Appendix A

CRSS Model Documentation

This appendix describes the reservoir operating rules and related data used in the Reclamation’s Colorado River Simulation System (CRSS), as implemented in the RiverWare™ modeling system.

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A.1 Background

Long-term policy and planning studies on the Colorado River have typically used computer modeling results from CRSS. Developed in the 1980’s as a Fortran-based modeling system, CRSS originally ran on a Cyber mainframe computer. CRSS modeled twelve major reservoirs and approximately 115 diversion points throughout the Upper and Lower Basins on a monthly time step. A major drawback of the Fortran-based CRSS was that the operating policies or rules were “hardwired” into the modeling code, making modification of those policies difficult.

Based on the need to initiate surplus and shortage studies for the Lower Basin in the early 1990s, Reclamation developed an annual time step model, CRSSez, implemented in Visual Basic (Bureau of Reclamation 1998). CRSSez primarily modeled the operation of Lake Powell and Lake Mead, representing the reservoirs above Lake Powell as one aggregate reservoir, and the effect of reservoirs below Lake Mead as part of the water demand necessary from Lake Mead. CRSSez was used in the Interim Surplus Criteria EIS process to facilitate the development of possible alternatives to be analyzed.

In 1994, Reclamation began a collaborative research and development program with the University of Colorado and the Tennessee Valley Authority with the goal of developing a general-purpose modeling tool that could be used for both operations and planning on any river basin. This modeling tool, known as RiverWare™, is now being used by the Upper and Lower Colorado Regions for both planning and operations (Fulp 1999). A major advantage of RiverWare™ is that the operational policies or rules are no longer "hardwired" into the modeling code (Zagona et al. 2001). The user expresses and prioritizes the rules through the RiverWare™ graphical user interface, and RiverWare™ then interprets the rules when the model is run. Multiple rule sets can be run with the same model and this provides the capability for efficient "what-if" analysis with respect to different policies.

Reclamation replaced the original CRSS model with a new model implemented in RiverWare™ in 1996. The new model has the same spatial and temporal resolution, uses the same basic input data (hydrology and consumptive use schedules), and uses the same physical process algorithms as the original CRSS. A rule set was also developed to mimic the policies contained in the original model. Comparison runs were made between the original CRSS and the new model and rule set, with typical differences of less than 0.5 percent (Bureau of Reclamation 1996).

Since 1996 enhancements to CRSS have consisted of developing new rule sets to reflect current operational policy as well as investigating and improving, where necessary, the physical process methodologies. A team of Reclamation engineers from the Upper and Lower Colorado Regions has been established for these purposes and continues to assess the need to further enhance CRSS to reflect new operational policies.

In 2005 a policy-screening model, CRSS-Lite was developed to replace CRSSez (Bureau of Reclamation 2005). CRSS-Lite was developed in RiverWare™ and preserves the complexity and accuracy of CRSS with a significantly shorter model execution time, an advantage over CRSSez. CRSS-Lite was used extensively to evaluate and compare a multitude of operational strategies to facilitate the development of the alternatives analyzed in this Draft EIS.

A.2 Description of the Model

In summary, twelve reservoirs are modeled (Fontenelle, Flaming Gorge, Taylor Park, Blue Mesa, Morrow Point, Crystal, Navajo, Starvation, Powell, Mead, Mohave, Havasu). Critical to this Draft EIS was the allocation of shortages, which required breaking out several of the approximately 115 modeled diversions (demands and return flows) throughout the basin that had been aggregated in the original CRSS, specifically within the state of Arizona. The hydrologic "natural" inflows (flows corrected for upstream regulation and consumptive uses and losses) at 29 inflow points throughout the basin were also used from the standard CRSS hydrology data set covering the period 1906–2004.

A.3 Initial Reservoir Conditions

Table A-1 provides the initial conditions for the Upper and Lower Basin reservoirs. Since the simulation begins in January, 2008, these values reflect the end-of-calendar year 2007 elevations, as projected by the August 2006 24-Month Study.

Table A-1
Initial Reservoir Conditions

Reservoir	Elevation (feet msl)	Storage (af)
Fontenelle	6,486.29	203,787
Flaming Gorge	6,029.67	3,336,300
Starvation	5,734.92	255,000
Taylor Park	9,308.32	67,260
Blue Mesa	7,489.99	581,270
Morrow Point	7,153.73	112,000
Crystal	6,753.04	16,970
Navajo	6,080.33	1,629,760
Powell	3,614.80	13,219,550
Mead	1,116.53	13,023,940
Mohave	638.71	1,582,960
Havasu	445.80	539,520

A.4 Reservoirs Above Lake Powell

The reservoirs above Lake Powell are operated to meet monthly storage targets (or "rule curves") and downstream demands. The basic procedure is that given the inflow for the current month, the release will be either the release necessary to meet the target storage or the release necessary to meet demands downstream of the reservoir, whichever is greater. The rule curves are input for each reservoir, but are modified during the run for Flaming Gorge, Blue Mesa, and Navajo to simulate operations based on the imperfect inflow forecasts that are encountered in actual reservoir operations. Furthermore, each reservoir is constrained to operate within user-supplied minimum and maximum releases (mean monthly release in cubic feet per second [cfs]) as specified in Table A-2:

Table A-2
Release Constraints for Reservoirs above Lake Powell

Reservoir	Minimum Release (cfs)	Maximum Release (cfs)
Fontenelle	500	18,700
Flaming Gorge	800	4,900
Starvation	100	5,000
Taylor Park	50	5,000
Blue Mesa	270	5,000
Morrow Point	300	5,000
Crystal	300	4,200
Navajo	300	5,900

For Flaming Gorge, Blue Mesa, and Navajo, the target storage is computed by using an inflow forecast for the spring runoff season (January to July), again to mimic the imperfect forecasts seen in actual operations. The forecast inflow (for the current month through July) is computed as a weighted average of the long-term average natural inflow and the natural inflow assumed for the year being modeled. The weights used are:

Table A-3
Weights for Inflow Forecast for Reservoirs above Lake Powell

Month	Natural Inflow Weight	Average Natural Inflow weight
January	0.3	0.7
February	0.4	0.6
March	0.5	0.5
April	0.7	0.3
May	0.7	0.3
June	0.7	0.3
July	0.6	0.4

The long-term, average natural inflows into each reservoir are (in thousand acre-feet [kaf]):

Table A-4
Average Natural Inflows for Reservoirs above Lake Powell (kaf)

Reservoir	Jan	Feb	Mar	Apr	May	Jun	Jul
Flaming Gorge	23.3	20.9	33.8	87.9	250.4	327.8	157.5
Blue Mesa	34.0	39.5	94.6	176.0	339.8	561.6	346.8
Navajo	18.8	24.6	69.3	176.9	297.3	284.7	120.1

Based on the inflow forecast, the rule computes the volume necessary to release from the current month through July, assuming the reservoir will fill in July:

Release needed for the current month = (current contents - live capacity + predicted remaining inflow) divided by the number of months remaining until the end of July

The target storage for the current month is then computed, adjusting for any gains or losses above the reservoir:

Target storage = previous storage - release needed + gains – losses

A.5 Lake Powell Operation

The operation of Lake Powell depends on a rule curve consisting of a forecast-driven, spring runoff operation (January through July) that attempts to fill the reservoir to a July target storage and a fall operation (August through December) that attempts to draw down the reservoir to a December target storage. The July and December targets are 23.822 million acre-feet (maf) (500,000 af of space) and 21.900 maf (2.422 kaf of space), respectively. Another rule simulates the occurrence of Beach Habitat Building Flows (BHBFs or “spike” flows). Two other higher priority rules ensure that the minimum objective release of 8.23 million acre-feet per year (mafy) is met and that equalization of Lake Powell and Lake Mead is accomplished when necessary. Release constraints that reflect the 1996 Record of Decision on the Operation of Glen Canyon Dam are also part of the Lake Powell rule set.

Sections A.5.1 through A.5.6 that follow describe modeling assumptions for Lake Powell operation that are common to all five alternatives. A summary comparison of the Lake Powell operational strategy for each alternative is provided in Table A-21, located in Section A.10.

A.5.1 Lake Powell Inflow Forecast

The unregulated Lake Powell inflow forecast from the current month through July is computed as:

> Unregulated Lake Powell inflow = natural flow into Lake Powell - estimated Upper Basin depletions + the forecast error
>
> where; the forecast error is computed using equations derived from an analysis of past Colorado River forecasts and runoff data for the period 1947 to 1983.

As detailed in the original CRSS overview document (Bureau of Reclamation 1985), analysis of these data reveals two strongly established patterns: (1) high runoff years are under-forecast, and low runoff years are over-forecast; (2) the error in the current month's seasonal forecast is strongly correlated with the error in the preceding month's forecast. A regression model was developed to aid in determining the error to be incorporated into the seasonal forecast for each month from January to June. The error is the sum of a deterministic and a random component. The deterministic component is computed from the regression equation. The random component is computed by multiplying the standard error of the regression equation by a random mean deviation selected from a standard normal distribution.

The forecast error equation has the following form (all runoff units are maf):

$$E_i = a_i X_i + b_i E_{(i-1)} + c_i + Z_r d_i$$

where:

i = month,

E_i = error in the forecast for month "i,"

X_i = natural runoff into Lake Powell from month "i" through July,

a_i = linear regression coefficient for Xi,

$E_{(i-1)}$ = previous month's forecast error,

b_i = linear regression coefficient for E(i-1),

c_i = constant term in regression equation for month "i,"

Z_r = randomly determined deviation, and

d_i = standard error of estimate for regression equation for month "i."

Table A-5 summarizes the regression equation coefficients for each month:

Table A-5
Lake Powell Inflow Forecast Regression Coefficients

Month	a_i	b_i	c_i	d_i
January	0.70	0.00	-8.195	1.270
February	0.00	0.80	-0.278	0.977
March	0.00	0.90	0.237	0.794
April	0.00	0.76	0.027	0.631
May	0.00	0.85	0.132	0.377
June	0.24	0.79	0.150	0.460

The magnitude of the June forecast error is constrained to not exceed 50 percent of the May forecast error and the July forecast error is equal to 25 percent of the June forecast error.

A.5.2 Spring Runoff Operation (January to July)

To accomplish the spring operation, the unregulated forecast is first adjusted to account for potential reservoir regulation above Lake Powell. This potential regulation is currently computed as just the sum of the available space (live capacity – previous month's storage) in Fontenelle, Flaming Gorge, Blue Mesa, and Navajo. Using the regulated forecast inflow, the total volume of water necessary to release from the current month through July is computed as:

total volume to release = previous storage – July target storage + forecast regulated inflow – loss due to evaporation – loss due to bank storage

The release for the current month is then computed by multiplying the total volume to release by a fraction for the current month, where the fraction reflects a user-supplied preferred weighting pattern. The weights and resulting fractions used for this study are as follows:

Table A-6
Lake Powell Spring Runoff Operation Weights

Spring Season	Weights	Fractions
January	0.170	0.170
February	0.160	0.193
March	0.130	0.194
April	0.100	0.185
May	0.100	0.227
June	0.160	0.471
July	0.180	1.000

The fraction is computed as current month's weight divided by the sum of the current and remaining month's weights for the season.

During the spring operation, however, the computed release is constrained to be at least as great as the total volume divided by the number of months remaining. This constraint ensures that sufficient water is released early in the season during high forecast years. Lake Powell's spring operational release is further constrained in each month to be within a minimum and maximum range (currently set to 6,500 and 25,000 cfs, respectively).

An additional constraint is placed on computed monthly release during spill avoidance. If the calculated average flow for a given month is in excess of 1.0 maf, then it is held to a maximum of 1.0 maf each month.

A.5.3 Fall Operation (August to December)

Conceptually, the computation for the fall operation is identical to that done for the spring operation. The regulated inflow forecast is simply the natural inflow, adjusted for Upper Basin depletions, and potential reservoir regulation with no forecast error added. The potential reservoir regulation is again computed as the sum of the available space in Fontenelle, Flaming Gorge, Blue Mesa, and Navajo, where the space is the target storage in December for each reservoir minus the previous month's storage. User-supplied weights are also used to compute the current month release from the total volume to release in the fall. The weights and resulting fractions are as follows:

Table A-7
Lake Powell Fall Operation Weights

Fall Season	Weights	Fractions
August	0.266	0.266
September	0.200	0.272
October	0.156	0.292
November	0.156	0.413
December	0.222	1.000

Two additional constraints are placed on the computed monthly release to ensure a smooth operation. In July, the release is constrained to be at least 1.0 maf if Lake Powell's storage is greater than 23.0 maf. From July through December, the release is constrained to not exceed 1.5 maf, as long as a 1.5 maf release results in a storage at Lake Powell less than 23.822 maf. Lake Powell's fall operational release is further constrained in each month to be within a minimum and maximum range (currently set to 6,500 and 25,000 cfs, respectively).

A.5.4 602(a) Storage Requirement

As stated in the CRSS overview document (Bureau of Reclamation 1985), "602(a) storage refers to the quantity of water required to be in storage in the Upper Basin so as to assure future deliveries to the Lower Basin without impairing annual consumptive uses in the Upper Basin." The current implementation of that storage requirement duplicates the original CRSS calculation. It computes the storage necessary in the Upper Basin to meet the minimum objective release and Upper Basin depletions over the next "n" years, assuming the inflow over that period would follow that seen in the most "critical period on record." The critical period in the Colorado River basin occurred in 1953–1964, a length of 12 years. Inflows from these years are used in the calculation of 602(a) storage.

At the beginning of each calendar year, a value for 602(a) storage is computed by the following formula:

$$602a = \{(UBDepletion + UBEvap) * (1 - percentShort/100) + minObjRel - criticalPeriodInflow\} * 12 + minPowerPoolStorage$$

where:

602a = the 602(a) storage requirement

UBDepletion = the average over the next 12 years of the Upper Basin scheduled depletions

UBEvap = the average annual evaporation loss in the Upper Basin (currently set to 560 kaf)

percentShort = the percent shortage that will be applied to Upper Basin depletions during the critical period (currently set to zero)

minObjRel = the minimum objective release to the Lower Basin (currently set to 8.23 maf)

criticalPeriodInflow = average annual natural inflow into the Upper Basin during the critical period (1953–1964) (currently set to 12.18 maf)

minPowerPoolStorage= the amount of minimum power pool to be preserved in Upper Basin reservoirs (currently set to 5.179 maf)

All parameter values currently used were as found in the original CRSS data files ported from the Cyber mainframe in 1994.

Additionally, since 2004, the Interim 602(a) Storage Guideline has been included in CRSS. This guideline necessitates that for the 602(a) storage requirement to be met, Lake Powell storage must be greater than 14.85 maf (elevation 3,630 feet msl) on September 30. This guideline is in effect through the year 2016. In CRSS simulation, following the 602(a) storage computation described above, a subsequent rule checks to see if Lake Powell is above 3,630 feet msl on September 30. The 602(a) requirement is not met if projected September 30 elevation of Lake Powell is below 3,630 feet msl, through the year 2016.

A.5.5 Predicting End-of-Water Year Volumes of Lake Powell and Lake Mead

Lake Powell end-of-water year (EOWY) volume is predicted each month by taking the previous month's storage, adding the estimated inflow, subtracting the estimated release, and subtracting the estimate of evaporation and change in bank storage. All estimated values are for the period from the current month through September. The estimated inflow is just the regulated inflow forecast previously discussed, where the forecast error is included through July. The estimated release is based on the spring operation (through July) and the fall operation for August and September. The estimated evaporation and bank storage losses are based on an initial estimate of the EOWY volume.

Similarly, the Lake Mead EOWY volume is predicted each month by taking the previous month's volume, adding the estimated Lake Powell release, subtracting the estimated Lake Mead release, adding the average gain between Lake Powell and Lake Mead, subtracting the Southern Nevada depletion, and subtracting the estimate of evaporation and change in bank storage. Again, all values are for the period from the current month through September. Lake Mead's release is estimated as the sum of the depletions downstream of Lake Mead and the reservoir regulation requirements (including evaporation losses) for Lakes Mohave and Havasu minus the gains below Lake Mead.

A.5.6 Beach/Habitat Building Flows

Under the current rule that implements Beach/Habitat Building Flows (BHBF), a BHBF is triggered for the current month if the following conditions are met:

- In January, if the unregulated inflow forecast for January through July (the natural flow – Upper Basin depletions plus forecast error) is greater than the "January trigger volume" (currently set to 13.0 maf).
- In January through July, if the current month's Lake Powell release is greater than the "release trigger" (currently set to 1.5 maf) or if the release volume for the current month through July equally distributed over those months would result in a release greater than the "release trigger."

Once a BHBF has been triggered, if Lake Powell would have had to spill in that month anyway, the total outflow from Lake Powell is not increased; rather the volume for the BHBF (currently set to 200 kaf) is taken from the total outflow already determined by the operational rule. If Lake Powell was not going to spill in that month, then the total outflow from Lake Powell is increased (i.e., the volume for the BHBF is taken from Lake Powell's storage). Under the case where the BHBF is triggered even though the current month's release is less than the "release trigger", the rule re-sets Lake Powell's outflow for that month to the trigger release amount (1.5 maf).

Under all circumstances, only one BHBF is made per calendar year.

A.5.7 Minimum Objective Release

Only under the No Action Alternative is a minimum objective release required from Lake Powell. The minimum release required under the action alternatives varies by alternative and Lake Powell volume. These releases are described in Section A.5.9.

A.5.7.1 No Action Alternative

Under the No Action Alternative, a higher priority rule ensures that the previously described Lake Powell operation will satisfy a minimum objective release to the Lower Basin, currently equal to 8.23 maf over each water year (October through September). Similar to the weighting and release fraction scheme used for the operational rule, a preferred release pattern for each month to meet the minimum objective release is supplied and a fraction is computed. The release pattern (in kaf) and resulting fractions are as follows:

Table A-8
No Action Alternative Lake Powell Release Pattern

Month	8,230 kaf	
	Release (kaf)	Fraction
October	600	0.073
November	600	0.079
December	800	0.114
January	800	0.128
February	600	0.110
March	600	0.124
April	600	0.142
May	600	0.165
June	650	0.215
July	850	0.357
August	900	0.588
September	630	1.000
Total	8,230	-----

The fraction is computed as current month's release divided by the sum of the current and remaining months' releases through September.

Each month the rule computes the volume of water remaining to meet the minimum objective release for the current water year (accounting for the water released previously in the water year) and multiplies that volume by the release fraction. The release determined by the operational rule must then be at least as great as this resulting minimum objective release for the month.

A.5.8 Equalization of Lake Powell and Lake Mead

A.5.8.1 No Action Alternative

Under the No Action Alternative, the equalization of storage between Lake Powell and Lake Mead is implemented in a rule that first determines if equalization needs to occur, and if so, determines how much water to release from Lake Powell to accomplish it. The rule is in effect from January through September of each year. The rule states that equalization needs to occur if two criteria are met: (1) if the storage in the Upper Basin meets the 602(a) storage requirement, and (2), if the projected EOWY storage in Lake Powell is greater than that in Lake Mead.

The storage in the Upper Basin is computed for each month (January–September) and consists of the predicted EOWY storage in Lake Powell, plus the sum of the previous month's storage for Flaming Gorge, Blue Mesa, and Navajo. That storage is then compared to the computed value of 602(a) storage, described above, to determine if the 602(a) storage requirement is met each month. The method of estimating the EOWY storage is described above.

The release for equalization is computed by taking half of the difference between the predicted EOWY volumes of Lake Powell and Lake Mead and dividing by the number of months remaining through September. Evaporation and bank storage losses at Lake Powell and Lake Mead are included in the calculation, resulting in an iterative procedure to arrive at the computed equalization release. The iteration stops when the forecast EOWY volumes of Lake Powell and Lake Mead are within a user-specified tolerance. That tolerance is currently set to 25,000 af.

The computed equalization release for each month is constrained in three ways: (1) if the additional release due to equalization would cause the total Upper Basin storage to drop below the 602(a) storage requirement, then the amount of the equalization release is reduced to prevent this from happening; (2) the equalization release is reduced if it would cause Lake Mead volumes to exceed its exclusive flood control space; and (3) the equalization release is constrained to be not greater than 25,000 cfs, the maximum normal release as per the Glen Canyon Operating Criteria.

A.5.8.2 Basin States Alternative

Under the Basin States Alternative, the equalization of storage between Lake Powell and Lake Mead is implemented in a rule that first determines if equalization needs to occur, and if so, then determines how much water to release from Lake Powell to accomplish it. The rule is in effect from January through September of each year. The rule states that equalization needs to occur if two criteria are met: (1) if the EOWY elevation of Lake Powell is predicted to be equal to or higher than the Equalization Level (see Table A-9); and (2) if the EOWY storage in Lake Powell is greater than EOWY storage in Lake Mead. The Basin States Alternative substitutes the 602(a) Storage and Interim 602(a) Storage Guideline with the Equalization Level for each year 2008 through 2026.

Table A-9
Basin States Alternative Lake Powell Equalization Elevation

Year	Equalization Level (feet msl)
2008	3636
2009	3639
2010	3642
2011	3643
2012	3645
2013	3646
2014	3648
2015	3649
2016	3651
2017	3652
2018	3654
2019	3655
2020	3657
2021	3659
2022	3660
2023	3662
2024	3663
2025	3664
2026	3666

In years when Lake Powell EOWY elevation is projected to be equal to or above the Equalization Level and the EOWY volume of Lake Powell is projected to be above the EOWY volume of Lake Mead, a volume of water greater than 8.23 maf is scheduled for annual release from Lake Powell to the extent necessary to equalize storage in the two reservoirs. Otherwise, if Lake Powell EOWY volume is not higher than Lake Mead EOWY volume, the annual release volume from Lake Powell is scheduled at 8.23 maf.

The release for equalization is computed by taking half of the difference between the predicted EOWY volumes of Lake Powell and Lake Mead and dividing by the number of months remaining through September. Evaporation and bank storage losses at Lake Powell and Lake Mead are included in the calculation, resulting in an iterative procedure to arrive at the computed equalization release. The iteration stops when the forecast EOWY volumes of Lake Powell and Lake Mead are within a user-specified tolerance. That tolerance is currently set to 25,000 af.

The computed equalization release for each month is constrained in four ways: (1) if the additional release due to equalization would cause the total Upper Basin storage to drop below the Equalization Line, then the amount of the equalization release is reduced to prevent this from happening; (2) the equalization release is reduced if it would cause

Lake Mead volumes to exceed its exclusive flood control space; (3) the equalization release is constrained to be not greater than 25,000 cfs, the maximum normal release as per the Glen Canyon Operating Criteria.

A.5.8.3 Conservation Before Shortage Alternative

The equalization method for Lake Powell with the Conservation Before Shortage Alternative are identical to those of the Basin States Alternative.

A.5.8.4 Water Supply Alternative

The equalization criteria for Lake Powell with the Water Supply Alternative are identical to those of the No Action Alternative.

A.5.8.5 Reservoir Storage Alternative

The equalization criteria for Lake Powell with the Reservoir Storage Alternative are identical to those of the No Action Alternative.

A.5.9 Water Year Releases When Equalization Does Not Apply

A.5.9.1 No Action Alternative

Under the No Action Alternative Lake Powell water releases are constrained by the minimum objective release as described in Section A.5.7.

A.5.9.2 Basin States Alternative

Under the Basin States Alternative, when the EOWY level of Lake Powell is below the equalization level (see Table A-9), a higher priority rule ensures that the Lake Powell operation will satisfy a water year release to the Lower Basin, between 7.00 maf and 9.50 maf, depending on elevations in Lake Powell and Lake Mead. Similar to the weighting and release fraction scheme used for the operational rule in the No Action Alternative, a preferred release pattern for each month to meet the water year release is supplied and a fraction is computed. The fraction is computed as current month’s release divided by the sum of the current and remaining months’ releases through September. Each month the rule computes the volume of water remaining to meet the release for the current water year (accounting for the water released previously in the water year) and multiplies that volume by the release fraction. The release determined by the operational rule must then be at least as great as this resulting release for the month.

Specific release patterns (in kaf) and resulting fractions for the Basin States Alternative are as follows:

Table A-10
Basin States Alternative Lake Powell Release Patterns

Month	7,000 kaf		7,480 kaf		8,230 kaf		9,000 kaf		9,500 kaf	
	Release (kaf)	Fraction	Release (kaf)	Fraction	Release (kaf)	Fraction	Release (kaf)	Fraction	Release (kaf)	Fraction
October	400	0.057	480	0.064	600	0.073	600	0.067	600	0.063
November	480	0.073	500	0.071	600	0.079	600	0.071	600	0.067
December	700	0.114	600	0.092	700	0.100	800	0.103	800	0.096
January	620	0.114	800	0.136	800	0.126	800	0.114	850	0.113
February	600	0.125	600	0.118	700	0.127	650	0.105	650	0.098
March	500	0.119	600	0.133	600	0.124	650	0.117	650	0.108
April	500	0.135	500	0.128	600	0.142	600	0.122	650	0.121
May	500	0.156	600	0.176	600	0.165	650	0.151	800	0.170
June	600	0.222	600	0.214	700	0.231	800	0.219	900	0.231
July	800	0.381	800	0.364	800	0.343	1000	0.351	1050	0.350
August	800	0.615	800	0.571	900	0.588	1050	0.568	1100	0.564
September	500	1.000	600	1.000	630	1.000	800	1.000	850	1.000
Total	7,000	-----	7,480	-----	8,230	-----	9,000	-----	9,500	-----

In years when Lake Powell EOWY elevation is projected to be lower than the Equalization Level and equal to or above 3,575 feet msl, and the projected Lake Mead EOWY elevation is equal to or above 1,075 feet msl, then the annual release volume is scheduled to be 8.23 maf. If the projected Lake Mead EOWY elevation is below 1,075 feet msl, however, then a volume of water is scheduled for annual release from Lake Powell to the extent necessary to balance storage in the two reservoirs, constrained by being no more than 9.00 maf and no less than 7.00 maf.

In years when Lake Powell EOWY elevation is projected to be lower than 3,575 feet msl and at or above 3,525 feet msl, and the projected Lake Mead EOWY elevation is equal to or above 1,025 feet msl, then the annual release volume is scheduled at 7.48 maf. However, if Lake Powell EOWY elevation is projected to be lower than 3,575 feet msl and at or above 3,525 feet msl, but the projected Lake Mead EOWY elevation is below 1,025 feet msl, then the annual release volume is scheduled at 8.23 maf.

In years when Lake Powell EOWY elevation is projected to be below 3,525 feet msl, then a volume of water is scheduled for annual release from Lake Powell to the extent necessary to balance storage in the two reservoirs, constrained by being no more than 9.50 maf and no less than 7.00 maf.

A.5.9.3 Conservation Before Shortage Alternative

Water year releases for Lake Powell with the Conservation Before Shortage Alternative are identical to those of the Basin States Alternative.

A.5.9.4 Water Supply Alternative

Under the Water Supply Alternative, when projected EOWY storage in the Upper Basin is less than the 602(a) storage requirement, a higher priority rule ensures that the Lake Powell operation will satisfy a water year release to the Lower Basin between 7.00 maf and 9.50 maf, depending on projected EOWY elevations in Lake Powell and Lake Mead. Similar to the weighting and release fraction scheme used for the operational rule, a preferred release pattern for each month to meet the water release is supplied and a fraction is computed. The fraction is computed as current month's release divided by the sum of the current and remaining months' releases through September. Each month the rule computes the volume of water remaining to meet the release for the current water year (accounting for the water released previously in the water year) and multiplies that volume by the release fraction. The release determined by the operational rule must then be at least as great as this resulting release for the month.

Specific release patterns (in kaf) and resulting fractions for the Water Supply Alternative are as follows:

Table A-11
Water Supply Alternative Lake Powell Release Patterns

Month	7,000 kaf		8,230 kaf		9,500 kaf	
	Release (kaf)	Fraction	Release (kaf)	Fraction	Release (kaf)	Fraction
October	400	0.057	600	0.073	600	0.063
November	480	0.073	600	0.079	600	0.067
December	700	0.114	700	0.100	800	0.096
January	620	0.114	800	0.126	850	0.113
February	600	0.125	700	0.127	650	0.098
March	500	0.119	600	0.124	650	0.108
April	500	0.135	600	0.142	650	0.121
May	500	0.156	600	0.165	800	0.170
June	600	0.222	700	0.231	900	0.231
July	800	0.381	800	0.343	1050	0.350
August	800	0.615	900	0.588	1100	0.564
September	500	1.000	630	1.000	850	1.000
Total	7,000	-----	8,230	-----	9,500	-----

In years when the Lake Powell EOWY volume is projected to be below the 602(a) storage requirement and equal to or above 3,575 feet msl, and the projected Lake Mead EOWY elevation is equal to or above 1,075 feet msl, then the annual release volume is scheduled to be 8.23 maf. If the projected Lake Mead EOWY elevation is below 1,075 feet msl, however, then a volume of water is scheduled for annual release from Lake Powell to the extent necessary to balance storage in the two reservoirs, constrained by being no more than 9.50 maf and no less than 7.00 maf.

In years when the Lake Powell EOWY elevation is projected to be less than 3,575 feet msl, then a volume of water is scheduled for annual release from Lake Powell to the extent necessary to balance storage in the two reservoirs, constrained by being no more than 9.50 maf and no less than 7.00 maf.

A.5.9.5 Reservoir Storage Alternative

Under the Reservoir Storage Alternative, when projected EOWY storage in the Upper Basin is less than the 602(a) storage requirement, a higher priority rule ensures that the Lake Powell operation will satisfy a water year release to the Lower Basin between 7.80 maf and 9.50 maf, depending on projected EOWY elevations in Lake Powell and Lake Mead. Similar to the weighting and release fraction scheme used for the operational rule, a preferred release pattern for each month to meet the water year release is supplied and a fraction is computed. The fraction is computed as current month's release divided by the sum of the current and remaining months' releases through September. Each month the rule computes the volume of water remaining to meet the release for the current water year (accounting for the water released previously in the water year) and multiplies that volume by the release fraction. The release determined by the operational rule must then be at least as great as this resulting release for the month.

Specific release patterns (in kaf) and resulting fractions for the Reservoir Storage Alternative are as follows:

Table A-12
Reservoir Storage Alternative Lake Powell Release Patterns

Month	7,800 kaf		8,230 kaf		9,500 kaf	
	Release (kaf)	Fraction	Release (kaf)	Fraction	Release (kaf)	Fraction
October	600	0.077	600	0.073	600	0.063
November	600	0.083	600	0.079	600	0.067
December	600	0.091	700	0.100	800	0.096
January	800	0.133	800	0.126	850	0.113
February	600	0.115	700	0.127	650	0.098
March	600	0.130	600	0.124	650	0.108
April	600	0.150	600	0.142	650	0.121
May	600	0.176	600	0.165	800	0.170
June	600	0.214	700	0.231	900	0.231
July	800	0.364	800	0.343	1050	0.350
August	800	0.571	900	0.588	1100	0.564
September	600	1.000	630	1.000	850	1.000
Total	7,800	-----	8,230	-----	9,500	-----

In years when Lake Powell EOWY volume is projected to be below the 602(a) storage requirement, and Lake Powell EOWY elevation is equal to or above 3,595 feet msl, then the annual release volume is scheduled at 8.23 maf.

In years when the Lake Powell EOWY elevation is projected to be lower than 3,595 feet msl and equal to or above 3,560 feet msl, then the annual release volume is scheduled at 7.80 maf.

In years when Lake Powell EOWY elevation is projected to be below 3,560 feet msl, the annual release is scheduled at the volume of water required to balance the volumes of Lake Powell and Lake Mead, constrained by being no more than 9.50 maf and no less than 7.80 maf.

A.6 Lake Mead Operation

Lake Mead is operated primarily to meet downstream demand, including downstream depletions (both U.S. and Mexico) and reservoir regulation requirements. In any month, the rule computes the downstream depletions based on schedules that have been set as input data (or by other rules) and the amount of water necessary to meet the storage targets for Lake Mohave and Lake Havasu and to overcome evaporation losses at those lakes. The rule sets the total release necessary each month from Lake Mead to meet the total downstream demand, taking into account gains and losses below Lake Mead.

The depletions from Lake Mead and downstream of Hoover Dam are affected by the determination of the water supply conditions (Normal, Surplus or Shortage). Additional rules determine the water supply condition and set the appropriate depletion schedule for the entities affected, as described in Sections A.6.2 and A.6.3.

Under certain conditions, Lake Mead may release water in addition to downstream demand. This condition is termed “flood control” and is guided by the U.S. Army Corps of Engineers’ [USACE]) flood control regulations as contained in the USACE’s Water Control Manual for Flood Control, Hoover Dam and Lake Mead, Colorado River, Nevada and Arizona (Water Control Manual) dated December 1982. These flood control operations and their simulation in the CRSS model are described in Section A.6.1.

A.6.1 Lake Mead/Hoover Dam Flood Control

There are three flood control procedures currently in effect for different times of the year. These procedures were developed in the original CRSS and were based on the Field Working Agreement between Reclamation and the Corps (U.S. Army Corps of Engineers 1982). The first procedure is in effect throughout the year. Its objective is to maintain a minimum space of 1.5 maf in Lake Mead, primarily for extreme rain events. This space is referred to as the exclusive flood control space and is represented by the space above elevation 1,219.61 feet msl. The second procedure is used during the spring runoff forecast season (January–July). The objective during this period is to route the maximum forecast inflow through the reservoir system using specific rates of Hoover Dam discharge, assuming that the lake will fill (to elevation 1,219.61 feet msl) at the end of July. The third procedure is used during the space building or drawdown period (August–December). The objective during this period is to gradually draw down the reservoir system to meet the total system space requirements in each month in anticipation of the next year's runoff.

A.6.1.1 Exclusive Flood Control Space Requirement

As previously noted, this requirement states that space in Lake Mead must be a minimum of 1.5 maf at all times. If the release computed to meet downstream demand results in a Lake Mead storage that would violate this space requirement, the rule computes the additional release necessary to maintain that space.

A.6.1.2 Spring Runoff Season (January to July)

The flood control policy requires that the maximum forecast be used where that forecast is defined as the estimated inflow volume that, on average, will not be exceeded 19 times out of 20 (a 95 percent non-exceedance). The rule first computes the inflow forecast to Lake Mead by taking the Lake Powell forecast previously described and adds the long-term, average natural tributary inflows between Lake Powell and Lake Mead. The maximum forecast is then estimated by adding an additional volume (the "forecast error term") to that inflow forecast. The forecast error term (in maf) is given in Table A-13, taken from the original CRSS data:

Table A-13
Lake Mead Spring Runoff Forecast Error

Forecast Period	Forecast Error Term
January – July	4.980
February – July	4.260
March – July	3.600
April – July	2.970
May – July	2.525
June – July	2.130
July – July	0.750

The Field Working Agreement defines an iterative algorithm by which the current month's release (in cfs) is determined. Certain release levels are specified and are given in Table A-14:

Table A-14
Lake Mead Flood Control Release Levels

Release Level	Release	Description
1	19,000	Parker Power Plant capacity
2	28,000	Davis Power Plant capacity
3	35,000	Hoover Power Plant capacity (in 1987)
4	40,000	Approximate maximum flow non-damaging to streambed
5	73,000	Hoover controlled discharge capacity

The flood control release needed for the current month is determined by:

> release needed for the current month = maximum forecast inflow – current storage space in Lake Powell (below 3,700 feet msl) – current storage space in Lake Mead (below 1,229 feet msl) + 1.5 maf (exclusive space) – evaporation and bank storage losses from Lake Powell and Lake Mead – Southern Nevada depletion – future volume of water released (assuming a release level from the table for the remaining months through July)

If the computed release for the current month is greater than that assumed for the future months, the future level is increased and the current month release is re-computed. The computation stops once the computed release for the current month is less than or equal to that assumed for the future months. If the computed release is greater than the previously assumed level, that release is used for the current month; otherwise, the previously assumed level is used.

The rule sets Lake Mead's release to the flood control release if it is greater than the release previously computed to meet downstream demands.

A.6.1.3 Space Building (August to December)

The flood control policy states the flood control storage space (in maf) in Lake Mead (storage below elevation 1,229 feet msl) required at the beginning of each month from August through January:

Table A-15
Lake Mead Flood Control Required Storage Space

Date	Space Required (maf)
August	1.50
September	2.27
October	3.04
November	3.81
December	4.58
January	5.35

However, these targets may be reduced to the minimum of 1.5 maf in each month if additional space is available upstream in active storage. Certain upstream reservoirs are specified with a maximum creditable space (in maf) for each:

Table A-16
Lake Mead Flood Control Creditable Storage Space

Reservoir	Maximum Creditable Storage Space (maf)
Powell	3.8500
Navajo	1.0359
Blue Mesa	0.7485
Flaming Gorge plus Fontenelle	1.5072

In each month (July–December), if the release computed to meet downstream demands results in an end-of-month Lake Mead storage that would violate the space requirement adjusted for upstream storage, the rule computes the additional release necessary to maintain that space. However, these releases are constrained to be less than or equal to 28,000 cfs.

A.6.2 Lower Basin Surplus Strategies

Under the No Action Alternative the Interim Surplus Guidelines (ISG) are assumed to be in effect through calendar year 2016. Beginning in 2017, surpluses are determined based on the 70R Strategy. The action alternatives use some or all of the Surplus conditions and vary by the duration that each type is in effect. A summary comparison of the surplus strategy for each alternative is provided in Table A-22, located in Section A.10. Surplus schedules by entity are provided in Appendix D. The ISG are specified in the Record of Decision (ROD), Colorado River ISG, Final Environmental Impact Statement, January 2001, and the model implements those as follows:

A.6.2.1 Normal Conditions

If the modeled January 1 Lake Mead elevation is below 1,125 feet msl, the model assigns the Normal schedules to all diversion points in the Lower Basin. The Normal schedules total 7.5 maf of annual consumptive use in the Lower Basin.

A.6.2.2 Partial Domestic Surplus

If the modeled January 1 Lake Mead elevation is at or above 1,125 feet msl and below 1,145 feet msl, the model assigns the Partial Domestic Surplus schedules to MWD and the SNWA. All other diversion points remain at Normal schedules. The Partial Domestic Surplus schedules yield the amount of surplus for MWD and SNWA as specified in the ROD, and are documented in the Final Environmental Impact Statement, Implementation Agreement, Inadvertent Overrun and Payback Policy, and Other Federal Actions (SIA-EIS, Bureau of Reclamation 2002).

A.6.2.3 Full Domestic Surplus

If the modeled January 1 Lake Mead elevation is at or above 1,145 feet msl but below the spill avoidance strategy assuming the runoff value of the 70th percentile of exceedance based on the historic record of runoff above Lake Powell (i.e., the 70R Strategy), the model assigns the Full Domestic Surplus schedules to MWD and SNWA. All other diversion points remain at Normal schedules. The Full Domestic Surplus schedules yield the amount of surplus for MWD and SNWA as specified in the ROD, and are documented in the SIA-EIS (Bureau of Reclamation 2002).

A.6.2.4 Quantified Surplus (70R Strategy)

If the modeled January 1 Lake Mead storage provides insufficient space for the coming year (based on the 70R Strategy), and is below the flood control release criteria listed below, the Secretary would determine annually the quantity of surplus water available. The quantity is determined by assuming the 70th percentile historical runoff, along with normal 7.5 maf delivery to Lower Division states, for the next year. Applying these values to current reservoir storage, the projected reservoir storage at the end of the next year is calculated. The surplus is determined if the estimated space available at the end of the next year is less than the space needed by flood control criteria. The quantity of the surplus is the difference between the space required and the estimated available space. Once the quantity of surplus water is known, the model computes each state’s share (50 percent to California, 46 percent to Arizona, and 4 percent to Nevada). The model then assigns the Full Domestic Surplus schedules to MWD and SNWA. Arizona’s share of the surplus is assigned to the CAP, up to their Full Surplus schedule. If surplus water is still available for California, up to 300 kaf is made available to the Imperial Irrigation District (IID) and the Coachella Valley Water District (CVWD).

A.6.2.5 Flood Control Surplus

If the modeled January 1 system volumes projects Hoover Dam flood control releases based on the Field Working Agreement between Reclamation and the Corps (U.S. Army Corps of Engineers 1982), the model assigns the Full Surplus schedules to MWD, SNWA, CAP, IID, and CVWD. All other diversion points remain at Normal schedules. The Full Surplus schedules are documented in the SIA-EIS (Bureau of Reclamation 2002).

A.6.3 Lower Basin Shortage Strategies

A summary comparison of the shortage strategy for each alternative is provided in Table A-22, located in Section A.10.

A.6.3.1 No Action Alternative

In the absence of specific shortage guidelines, modeling assumptions were made that follow assumptions for previous environmental compliance documents. Based on these assumptions a “two-level” shortage protection strategy was employed. These levels established the elevations in Lake Mead to protect and the protection strategy (probabilistic or absolute). Within the two protection levels are two methods or stages for allocating the required shortage amount as explained below. See Section 4.2 for a description of the methodology regarding the shortage sharing assumptions under the two stages of shortage.

In Level 1 protection, the shortage determination is based on comparing the January 1 Lake Mead elevation to a user-input trigger elevation, where the trigger elevations are determined from other modeling studies to protect a significant elevation within a given degree of confidence. The trigger elevations are presented in Table A-17.

Table A-17
Level 1 Shortage Trigger Elevations

Year	Elevations (feet msl)	Year	Elevations (feet msl)	Year	Elevations (feet msl)
2008	1,079	2026	1,101	2043	1,127
2009	1,082	2027	1,103	2044	1,129
2010	1,083	2028	1,104	2045	1,132
2011	1,084	2029	1,106	2046	1,133
2012	1,085	2030	1,107	2047	1,135
2013	1,086	2031	1,108	2048	1,137
2014	1,086	2031	1,108	2049	1,138
2015	1,087	2032	1,109	2050	1,140
2016	1,088	2033	1,110	2051	1,142
2017	1,090	2034	1,112	2052	1,144
2018	1,091	2035	1,113	2053	1,145
2019	1,093	2036	1,114	2054	1,147
2020	1,094	2037	1,116	2055	1,149
2021	1,095	2038	1,117	2056	1,151
2022	1,096	2039	1,119	2057	1,152
2023	1,097	2040	1,120	2058	1,154
2024	1,098	2041	1,123	2059	1,156
2025	1,100	2042	1,125	2060	1,157

Under Level 1 protection, if Lake Mead’s elevation at the beginning of the year is less than the trigger elevation, a Stage 1 shortage is declared and certain Lower Basin depletions are reduced. The shortage remains in effect for that calendar year. A Stage 1 shortage is defined as a shortage of magnitude less than that which would cause Arizona 4th priority uses to be reduced to zero.

Level 1 protection of elevation 1,050 feet msl (minimum water level for operation of Southern Nevada’s upper diversion intake and minimum power pool) was used in this study. Trigger elevations were input to protect each elevation with an approximately 80 percent probability; however, actual model runs showed that the protection was less (approximately 70% over the entire simulation period). Under Level 1 protection a Stage 1 shortage is declared and the Central Arizona Project (CAP) depletion is set to 1.0 maf and other Arizona 4th priority uses are reduced proportionately, as described in the equations below.

$$CAP_{short} = CAP_{norm} - 1.0maf$$

$$OtherAZP4_{short} = (CAP_{short} * \frac{CAP_{norm} + OtherAZP4_{norm}}{CAP_{norm}}) - CAP_{short}$$

Where: the subscript norm denotes the normal depletion amount and the subscript short denotes the shortage amount. The shortage amount is subtracted from the normal depletion amount to solve for the shorted depletion amount.

The percent shortage applied to each Arizona 4th priority in OtherAZP4 is computed as a fraction of their normal use divided by the total other Arizona 4th priority use.

Other Lower Basin depletions are reduced according to the percents presented in Table A-18.

Table A-18
Modeling Assumptions for Distribution of Stage 1 Shortages[a]

Entity	Percentage of Total Lower Basin Shortage	Calculation
Arizona[b]	80%	▪ Computed assuming that Arizona takes the remaining amount of shortage after Nevada and Mexico take their respective shares ▪ Calculated as: 1.0 – 0.1667 – 0.0333 = 0.80 or 80.0%
California	0%	▪ Does not receive shortage under Stage 1
Nevada	3.33%	▪ Computed as a ratio of Nevada's apportionment to the total apportionments of the Lower Division states and Mexico ▪ Calculated as: 0.3 maf / 9.0 maf – 0.0333 or 3.33%
Mexico [1]	16.67%	▪ Computed as a ratio of Mexico's allotment to the total allotments of the Lower Division states and Mexico ▪ Calculated as: 1.5 maf / 9.0 maf = 0.1667 or 16.67%

a. These modeling assumptions do not reflect policy decisions and are not intended to constitute an interpretation or application of the 1944 Treaty. They have been developed for comparison of the alternatives.

b. Within the CAP, Ak-Chin and Salt River Pima-Maricopa Indian Community tribes have pre-1968 contracts for the delivery of 72 kaf that is not reduced until a Stage 2 Shortage is applied.

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[1] The proposed federal action is for the purpose of adopting additional operational strategies to improve the Department's annual management and operation of key Colorado River reservoirs for an interim period through 2026. However, in order to assess the potential effects of the proposed federal action in this Draft EIS, certain modeling assumptions (discussed in Chapter 2) are used that display projected water deliveries to Mexico. Reclamation's modeling assumptions are not intended to constitute and interpretation or application of the 1944 Treaty or to represent current or future United States policy regarding deliveries to Mexico.

The United States will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Treaty with Mexico through the IBWC in consultation with the Department of State.

The percent shortage applied to each Arizona 4th priority in OtherAZP4 is computed as a fraction of their normal use divided by the total other Arizona 4th priority use. Both Mexico and the Southern Nevada Water Authority (SNWA) are reduced by 16.67 and 3.33 percent of the total Stage 1 shortage, respectively. The Metropolitan Water District of Southern California (MWD) does not take a Stage 1 shortage. The total Stage 1 shortage is computed as,

$$TotalStage1Short = \frac{CAP_{short} + OtherAZP4_{short}}{100\% - (3.33\% + 16.67\%)}$$

Under Level 2 protection, further cuts are imposed to keep Lake Mead above 1,000 feet msl (minimum water level for operation of Southern Nevada's lower diversion intake). In each month January through September, a rule estimates the end-of-April through end-of-September Lake Mead elevation (using Stage 1 shortage schedules and normal schedules for other users). April through September is generally the high demand period from Lake Mead. If in any month during the high demand period the estimated Lake Mead elevation is below 1,000 feet msl, Arizona 4th priority users are reduced to zero and SNWA and Mexico take their respective percents of the total shortage, for the current month. This type of pre-emptive shortage approach is required to avoid the situation when, in a given month, the shortage required to keep Lake Mead above 1,000 feet msl is greater than the available demand. If, in the current month the shortage required to protect 1,000 feet msl does not require Arizona 4th priority users to be reduced to zero, the lesser shortage amount is allocated.

If, in any month additional shortage beyond Stage 1 is required to protect Lake Mead elevation 1,000 feet msl, a Stage 2 shortage is declared. The Stage 2 shortage amount is the amount in excess of the Stage 1 shortage amount required to protect 1,000 feet msl absolutely. In a Stage 2 shortage Mexico and SNWA are further reduced and Arizona 2nd and 3rd priority uses and MWD are reduced. These entities are reduced according to the percents in Table A-19.

Table A-19
Modeling Assumptions for Distribution of Stage 2 Shortages[1]

Entity	Percentage of Total Lower Basin Shortage	Calculation
Arizona	15-20%	▪ The percentage changes as Arizona's 4th priority use schedule changes and ranges between 15 and 20% ▪ Computed as a ratio of Arizona's apportionment less the amount of shortage applied to Arizona under Stage 1, to the total apportionments of the Lower Division states and Mexico less the total amount shorted to users under Stage 1 ▪ Calculated as: (2.8 – AZ Stage 1 shortage) / (9.0 – total Stage 1 shortage)
California	60-65%	▪ California shortage sharing percentage changes as Arizona's 4th priority use schedule changes and ranges between 60 and 65% ▪ Computed assuming that California takes the remaining amount of the additional shortage ▪ Calculated as: 1.0 – 0.1667 – 0.0333 – Arizona's Stage 2 percentage expressed as a fraction

Table A-19
Modeling Assumptions for Distribution of Stage 2 Shortages[1]

Entity	Percentage of Total Lower Basin Shortage	Calculation
Nevada	3.33%	▪ Computed as a ratio of Nevada's apportionment less the amount of shortage applied to Nevada under Stage 1, to the total apportionments of the Lower Division states and Mexico less the amount shorted to users under Stage 1 ▪ Calculated as: (0.3 – NV Stage 1 shortage) / (9.0 – total Stage 1 shortage) = 0.0333 or 3.33%
Mexico	16.67%	▪ Computed as a ratio of Mexico's apportionment less the amount of shortage applied to Mexico under Stage 1, to the total apportionments of the Lower Division states and Mexico less the total amount shorted to users under Stage 1 ▪ Calculated as: (1.5 – Mexico Stage 1 shortage) / (9.0 – total Stage 1 shortage) = 0.1667 or 16.67%

1. These modeling assumptions do not reflect policy decisions and are not intended to constitute an interpretation or application of the 1944 Treaty. They have been developed for comparison of the alternatives.

The maximum amount of Stage 2 shortage that can be applied is dictated by MWD demand. If the amount of Stage 2 required is greater than MWD demand, than the Stage 2 shortage amount becomes,

$$TotalStage2Short_{Constrained} = \frac{MWD_{norm}}{100\% - (3.33\% + 16.67\% + AZP2and3Short\%)}$$

In the event that a Stage 2 shortage is constrained and not fully allocated, Lake Mead will drop below 1,000 feet msl. If Lake Mead goes below 1,000 feet msl, SNWA is reduced to zero (due to physical limitations) for the current month and the other users maintain their shortage amounts as if SNWA had not been completely reduced.

A.6.3.2 Basin States Alternative

The Basin States Alternative provides discrete stepped levels of shortage associated with specific Lake Mead elevations. These shortage amounts and the corresponding elevations are provided in the summary Table A-22, located in Section A.10. The maximum shortage is 600 kaf below elevation 1,025 feet msl. The shortage determination is based on comparing the January 1 Lake Mead elevation to the specific Lake Mead trigger elevations. If Lake Mead's elevation at the beginning of the year is less than the trigger elevation, a shortage of the corresponding amount is declared and certain Lower Basin depletions are reduced. The shortage remains in effect for that calendar year. The shortage is allocated according to the percents used under a Stage 1 shortage in the No Action Alternative provided in Table A-19. As in the No Alternative, SNWA is reduced to zero for the current month if, in the previous month the Lake Mead elevation is below 1,000 feet msl.

A.6.3.3 Conservation Before Shortage Alternative

The shortage strategy under the Conservation Before Shortage Alternative is identical to the Level 2 shortage protection in the No Action Alternative. The Level 1 shortage protection in the No Action Alternative is replaced with various levels of voluntary conservation in the Conservation Before Shortage Alternative. Modeling assumptions regarding the voluntary conservation portion of this alternative are located in Appendix M. The amounts of voluntary conservation and the corresponding elevations are identical to the shortage amounts and corresponding elevations under the Basin States Alternative.

A.6.3.4 Water Supply Alternative

There is no shortage strategy in place in the Water Supply Alternative. The only reduction in use occurs when, in the previous month the Lake Mead elevation is below 1,000 feet msl. In this event SNWA is reduced to zero for the current month.

A.6.3.5 Reservoir Storage Alternative

Like the Basin States Alternative, the Reservoir Storage Alternative provides discrete stepped levels of shortage associated with specific Lake Mead elevations. These shortage amounts and the corresponding elevations are provided in the summary Table A-22, located in Section A.10. The maximum shortage is 1,200 kaf below elevation 1,025 feet msl. Shortage determination and allocation occurs in the same way as the Basin States Alternative.

A.6.4 Lake Mead Storage & Delivery of Conserved System & Non-system Water

Detailed modeling assumptions regarding the Lake Mead storage and delivery mechanism for conserved system and non-system water as part of the Basin States, Conservation Before Shortage and Reservoir Storage alternatives is provided in Appendix M.

A.7 Summary of Lake Powell and Lake Mead Operation

A summary comparison of the Lake Powell and Lake Mead operations for each alternative is provided in Attachment 1-1 (Tables A-21 and A-22, respectively).

A.8 Lakes Mohave and Havasu Operation

Lake Mohave and Lake Havasu are operated to meet user-specified target storages at the end of each month. This operation remained consistent for all alternatives. The storage targets and the corresponding elevations are presented in Tables B-4 and B-5 of Appendix B.

A.9 Energy Generation

RiverWare™ includes a variety of methods that can be chosen to compute power generation. All methods used compute power and energy on a monthly basis. The following sections describe the methods used to compute power at Glen Canyon, Hoover, Davis and Parker Dams.

A.9.1 Glen Canyon Dam

The computation of power and energy generated at Glen Canyon Dam is based on the turbine release for the current month and a power coefficient which is a function of the turbine release and operating head. Turbine release is the lesser value of the maximum power release or the result of outflow minus spill. The power coefficient is computed through table interpolation given the operating head. The table used for interpolation is chosen based on the turbine release and can represent either flow through the turbine for most efficient power generation or the maximum flow through the turbine. The power coefficient may also be an intermediate value, computed through interpolation of both tables, if the turbine release is between the most efficient for power generation and the maximum flow through the turbine.

Once the power coefficient is computed, power generated for the current month is computed as,

$$Power = PowerCoefficient * Turbine\,\mathrm{Re}\,lease$$

Energy is calculated as the power multiplied by the length of the month in hours.

If the previous month’s elevation is less than 3,490 feet msl, there is no power or energy generated for the current month. This elevation reflects the minimum power pool elevation at Lake Powell.

A.9.2 Hoover Dam

The method that computes power and energy generated at the Hoover Dam assumes two levels of power generation. The lower level of generation occurs at base flow while the upper level occurs at peak flow. The method computes the fraction of the month that the powerplant is operated at peak flow and base flow. The peaking flow is the most efficient flow through the turbines for the current operating head while the baseflow represents the minimum flow through the turbines to produce energy.

The base flow and corresponding power generation is based on the outflow for the current month. The peak flow must be computed through an iterative procedure using operating head, tailwater elevation and turbine release. The initial turbine release is assumed to be that corresponding to maximum power production. Tailwater elevation at Hoover Dam is computed as function of the elevation at Lake Mohave and Hoover Dam release.

The monthly release volume at base flow is computed by applying the base flow over the month. The monthly release volume at peak flow is computed as,

$$PeakFlowVolume = Turbine\,\mathrm{Re}\,leaseVolume - BaseFlowVolume$$

Next, the number of hours required for operation at base and peak flows are then computed as,

$$PeakHours = \frac{PeakFlowVolume}{(PeakFlow - BaseFlow) * 3600}$$

$$BaseHours = \frac{SecondsInMonth}{3600} - PeakHours$$

where, 3600 is the amount of seconds per hour. If peak hours is greater than the length of the month, peak hours is set equal to the length of the month and base hours is set to zero. The peak and base hours are then multiplied by the powerplant capacity at each level and added together to obtain the total energy produced for the month. Power is computed as the energy divided by the length of the month in hours.

The algorithm described here allows generation at elevations below 1,050 feet msl, the minimum power pool at Lake Mead. According to the algorithm, power is generated as long as the minimum operating head of 360 feet is available, corresponding to an elevation of about 1,011 feet msl. Because there is no operating experience at these levels, it is impossible to verify if CRSS mimics reality at such low heads. It is therefore critical then to view energy results from CRSS in a relative manner and not a strict numeric sense.

A.9.3 Davis Dam

The method that computes power and energy generation at Davis Dam is the same method used for Hoover Dam.

A.9.4 Parker Dam

The method that computes power and energy generation at Parker Dam is the same method used for Hoover Dam.

A.10 Model Input and Simulation

CRSS is used to simulate the future conditions of the Colorado River system on a monthly time step. Output data include reservoir storage, releases from dams, hydroelectric generation, etc. Input data for the model includes monthly natural flow at 29 nodes throughout the Colorado River system. Input data also includes physical parameters (such as individual reservoir storage capacity, evaporation rates, reservoir release capabilities, etc.), initial reservoir conditions, and the diversion and depletion schedules for entities in the Basin States and Mexico. Operating rules for current or proposed operating policies are considered input.

Although several methods are available for ascertaining the range of possible future inflows, Reclamation utilized the existing historical record of natural flows to create several distinct and synthetic hydrologic sequences that are then used in a series of simulations. For this process, Reclamation used a particular technique for sampling from the historical record known as the Indexed Sequential Method, or ISM (USBR, 1985; Ouarda, et al., 1997). Each future hydrologic sequence is generated from the historical natural flow record by “cycling” through the record. This method produces the “n” possible flow sequences, where n corresponds to the number of years in the flow data set. Using the historical natural flow data from 1906 through 2004 results with ISM results in a set of 99 separate simulations referred to as “traces.” This enables an evaluation of proposed criteria over a broad range of possible future hydrologic conditions. Evaluations typically include all 99 traces using statistical techniques.

A.11 Model Uncertainty

Using ISM, CRSS generates a wide range of hydrologic possibilities which include periods of extreme drought and periods of much above average flow, allowing evaluation of proposed federal actions under a wide range of future flow. It is possible; however, that future flows may include periods of wet or dry conditions that are outside of all the possible sequences seen in the historical record. See Appendix N for an evaluation of alternative hydrologic possibilities.

Model output is also sensitive to input diversion and depletion schedules. The best available data for future diversions and depletions are input to CRSS. Actual future depletion schedules, especially when simulating system conditions far into the future (beyond about 20 years from the present) may differ.

A.12 References

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Attachment 1

Summary Comparison of Lake Powell and Lake Mead Operations Under No Action and Action Alternatives

Table A-20

Comparison of Alternatives – Lake Powell

Lake Powell Elevation (feet msl)	No Action Alternative	Basin States Alternative	Conservation Before Shortage Alternative	Water Supply Alternative	Reservoir Storage Alternative	Lake Powell Storage (maf)
3,700	Equalize or Release 8.23 maf	Equalize or Release 8.23 maf	Equalize or Release 8.23 maf	Equalize or Release 8.23 maf	Equalize or Release 8.23 maf	**24.3**
Equalization	**602(a)**	**Upper Equalization Line**	**Upper Equalization Line**	**602(a)**	**602(a)**	**Equalization**
	Release 8.23 maf	Release 8.23 maf; if Lake Mead < 1,075 feet msl, balance contents with a min/max release of 7.0 and 9.0 maf	Release 8.23 maf; if Lake Mead < 1,075 feet msl, balance contents with a min/max release of 7.0 and 9.0 maf	Release 8.23 maf; if Lake Mead < 1,075 feet msl, balance contents with a min/max release of 7.0 and 9.5 maf	Release 8.23 maf	
3,595					Release 7.8 maf	**11.3**
3,575		Release 7.48 maf; if Lake Mead < 1,025 feet msl, release 8.23 maf	Release 7.48 maf; if Lake Mead < 1,025 feet msl, release 8.23 maf	Balance contents with a min/max release of 7.0 and 9.5 maf		**9.5**
3,560					Balance contents with a min/max release of 7.8 and 9.5 maf	**8.3**
3,525		Balance contents with a min/max release of 7.0 and 9.5 maf	Balance contents with a min/max release of 7.0 and 9.5 maf			**5.9**
3,490						**4.0**
3,370						**0**

Table A-21

Comparison of Alternatives – Lake Mead

Lake Mead Elevation (feet msl)	No Action Alternative	Basin States Alternative	Conservation Before Shortage Alternative	Water Supply Alternative	Reservoir Storage Alternative	Lake Mead Storage (maf)
1,220	Flood Control Surplus	Flood Control Surplus	Flood Control Surplus	Flood Control Surplus	Flood Control Surplus	**25.9**
1,200	Full Domestic Surplus (through 2016)	Full Domestic Surplus	Full Domestic Surplus	Full Domestic Surplus	Normal Operations	**22.9**
1,145	Partial Domestic Surplus (through 2016)	Normal Operations	Normal Operations	Partial Domestic Surplus		**15.9**
1,125	Normal Operations			Normal Operations		**13.9**
1,100					Shortage 600 kaf	**11.5**
1,075	Shortage 80 Percent Protection of elevation 1,050 feet msl	Shortage 400 kaf	Voluntary Conservation		Shortage 800 kaf	**9.4**
1,050		Shortage 500 kaf			Shortage 1,000 kaf	**7.5**
1,025		Shortage 600 kaf and Reconsultation			Shortage 1,200 kaf	**5.8**
1,000	Shortage Absolute Protection of elevation 1,000 feet msl		Shortage Absolute Protection of elevation 1,000 feet msl			**4.3**
895						**0**

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