Appendix I

Sensitivity Analysis – Effects of Alternate Upper Basin Demand Scenarios on Operations at Lake Powell and Lake Mead

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Acronyms and Abbreviations

Acronym or Abbreviation	Full Phrase
2007 Interim Guidelines	2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead
2016 UCRC	Upper Colorado River Commission Updated 2016 Depletion Demand Schedule
CCS	Continued Current Strategies
CRSS	Colorado River Simulation System
CU&L	consumptive use and loss
DMDU	Decision Making Under Deep Uncertainty
EIS	environmental impact statement
EOCY	end of calendar year
EOWY	end of water year
kaf	thousand acre-feet
LB Priority	Lower Basin Priority
maf	million acre-feet
Mexico	United Mexican States
PIP	Powell Infrastructure Protection
Reclamation	Bureau of Reclamation

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Appendix I. Sensitivity Analysis – Effects of Alternate Upper Basin Demand Scenarios on Operations at Lake Powell and Lake Mead

I.1 Introduction

Future water depletion demands are required inputs to the Colorado River Simulation System (CRSS) and are one of the key future uncertainties for which assumptions must be developed. This appendix presents a sensitivity analysis that evaluates how future depletion demand assumptions influence modeled system conditions and vulnerabilities. Because of hydrologic and institutional differences between the Upper and Lower Basins, scenarios are treated differently for each basin.

In the Upper Basin, hydrology varies significantly both geographically and from year to year, resulting in shortages when the available supply is insufficient to meet demands. Because water users are subject to this hydrologic variability and the Upper Basin is currently using less than its 7.5 million acre-feet (maf) apportionment, future depletion demand scenarios generally assume depletions will increase over time. In contrast, Lower Basin demands are assumed to equal full apportionment and are met through deliveries from Lake Mead, adjusted for tributary inflows and losses below the reservoir. Shortages in the Lower Basin arise primarily through prescribed delivery reductions under existing operational guidelines and agreements, including shortages and contributions established in the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead and the 2019 Drought Contingency Plan.

Long-term planning studies in the Basin have typically used narrative-based scenarios to project future demands, often assuming increasing Upper Basin demands and fixed apportionments for the Lower Division States and the United Mexican States (Mexico) (7.5 maf and 1.5 maf, respectively), with reductions implemented according to operating policies. Although useful, narrative-based scenarios embed assumptions about the timing and magnitude of future change, making it difficult to isolate the relationships between input assumptions and modeled system vulnerabilities.

The purpose of this sensitivity analysis is to evaluate how alternatives respond to different Upper Basin demand assumptions (differences in Lower Basin demands are already represented through the alternatives' shortage and surplus provisions). To more transparently examine how combinations of supply and demand affect system vulnerability, this appendix evaluates multiple Upper Basin depletion demand scenarios, including several steady-state depletion demand levels. These steady-state scenarios span a broad range of plausible future depletion demands without relying on narrative assumptions about how those depletion demands may evolve over time.

The analysis performed in this appendix is designed to inform a comparison among alternatives in this Final Environmental Impact Statement (EIS) and is not an interpretation or determination of the quantity of water legally available for use in the Upper Basin under the Law of the River and existing legal frameworks.

The Upper Basin depletion demand scenarios evaluated in this sensitivity analysis include:

- Upper Colorado River Commission's updated 2016 Depletion Demand Schedule (2016 UCRC)[1]
- 90 percent 2016 UCRC
- Steady-State 4.5 maf
- Steady-State 5.0 maf
- Steady-State 5.5 maf
- Steady-State 6.0 maf

Section I.2 describes these scenarios in more detail, and **Section I.3** presents a sensitivity analysis comparing the effects of the different depletion demand scenarios on system metrics, robustness, and vulnerability across the alternatives evaluated in this Final EIS.

I.2 Alternative Upper Basin Depletion Demand Scenarios

The 2016 UCRC depletion demand schedule, adopted by the Upper Colorado River Commission on June 14, 2022, is the depletion demand scenario used in the official version of CRSS and the depletion demand scenario used in the Final EIS modeling outside of this sensitivity analysis[2]. This depletion demand schedule is provided by the Upper Division States and the UCRC on a decadal and sector basis; the Bureau of Reclamation (Reclamation) then worked with the states to disaggregate to the spatial (sector by CRSS sub-basin) and temporal (monthly) level necessary for CRSS. The Arizona portion of the Upper Basin demand schedule was developed by Reclamation and is primarily comprised of Navajo Nation uses. The representation of the Upper Colorado Basin Tribes in the UCRC depletion demand schedule was presented in documentation dated July 13, 2022, that outlines the differences between the 2018 Tribal Water Study demand schedules and the

[1] Upper Colorado River Commission (UCRC) & Upper Division States. (2022, June 14). *Combined Resolution and Updated 2016 Depletion Demand Schedule*. Upper Colorado River Commission. Retrieved from http://www.ucrcommission.com/wp-content/uploads/2022/06/UCRC-and-Upper-Division-States-Combined-Resolution-and-Updated-2016-Depletion-Demand-Schedule-June-14-2022-1.pdf.

[2] CRSS explicitly models select reservoir evaporation, so the demand schedules used in CRSS do not include reservoir evaporation from Lake Powell, and Flaming Gorge, Blue Mesa, Morrow Point, Navajo, McPhee, Dillon, Granby, Homestake, and Willow Creek Reservoirs.

updated 2016 Depletion Demand Schedule[3,4]. See **Appendix L**, Upper Division States Depletion Schedules, for additional details.

For this sensitivity analysis, five additional Upper Basin depletion demand scenarios were developed using the 2016 UCRC depletion demand schedule as the baseline. The "90 percent 2016 UCRC" scenario was created by multiplying the 2016 UCRC depletion demand schedule by 0.9 for all months. Four additional steady-state depletion demand scenarios span a range of plausible future depletion demands from 4.5 to 6.0 maf in 0.5-maf increments. These steady-state scenarios were created by scaling the 2042 depletion demands from the 2016 UCRC depletion demand schedule so that the total Upper Basin depletion demand equals the target steady-state volume. The year 2042 was selected because it is the midpoint of a 30-year simulation period[5]. Together, these incremental steady-state depletion demand scenarios allows for a more systematic analysis of how combinations of supply and depletion demands affect system vulnerability.

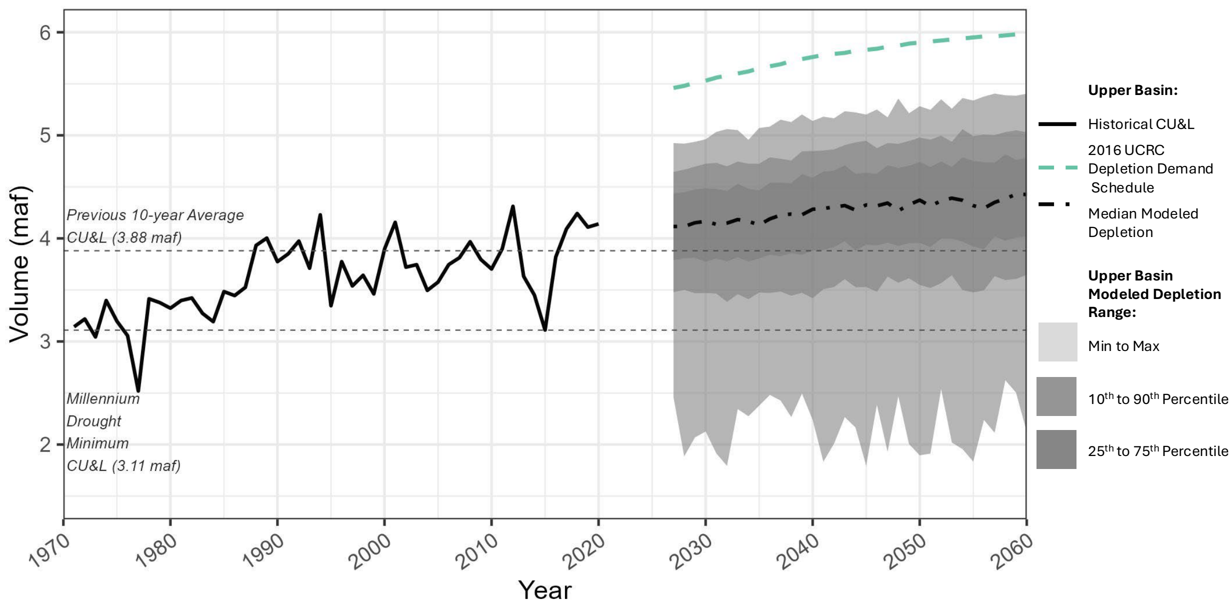
Figure I-1 through **Figure I-6** show the six Upper Basin depletion demand scenarios used in this sensitivity analysis, along with the modeled Upper Basin depletions from the Continued Current Strategies (CCS) Comparative Baseline. For each depletion demand scenario, modeled Upper Basin depletions under the other alternatives would be very similar to those under CCS because all alternatives use the same assumptions for hydrology and modeled operations in reservoirs and reaches above Lake Powell. The only differences in modeled Upper Basin depletions occur when Powell Infrastructure Protection (PIP) releases are made, which differ among alternatives. PIP releases are made from Flaming Gorge, Blue Mesa, or Navajo when Lake Powell reaches low elevations (see **Appendix A**, CRSS Modeling Assumptions, for more details). These figures show how the modeled Upper Basin depletions compare to historical consumptive use and to the depletion demand schedule for a given depletion demand scenario. Because the results would not vary much by alternative, only CCS results are included.

The 2016 UCRC (**Figure I-1**) and 90 percent 2016 UCRC (**Figure I-2**) depletion demand scenarios are the only two scenarios that vary over time. The 2016 UCRC depletion demand scenario begins with a scheduled depletion demand of 5.46 maf in 2027 and increases to a maximum scheduled depletion demand of 5.99 maf in 2060. The 90 percent 2016 UCRC depletion demand schedule is 10 percent lower, with a beginning scheduled depletion demand of 4.91 maf in 2027 and increasing to a maximum scheduled depletion demand of 5.39 maf in 2060. **Appendix L,** Upper Division States Depletion Schedules, provides additional background on the development of the 2016 UCRC

[3] The Post-2026 modeling is based on water rights of the Ute Indian Tribe of the Uintah & Ouray Reservation that have not been ratified by all parties. The Ute Indian Tribe of the Uintah & Ouray Reservation has federally reserved Indian water rights, a portion of which were federally decreed in 1923 and a portion of which have been separately recognized and put to use by the United States and the State of Utah, which are not fully resolved.
[4] The information reflected in the baseline depletion demands schedule relies on information about projected future Tribal water demands. The projections were based on information compiled in a Colorado River Basin Ten Tribes Partnership Tribal Water Study (December 2018). As discussed in Chapter 8 of that Study, the technical approach was based on the best science and information available at the time, given limitations related to timeframes and resource constraints, among other things. The Navajo Nation informed Reclamation that it was developing updated projections as part of its water development planning. Reclamation worked with the Navajo Nation as needed to update demand schedules prior to the publication of the Final EIS.
[5] This was selected before it was known if the Draft EIS would analyze 30 or 34 years and the depletion demand scenarios were not modified between the Draft and Final EIS.

schedule and its integration into CRSS. In general, these schedules represent anticipated water demands under assumed economic and hydrologic conditions, while the CRSS-simulated depletions (modeled Upper Basin depletions) represent modeled consumptive use under simulated hydrologic conditions.

Figure I-1
Annual Upper Basin Historical Consumptive Uses and Losses with 2016 UCRC Future Depletion Demand Schedule and Upper Basin Modeled Depletions, Continued Current Strategies Comparative Baseline

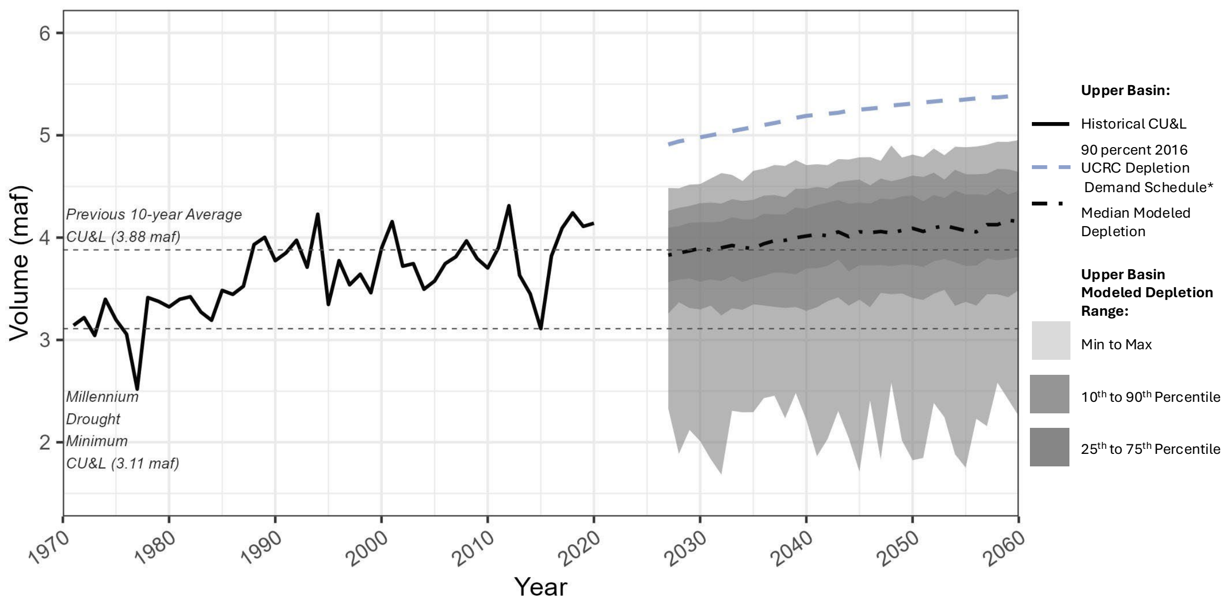


Note: Future depletion demand schedules exclude reservoir evaporation volumes from reservoirs undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation[2]. CRSS simulates consumptive use based on the provided depletion demand scenarios, and the available supply in each year of each simulation. To be comparable to the CRSS input and results, the historical consumptive uses and losses (CU&L) does not include reservoir evaporation undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation but does include remaining Upper Basin reservoirs.

Across all six scenarios, modeled Upper Basin depletions (shown as shaded areas in **Figure I-1** through **Figure I-6**) are lower than the input Upper Basin depletion demand schedule(shown as the colored dashed line in **Figure I-1** through **Figure I-6**), indicating that the CRSS simulations result in some level of modeled shortage in every scenario.

For the steady-state depletion demand scenarios (**Figure I-3** through **Figure I-6**), the median modeled Upper Basin depletions exhibit a slight decreasing trend over the simulation period. This trend reflects the future hydrology ensemble, which also exhibits a slight decreasing trend over time. For more information about the future hydrology used in this analysis, see **Appendix F**, Approach to Hydrologic Uncertainty. Further discussion on the Upper Basin modeled depletions is included below in **Section I.3.1**, Upper Basin Modeled Depletions.

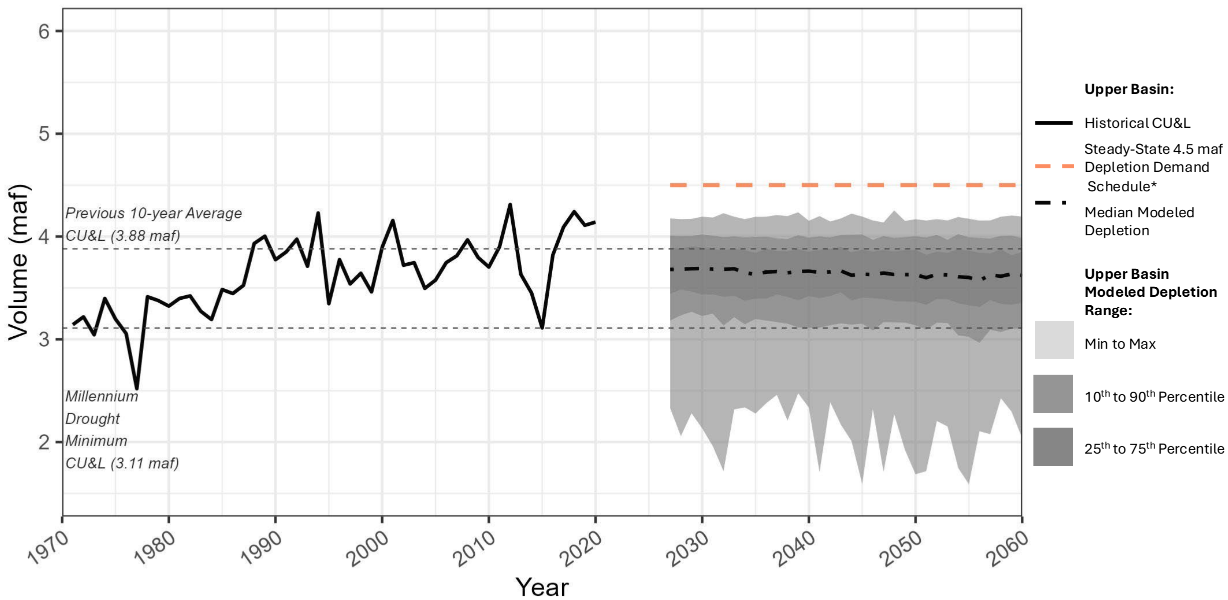
Figure I-2
Annual Upper Basin Historical Consumptive Uses and Losses with 90 percent 2016 UCRC Future Depletion Demand Schedule and Upper Basin Modeled Depletions, Continued Current Strategies Comparative Baseline



* The 90 percent 2016 UCRC depletion demand schedule is one of six depletion demand scenarios used in the sensitivity analysis in this appendix.

Note: Future depletion demand schedules exclude reservoir evaporation volumes from reservoirs undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation[2]. CRSS simulates consumptive use based on the provided depletion demand scenarios, and the available supply in each year of each simulation. To be comparable to the CRSS input and results, the historical CU&L does not include reservoir evaporation undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation but does include remaining Upper Basin reservoirs.

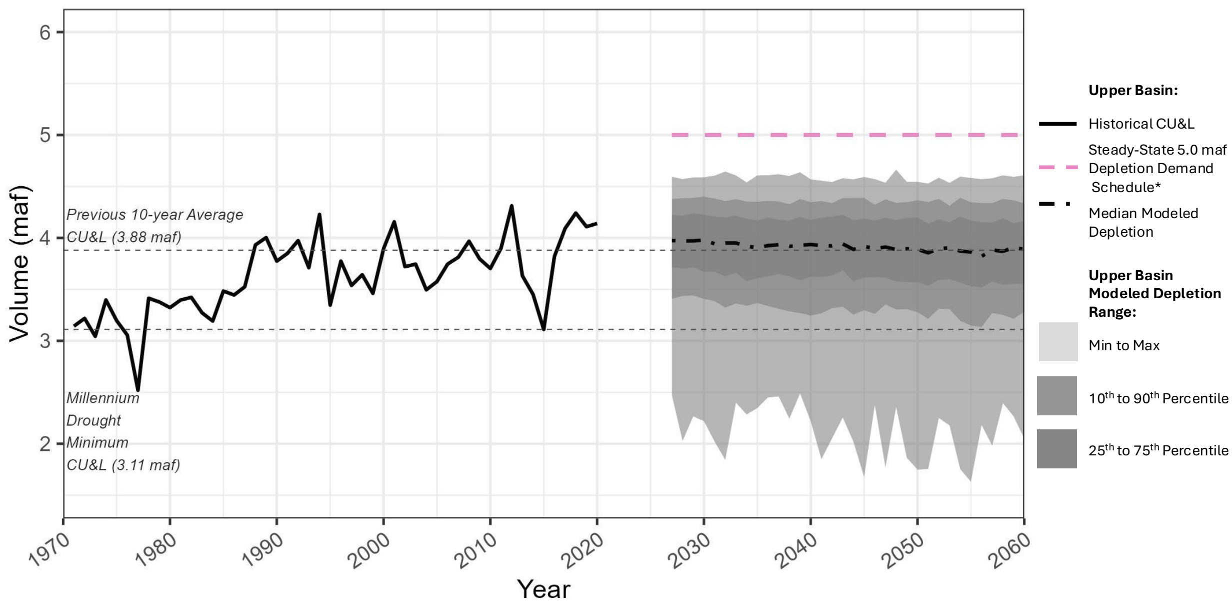
Figure I-3
Annual Upper Basin Historical Consumptive Uses and Losses with Steady-State 4.5 maf Future Depletion Demand Schedule and Upper Basin Modeled Depletions, Continued Current Strategies Comparative Baseline



* The Steady-State 4.5 maf depletion demand schedule is one of six depletion demand scenarios used in the sensitivity analysis in this appendix.

Note: Future depletion demand schedules exclude reservoir evaporation volumes from reservoirs undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation[2]. CRSS simulates consumptive use based on the provided depletion demand scenarios, and the available supply in each year of each simulation. To be comparable to the CRSS input and results, the historical CU&L does not include reservoir evaporation undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation but does include remaining Upper Basin reservoirs.

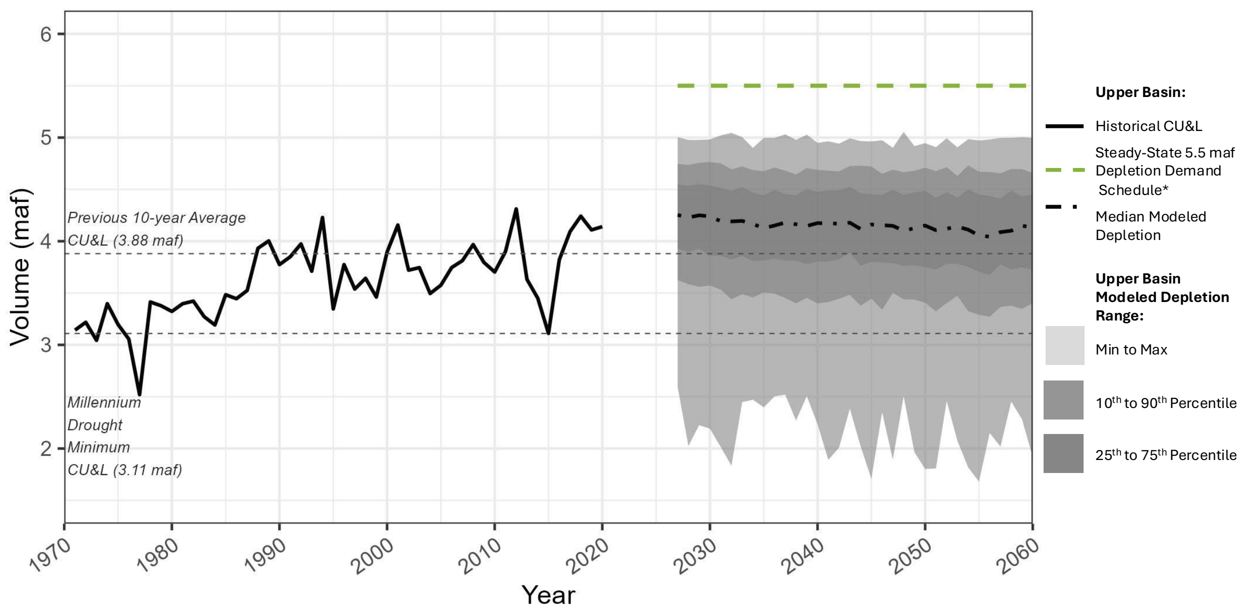
Figure I-4
Annual Upper Basin Historical Consumptive Uses and Losses with Steady-State 5.0 maf Future Depletion Demand Schedule and Upper Basin Modeled Depletions, Continued Current Strategies Comparative Baseline



* The Steady-State 5.0 maf depletion demand schedule is one of six depletion demand scenarios used in the sensitivity analysis in this appendix.

Note: Future depletion demand schedules exclude reservoir evaporation volumes from reservoirs undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation[2]. CRSS simulates consumptive use based on the provided depletion demand scenarios, and the available supply in each year of each simulation. To be comparable to the CRSS input and results, the historical CU&L does not include reservoir evaporation undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation but does include remaining Upper Basin reservoirs.

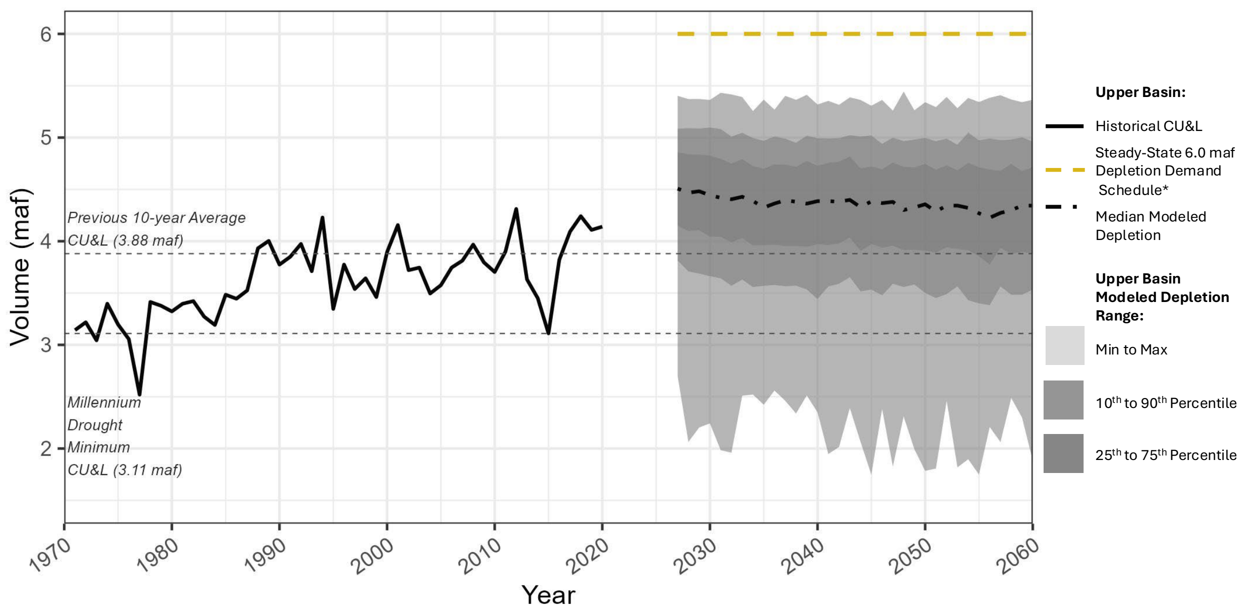
Figure I-5
Annual Upper Basin Historical Consumptive Uses and Losses with Steady-State 5.5 maf Future Depletion Demand Schedule and Upper Basin Modeled Depletions, Continued Current Strategies Comparative Baseline



* The Steady-State 5.5 maf depletion demand schedule is one of six depletion demand scenarios used in the sensitivity analysis in this appendix.

Note: Future depletion demand schedules exclude reservoir evaporation volumes from reservoirs undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation[2]. CRSS simulates consumptive use based on the provided depletion demand scenarios, and the available supply in each year of each simulation. To be comparable to the CRSS input and results, the historical CU&L does not include reservoir evaporation undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation but does include remaining Upper Basin reservoirs.

Figure I-6
Annual Upper Basin Historical Consumptive Uses and Losses with Steady-State 6.0 maf Future Depletion Demand Schedule and Upper Basin Modeled Depletions, Continued Current Strategies Comparative Baseline



* The Steady-State 6.0 maf depletion demand schedule is one of six depletion demand scenarios used in the sensitivity analysis in this appendix.
Note: Future depletion demand schedules exclude reservoir evaporation volumes from reservoirs undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation[2]. CRSS simulates consumptive use based on the provided depletion demand scenarios, and the available supply in each year of each simulation. To be comparable to the CRSS input and results, the historical CU&L does not include reservoir evaporation undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation but does include remaining Upper Basin reservoirs.

I.3 Sensitivity Analysis

For this sensitivity analysis, the six Upper Basin depletion demand scenarios were evaluated in combination with the seven different reservoir operating policies analyzed in this Final EIS:

- No Action Alternative
- Basic Coordination Alternative
- Enhanced Coordination Alternative
- Maximum Operational Flexibility Alternative
- Supply Driven Alternative (Lower Basin [LB Priority] approach)
- Representative Preferred Alternative
- Continued Current Strategies (CCS) Comparative Baseline

Only the Supply Driven Alternative using the LB Priority shortage distribution approach is used for this sensitivity analysis, as the emphasis is not on how different Lower Division State shortage distributions affect the results.

Each model was run with the same hydrologic ensemble and the initial reservoir conditions used throughout the Final EIS. See **Appendix A**, CRSS Modeling Documentation, for modeling assumptions associated with each alternative, and **Appendix F**, Approach to Hydrologic Uncertainty, and **Appendix G**, Initial Reservoir Conditions, for additional details on hydrology and initial condition assumptions.

The analyses presented in this appendix are based on the Decision Making Under Deep Uncertainty (DMDU) framework used in this Final EIS. DMDU is a non-probabilistic evaluation framework that compares scenarios across a broad range of plausible future conditions and evaluates their performance under varying hydrologic conditions. Additional background and technical information on the DMDU framework are provided in **Appendix E**, DMDU Overview and Approach, and **Chapter 3**, **Section 3.2.6** includes additional details on interpreting the figures and analyses.

The results were analyzed using the following metrics to better understand the impact of the six depletion demand scenarios on "system conditions" under each alternative:

- Upper Basin modeled depletions and modeled shortages
- Lake Powell and Lake Mead pool elevations
- Lee Ferry Compact Point 10-year volume
- Total Lower Basin reductions (shortage plus Lake Mead dead pool-related reductions)

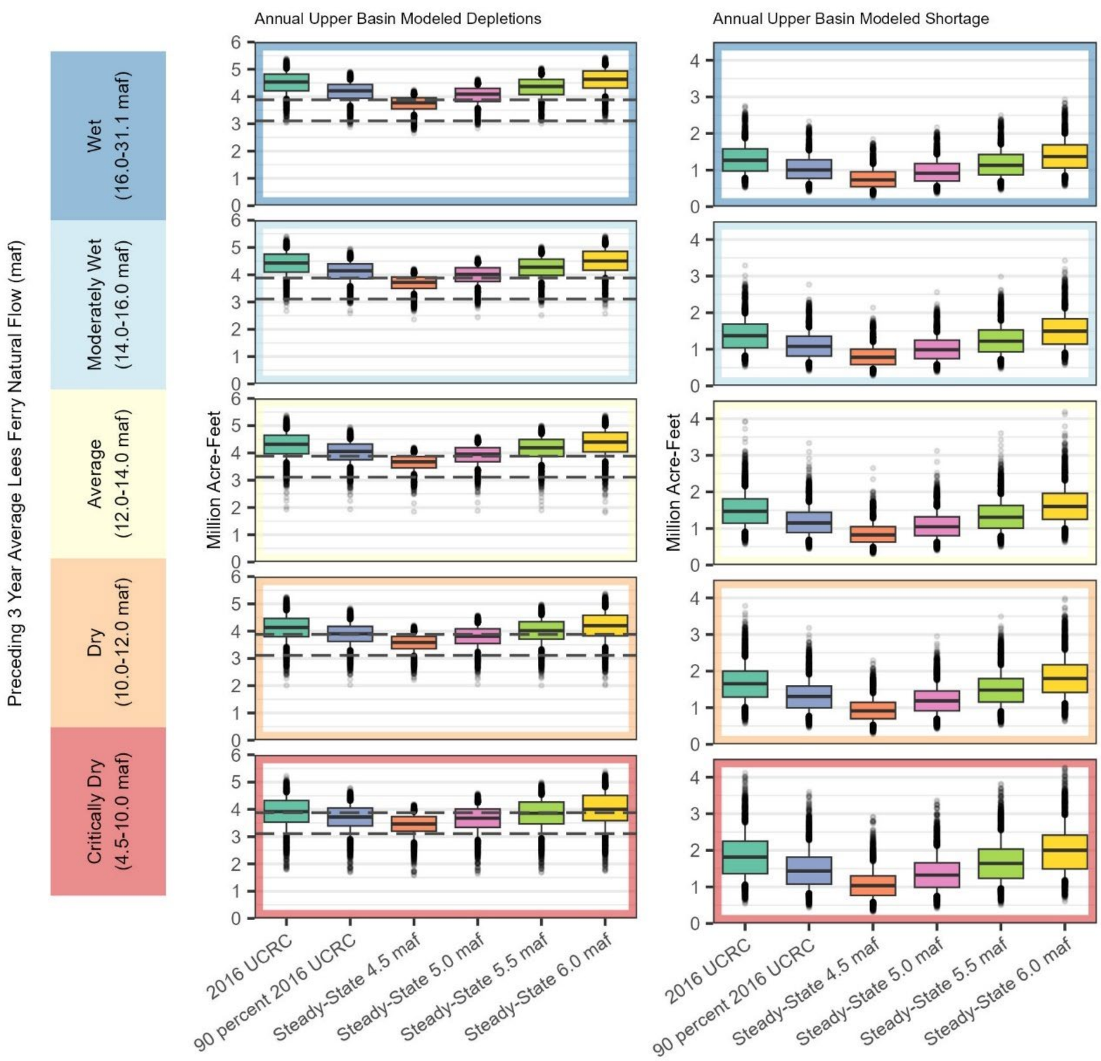
The analysis is organized into four sections. **Section I.3.1** presents Upper Basin modeled depletions and modeled shortages using conditional boxplots. **Section I.3.2** presents Lake Powell and Lake Mead pool elevations, Lee Ferry Compact Point 10-year volume, and total Lower Basin reductions using conditional boxplots. **Sections I.3.3** and **I.3.4** present robustness and vulnerability analyses, respectively, for selected Lake Powell and Lake Mead elevation thresholds.

I.3.1 Upper Basin Modeled Depletions and Modeled Shortages

Figure I-7 shows annual Upper Basin modeled depletions and modeled shortages for the CCS Comparative Baseline across all depletion demand scenarios organized by the preceding three-year average Lees Ferry natural flow. Upper Basin modeled depletions and modeled shortages are only shown for the CCS Comparative Baseline as they do not vary significantly between alternatives, as discussed in **Section I.2**. The bold center line of each box represents the median value. The top and bottom of each box captures the 25th to 75th percentile of the modeled results, respectively. The lines extend to the 10th and 90th percentiles, and the outliers are shown as dots beyond these lines.

Dashed lines on the graph represent the previous 10-year average (3.88 maf) and the millennium drought minimum (3.11 maf) annual Upper Basin consumptive uses and losses, excluding reservoir evaporation for reservoirs with evaporation modeled explicitly in CRSS[2].

Figure I-7
Projected Annual Upper Basin Modeled Depletions and Shortage Across the 2016 UCRC Depletion Demand Schedule and Five Alternate Upper Basin Depletion Demand Scenarios Simulated Using Continued Current Strategies Comparative Baseline



Note: Future depletion demand schedules exclude reservoir evaporation volumes from reservoirs undistributed by state and other reservoirs where CRSS explicitly models reservoir evaporation[2]. CRSS simulates consumptive use based on the provided depletion demand scenarios, and the available supply in each year of each simulation.

In the Dry Flow Category, the median Upper Basin modeled depletion exceeds the 3.88 maf threshold for all depletion demand scenarios except the Steady State 4.5 maf and Steady State 5.0 maf scenarios. For the Steady State 4.5 maf depletion demand scenario, the 75th percentile is within 77.0 thousand acre-feet (kaf) of the average consumptive use over the last 10 years, while the median is 294.0 kaf less than the historical average consumptive use. For the Steady State 5.0 maf depletion demand scenario, the median is 68.0 kaf less than the historical average consumptive use.

The interquartile range of the Upper Basin modeled depletions increases as the average annual depletion demand increases. In the Dry and Critically Dry Flow Categories, the interquartile ranges differ less between the depletion demand scenarios. In drier conditions, limited water availability constrains depletions, so higher depletion demands do not result in proportionally higher depletions. Across all flow categories, the interquartile ranges remain above the minimum annual Upper Basin consumptive uses and losses (excluding reservoir evaporation) from the millennium drought. The Steady State 4.5 maf depletion demand scenario is the only depletion demand scenario with a 75th percentile below the historical average consumptive use of 3.88 maf; this occurs in the Average, Dry and Critically Dry Flow Categories.

Upper Basin modeled shortages were calculated as the difference between the annual Upper Basin depletion demand scenario and the annual Upper Basin modeled depletions. The annual Upper Basin modeled shortages range between 246.0 kaf and 4.25 maf across all depletion demand scenarios, showing that modeled shortages occurred in every year of the model simulation under all analyzed hydrology sequences. Median Upper Basin modeled shortages typically range between 1.0 maf and 2.0 maf. Only the Steady State 6.0 maf depletion demand scenario reaches 2.0 maf of modeled shortage in the Critically Dry Flow Category. Both the magnitude and the interquartile range of Upper Basin modeled shortages increase under drier hydrologic conditions because a smaller portion of the depletion demand can be met. Similarly, Upper Basin modeled shortages increase as depletion demand schedules increase.

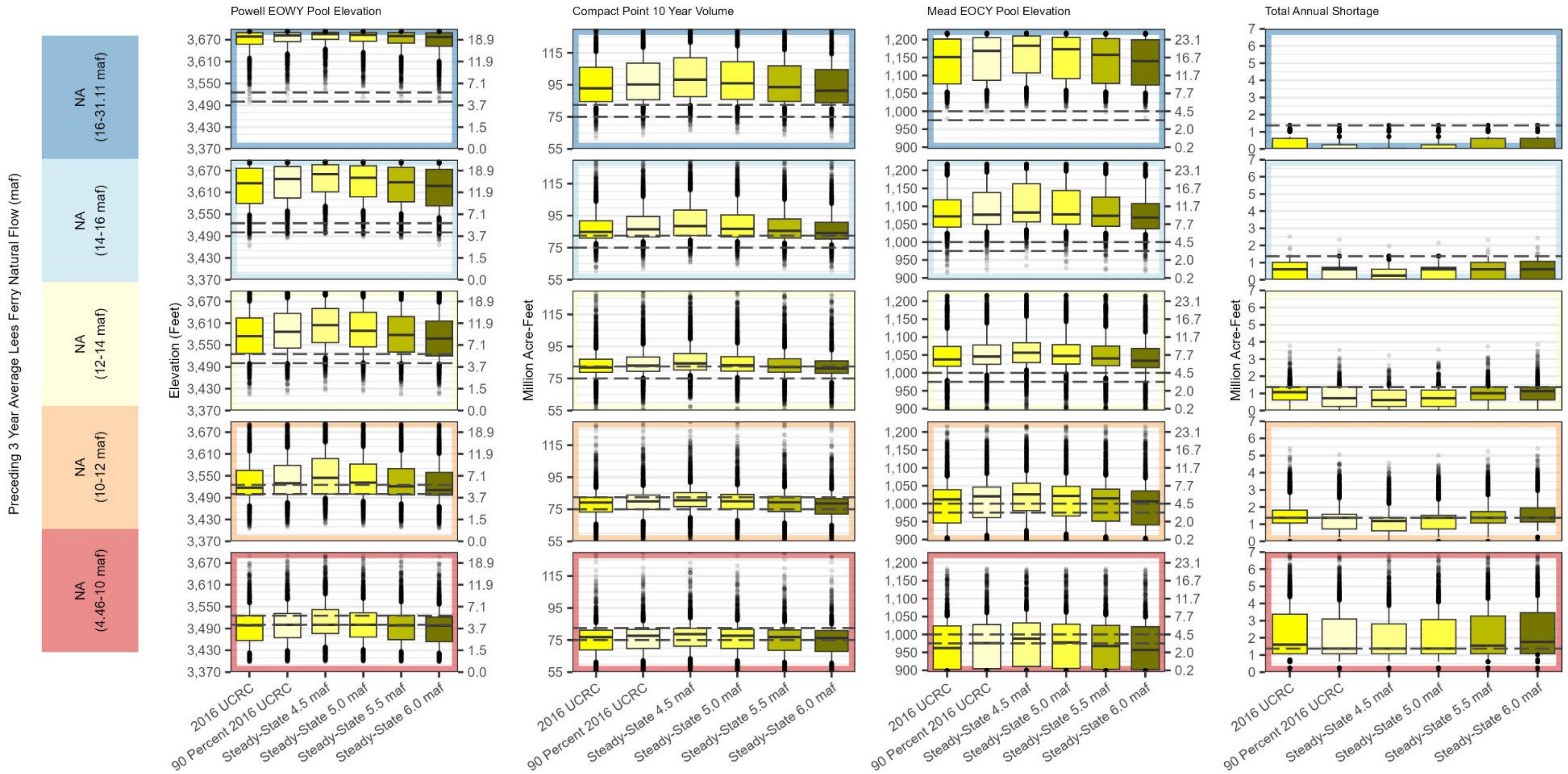
I.3.2 Impact on System Conditions

Figure I-8 through **Figure I-14** show Lake Powell end-of-water-year (EOWY) pool elevations, Lee Ferry Compact Point 10-year volumes, Lake Mead end-of-calendar-year (EOCY) pool elevations, and total Lower Basin shortage by flow category across all depletion demand scenarios for the CCS Comparative Baseline and all alternatives.

Dashed lines are included on the boxplots to identify critical elevations and thresholds. At Lake Powell, elevations 3,525 feet and 3,500 feet are included because of their importance to protecting infrastructure, power generation, and the ability to make downstream deliveries. At Lake Mead, elevations 1,000 feet and 975 feet are highlighted for the same reasons. The flow volumes of 82.5 maf and 75.0 maf are included in the Lee Ferry Compact Point 10-year volume. Finally, the Lower Basin total annual shortage (Lower Basin shortage plus dead pool-related reductions) for each alternative includes a dashed line to indicate the maximum shortage for the alternative. Total annual shortage may exceed this value because it includes dead pool-related reductions.

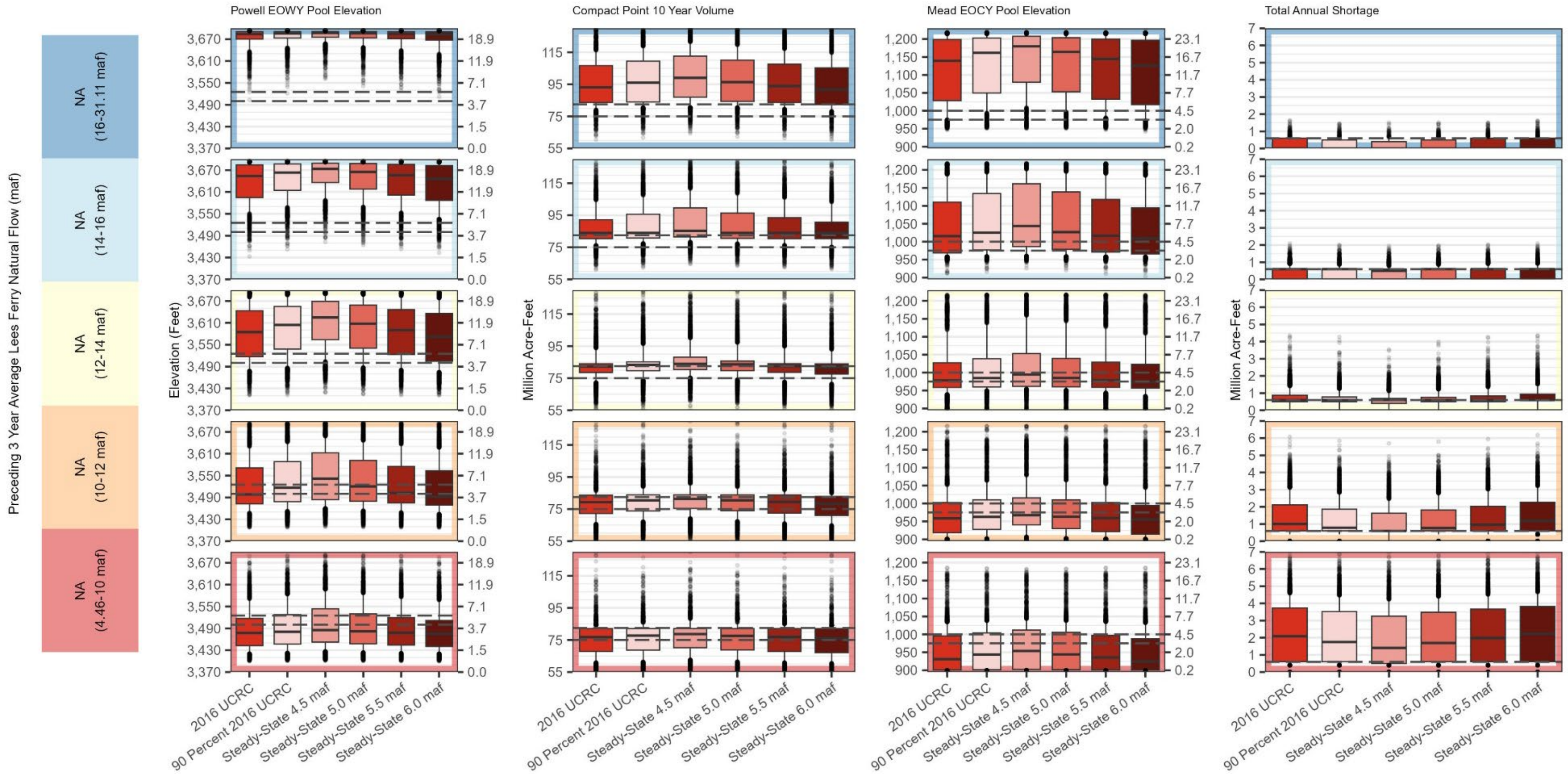
Except for the Supply Driven Alternative (LB Priority Approach), all alternatives and the CCS Comparative Baseline exhibit the same general trend. Compared with higher depletion demand scenarios, lower depletion demand scenarios result in higher Lake Powell elevations, higher Lee Ferry Compact Point 10-year volumes, higher Lake Mead elevations, and lower total Lower Basin shortages. Because higher depletion demand scenarios result in greater modeled Upper Basin depletions (see **Figure I-7**), less water flows into Lake Powell, reducing the volume of water available for release to Lake Mead.

Figure I-8
Lake Powell EOWY Elevation, Lee Ferry Compact Point 10-Year Volumes, Lake Mead EOCY Elevation, and Total Annual Shortage (Lower Basin Shortage and Dead Pool-Related Reductions) for Continued Current Strategies Across the Six Depletion Demand Scenarios



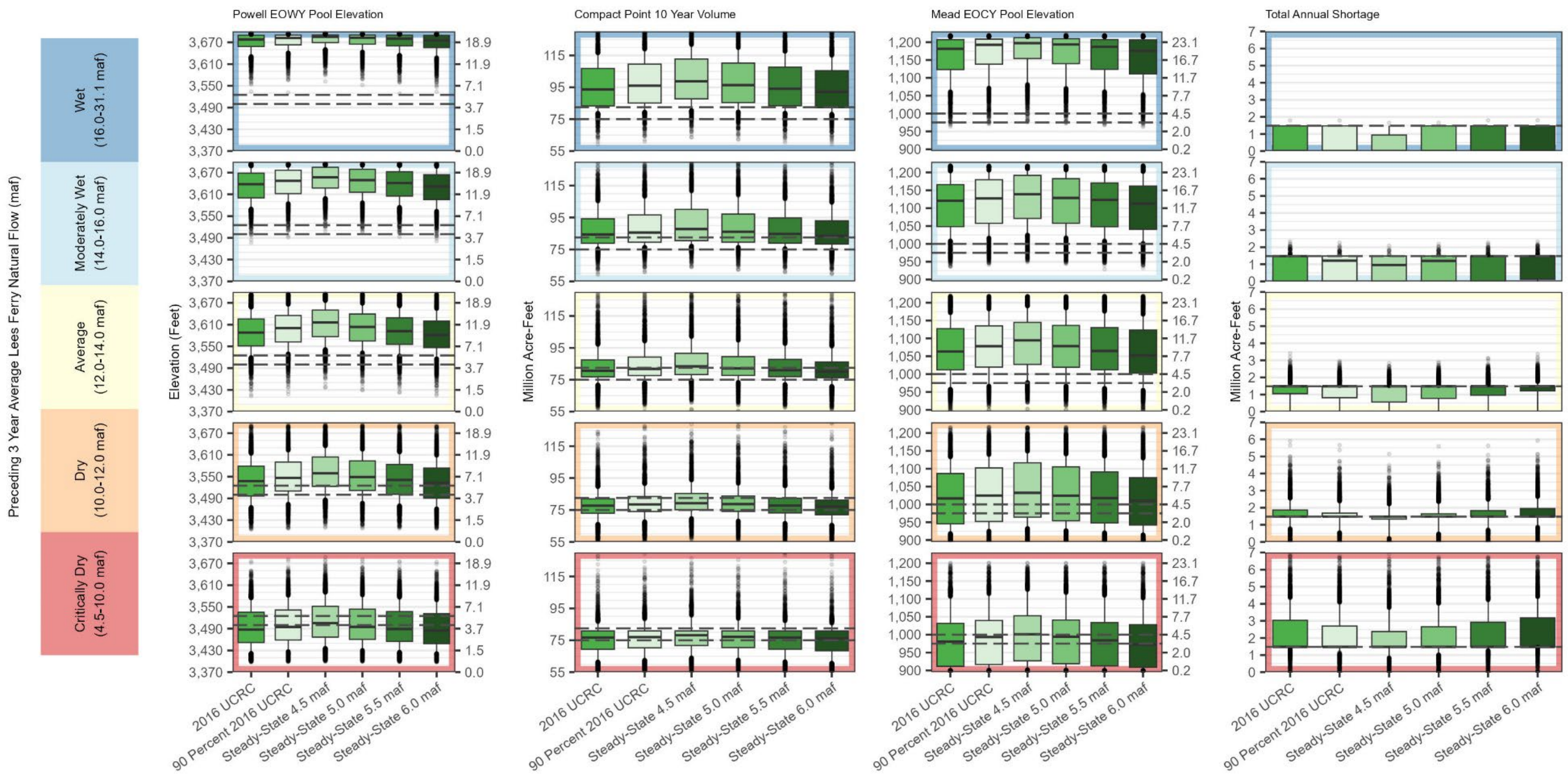
Note: The dashed line in the Total Annual Shortage column indicates a maximum reduction of 1.375 maf in the CCS Comparative Baseline.

Figure I-9
Lake Powell EOWY Elevation, Lee Ferry Compact Point 10-Year Volumes, Lake Mead EOCY Elevation, and Total Annual Shortage (Lower Basin Shortage and Dead Pool-Related Reductions) for the No Action Alternative Across the Six Depletion Demand Scenarios



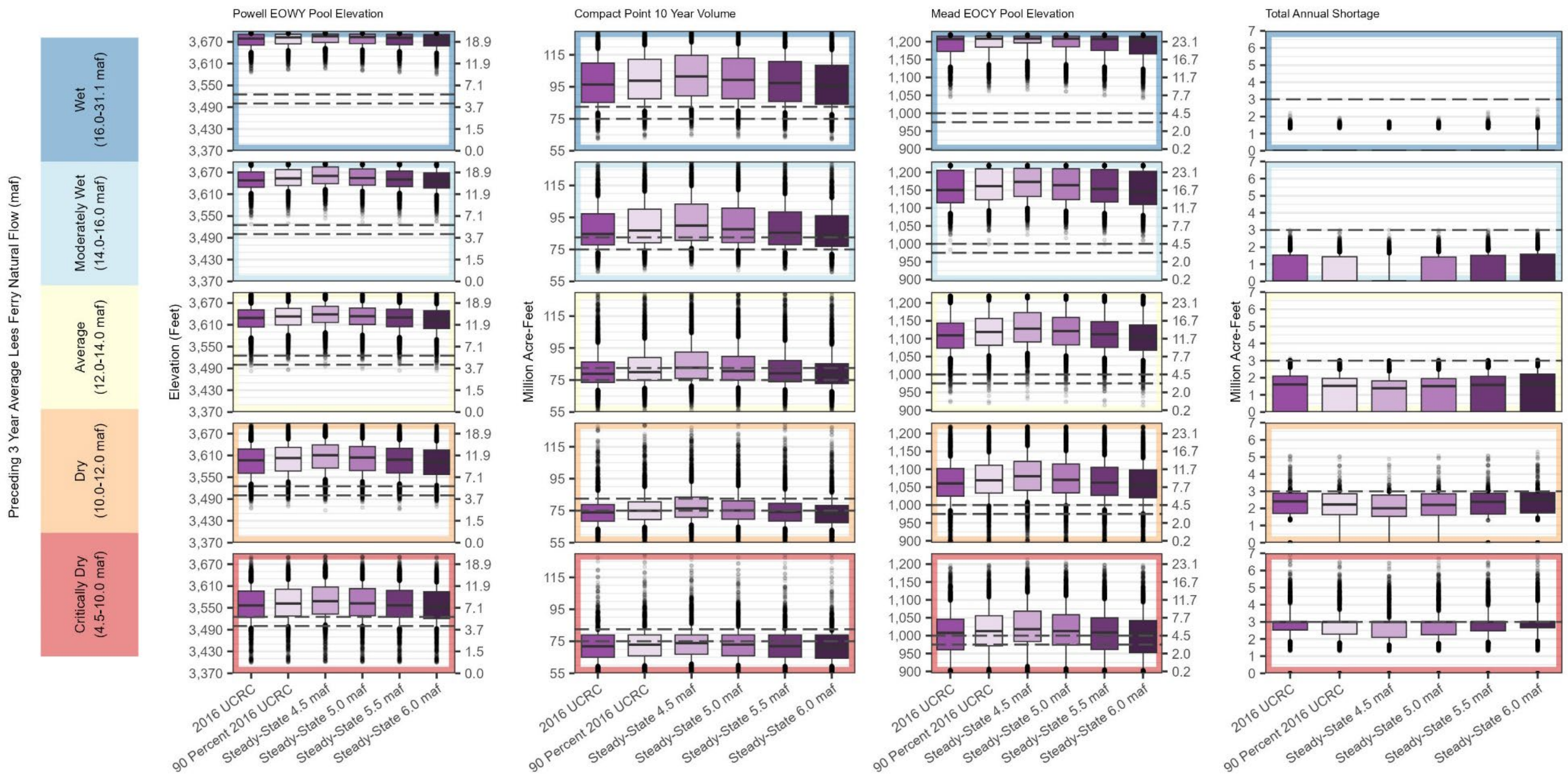
Note: The dashed line in the Total Annual Shortage column indicates a maximum shortage of 0.6 maf in the No Action Alternative.

Figure I-10
Lake Powell EOWY Elevation, Lee Ferry Compact Point 10-Year Volumes, Lake Mead EOCY Elevation, and Total Annual Shortage (Lower Basin Shortage and Dead Pool-Related Reductions) for the Basic Coordination Alternative across the Six Depletion Demand Scenarios



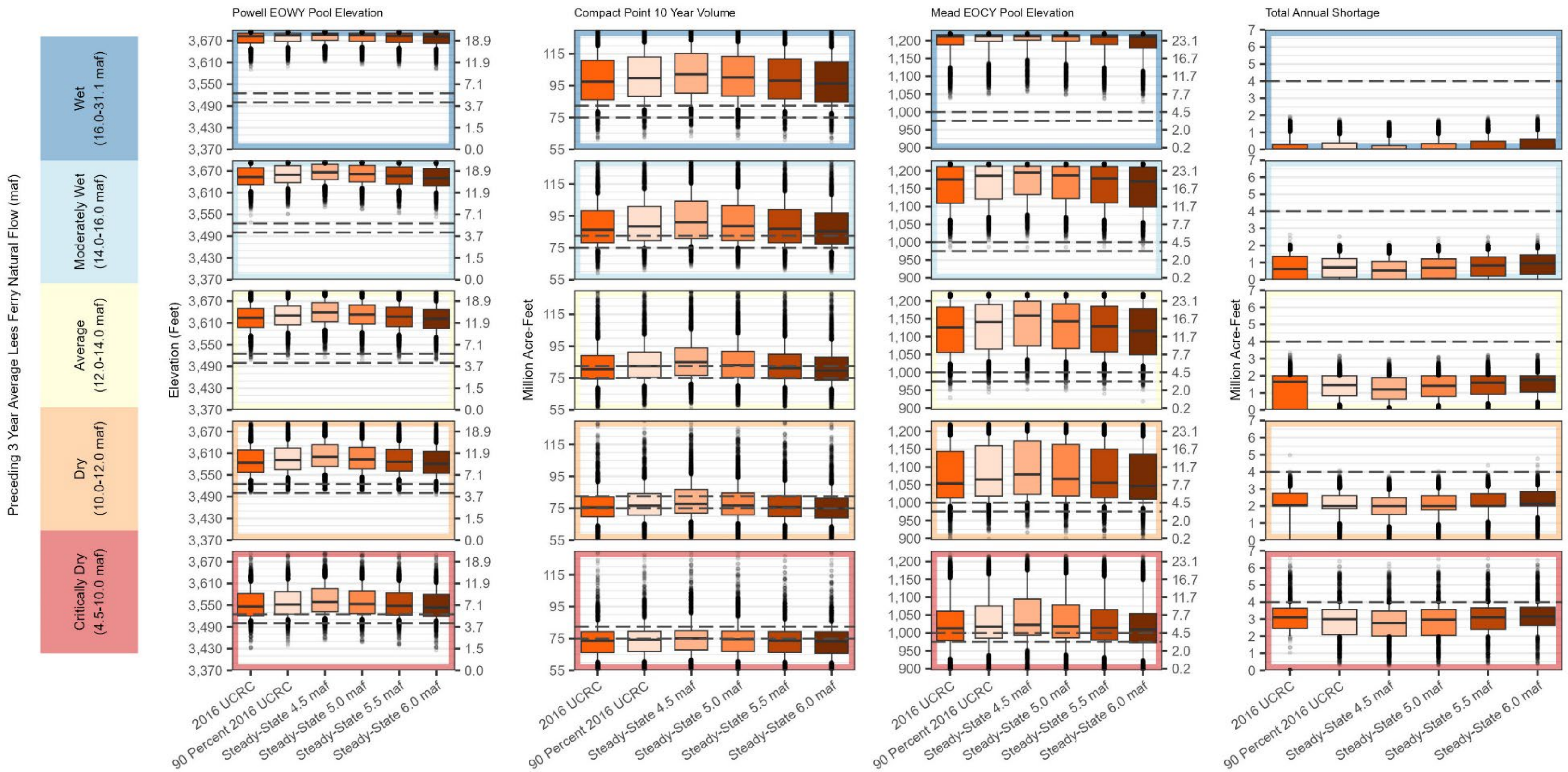
Note: The dashed line in the Total Annual Shortage column indicates a maximum shortage of 1.48 maf in the Basic Coordination Alternative.

Figure I-11
Lake Powell EOWY Elevation, Lee Ferry Compact Point 10-Year Volumes, Lake Mead EOCY Elevation, and Total Annual Shortage (Lower Basin Shortage and Dead Pool-Related Reductions) for the Enhanced Coordination Alternative Across the Six Depletion Demand Scenarios



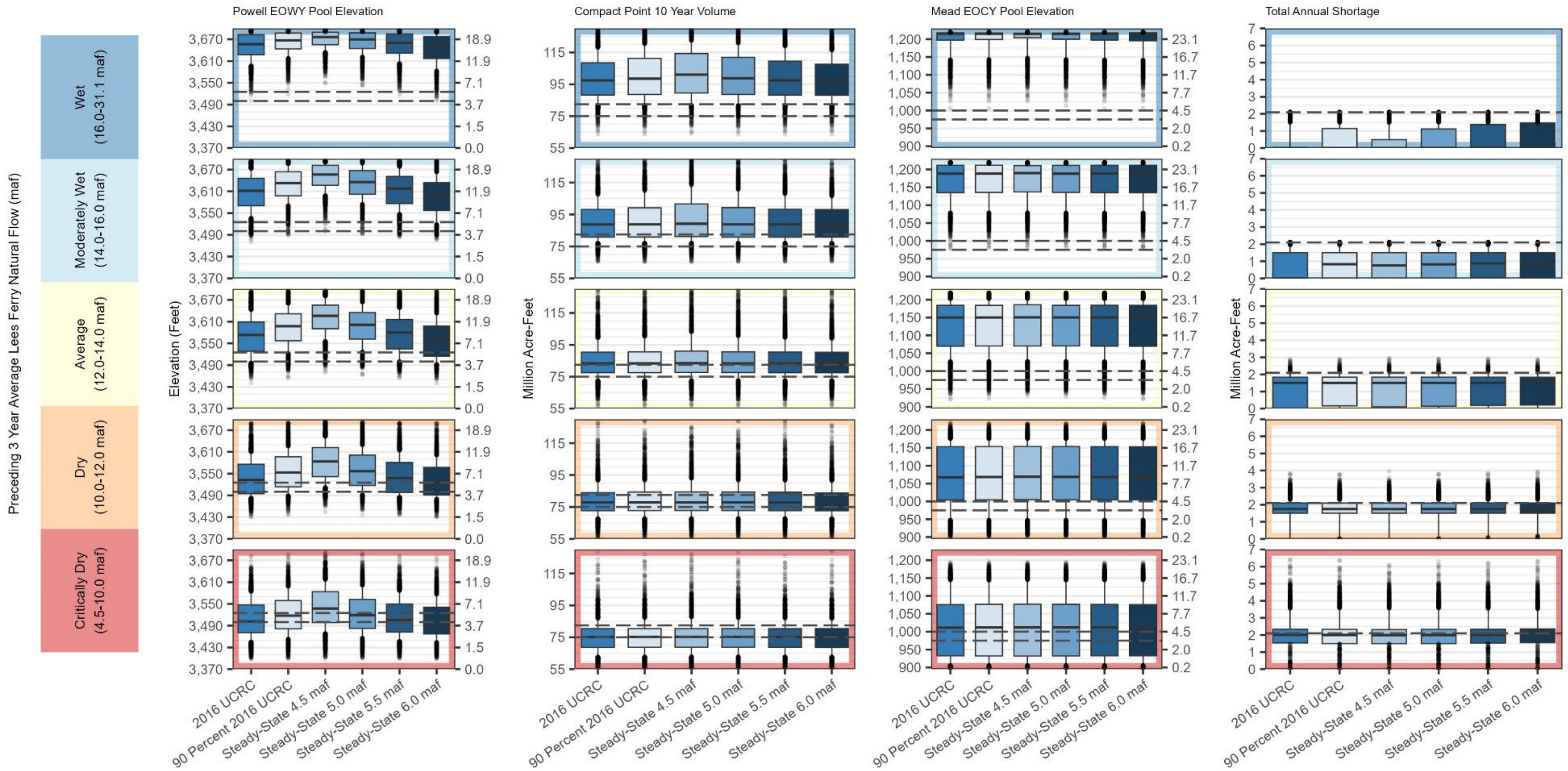
Note: The dashed line in the Total Annual Shortage column indicates a maximum shortage of 3.0 maf in the Enhanced Coordination Alternative.

Figure I-12
Lake Powell EOWY Elevation, Lee Ferry Compact Point 10-Year Volumes, Lake Mead EOCY Elevation, and Total Annual Shortage (Lower Basin Shortage and Dead Pool-Related Reductions) for the Maximum Operational Flexibility Alternative Across the Six Depletion Demand Scenarios



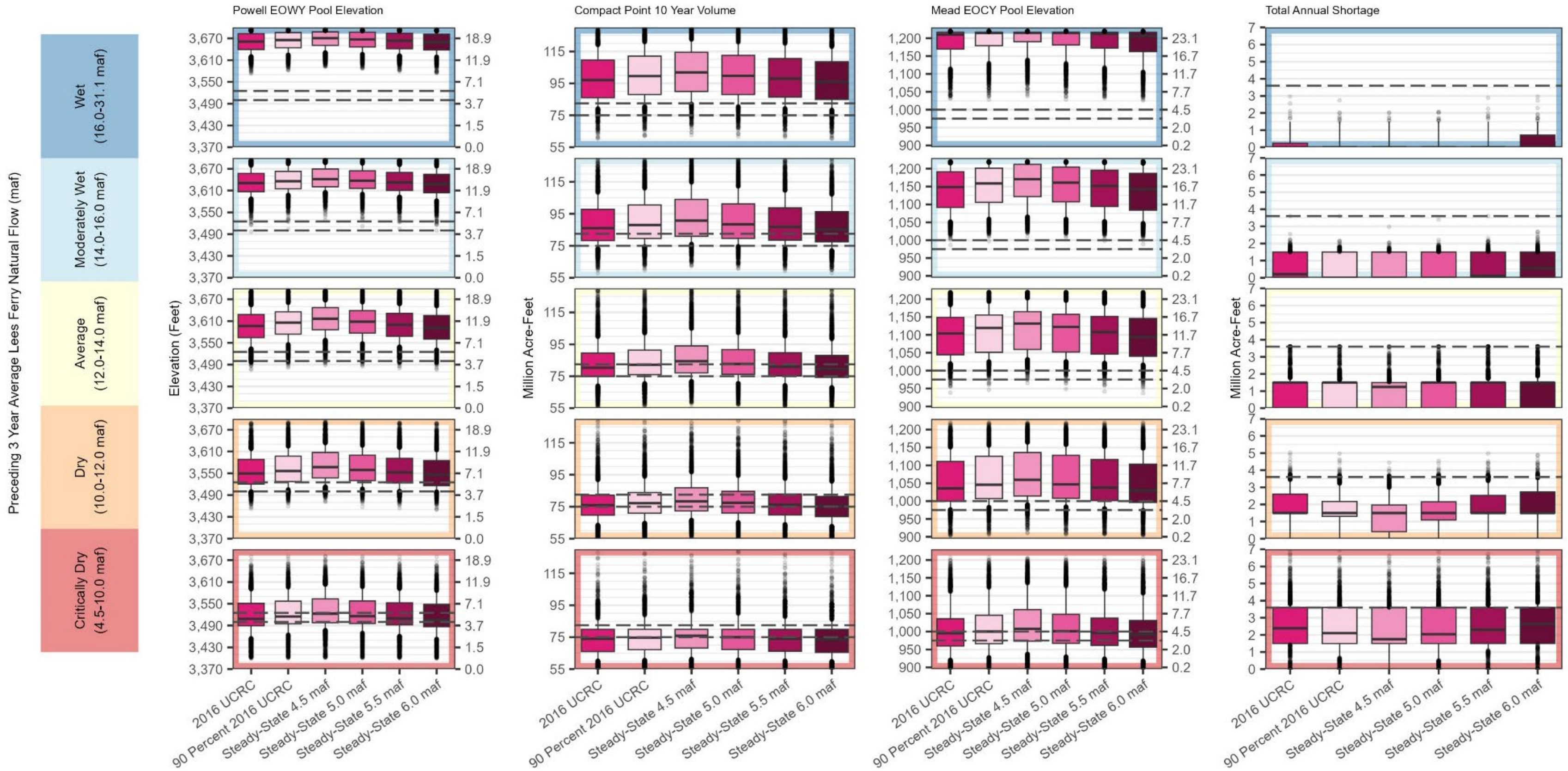
Note: The dashed line in the Total Annual Shortage column indicates a maximum shortage of 4.0 maf in the Maximum Operational Flexibility Alternative.

Figure I-13
Lake Powell EOWY Elevation, Lee Ferry Compact Point 10-Year Volumes, Lake Mead EOCY Elevation, and Total Annual Shortage (Lower Basin Shortage and Dead Pool-Related Reductions) for the Supply Driven Alternative (LB Priority Approach) Across the Six Demand Scenarios



Note: The dashed line in the Total Annual Shortage column indicates a maximum shortage of 2.1 maf in the Supply Driven Alternative (LB Priority Approach).

Figure I-14
Lake Powell EOWY Elevation, Lee Ferry Compact Point 10-Year Volumes, Lake Mead EOCY Elevation, and Total Annual Shortage (Lower Basin Shortage and Dead Pool-Related Reductions) for the Representative Preferred Alternative Across the Six Demand Scenarios



Note The dashed line in the Total Annual Shortage column indicates a maximum shortage of 3.6 maf in the Representative Preferred Alternative.

For the Supply Driven Alternative (LB Priority approach) (**Figure I-13**), lower steady-state depletion demand scenarios also result in higher Lake Powell elevations. Because Lake Powell releases are based on 65 percent of the preceding 3-year average Lees Ferry natural flow, there are few differences in Lake Mead elevations among the depletion demand scenarios. Under this alternative, Lake Powell releases are determined irrespective of Lake Powell elevation, resulting in similar downstream conditions regardless of the depletion demand scenario. Similarly, there are also few differences in total Lower Basin shortage across the depletion demand scenarios because shortages are based on Lake Mead elevation. Differences in the Compact Point 10-year volumes are observed across depletion demand scenarios, primarily due to infrastructure constraints at high and low Lake Powell elevations. At higher Lake Powell elevations, which occur more frequently in the Moderately Wet and Wet Flow Categories, lower steady-state depletion demand scenarios result in more instances of spill avoidance releases, which increases the Compact Point 10-year volumes.

I.3.3 Robustness

A robustness analysis was used to evaluate each alternative's ability to maintain Lake Powell and Lake Mead above critical elevation thresholds. In this context, robustness is defined as an alternative's ability to achieve a specified level of performance across a broad range of potential future conditions under a given depletion demand scenario.

For this analysis, the specified levels of performance are maintaining Lake Powell above elevation 3,500 feet[6] and Lake Mead above elevation 975 feet[7] during every month of the 34-year simulation period. A modeled future that meets these performance criteria is considered a "successful future." Robustness is expressed as the percentage of the 400 modeled futures that are successful for each alternative–depletion demand scenario combination.

Table I-1 and **Table I-2** compare the robustness of each alternative and depletion demand scenario with respect to maintaining reservoir elevations above 3,500 feet at Lake Powell and 975 feet at Lake Mead, respectively. Of note, the Representative Preferred Alternative results presented in this appendix do not include PIP releases, which would provide additional protection against reaching critical thresholds. In **TA 3**, Hydrologic Resources, **Figures TA 3-7** and **TA 3-12** present the robustness of Lake Powell at elevation 3,500 feet and Lake Mead at elevation 975 feet, respectively, with PIP releases included.

[6] This elevation at Lake Powell provides a 10-foot buffer to protect critical infrastructure, water delivery, and hydropower, which are critically impacted at an elevation of 3,490 feet. See **Section TA 3.2.1**, Issue 1, in **TA 3,** Hydrologic Resources.
[7] This elevation at Lake Mead provides 25-foot buffer from 950 feet - the elevation below which water can only be released through the intake towers, constraining both the volume of water able to be released as well as the ability to generate power.

Table I-1
Robustness of Lake Powell Elevation 3,500 Feet

	Continued Current	No Action	Basic Coordination	Enhanced Coordination	Max Flexibility	Supply Driven (LB Priority)	Representative Preferred
2016 UCRC	18%	4%	13%	74%	86%	18%	28%
90% 2016 UCRC	23%	4%	14%	77%	91%	28%	34%
Steady-State 4.5 maf	25%	4%	16%	79%	94%	45%	40%
Steady-State 5.0 maf	23%	4%	14%	76%	91%	30%	35%
Steady-State 5.5 maf	19%	3%	13%	73%	89%	21%	31%
Steady-State 6.0 maf	17%	3%	11%	70%	86%	15%	26%

Note: Percent of futures in which Lake Powell remains above 3,500 feet in 100 percent of months.

Table I-1 shows that, across all alternatives, the Steady State 4.5 maf scenario resulted in the highest robustness, while the Steady State 6.0 maf scenario resulted in the lowest robustness for maintaining Lake Powell above 3,500 feet. For most alternatives, the different depletion demand scenarios resulted in similar levels of robustness, with differences typically ranging from 1 to 14 percent. The Supply Driven Alternative (LB Priority approach) is the clear outlier. Its robustness varies by 30 percent, ranging from 45 percent of futures for the Steady State 4.5 maf scenario to 15 percent of futures for the Steady State 6.0 maf scenario. Because Lake Powell releases are based on 65 percent of the preceding 3-year average natural flow rather than reservoir elevation, the required release in Supply Driven Alternative (LB Priority approach) is the same regardless of the Lake Powell elevation. As a result, there is a large difference in robustness at Lake Powell across the assumed depletion demand scenarios. The Representative Preferred Alternative exhibits the next largest difference in robustness between the Steady State 4.5 maf and Steady State 6.0 maf scenarios, at 14 percent.

Table I-2 compares the robustness of alternatives with respect to Lake Mead's monthly pool elevation remaining above elevation 975 feet in all months.

Table I-2
Robustness of Lake Mead Elevation 975 Feet

	Continued Current	No Action	Basic Coordination	Enhanced Coordination	Max Flexibility	Supply Driven (LB Priority)	Representative Preferred
2016 UCRC	38%	21%	50%	65%	70%	61%	50%
90% 2016 UCRC	43%	24%	55%	69%	75%	61%	54%
Steady-State 4.5 maf	48%	25%	58%	72%	79%	61%	61%
Steady-State 5.0 maf	43%	24%	55%	68%	75%	61%	54%
Steady-State 5.5 maf	39%	22%	51%	65%	70%	61%	52%
Steady-State 6.0 maf	35%	18%	46%	61%	68%	60%	49%

Note: Percent of futures in which Lake Mead remains above 975 feet in 100 percent of months.

As at Lake Powell, the Steady State 4.5 maf scenario resulted in the highest robustness, while the Steady State 6.0 maf scenario resulted in the lowest robustness for maintaining Lake Mead above elevation 975 feet. Also consistent with the Lake Powell results, all alternatives except the Supply Driven Alternative (LB Priority approach) exhibited similar levels of robustness across the depletion demand scenarios, with differences typically ranging from 7 to 13 percent. In contrast to Lake Powell results, the Supply Driven Alternative (LB Priority approach) showed no change in robustness at Lake Mead across the depletion demand scenarios. This is because Lake Powell releases are computed as 65 percent of the preceding 3-year average natural flow, producing the same release for a given hydrologic year regardless of the assumed Upper Basin depletion demand scenario.

I.3.4 Vulnerability

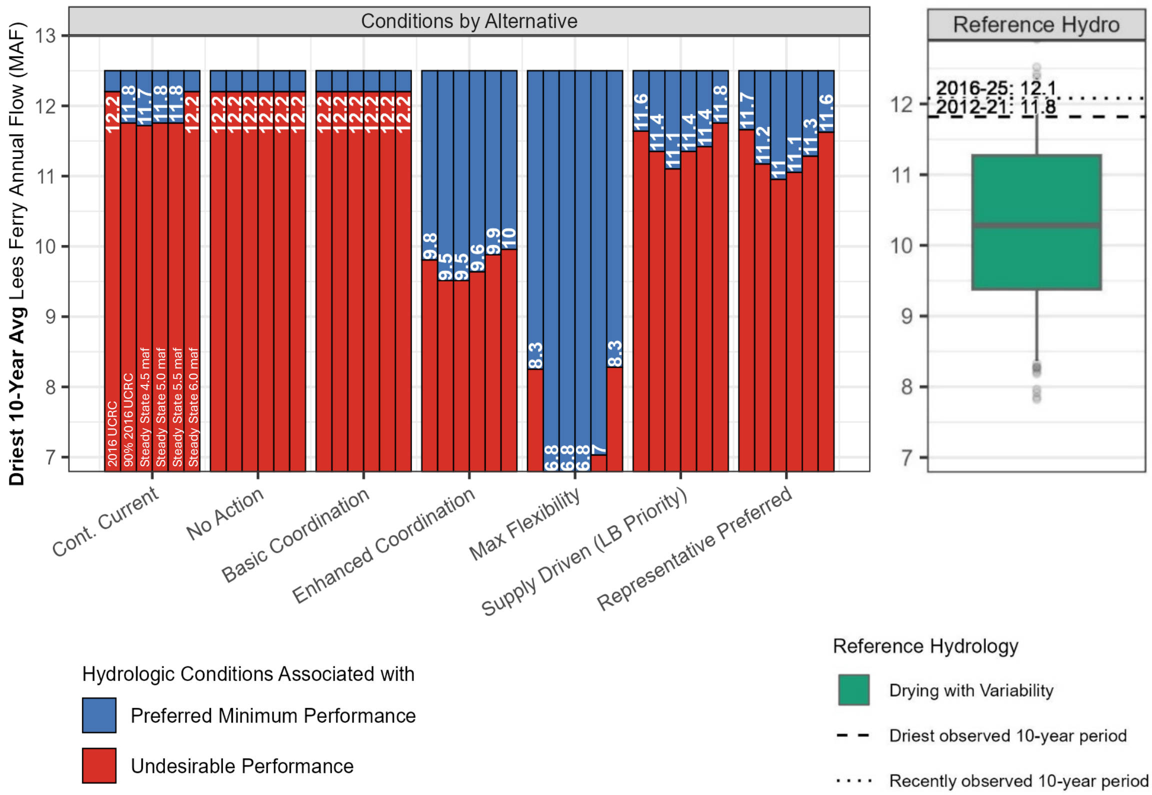
A vulnerability analysis was used to identify the hydrologic conditions that tend to result in an undesirable outcome. In this context, vulnerability was defined as an alternative's susceptibility to undesirable performance under a given depletion demand scenario across a broad range of potential future hydrologic conditions.

For this analysis, undesirable performance is defined as Lake Powell falling below elevation 3,500 feet or Lake Mead falling below elevation 975 feet at any time during the 34-year simulation period. Vulnerability complements the robustness analysis by using information from both successful and unsuccessful modeled futures to identify a skillful hydrologic predictor that relates hydrologic conditions to the likelihood a modeled outcome will be successful or unsuccessful under a given alternative and depletion demand scenario. This analysis is useful because it characterizes each alternative-depletion demand scenario combination in terms of the hydrologic conditions that are likely to result in undesirable performance, thereby identifying the conditions under which an alternative is vulnerable.

Figure I-15 shows the flow conditions likely to cause Lake Powell elevations to fall below 3,500 feet for each alternative and depletion demand scenario. This definition of undesirable performance is based on the robustness analysis presented in **Table I-1** above, which defined a future as successful when an alternative maintains elevations above 3,500 feet in every month.

For this vulnerability analysis, the driest 10-year average Lees Ferry annual flow was identified as the streamflow summary statistic most skillful at predicting undesirable performance (see **Appendix E**, DMDU Overview and Approach, **Section E.3** for further information). Vulnerability thresholds for each alternative-depletion demand scenario combination are compared to the observed record and the Drying with Variability Ensemble (shown in the Reference Hydrology panel) using this streamflow summary statistic. For reference, the driest observed 10-year average flow (2012-2021; 11.8 maf) and the most recent 10-year average flow (2016-2025; 12.1 maf) are also shown as dashed and dotted lines, respectively.

Figure I-15
Conditions that Could Cause Lake Powell Elevation to Fall below 3,500 feet in One or More Months Across All Depletion Demand Scenarios and Alternatives



Across all alternatives, the Steady State 4.5 maf scenario generally has the lowest vulnerability threshold, indicating that the alternatives are less vulnerable under this depletion demand scenario than under the higher depletion demand scenarios. Vulnerability under the 2016 UCRC scenario follows closely behind that of the Steady State 6.0 maf scenario.

The range of vulnerability thresholds across depletion demand scenarios indicates how sensitive each alternative is to the assumed depletion demands. The No Action and Basic Coordination Alternatives show negligible sensitivity, with identical vulnerability thresholds across all depletion demand scenarios. This is consistent with the robustness scores in **Table I-1**, which indicate these alternatives perform poorly regardless of depletion demand scenario.

The CCS Comparative Baseline and Enhanced Coordination Alternative have vulnerability thresholds that vary by 0.5 maf across depletion demand scenarios, while the Supply Driven Alternative (LB Priority approach) and the Representative Preferred Alternative have vulnerability thresholds that vary by 0.7 maf. These small ranges indicate relatively low sensitivity to the depletion demand scenario. For the Maximum Operational Flexibility Alternative, the vulnerability threshold is at or near the bottom of the figure (ranging from 6.8 to 7.0 maf) for the 90 percent 2016 UCRC, Steady State 4.5, 5.0, and 5.5 maf scenarios. Under the 2016 UCRC and Steady State 6.0 maf scenarios, the thresholds are noticeably higher at 8.3 maf. However, this is likely due to the high robustness scores obtained by the Maximum Operational Flexibility Alternative, which can make it difficult to identify and compare vulnerability thresholds across depletion demand scenarios. In this case, robustness scores are a better indicator of sensitivity, which only vary between 86 percent under the Steady State 6.0 maf scenario to 94 percent under the Steady State 4.5 maf scenario.

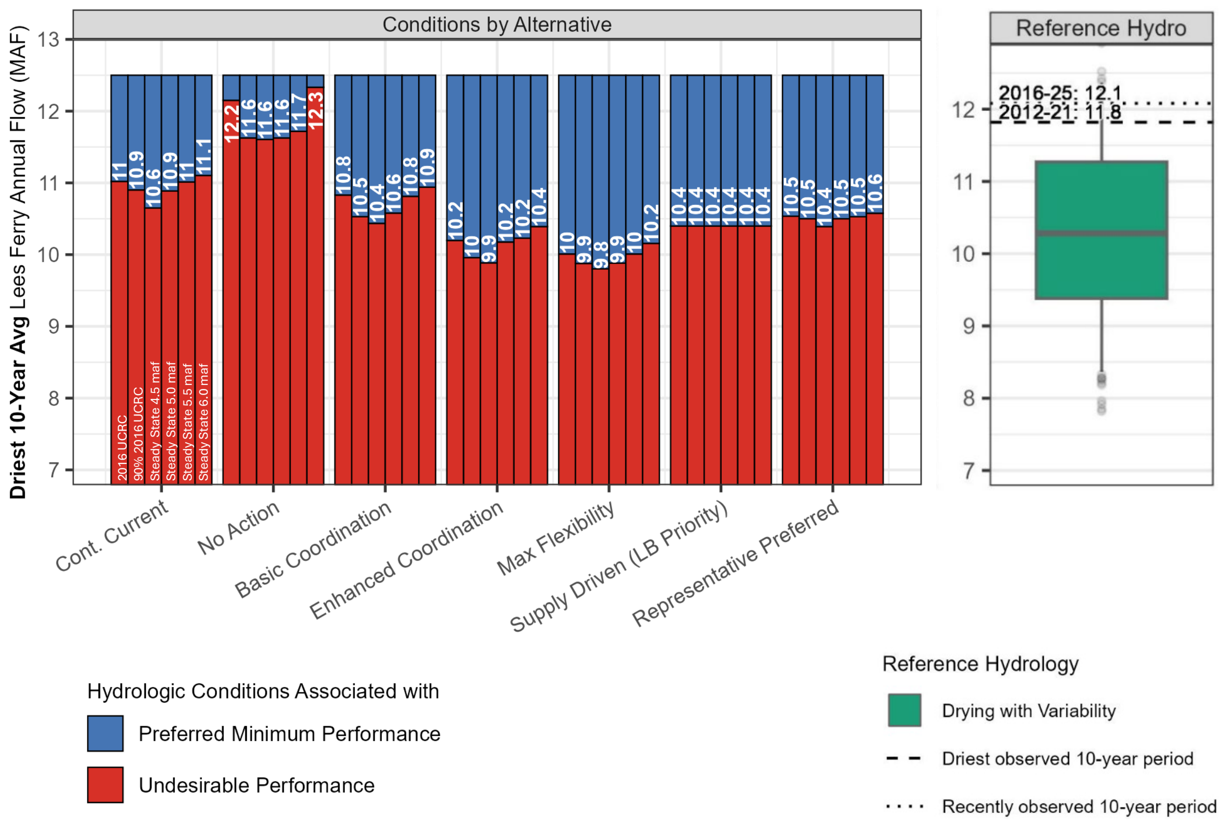
Comparing the vulnerability thresholds with the reference hydrology panel indicates that all alternatives except the Enhanced Coordination and Maximum Operational Flexibility Alternatives would be reasonably likely to experience Lake Powell elevations below 3,500 feet over the next 34 years, regardless of the depletion demand scenario. This is because the alternatives are vulnerable to about 75 percent or more of the traces in the Drying with Variability Ensemble, which represents a drier future with conditions like those experienced in recent history. The Enhanced Coordination Alternative may or may not be vulnerable, since it is vulnerable under nearly 50 percent of the traces in the Drying with Variability Ensemble but not vulnerable based on conditions that have occurred historically, regardless of the depletion demand scenarios. The Maximum Operational Flexibility Alternative is reasonably unlikely to experience elevations below 3,500 feet because it is vulnerable under less than 10 percent of the traces in the Drying with Variability Ensemble and not vulnerable under historical conditions, regardless of the depletion demand scenarios.

Figure I-16 shows the flow conditions likely to cause Lake Mead to fall below 975 feet for each alternative-depletion demand scenario combination. This definition of undesirable performance is based on the robustness analysis presented in **Table I-2** above, which defined a future as successful when an alternative maintains elevations above 975 feet in every month.

Like the Lake Powell vulnerability analysis, this vulnerability analysis identified the driest 10-year average Lees Ferry annual flow as the streamflow summary statistic most skillful at predicting undesirable performance.

Similar to the Lake Powell vulnerability analysis, the Steady State 4.5 maf scenario generally has the lowest vulnerability thresholds across depletion demand scenarios, while the Steady State 6.0 maf scenario generally has the highest vulnerability thresholds. The Supply Driven Alternative (LB Priority approach) is not sensitive to the depletion demand scenario, with the same vulnerability threshold across all depletion demand scenarios. The Representative Preferred Alternative is relatively insensitive, with vulnerability thresholds varying by only 0.2 maf. The remaining action alternatives and the CCS Comparative Baseline are also relatively insensitive, with thresholds varying by 0.4 maf for the Maximum Operational Flexibility Alternative and 0.5 maf for both the CCS Comparative Baseline and Enhanced Coordination Alternative. The No Action Alternative is the most sensitive, with vulnerability thresholds varying by 0.7 maf.

Figure I-16
Conditions that Could Cause Lake Mead Elevation to Fall B 975 feet in One or More Months Across All Depletion Demand Scenarios and Alternatives



Comparing the vulnerability thresholds with the Drying with Variability Ensemble indicates that the CCS Comparative Baseline, No Action Alternative, and Basic Coordination Alternative would be reasonably likely to experience elevations below 975 feet over the next 34 years, regardless of the depletion demand scenario. The No Action Alternative is vulnerable under conditions similar to those observed in recent history and in over 75 percent of traces in the Drying with Variability Ensemble. Although the CCS Comparative Baseline and Basic Coordination Alternative are not vulnerable to historical flows, they are vulnerable in 50 to 75 percent of traces in the Drying with Variability Ensemble, regardless of the depletion demand scenario. The remaining alternatives may or may not be vulnerable, as they are vulnerable to about 50 percent of traces in the Drying with Variability Ensemble but not under historical conditions.

I.4 Summary and Conclusions

This sensitivity analysis examined how sensitive the different alternatives are to different Upper Basin depletion demand assumptions. Differences in Lower Basin demands are already represented through the alternatives' different shortage and surplus provisions. Multiple Upper Basin depletion demand scenarios, including steady-state demand levels ranging from 4.5 maf to 6.0 maf, were evaluated in all hydrologic scenarios for all alternatives and the CCS Comparative Baseline. The Upper Basin modeled depletions and modeled shortages, impact on system conditions, robustness, and vulnerability were compared to evaluate their sensitivity to Upper Basin demand assumptions.

Across nearly all alternatives and performance metrics, lower Upper Basin steady-state depletion demand scenarios (e.g., 4.5 maf) resulted in higher elevations at Lake Powell and Lake Mead, greater 10-year Lee Ferry volumes, and smaller Lower Basin shortages compared to higher steady-state depletion demand scenarios. Consistent with these results, the Steady State 4.5 maf scenario resulted in the highest robustness at maintaining Lake Powell above elevation 3,500 feet and Lake Mead above elevation 975 feet, whereas the Steady State 6.0 maf scenario resulted in the lowest robustness.

The CCS Comparative Baseline, No Action, Basic Coordination, and Enhanced Coordination, Alternatives each showed relatively little variation in robustness and vulnerability across the different Upper Basin depletion demand scenarios. These alternatives consistently showed only minor changes in robustness scores and in the drought severity associated with vulnerability (differences in vulnerability thresholds typically range from 0.0 to 0.5 maf), indicating that their performance is less sensitive to assumed Upper Basin depletion demands than that of the other alternatives.

The Maximum Operational Flexibility Alternative followed similar trends to the CCS Comparative Baseline, No Action, Basic Coordination and Enhanced Coordination Alternatives except when considering the vulnerability at Lake Powell. Like the other alternatives, vulnerability thresholds for the Maximum Operational Flexibility Alternative changed modestly across the lower depletion demand scenarios, but changed sharply at the 6.0 maf depletion demand scenario. However, this sensitivity is likely due to the high robustness scores exhibited by this alternative (86 to 94 percent), which can make it difficult to identify and compare vulnerability thresholds.

The Supply Driven Alternative (LB Priority approach) behaved differently from all others. Because releases from Lake Powell are fixed at 65 percent of the preceding 3-year average natural flow, Lake Powell releases are typically the same for all depletion demand scenarios. As a result, at Lake Powell, robustness exhibited the largest spread of any alternative (a 30 percent range between Steady State 4.5 and 6.0 maf scenarios), and vulnerability thresholds varied by a 0.7 maf range. In contrast, at Lake Mead, both robustness and vulnerability were nearly identical across all depletion demand scenarios, making the Supply Driven Alternative the least sensitive alternative at Lake Mead to Upper Basin depletion demand assumptions.

The Representative Preferred Alternative exhibited a larger range in robustness across the depletion demand scenarios at Lake Powell (a 14 percent range between the Steady State 4.5 and 6.0 maf scenarios), second only to the Supply Driven Alternative (LB Priority approach), indicating a greater degree of sensitivity to the depletion demand scenarios. At Lake Mead, the range of vulnerability thresholds was lower than other alternatives except for the Supply Driven Alternative (LB Priority approach), showing a 0.2 maf difference between the Steady State 4.5 maf and 6.0 maf depletion demand scenarios. However, robustness scored varied from 49 to 61 percent across the depletion demand scenarios, a range similar to the other action alternatives except Supply Driven (LB Priority approach).

For all alternatives, different depletion demand scenarios did not change conclusions when comparing vulnerability thresholds to the Reference Hydrology. For Lake Powell, all alternatives except the Enhanced Coordination and Maximum Operational Flexibility Alternatives are reasonably likely to experience at least one occurrence below elevation 3,500 feet. For Lake Mead, the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (LB Priority) Alternatives may or may not be vulnerable to elevations below 975 feet because they are vulnerable in about 50 percent of traces in the Drying with Variability ensemble. In contrast, the CCS Comparative Baseline, No Action Alternative, and Basic Coordination Alternative are reasonably likely to experience elevations below 975 feet.

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