APPENDIX D:

HYDROLOGY TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX D:

HYDROLOGY TECHNICAL INFORMATION AND ANALYSIS

D.1 ANALYSIS METHODS

The Colorado River Simulation System (CRSS) is the modeling tool used to assess the effects of the Long-term Experimental and Management Plan (LTEMP) alternatives on water resources and to provide relevant information to other models used to assess other resources. This section provides a background on CRSS, all relevant modeling assumptions used in CRSS, and a description of any changes that were made to CRSS, specifically for the LTEMP modeling.

D.1.1 Background

The CRSS, the Bureau of Reclamation's (Reclamation's) long-term planning model that covers the Colorado River Basin (Basin) from the natural inflow points in the Upper Basin (see Figure D-3) to Imperial Dam, was the first model used in LTEMP Draft Environmental Impact Statement (DEIS) analysis process. CRSS simulates future system conditions based on different hydrologic inflow scenarios and assumed reservoir operations for the evaluation period (2013–2033). The model framework used for this process is a commercial river modeling software called RiverWare™ (Zagona et al. 2001), 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 and provides information regarding the projected future state of the system on a monthly basis 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 basis of the simulation is a mass balance (or water budget) calculation that accounts 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 2013 through 2033.

The input data for the model includes monthly natural inflows,[1] various physical process parameters such as the evaporation rates for each reservoir, initial reservoir conditions on January 1, 2013, and the future diversion and depletion schedules for entities in the Basin States and for the United Mexican States (Mexico). These future schedules were based on the Current

[1] Calculated as gaged flow corrected for the effects of upstream reservoirs and depletions. Natural flow data and supporting documentation are available at http://www.usbr.gov/lc/region/g4000/NaturalFlow/index.html.

Projected demand scenario (Schedule A) from the Colorado River Basin Water Supply and Demand Study (Basin Study [Reclamation 2012b]).

The rules of operation of the Colorado River mainstream reservoirs including Lake Powell and Lake Mead are also provided as input to the model. This set of operating rules describes how water is released and delivered under various hydrologic conditions and aims to reflect actual operations. However, limitations inherently exist in the model's ability to reflect actual operations, particularly when responding to changing hydrological conditions and other operational constraints such as dam maintenance.

The future hydrology used as input to the model consisted of samples taken from the historical record of natural flow in the river system over the 105-year period from 1906 through 2010 and the "Downscaled GCM Projected" water supply scenario from the Basin Study (Reclamation 2012a). Each sequence is input as natural flow at 29 individual inflow points (or nodes) on the system. The future hydrology is merely a projection of what future conditions might be based upon the 105-year record, and is not a prediction of the likelihood of these future hydrologic conditions occurring.

The following sections describe the CRSS modeling assumptions and configuration associated with the modeling undertaken for the LTEMP DEIS process. The version of CRSS used for the LTEMP modeling started from the version of CRSS used for the Basin Study and was updated with more recent initial conditions and other changes necessary to reflect the different alternatives, as described below.

D.1.2 Initial Conditions

The model was initialized with the observed 2012 end-of-calendar-year (EOCY) reservoir conditions shown in Table D-1.

D.1.3 Reservoir Operations

D.1.3.1 Upper Basin Reservoirs above Lake Powell

The Taylor Park, Fontenelle, and Starvation reservoirs are operated in accordance with their existing rule curves (Reclamation 2007), although Fontenelle's operating rules in CRSS have been updated since the 2007 Interim Guidelines (DOI 2007). Aspinall Unit operations do not reflect the *Record of Decision* (ROD) *for the Aspinall Unit Operations Final Environmental Impact Statement* (Reclamation 2012c) because the modeling for the LTEMP DEIS began before the latest Aspinall ROD could be reflected in CRSS. Instead, Aspinall Unit operations are also operated in accordance with their previous rule curves as documented in the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead Final Environmental Impact Statement* (2007 Interim Guidelines Final EIS [Reclamation 2007]).

TABLE D-1 Initial Reservoir Conditions (2012 Observed End-of-Calendar-Year Values)

Reservoir	Elevation (ft AMSL)	Storage (ac-ft)
Fontenelle	6,485.19	196,963
Flaming Gorge	6,020.63	3,001,912
Starvation	5,734.92	255,000
Taylor Park	9,301.09	56,647
Blue Mesa	7,452.65	327,537
Morrow Point	7,146.50	106,381
Crystal	6,749.11	15,830
Navajo	6,024.73	956,630
Powell	3,609.82	12,712,205
Mead	1,120.36	13,636,479
Mohave	638.30	1,572,110
Havasu	446.41	550,689

Navajo and Flaming Gorge operations reflect the recent RODs (Reclamation 2006a and 2006b, respectively). In general, both RODs contain downstream flow targets that the reservoirs attempt to meet according to the rules within the RODs. In summary, Flaming Gorge operations are governed by the April through July unregulated inflow into the reservoir, which determines which downstream flow targets should be met; for example, in a wet year (larger inflow into the reservoir), higher downstream flows are targeted. The flow targets are specified at the sub-monthly time step, which historically could not be reflected within CRSS. In order to capture the sub-monthly component of the flow targets, and thus Flaming Gorge's operations, the model was programmed to determine typical daily operations before summing to a monthly release (Butler 2011).

Similarly, Navajo's ROD contains multiple downstream flow targets, specified at sub-monthly time intervals. In this case, a September 30 storage target guides Navajo's operations. A release pattern is selected to bring Navajo as close as possible to the September 30 storage target while helping meet the downstream flow targets stated in the ROD (Butler 2011).

D.1.3.2 Lake Powell and Lake Mead

For 2013 through 2026, Lake Powell and Lake Mead would be operated according to the 2007 Interim Guidelines (DOI 2007). For modeling purposes, after the expiration of the 2007 Interim Guidelines in 2026, operations are assumed to conform to those specified in the No-Action Alternative from the 2007 Interim Guidelines Final EIS (Reclamation 2007). Both operations are briefly described below.

Lake Mead flood control procedures are in effect for the entire simulation period. In addition, if Lake Mead elevation falls below 1,000 feet above mean sea level (AMSL), deliveries to the Southern Nevada Water Authority (SNWA) are assumed to continue.

If Lake Mead is sufficiently low such that after the maximum shortage (per the 2007 Interim Guidelines or No-Action Alternative post 2026) is applied and water is still unavailable to meet the remaining deliveries, the remaining deliveries were shorted hydrologically with respect to their physical location on the river.

Operations during the Interim Guidelines (2013–2026)

Operations of Lake Powell and Lake Mead are coordinated as specified in the 2007 Interim Guidelines (DOI 2007). Figure D-1 summarizes the different operating tiers at both reservoirs. Based on rules programmed in the model, CRSS determines which tier Powell is operating in, and simulates releases consistent with the selected tier. Similarly, CRSS is configured to simulate normal, shortage, and surplus deliveries in the Lower Basin, consistent with the Interim Guidelines.

Operations after the Interim Guidelines Expire (2027–2033)

The operating rules reverted to the rules of the 2007 Interim Guidelines Final EIS No-Action Alternative for simulations starting in 2027 and continuing through 2033. The No-Action Alternative assumed the following for shortage, surplus, and coordinated operations. There was no intentionally created surplus (ICS) assumed in the No-Action Alternative, however; consistent with the 2007 Interim Guidelines, ICS deliveries would be permissible through 2036. See Appendix A of the 2007 Interim Guidelines Final EIS (Reclamation 2007) for additional details regarding the No-Action Alternative.

Three factors that affect Lake Powell's release are (1) the minimum objective release of 8.23 maf, (2) equalization, and (3) spill avoidance. For equalization to occur, the 602(a) storage requirement must be met.[2]

Stage 1 shortage is triggered to prevent Lake Mead from declining below 1,050 feet AMSL. Stage 1 shortages range in volume from approximately 350 to 500 kaf. If Lake Mead's elevation continues to decline, a Stage 2 shortage is imposed to keep Lake Mead above 1,000 feet AMSL. Stage 2 shortages can be up to 3.0 maf.

[2] See Appendix A of the 2007 Interim Guidelines Final EIS (Reclamation 2007) for the full 602(a) storage requirement computation.

Lake Powell

Elevation (feet)	Operation According to the Interim Guidelines	Live Storage (maf)[1]
3,700	**Equalization Tier** Equalize, avoid spills or release 8.23 maf	24.3
3,636 - 3,666 (2008-2026)	**Upper Elevation Balancing Tier**[3] Release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf	15.5 - 19.3 (2008-2026)
3,575	**Mid-Elevation Release Tier** Release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf	9.5
3,525	**Lower Elevation Balancing Tier** Balance contents with a min/max release of 7.0 and 9.5 maf	5.9
3,490		4.0
3,370		0

Lake Mead

Elevation (feet)	Operation According to the Interim Guidelines	Live Storage (maf)[1]
1,220	**Flood Control Surplus or Quantified Surplus Condition** Deliver > 7.5 maf	25.9
1,200 (approx.)[2]	**Domestic Surplus or ICS Surplus Condition** Deliver > 7.5 maf	22.9 (approx.)[2]
1,145	**Normal or ICS Surplus Condition** Deliver ≥ 7.5 maf	15.9
1,105		11.9
1,075	**Shortage Condition** Deliver 7.167[4] maf	9.4
1,050	**Shortage Condition** Deliver 7.083[5] maf	7.5
1,025	**Shortage Condition** Deliver 7.0[6] maf Further measures may be undertaken[7]	5.8
1,000		4.3
895		0

Diagram not to scale

1 Acronym for million acre-feet

2 This elevation is shown as approximate as it is determined each year by considering several factors including Lake Powell and Lake Mead storage, projected Upper Basin and Lower Basin demands, and an assumed inflow.

3 Subject to April adjustments which may result in a release according to the Equalization Tier

4 Of which 2.48 maf is apportioned to Arizona, 4.4 maf to California, and 0.287 maf to Nevada

5 Of which 2.40 maf is apportioned to Arizona, 4.4 maf to California, and 0.283 maf to Nevada

6 Of which 2.32 maf is apportioned to Arizona, 4.4 maf to California, and 0.280 maf to Nevada

7 Whenever Lake Mead is below elevation 1,025 feet, the Secretary shall consider whether hydrologic conditions together with anticipated deliveries to the Lower Division States and Mexico is likely to cause the elevation at Lake Mead to fall below 1,000 feet. Such consideration, in consultation with the Basin States, may result in the undertaking of further measures, consistent with applicable Federal law.

FIGURE D-1 Operating Tiers as Specified by the 2007 Interim Guidelines (DOI 2007) for the Operations of Lake Powell and Lake Mead

Surplus determinations are per flood control surplus conditions or the 70R Strategy.[3]

Modeling Assumptions for Annual Releases Extending Beyond the Water Year

Modeling assumptions for equalization operations need to be performed for a full analysis of monthly and annual operations in this DEIS. These assumptions are for analytical purposes only and do not, and cannot, modify the Secretary's approach to operations of equalization releases that are made pursuant to the Colorado River Basin Project Act of 1968. Modeled equalization release volumes can be affected by the annual pattern of monthly volumes. Alternatives that have higher releases earlier in the water year are able to release more water in years when the maximum release through the powerplant becomes a potential limiting factor to equalizing within the water year, which is consistent with the objectives of the Law of the River. A limitation of the current modeling assumptions is that they cannot fully mimic or predict operator judgment or actions to achieve full equalization within the relevant timeframe. Reclamation will continue to operate Glen Canyon Dam to achieve equalization releases in a manner fully consistent with the Law of the River and in consultation with the Colorado River Basin States.

For LTEMP modeling, logic was added to CRSS to handle instances when Powell could not meet annual release requirements by the end of the water year. If the computed remaining release in September is greater than Powell's power plant capacity, then the volume above powerplant capacity necessary meet annual release requirements is released in the subsequent months. Releases, beginning in October, are increased above the normal release requirements (e.g., 600 kaf in an 8.23-maf release year of Alternative A, the no-action alternative) up to power plant capacity, for as many months as necessary to release the remaining equalization volume. The volume of annual releases extending beyond the water year and the frequency at which these releases would be necessary were reported as one of the calculated water resource metrics.

Setting Powell's Monthly Release Volumes

In order to more efficiently model the different alternatives being evaluated in the LTEMP DEIS, CRSS logic was modified to use an input release table, and to allow minimum release constraints to vary among alternatives. The tables include monthly release volumes for water year releases of 7.0, 7.48, 8.23, 9.0, 9.5, 10.5, 11.0, 12.0, 13.0, and 14.0 maf. In fixed release volume years (e.g., 8.23-maf release years), the monthly volumes used were directly from the input release tables presented in Section D.1.4, subject to other constraints such as ensuring Powell stays at a safe operating capacity. In years with computed release volumes

[3] Under the 70R Strategy, a surplus condition is based on the system space requirement at the beginning of each year. Based on the 70th percentile historical runoff, a normal 7.5-maf delivery to the Lower Division states, the Upper Basin scheduled use, and Lake Powell and Lake Mead volumes at the beginning of the year, the volume of water in excess of the system space requirement at the end of the year is estimated. If that volume is greater than zero, a surplus is declared. See Appendix A of the 2007 Interim Guidelines Final EIS (Reclamation 2007) for the full 70R computation.

(e.g., equalization releases), the necessary water year release volume is computed, and the monthly release is interpolated between the two closest water year releases. For example, if the equalization release is computed to be 12.5 maf, then the monthly release would be interpolated between the 12.0- and 13.0-maf monthly release volumes.

The minimum release constraints were also incorporated into CRSS because there are certain instances when the release from Powell may be computed to be less than the alternative's minimum release constraints. In these cases, the alternative's minimum release constraint is used, subject to the physical ability to release the water. Furthermore, the implementation of these constraints does not result in a modification of the annual release volume.

D.1.3.3 Lake Mohave and Lake Havasu

Lake Mohave and Lake Havasu are operated in accordance with their existing rule curves.

D.1.4 Representation of the Different Alternatives in CRSS

For each alternative, tables were developed that include the monthly release volumes that are modeled to occur under differing water year release volumes. In most cases, the volumes in the tables represent some desired aspect of the alternatives and were developed by proportionally scaling monthly volumes to the water year volume. However, in the minimum (7.0-maf) water release years and in the higher water release years, the proportionally scaled monthly volumes in the tables were sometimes adjusted up to meet minimum release constraints or down to powerplant capacity. All alternatives met the minimum release constraints and were within powerplant capacity in an 8.23-maf release year. However, in some months for some alternatives the proportionally scaled monthly volumes in the tables required adjustment to meet these constraints.

For example, the proportionally scaled monthly volumes in a 7.0-maf year were not always adequate to meet the minimum release requirement, as computed by the minimum hourly releases and ramping constraints. In these instances, the monthly release volume was set to the volume necessary to maintain minimum flow throughout the entire month. Similarly, in high-volume water release years, the proportionally scaled monthly volumes in the tables were sometimes greater than the physical capacity of Glen Canyon Powerplant. In these instances, the monthly release volume in the table was set to powerplant capacity, reallocating the excess into other months of the water year. The annual release volume was not affected by these modifications.

In addition to the physical capacity of the powerplant represented in the monthly tables input to CRSS, the maximum release capacity of Glen Canyon Dam (powerplant and bypass volume) can also affect modeled monthly release volumes, particularly in years with an annual release volume greater than 14.0 maf. The maximum release was modeled explicitly in CRSS as a function of reservoir head. Generally speaking, the maximum release was computed as

45,000 cfs; this flow was converted to a daily volume and then multiplied by the number of days in the month to determine the monthly maximum release volume. In months when the monthly release prescribed by the alternative was greater than the maximum capacity for the month, the monthly volume was capped at the physical capacity, and the remaining volume was released in the following month(s).

Monthly release volume can also be affected by high-flow experiments (HFEs). For HFEs that required more water than was already allocated for the given month of the HFE, water was reallocated from later months to ensure the water year release volume remained the same. For this DEIS, the monthly reallocation of water for HFEs was modeled as a post-process to the sand-budget model (i.e., after the model determined the magnitude and duration of the HFE). Reservoir mass balance was computed for the affected months and the resulting monthly releases and reservoir elevations were then passed to the hydropower model.

The monthly reallocation of releases to support a HFE does not affect the Lake Powell operating tier (and thus did not need to be explicitly modeled in CRSS). Operationally, the magnitude and duration of a HFE would be determined in either October–November or March–April. Because the Lake Powell annual operating tier is determined based on the August projection of the January 1 elevation, it is not yet known whether an HFE will take place that water year. Therefore, a modeled reallocation of water into November, for example, should not be considered when determining the annual operating tier because, operationally, this information would not be known until after the operating tier was already set.

Tables D-2 through D-11 include the monthly release tables used for all alternatives in CRSS, and Table D-12 summarizes the minimum release constraints used for each alternative. Figure D-2 shows the 8.23-maf release year pattern for all alternatives. In addition, the experimental components of LTEMP that are modeled in CRSS are also discussed.

Long-term strategies (various implementations of the seven LTEMP alternatives; described in Appendix C) that would not affect monthly or annual releases from Powell were not simulated in CRSS. These long-term strategies are labeled in the figures in this appendix as identical to another long-term strategy. For example, the only difference between long-term strategies D1 and D3 is that D1 includes trout management flows. Because trout management flows were not included in CRSS, results for D1 and D3 are identical and labeled as such in the water delivery results.

TABLE D-2 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative A

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
November	500,000	500,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
December	600,000	600,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000
January	600,000	800,000	800,000	800,000	850,000	950,000	950,000	1,000,000	1,000,000	1,000,000
February	600,000	600,000	600,000	650,000	650,000	650,000	700,000	800,000	800,000	900,000
March	500,000	600,000	600,000	650,000	650,000	650,000	700,000	900,000	950,000	1,100,000
April	500,000	500,000	600,000	600,000	650,000	750,000	900,000	1,000,000	1,100,000	1,413,000
May	500,000	600,000	600,000	650,000	800,000	1,100,000	1,100,000	1,100,000	1,250,000	1,537,000
June	600,000	600,000	650,000	800,000	900,000	1,100,000	1,150,000	1,200,000	1,400,000	1,488,000
July	800,000	800,000	850,000	1,000,000	1,050,000	1,150,000	1,250,000	1,400,000	1,537,000	1,537,000
August	800,000	800,000	900,000	1,050,000	1,100,000	1,200,000	1,250,000	1,500,000	1,537,000	1,537,000
September	520,000	600,000	630,000	800,000	850,000	950,000	1,000,000	1,100,000	1,426,000	1,488,000

TABLE D-3 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative B

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
November	500,000	500,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
December	600,000	600,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000
January	600,000	800,000	800,000	800,000	850,000	950,000	950,000	1,000,000	1,000,000	1,000,000
February	600,000	600,000	600,000	650,000	650,000	650,000	700,000	800,000	800,000	900,000
March	500,000	600,000	600,000	650,000	650,000	650,000	700,000	900,000	950,000	1,100,000
April	500,000	500,000	600,000	600,000	650,000	750,000	900,000	1,000,000	1,100,000	1,413,000
May	500,000	600,000	600,000	650,000	800,000	1,100,000	1,100,000	1,100,000	1,250,000	1,537,000
June	600,000	600,000	650,000	800,000	900,000	1,100,000	1,150,000	1,200,000	1,400,000	1,488,000
July	800,000	800,000	850,000	1,000,000	1,050,000	1,150,000	1,250,000	1,400,000	1,537,000	1,537,000
August	800,000	800,000	900,000	1,050,000	1,100,000	1,200,000	1,250,000	1,500,000	1,537,000	1,537,000
September	520,000	600,000	630,000	800,000	850,000	950,000	1,000,000	1,100,000	1,426,000	1,488,000

TABLE D-4 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative C

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	436,260	436,260	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
November	436,260	436,260	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
December	754,360	754,360	830,000	830,000	830,000	830,000	830,000	830,000	830,000	830,000
January	692,498	754,360	830,000	929,239	993,680	1,122,562	1,187,003	1,315,885	1,444,767	1,537,189
February	609,215	663,640	730,180	817,484	874,175	987,557	1,044,248	1,157,630	1,271,012	1,388,429
March	643,264	700,730	770,990	863,174	923,033	1,042,752	1,102,611	1,222,330	1,342,049	1,474,882
April	572,129	623,240	685,730	767,719	820,959	927,439	980,679	1,087,159	1,193,639	1,311,782
May	592,562	645,500	710,220	795,138	850,279	960,562	1,015,703	1,125,985	1,236,268	1,358,631
June	619,811	675,180	742,880	831,703	889,380	1,004,734	1,062,411	1,177,765	1,293,119	1,421,109
July	692,498	754,360	830,000	929,239	993,680	1,122,562	1,187,003	1,315,885	1,444,767	1,537,189
August	550,661	599,850	660,000	738,913	790,155	892,640	943,882	1,046,366	1,148,851	1,262,562
September	400,482	436,260	480,000	537,391	574,659	649,192	686,460	760,995	835,528	918,227

TABLE D-5 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative C with Low Summer Flows

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	436,260	436,260	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
November	436,260	436,260	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
December	754,360	754,360	830,000	830,000	830,000	830,000	830,000	830,000	830,000	830,000
January	692,498	754,360	830,000	929,239	993,680	1,122,562	1,187,003	1,315,885	1,444,767	1,537,189
February	609,215	663,640	730,180	817,484	874,175	987,557	1,044,248	1,157,630	1,271,012	1,388,429
March	643,264	700,730	770,990	863,174	923,033	1,042,752	1,102,611	1,222,330	1,342,049	1,474,882
April	708,598	771,899	849,296	950,842	1,016,781	1,148,660	1,214,599	1,346,477	1,478,355	1,487,603
May	733,905	799,467	879,628	984,801	1,053,095	1,189,683	1,257,977	1,394,566	1,531,154	1,537,189
June	767,648	836,224	920,070	1,030,079	1,101,513	1,244,381	1,315,815	1,458,684	1,488,000	1,487,603
July	410,410	447,074	491,901	550,715	588,906	665,288	703,479	779,862	894,506	1,110,981
August	410,410	447,074	491,901	550,715	588,906	665,288	703,479	779,862	894,506	1,110,981
September	397,172	432,652	476,034	532,951	569,911	643,829	680,789	754,704	865,651	1,075,143

TABLE D-6 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative D

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	642,583	642,583	642,583	642,583	642,583	642,583	642,583	642,583
November	500,000	500,000	641,532	641,532	641,532	641,532	641,532	641,532	641,532	641,532
December	600,000	600,000	715,885	715,885	715,885	715,885	715,885	715,885	715,885	715,885
January	664,609	723,467	763,000	858,351	919,662	1,042,283	1,103,594	1,226,216	1,348,837	1,471,459
February	587,262	639,271	675,000	758,457	812,632	920,983	975,159	1,083,510	1,191,860	1,300,211
March	620,206	675,132	713,000	801,004	858,219	972,648	1,029,863	1,144,292	1,258,721	1,373,150
April	552,170	601,070	635,000	713,134	764,072	865,949	916,887	1,018,763	1,120,640	1,222,516
May	571,506	622,119	657,000	738,108	790,830	896,274	948,996	1,054,440	1,159,884	1,265,328
June	598,005	650,965	688,000	772,331	827,497	937,830	992,997	1,103,330	1,213,663	1,323,996
July	651,718	709,434	749,000	841,702	901,823	1,022,067	1,082,188	1,202,431	1,322,674	1,442,918
August	652,434	710,214	750,000	842,627	902,814	1,023,190	1,083,377	1,203,753	1,324,128	1,444,503
September	522,090	568,328	600,000	674,286	722,451	818,776	866,939	963,265	1,059,593	1,155,919

TABLE D-7 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative D with Low Summer Flows

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	642,583	642,583	642,583	642,583	642,583	642,583	642,583	642,583
November	500,000	500,000	641,532	641,532	641,532	641,532	641,532	641,532	641,532	641,532
December	600,000	600,000	715,885	715,885	715,885	715,885	715,885	715,885	715,885	715,885
January	664,609	723,467	763,000	858,351	919,662	1,042,283	1,103,594	1,226,216	1,348,837	1,471,459
February	587,262	639,271	675,000	758,457	812,632	920,983	975,159	1,083,510	1,191,860	1,300,211
March	620,206	675,132	713,000	801,004	858,219	972,648	1,029,863	1,144,292	1,258,721	1,373,150
April	730,640	795,346	840,007	943,631	1,011,033	1,145,837	1,213,239	1,348,044	1,482,848	1,487,603
May	756,226	823,198	869,423	976,676	1,046,439	1,185,964	1,255,726	1,395,252	1,534,777	1,537,189
June	791,289	861,367	909,735	1,021,961	1,094,958	1,240,952	1,313,949	1,459,944	1,487,603	1,487,603
July	427,856	465,748	491,901	552,582	592,052	670,992	710,463	789,403	908,217	1,126,373
August	427,856	465,748	491,901	552,582	592,052	670,992	710,463	789,403	908,217	1,126,373
September	414,056	450,723	476,033	534,756	572,953	649,349	687,544	763,936	878,920	1,090,039

TABLE D-8 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative E

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	642,583	642,583	642,583	642,583	642,583	642,583	642,583	642,583
November	500,000	500,000	641,532	641,532	641,532	641,532	641,532	641,532	641,532	641,532
December	600,000	600,000	715,885	715,885	715,885	715,885	715,885	715,885	715,885	715,885
January	683,468	747,279	781,296	883,660	950,130	1,083,070	1,149,540	1,282,480	1,415,420	1,548,360
February	604,808	661,275	691,377	781,960	840,780	958,420	1,017,240	1,134,880	1,252,520	1,370,160
March	638,457	698,066	729,843	825,465	887,558	1,011,743	1,073,835	1,198,020	1,322,205	1,446,390
April	568,537	621,618	649,915	735,065	790,357	900,942	956,235	1,066,820	1,177,405	1,287,990
May	588,202	643,119	672,394	760,490	817,695	932,105	989,310	1,103,720	1,218,130	1,332,540
June	615,733	673,220	703,866	796,085	855,967	975,732	1,035,615	1,155,380	1,275,145	1,394,910
July	670,795	733,423	766,809	867,275	932,513	1,062,988	1,128,225	1,258,700	1,389,175	1,519,650
August	560,700	599,148	659,223	720,900	760,950	841,050	881,100	961,200	1,041,300	1,121,400
September	489,300	522,852	575,277	629,100	664,050	733,950	768,900	838,800	908,700	978,600

TABLE D-9 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative E with Low Summer Flows

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	642,583	642,583	642,583	642,583	642,583	642,583	642,583	642,583
November	500,000	500,000	641,532	641,532	641,532	641,532	641,532	641,532	641,532	641,532
December	600,000	600,000	715,885	715,885	715,885	715,885	715,885	715,885	715,885	715,885
January	683,468	747,279	781,296	883,660	950,130	1,083,070	1,149,540	1,282,480	1,415,420	1,537,189
February	604,808	661,275	691,377	781,960	840,780	958,420	1,017,240	1,134,880	1,252,520	1,381,331
March	638,457	698,066	729,843	825,465	887,558	1,011,743	1,073,835	1,198,020	1,322,205	1,446,390
April	714,353	775,725	823,598	922,047	985,976	1,113,833	1,177,761	1,305,618	1,433,475	1,487,603
May	739,062	802,556	852,085	953,940	1,020,080	1,152,359	1,218,499	1,350,778	1,483,058	1,537,189
June	773,654	840,120	891,967	998,589	1,067,825	1,206,296	1,275,531	1,414,002	1,487,603	1,487,603
July	426,654	463,308	491,901	550,701	588,883	665,246	703,428	779,792	878,014	1,052,213
August	426,654	463,308	491,901	550,701	588,883	665,246	703,428	779,792	878,014	1,052,213
September	412,890	448,363	476,032	532,937	569,885	643,787	680,738	754,638	849,691	1,018,269

TABLE D-10 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative F

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	444,800	444,800	493,860	493,860	493,860	493,860	493,860	493,860	493,860	493,860
November	430,450	430,450	477,930	477,930	477,930	477,930	477,930	477,930	477,930	477,930
December	444,800	444,800	493,860	493,860	493,860	493,860	493,860	493,860	493,860	493,860
January	399,780	444,800	493,860	566,090	587,333	697,737	762,803	849,488	1,127,401	1,405,315
February	491,970	541,610	599,950	679,580	713,503	847,624	926,667	1,388,429	1,388,429	1,388,429
March	701,570	767,290	848,690	954,120	1,009,323	1,199,050	1,310,865	1,537,189	1,537,189	1,537,189
April	830,780	904,790	999,830	1,118,560	1,189,069	1,412,584	1,487,603	1,487,603	1,487,603	1,487,603
May	1,101,480	1,170,880	1,279,340	1,390,680	1,521,482	1,576,859	1,576,859	1,576,859	1,576,859	1,576,859
June	1,123,140	1,176,360	1,259,500	1,344,870	1,487,603	1,487,603	1,487,603	1,487,603	1,487,603	1,487,603
July	347,480	388,920	432,370	498,850	514,205	610,863	667,828	743,719	987,030	1,230,340
August	347,480	388,920	432,370	498,850	514,205	610,863	667,828	743,719	987,030	1,230,340
September	336,270	376,380	418,440	482,750	497,627	591,167	646,294	719,741	955,206	1,190,672

TABLE D-11 Monthly Release Volumes (in ac-ft) by Water Year Release for Alternative G

	Water Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	635,300	635,300	699,000	699,000	699,000	699,000	699,000	699,000	699,000	699,000
November	635,300	635,300	699,000	699,000	699,000	699,000	699,000	699,000	699,000	699,000
December	615,305	615,305	677,000	677,000	677,000	677,000	677,000	677,000	677,000	677,000
January	580,721	635,300	699,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,121
February	524,523	614,396	676,000	710,256	761,538	864,103	915,385	1,017,949	1,120,513	1,223,077
March	580,721	635,300	699,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,121
April	561,988	635,300	699,000	760,989	815,934	925,824	980,769	1,090,659	1,200,549	1,310,440
May	580,721	573,497	631,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,121
June	561,988	635,300	699,000	760,990	815,934	925,824	980,768	1,090,659	1,200,549	1,310,440
July	580,721	614,396	676,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,120
August	580,721	635,300	699,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,120
September	561,991	615,306	677,000	760,990	815,934	925,824	980,768	1,090,658	1,200,549	1,310,440

TABLE D-12 Minimum Release Constraints (cfs) Used for Each Alternative

Alternative	Minimum Release (cfs)
A	6,562.50
B	6,500.00
C	6,520.83
D[a]	6,520.83
E	6,520.83
F	5,000.00
G	8,000.00

[a] For Alternative D, with steady weekend flows for invertebrate production, the May–August minimum release constraint is 8,000 cfs.

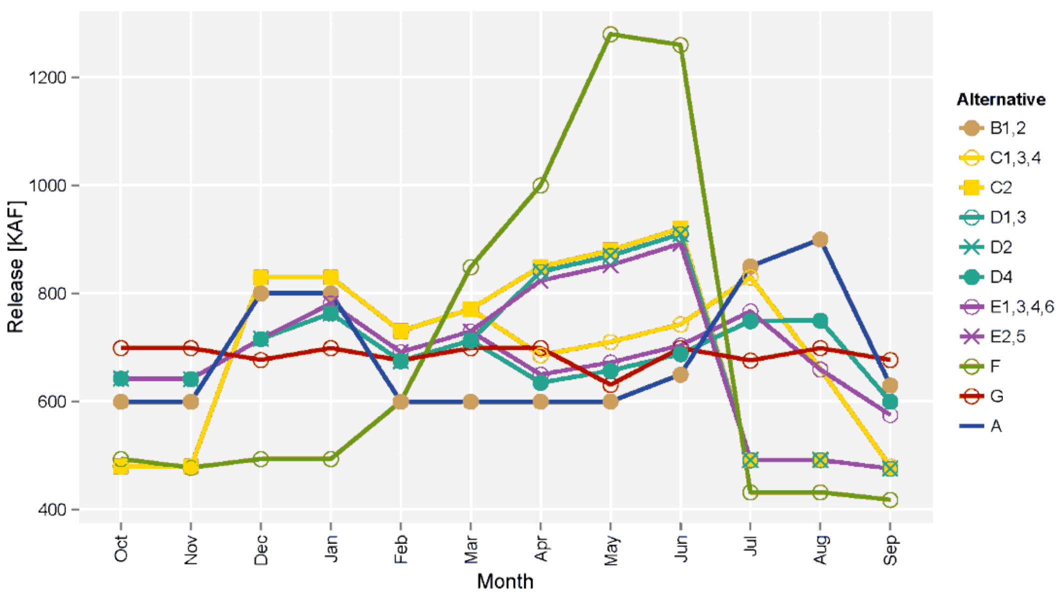

FIGURE D-2 Monthly Releases in kaf for Each Alternative in an 8.23-maf Release Year (Note that long-term strategies C2, D1, D2, D3, E2, and E5 are shown with the monthly distributions when low summer flows are implemented. Low summer flows would not be implemented in all years.)

D.1.4.1 Experimental Components Modeled in CRSS

Specific to the LTEMP DEIS, both experimental treatments—low summer flows and May through August steady weekend flows for invertebrate production—were incorporated into CRSS. The following sections discuss how these experimental components were modeled in CRSS.

Low Summer Flows

Low summer flows were implemented in CRSS as an experimental component under Alternatives C, D, and E. The objective of low summer flows is to produce warmer temperatures (i.e., greater than 13°C [55°F] for Alternatives C and E and greater than 14°C [57°F] for Alternative D) at the confluence with the Little Colorado River (T_{LCR}) in July, August, and September. In May, these alternatives would switch to a low summer flow pattern, releasing less water during these months, if all three of the following conditions are true: (1) the projected annual water year release is <10 maf, (2) projected T_{LCR} is cold[4] in any of the three target months using the base release pattern, and (3) switching to the low summer flow pattern would result in warm[5] temperatures in all three of the target months. Alternatives that have low summer flows as an experimental component would use the base release tables, unless these three conditions were met. For example, Alternative E (long-term strategy 2) would use release volumes from Table D-8, but would switch to the release volumes in Table D-9 if the above conditions were met. Note that Alternatives C and E were modeled with low summer flows during the entire 20-year LTEMP period, whereas Alternative D was modeled with implementation of low summer flows only during the second 10 years of the LTEMP period.

The projected temperature conditions were calculated using regression equations that considered monthly elevations and releases and the calendar year inflow at Lake Powell, and were empirically developed from observed conditions. The regression equations[6] to solve for T_{LCR} in July, August, and September were as follows:

July: $T_{LCR} = T_o + 3.791 / (0.000461 \times \textit{Apr Projected Release}_{JUL})^{0.63} \times (36.31 - T_o)$,
where: $T_o = 249.4 - (0.0668 \times \textit{Apr Projected EOM Elev}_{JUL}) + (3.766\text{E-}7 \times \textit{Apr Projected CY Inflow})$

4 Cold is defined as <13°C (55°F) for long-term strategies C2, E2, and E5 and <14°C (57°F) for long-term strategies D1, D2, and D3.

5 Warm is defined as >13°C (55°F) for long-term strategies C2, E2, and E5 and >14°C (57°F) for long-term strategies D1, D2, and D3.

6 Regression equations were log-transformed for inclusion into CRSS.

August: $T_{LCR} = T_o + 3.791 / (0.000461 \times \textit{Apr Projected Release}_{AUG})^{0.63} \times (34.81 - T_o)$,
where: $T_o = 297.2 - (0.0802 \times \textit{Apr Projected EOM Elev}_{AUG}") + (4.915E\text{-}7 \times \textit{Apr Projected CY Inflow})$

September: $T_{LCR} = T_o + 3.791 / (0.000476 \times \textit{Apr Projected Release}_{SEP})^{0.63} \times (30.01 - T_o)$,
where: $T_o = 327.9 - (0.0886 \times \textit{Apr Projected EOM Elev}_{SEP}) + (5.342E\text{-}7 \times \textit{Apr Projected CY Inflow})$

where:

T_{LCR} = temperature at the Little Colorado River Confluence, °C

T_o = Lake Powell release temperature, °C

EOM Elev = Lake Powell projected end-of-month elevation, ft

CY Inflow = Lake Powell projected calendar year inflow, ac-ft

Release = Lake Powell projected monthly release volume, ac-ft

Steady Weekend Flows For Invertebrate Production

Steady weekend flows for invertebrate production were an experimental component of Alternative D. For the long-term strategy that included these flows, the May–August minimum release constraint was increased to 8,000 cfs.

D.1.5 Input Hydrology

The future hydrology used as input to the model consisted of samples taken from the historical record of natural flow in the river system over the 105-ear period from 1906 through 2010, from 29 individual inflow points (or nodes) on the system. The locations of the hydrologic input sites are shown in Figure D-3.

Typically, CRSS is run with the full suite of available natural flow traces created using a resampling technique known as the Indexed Sequential Method (ISM) (Ouarda et al. 1997). Using the ISM on a 105-year record (1906–2010) results in 105 inflow traces (i.e., plausible inflow sequences). For this DEIS, however, due to the complexity, resource and timing constraints, and number of loosely coupled models used to analyze other resource impacts, every fifth trace from the 105 natural flow traces was selected, resulting in 21 traces.

Figures D-4 and D-5 compare the differences between using 105 traces versus 21, and indicate that the distribution of 21 traces is very similar to the distribution of the full 105 traces for Lake Powell annual inflow, annual and monthly releases, and end of December pool elevation.

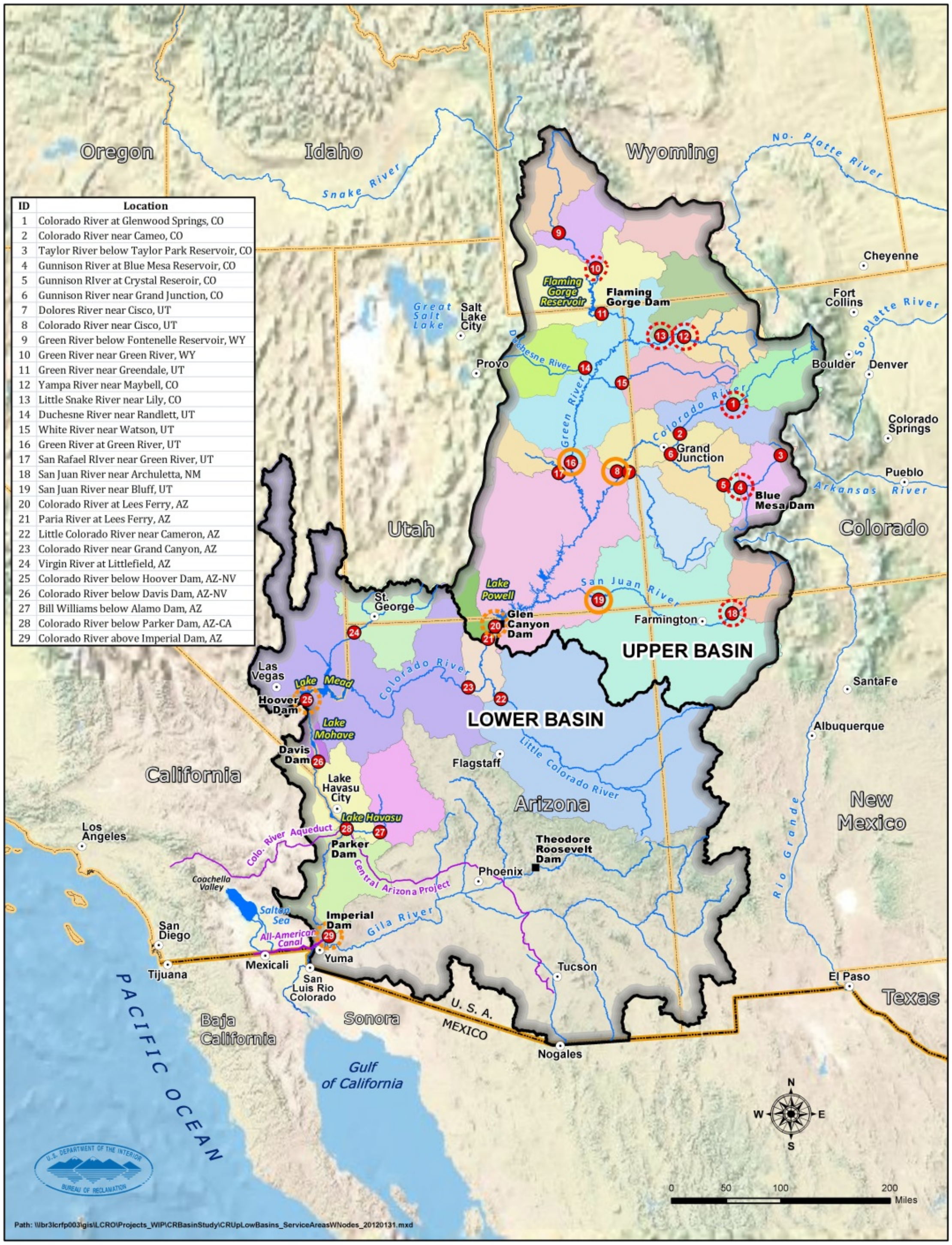

FIGURE D-3 Locations of CRSS 29 Natural Flow Nodes

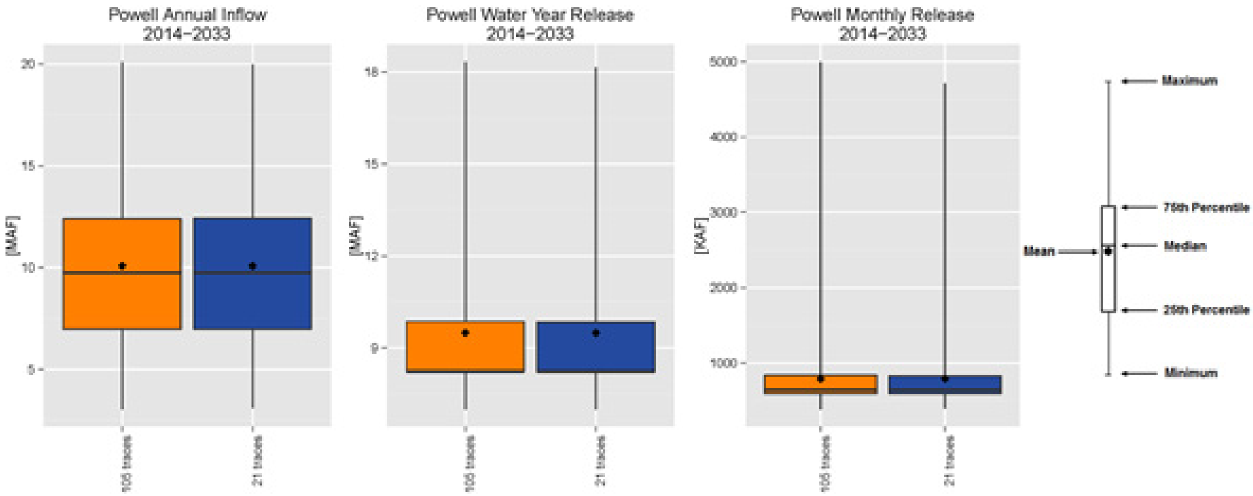

FIGURE D-4 Comparison of CRSS Results Generated Using 105 Traces (orange) and 21 Traces (blue) for Lake Powell Annual Inflow (left), Lake Powell Water Year Release Volume (center) and Lake Powell Monthly Release Volume (right)

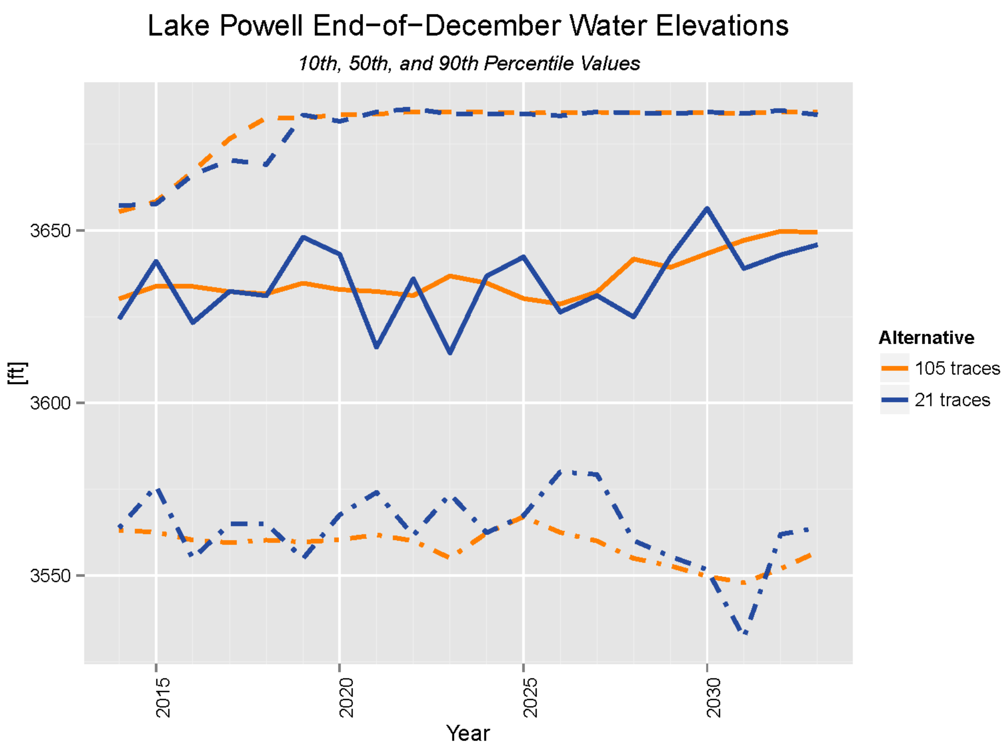

FIGURE D-5 Comparison of CRSS Results Generated Using 105 Traces (orange) and 21 Traces (blue) for Lake Powell End of December Water Elevations at the 10th (dashed and dotted lines), 50th (solid lines), and 90th (dashed lines) Percentiles

D.1.6 Input Demands

The LTEMP modeling utilized the Basin Study Current Projected demand scenario (Reclamation 2012b) for the input demands into CRSS. Table D-13 summarizes the demands by state.

D.1.7 Other Key Assumptions

A number of changes to CRSS were described in the Basin Study (Appendix G-2) including how the model treats implementation of Upper Colorado River water rights and intentionally created surplus.

Future water deliveries to Mexico were modeled as follows:

1. The model accounts for the entire delivery to Mexico at the Northerly International Boundary (NIB).

2. Water deliveries to Mexico are pursuant to the requirements of the 1944 Treaty. This provides annual deliveries of 1.5 maf to Mexico and up to 1.7 maf during Lake Mead flood control release conditions.

3. For modeling purposes, it is assumed that during shortage conditions, Mexico shares shortage in proportion to U.S. users in the Lower Basin (16.67 percent). This assumption is consistent with that used in the modeling supporting 2007 Interim Guidelines Final EIS (Reclamation 2007).[7]

4. Minute No. 318 and Minute No. 319 were not modeled as part of the LTEMP DEIS because modeling began before they could be incorporated into CRSS.

The Warren H. Brock Reservoir was assumed to operate every year beginning in 2013 and is assumed to conserve approximately 90 percent of non-storable flows. This reduces the average annual volume of non-storable flows delivered to Mexico from 73 kaf/yr (historical average from 1964 through 2010, excluding flood years on the Gila or flood control releases) to 7 kaf/yr.

Bypass of return flows from the Welton-Mohawk Irrigation and Drainage District to the Cienega de Santa Clara in Mexico was assumed to be 109 kaf/yr (historical average from 1990 through 2010) and was not counted as part of the 1944 Treaty delivery to Mexico.

The Yuma Desalting Plant was assumed to not operate during the LTEMP period.

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7 Allocation of Colorado River water to Mexico is governed by the 1944 Treaty. Reclamation’s modeling assumptions are not intended to constitute an interpretation or application of the 1944 Treaty or to represent current United States policy or a determination of future United States policy regarding deliveries to Mexico.

TABLE D-13 Input Demands, by State (in ac-ft)

	Upper Division States				Lower Division States		
Year	CO	NM	UT	WY	AZ[a]	CA	NV
2013	2,524,327	592,772	1,017,031	539,545	2,800,000	4,400,000	300,000
2014	2,524,552	601,496	1,018,144	539,755	2,800,000	4,400,000	300,000
2015	2,524,776	610,220	1,019,258	539,965	2,800,000	4,400,000	300,000
2016	2,536,669	618,944	1,020,371	542,900	2,800,000	4,400,000	300,000
2017	2,548,562	627,668	1,021,485	545,835	2,800,000	4,400,000	300,000
2018	2,560,455	636,392	1,022,599	548,769	2,800,000	4,400,000	300,000
2019	2,572,347	645,116	1,023,712	551,704	2,800,000	4,400,000	300,000
2020	2,584,240	653,840	1,029,826	554,639	2,800,000	4,400,000	300,000
2021	2,596,133	658,483	1,033,820	557,574	2,800,000	4,400,000	300,000
2022	2,608,026	663,126	1,037,813	560,509	2,800,000	4,400,000	300,000
2023	2,619,919	667,769	1,041,807	563,443	2,800,000	4,400,000	300,000
2024	2,631,812	672,412	1,045,801	566,378	2,800,000	4,400,000	300,000
2025	2,643,705	677,055	1,049,794	569,313	2,800,000	4,400,000	300,000
2026	2,655,597	681,698	1,053,788	572,248	2,800,000	4,400,000	300,000
2027	2,667,490	686,341	1,057,781	575,183	2,800,000	4,400,000	300,000
2028	2,679,383	690,984	1,061,775	578,117	2,800,000	4,400,000	300,000
2029	2,691,276	695,627	1,065,769	581,052	2,800,000	4,400,000	300,000
2030	2,703,169	700,270	1,074,762	583,987	2,800,000	4,400,000	300,000
2031	2,715,062	702,863	1,080,156	586,922	2,800,000	4,400,000	300,000
2032	2,726,954	705,456	1,085,550	589,857	2,800,000	4,400,000	300,000
2033	2,738,847	708,049	1,090,943	592,791	2,800,000	4,400,000	300,000

[a] There are an additional 50,000 ac-ft/yr of Arizona demands within the Upper Basin, represented in CRSS.

D.2 SUPPLEMENTAL INFORMATION ON IMPACT MODELING

The following sections provide more detailed information on the impacts of the different LTEMP alternatives, particularly for low summer flows, the carryover equalization release metric, and alternative-specific comparisons to Alternative A (no-action alternative). These results supplement those covered in Section 4.1 of this DEIS.

D.2.1 Low Summer Flows

During years with low summer flows, releases would be lower than typical in July, August, and September and proportionally higher in May and June, in order to maintain the same annual release volume. In years when the required annual release volume is not known until the end of the water year (e.g., during balancing or equalization), the low summer flows monthly volumes may end up being higher or lower than those originally projected in April, due to changing hydrologic conditions. Figure D-6 shows the modeled frequency of occurrence of low summer flows. Note that Alternatives C and E were modeled with implementation of low summer flows during the entire 20-year period, whereas Alternative D was modeled with low

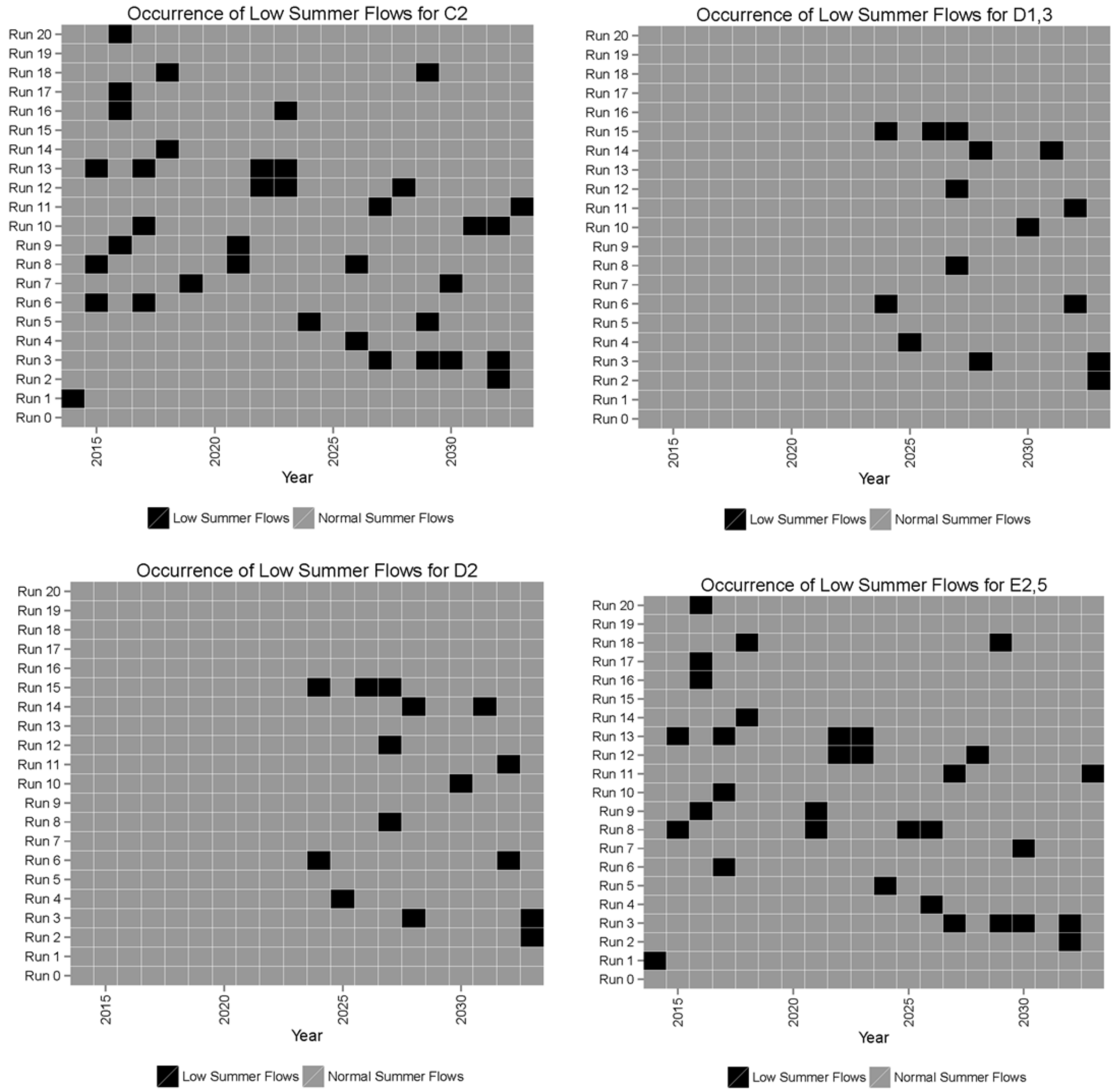

FIGURE D-6 Occurrences of Low Summer Flows in Applicable Alternatives (Numbers after alternative letter designations represent the long-term strategies that would implement low summer flows.)

summer flows only during the second 10 years of the LTEMP period. For those alternatives with low summer flows, the modeled number of low summer flows in the 20-year period ranged from zero to four occurrences per trace. Depending on the alternative, the average ranged from 0.7 to 1.8 low summer flows per 20-year run.

D.2.2 Modeled Annual Releases Extending Beyond the End of the Water Year

The frequency (Figure D-7) and volume (Figure D-8) of exceptions to meeting the annual release target volumes specified by the Interim Guidelines were one of the calculated water

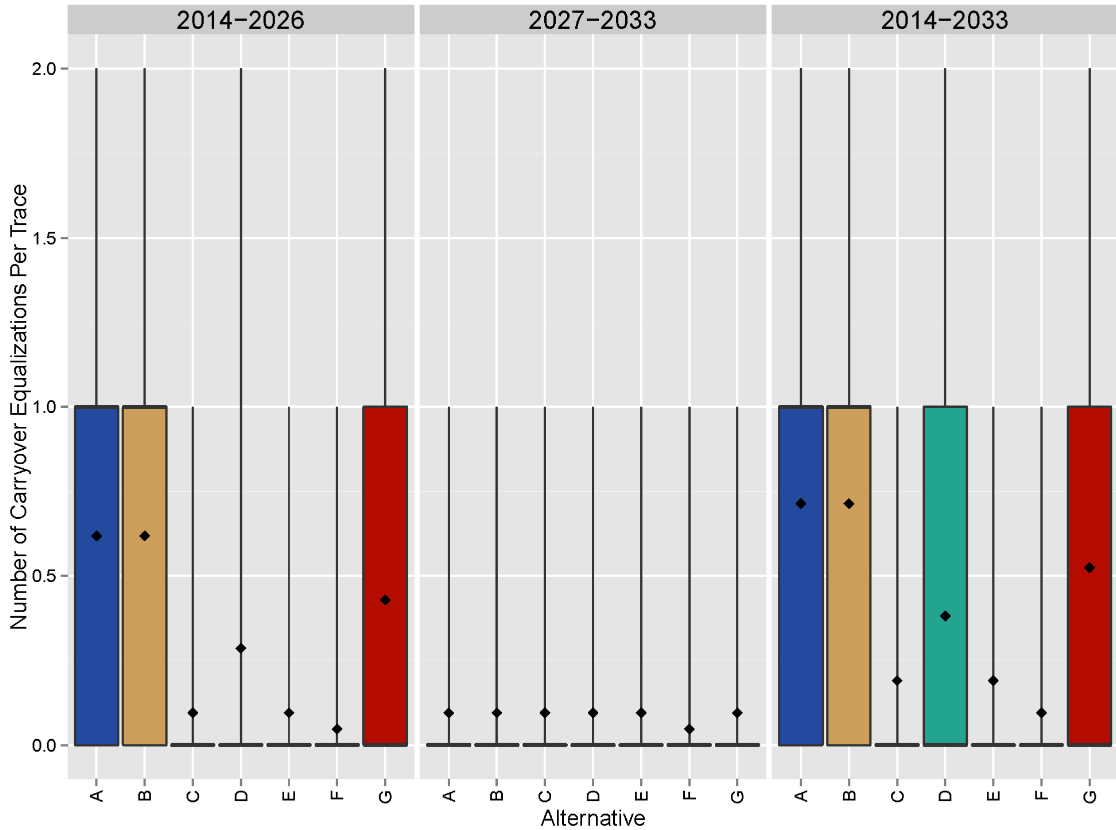

FIGURE D-7 Frequency of Occurrence of Modeled Annual Releases Extending beyond the End of the Water Year per 20-Year Trace for Each of the Alternatives (See Figure 4-2 for an explanation of how to interpret this graph. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

resource metrics. Note that there is the possibility of exceptions occurring under all alternatives, including Alternative A (the no-action alternative).

D.2.3 Lake Elevation

The following figures present end-of-December elevations for Lake Powell (Figures D-9 through D-14) and percent of traces below Lake Powell's minimum power pool (Figures D-15 through D-20) for each alternative, and compares them to Alternative A. These graphs show different implementations of each alternative (referred to here as long-term strategies). These are given the letter designation of the alternative (A–G), and a number designating the long-term strategy for the alternative. See Section 4.1 and Appendix C for descriptions of the experiments included in each long-term strategy. For both of these parameters, only very small differences between Alternatives B-G and Alternative A were found.

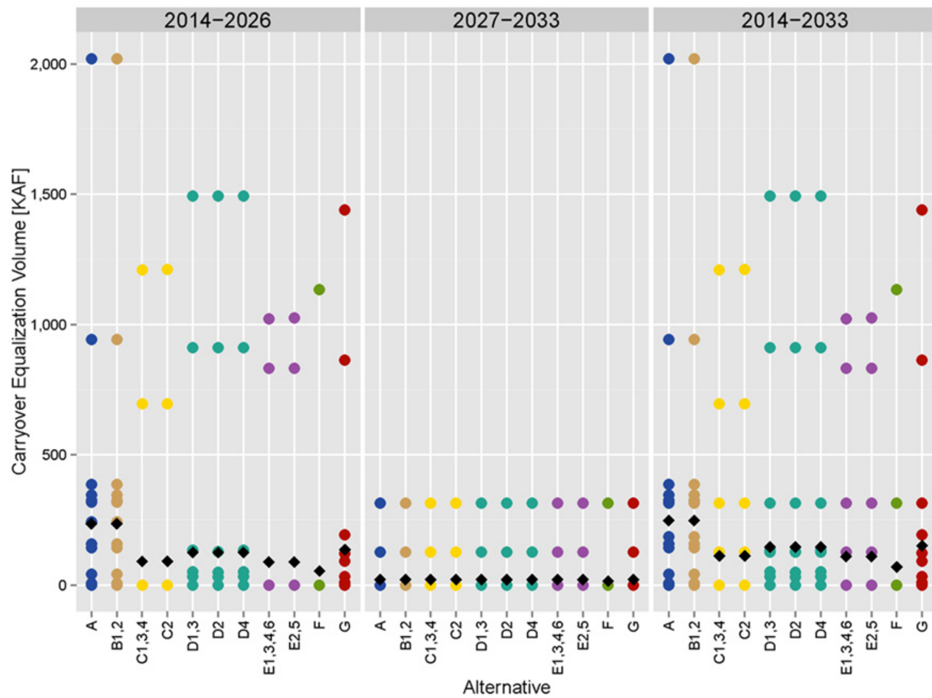

FIGURE D-8 Median Volume of Modeled Annual Releases Extending beyond the End of the Water Year Releases by Trace for Each of the Alternatives (Each value represents the median carryover equalization volume for one trace. Because there are few traces with more than one occurrence, the median value typically represents the only nonzero instance. For each alternative there are 21 possible carryover equalization values for each period and alternative combination [21 traces].)

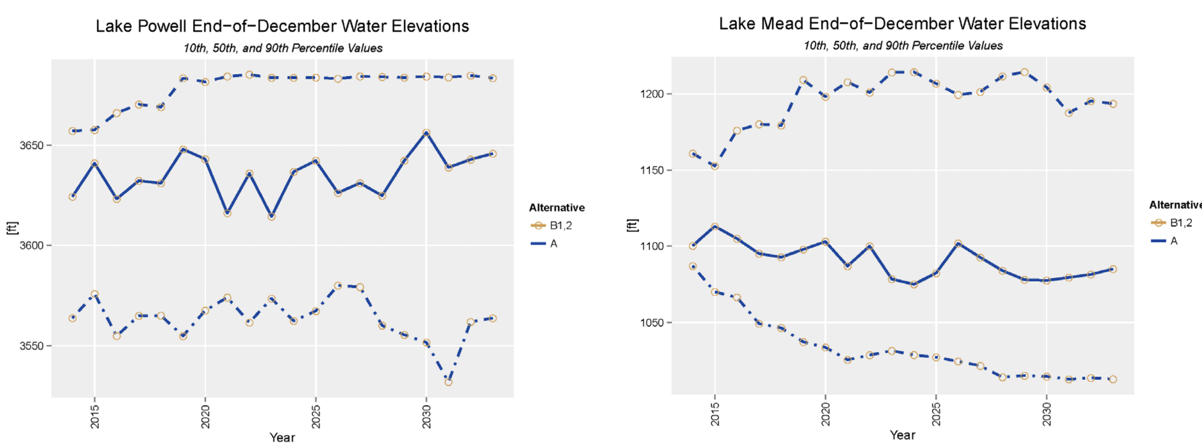

FIGURE D-9 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and B

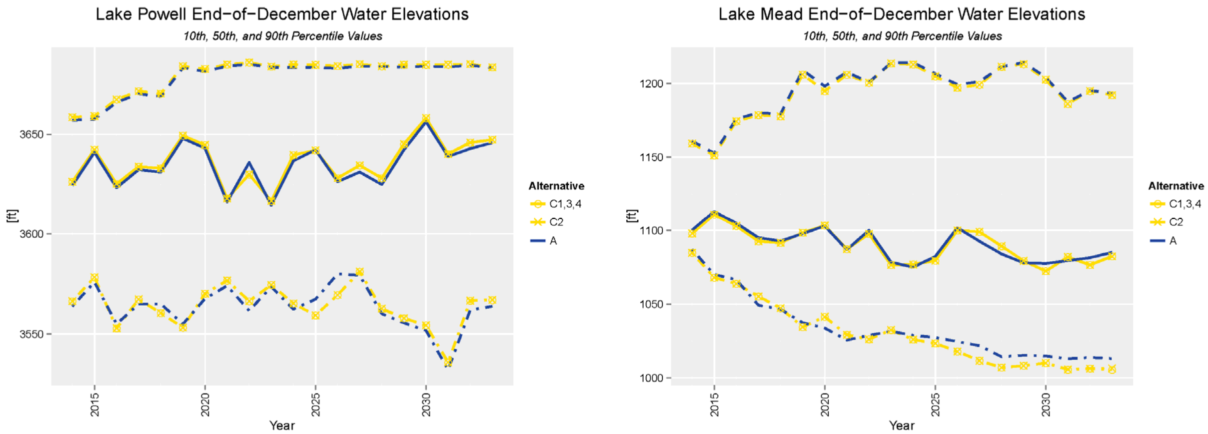

FIGURE D-10 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and C

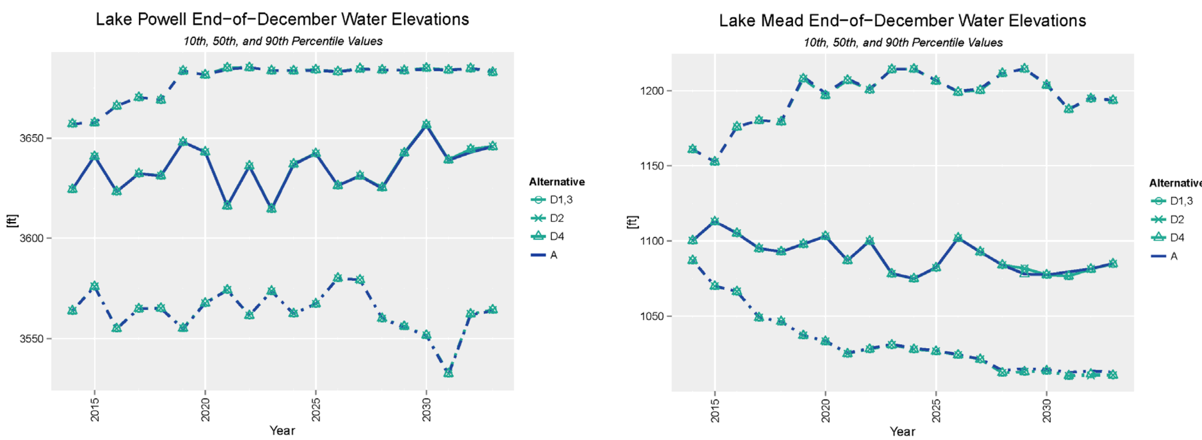

FIGURE D-11 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and D

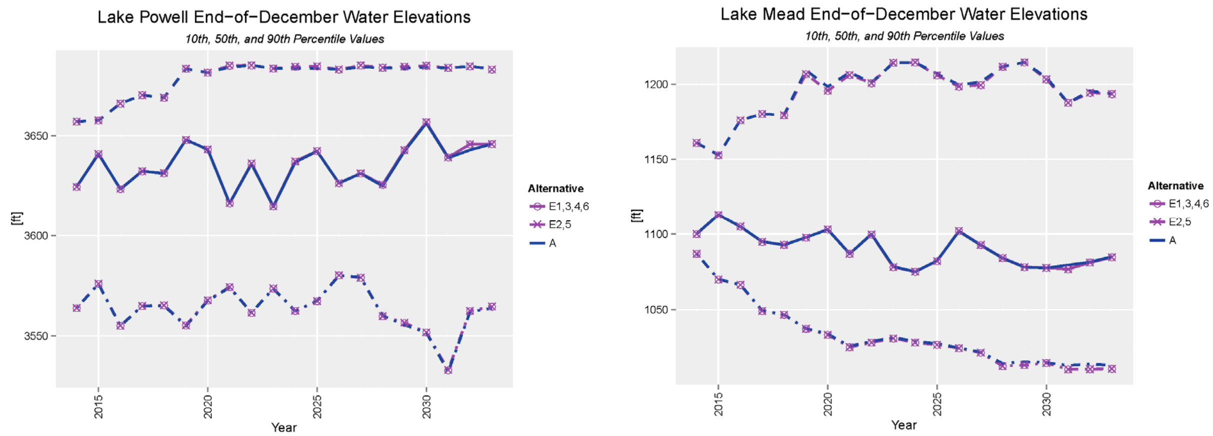

FIGURE D-12 Lake Powell (left) and Lake Mead (right) End-of-December Year Pool Elevation for 21 Hydrology Traces under Alternatives A and E

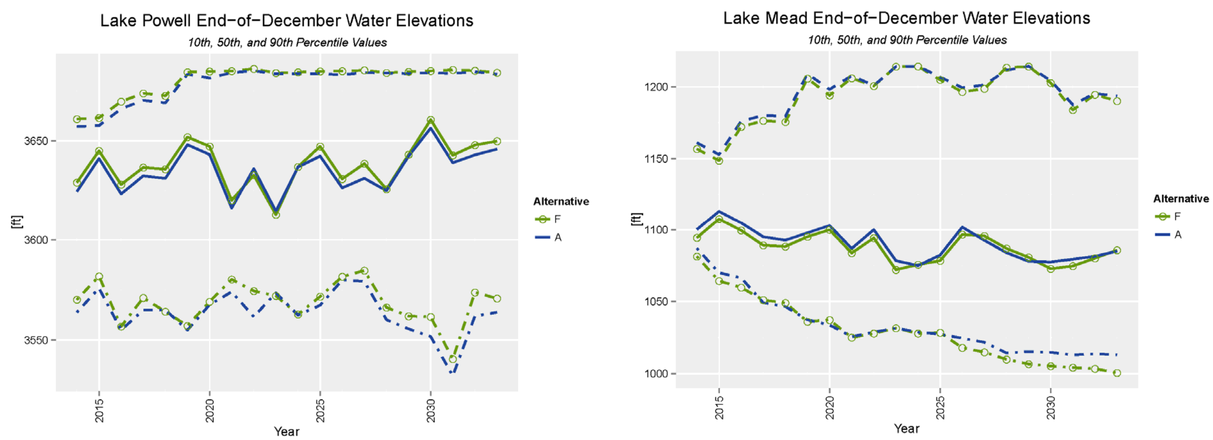

FIGURE D-13 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and F

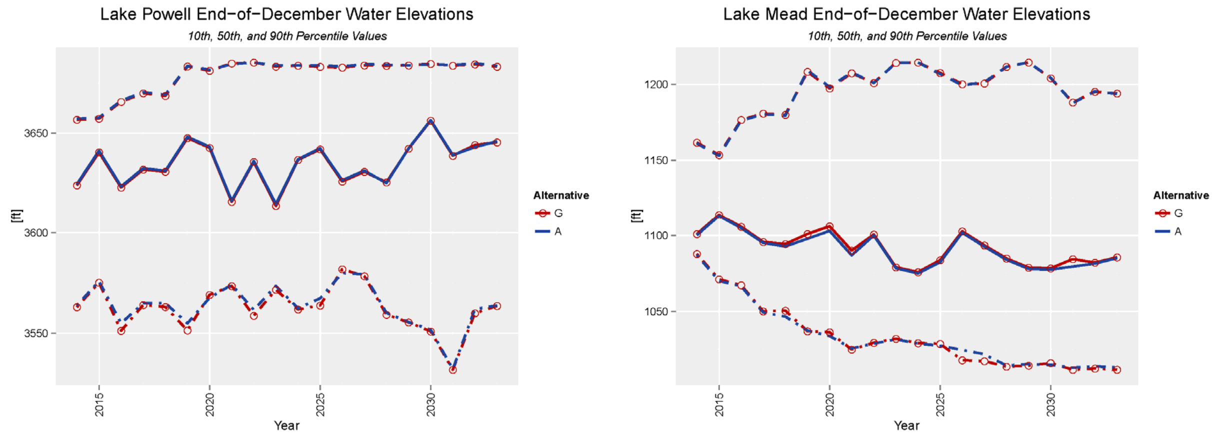

FIGURE D-14 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and G

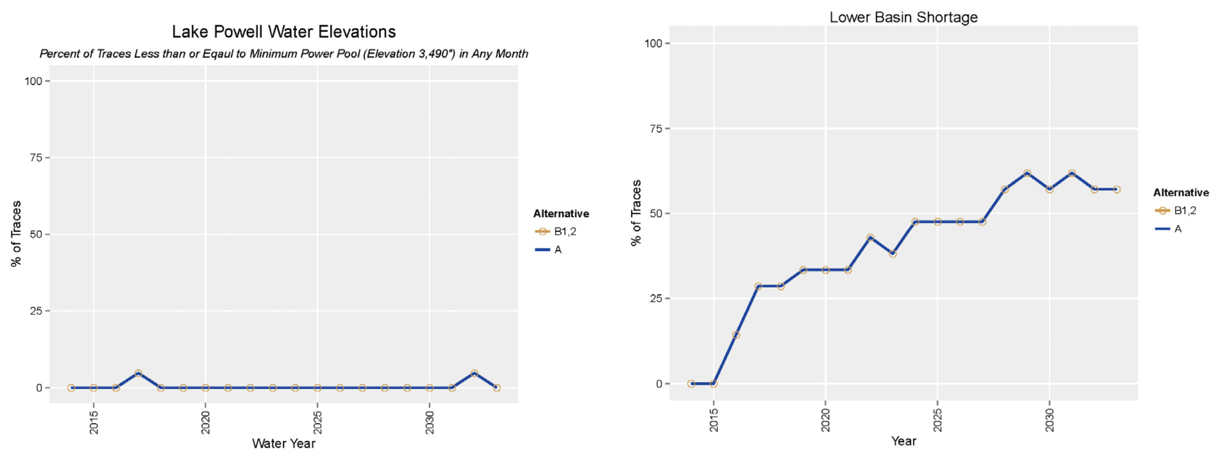

FIGURE D-15 Percent of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percent of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and B

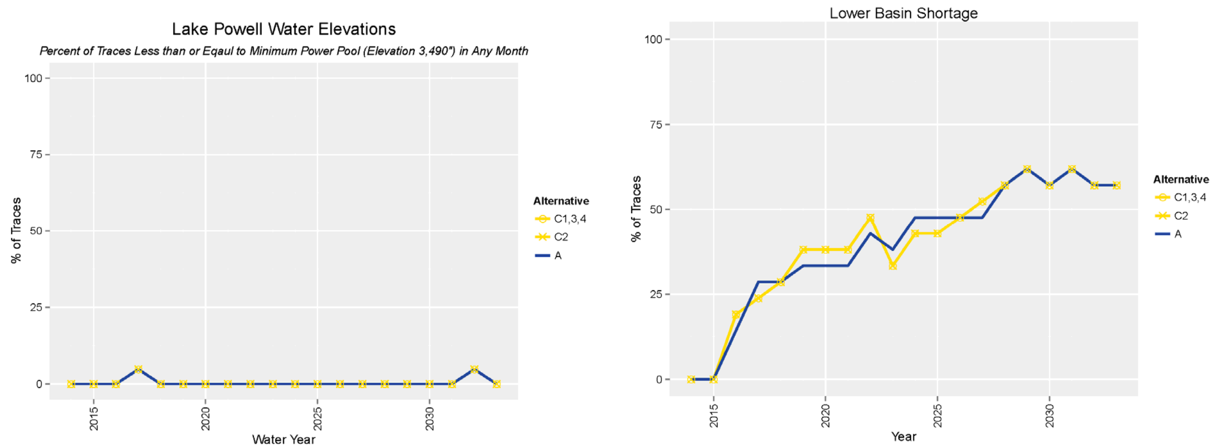

FIGURE D-16 Percent of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percent of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and C

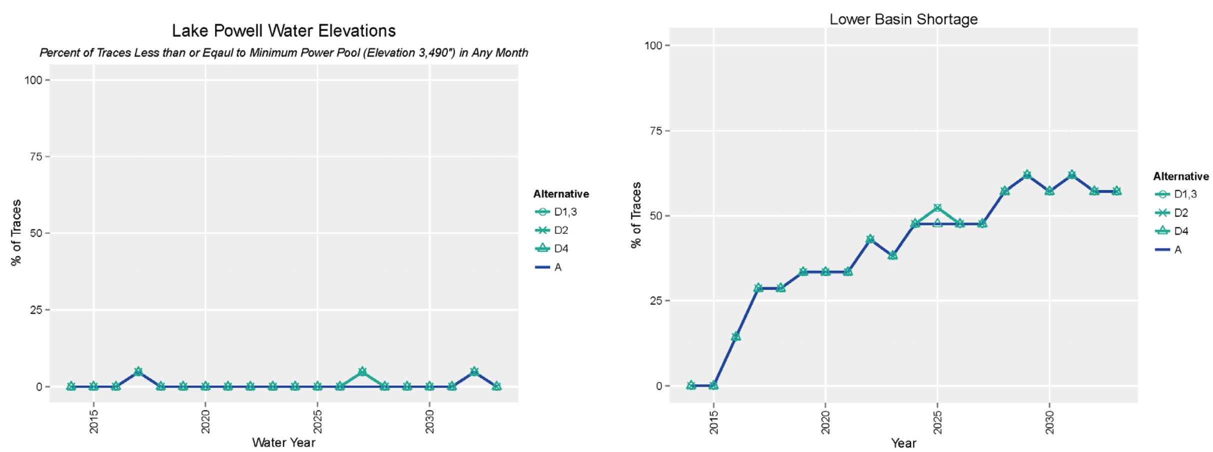

FIGURE D-17 Percent of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percent of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and D

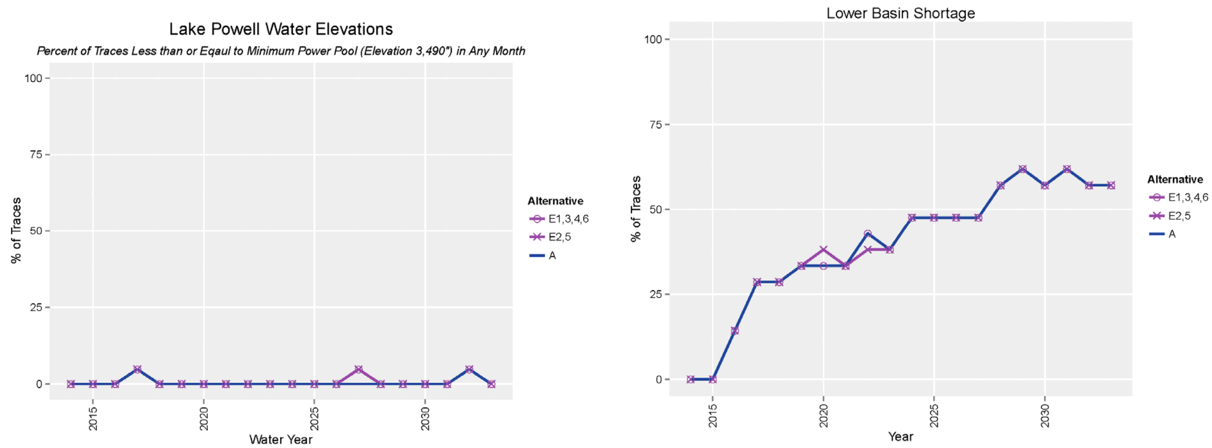

FIGURE D-18 Percent of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percent of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and E

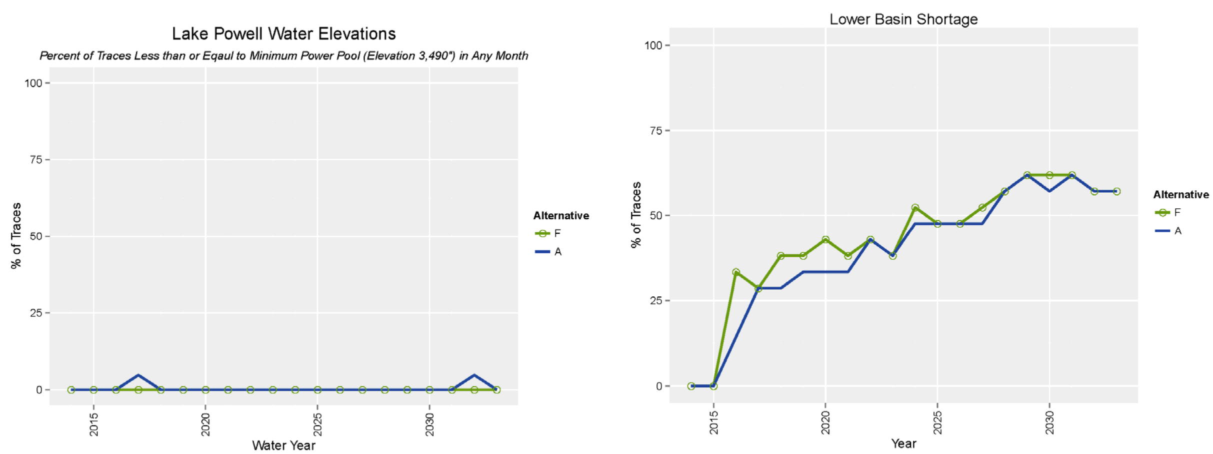

FIGURE D-19 Percent of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percent of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and F

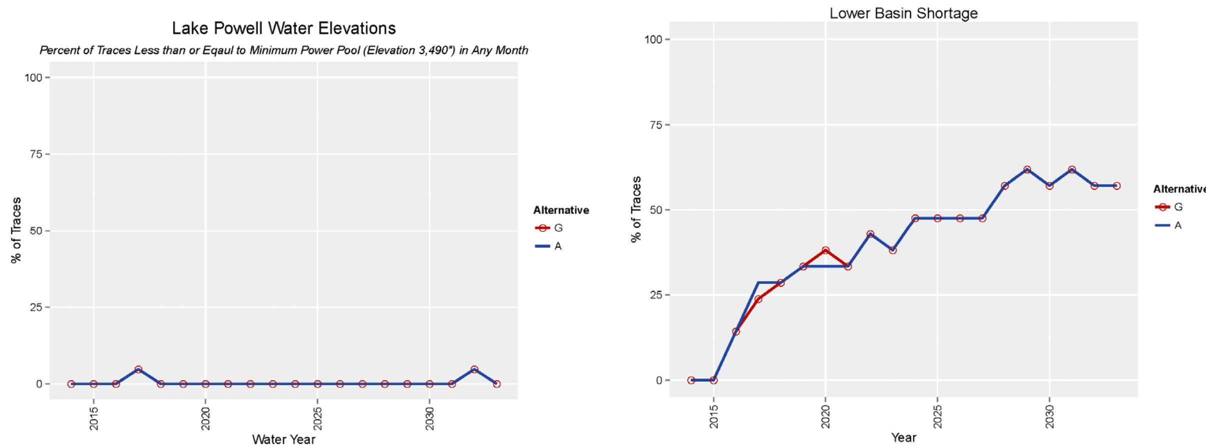

FIGURE D-20 Percent of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percent of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and G

D.3 REFERENCES

Butler, R.A., 2011, *Modeling Techniques to Assess Long-term Reliability of Environmental Flows in Basin Scale Planning*, Master's Thesis, University of Colorado.

DOI (U.S. Department of the Interior), 2007, *Record of Decision for Colorado River Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead*.

Ouarda, T., D. Labadie, and D. Fontare, 1997, "Indexed Sequential Hydrologic Modeling for Hydropower Capacity Estimates," *Journal of the American Water Resources Association* 33(6), Dec.

Reclamation (Bureau of Reclamation), 2006a, *Record of Decision for the Navajo Reservoir Operations, Navajo Unit–San Juan River New Mexico, Colorado, Utah, Final Environmental Impact Statement*.

Reclamation, 2006b, *Record of Decision for the Operation of Flaming Gorge Dam Final Environmental Impact Statement*.

Reclamation, 2007, *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead Final Environmental Impact Statement*.

Reclamation, 2012a, *Colorado River Basin Water Supply and Demand Study*, Technical Report B—Water Supply Assessment.

Reclamation, 2012b, *Colorado River Basin Water Supply and Demand Study*, Technical Report C—Water Demand Assessment.

Reclamation, 2012c, *Record of Decision for the Aspinall Unit Operations, Final Environmental Impact Statement.*

Zagona, E., T. Fulp, R. Shane, T. Magee, and H. Goranflo, 2001, "RiverWare™: A Generalized Tool for Complex Reservoir Systems Modeling," *Journal of the American Water Resources Association* 37(4):913–929.

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