam during the agricultural growing season from July through the end of September. The 2006 Flaming Gorge Record of Decision (FGROD) operations remained consistent throughout each alternative. Reclamation made a commitment in the FGROD to maintain Reach 1 and 2 flow target levels as measured by the USGS streamgage on the Green River at Greendale (Reach 1) and the Green River at Jensen, Utah (Reach 2). The GRB depletion maintains FGROD operations and no change to operations are made under the GRB scenario. Flaming Gorge Dam releases maintain Reach 1 and 2 flow thresholds. The two depletion schedules differ based on the assumed future water available in the Green River Basin. In both depletion schedules the GRB maximum annual depletion is 58,957 acre-feet. In this modeling, the Green, Yampa and White depletions that are reasonably foreseeable are lower than those modeled in the 2012 Basin Study. This is because for the purposes of this analysis all depletions were held constant at 2018 depletion levels.

3. GRB and Full Depletion Scenario
Under the GRB and Full Depletion Scenario, all assumptions from the GRB scenario are maintained with the addition of reasonably foreseeable depletions held constant at 2060 levels with all other depletions held constant at 2018 depletion levels. In this modeling, the Green, Yampa and White depletions that are reasonably foreseeable are lower than those modeled in the 2012 Basin Study but represent the largest potential future depletions on the Green River system. Table 1 contains the 2018 and 2060 levels of each of the Upper Basin States modeled in CRSS. Colorado, New Mexico and Wyoming depletions were held constant at 2018 levels under all scenarios. Table 2 below contains the Reasonably Foreseeable Depletions with both 2018 and 2060 levels. The difference between total State of Utah depletions at 2060 levels and the Reasonably Foreseeable levels is 60 thousand acre-feet (kaf), which represents the depletions that do not meet the strict criteria to be included in the cumulative analysis. The additional depletions are also below Reach 2 and therefore not included in the geographical boundaries of this analysis.
Table 1. CRSS state depletion totals. This modeling assumed 2018 levels for Colorado, New Mexico and Wyoming depletions in both the GRB Scenario and the Full Depletion Scenario in order to isolate the impacts of signing the exchange contract with the State of Utah.

<table>
<thead>
<tr>
<th>State</th>
<th>2018</th>
<th>2060</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado</td>
<td>2,833</td>
<td>2,955</td>
</tr>
<tr>
<td>New Mexico</td>
<td>594</td>
<td>642</td>
</tr>
<tr>
<td>Utah</td>
<td>945</td>
<td>1,163</td>
</tr>
<tr>
<td>Wyoming</td>
<td>609</td>
<td>763</td>
</tr>
</tbody>
</table>

Table 2. Reasonably Foreseeable Future Depletions Nodes in CRSS for the Ultimate Phase Modeling at 2018 and 2060 levels.

**Future Inflow Hydrology Scenarios**

1. **Historic Hydrology - Direct Natural Flow (DNF)**

   The future hydrology used as input to the model in this scenario consisted of samples taken from the historic record of natural flow in the river system over the 110-year period from 1906 through 2015 from 29 individual inflow points (or nodes) on the Colorado River System. Natural flow is the observed flow adjusted for the effects of diversions and the operation of reservoirs upstream of the flow gage. This natural flow record\(^3\) was developed by Reclamation and is used extensively in their hydrologic modeling and Environmental Impact Statements (EIS). In this inflow scenario, the existing historical record of natural flows was used to create a number of different future hydrologic sequences using a resampling technique known as the Index Sequential Method (ISM\(^4\)). The ISM provides the basis for quantification of the uncertainty and an assessment of the

---

\(^3\) Colorado River Basin Natural Flow and Salt Data, available at: [http://www.usbr.gov/lc/region/g4000/NaturalFlow/](http://www.usbr.gov/lc/region/g4000/NaturalFlow/)

risk with respect to future inflows and is based upon the best available measured data. This inflow dataset and methodology was used as the primary inflow scenario in the 2007 Shortage EIS and one of the inflow scenarios used in the 2012 Basin Study.

**Methodology**

Hydrologic modeling of the Colorado River system was conducted using Reclamation’s long-term planning model, CRSS. The hydrologic modeling provides projections of potential future Colorado River system conditions (e.g., reservoir elevations, reservoir releases, river flows) under the No Action scenario for comparison with conditions under the GRB scenario. Due to uncertainties associated with future inflows into the system, multiple simulations were performed for each depletion scenario to quantify the uncertainties in future conditions, and the modeling results are typically expressed in probabilistic terms.

This document provides an overview of the hydrologic modeling and the framework within which the many simulations were undertaken.

In 2000, the Recovery Program issued Flow and Temperature Recommendations for Endangered Fishes in the Green River Downstream of Flaming Gorge Dam (Muth et al., 2000; Flow Recommendations). The Flow Recommendations provide the basis for the proposed action described and analyzed in the FEIS. The ROD implements the proposed action by modifying the operations of Flaming Gorge Dam, to the extent possible, to assist in the recovery of endangered fishes and their critical habitat downstream from the dam and, at the same time, maintains and continues all authorized purposes of the Colorado River Storage Project (Reclamation 2006). Table 2.1 in the FEIS summarizes the Flow Recommendations and can be found in Appendix A.

The ROD directs Reclamation to operate to achieve, to the extent possible, the Flow Recommendations as described in the FEIS (Reclamation 2006). The Flow Recommendations divide the Green River below Flaming Gorge Dam into three river reaches. Reach 1 begins directly below the dam and extends to the confluence with the Yampa River. Reach 2 begins at the Yampa River confluence and continues to the White River confluence. Reach 3 is between the White River and Colorado River confluences (Muth et. al 2000). The Flow Recommendations and FGROD limit Reclamation’s compliance responsibility to meeting flow targets at Reach 2 measured on the Green River at Jensen, Utah. This analysis looks at the impact of the GRB depletion scenario at Reach 2, according to the modeled information.

The ROD classifies annual hydrology into five hydrologic classifications dry (>90% exceedance); moderately dry (<70% and >90% exceedance); average (<30% and >70% exceedance); moderately wet (<10% and >30% exceedance); and wet (>10% exceedance).
Scenarios Modeled
A no action scenario, GRB scenario and full depletion scenario were modeled, as described above. The action scenario is the 58,957 acre-foot depletion scenario described above. The no action scenario is the August 2017 official CRSS run with the following two exceptions to the model assumptions (1) the 2007 Upper Colorado River Commission (UCRC) depletion schedule was used, and (2) all Upper Basin depletions were held constant at 2018 levels except those identified as reasonably foreseeable, which are held at 2060 levels in the Full Depletion scenario.

Period of Analysis
Hydrologic modeling extends from 2018 through 2060.

Model Description
Future Colorado River system conditions under the action and no action alternatives were simulated using CRSS. The model framework of CRSS is a commercial river modeling software called Riverware⁵; a generalized river basin modeling software package developed by the University of Colorado through a cooperative arrangement with Reclamation and the Tennessee Valley Authority. CRSS was originally developed by Reclamation in the early 1970s and was implemented in Riverware in 1996.

CRSS simulates the operation of the major reservoirs on the Colorado River on a monthly time-step and provides information regarding the projected future state of the system in terms of output variables including the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points throughout the system, and the diversions to and return flows from the water users throughout the system. The simulation uses a mass balance (or water budget) approach to account for water entering the system, water leaving the system (e.g., from consumptive use of water, trans-basin diversions, evaporation), and water moving through the system (i.e., either stored in reservoirs or flowing in river reaches). The model was used to project the future conditions of the Colorado River system on a monthly time-step for the period 2018 through 2060.

The input data for the model includes monthly future inflows, various physical process parameters such as the evaporation rates for each reservoir, initial reservoir conditions on January 1, 2018, and the future diversion and depletion schedules for entities in the Basin States and for Mexico. These future schedules were based on demand and depletion projections prepared and submitted by the Basin States based on the official 2007 Upper Colorado River Commission future depletions. In this analysis, except for reasonably foreseeable depletions, future Upper Basin depletions from the 2007 UCRC schedule was assumed constant at 2018 levels; this assumption results in depletions significantly lower than the future depletion projections used in long term planning studies such as the Basin Study, which assumed that Upper Basin depletions will grow through 2060. Depletions

---

(or water use) are defined here as diversions from the river less return flow credits, where applicable.

The rules of operation of the Colorado River mainstream reservoirs including Flaming Gorge are also provided as input to the model. These sets of operating rules describe how water is released and delivered under various hydrologic conditions.

The Flaming Gorge ROD outlines spring and base flow recommendations that Reclamation is obligated to meet in Reaches 1 and 2. The spring peak flow recommendations are measured during April-July or until the cessation of the spring peak release and base flows are measured from the cessation of the spring peak releases or August through February of the next year. March and April are transition months to meet a variable May 1 elevation target for dam safety purposes.

Reach 1 releases from Flaming Gorge are calculated based on the Reach 2 requirements that include Yampa River flows. Reach 2 model results are measured at Jensen, Utah. The model utilizes a k-NN daily disaggregation method for the Yampa River April-July largely unregulated flows to determine frequency of meeting spring peak timing, magnitude and duration daily. Yampa River flows during the base flow period use the monthly flow and calculate a daily average for the entire month from that value.

Flaming Gorge powerplant capacity release is 4,600 cubic feet per second (cfs). Two hollow jet valves or bypass tubes each with a capacity of 2,000 cfs can be utilized for a total release from Flaming Gorge of 8,600 cfs. Flaming Gorge does have a gated spillway that can be used in a hydrologic emergency, which has been shown to be unnecessary in the current modeling.

**General model assumptions:**
- January 2018 initial conditions for all modeled reservoirs
  - Flaming Gorge 6,028.38 ft
- Run duration: 2018-2060

**Modifications to CRSS**
Modifications were made to the official version of CRSS to model the GRB depletion for this analysis. The base flow release calculation during July-September for Reaches 1 and 2 included an average depletion divided into daily releases for the time period, and all minimum release thresholds were met.

**Results**
Each alternative (no action, GRB and full depletion scenarios) was modeled using the DNF future inflow scenarios, resulting in three model runs. For comparison purposes, the two action scenarios are compared to the no action alternative designated as basecase.
The comparisons are made using the DNF future inflow scenarios. The following variables were evaluated:

- Flaming Gorge pool elevation on April 31st
- Flaming Gorge elevation \( \leq 5,980 \) ft
- Flaming Gorge Release and Jensen Flows (January-February)
- Flaming Gorge Release and Jensen Flows (March)
- Flaming Gorge Release (April)
- Flaming Gorge Release and Jensen Flows (July-September)
- Flaming Gorge Release and Jensen Flows (October-December)
- Jensen Flows (April-July)
- Jensen Maximum Annual Flow (April-July)
- Jensen Sustained 14-Day Duration Flows (April-July)
- Jensen Flows (August-September)

**Post-processing and Interpretation Procedures**

CRSS generates data on a monthly time-step for over 300 points (or nodes) on the Colorado River system. Furthermore, using the ISM on the natural flow record, the model generated 110 possible outcomes for each node for each month of the model run. Flaming Gorge data is further disaggregated to a daily hydrograph for Flaming Gorge releases and flows at Jensen, Utah below the confluence of the Green and Yampa Rivers. These very large data sets generated for each alternative can be visualized as three-dimensional data “cubes” with the axes of time, space (or node) and trace (or outcome for each future hydrology). The data were aggregated to reduce the volume of data and to facilitate comparison of the alternatives.

For aggregation of data, simple techniques were employed. For example, Flaming Gorge pool elevations were evaluated on an annual basis (i.e., end of April) to show long-term lake elevation trends and compliance with the May 1 elevation target as opposed to short-term fluctuations. Standard statistical techniques were used to analyze the 110 possible outcomes for a fixed time or particular temporal span. Statistics were generated for the percent exceedance over certain time periods at critical river threshold levels. Inverse cumulative density probabilities were determined by simply ranking the outcomes for all 110 possible outcomes over each temporal scale (from lowest to highest) and determining the probability of being at or above that value. For example, 110 Flaming Gorge release values were generated for January 1, 2018, one for each natural flow inflow trace. These 110 values were compiled with all daily Flaming Gorge release values for the January 1-December 31 time period. These statistics are then used to determine the probability of Flaming Gorge elevations or releases and Jensen flows being at certain thresholds throughout the run period (each separate scenario result contains 56,760 individual points of data for a CDF that contains every month of all 110 runs throughout the 2018-2060 period, 577,060 individual points for the daily data during the April-July period).

Concerns over a changing climate have been prominent in environmental and water resources. The DNF hydrology set contains multiple period of drought, including the decades of drought that occurred in the 1930s, 1950s, 1970s and 2000 up to 2015. In order to determine the impacts of continued drought, the trace with the lowest elevation has
been isolated and its results have been included. Trace 63 begins with the initial conditions and then historic year 1979 is the first hydrologic year of that trace. This trace moves through the wet years in the 1980s, but ends with the drought in 2000-2015. It is the period of operations between 2000-2015 that have the greatest impact on elevation. The impact trends of implementing the exchange agreement are seen in the worst-case scenario. The illustrations in the drought trace 63 should be considered one representation of potential possibilities of future hydrology and it is statistically unlikely that trace 63 will happen.

**Direct Natural Flow Results**

Figures 1 and 2 show the differences in Flaming Gorge pool elevation in April between the action scenarios and the no action scenario at all probability percentiles. April was chosen because the 2006 FEIS identified this month as the reservoir elevation target to meet that varies depending upon percent exceedance of forecasted inflow. The difference between the no action and implementation of the GRB depletion results in a maximum six foot drop in the reservoir. The addition of Full Depletion scenario into the future increase the maximum difference in elevation to 30 feet, yet still within the FEIS range that extends to elevation 5980 feet as analyzed in the FEIS.

Figure 1 illustrates impacts that are seen throughout the graphical results comparing the impact between implementing the Green River Block depletion and incorporating the official UCRC 2060 depletions on the Green River. The impacts of incorporating full depletion development on the Green River are greater than impacts from the 58,957 acre-feet depletion.

Figures 3 and 4 show the probability of Flaming Gorge pool elevation being below 5,980 ft (minimum elevation in FEIS) in April. Under all scenarios, the modeling showed no traces (out of 110 traces) below minimum power pool (5,890 ft).
Figure 1. Flaming Gorge pool elevation, April. Direct natural flow inflows, 59kaf Green River maximum depletion. Illustrates the probability of Flaming Gorge pool elevation being below 5,980 ft (minimum elevation in FEIS) in April. Under all scenarios, the modeling showed no traces (out of 110 traces) below minimum power pool (5,890 ft).
Figure 2. Flaming Gorge pool elevation, April. Direct natural flow inflows, 59kaf Green River maximum depletion, trace 63. Illustrates the probability of Flaming Gorge pool elevation being below 5,980 ft (minimum elevation in FGFEIS) in April. Under all scenarios, the modeling showed no traces (out of 110 traces) below minimum power pool (5,890 ft).

Figure 3. Probability of Flaming Gorge pool elevation below 5,980 feet (minimum elevation in FEIS) in April. Direct natural flow inflows, 59kaf Green River maximum depletion. Illustrates the probability of Flaming Gorge pool elevation being below 5,980 ft (minimum elevation in FGFEIS) in April. Under all scenarios, the modeling showed no traces (out of 110 traces) below minimum power pool (5,890 ft).
Figure 4. Probability of Flaming Gorge pool elevation below 5,980 feet (minimum elevation in FEIS) in April. Direct natural flow inflows, 59kaf Green River maximum depletion. Illustrates the probability of Flaming Gorge pool elevation being below 5,980 ft (minimum elevation in FGFEIS) in April. Under all scenarios, the modeling showed no traces (out of 110 traces) below minimum power pool (5,890 ft).

Figures 5-8 present Flaming Gorge and Jensen releases during the January and February base flow period. Releases from Flaming Gorge in the no action and GRB depletion scenarios are almost identical. The addition of full depletion scenario causes a decrease in Flaming Gorge elevation that in turn decreases base flow releases to increase elevation where flexibility exists in Flaming Gorge operations. Between both the 80 to 90 and 50 to 60 percent exceedance levels the full depletion scenario extends the minimum base flow duration at Jensen, Utah. The historic record includes some high precipitation months in January and February that are seen in the Jensen flows reaching above 4,500 cfs < 0.01 percent of the time.
Figure 5. Probability of Flaming Gorge releases during January-February. Direct natural flow inflows, 59kaf Green River maximum depletion. Releases from Flaming Gorge in the no action and GRB depletion scenarios are almost identical. The addition of full depletion scenario causes a decrease in Flaming Gorge elevation that in turn decreases base flow releases to increase elevation where flexibility exists in Flaming Gorge operations.
Figure 6. Probability of Flaming Gorge releases during January-February. Direct natural flow inflows, 59kaf Green River maximum depletion. Releases from Flaming Gorge in the no action and GRB depletion scenarios are almost identical. The addition of full depletion scenario causes a decrease in Flaming Gorge elevation that in turn decreases base flow releases to increase elevation where flexibility exists in Flaming Gorge operations.
Figure 7. Probability of Jensen flows during January-February. Direct natural flow inflows, 59kaf Green River maximum depletion. Between both the 80 to 90 and 50 to 60 percent exceedance levels the full depletion scenario extends the minimum base flow duration at Jensen, Utah. The historic record includes some high precipitation months in January and February that are seen in the Jensen flows reaching above 4,500 cfs < 0.01 percent of the time.
Figure 8. Probability of Jensen flows during January-February. Direct natural flow inflows, 59kaf Green River maximum depletion. Between both the 80 to 90 and 50 to 60 percent exceedance levels the full depletion scenario extends the minimum base flow duration at Jensen, Utah. The historic record includes some high precipitation months in January and February that are seen in the Jensen flows reaching above 4,500 cfs < 0.01 percent of the time.

March is a transition month where Flaming Gorge releases can be significantly higher or lower than the base flow period from August-February to achieve the May 1 elevation drawdown level as evidenced during the low exceedance probabilities (higher percentiles) for Flaming Gorge releases and subsequent Jensen flows in Figures 10-12. Releases above powerplant capacity (4,600 cfs) occur 4 percent of the time in all scenarios.

Figures 9-12 also present a similar story to the previous figures. Flaming Gorge and Jensen releases are nearly identical between the no action and GRB depletion scenarios, while the addition of the full depletion scenario extends minimum releases in March from 60 to 70 percent exceedance levels. Continued lower release levels, albeit not minimum releases, occur from 10 to 60 percent exceedance levels (50 percent of the time) to increase reservoir storage under the full depletion scenario.
Figure 9. Probability of Flaming Gorge releases in March. Direct natural flow inflows, 59kaf Green River maximum depletion. March is a transition month where Flaming Gorge releases can be significantly higher or lower than the base flow period from August-February to achieve the May 1 elevation drawdown level as evidenced during the low exceedance probabilities (higher percentiles) for Flaming Gorge releases and subsequent Jensen flows in Figures 5 and 6. Releases above powerplant capacity (4,600 cfs) occur 4 percent of the time in all scenarios.
Figure 10. Probability of Flaming Gorge releases in March. Direct natural flow inflows, 59kaf Green River maximum depletion. March is a transition month where Flaming Gorge releases can be significantly higher or lower than the base flow period from August-February to achieve the May 1 elevation drawdown level as evidenced during the low exceedance probabilities (higher percentiles) for Flaming Gorge releases and subsequent Jensen flows in Figures 5 and 6. Releases above powerplant capacity (4,600 cfs) occur 4 percent of the time in all scenarios.
Figure 11. Probability of Jensen flows in March. Direct natural flow inflows, 59kaf Green River maximum depletion. March is a transition month where Flaming Gorge releases can be significantly higher or lower than the base flow period from August-February to achieve the May 1 elevation drawdown level as evidenced during the low exceedance probabilities (higher percentiles) for Flaming Gorge releases and subsequent Jensen flows in Figures 5 and 6. Releases above powerplant capacity (4,600 cfs) occur 4 percent of the time in all scenarios.
Figure 12. Probability of Jensen flows in March. Direct natural flow inflows, 59kaf Green River maximum depletion. March is a transition month where Flaming Gorge releases can be significantly higher or lower than the base flow period from August-February to achieve the May 1 elevation drawdown level as evidenced during the low exceedance probabilities (higher percentiles) for Flaming Gorge releases and subsequent Jensen flows in Figures 5 and 6. Releases above powerplant capacity (4,600 cfs) occur 4 percent of the time in all scenarios.

Spring peak releases during the month of April are nearly identical under all scenarios. The full depletion scenario continues to release slightly less and minimum releases are extended an additional 10 percent of the time, as evidenced in Figure 13-14.
Figure 13. Probability of Flaming Gorge releases in April. Direct natural flow inflows, 59kaf Green River maximum depletion. Spring peak releases during the month of April are nearly identical under all scenarios. The full depletion scenario continues to release slightly less and minimum releases are extended an additional 10 percent of the time.
Figure 14. Probability of Flaming Gorge releases in April. Direct natural flow inflows, 59kaf Green River maximum depletion. Spring peak releases during the month of April are nearly identical under all scenarios. The full depletion scenario continues to release slightly less and minimum releases are extended an additional 10 percent of the time.

Jensen flows for the April-July period are presented in Figure 15(a) and (b) and 16(a) and (b). The largely unregulated nature of the Yampa River and the daily disaggregation algorithm provide a significant range of flows on the Yampa that are illustrated in Figure 15(a) and 16(a). Jensen flows are below 5,000 cfs approximately 45 percent of the time, and Figure 15(b) and 16(b) focuses on those flows for increased optics. Jensen flows in the GRB scenario and the full depletion scenario are higher approximately 5 percent of the time when Flaming Gorge releases are increased in July to maintain Reach 2 flows, and are higher than the no action scenario. The slight decrease approximately 1 percent of the time can be attributed to April flows that are outside the shift in timing for the GRB scenario releases.
Figure 15. Probability of Jensen flows during April-July. Direct natural flow inflows, 59kaf Green River maximum depletion. The largely unregulated nature of the Yampa River and the daily disaggregation algorithm provide a significant range of flows on the Yampa that are illustrated in Figure 15(a). Jensen flows are below 5,000 cfs approximately 45 percent of the time, and Figure 15(b) focuses on those flows for increased optics. Jensen flows in the GRB scenario and the full depletion scenario are higher approximately 5 percent of the time when Flaming Gorge releases are increased in July to maintain Reach 2 flows, and are higher than the no action scenario. The slight decrease approximately 1 percent of the time can be attributed to April flows that are outside the shift in timing for the GRB scenario releases.
Figure 16. Probability of Jensen flows during April-July. Direct natural flow inflows, 59kaf Green River maximum depletion. The largely unregulated nature of the Yampa River and the daily disaggregation algorithm provide a significant range of flows on the Yampa that are illustrated in Figure 16(a). Jensen flows are below 5,000 cfs approximately 45 percent of the time, and Figure 16(b) focuses on those flows for increased optics. Jensen flows in the GRB
scenario and the full depletion scenario are higher approximately 5 percent of the time when Flaming Gorge releases are increased in July to maintain Reach 2 flows, and are higher than the no action scenario. The slight decrease approximately 1 percent of the time can be attributed to April flows that are outside the shift in timing for the GRB scenario releases.

The maximum daily flow at the Jensen gage is presented in Figures 17-20. The ROD requires meeting a daily maximum of 18,600 cfs 50 percent of the time, which is indicated by the horizontal black line on the graph. The no action along with the GRB and full depletion scenarios have similar results for the maximum daily flow at Jensen. All three scenarios indicate that meeting the daily maximum flow at Jensen at or above 18,600 cfs 50 percent of the time is not achievable under historic hydrology used in this modeling scenario. Differences between this analysis and the analysis outlined in the FGFEIS are responsible for the result regarding achievability of annual peak flows at Jensen, Utah. The FGFEIS historic record ended in 1996, while this hydrologic record continues through 2015. The extended record includes the lowest hydrologic period on record beginning in the year 2000. Additionally, the modeling ruleset makes assumptions regarding use of bypass and operational constraints in order to determine necessary steps needed to meet target flows. These modeling results provide information to Reclamation that will be used to operate to meet the 18,600 cfs annual peak target at Jensen, Utah at least 50 percent of the time.

Flaming Gorge ROD commitments also include flows at Jensen to meet or exceed 18,600 cfs for a duration of 14 days at least 40 percent of the time. Figure 10 illustrates the probability of meeting 18,600 cfs for a consecutive 14-day period, which is a stricter standard than the ROD that requires 18,600 cfs for a cumulative total of 14 days at least 40 percent of the time during the spring release period. Based on the conservative estimate, Figure 10 indicates that Jensen flows would remain at or above 18,600 cfs for a consecutive 14-day period approximately 25 percent of the time under all three scenarios. No difference exists between the no action and action alternatives, while the full depletion scenario indicates slightly lower releases caused by the increased depletions in the system.
Figure 17. Probability of Jensen annual maximum flow during April-July. Direct natural flow inflows, 59kaf Green River maximum depletion.

Figure 18. Probability of Jensen annual maximum flow during April-July. Direct natural flow inflows, 59kaf Green River maximum depletion.
Figure 19. Probability of Jensen annual maximum flow sustained for 14 consecutive days during April-July. Direct natural flow inflows, 59kaf Green River maximum depletion.

Figure 20. Probability of Jensen annual maximum flow sustained for 14 consecutive days during April-July. Direct natural flow inflows, 59kaf Green River maximum depletion.
Flaming Gorge Dam is operated to meet Reach 2 targets by incorporating the Yampa River flows and accounting for the GRB depletions total volume averaged daily over the July through September period. The results of the GRB depletion can be seen in Figures 21 and 22 where the full depletion scenario results in slightly lower flows around 50 percent of the time. The GRB depletions and total depletion releases from Flaming Gorge are similar above 65 percent exceedance, or 35 percent of the time, at higher releases than the no action scenario. The GRB depletion and full depletion scenarios are higher to maintain Reach 2 flows and compensate for higher depletion rates below Flaming Gorge Dam.

The results of Flaming Gorge releases on Reach 2 flows can be seen in Figures 19 and 20 on the Green River at Jensen. Figures 23-24 illustrates the likelihood of wet year flows extending into July with the total flows at Jensen approximately 26,000 cfs at the highest levels. Targeting the impacts of releases from Flaming Gorge to flows at Jensen during lower baseflows can be seen in Figures 25-26, which illustrates Jensen flows for August through September. The more granular view of Reach 2 flows during the August through September period indicates that Yampa flows provide a significant portion of Reach 2 flows with the no action and GRB scenario flows similar until approximately 65 percent exceedance level or 35 percent of the time, when the GRB scenario increases releases above the no action. The full depletion scenario remains lower than the base case to increase reservoir storage at less than 70 percent exceedance or 30 percent of the time, at which time Flaming Gorge releases increase the full depletion scenario above the base case. The no action scenario has lower flows than either GRB or full depletion scenarios when the minimum flow release target from Flaming Gorge Reservoir has essentially been altered to compensate for the depletion scenarios during drier hydrology.
Figure 21. Probability of Flaming Gorge releases during July-September. Direct natural flow inflows, 59kaf Green River maximum depletion.

Figure 22. Probability of Flaming Gorge releases during July-September. Direct natural flow inflows, 59kaf Green River maximum depletion.
Figure 23. Probability of Jensen flows during July-September. Direct natural flow inflows, 59kaf Green River maximum depletion.

Figure 24. Probability of Jensen flows during July-September. Direct natural flow inflows, 59kaf Green River maximum depletion.

Figure 25. Probability of Jensen flows during August-September. Direct natural flow inflows, 59kaf Green River maximum depletion.
Figure 26. Probability of Jensen flows during August-September. Direct natural flow inflows, 59kaf Green River maximum depletion.

The GRB depletion ends on September 30, and the remaining months of the year are used to increase reservoir storage within the ROD base flow requirements. The base flows during the October through December time frame are evaluated in Figures 27 and 28 for Flaming Gorge releases and Figures 29-30 for Jensen flows. Flaming Gorge releases are maintained at minimum 800 cfs levels approximately 10 percent more time than the no action, and are at minimum releases for 25 percent of the time. The GRB depletion scenario maintains slightly lower releases as compared to the no action until 45 percent of the time after which releases converge with the no action scenario during October-December. The full depletion scenario increases the duration at minimum 800 cfs releases 20 percent of the time as compared against the no action, and releases are lower than the no action during the entire October through December period.

The impact to Reach 2 Jensen flows for the GRB depletion during October through December is negligible as shown in Figures 27 and 28, with the addition of Yampa River flows assisting overall flows at Jensen. The full depletion scenario maintains approximately 250 cfs lower flows at Jensen 80 percent of the time. This corresponds to 13-17 percent of the total flow volume seen at Jensen.
Figure 27. Probability of Flaming Gorge releases during October-December. Direct natural flow inflows, 59kaf Green River maximum depletion.

Figure 28. Probability of Flaming Gorge releases during October-December. Direct natural flow inflows, 59kaf Green River maximum depletion.
Figure 29. Probability of Jensen flows during October-December. Direct natural flow inflows, 59kaf Green River maximum depletion.

Figure 30. Probability of Jensen flows during October-December. Direct natural flow inflows, 59kaf Green River maximum depletion.
Discussion

The results from these hydrologic model runs should be interpreted with consideration to the model assumptions. Unique to this analysis is the model assumption that no new projects or depletions will occur in the Upper Basin. This model assumption adopts a rigorous definition of what reasonably foreseeable future depletions are in the Upper Basin and is consistent with Reclamation’s NEPA guidelines. Under this approach, a reasonably foreseeable future depletion is one which has state legislation, or a tribal resolution or federal Indian water settlement, or a federal finding of no significant impact (FONSI) or record of decision (ROD). These are the criteria of certainty that a future depletion would occur at a particular time and place. This is a conservative approach to modeling the alternatives and takes the strictest approach to defining what is included and excluded for the cumulative impact analysis required by the Council on Environmental Quality’s regulations 40 CFR 1508.7.6

It is recognized that the Upper Basin States plan to develop their compact allocated Colorado River water and, as such, it is highly unlikely that depletions will remain at the 2018 level in the future.

It should also be noted that the modeling effect of holding most Upper Basin depletions constant at 2018 levels results in depletions significantly lower than the future long-term depletion projections provided by the Upper Basin States which assume that Upper Basin depletions will grow through 2060. The current ROD at Flaming Gorge and its five hydrologic classifications has essentially turned the operations into a pass-through reservoir where the inflows equal the outflows during most years, except for extremely dry years when minimum releases decrease reservoir elevations. Lower depletions would result in higher reservoir elevations overall, but releases would essentially remain the same.

Note that these model results do not represent what the actual reservoir elevations or releases will be in any particular year. Model results should be interpreted based on the relative differences between the action and no action alternatives.

The results presented in this report are the product of statistical analysis performed on model results from the 110 (DNF) model traces.

---

6 Cumulative impact is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.
## Appendix A

### Flaming Gorge Final Environmental Impact Statement

**Table 2.1:** Recommended Magnitudes and Durations Based on Flows and Temperatures for Endangered Fishes in the Green River Downstream from Flaming Gorge Dam as Identified in the 2000 Flow and Temperature Recommendations

<table>
<thead>
<tr>
<th>Location</th>
<th>Flow and Temperature Characteristics</th>
<th>Flow and Temperature Parameters</th>
<th>Hydrologic Conditions and 2000 Flow and Temperature Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wet^a (90-100% Exceedance)</td>
<td>Moderately Wet^a (70-90% Exceedance)</td>
</tr>
<tr>
<td>Reach 1</td>
<td>Maximum Spring Peak Flow</td>
<td>6,800 cfs (244 cubic meters per second [m³/s])</td>
<td>6,800 cfs (130 m³/s)</td>
</tr>
<tr>
<td></td>
<td>Peak flow duration depends upon the amount of unregulated inflows into the Green River and the flows needed to achieve the recommended flows in Reaches 2 and 3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Summer-Winter Base Flow</td>
<td>1,800–2,700 cfs (50–70 m³/s)</td>
<td>1,800–2,600 cfs (50–70 m³/s)</td>
</tr>
<tr>
<td></td>
<td>Above Yampa River Confluence</td>
<td>Water Temperature Target</td>
<td>64°F (18°C) for 3–5 weeks from mid-August to March 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum Spring Peak Flow</td>
<td>894,400 cfs (3,240 m³/s)</td>
</tr>
<tr>
<td></td>
<td>Peak Flow Duration</td>
<td>Flows greater than 22,700 cfs (663 m³/s) should be maintained for 2 weeks or more, and flows exceeding 20,000 cfs (572 m³/s) for 4 weeks or more.</td>
<td>Flows greater than 18,600 cfs (527 m³/s) should be maintained for 2 weeks or more.</td>
</tr>
<tr>
<td></td>
<td>Summer-Winter Base Flow</td>
<td>2,400–3,500 cfs (69–102 m³/s)</td>
<td>2,400–2,900 cfs (69–102 m³/s)</td>
</tr>
<tr>
<td></td>
<td>Below Yampa River Confluence</td>
<td>Water Temperature Target</td>
<td>64°F (18°C) cooler than Yampa River during summer base flow period.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum Spring Peak Flow</td>
<td>98,000 cfs (3,240 m³/s)</td>
</tr>
<tr>
<td></td>
<td>Peak Flow Duration</td>
<td>Flows greater than 24,000 cfs (663 m³/s) should be maintained for 2 weeks or more, and flows exceeding 22,000 cfs (623 m³/s) for 4 weeks or more.</td>
<td>Flows greater than 22,000 cfs (623 m³/s) should be maintained for 2 weeks or more.</td>
</tr>
<tr>
<td></td>
<td>Summer-Winter Base Flow</td>
<td>3,200–4,700 cfs (92–133 m³/s)</td>
<td>2,700–4,700 cfs (76–133 m³/s)</td>
</tr>
</tbody>
</table>

---

1. Recommended values are based on the best available information and may be adjusted in the future as new data become available.

---

**Flaming Gorge Final Environmental Impact Statement**

**Table 2-1:**—Recommended Magnitudes and Duration of Maximum Spring Peak and Summer-to-Winter Base Flows and Temperatures for Endangered Fishes in the Green River Downstream from Flaming Gorge Dam as Identified in the 2000 Flow and Temperature Recommendations.